# STANDARD BOILER OPERATORS' QUESTIONS AND ANSWERS

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**STANDARD BOILER OPERATORS' QUESTIONS AND ANSWERS**

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# USAGE AND APPLICATION

## INTRODUCTION

Before we study the subject of boilers in detail, let us briefly discuss such terms as boilers, steam generators, critical-pressure boilers, low pressure, high pressure, steam, hot-water-heating boilers, hot-water-supply boilers, and also some Boiler Code requirements.

A number of these terms are directly related to legal requirements drawn up by state and city laws. Thus they are of great importance not only to boiler operators, operating and mechanical engineers, maintenance and service people, but also to those in management. These are the people in charge of (1) plant safety, (2) fiscal and legal policy affected by plant insurance, costs, and hazards, and (3) the city or state governments having jurisdiction over plant equipment.

**Q** We know that boilers have a great potential for causing loss of life and damage to property. But in addition to safety, what other knowledge is required when working with boilers?

**A** The use of fired and unfired pressure vessels is rapidly expanding in industry, commercial buildings, apartment houses, and in every economic activity around the world. Most of us working with machinery sooner or later come in contact with fired and unfired pressure vessels. Thus, we should become familiar with this equipment. Today, control devices, automatic equipment, computers, and other sophisticated items are being applied to fired pressure vessels.

But do not make the mistake of thinking that boilers and other pressure vessels thus automated are perfectly reliable because they operate like a robot. On the contrary, these safety devices make the inherent danger even greater when complete dependence is placed on them.

The use of nuclear reactors is also expanding, but a reactor is also basically a heated pressure vessel. Thus certain boiler fundamentals also apply to the construction and operation of reactors.

State and municipal laws involving boilers and pressure vessels require a knowledge of this subject to comply with legal statutes. And not



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to be forgotten when working with this equipment are the factors of reliability, service, efficiency, costs, loss of use, and, of course, safety.

**Q** Do state laws apply only to *high-pressure boilers*?

**A** Certainly not. At one time this was true, but with the advent of more and more automatic devices on boilers, with less and less reliance on full-time boiler operator attendance, coupled with some serious explosions on *low-pressure boilers*, more and more states have adopted, and *are* adopting, low-pressure boiler laws and even *unfired pressure vessel* laws. The trend for more rigid laws affecting pressure equipment is going to continue because *low pressure* on a fired vessel, under certain conditions, becomes *high pressure* in a matter of minutes.

**Q** How would you define a *boiler*?

**A** A *boiler* is a closed pressure vessel in which a fluid is heated for use external to itself by the direct application of heat resulting from the combustion of fuel (solid, liquid, or gaseous) or by the use of electricity or nuclear energy.

**Q** What is a *steam boiler*?

**A** A *steam boiler* is a closed vessel in which steam or other vapor is generated for use external to itself by the direct application of heat resulting from the combustion of fuel (solid, liquid, or gaseous) or by the use of electricity or nuclear energy.

**Q** What is a *high-pressure steam boiler*?

**A** A *high-pressure steam boiler* is one which generates steam or vapor at a pressure of more than 15 pounds per square inch gage (psig). Below this pressure it is classified as a low-pressure steam boiler.

**Q** Define a *miniature high-pressure boiler*.

**A** According to Section I of the Boiler & Pressure Vessel Code of the American Society of Mechanical Engineers (ASME), a *miniature boiler* is a high-pressure boiler which does not exceed the following limits: (1) 16 in. inside diameter of shell, (2) 5 cu ft gross volume exclusive of casing and insulation, and (3) 100 psig pressure. If it exceeds any of these limits, it is a *power boiler*. Most states follow this definition.

**Q** What is a *power boiler*?

**A** A *power boiler* is a steam or vapor boiler operating above 15 psig and exceeding the miniature boiler size. This *also includes* hot-water-heating or hot-water-supply boilers operating above 160 psi or 250 degrees Fahrenheit (°F).

**Q** Define a *hot-water-heating boiler*.

**A** A *hot-water-heating boiler* is a boiler used for space hot-water heating, with the water returned to the boiler. It is further classified as low

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pressure if it does not exceed 160 psi or 250°F. But if it exceeds any of these, it becomes a high-pressure boiler.

**Q** What is a *hot-water-supply boiler?*

**A** A *hot-water-supply boiler* is a boiler furnishing hot water to be used externally to itself for washing, cleaning, etc. If it exceeds 160 psi or 250°F, it becomes a high-pressure power boiler.

NOTE: The ordinary domestic type hot-water-supply heater directly fired with oil, gas, or electricity may be classified as a hot-water-supply boiler, depending on the state. The ASME Low-pressure Heating Boiler Code, Section IV, stipulates that it becomes a hot-water-supply boiler if any of the following is exceeded: (1) Heat input over 200,000 Btu per hr, (2) water temperature over 200°F, and (3) nominal water-containing capacity of 120 gal. If it is below these limitations, it is designed under Section VIII, Unfired Pressure Vessels, ASME Boiler & Pressure Vessel Code. Some state laws start classifying these hot-water heaters as hot-water-supply boilers if the input exceeds 100,000 Btu. Other states incorporate all fired vessels (including those electrically fired) under the Boiler Code Regulations, excluding only vessels in private residences or apartment houses with six families or less. So always check your state law.

**Q** The latest ASME Boiler & Pressure Vessel Code is very important when working with boilers. How did this Code come to be applied and administered?

**A** Before the ASME Code, manufacturers had their own individual construction techniques. There were no fixed legal standards, but after more and more boiler accidents occurred as the country became more industrialized, the public demanded laws for protection. One of the first states to adopt a state code was Massachusetts, but it took a boiler explosion which killed 58 persons and injured 117. Thus the ASME set up a committee in 1911 to formulate standards of construction of steam boilers and pressure vessels. This committee is now called the Boiler & Pressure Vessel Code Committee, and the codes drawn up are called the ASME Boiler & Pressure Vessel Code, consisting of the following: Section I, Power Boilers; Section II, Material Specifications; Section III, Nuclear Vessels; Section IV, Low-pressure Heating Boilers; Section VII, Suggested Rules for Care of Power Boilers; Section VIII, Unfired Pressure Vessels; Section IX, Welding Qualifications.

In time, the ASME Code became recognized as a standard in the United States and even in foreign countries. States and cities started to adopt one or more sections of the Code to make it legal. Many state and city representatives, including some from Canada, are now on the ASME

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Boiler and Pressure Vessel Code Committee. There are also various technical groups, called subcommittees, covering such subjects as power boilers; fire-tube boilers; steam boilers in service; material specifications; steel plates; steel tubular products; steel castings, forgings, and boltings; non-ferrous materials; properties of metals (with subgroups on toughness, fatigue strength, strength properties); strength of weldments; nuclear power; heating boilers; unfired pressure vessels; welding; safety-valve requirements; code symbols and stamps; openings and bolted connections; special design; nondestructive testing; and vessels under external pressure.

**Q** What is a *supercritical pressure* boiler?

**A** Steam and water have a critical pressure at 3,206.2 psi absolute (psia). At this pressure steam and water are at the same density, which means that the steam is compressed as tightly as the water. When this mixture is heated above the corresponding saturation temperature of 705.4°F for this pressure, dry, superheated steam is produced to do useful high-pressure work. This dry steam is especially well-suited for driving turbine-generators. A supercritical boiler is thus one that operates above the supercritical pressure of 3,206.2 psia and 705.4°F saturation temperature. (See the sections on enthalpy and heat of vaporization in Chap. 10.)

**Q** What is a *once-through boiler?*

**A** This refers to a boiler or steam generator which receives feedwater at one end of continuous tubes and discharges steam at the other end. (See Chap. 4.)

**Q** Define a *waste-heat boiler.*

**A** This is a boiler which uses by-product heat such as from a blast furnace in a steel mill, exhaust from a gas turbine, or by-products from a manufacturing process. The waste heat is passed over heat-exchanger surfaces to produce steam or hot water for conventional use.

**Q** Do Code rules apply to waste-heat boilers?

**A** Yes. The same basic construction rules still apply, and the usual auxiliaries and safety features normally required on any fired pressure vessel are needed.

**Q** What is a *steam generator?*

**A** Engineers prefer to use the term *steam generator* instead of *steam boiler*, as *boiler* refers to the physical change of the contained fluid whereas the term *steam generator* covers the whole apparatus in which this physical change is taking place. But in ordinary usage, both are essentially the same thing. Most state laws are still written under the old, basic *boiler* nomenclature.

**Q** Are there any other classifications of boilers dependent on the nature of service intended?

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**A** Yes, the traditional classifications are *stationary, portable, locomotive,* and *marine,* defined as follows. A stationary boiler is one which is installed permanently on a land installation. A portable boiler is a boiler mounted on a truck, barge, small river boat, or any other such mobile-type apparatus. A locomotive boiler is a specially designed boiler, specifically meant for self-propelled traction vehicles on rails (also used for stationary service). A marine boiler is usually a low-head-type special-design boiler meant for ocean cargo and passenger ships with an inherent fast-steaming capacity.

**Q** Are boilers used for steam heating different from those used for supplying steam for power generation or process? If so, how?
**A** Yes. Heating boilers are usually low-pressure units of cast-iron or steel construction, although high-pressure steel boilers may also be used for large buildings or for large, complex areas. Usually if this is done, pressure-reducing valves in the steam lines lower the pressure to the radiators, convectors, or steam coils. The term *steam heating* also generally implies that all condensate is returned to the boiler in a closed-loop system.

**Q** Is there a maximum pressure allowed in a low-pressure steam-heating boiler?
**A** Yes, it is 15 psig.

**Q** What *hydrostatic test* is required on low-pressure steam-heating boilers?
**A** A hydrostatic test of 60 psig is required at the shop where the boiler is constructed. After the unit is in service, the hydrostatic test is limited to 1½ times the maximum allowable working pressure (MWP).

**Q** Is it permissible to build *cast-iron boilers* for steam usage above 15 psig?
**A** No. Under the present Boiler Code, cast-iron boilers for steam usage are limited to an MWP of 15 psig.

**Q** May cast-iron boilers be used for process work if they are operated under 15 psig steam pressure?
**A** No. Cast-iron boilers are specifically restricted by the ASME Code, Section IV to be used exclusively for low-pressure steam *heating*. Process work usually means heavy-duty service of continuous steaming and heavy makeup of fresh cold water. This will cause rapid temperature changes in a cast-iron boiler, resulting in cracking of the cast-iron parts. Thus the Code restricts their use to steam-heating service only.

**Q** In heating-load calculations, the terms *IBR rated, SBI rated,* and *EDR* are often used. What do these terms mean?
**A** These terms affect the output rating of a boiler. Thus they are important in sizing a boiler for heating a certain size space. They also affect

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| Boiler number | Gross boiler hp | Gross IBR output, Mbh | Net IBR rating* | | IBR burner capacity based on 150,000 Btu/gal (heavy oil), gph | IBR gas input, Mbh | IBR chimney size for heavy oil† | | Inside diam of rectang. smoke pipe to fit over smokehood outlet, in. | Burner capacity based on 140,000 Btu/gal (light oil), gph |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sq ft steam | Mbh water | | | Size, in. | Height, ft | | |
| 450–8 | 47.3 | 1,584 | 5,060 | 1,214.7 | 13.20 | 1,980 | 16 × 20 | 25 | 15 × 19 | 14.15 |
| 450–9 | 53.7 | 1,796 | 5,795 | 1,391.2 | 14.90 | 2,238 | 16 × 20 | 26 | 15 × 19 | 16.00 |
| 450–10 | 60.0 | 2,008 | 6,495 | 1,559.0 | 16.65 | 2,496 | 20 × 20 | 27 | 15 × 19 | 17.85 |
| 450–11 | 66.3 | 2,220 | 7,180 | 1,723.6 | 18.35 | 2,753 | 20 × 20 | 28 | 15 × 19 | 19.70 |
| 450–12 | 72.6 | 2,428 | 7,855 | 1,885.1 | 20.10 | 3,011 | 20 × 20 | 29 | 15 × 19 | 21.50 |
| 450–13 | 78.9 | 2,640 | 8,540 | 2,049.7 | 21.80 | 3,269 | 20 × 24 | 30 | 19 × 19 | 23.35 |
| 450–14 | 85.2 | 2,852 | 9,225 | 2,214.3 | 23.50 | 3,527 | 20 × 24 | 31 | 19 × 19 | 25.20 |
| 450–15 | 91.5 | 3,064 | 9,910 | 2,378.9 | 25.25 | 3,785 | 20 × 24 | 32 | 19 × 19 | 27.05 |
| 450–16 | 97.7 | 3,270 | 10,580 | 2,538.8 | 26.95 | 4,043 | 24 × 24 | 33 | 19 × 19 | 28.90 |
| 450–17 | 104.0 | 3,490 | 11,290 | 2,709.6 | 28.70 | 4,300 | 24 × 24 | 34 | 24 × 19 | 30.70 |
| 450–18 | 110.2 | 3,700 | 11,970 | 2,872.7 | 30.40 | 4,558 | 24 × 24 | 35 | 24 × 19 | 32.55 |
| 450–19 | 116.8 | 3,910 | 12,650 | 3,035.7 | 32.10 | 4,816 | 24 × 24 | 36 | 24 × 19 | 34.40 |
| 450–20 | 123.1 | 4,120 | 13,330 | 3,198.8 | 33.85 | 5,074 | 24 × 28 | 37 | 24 × 19 | 36.25 |

*Net IBR ratings shown include allowance for piping loss and pickup load.

†If the heavy oil burner being used requires a draft over the fire greater than 0.06 in, the chimney height shall be adjusted accordingly.

**Fig. 1-1. Typical IBR ratings for cast-iron boilers from manufacturer's catalog.** (*Continued on next page.*)

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| Boiler number | Heating surface, sq ft | Furnace volume above base, cu ft | Covering surface including drums, sq ft | Length overall A, in. | Length firepot B, in. | Length foundation C, in. |
|---|---|---|---|---|---|---|
| 450–8 | 288.7 | 29.43 | 70 | 86½ | 42 | 49 |
| 450–9 | 325.3 | 33.54 | 77 | 92½ | 48 | 55 |
| 450–10 | 361.3 | 37.64 | 84 | 98½ | 54 | 61 |
| 450–11 | 398.0 | 41.75 | 91 | 104½ | 60 | 67 |
| 450–12 | 434.0 | 45.86 | 98 | 110½ | 66 | 73 |
| 450–13 | 470.7 | 49.96 | 105 | 116½ | 72 | 79 |
| 450–14 | 506.7 | 54.07 | 112 | 122½ | 78 | 85 |
| 450–15 | 543.3 | 58.18 | 119 | 128½ | 84 | 91 |
| 450–16 | 579.3 | 62.28 | 126 | 134½ | 90 | 97 |
| 450–17 | 616.0 | 66.39 | 133 | 140½ | 96 | 103 |
| 450–18 | 652.0 | 70.50 | 140 | 146½ | 102 | 109 |
| 450–19 | 688.7 | 74.60 | 147 | 152½ | 108 | 115 |
| 450–20 | 724.7 | 78.71 | 154 | 158½ | 114 | 121 |

NOTE: All boilers hydrostatically tested, ASME Standard. Maximum allowable working pressure, steam, 15 lb; water, 40 lb.

Fig. 1-1 *(Continued)*. Typical IBR ratings for cast-iron boilers from manufacturer's catalog.

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the safety valve required on a boiler. The preferred modern trend is to rate a boiler by the Btu-per-hour-output method. The terms mean the following:

IBR stands for the Institute of Boiler and Radiator Manufacturers, which rates cast-iron boilers. IBR-rated boilers usually have a nameplate indicating net and gross output in Btus per hour. Gross output is further defined as the net output plus an allowance for starting, or pickup load, and a piping heat loss. The net output will show the actual useful heating effect produced. The ASME Code states it is the gross heat output of the equipment that should be matched in specifying relief-valve capacity.

SBI stands for the Steel Boiler Institute. The nameplate data shown on SBI-rated boilers are not uniform, but the style or product number may be shown. The manufacturer's catalog will often show an SBI rating and an SBI net rating. The SBI rating tends to show the sum of SBI net ratings, plus 20 percent extra for piping loss, not including the pickup allowances noted under IBR ratings. Thus, it is difficult to obtain the true gross output to determine safety relief capacity from these data. But the SBI does require the square feet of heating surface to be stamped on the boiler. With this, the ASME rule of minimum steam sv capacity in pounds per hour per square foot of heating surface is used. (See Chap. 13.)

EDR means *equivalent square feet of steam radiation surface*. It is further defined as a surface which emits 240 Btu per hr with a steam temperature of 215°F at a room temperature of 70°F. With hot-water heating, the value of 150 Btu per hr is used with a 20°F drop between inlet and outlet water. This term is used by architects and heating engineers in determining the area of heat transfer equipment required to heat a space. Thus boiler capacity is obtained indirectly from a summation of the EDRs. Figure 1-1 shows typical cast-iron boiler ratings from a manufacturer's catalog. Figure 1-2 shows ratings of the Steel Boiler Institute.

**Q** What other terms are used to indicate boiler output?

**A** These three terms are often used with pressure and temperature listings.

1. For steam boilers, the actual evaporation in pounds per hour. For hot-water boilers, the Btu-per-hour output for the given pressures and temperatures are stamped on the boiler. Today this is the preferred method. Also used are
2. Square feet of heating surface.
3. Boiler horsepower.

**Q** What is meant by *heating surface* in a boiler?

**A** This is the (fireside) area in a boiler exposed to the products of combustion. This area is usually calculated on the basis of areas on the following boiler element surfaces: tubes, fireboxes, shells, tube sheets,

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| | Boiler number | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [illegible] | [illegible] | [illegible] | HM-883 | HM-884 | HM-885 | HM-886 | HM-887 | HM-888 | HM-889 | HM-890 | HM-891 | HM-892 | HM-893 |
| ...utput, hp | 64 | 75 | 91 | 108 | 134 | 161 | 188 | 215 | 269 | 322 | 376 | 430 | 483 | 537 |
| ...q ft | 9,000 | 10,500 | 12,750 | 15,000 | 18,750 | 22,500 | 26,250 | 30,000 | 37,500 | 45,000 | 52,500 | 60,000 | 60,000 | 75,000 |
| ...sq ft | 14,400 | 16,800 | 20,400 | 24,000 | 30,000 | 36,000 | 42,000 | 48,000 | 60,000 | 72,000 | 84,000 | 96,000 | 108,000 | 120,000 |
| ... | 2160 | 2520 | 3060 | 3600 | 4500 | 5400 | 6300 | 7200 | 9000 | 10800 | 12600 | 14400 | 16200 | 18000 |
| Steam per hr (212°F), lb | 2,208 | 2,588 | 3,140 | 3,726 | 4,623 | 5,555 | 6,486 | 7,418 | 9,281 | 11,109 | 12,972 | 14,835 | 16,664 | 18,527 |
| Certified output, hp | 78 | 92 | 111 | 131 | 164 | 195 | 228 | 261 | 326 | 392 | 456 | 521 | 585 | 651 |
| Certified output, Mbh | 2625 | 3060 | 3718 | 4374 | 5464 | 6559 | 7650 | 8745 | 10929 | 13114 | 15300 | 17485 | 19671 | 21855 |
| Firing rate: | | | | | | | | | | | | | | |
| Oil, gph | 22 | 26 | 31 | 37 | 46 | 54 | 64 | 73 | 91 | 110 | 127 | 146 | 167 | 182 |
| Gas, Mbh | 3280 | 3830 | 4650 | 5460 | 6840 | 8200 | 9560 | 10920 | 13670 | 16400 | 19120 | 21900 | 24600 | 27300 |
| Heating surface (waterside), sq ft | 429 | 500 | 608 | 715 | 893 | 1,072 | 1,250 | 1,429 | 1,786 | 2,143 | 2,500 | 2,857 | 3,214 | 3,571 |
| Heating surface (fireside), sq ft | 397 | 463 | 563 | 662 | 827 | 993 | 1,157 | 1,323 | 1,654 | 1,985 | 3,215 | 2,645 | 2,976 | 3,307 |
| Furnace volume (SBI min), cu ft | 52.1 | 60.8 | 73.8 | 86.8 | 108.5 | 130.2 | 151.8 | 173.5 | 216.9 | 260.3 | 303.6 | 346.9 | 390.3 | 433.6 |
| Net furnace volume, cu ft | 62.5 | 67.7 | 85.4 | 94.2 | 118.5 | 149.9 | 164.1 | 185.1 | 228.2 | 271.3 | 333.5 | 348.7 | 393.1 | 437.6 |
| Safety valve capacity lb steam/hr | 3,432 | 4,000 | 4,864 | 5,720 | 7,144 | 8,576 | 10,000 | 11,432 | 14,288 | 17,144 | 20,000 | 22,856 | 25,712 | 28,568 |

Fig. 1-2. Data of SBI-rated steel boilers for steam or hot-water heating.



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and projected area of headers. (See the section on safety valve calculation, Chap. 13.) Heating surface is another method of measuring boiler output.

**Q** What is meant by a *boiler horsepower*?

**A** This is an old method of rating output, dating back to boiler–steam engine usage. But it is slowly being replaced by the Btu-per-hour-output method or the pounds-per-hour-output method. A boiler horsepower (boiler hp) is defined as the evaporation into dry saturated steam of 34.5 lb of water per hour at a temperature of 212°F. Thus 1 boiler hp by this method is equivalent to an output of 33,475 Btu per hr and was commonly taken as 10 sq ft of boiler heating surface. But 10 sq ft of boiler heating surface in a modern boiler will generate anywhere from 50 to 500 lb of steam per hour. Today the capacity of larger boilers is stated as so many *pounds of steam per hour*, which is simple and sensible, instead of in terms of boiler hp.

**Q** Is there any movement by manufacturers to *standardize ratings* under a common term for heating boilers?

**A** Yes. There is a movement to standardize terminology, but past usage by owners, users, contractors, mechanics, and operators is not easy to ignore. Just remember that English is easier to write than Chinese, but it is hard to sell the idea to the Chinese. Today the Btu-per-hour method is favored.

Also involved is competition among manufacturers as to how to rate the output in a competitive manner and not jeopardize the past ratings of their product. But it does point out that care should be taken not only in specifying the boiler capacity required, but also in matching this capacity with the manufacturer's listing of output.

**Q** We know that a steam boiler is potentially dangerous as a source of explosion, but how can a hot-water boiler *explode*, since it is filled with water at all times?

**A** Figure 1-3 illustrates a typical hot-water-heating boiler setup. Explosions occur in hot-water boilers from the following two very basic elementary sources (assuming improper safety-valve protection).

1. In a runaway firing condition (defective temperature cutout switch) the water turns into steam. Then the boiler becomes a high-pressure steam boiler for which it was not designed. Thus the pressure buildup can lead only to an explosion, with the compressed gas (steam) causing destruction until reduced to atmospheric pressure. For example, take a basement wall measuring 7 × 20 ft (140 sq ft). If 100 psi acts on this wall, a force of 2,016,000 lb will push against the wall (1,013 tons), which it was not built to withstand.

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2. Even if water does not reach the steam state, in a runaway firing condition, the water will get hotter and hotter, and the pressure will build up as more heat is applied. If the boiler ruptures while full of water above 212°F, it will flash into steam when relieved at atmospheric pressure. The flashing will be so spontaneous that pressures corresponding to saturation temperature will build up in the room where the boiler is located. This pressure buildup will depend on the amount of water in the boiler, the size of the room, the temperature of the water, leakage from the room, etc.

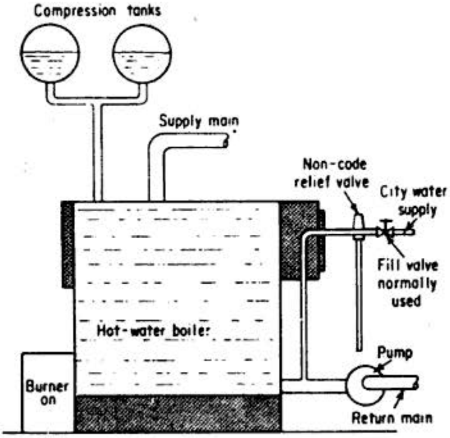


**Fig. 1-3. Non-Code hookup of hot-water-heating boiler.**

**Q** What can cause an overfiring condition of a *hot-water boiler*?

**A** Overfiring may be caused in numerous ways, such as:

1. Failure of a limit control to stop the burner because of a relay or mechanical defect.

2. Mechanical failure of a fuel valve or dirt lodged in a valve so it cannot close.

3. Burner on manual operation with no one watching the temperature.

4. Residual heat with coal firing, with no one watching the temperature.

5. Burner considerably oversized in relation to the boiler and the system. Also if demand is mild on a day of use with pump not operating.

6. Wiring short, causing controls to be bypassed.

7. Fusing of contacts on a *stop-go* switch into the *go* position.

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8. Solenoid- or air-operated valves isolating the boiler from the load because of mechanical or electrical defect of the controls on the solenoid or on the air *stop-go* device.

**Q** If a *liquid relief valve* is installed on a hot-water boiler, would not this release the increased volume of steam?

**A** No, because such a valve may be sized to handle liquids only. In a runaway firing condition, the water will flash into steam with approximately a thousandfold increase in volume. Obviously, the lifting of a typical liquid-type relief valve is not adequate to handle this volume of steam. Thus the pressure would still build up, causing rupture and property destruction.

**Q** Is any device for overpressure protection required on a hot-water boiler or on a hot-water heater?

**A** Yes. A safety relief valve of ASME-approved design is required, which must be set for the highest pressure allowed on the boiler. And it must be stamped to show Btu capacity (in Btu per hour) to match the Btu output (in Btu per hour) of the boiler or heater.

**Q** If a hot-water storage tank is heated by a *steam coil*, is a Btu-type safety relief valve required on the tank?

**A** Yes. If the steam coil uses steam from a low-pressure boiler and the boiler has a proper 15-psi safety valve, a safety relief valve (minimum 1-in. diam) must be installed on the tank. But the relief valve on the tank must be set *at* or *below* the allowable working pressure of the tank. If the tank is supplied by steam from a steam line, the following precautions are required:

1. The pressure of the steam used in the coil cannot exceed the safe working pressure of the hot-water tank.
2. A combination pressure-Btu (ASME type) relief valve is required on the tank, set at or below the maximum pressure allowed on the tank. The relief valve must have a relieving capacity based on the steam coil Btu heat transfer rating.

**Q** Can *low water* occur in a hot-water-heating-type boiler?

**A** Yes. There are numerous reasons, such as the following: (1) Loss of water due to carelessness in (*a*) draining the boiler for repair or summer lay-up without eliminating the possibility of firing, (*b*) drawing hot water from the boiler; (2) loss of water in the distribution system because of (*a*) leaks in the piping caused by expansion breakage or corrosion, (*b*) leaks in the boiler, (*c*) leaks through the pump or other operating equipment; (3) relief valve discharge caused by overfiring; (4) closed or stuck city makeup line.

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NOTE: Many boilers are damaged because of a common misconception that a pressure-reducing valve, used to fill a hot-water system initially, will keep the boiler and system full under all circumstances. With a 30-psi relief valve and a pressure-reducing valve which opens at 12 psi and closes at 16 psi, it becomes obvious that the pressure-reducing valve cannot supply water during the time the relief valve is functioning.

CAUTION: If a hand-fill valve is used, then any leak in the system can quickly cause a low-water condition. Also don't forget that the makeup water may not match the burner's capability for generating steam, as on larger heating boilers.

**Q** In addition to the ASME pressure Btu safety relief valve, what other *safety relief device* should be installed on a hot-water-heating boiler?

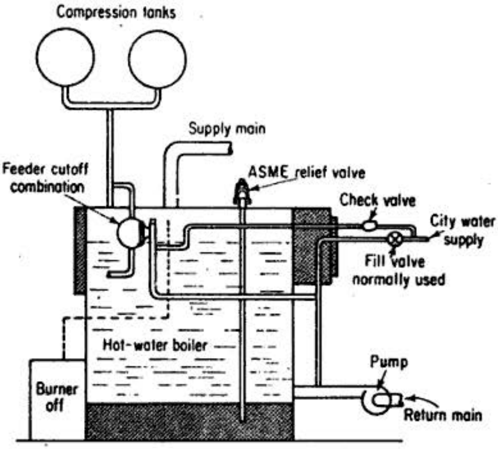


**Fig. 1-4. Preferred hookup of hot-water-heating boiler.**

**A** A low-water fuel cutoff for an automatic-fired boiler, hooked up as shown in Fig. 1-4. Note that the safety relief valve is connected to the boiler proper. A low-water fuel cutoff is also included to guard against low-water failure.

**Q** What size *expansion tanks* are required on a hot-water heating boiler of the closed type?

**A** The required minimum capacity of the air cushion tank (mandatory to have when system is of the closed type) may be determined as follows:

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| EDR (equivalent direct radiation), sq ft | Boiler output, Btu/hr | Required size tank, gal |
|---|---|---|
| Up to 350 | 52,500 | 18 |
| Up to 450 | 67,500 | 21 |
| Up to 650 | 97,500 | 24 |
| Up to 900 | 135,000 | 30 |
| Up to 1,100 | 165,000 | 35 |
| Up to 1,400 | 210,000 | 40 |
| Up to 1,600 | 240,000 | 20 (2 tanks) |
| Up to 1,800 | 270,000 | 30 (2 tanks) |
| Up to 2,000 | 300,000 | 35 (2 tanks) |
| Up to 2,400 | 360,000 | 40 (2 tanks) |

For systems with more than 2,400 sq ft of equivalent direct water radiation (EDR), the required capacity of the cushion tank shall be increased on the basis of 1 gal tank capacity per 33 sq ft of additional EDR. The above table is based on the following formula, which should be used if all information required is available:

$$Vt = \frac{(0.00041T - 0.0466)\ Vs}{(Pa/Pf) - (Pa/Po)}$$

where $Vt$ = minimum volume of expansion tanks required, gal
$Vs$ = volume of hot water system, not including tanks, gal
$T$ = average operating temperature, °F
$Pa$ = atmospheric pressure (absolute, not gage pressure)
$Pf$ = fill pressure (absolute, not gage pressure)
$Po$ = maximum operating pressure (absolute, not gage pressure)

**Q** On cast-iron steam-heating boilers, where should the *makeup* water be introduced to the boiler?
**A** Always to the return line, never to a cast-iron section, as this may thermal-shock the section and cause it to crack.

**Q** What is a Hartford loop on a steam-heating boiler?
**A** The Hartford loop (Fig. 1.5) is the piping connecting the steam supply line with the condensate return line at the middle of the loop. The loop then is fed to the bottom of the boiler. This is used in a gravity return system and ensures a water level *above* the lowest safe water level, which could otherwise occur when the boiler is firing (and the steam pressure is higher than the condensate return pressure).

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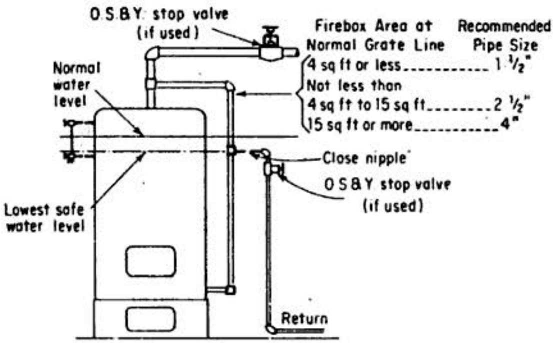


**Fig. 1-5. Recommended return-pipe loop connection (Hartford loop.**

**Q** Are *stop valves* on the steam supply line required for a single boiler installation that is used for low-pressure heating?

**A** Not if there are no other restrictions in the steam and condensate line and all condensate is returned to the boiler. But if a stop valve (or trap) is placed in the condensate return line, a valve is required on the steam supply line.

**Q** Is a stop valve required on the steam supply line where *more than one heating boiler* is used on the same steam supply system?

**A** Yes. A stop valve must be used on the steam supply line from each boiler and also on the condensate return line to each boiler.

**Q** In a steam-heating boiler installation, is it permissible to use the *same pipe* to distribute the steam and also to return the condensate?

**A** Yes. This is called a one-pipe system, whereas a two-pipe system has the steam going out from the boiler in one pipe and condensate returning in another pipe. But the one-pipe system is susceptible to water hammer (at elbows and dead pockets). Thus the high-velocity steam will drive the returning water against the elbows or dead pockets of the piping with an effect similar to a hammerblow. The one-pipe system is becoming obsolete.

**Q** What is the difference between a *gravity return* and a *mechanical return* on a steam-heating system?

**A** When all the heating elements such as radiators, convectors, and steam coils are located above the boiler and no pumps are used, it is called a gravity return, as all the condensate returns to the boiler by gravity. If traps or pumps are installed to aid the return of condensate,

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the system is called a mechanical return system. In addition to traps, this system usually includes a condensate tank, a condensate pump, or a vacuum tank or vacuum pump.

**Q** What is the advantage of a *vacuum-pump return system?*

**A** The supply steam pressure required to force the steam up a riser will be less. Also, greater circulation of steam and condensate through the piping system can be obtained, thus accomplishing faster heat transfer.

**Q** How is the size of the condensate tank required for a steam heating system determined?

**A** This depends on how fast circulation is obtained on the condensate and return line. For example, in a high-head installation, the condensate will return faster than in a spread-out installation of low head. Generally, a condensate tank should be about one-half the output rating of the boiler. This means that the condensate tank should be sized to handle one-half the pounds-per-hour rating of the boiler. Thus a boiler rated at 5,000 lb per hr would require the following size condensate tank by this rule:

$$\frac{5{,}000}{2} = 2{,}500 \text{ lb}$$

$$\frac{2{,}500}{8.33 \text{ lb/gal}} = 300 \text{ gal}$$

But this should be increased by 25 percent as only 75 percent of the tank will normally be filled. Thus a tank of 375 gal is required.

> NOTE: Condensate tank sizes may be governed by local plumbing and piping codes, so always check them. This is not a boiler code item.

**Q** Some cast-iron and steel heating boilers are stamped *15 psi* steam and *30 psi* water. Can this type of boiler be used for hot water (hw) supply service with a city pressure of 75 psi? (Assume that there is no coil in the boiler.)

**A** No. The maximum water pressure allowed on this boiler is 30 psig. A hot-water-supply boiler designed for the maximum pressure of 75 psi is required, or a reducing valve must be installed on the city line to reduce the pressure to 30 psi or less. A heat exchanger can also be used with one side for hw supply, the other side using the hw from the boiler.

**Q** Some of the *older heating boilers,* both of cast-iron and steel construction, are not stamped as to pressure. What is the allowable pressure on these boilers?

**A** The maximum allowable pressure is 15 psi steam and 30 psi water.

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This is the standard, old ASME specification before the states adopted stamping laws for low-pressure heating boilers.

**Q** To *what pressure* can hw heating or hw supply boilers be built and still qualify as low-pressure boilers?
**A** Pressure of 160 psi and 250°F. If either is exceeded, the boiler qualifies as a high-pressure boiler and must be built under Section I of the ASME Code, Power Boilers.

**Q** What *hydrostatic test* is required on hw heating or hw supply boilers built of cast-iron and operating over a pressure of 30 psi?
**A** Each section of a cast-iron boiler must be subjected to a hydrostatic test of 2½ times the maximum allowable pressure *at the shop* where it is built. Cast-iron boilers marked for working pressures over 40 psi must be subjected to a hydrostatic test of 1½ times the maximum allowable pressure in the field (when erected and ready for service). After the boiler is in service and a hydrostatic test is required, the test shall be at 1½ times the maximum allowable pressure.

**Q** What *stamping* does the ASME require on cast-iron boilers?
**A** The marking shall consist of the following: (1) manufacturer's name, (2) maximum allowable pressure in psi, (3) capacity in pounds per hour for steam, or Btu per hour for water service.

**Q** The symbol NB is often noted on boilers, with a number following it. What does this stand for?
**A** NB stands for National Board of Boiler and Pressure Vessel Inspectors. It means that the boiler's design and fabrication were followed in the shop by an NB-commissioned inspector, including the witnessing of the hydrostatic test and signing of data sheets required by the ASME.

**Q** If a high-pressure boiler is used for heating low-pressure apparatus through a *reducing valve*, what should be guarded against on the low-pressure side of the system?
**A** Overpressure, due to lack of proper pressure setting and capacity of a safety valve (sv) or to no sv should the reducing valve fail or stick in the open position. To guard against overpressure, install a safety relief valve on the low-pressure side of the reducing valve, with adequate capacity in pounds per hour to match the reducing-valve capacity.

The pressure setting of the sv should always be based on the maximum allowable pressure of the weakest equipment on the low-pressure side of the reducing valve. The sv should be as near the reducing valve as possible. In the event of multiple vessels on the low-pressure side of the reducing valve, do *not* combine total svs on each vessel. *Always assume* only one vessel may be operating, and, therefore, total relieving capacity of all svs may be *no protection*.

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For example, suppose there are six kettles, each with an sv rated for 200 lb per hr, supplied by a common steam line off a reducing valve. If the reducing valve can pass 900 lb per hr, and if five kettles are shut off, the vessel operating will not be properly protected. Why? Because it will have only 200 lb per hr of protection against 900 lb per hr of steam flow. In this type of situation, an sv on the common line, right after the reducing valve, is required, with a minimum relieving capacity of 900 lb per hr. Proper *overpressure* protection requires both pressure and capacity to be matched with the reducing valve capacity to avoid a serious explosion. There have been numerous explosions for this very reason, *lack of overpressure protection on the low-pressure side of reducing valves.*

The NB has drawn up the following method to calculate the required relief-valve capacity in pounds per hour on the low-pressure side of a reducing station. These rules are drawn from thermodynamic principles, involving flow through a nozzle. A coefficient of discharge had to be assumed (around 70 percent). Check with the reducing-valve manufacturer for the maximum flow and then install his recommended capacity. In lieu of data from the manufacturer, use the following formula:

$$RVC = \tfrac{1}{3} \times OC \times VSPA$$

where RVC = relief valve capacity required, lb of steam/hr
OC = orifice capacity, lb steam/(hr) (sq in.) (Fig. 1-6)
VSPA = valve size pipe areas, sq in. (Fig. 1-7)

Where a pressure-reducing valve is supplied by steam from the boiler, the capacity of the sv or valves on the low-pressure side of the system need not exceed the capacity of the boiler for obvious reasons.

NOTE: Most pressure-reducing valves are arranged with a valved bypass, which also acts as a potential steam source hazard in case the bypass is left open. Where such a valved bypass is used, the following formula should be used to determine the steam flow rate through the *bypass:*

$$RVC = \tfrac{1}{2} \times OC \times BPA$$

where RVC = relief valve capacity, lb steam/hr
OC = orifice capacity, lb steam/(hr) (sq in.) (Fig. 1-6)
BPA = bypass pipe area, sq in. (Fig. 1-7)

The *larger* of the relief-valve capacities calculated by the above two formulas should be used for selecting the relief valve for the vessel.

EXAMPLE: Suppose a high-pressure boiler operating at 125 psi distributes steam to a series of 40-psi ASME-constructed retorts through

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Orifice Relieving Capacities, lb per hr per sq in. for Determining the Proper Size of Relief Valves Used on Low-pressure Side of Reducing Valves

| Outlet pressure, psi | Pressure-reducing valve inlet pressure, psi | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 125 | 100 | 85 | 75 | 60 | 50 | 40 | 30 | 25 |
| 110 | 4,550 | | | | | | | | |
| 100 | 5,630 | | | | | | | | |
| 85 | 6,640 | 4,070 | | | | | | | |
| 75 | 7,050 | 4,980 | 3,150 | | | | | | |
| 60 | 7,200 | 5,750 | 4,540 | 3,520 | | | | | |
| 50 | 7,200 | 5,920 | 5,000 | 4,230 | 2,680 | | | | |
| 40 | 7,200 | 5,920 | 5,140 | 4,630 | 3,480 | 2,470 | | | |
| 30 | 7,200 | 5,920 | 5,140 | 4,630 | 3,860 | 3,140 | 2,210 | | |
| 25 | 7,200 | 5,920 | 5,140 | 4,630 | 3,860 | 3,340 | 2,580 | 1,485 | |
| 15 | 7,200 | 5,920 | 5,140 | 4,630 | 3,860 | 3,340 | 2,830 | 2,320 | 1,800 |
| 10 | 7,200 | 5,920 | 5,140 | 4,630 | 3,860 | 3,340 | 2,830 | 2,320 | 2,060 |
| 5 | 7,200 | 5,920 | 5,140 | 4,630 | 3,860 | 3,340 | 2,830 | 2,320 | 2,060 |

Fig. 1-6. Table showing orifice relieving capacities needed for sizing reducing valves.

| Nominal pipe size, in. | Standard | | |
|---|---|---|---|
| | Actual ext diam, in. | Approx int diam, in. | Approx int area, sq in. |
| ⅜ | 0.675 | 0.49 | 0.19 |
| ½ | 0.840 | 0.62 | 0.30 |
| ¾ | 1.050 | 0.82 | 0.53 |
| 1 | 1.315 | 1.05 | 0.86 |
| 1¼ | 1.660 | 1.38 | 1.50 |
| 1½ | 1.900 | 1.61 | 2.04 |
| 2 | 2.375 | 2.07 | 3.36 |
| 2½ | 2.875 | 2.47 | 4.78 |
| 3 | 3.5 | 3.07 | 7.39 |
| 3½ | 4.0 | 3.55 | 9.89 |
| 4 | 4.5 | 4.03 | 12.73 |
| 5 | 5.563 | 5.05 | 19.99 |
| 6 | 6.625 | 6.07 | 28.89 |
| 8 | 8.625 | 8.07 | 51.15 |
| 10 | 10.750 | 10.19 | 81.55 |
| 12 | 12.750 | 12.09 | 114.80 |

NOTE: In applying these rules, the area of the pipe is always based upon standard weight pipe and the inlet size of the pressure-reducing valve (high pressure inlet side to reducing valve).

Fig. 1-7. Table showing valve size pipe areas.

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a 1½-in. pressure-reducing valve provided with a 1-in. globe valve bypass. Determine the proper ASME relief-valve protection for the retorts. Using data in Figs. 1-6 and 1-7 and the first of the two formulas above:

$$W = \frac{1}{3} \times 7{,}200 \times 2.04 = 4{,}896 \text{ lb steam per hr}$$

Checking the bypass steam flow according to the second formula gives:

$$W = \frac{1}{2} \times 7{,}200 \times 0.86 = 3{,}100 \text{ lb steam per hr}$$

The potential steam flow through the pressure-reducing valve is 4,896 lb per hr rated capacity, or 4,896 × 1,000, or 4,896,000 Btu per hr. This is the minimum capacity required of the sv to protect the low-pressure side against overpressure.

**Q** To what does the term *packaged boiler* refer?

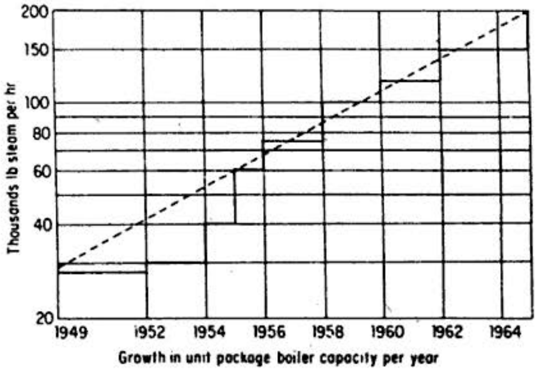


**Fig. 1-8. Growth in capacity of packaged boilers.**

**A** A packaged boiler is a completely factory-assembled boiler, either water tube, or fire tube, including boiler firing apparatus, controls, and boiler safety appurtenances. The trend today is to apply these units for industrial use as well as for some power generation. In the low-pressure field, most boilers are packaged units, unless a problem arises at the installation site because of headroom, access opening into the plant, etc. Figure 1-8 shows the growth in the size of boilers being built of packaged design.

A shop-assembled boiler is less costly than a field-erected unit of equal steaming capacity. While it is not an off-the-shelf item, it can

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generally be put together and delivered much faster than a field-erected boiler. Installation and start-up times are substantially shorter. Shop-assembled work can usually be better supervised and done at lower cost. In addition, packaged boilers require much less space, often 50 percent less in overall volume. Pressures are also rising in packaged boilers. Latest trends indicate that 950 psi is available, and higher pressure will be built into these units.

**Q** Name five important factors to consider when selecting a boiler.

**A** 1. Because most boiler manufacturers design their boilers around the fuel to be burned, carefully consider the available fuel. Fuel selection may be a question of local price conditions, licensing laws for operators (see *Standard Plant Operator's Questions and Answers*, Vol. II for 56 pages of requirements in the United States and Canada), smoke ordinances, auxiliary equipment needed to burn the fuel, availability of a second fuel to supplement the primary fuel during normal operation (or emergency conditions), and experience of operating personnel with a particular fuel.

2. Capacity and pressure required will determine the type of boiler, since some boilers are limited on capacity and pressure, others are not.

3. Space conditions in the building or property will have a marked effect on the capacity of the unit considered. They will also affect the type of firing and even the fuel that can be used.

4. Cost is a very vital element, but a word of caution. First cost may be high on one make of boiler, but it may more than compensate by lower operating and maintenance expenses. So a careful evaluation is required rather than selection of the unit on first cost alone.

5. Individual preference may have a heavy bearing on the type of boiler selected, just as it does on other equipment. Experience with a scotch marine boiler, for example, may cause the user to prefer this type of boiler.

**Q** What is the most common *size* boiler sold in the United States?

**A** A capacity range of 50,000 lb per hr or less accounts for 60 to 80 percent of unit sales per year.

**Q** Of what *pressure range* are these boilers?

**A** Most of these boilers are under 300 psi, indicating the tremendous amount of boilers being used at moderate pressures and temperatures for process, industrial work, incidental power, and heating purposes.

**Q** What is the trend for pressure and capacity in the public utility boiler field?

**A** The trend is for single boiler-turbine installations: one boiler supplies one steam turbine-generator. While 5,000 psi and 1100°F tempera-

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tures are presently accepted, pressures of 10,000 psi are being considered. Capacity is increasing, and the largest units are of capacities of well over 6,000,000 lb per hr.

**Q** Is higher pressure and temperature progress gradual because we cannot calculate the stresses imposed on such units?
**A** No; although partly true, the main problem is developing materials that will physically and chemically withstand higher temperatures and pressures. The goal of metallurgists in the boiler field and the steel industry is to develop alloys that have the following desirable characteristics. (1) high-temperature strength to resist long-term creep, (2) structural stability to resist intergranular crystal changes from service conditions, (3) surface stability to resist corrosion, erosion, and oxidation both on the waterside and fireside, and (4) alloys that can be reasonably well machined, welded, and otherwise fabricated for the boiler shapes required and that can also be reasonably priced for boiler and pressure-vessel usage.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less
*Power Handbook*, 64 pages
*Steam Generation*, 48 pages

Books
Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.
Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.
*ASME Boiler and Pressure Vessel Code*, Section IV, Low-pressure Heating Boilers; Section VIII, Unfired Pressure Vessels; Section I, Power Boilers. American Society of Mechanical Engineers, New York.

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# 2

# HEAT TRANSFER AND DESIGN

**Q** Why are boilers shaped and constructed in so many different ways?

**A** Early boilers were very simple, usually a shell or cylinder full of water suspended over a brick-enclosed fire. Heat was applied on the bottom of the shell, and there were no tubes or flues. But as the science of heat transfer became better known, designers began to apply this knowledge to the simple shell vessels so as to produce more efficient and economical boilers. Thus a variety of specialized forms and arrangements are used to extract as much heat as possible from the fuel source.

New designs had also to be evolved for the greater capacity that was required, for new fuels, new materials, rising pressures and temperatures, new methods of construction, and better knowledge of stresses. And the search for better boilers to convert the inherent heat energy of a fuel into a useful heat medium goes on year after year.

**Q** Is heat a form of energy?

**A** Yes. From an atomic point of view, heat makes the atoms, or molecules, of a substance move around more rapidly. For example, if the atoms of a gas are confined in a closed vessel, the pressure rises in the vessel. But as we know when pumping a bicycle tire full of air by hand, it takes work to raise the pressure. Fact is, the relation between work and heat is called the *mechanical equivalent of heat* and is equal to 778 ft lb of work per Btu.

The Btu (British thermal unit) is the amount of heat required to raise one pound of pure water one degree Fahrenheit at normal atmospheric pressure.

**Q** The shapes of a boiler are influenced by the arrangement of the heat transfer components. How is heat transferred from one substance to another?

**A** The basic laws of heat transfer stipulate that when energy is transferred from one body to another a temperature difference must exist. Another fundamental law is that heat may be transferred from a high-temperature region to one of lower temperature, but *never* from a lower



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temperature region to one of higher temperature. And this flow of heat may occur in one of, or a combination of, these three ways: (1) *conduction,* (2) *convection,* and (3) *radiation.* These three methods of heat transfer are utilized in boiler design to convert fuel energy into a useful heat medium.

**Q** What is *conduction?*

**A** Conduction is the transfer of heat from one part of a material to another or to a material with which it is in contact. Heat is visualized as molecular activity—crudely speaking, as the vibration of the molecules of a material. When one part of a material is heated, the molecular vibration increases. This excites increased activity in adjacent molecules, and heat flow is set up from the hot part of the material to the cooler parts. In boilers, considerable surface conductance between a fluid and a solid takes place, for example, between water and a tube and gas and a tube, in addition to conductance through the metal of a tube, shell, or furnace.

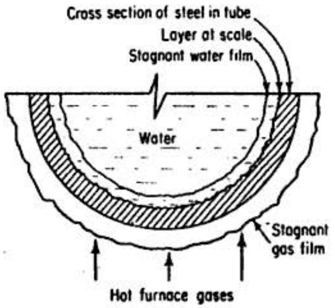


**Fig. 2-1. Film coefficient of stagnant water and gas affect heat transfer through boiler tube.**

While surface conductance plays a vital part in boiler efficiency, it can also lead to metal failures when heating surfaces become over-

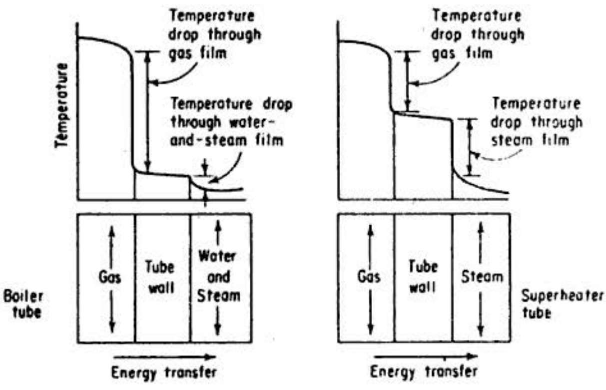


**Fig. 2-2. Temperature gradients from hot gas, through tube wall, to fluid inside, depend greatly on resistance of thin films on tube surfaces.**

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heated, as may occur when surfaces become insulated with scale. The surface conductance, when expressed in Btu per hour per square foot of heating surface for a difference of one degree Fahrenheit in temperature of the fluid and the adjacent surface, is known as the *surface coefficient* or *film coefficient*. Figure 2-1 shows stagnant areas near the tube where the film coefficient will reduce heat transfer. Figure 2-2 shows the effect on the temperature gradient as heat flows across the films and tube metal.

**Q** How is *conductance* expressed?

**A** As the coefficient of thermal (heat) conductivity, defined further as the quantity of heat that will flow across a unit area in unit time if the temperature gradient across this area is unity. In physical units it is expressed as *Btu per hour per square foot per degree Fahrenheit per foot.* Expressed mathematically, the rate of heat transfer $Q$ by conduction across an area A, through a temperature gradient of degrees Fahrenheit per foot $T/L$ is

$$Q = kA\frac{T}{L}$$

where $k$ = coefficient of thermal conductivity.

Note that $k$ varies with temperature. For example, mild steel at 32°F has a thermal conductivity of 36 Btu/(hr) (sq ft) (°F) (ft), whereas at 212°F it is 33.

**Q** How would you define *convection*?

**A** *Convection* is the transfer of heat to or from a fluid (liquid or gas) flowing over the surface of a body. It is further refined into *free* and *forced convection*. Free convection is *natural* convection causing circulation of the transfer fluid due to a difference in density resulting from temperature changes.

EXAMPLE: In Fig. 2-3 the heated water and steam rise on the left, are displaced by cooler (heavier) water on the right. This causes free convection of heat transfer between heat on one side of the U tube and cooler water on the other side. Actually, conduction has to take place first between the gas film and metal of the tube, then the water. But if the water did not circulate, eventually equal temperatures would result. Heat transfer would then cease.

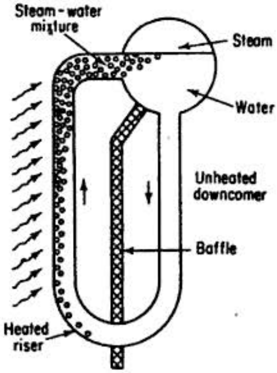


**Fig. 2-3. Heated water rises while cooler water descends to replace it.**

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*Forced* convection results when circulation of the fluid is made positive by some mechanical means, such as a pump for water or a fan for hot gases. The heat transfer by convection is thus aided mechanically.

**Q** How is heat transfer by *convection* expressed?

**A** As *Btu per hour per square foot per degree Fahrenheit.* Calculations of free and forced convections involve fluid flow, streamline flow, turbulent flow, critical velocity, film theory, dimensional analysis, and friction. All these are beyond the scope of this book. But no matter what kind of boiler, remember that heat transfer by convection is involved in water circulation and also, except for atomic plants, in draft or hot gas circulation.

**Q** If forced convection increases the rate of heat transfer by convection, why not add more heating surface and thus increase the overall efficiency of energy conversion?

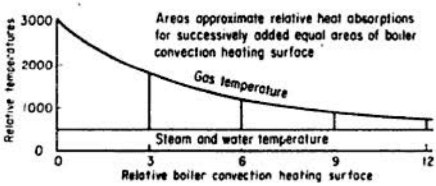


**Fig. 2-4. Adding boiler surface increases heat absorption, then gradually lowers it.**

**A** Adding boiler surface may increase the heat absorption, but as shown in Fig. 2-4, the temperature gradient will drop more and more. Then at some point the gain in efficiency will be far less than the cost of adding heating surface. Further, the mechanical power required for forced circulation will also increase with the addition of heating surface by convection.

**Q** How does the pressure in a boiler affect water circulation by convection?

**A** Note that in Fig. 2-5*a* more tube area is required at lower pressure than higher pressure for the same circulation to exist. But the force producing circulation is less at high pressure than at low pressure. This involves the change in the specific weight of water and steam as pressures increase. The mixture actually weighs less in pounds per cubic foot at higher pressures. For example, in the sketch in Fig. 2-5*b* at the critical pressure (3,206.2 psia) water and steam have the same specific weight. Friction losses due to flow are generally less at higher pressure. This is primarily due to more laminar, or streamlined flow, and less turbulent flow in the tubes.

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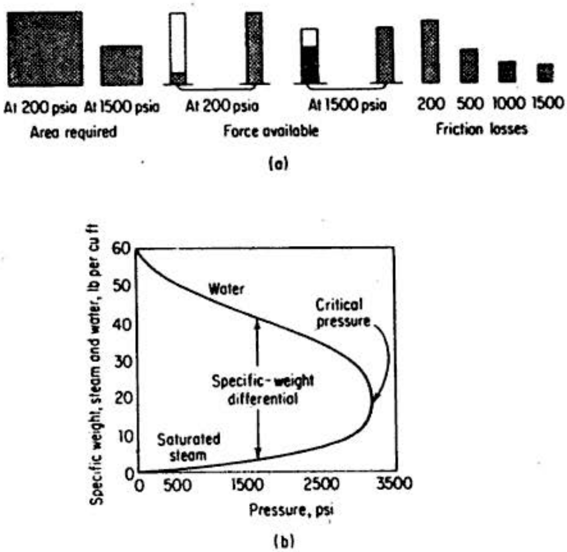


**Fig. 2-5. Forces creating water circulation in a boiler.**

**Q** How does the boiling of water in a tube affect *heat transfer*?

**A** When boiling occurs in a tube, bubbles of vapor are formed and liberated from the surface in contact with the liquid. This bubbling action creates voids (Fig. 2-6*a*) of the on-again-off-again type, because of the rapidness of the action. This creates a turbulence near the heat-transfer surfaces, which generally increases the heat-transfer rate. But the loss of wetness as the bubbles are formed may diminish heat transfer.

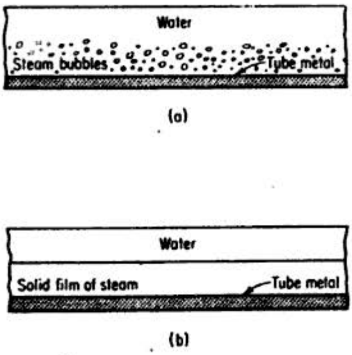


**Fig. 2-6. Bubbles or solid film of steam is formed, depending on pressure.**

Pressure has a marked effect on the boiling and heat-transfer rate. With higher pressures (Fig. 2-6*b*), bubbles tend to give way to what is called film boiling, in which a film of steam covers the heated surface. This phenomenon is very critical in boiler operation, often causing water-

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tube failures due to starvation, even though a gage glass may show water. It is further compounded by the formation of scale and other impurities along the boiling area of a tube.

**Q** Define *radiation*.

**A** *Radiation* is a continuous form of interchange of energy by means of electromagnetic waves without a change in the temperature of the medium between the two bodies involved. Radiation is present in all boilers. In fact, all boilers utilize all three means of heat transfer: *conductance, convection*, and *radiation*.

**Q** With heat transfer playing such an important part in boiler design, how are boilers classified on the basis of *heat* transfer?

**A** There are two broad general classifications, *fire tube* and *water tube*, into which most boilers can be grouped, no matter what the arrangement. The exception is cast-iron boilers, which are grouped separately. A fire-tube (ft) boiler is one in which the products of combustion, or flue-gasses, pass on the inside of the tubes. A water-tube (wt) boiler is one in which water passes on the inside of the tubes. A combination ft and wt boiler is one in which part of the tube arrangement is of the ft type and part is of the wt type.

**Q** What is the principal difference between wt and ft boilers in addition to water and gas passages?

**A** The tubes in the ft boiler are contained within the shell or drum. In contrast, the tubes in most wt boilers are located outside the shell or drum. Because smaller sizes of ft boilers can be built into compact factory-assembled units, this design lends itself to good engineering of the entire assembly, including controls. But as the units become larger, the capacity of the ft boiler becomes limited because of the larger size shell required. It is here that the wt boiler has a distinctive advantage, as tube arrangement can take many different forms to obtain more and more heating surface. Thus the wt units are capable of greater capacity and pressure, which would be impossible in an ft boiler. The largest modern steam generators are of the wt design.

But the wt unit is not limited to only larger sizes. Compact coil-type boilers (see Chap. 6) are also of the wt type. Here the water goes through the coils, while hot gases scrub the outside of the coils. The coil-type boiler is directly competitive with the ft vertical tubular (vt) type boiler.

**Q** Name some advantages and disadvantages of ft boilers.

**A** As a class, ft boilers are of simple and rugged construction and of relatively low first cost. Their larger water capacity makes them somewhat slow in steaming up to operating pressure. But this larger hot-water ca-

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pacity provides accumulator action (heat storing) that makes it possible to meet steam load changes quickly.

Because a sphere is the ideal shape to resist internal pressure, noncylindrical sections and flat surfaces must be stayed to give added resistance to internal pressure. This is a big disadvantage.

In any shell the force tending to burst it along the length is twice that tending to burst it around the girth. In the critical longitudinal direction, the strength required to resist bursting is proportional to the product of pressure and diameter. That is why high pressures and large diameters would lead to extremely thick shell plates. Hence, there is a definite economical limit on pressure (250 psi) and capacity that can be reached with shell-type boilers of the ft type. In the United States, capacity rarely exceeds 25,000 lb of steam per hour, which is roughly 750 boiler hp. In Europe, where larger ft boilers have always been popular and economical and boiler codes are different, units reach 30,000 lb per hr.

**Q** Name five advantages of wt boilers.

**A** Principal advantages are:

1. Greatly higher capacity can be obtained. Thus larger heating surfaces are exposed to the radiant heat of the fire.

2. Because the shell or drum (used for water and steam storage only) is not exposed to the radiant heat of the fire, it is not subjected to overheating. Thus it can be constructed of heavier plate. Accordingly, it can also be designed for much higher pressures.

> EXAMPLE: Fire-tube boilers generally are limited to a maximum design working pressure of 250 psi. Water-tube boilers range from 15 psi to above the supercritical to 5,000 psi.

3. Most parts of the boiler are accessible for cleaning, repair, and inspection.

4. The general design permits higher operating efficiencies.

5. The furnace proportions are such that various fuels can be used without making alterations. Thus, during price fluctuations of various fuels, economy can be gained by using the lower-priced level.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook*, 64 pages

*Steam Generation*, 48 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

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# 3

# FIRE-TUBE BOILERS

**Q** How are tubes attached to the tube sheets in ft boilers?

**A** Tubes in all ft boilers must be rolled and beaded (Fig. 3-1) or rolled and welded. If rolled and welded in high-pressure boilers, see Power Boilers, Section I, ASME Boiler Code. Tubes are beaded to prevent the ends from being burned off by the hot gases in this area. Beading also increases heat transfer near the tube sheet and tube juncture.

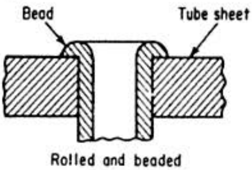


**Fig. 3-1. Rolled and beaded tube for fire-tube boiler.**

**Q** What would cause a fire tube to burst or explode?

**A** Fire tubes are normally under external pressure; thus they may collapse but not burst. The biggest problems are loosening of tubes in the tube sheet, cracking, burning, and corrosion of tube ends, waterside pitting and corrosion leading to leakage, fireside corrosion and pitting leading to leakage or pulling out of the tube sheet (due to poor rolling). Also scale buildup on the water side, leading to overheating and possible sagging and loosening in the tube sheet.

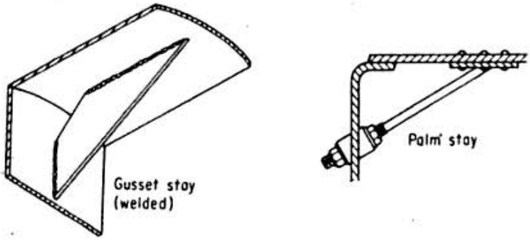


**Fig. 3-2. Diagonal stays used in fire-tube boilers.**



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**Q** What is the Code requirement for stay bolts, or stays screwed through plates?

**A** See Figs. 3-2 and 3-3. The ends of the stay bolts, or stays screwed through the plate, must extend beyond the plate not less than two threads when installed, after which the ends must be riveted over without excessive scoring of the plate. They may also be fitted with threaded nuts, provided the stay bolts, or stays, extend through the nut.

If stay bolts are solid, 8 in. in length or less, and threaded, they must be drilled with telltale holes (Fig. 3-3) at least 3/16 in. in diameter to a depth extending at least ½ in. beyond the inside of the plate. If the stay bolt is reduced in diameter between the ends, the telltale hole must extend ½ in. beyond the point where the reduction in diameter begins. For bolts over 8 in. in length, telltale holes are not required, nor if the stay bolt is attached by welding and Code rules have been followed. Since stay bolts usually break near the plate supported, warning is given by water flashing from the telltale hole.

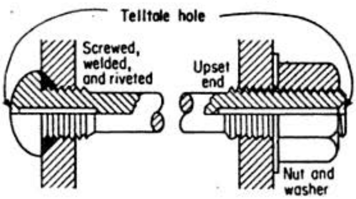


Fig. 3-3. Stay bolt used for strengthening flat areas.

**Q** What are the requirements for welded-in stay bolts on high-pressure boilers?

**A** The stay bolts and stays must be inserted in countersunk holes through the plate, except for diagonal stays, which can be fillet-welded to the shell but not the head, provided the weld is not less than ⅜ in. and the fillet weld continues the full length of the stay. Stay bolts inserted by welding cannot project more than ⅜ in. beyond the plate exposed to products of combustion. The welding must be stress-relieved after it is completed. Radiographing (x-ray photograph) is not required.

## HORIZONTAL-RETURN-TUBULAR BOILERS

**Q** What was the first boiler evolved from the simple shell boiler design?

**A** The horizontal-return-tubular (hrt) boiler (Fig. 3-4), available today in smaller sizes as packaged units. The hrt boiler consists of a cylindrical shell, today usually fusion-welded, with tubes of identical diameter running the length of the shell throughout the water space. The space above the water level serves for steam separation and storage. A baffle plate (or dry pipe) is ordinarily provided near the steam outlet to obtain greater steam dryness.

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The hrt boiler is simple in construction, has a fairly low first cost, and is a good steamer. It is more economical than the vertical tubular or locomotive types, but the scotch marine boiler is replacing it. One disadvantage is that hard deposits of scale are difficult to remove from water surfaces of inner rows of tubes. Another disadvantage is the danger of burning the shell plates above the fire if thick scale or deposits of mud form on the waterside on these plates. But difficulty of cleaning scale from the tubes holds true for all other types of ft boilers.

Hrt boilers are not very practical in shell sizes over 96 in. in diameter or for pressures exceeding 200 psi. Thick plates for higher pressures exposed directly to the flames would deteriorate very rapidly from overheating, because of poor heat transfer to the water. This could lead to bags (bulges) in the shell.

Bags also result when mud or other sediment from water settles on the bottom of the shell. For this reason an hrt boiler should be pitched

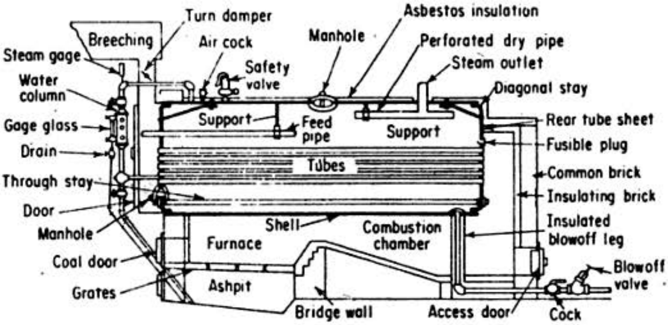


**Fig. 3-4. Horizontal-return-tubular boilers are still used today.**

1 to 2 in. toward the blowdown connection. Also, proper blowdown and water chemical treatment must be used to avoid scale or sediment formation and to keep solids to a minimum.

**Q** Why is a brick pier (Fig. 3-4) built in front of the blowdown pipe on older hrt boilers, and what other precautions are needed on blowdown pipes?

**A** On older hrt boilers the blowdown line is in the path of the hot gases, thus must be protected from overheating. A V-shaped pier of firebrick, usually in front of the blowdown pipe, deflects the hot gases.

CAUTION: If not properly protected, the blowdown pipe may melt under certain conditions and drain the boiler, possibly leading to a serious explosion.

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The blowdown connection is usually a steel pad on the shell. On older boilers, the blowdown pipe runs through a section of the furnace and out through a bushing in the rear brick wall. Three points of possible distress are:

1. The blowdown pad and the screwed or welded-in blowdown pipe may develop leakage due to expansion and contraction.
2. The blowdown pipe firebrick protective wall may deteriorate, leading to possible overheating of the blowdown pipe, then rupture, thus draining the boiler.
3. The rear brick wall may settle and bear on the blowdown pipe where it goes through the wall, causing the pipe to break.

**Q** Describe the outside suspension type of setting for an hrt boiler.
**A** See Fig. 3-5. This type of steel structural suspension support is required on all hrt boilers 72 in. in diameter and over, as brickwork cannot

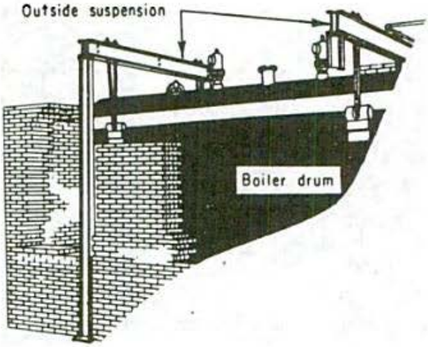


**Fig. 3-5. Horizontal-return-tubular boiler of over 72-in. diam must have outside suspension.**

support this heavier weight. On older boilers the pad on the shell was riveted to the shell, with rivets designed with a safety factor of 12½. But if the pads are welded, full peripheral fillet welds are required, and these must be stress-relieved on high-pressure boilers. Radiographing is not required.

**Q** How is feedwater introduced into an hrt boiler?
**A** Usually through the front head or top part of the shell by means of a bushing. If the shell is 40 in. in diameter, the discharge of the feedwater line must be about three-fifths the length of the boiler from the hottest end. This prevents solids from the feedwater settling on the hottest boiler surfaces.

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**Q** What are the most common staying methods used on an hrt boiler?
**A** Four methods are used:

1. Through stays below the tubes because there is insufficient room for other stays, which would accumulate deposits more readily.

2. Diagonal stays above the tubes to support the flat unstayed tubesheet above the tubes.

3. Gusset stays above the tubes.

4. If not over 36 in. in diameter and not over 100 psi, structural shapes can be used if arranged according to ASME Code requirements.

**Q** What causes water to circulate in an hrt boiler?
**A** As Fig. 3-6 shows, feedwater is introduced near the bottom of the shell, is heated, and thus rises to the top as it lowers in density. The

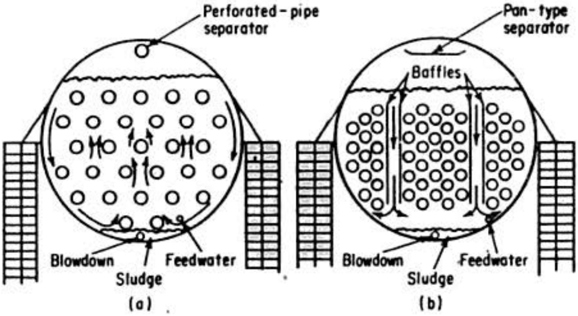


**Fig. 3-6. Two methods of water circulation in horizontal-return-tubular boilers.**

staggered tubes (Fig. 3-6*a*) allow better heat transfer because upcoming water must flow around a greater surface area of each hot tube. As Fig. 3-6*b* shows, baffled passages between parallel tube arrangements allow colder (heavier) water to drop unobstructed to the bottom, where it is heated and must wash against the hot tubes in rising.

**Q** Name three causes of bagging (bulging) of the shell of an hrt boiler.
**A** 1. Oil (from lubricated pump rods, etc.) getting into the boiler feedwater and being carried to the lower part of the shell, which is exposed to fire, and thus causing overheating.

2. Scale or mud (from sediment in the water) deposits on the lower portion of the shell, thus restricting heat transfer.

3. Excessively localized flame on a portion of the shell, thus causing overheating.

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**Q** What is the difference between a bag and a blister on the shell of a boiler?

**A** A bag is a bulged-out section of a portion of the shell, extending through the full thickness of the shell, caused by overheating and pressure. A bag can be driven (hammered) back if the remaining thickness is at least as strong as the longitudinal joint and if the quality of the metal has not been affected. A blister is actually a separation of the metal from the shell plate, caused by impurities rolled into the shell plate when formed. But only the outside layer will blister from the heat because the remaining thickness is not affected. A blister cannot be driven back but must be cut out and the edges trimmed; if the remaining metal is sound, the pressure on the boiler must be reduced to correspond to the thickness of the remaining sound metal. If pressure cannot be reduced, the entire blistered section, including sound metal, must be cut out, a flush-welded patch formed and butt-welded in, with localized stress relieving required after welding. If the diameter of the blister is over 8 in., the weld must be radiographed. After this is shown to be satisfactory, a hydrostatic test of 1½ times the maximum allowable pressure is required to check the repair. All welding must be done by a certified weldor, and the repair must be approved by a commissioned boiler inspector.

> WARNING: If a repair of this kind is made without the approval of a commissioned boiler inspector, the entire boiler can be condemned by the local enforcing authorities, and in a non-Code state, the insurance on the boiler may be canceled.

**Q** Is oil at the waterline of an hrt boiler serious? How is oil removed from inside the boiler?

**A** Oil on any part of the waterside is serious. First check the fuel-oil heater (if oil-fired) for leaks, then the piping to the oil heater. As soon as the source of contamination is found, take measures to prevent oil from entering the boiler. A check valve installed on the steam line supplying a fuel-oil heater will prevent oil from backing into the boiler. Condensate should go to an open drain. If condensate goes to a condensate tank, install an oil separator and keep it in good condition. Also, there are double-shell oil heaters on the market which confine the leakage of an oil break to the inner shell.

Oil may be removed from a boiler by boiling it out with soda ash and caustic soda, using 1 lb of each per 1,000 lb of water in the boiler. Carry the boiler at about 5 psi pressure and continue boiling for two or three days, depending on the extent of oil contamination. Then empty the boiler, wash it thoroughly with fresh water, and again check the internal surfaces.

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**Q** What is the lowest permissible water level in an hrt boiler?

**A** The lowest level should never be less than 3 in. above the tubes.

**Q** During an inspection, what are some of the areas to check carefully on an hrt boiler?

**A** Internally, on the section above the tubes, check for corrosion and pitting. Look for grooving on the knuckles of heads, shells, welds, rivets, and tubes. Check the seams for cracks, broken rivet heads, porosity, and any thinning near the waterline of the shell plate. Check all stays for soundness and proper tension. Examine the internal feed pipe for soundness and support, and see that it is not partially plugged. Check the openings to the water column connections, safety valve, and pressure gage for scale obstruction. Also check shell and tube surfaces for scale buildup. Follow the same procedure internally below the tubes. Then check the opening to the blowdown connections and make sure that the bottom of the shell is pitched toward blowdown and that it has no blisters or bulges.

Externally, remove the plugs from the crosses of water column connections and make sure they are free of scale. Examine blowoff piping pad and the blowoff pipe to make sure it is protected from the fire, that the pipe is sound, and that blowoff valves are in good order. Examine tube ends and rivets or welds for cracks and weakening of the tube to the tube sheet connection. Check for fire cracks around the circumferential seam and for leakage at the calked edge. Then examine the setting and supports for soundness.

## ECONOMIC, OR FIREBOX, BOILER

**Q** What boiler is an adaptation of the hrt boiler?

**A** The so-called economic, or firebox, type in which the flue gases make two or three passes (Fig. 3-7), built for both low and high pressure. The boiler is self-supported in its special casing, and thus requires little brickwork. But this type has the same size and pressure limitations as the hrt boiler. The flat surfaces on each side require staying. The front water legs are stayed to each other by means of stay bolts. In the back, the side sheets are stayed by through-braces passing between the horizontal tubes.

The economic-type boiler is considered to be an externally fired, ft design because its steel-encased combustion chamber is not a pressure part of the boiler. Boilers of this type are usually shipped as a unit and thereby qualify as being among the first so-called compact designs.

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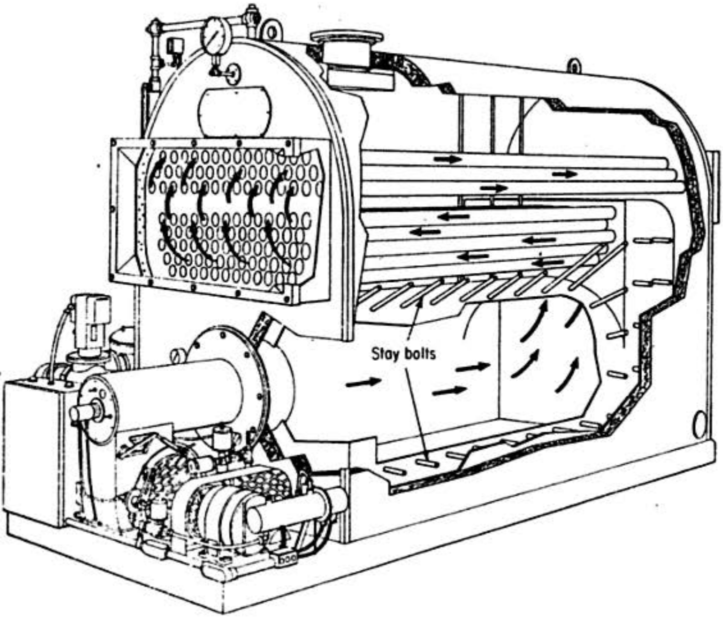


**Fig. 3-7. Economic three-pass firebox boiler has arched crown sheet and many stayed surfaces.**

## LOCOMOTIVE FIREBOX BOILERS

**Q** Describe the locomotive firebox (lfb) boiler and name all its parts.
**A** See Fig. 3-8. Like the vt and scotch marine types, the lfb boiler is an internally fired ft unit. But its shell is horizontal, and the firebox is not contained within the cylindrical portion of the boiler. The firebox is rectangular in shape with a curved top known as a crown sheet. This crown sheet is supported by radial stays screwed into the crown sheet and the outer wrapper sheet. Ends of radial stays are riveted over. The inner sheets of the firebox are connected to the outer side sheets by stay bolts. Space between these sheets is called the water legs. The fire tubes are within the barrel and run from the firebox tube sheet to the smokebox head of the barrel (see Fig. 3-8). This head in the smokebox is formed by extending the barrel beyond the tube sheet.

The firebox front sheet above the crown sheet, and the smokebox tube sheet above the tubes, are supported by longitudinal stays. In some

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cases diagonal stays also are used for this purpose. The steam dome provides additional steam storage space and allows the main steam outlet to be taken off at a considerable height above the waterline, thus reducing the possibility of water carrying over with steam. The steam space extends over both the furnace and the barrel, which usually has 3-in. tubes. All tubes are of one diameter and length.

As is true of most internally fired ft boilers, some water spaces are very difficult to clean, either mechanically or manually. Also, the lfb boiler is limited as to pressure and capacity, just as is the hrt boiler.

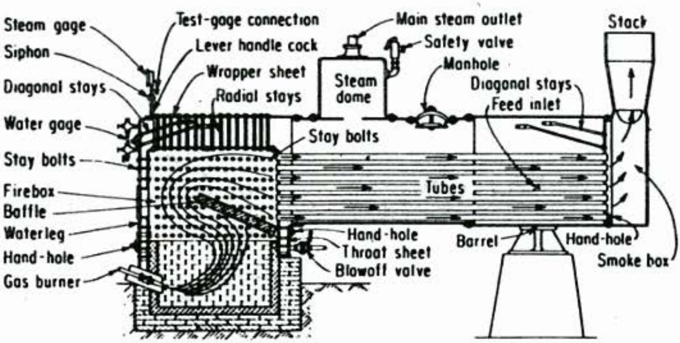


**Fig. 3-8. Locomotive-type boiler has only one pass for flue gas.**

**Q** Where are stay bolts most likely to break in the lfb boiler?

**A** Usually the top row of stay bolts and the first row of radial stays, with fracture occurring close to the inner surface of the outer sheet (wrapper sheet). This area is a high-heat zone, causing large expansion and contraction movements.

**Q** Where does internal and external corrosion occur on an lfb boiler?

**A** For internal corrosion, check: (1) Waterline and top row of the tubes because of oxygen and other impurities released when boiling; (2) top of the crown sheet, on and around the ends of the radial stays and stay bolts; (3) water legs because of oxygen release and the presence of corrosive sediment; and (4) bottom of the barrel where pitting occurs if the boiler is improperly laid up when out of service.

External corrosion on an lfb boiler should be especially looked for around handhole plates and at the bottom of the first head. Rainwater wetting the sooty smokebox will corrode its bottom and also the handholes in this area. The bottom of the barrel should be watched for corrosion because of possible dampness or leakage. Corrosion due to sedi-

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ment deposits forming at the bottom of water legs and their handholes may eat through the plate and gaskets of handholes. Leaking tubes or stay bolts cause corrosion at the furnace end of the tube sheets.

**Q** In case of low water, what is the most dangerous part of the lfb boiler?
**A** The crown sheet because it is first uncovered by low water and therefore will overheat, leading to a possible explosion.

**Q** What is the lowest permissible water level in an lfb boiler?
**A** Three inches above the crown sheet if the shell is *more* than 36 in. in diameter, but only 2 in. above the crown sheet if the shell is *less* than 36 in. in diameter.

**Q** From which end are the tubes removed and replaced in the lfb boiler?
**A** Because all tubes in the lfb boiler are removed and replaced from the smokebox end, always provide sufficient room at this end. In fact, in any boiler installation, there must be room for removing old tubes and inserting new ones without having to break building walls, remove doors or windows, etc.

**Q** Explain the meaning of externally and internally fired boilers.
**A** Externally fired boilers have a separate furnace built outside the boiler shell. The hrt boiler is probably the most widely known example of the externally fired boiler.

In internally fired boilers, the furnace forms an integral part of the boiler structure. The vt, lfb, and the scotch marine (sm) are well known examples of internally fired boilers.

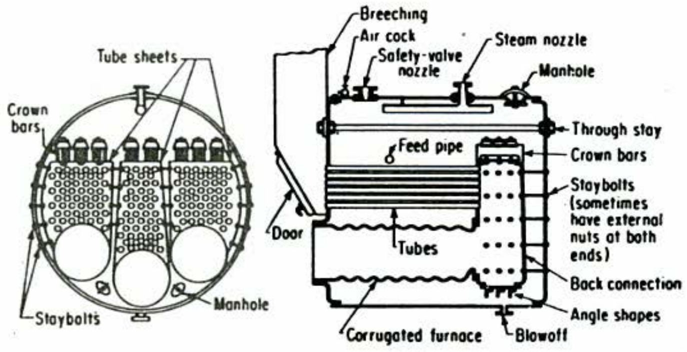


**Fig. 3-9. Scotch marine wet-back boiler with three corrugated furnaces.**

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## PACKAGED FT BOILERS

**Q** What is a packaged ft boiler?

**A** These boilers are the lineal descendants of the basic scotch design. They represent the bulk of ft boilers being manufactured today. The American Boiler Manufacturers Association (ABMA) defines a packaged ft boiler as "a modified scotch-type boiler unit, engineered, built, fire-tested before shipment, and guaranteed in material, workmanship, and performance by one firm, with one manufacturer furnishing and assuming responsibility for all components in the assembled unit, such as burner, boiler, controls, and all auxiliaries . . ."

The sm, or scotch dry-back type, may have two to four circular furnaces when the boiler is of large diameter. Figure 3-9 shows an sm-type boiler with three furnaces and wet-back construction. Note the stay bolts in the back, girder stays on the crown sheets in the back furnace, through stay rods above and below the tubes, and corrugated furnaces.

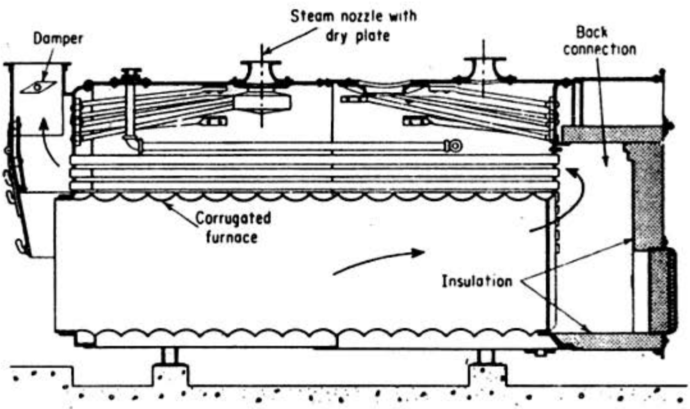


**Fig. 3-10. Dry-back scotch marine boiler with one corrugated furnace.**

**Q** Describe the dry-back sm-type boiler.

**A** This boiler (Fig. 3-10) is an adaptation to stationary practice of the well-known sm wet-back boiler. It consists of an outer cylindrical shell, a furnace, front and rear tube sheets, and crown sheet. The hot gases from the furnaces pass into a refractory-lined combustion chamber at the back (sometimes built into a hinged or removable plate) and are returned through the fire tubes to the front of the boiler and thence to the uptake. This boiler is suitable for coal, gas, and oil firing.

In the wet-back design (Fig. 3-9) the shell, tube, and furnace con-

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struction are similar to the dry-back type, but the combustion chamber, being inside the shell, is surrounded by water. Thus no outside setting or combustion chamber refractory is needed. The dry-back type is a quick steamer because of its large heating surface. It is also compact and easily set up and shows fairly good economy.

The internal furnace is subject to compressive forces and so must be designed to resist them. Furnaces of relatively small diameter and short length may be self-supporting if the wall thickness is adequate. For larger furnaces, one of these four methods of support may be used: (1) Corrugating the furnace walls; (2) dividing the furnace length into sections with a stiffening flange (Adamson ring) between sections; (3) using welded stiffening rings; and (4) installing stay bolts between the furnace and the outer shell. If solid fuel (coal, wood, etc.) is to be fired, a bridge wall may be built into the furnace at the end of the grate section.

**Q** How many passes do the flue gases usually take in an sm boiler?
**A** Up to four passes (Fig. 3-11) are taken by flue gases, depending on

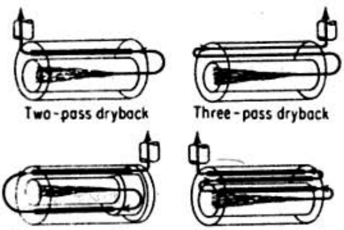


**Fig. 3-11. Typical gas-flow patterns in fire-tube boilers.**

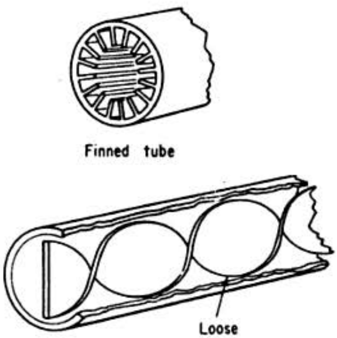


**Fig. 3-12. Finned tube and retarder inside tube.**

the design. While more passes can be used, today four is the practical limit. The two-pass design is the most popular for average plants, whether for high- or low-pressure service. Designers also give attention to the number and arrangement of the second-pass tubes. For example, water-side inspection and cleaning are easier when the tubes are aligned uniformly both vertically and horizontally. But a staggered layout of tubes tends to give a more circuitous flow of water around these tubes, thus promoting increased heat transfer. Improved transfer from gas to water is

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also obtained by using slip-in spiral fittings (retarders) at the tube inlet to impart a swirl to the hot gases (Fig. 3-12). Some boilers have tubes finned on the fireside known as extended-surface tubes.

**Q** How are performance and ratings established on packaged boilers?
**A** It was rare for the makers of older conventional field-assembled ft boilers to know what firing setting and draft conditions their units would encounter in actual application. So it became customary to assume that, as a guide, under average conditions, 10 sq ft of heating surface would produce 34.5 lb of steam per hour, from and at 212°F. This was established as one boiler horsepower. But with such ratings boilers working under favorable conditions would operate at 150 to 200 percent of rating.

In contrast, today ratings of continuous maximum boiler output mean exactly what they say. This is of great importance when an older boiler is replaced by a packaged unit. Thus, instead of using the rating of the old boiler, we must estimate actual steam loads to be met, then select the capacity of the new unit to meet these needs. If we do not, the packaged boiler will be forced beyond its rating, and rapid tube deterioration, tube sheet cracking, weld deterioration, and general heavy accelerated wear will take place, even though the waterside is kept clean from impurities and operated with care. Under forced conditions, the danger of low water is also increased, as the safety margin has been narrowed down.

**Q** How does the more efficient use of heating surfaces in packaged boilers affect the boiler operator?
**A** One result of working heat exchanger surfaces harder has been the necessity of keeping both fireside and waterside clean. Thus good water treatment and maintenance are important. Compact designs also tend to make surfaces less accessible for inspection and cleaning. Thus today's higher heat transfer rates can easily cause overheating, especially if forced. This results in loose tubes in tube sheets, cracks between ligaments on tube sheets, weld cracks in high-heat zones, bulged furnaces, and low water. Even more dangerous is the complete reliance on automatic controls to safely cycle a boiler, without periodically checking the controls for (1) conditions of electrical contacts, (2) electrical connections, (3) water column connections, (4) waterside plugging of pressure switches, (5) low-water fuel cutoffs, (6) soot accumulation in tubes, (7) operation of solenoid valves in fuel cutoff lines, (8) firing equipment timing and operation of flame failure devices, and (9) operation of safety valves.

But being automatic does not mean that everything has been designed into the unit, including self-maintenance. Remember that more highly skilled operators are required for the packaged, automatic units and that more knowledge is required on how the controls and safety de-

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vices function. Many boilers have lost days of service because untrained personnel did not even know what control was malfunctioning, so they could not keep the boiler in operation.

Boiler accidents are frequently caused by someone manipulating the controls without knowing the dangerous effects this can produce. The blocked-in relay, shorted-out control and jumper wires, rapid introduction of fresh cold water into a boiler, all are caused by unskilled operators. In contrast, properly trained operators quickly diagnose the malfunctioning boiler components, thus contribute to boiler safety and dependability on packaged, automatic boilers as they did on older, manual-operated units. By careful maintenance and operation, the efficiency of modern units will also be kept at a peak.

## VERTICAL TUBULAR BOILERS

**Q** What is a vertical tubular boiler?

**A** The vertical tubular (vt) boiler is an internally fired ft unit. It is a self-contained unit requiring little or no brickwork. Requiring little floor space, it is popular for portable service, such as on cranes, pile

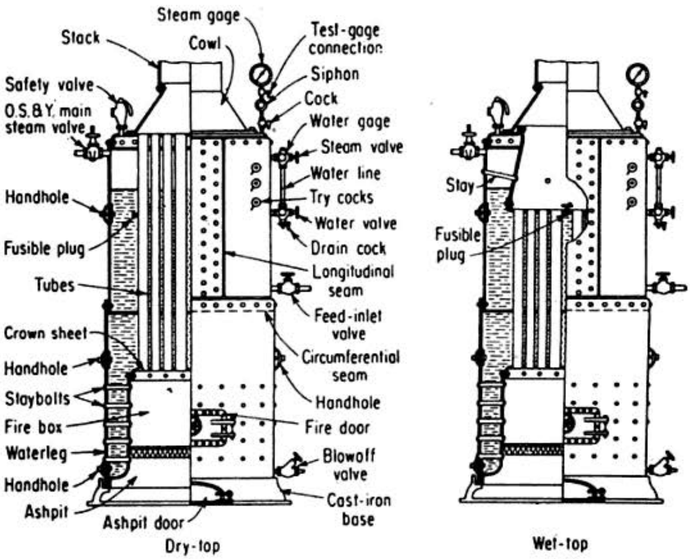


**Fig. 3-13. (a) Dry-top vertical-tubular boiler. (b) Wet-top design has submerged head.**

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drivers, hoisting engines, and similar construction equipment. Vertical tubular boilers are used for stationary service where moderate pressures and capacity are required for process work, such as pressing, drying roll applications in various small laundries, and in the plastics industry.

The coil-type wt boiler (see Chaps. 4 and 6) is a competitor of the vt boiler for small capacities and lower pressures to 150 psi. But the vt boiler is limited in capacity and pressure even more than the horizontal ft boiler. For this reason, most vt boilers of the ft type seldom exceed 300 hp, or about 10,000 lb per hr capacity with a maximum pressure of 200 psi.

**Q** What are the most common vertical ft boilers?

**A** There are five general classifications:

1. Standard straight shell type with dry top (Fig. 3-13*a*).
2. Straight shell type with wet top (Fig. 3-13*b*).
3. Manning boiler with enlarged firebox.
4. Tapered course bottom with enlarged firebox.
5. For even smaller capacity, the vertical tubeless unit (Fig. 3-14).

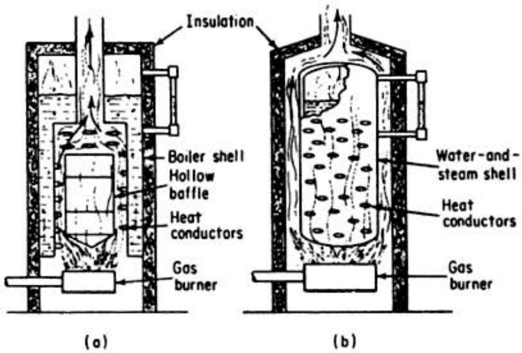


**Fig. 3-14. Vertical tubeless boiler with (a) waterleg and (b) water and steam shell.**

**Q** Describe the vertical dry-top boiler.

**A** The vertical, internally fired, ft boiler (Fig. 3-13*a*) consists of a vertical cylindrical shell which contains a cylindrical firebox and a number of small fire tubes. Heat radiated from the fire passes through the firebox plates to the water in the boiler. The hot gases pass upward through the fire tubes to the smoke stack, giving up part of their heat to the metal of the tubes, which in turn transfer the heat to the water inside the boiler.

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The upper tube plate forms the top head of the boiler. As the water level is carried about two-thirds of the length of the tubes above the lower tube sheet, or down sheet, the top tube sheet is dry (steam on one side, hot gases on other side). Hence the name dry top. The main drawback is that tubes may become overheated above the waterline. Then they loosen in the tube sheet. But one advantage is that the upper third of the tubes being dry, they give a slight amount of superheat to the steam.

Handholes and cleanout plugs are provided at convenient points for washing out and inspection. In the smaller sizes, the bottom of the shell rests on a cast-iron base that also forms the ashpit.

The vertical flueless type (Fig. 3-14) is popular for low-capacity steam of up to about 150 psi. There are several designs. Instead of tubes, the water is either in a jacket around the furnace (Fig. 3-14*a*) or in a water-and-steam cylinder (Fig. 3-14*b*) inside the furnace. On one type, reversal of gas flow takes place between openings on the jacket connected to the upper cylinder. Some designs have down-firing. There are no stay bolts or stays, as flat-surface widths are kept narrow or small in area. Thus the boiler plate thickness is adequate for resisting the bending stresses. Numerous solid U-shaped heat conductors are welded to the surface of the shell to provide better heat transfer.

**Q** Describe the vertical wet-top, or submerged-top, boiler.

**A** This boiler is similar in construction to the dry-top vertical, except for the top head. In the wet-top boiler (Fig. 3-13*b*), a conical-shaped plate is welded (in modern boilers) to the top head, and the upper tube sheet forms the bottom of this cone. Thus the waterline can be carried above the upper tube sheet so that it and all the tubes are below the water level. Other construction details are the same as in the dry-top boiler.

**Q** What are the advantages and disadvantages of vt ft boilers?

**A** Advantages are (1) compactness and portability, (2) low first cost, (3) very little floor space required per boiler horsepower, (4) no special setting required, and (5) quick and simpler installation.

Disadvantages are that the (1) interior is not easily accessible for cleaning, inspection, or repair, (2) water capacity is small, making it difficult to keep a steady steam pressure under varying load, (3) boiler is liable to prime (carry over with steam) when under heavy load because of the small steam space, and (4) the efficiency is low in smaller sizes because hot gases have a short, direct path to the stack, thus much of the heat goes to waste.

**Q** What is the safe water level in the dry-top vt boiler?

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**A** The Code indicates no specific water level for this type boiler, except to state: "It shall be at a level at which there shall be no danger of overheating any part of the boiler when in operation at that level." But the level is generally taken as a minimum at a point two-thirds the height of the shell, above the bottom head, or crown sheet or tube sheet. This is the same minimum requirement as for miniature vertical ft boilers.

For the submerged wet-top type, the minimum water level must be at least 2 in. above the top tube ends, except for miniature boilers, where it can be 1 in.

**Q** Where does sludge usually settle in a vt boiler?

**A** Deposits settle in the 4-in.-wide water legs (maximum per Code) because they have restricted circulation. Cleanout openings should be periodically opened around the circumference in the water legs and bottom tube sheet so all areas are accessible for cleaning. Some units have a continuous drain in the bottom of the water legs. When this boiler is opened for cleaning, a length of chain can be pulled around inside to get the sludge and scale to a cleanout opening for removal.

**Q** In calculating furnaces for external pressure (especially for vt boilers), the terms tubes, flues, and furnaces are often used. Is there a difference?

**A** Yes. Tubes are hollow cylindrical elements of up to 5 in. in diameter. Flues are hollow cylinders exceeding 5 in. in outside diameter and used for the conveyance of gases with temperatures of 850°F or less. Furnaces are hollow cylinders exceeding 5 in. in outside diameter in which combustion takes place, or which are used for the conveyance of gases having temperatures exceeding 850°F.

**Q** Where does internal and external corrosion usually take place in a vt boiler?

**A** Internal corrosion:

1. At the waterline, usually on the tubes. This is due to oxygen and organic materials being released there during the process of boiling.
2. In the vicinity of the feedwater discharge, as a result of oxygen release.
3. On top of the lower tube sheet, because of scale formation.
4. On and around the ends of the stay bolts, as a result of the stresses imposed and the subsequent expansion and contraction (this leads to stress corrosion).
5. In the water legs, especially at the bottom, where grooving may occur in addition to the usual pitting under the scale.

External corrosion:

1. On top of the top tube sheet, bottom tube sheet, and tube ends,

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because of acid formed by the damp soot in contact with the products of combustion.

2. Around all manhole, handhole, and washout openings. Here corrosion is from leakage due to poor gaskets, improper handhole cover installation, and thermal expansion and contraction which loosens opening closures.

3. At the bottom of shell, water legs, and furnace sheet, as a result of soot attack.

4. Around all openings including gage connections, safety valve connections, steam outlet connection, feedwater connection, blowdown connection, and water column connection, because of leakage.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook*, 64 pages
*Steam Generation*, 48 pages
*Fuels and Firing*, 48 pages
*Gaskets*, 20 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

*ASME Boiler and Pressure Vessel Code*, Sections I-IV, American Society of Mechanical Engineers, New York.

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# 4

# WATER-TUBE BOILERS

**Q** What is a wt boiler?
**A** In contrast to the ft design, wt-type boilers (Fig. 4-1) feature one or more relatively small drums with a multiplicity of tubes in which a water-

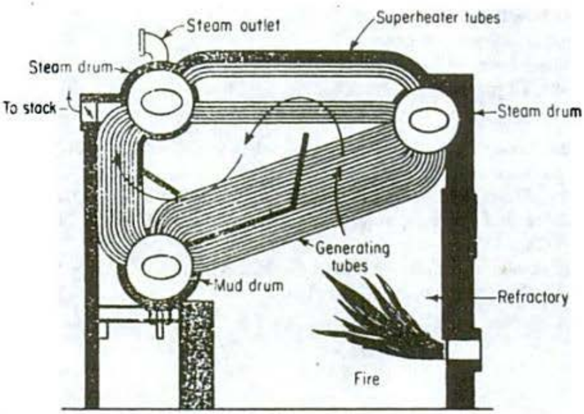


**Fig. 4-1. Water-tube boiler design.**

steam mixture circulates. Heat flows from outside the tubes in this mixture. This subdivision of pressure parts makes possible large capacities and high pressures.

**Q** Have wt boilers any advantages over ft types?
**A** The wt boiler is safer, largely because most of the water at the hottest part of the furnace is in small components (tubes). Thus if a tube ruptures, only a comparatively small volume of water is instantly released to flash into steam. As a rule, all parts of the wt boiler are more accessible for cleaning, inspection, and repairs. But very long, bent tubes may be difficult to clean on some designs. Water-tube boilers in the



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larger sizes are faster steamers because of their large heating surface, long gas travel, and rapid and positive water circulation. On small coil-type wt boilers, there may be no difference in steaming time. For the same reasons, larger wt boilers can carry much greater overloads and respond more readily to sudden changes and fluctuations in demand. Also, the drum in wt boilers is not exposed to the radiant heat of the fire.

The biggest advantage over ft boilers is the freedom to increase the capacities and pressures. That is impossible with ft boilers because the thick shells and other structural requirements become prohibitive over 30,000 lb per hr capacity and over 300 psi. The large capacities and pressures of the wt boiler have made possible the modern large utility-type steam generators.

**Q** Is it true that for the same diameter and thickness of tube, a wt boiler has more heating surface than an ft type?

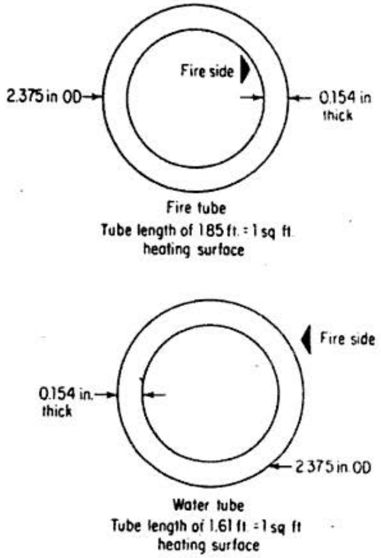


**Fig. 4-2. Comparison of tubes of wt and ft boilers.**

**A** According to the ASME Code, the heating surface is always calculated from the side exposed to the products of combustion. And since in a wt the products of combustion are on the outside of the tube, the outside diameter (OD) of the tube is used in calculating the heating sur-

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face. In an ft, the products of combustion are on the inside of the tube; thus the inside diameter (ID) is used in calculating the heating surface. Since the OD is larger than the ID, it is assumed that a wt has a larger heating surface area than an ft (Fig. 4-2).

But heating surface depends on other factors such as tube arrangement, length of gas travel, use of efficient burning equipment, and cleanliness and maintainability of heat-exchanger surfaces. So don't assume that wt boilers are always more efficient than ft boilers.

**Q** What materials are used in boiler tubes?

**A** Large modern boilers consist of thousands of feet of steel tubes of various diameters and wall thicknesses, so the type metal used is of great importance. Low-carbon steel is used in most wt boilers operating over a wide temperature range. Convection temperatures run between 500 and 700°F. Medium-carbon steel, with 0.35 percent maximum of carbon, permits higher stress levels than low-carbon steel at temperatures up to 950°F. For superheater tubes, which must resist temperatures above 950°F, alloy steels are required. These may contain chromium, chromium-molybdenum, and chromium-nickel. They may be of ferritic structure, or, for higher furnace temperatures, of an austenitic structure.

**Q** How are water tubes attached in a wt boiler?

**A** For high-pressure service, the ASME Code stipulates the following attachment of wt tubes to tube sheets, headers, and drains: (1) Expanded or rolled and flared (Fig. 4-3); (2) flared not less than ⅛ in., rolled, and beaded; (3) flared, rolled, and welded; (4) rolled and seal-welded, provided the throat of the seal weld is not more than ⅜ in. and the tubes are rerolled after welding; (5) Superheater, reheater, waterwall, or economizer tubes may be welded without rolling or flaring, provided that the welds are heat-treated after welding and the welding is done according to Code requirements.

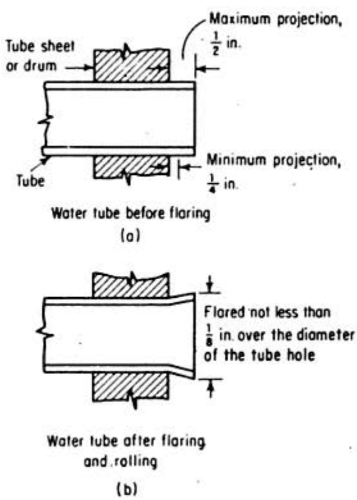


**Fig. 4-3. Methods of attaching water tubes.**

**Q** The term *tube sheet* is often applied to a wt boiler equipped with only steam drums and mud drums. Is not this term incorrect as applied to wt boilers?

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**A** No. The term *tube sheet* refers to any sheet of a wt boiler where tubes are inserted, whether in a flat sheet or a drum.

**Q** How is the term *ligament* defined, and how does this term affect wt boiler design?
**A** A ligament is the section of solid plate between tube holes. But the drilling of these holes in a pattern weakens the solid plate. Thus in designing or calculating the strength of a boiler drum, the ligament efficiency must be considered in determining the safe working pressure. And the ligament efficiency will always be in reference to tube hole arrangement, whether a steam drum or mud drum. The term *tube sheet* may be used, even though a tube sheet such as on ft boilers does not actually exist. In wt boiler drum design, the weld or rivet and the ligament tube efficiency of the drum are very crucial in establishing plate thickness required for a given pressure with a given material (see Chap. 9).

**Q** Why are tubes flared in a wt boiler?
**A** To add to the holding power of the tubes after rolling, and also to prevent the tubes from pulling out of the tube holes if the holes should become enlarged from overheating caused by low water or other reasons.

**Q** What precautions should be used when rolling or expanding tubes in wt boilers?
**A** Most tubes today are expanded with power-driven expanders instead of by hand rolling. This results in rolling just enough to obtain tight joints. But with power-driven rollers, there is always the danger of overrolling, thus damaging the metal by cold-working, which causes the metal to become harder and more brittle. It may also result in loss of ductility and ability to stretch and contract with temperature changes. Coldworking often causes surface tears and marks which will reduce resistance to corrosion. Thus it is better to under-roll, whether on new or repair work. One aid to properly rolling a new tube is to note when the mill scale (or paint) on the tube sheet around the tube begins to flake off. Stop rolling at this time as the joint is tight enough.

Before tubes are inserted for rolling, all tube ends and tube seats should be cleaned of oil, grease, rust, etc. Rust should be removed with a fine abrasive cloth. Expanders should be kept clean and washed frequently with kerosene. Vegetable oil or other specially prepared expander lubricant should be used to lubricate the expander rolls. One end of the tube should be held in place with a wedge while being expanded so it does not move in the seat. The tubes should enter the holes parallel to the center line of the holes and have equal projection from the tube sheet or header at each side of the tube sheet.

The bottom tubes should always be rolled in first, then the next row

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upward so that oil, dirt, etc., do not drip off the ends of the tubes into empty tube seats not yet filled with tubes. Be sure to use the correct expander to suit the size and thickness of the tubes and tube seats.

## STRAIGHT-TUBE WT BOILERS

**Q** What was the first widely used wt boiler?

**A** Figure 4-4 shows an early straight-tube wt boiler. The tubes are placed in the furnace, and the shell above is used primarily as a storage

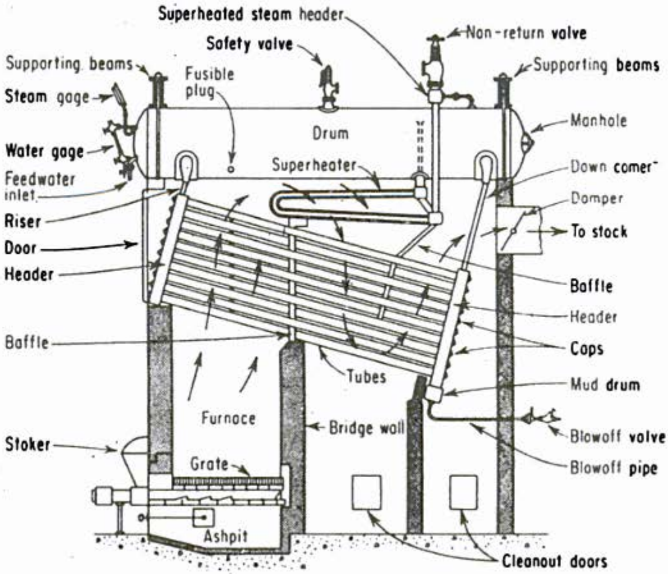


**Fig. 4-4. Early straight-tube water-tube boiler.**

tank for water and steam. Circulation from the drum is down the back headers, through the water tubes, and up through the front header. With this arrangement the tubes on boilers began to be separated from the internal shell, in contrast to ft boilers. The design shown has one drum; larger boilers had two or three drums. The drum runs from the front to the rear of boiler. The inclined straight steel tubes, usually of 4-in. OD, are connected with the drum by pressed-steel headers of the sectional type, the tubes being staggered in pairs. The mud drum below the rear

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headers collects sediment and is blown out from time to time. Tube headers are in one piece for each vertical row of tubes.

Header handholes (for tube cleaning) are closed by bolted covers with machined joints. The superheater, usually fitted in the space below the steam drum, is a set of U tubes. Saturated steam from the drum passes downward to be superheated in these tubes, then passes from the bottom superheater header to the main stop valve. The headers are connected with the steam drum by short tubes expanded into a cross box.

**Q** Name the various types of straight-tube wt boilers.

**A** The straight-tube design is usually classified by the type of header and by the direction of the drums or the tubes. As a result there are, in general, six types: (1) sinuous- or sectional-header, (2) box-header, (3) longitudinal-drum, (4) cross-drum, (5) horizontal-tube, and (6) vertical-tube types.

**Q** The terms *sectional header* and *sinuous header* are often used with wt boilers. How do they differ?

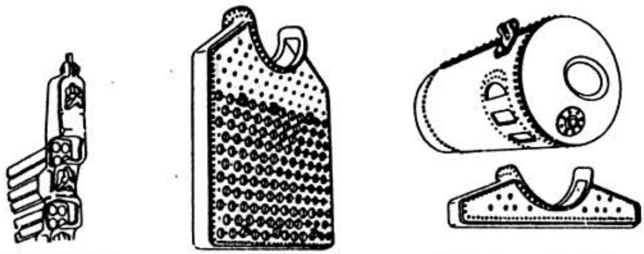


**Fig. 4-5.** (a) Sinuous vertical sectional header with four tubes per handhole. (b) Box header for horizontal-straight-tube boiler.

**A** The sectional header, which is also referred to as a sinuous, or serpentine, header (Fig. 4-5*a*), is either a casting or forging. In older low-pressure boilers, the headers were also constructed of cast iron. But for high pressure, they were limited by the ASME Code to a maximum design pressure of 160 psi and 350°F. In contrast, headers constructed of forged steel have been used for pressures up to 1,200 psi.

**Q** What is a box header?

**A** A box header (Fig. 4-5*b*) is constructed of flat plates, referred to as a tube sheet and tube cap sheet. But these surfaces must be stayed to

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prevent deformation. The sides, top, and bottom are flanged and riveted (welded on new boilers) to the tube sheets and cap sheets. The staying of sheets limits pressure for a box header to about 600 psi.

**Q** Describe the longitudinal-drum and the cross-drum wt boilers; name advantages and disadvantages of each.
**A** The longitudinal-drum type (Fig. 4-6*a*) has the drum, or drums, parallel to the inclined tubes and above the headers. In the longitudinal-drum box-header type, the water leg at the high end of the tubes has a flanged semicircular throat, which is welded directly to the drum (or drums). At the low end of the tubes, the rear box header is connected with the drum (or drums) by tubes expanded into the top of the headers and into a throat connection welded to the drum (or drums).

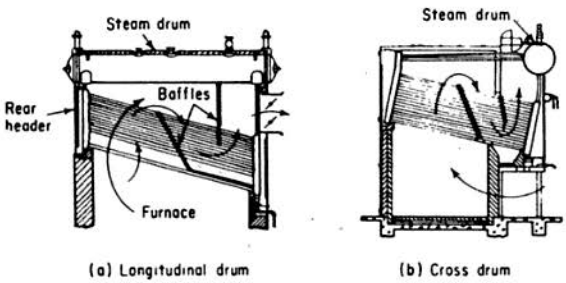


**Fig. 4-6. (*a*) Longitudinal-drum and (*b*) cross-drum boilers.**

The cross-drum type (Fig. 4-6*b*) has tubes running from the upper part of the front header (or headers) to the drum, then entering the drum steam space. The rear header (or headers) is connected by tubes rolled into the tube holes in the lower (water space) part of the drum, and also into the tube holes in the top of the headers. The cross-drum type, in addition to being more economical to build, provides for better circulation of water.

**Q** How are longitudinal-drum wt boilers supported?
**A** They are suspended from crossbeams attached to the steam drum and supported by steel columns. One method is the U-bolt support shown in Fig. 4-7. The channels are mounted on vertical steel columns, away from the high-temperature zones of the boiler drum setting and thus protected from heat.

> CAUTION: If encased in brickwork (older boilers), periodically remove the brickwork to check for corrosion of the U bolts.

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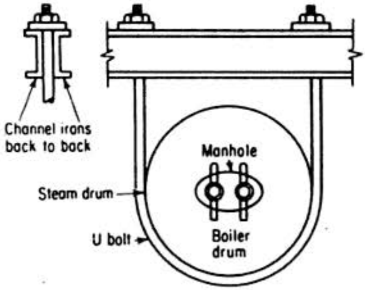


**Fig. 4-7. U-bolt method of supporting longitudinal-drum water-tube boiler.**

**Q** Where does most of the corrosion take place on box-header boilers?
**A** Heavy leakage at handhole plates causes corrosion on the wrapper or external sheet where the closing caps are located. Leakage of these handholes finds its way down to the bottom of the headers (Fig. 4-5), which is usually concealed in brickwork. Thus leakage from above causes undetected corrosion. When inspecting box-header boilers having bricked-in bottom headers, always remove the brickwork and check this surface for corrosion.

**Q** Where do sinuous-header boilers usually corrode?
**A** On the tube entrance outer plate, from leakage at the handholes, or on caps on the openings. Also between the sinuous headers, which are usually packed or filled with asbestos yarn.

**Q** Describe a vertical wt boiler and list its advantages.
**A** One common type of a vertical wt boiler (Fig. 4-8) has a steam drum at the top and a mud drum at the bottom. The vertical tubes are rolled into the flat tube sheets of both drums. Sling stays brace the tube sheets. Obviously, the dished heads opposite the tube sheets require no staying. The main advantage of this type boiler is that it requires less floor space per unit of capacity.

The Wickes boiler has a large number of vertical water tubes. The

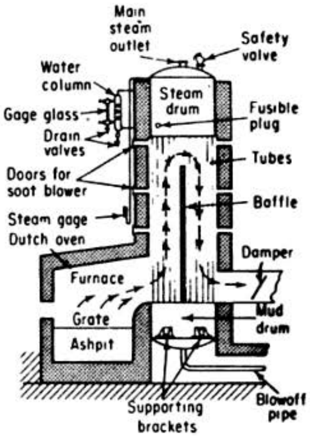


**Fig. 4-8. Vertical straight-tube type water-tube boiler.**

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boiler is enclosed in a brick setting and supported by brackets fastened to the lower drum, which rest on steel or concrete pillars. This design allows the boiler to expand and contract freely without greatly disturbing the setting. A vertical tile baffle in the center of the tube bank extends downward through the rear bank. The water circulation is in the same direction, up the front tubes and down the rear tubes. The primary combustion takes place in the furnace, which is called a Dutch oven. Feedwater enters through the top steam drum, while blowdown is from the mud drum. Both top and bottom drums have manholes for tube replacement and for cleaning purposes. The manholes usually are flanged into the dished heads.

**Q** Why are baffles used in the passages of wt boilers?
**A** Baffles deflect the hot gases back and forth between the tubes a number of times to enable greater heat absorption by the boiler tubes. They also permit designing for better temperature differences between tubes and gases throughout the boiler. Baffles help maintain gas velocity, eliminate dead pockets, deposit flyash and soot for proper removal, and prevent high draft losses.

**Q** What happens when a furnace baffle breaks?
**A** The gases short-circuit one or more passes, causing excessive flue-gas temperatures and a loss in efficiency and also capacity. Overheating and damage might result in those parts of the boiler designed for low gas temperatures. Thus on any outage inspection, the baffles should always be carefully checked for erosion, breaks, leakage (around tubes), or dislocation, as tube failure may result.

**Q** What type of firing door is required on wt boilers?
**A** The inward-opening type, or a type provided with self-locking door latches which omit springs or friction contact. Reason? So the door cannot be blown open from pressure inside the furnace in case of tube rupture or furnace explosion, and thus possibly burn or scald personnel standing nearby.

> IMPORTANT: Explosion doors, if used, and if located in the setting walls within 7 ft of the firing floor or operating platform, must have deflectors to divert any blast.

**Q** What are some causes of tube failures in wt boilers?
**A** (1) Solid deposits, (2) low-water conditions, (3) corrosion, (4) slagging of gas passages which restrict normal heat transfer, (5) high concentration of heat in some tube areas, (6) stress corrosion, (7) flame impingement, (8) poor circulation, and (9) steam cutting and

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external erosion and corrosion by soot blowers that are improperly located or in poor condition.

## BENT-TUBE WT BOILERS

**Q** Why are bent tubes used in wt boilers?

**A** Bent tubes are more flexible than straight tubes. Boilers can be made wide and low, where headroom is limited, or narrow and high where floor space is at a premium. Also, bent-tube boilers allow more heating surface to be exposed to the radiant heat of the flame. Drums serve as convenient collecting points in the steam-water circuit and for separation of steam and water. Thus boilers with two, three, and sometimes four drums have been used. As boilers grew in size (made possible by bent-tube design), the demand for more active furnace cooling increased. It was then that waterwalls and other improvements in design were made. A better knowledge of fluid dynamics resulted in simpler and much safer methods for the circulation of waterwall fluids, both on the gas and steam sides.

Two-drum boilers, even boilers with but one drum on top and one or two large headers at the bottom, became commonplace. Thousands of boilers of the vertical-header type and of multidrum bent-tube design are still operating today. The tubes are bent because:

1. Heat transfer reasons make it impossible to use straight tubes.
2. The bent tube allows for free expansion and contraction of the assembly, usually on the lower mud-drum end, as the upper drum (or drums) is separated or suspended by steel structures.
3. The bent tubes enter the drum radially to allow many banks of tubes to enter the drum.
4. Bent tubes allow greater flexibility in boiler-tube arrangement than is possible in straight-tube boilers.

**Q** What was one of the first bent-tube boiler designs that is still in use?

**A** The Stirling boiler (Fig. 4-9), which has three steam drums and one mud drum. Steam-equalizing tubes are between the middle and rear

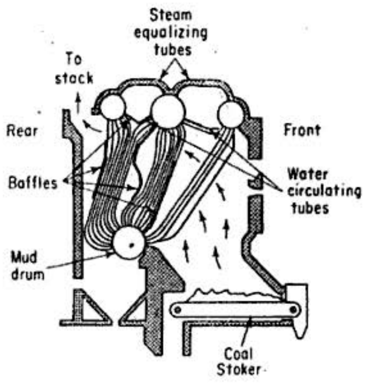


**Fig. 4-9. Stirling water-tube boiler was early bent-tube type.**

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steam drum and between the front and rear drums. Water-circulating tubes connect the front and middle steam drums below the waterline for the boiler. Rear tubes connecting the middle drum to the mud drum deviate from the middle bank to the generating tubes. They join in the rear bank of generating tubes on the back steam drum, to ensure positive circulation throughout the boiler.

Baffles protect the three steam drums the full width of the setting, thus protecting the longitudinal riveted seam, on each drum, from contact with flue gas. Feedwater enters the back top drum through a welded-in feed pipe. The water circulates downward through the back tubes to the mud drum and then up to the middle and front drums. The equalizing tubes keep the water level equal in these two drums.

**Q** In the three-drum boiler of the Stirling type, what areas have to be watched for possible sources of trouble?

**A** Figure 4-10 shows a unit with front and middle boiler banks connected into both the front and middle upper drums. This arrangement equalizes the discharge of the steam-and-water mixture to improve circulation and reduce carryover with the steam. Boilers of this general type were usually designed for pressures from 160 to 1,000 psi, and capacity range from 7,500 to 350,000 lb per hr steam. Both the top and bottom drums have brickwork built partly around them. Because the Boiler Code required the longitudinal joint to be away from furnace heat, the joint was usually under this brickwork. Even if it means removing some brickwork, always check the condition of longitudinal and circumferential rivets, including the calked edges, and look for caustic embrittlement affecting the drums.

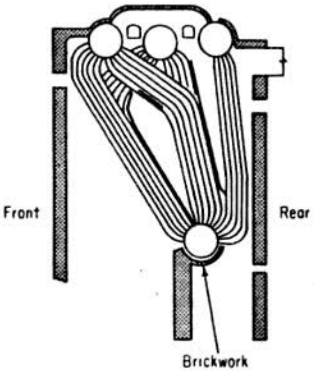


**Fig. 4-10. Stirling-type unit with first boiler bank connected with both front and middle upper drums.**

**Q** What is meant by an integral-furnace boiler?

**A** The integral-furnace bent-tube wt boiler (Fig. 4-11) is so-called because the bottom drum (near the bottom of the furnace) makes it possible to package the furnace integrally with the boiler. Thus on older units only insulation and brickwork had to be erected at the site. Of the bent-tube boilers, the two-drum types are the simplest.

Today these two-drum boilers are available in standard sizes, ranging

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from 15,000 to 300,000 lb per hr of steam with pressures from 160 to 1,000 psi to 900°F temperatures. The demand for compact, standardized wt boilers is growing, with the two-drum bent-tube type a leader in the field. They are shop-assembled, equipped with a watercooled furnace, and arranged for pressure-firing of either oil or gas. And they are ready for shipment by truck or railway car, completely equipped with firing equipment, oil pumps, oil heater, forced-draft fan, boiler trip, feedwater regulator, soot blowers, casing, setting, and automatic control system. Thus with pressure firing, good arrangement of heating surfaces, tight baffles, tight casing construction, and automatic combustion control, more efficient operation is possible.

Steam generators of the integral type arranged for pulverized coal, oil, or gas firing are built in sizes up to 425,000 lb per hr steam. While pulverized fuel, oil, or gas are most frequently used, stokers can also be applied.

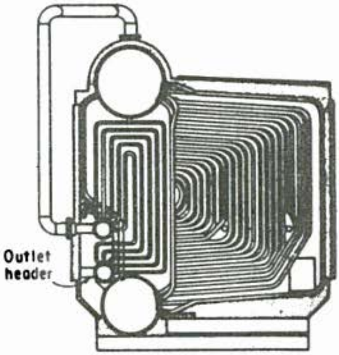

**Fig. 4-11. Integral furnace bent-tube water-tube boilers.**

**Q** How does water circulate through a two-drum bent-tube boiler?

**A** Figure 4-12 shows a Keeler steel-encased unit with a full-length steam drum and a half-length mud drum. Feedwater enters (dotted line) the boiler through the front head of the upper drum, to which an internal feed pipe is attached. This pipe discharges the water at the rear

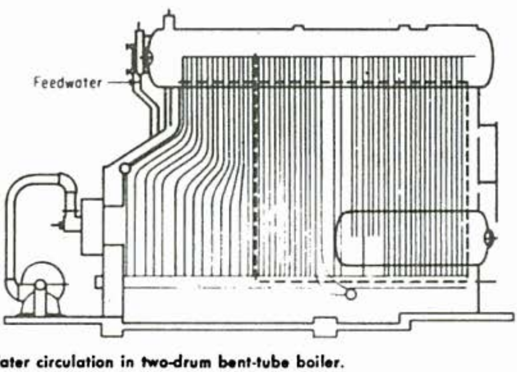

**Fig. 4-12. Water circulation in two-drum bent-tube boiler.**

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end of the upper drum, from where it flows down the rear bank of tubes into the rear end of the lower drum, then horizontally through the short circulating tubes into the waterwall headers, forward and up through the side waterwall tubes into the upper drum, thus completing the cycle of circulation.

A second cycle of circulation occurs in the main bank of boiler tubes, flowing downward from the rear end of the upper drum to the rear end of the lower drum at the rear of the tube nest, then upward from the forward end of the lower drum directly above. This circulation occurs without the use of internal baffle plates, thus making it possible to operate at high overloads with dry steam and with no disturbance of water level (normally at the center of the upper drum). The furnace waterwall tubes do not depend upon the upper drum for their water supply, but receive water directly from the lower drum. Also, the steam generated in the furnace waterwall tubes is freely discharged directly into the upper drum without the use of intermediate headers.

**Q** How do water and gas circulate in bent-tube boilers?

**A** Figure 4-13 features some common bent-tube boilers with the water

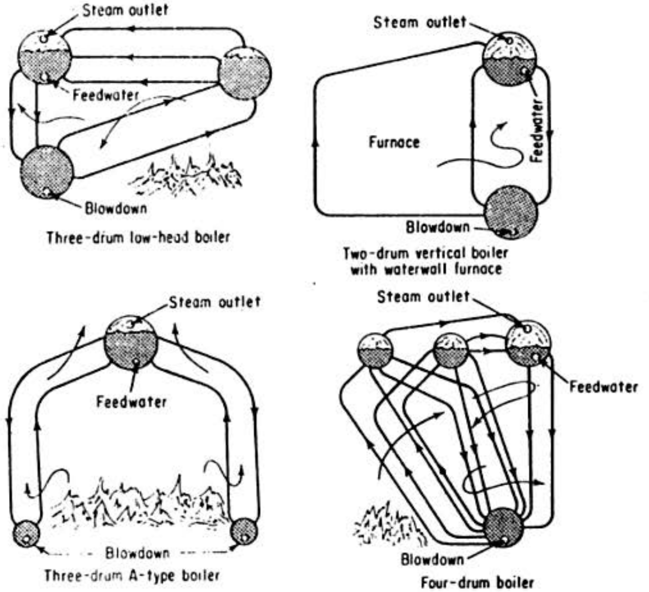


**Fig. 4-13.** Circulation of water and gas in water-tube boilers.

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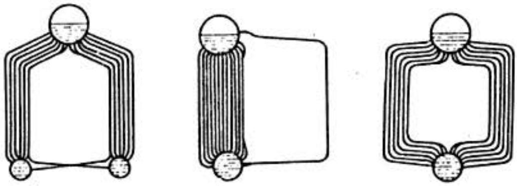
and gas circulation shown in each. Note that blowdown is always from the bottom drum, where sediment gathers. Some of these boilers come equipped with automatic surface-blow equipment, which is different from blowdown (bottom-blow). Surface blow refers to blowing the floating scum from the waterline level in the steam drums.

**Q** Are wt boilers also packaged?
**A** Yes. Modern packaged boilers have grown in popularity and size since their inception in the 1940s. Today, most packaged wt boilers follow one of the three designs shown in Fig. 4-14. These are known as A, D, and O types.



(a) A type (b) D type (c) O type

**Fig. 4-14. Typical packaged water-tube boiler structural configurations.**

**Q** What purpose do waterwalls serve in a boiler?
**A** Waterwalls consist of relatively close-spaced vertical tubes forming the four walls of the furnace. They were originally developed to cool and protect the furnace lining. One design of large power-generating boilers has 144-ft high, 0.340-in. thick tubes at the hottest furnace zone (below 85-ft elevation) but only 0.320-in. thick tubes above.

Depending on the type of boiler, the waterwall heating surface may account for only 10 percent of the boiler's total heating surface, yet represent as much as 50 percent of the total heat absorption. Waterwalls perform three basic functions: (1) protect the insulated walls of the furnace, (2) absorb heat from the furnace to increase the unit's generating capacity, and (3) make the furnace air tight (on pressurized furnaces with tangent welded tubes).

**Q** Describe a typical steam generator used in industry and small utilities today.
**A** Figure 4-15 illustrates a 40,000 lb per hr unit operating at 450 psi and 750°F. Note the comparatively large diameter drums and headers designed for easy access. Other features include wide spacing of wall tubes backed by refractory. The air heater on this unit can be bypassed at low ratings.

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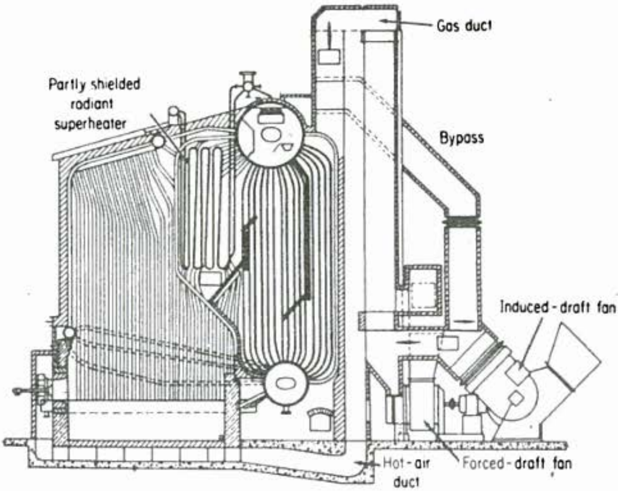


**Fig. 4-15. A typical modern steam generator used in industry and in small utilities.**

**Q** How is furnace heat transferred to the waterwalls?
**A** Heat is transferred to the waterwall tubes as radiant heat from the zone of highest temperature in the furnace.

> NOTE: Because of the great amount of heat absorbed by that part of the boiler, feedwater must be of the best quality. Also, the circulation of water must be rapid and plentiful to ensure positive flow through each tube at all times.

**Q** Should waterwall headers be blown down while the boiler is under load?
**A** Positively not.

> WARNING: Under no circumstance should waterwall headers be blown down while the boiler is operating. If blown, the boiler's normal circulation will be upset and the overheated tubes will bulge or rupture.

**Q** Is the waterwall arrangement on wt boilers important? How are they assembled?
**A** Figure 4-16 shows some typical arrangements. The waterwall in Fig. 4-16*a* is designed for moderate cooling. This design has the tubes spaced apart and the wall surface composed of part firebrick. The brick is backed with several layers of insulation and strong steel casing. Reinforcing

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metal lath is often used in wall construction. Figure 4-16*b* shows how tangent tubes are placed in the furnaces of many large and small boilers. The staggered tube arrangement offers a high heat-absorbing surface that is backed by solid block, or plastic, insulation and a strong steel external casing. Figure 4-16*c* shows steel lugs or longitudinal fins welded to non-tangent wall tubes. In some designs the lugs protrude from the tube into the furnace and are covered with a chrome-base refractory or slag. To ensure furnace tightness, adjacent fins are often welded.

Figure 4-16*d* shows newer gas-tight casings, known as membrane walls. Here tightness is obtained by welding a flat strip of metal between the tubes. This eliminates the casing and many of its problems. Insulation is applied directly to the outside of the tubes, while metal lagging is attached to give the outer surface durability and good appearance. Figure 4-16*e* shows how the outer casing, insulation, and steel-skin casing are often constructed.

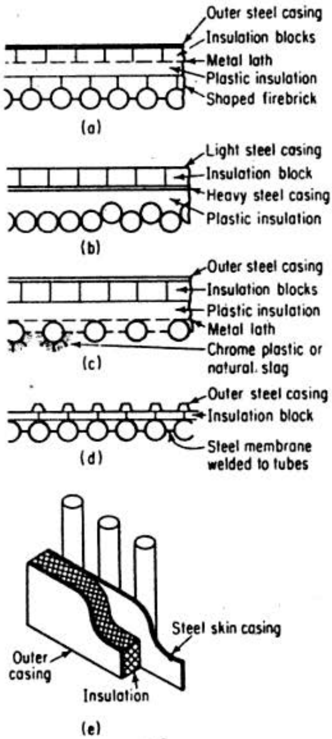


**Fig. 4-16. Typical design variations of water-cooled walls.**

**Q** Briefly explain tubes other than waterwalls used on wt boilers.

**A** Depending on the design for pressure, capacity, and final temperature, a modern, large steam generator will have superheater, economizer, reheater, and air-heater tubes. The basic purpose of these tubes is to extract all possible heat from the fuel input, thus lowering the exit temperature going up the stack.

Figure 4-17 shows two typical curves; the upper curve indicates gas temperatures to the exit portion, and the lower curve shows feedwater temperature entering the boiler, then slowly being raised by the hot gas to its final steam temperature. Of course the various tubes provide the necessary heat transfer to accomplish just this.

Figure 4-18 shows how the various tubes perform in a typical boiler

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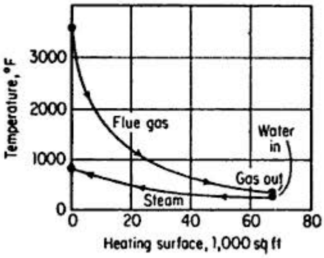


**Fig. 4-17.** Flue gas versus water and steam temperature in boiler of 60,000 sq ft heating surface.

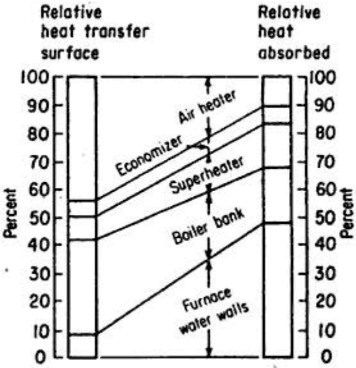


**Fig. 4-18.** Relative percentage of heat absorbed through heat transfer of large boilers.

as to percentage of total heat absorbed by the furnace-wall tubes, main boiler bank tubes, superheater, economizer, and air heater. Note how the furnace-wall tube heating surface of only 10 percent absorbs 50 percent of total heat transfer surface. The reason for this is a basic heat transfer law. As the gas temperatures are cooled in their passage through the boiler, the temperature drop slowly brings into effect the law of diminishing returns as the temperature difference becomes smaller and smaller. Thus to get a certain temperature rise, it takes more heating surface. Because the furnace is the highest temperature zone where the greatest temperature difference exists, most heat absorption takes place even with a moderate heat surface area.

**Q** Name some types of superheaters in general use.

**A** Figure 4-19 shows some typical superheaters and their locations in the boiler. The general classification includes radiant and convection types, depending on whether they absorb radiant or convection heat. The interdeck type has tubes arranged between banks of primary boiler tubes. The pendent type is a suspended series of coils, usually shielded against radiant heat by a screen of boiler tubes. It is often arranged as the first steam heater before the steam goes to the superheater outlet header. The platen type is similar to the pendant type, but the tubes are in one plane. Usually the steam goes through the platen superheater before it enters the pendant superheater.

**Q** What are economizers, and how are they classified?

**A** Economizers serve as traps for removing heat from the flue gases

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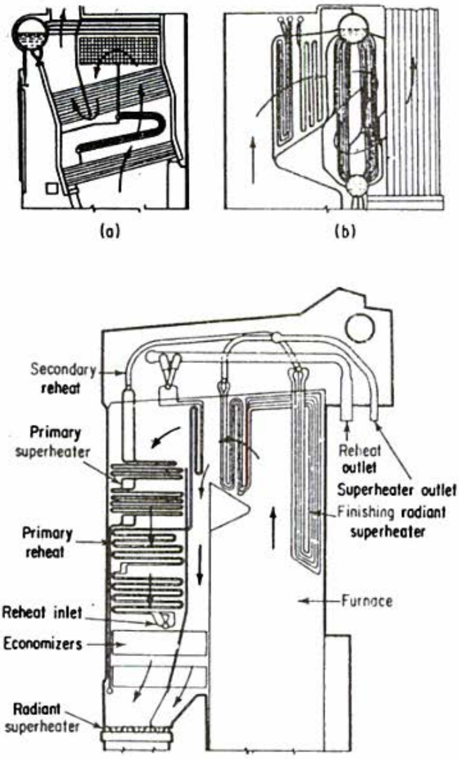


**Fig. 4-19. Typical superheaters and their locations in the boiler.**

at moderately low temperature, after they have left the steam-generating and superheating sections of the boiler. The general classification is:

1. Horizontal- or vertical-tube, according to the direction of gas flow with respect to the tubes in the bank.
2. Parallel flow or counterflow, with regard to the relative direction of gas and water flow.
3. Steaming or nonsteaming, according to thermal performance.
4. Return-bend or continuous-tube types.
5. Plain-tube or extended-surface types, according to the details of design and the form of the heating surface.

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The tube bank may be further designated as of the staggered or in-line arrangement, with regard to the pattern and spacing of tubes which affect the path of gas flow through the bank, its draft loss, heat-transfer characteristics, and ease of cleaning.

Figure 4-20 shows some extended-tube types used for economizers. Theoretically, economizer heating surface could be added to a boiler until the exit temperature neared the outside air temperature. But an abnormally high heat-surface area would be needed. Further, each fuel burned has a dew point temperature which can cause moisture accumulation on the economizer and corrode the surface in a short time.

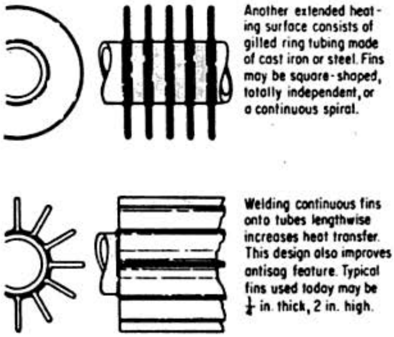


**Fig. 4-20. Extended surface designs used for economizer tubes.**

**Q** Describe the reheater.

**A** A reheater is essentially another superheater used in modern utility boilers for boosting plant efficiency. While the superheater takes steam from the boiler drum, the reheater obtains used steam from the high-pressure turbine at a pressure below boiler pressure. This lower-pressure steam passing through the reheater is heated to 1,000°F and then is introduced into the intermediate, or low-pressure turbine. Reheaters, like superheaters, are also classified according to their location in the boiler as convection or radiant. Convection superheaters and reheaters may be of the horizontal or pendant type.

**Q** What is the purpose of air heaters?

**A** Air heaters make the final heat recovery from boiler flue gases with which they preheat the incoming furnace air for its combustion with fuel. Thus some fuel is saved which would otherwise be used in heating the air-fuel mixture up to its ignition point. But the temperature of the flue

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gas must not be reduced below its dew point since moisture would condense out of the flue gas. That would cause water to combine with sulfur and possibly carbon dioxide, also carbon monoxide, to form highly corrosive sulfurous and carbonic acids. Figure 4-21*a* shows a design with air passing inside the tubes, while hot gas crosses at right angles. The design in Fig. 4-21*b* has hot gases flowing through the tubes, while air is directed across the tubes by baffles.

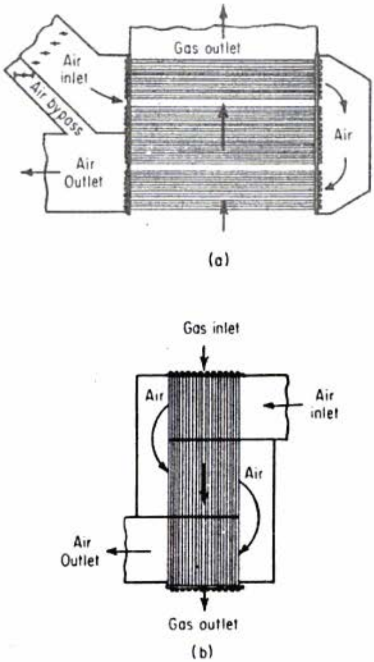


**Fig. 4-21. Air heaters recover low-temperature heat.**

**Q** What is a regenerative air heater?

**A** This type air heater (Fig. 4-22) offers a large surface of contact for heat transfer. It usually consists of a rotor which turns at about 2 to 3 rpm, and is filled with thin, corrugated metal elements. Hot gases pass through one half of the heater, air through the other half. As the rotor turns, the heat storage elements transfer the heat picked up from the hot zone to the incoming air zone.

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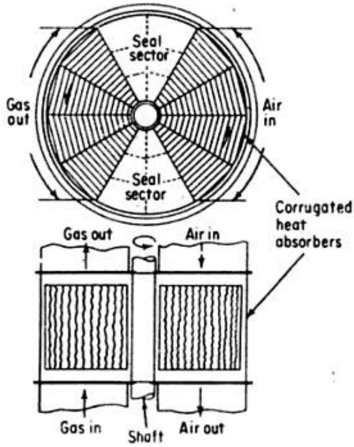


**Fig. 4-22. Regenerative air heater has rotating heat-storage elements.**

**Q** What is a downcomer?
**A** A large vertical tube or pipe for circulating water from the water space of the steam drum to waterwall headers.

> NOTE: The downcomer is always placed outside the boiler casing so that it does not absorb heat from the furnace or boiler proper. And it must not disturb the natural gravity circulation of the cooler water downward, which might occur if it absorbed heat.

**Q** How are heating surfaces distributed on larger utility-type boilers?
**A** An example is a natural circulation, reheat-type steam generator: capacity 2,390,000 lb per hr, superheated steam at 2,460 psig and 1005°F at the outlet, 2,141,000 lb per hr reheated steam at 455 psig and 1000°F at outlet, oil-fired. Here are the heating areas:

Boiler, 8,080 sq ft
Waterwalls, 20,250 sq ft
Radiant superheater, 23,225 sq ft
Convection superheater, 59,750 sq ft
Economizer, 86,500 sq ft
Air heater, 302,000 sq ft
Reheater, 84,900 sq ft
Total furnace volume, 184,000 cu ft
Total furnace surface, 41,000 sq ft

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**Q** Describe a once-through steam generator and system.

**A** Once-through boilers receive feedwater at one end and discharge steam at the other end (see Fig. 6-1 for a small, helically wound unit). Figure 4-23 shows a typical plant layout of a large utility unit. The entire process of heating, steam formation, and superheating is carried out in a continuous flow; thus a steam drum is not needed.

The design consists of many once-through circuits discharging into a common outlet. The system illustrated handles pressures either below or above the critical pressure of 3,206 psia. Water-steam flow is through

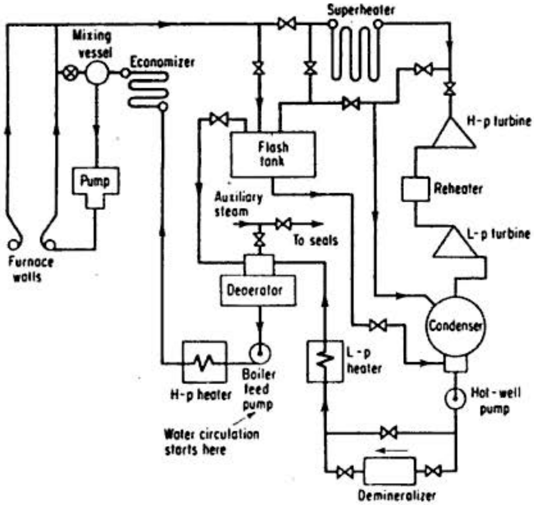


**Fig. 4-23. Once-through unit plant layout and flow diagram.**

the furnace walls, the primary horizontal superheater, and, finally, the first and second sections of the secondary (pendent) superheater.

A supercritical-pressure cycle must maintain active furnace-wall circulation at low loads and start up when little or no steam goes to the turbine. In the system shown, the steam generated discharges to a flash tank. The steam separated from this fluid is directed to turbine seals, deaerator, and high-pressure heater. It can also be used for rolling the turbine. But an automatically controlled high-pressure stop valve and a return-line valve between flash tank and superheater return the cycle to normal when quarter load is reached.

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**Q** What is meant by controlled circulation in a large steam generator?
**A** Controlled circulation is a design by which water can be carefully apportioned to furnace walls, boiler-tube sections, parallel tubes or tube, in accurate, predetermined amounts. Water can even be changed in total flow or distribution within a certain range at any subsequent time in operation. This is usually done by installing circulating pumps between the boiler drum and water inlet to the heat-absorbing surfaces. The result is positive flow in one direction at all times, regardless of heat application.

By using forced circulation, small-diameter, thin-walled tubes can be used where natural circulation design would not be possible because of the high temperature the natural circulation may have to operate against. This is especially true of large-flow and high-pressure units (supercritical) and once-through designs.

**Q** Describe a supercritical-pressure steam generator.
**A** One such generator is a 900-Mw unit that produces 6.4 million lb of steam per hour. The steam generator is of the twin-furnace type with a water-cooled center wall in between. Feedwater enters at 550°F and picks up about 100°F in the economizer. A recirculating pump circulates the fluid between successive waterwalls. But when it reaches the first section of the horizontal superheater at a temperature of around 800°F, the fluid is no longer water, but a vapor mixture which must be dried and superheated.

After passing through finishing superheaters, 1003°F steam is ready for the high pressure (hp) turbine. Temperature is maintained at the exact control point by attemperation (spraying water into the steam) before it enters the finishing superheater. When that area is reached, the steam has absorbed about 83 percent of boiler capacity. Most of the energy is then released in the hp turbine. The exhaust steam from the hp turbine returns to the boiler and circulates through two sets of reheaters, bringing the temperature back up to 1003°F. The reheated steam discharges to an intermediate-pressure turbine, then to a low-pressure (lp) turbine and condenser. The resulting condensate is treated by a filter-demineralizer, and more heat is added in a series of feedwater heaters and a deaerator. The feedwater is pumped through hp heaters into the steam generator and is ready for a new cycle.

**Q** How thick are the steam drums of large utility-type boilers?
**A** The thickness depends on the design pressure, the diameter of the drum, and the material being used. For a general idea, consider the drum specifications of a steam generator with natural circulation, reheater section, economizer, waterwall heating surface, combination radiant and convection superheater, convection-type reheater, and regenerative-type air preheaters fired by oil, gas, or coal. Also assume that the unit has a

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continuous output rating of 2,390,000 lb per hr and design pressures of 2,574 psi at the drum and 2,460 psi at the superheater outlet.

The drum specifications are 60 in. ID and $6\frac{11}{16}$-in. thick SA-212 Grade-B firebox steel. The overall length of the drum is 100 ft between the feed pipe nozzle walls. The hemispherical heads are 60 in. ID and $5\frac{7}{8}$-in. thick SA-212 Grade-B firebox steel.

**Q** On modern large steam generators, what components are placed inside the steam drum? Why?

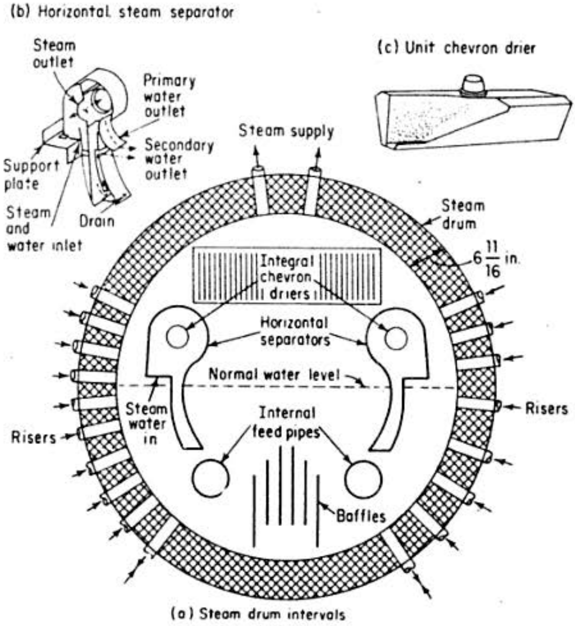


**Fig. 4-24. Steam drum has horizontal steam separator and integral chevron drier.**

**A** Figure 4-24 illustrates the internals of a typical drum, which performs two essential functions:

1. Separates steam from water to provide the downcomer system with steam-free water necessary for proper and safe circulation.
2. Separates moisture from steam to provide high steam quality.

The drum internals shown provide both functions by means of two stages of separation. The normal water level is $1\frac{1}{2}$ in. below the horizon-

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tal center line of the drum. Vortex eliminators separate the steam and water passages in the drum.

The total circulating steam and water mixture from the steam-generating tubes is directed to the horizontal turboseparators (Fig. 4-24*b*). The steam and water mixture enters the separators and is centrifuged by following the curved contour of the separator dome. Most of the separated water is discharged horizontally at the water level of the drum. The separated steam flows to the chevron driers at the top of the drum. The steam flows from the chevron through the dry box, then out the top of the drum via steam tubes across the roof to the partition wall superheater.

**Q** Do not the integral chevron driers, separators, and other hardware restrict the flow of steam outward from any opening in the drum and thus restrict the opening to a safety valve?

**A** The opening to the main steam line will usually be adequate to handle the design flow capacity. The ASME Boiler Code has definite rules on the opening to a safety valve. For example, internal collecting steam pipes, splash plates, or pans are permitted to be used near safety valve openings, provided "the total area for inlet of steam thereto is not less than twice the aggregate areas of the inlet connections of the attached safety valves. The holes in such collecting pipes must be at least ¼ in. in diameter."

In the case of steam scrubbers or driers, the ¼ in. diam opening does not apply, provided "the net free steam inlet area of the scrubber or drier is at least 10 times the total area of the boiler outlets for the safety valves." Therefore, when inspecting the internals of drums, check the condition of the ¼-in. diameter holes in the collecting pipes. They must be free and clear. The same applies to the openings on driers, because plugged driers on collecting pipes could lead to restrictions of the safety-valve openings. That would reduce relieving capacity flow, which could be dangerous.

**Q** Have special ASME and Code exceptions or rules been made in reference to once-through forced-flow steam generators which have no fixed waterlines and steam lines?

**A** Yes, quite a few. For example:

1. It is permissible to design the pressure parts for different pressure levels along the path of water-steam flow.

2. No bottom blowoff pipe is required.

3. If stop valves are installed in the water-steam flow path between any two sections of line, certain safety valves or power-actuated pressure-relief valves, with control impulse interlocks, are required (this is different from the typical boiler with safety valves protecting the entire boiler).

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4. Pressure gages required are more numerous at various sections. No water-gage glass or gage cocks are required.

**Q** Describe the LaMont boiler.

**A** See Fig. 4-25. This design is called a controlled-circulation boiler because the quantity of water passing through the boiler is from 3 to 20 times the amount evaporated. Thus two pumps are required, one for circulating the high rate of flow through the tubes (no natural circulation), the other as a conventional boiler feed pump. The feed pump operates on the same principle as most boiler feed pumps by maintaining a constant level of water in the drum.

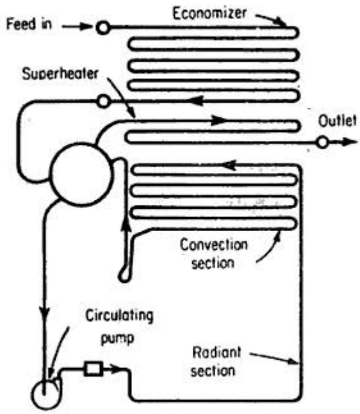

**Fig. 4-25.** Schematic diagram of controlled (forced) circulation boiler of the LaMont type.

The function of controlled circulation is to establish a flow through the first section of inlet (Fig. 4-25 shows a flow diagram) to the boiler to prevent the water in the tubes from evaporating to complete dryness. Instead, evaporation is only to the extent that dissolved solids and salts will remain in solution. This solution (a mixture of water and steam) passes to the steam and water drum, where the steam is separated out, while the excess water is removed. The separated water, along with feedwater, is returned to the pumps through downcomers.

By means of continuous or intermittent blowdown, some water and solids in solution are removed. The separated steam is passed through the superheater for final usage. These boilers have been built for pressures up to the supercritical and for capacities in excess of 100,000 lb per hr.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook*, 64 pages

*Steam Generation*, 48 pages

*Fuels and Firing*, 48 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

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# 5

# CAST-IRON AND HEATING BOILERS

**Q** In a broad, general sense, is the cast-iron boiler an ft or a wt type?
**A** The cast-iron (ci) boiler is basically a wt type because the water is inside the cast sections (no tubes) and the products of combustion are on the outside. But because of the limitations of cast iron, the Boiler Code treats ci boilers as a special type, without considering the heat-transfer method. Many ci boilers are stamped by the manufacturer as ci wt boilers, which should not be misinterpreted as a Code classification.

**Q** Why are boilers built of cast iron?
**A** Primarily because of the high resistance of cast iron to corrosion. Also ci boilers retain heat longer because of the more massive construction of the components. On early boilers, cast parts eliminated the need for riveted, and later for welded, joints at seams of drum and headers. Cast iron also eliminated the costlier labor involved in assembling a steel boiler. Sections were cast to a pattern and then assembled without too much trouble, compared with the many details needed on earlier steel boilers. Then with the growth of central heating, ci boilers, along with room radiators, became immediately acceptable.

**Q** What grade of cast iron is used for ci boilers?
**A** *Cast iron* is a term applied to many iron-carbon alloys which can be cast in a mold to make a particular shape. But for ci boilers, gray cast iron is generally used. When the casting is cooled slowly in the molds, part of the carbon separates out as graphite. This makes the gray cast iron less brittle and easier to machine. Also, alloyed with nickel, chromium, molybdenum, vanadium, or copper, considerable tensile strength properties can be achieved. The general practice is to classify cast iron by class:

| Class No. | Ultimate tensile strength, lb/in.$^2$ |
|---|---|
| 20 | 20,000 |
| 25 | 25,000 |
| 30 | 30,000 |
| 35 | 35,000 |
| 40 | 40,000 |



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**Q** In testing a steam or hot water ci boiler that has been in service, what hydrostatic test pressure should be used?

**A** Cast-iron boilers are limited to a maximum working pressure of 15 psi for steam usage. The Code allows field testing at a maximum of 1½ times the allowable pressure for either steam or hot-water boilers. There is a further stipulation that the test pressure must be controlled so the hydrostatic pressure imposed cannot be exceeded by more than 10 psi. Thus, for a steam boiler of ci construction, 22.5 psi would be the hydrostatic pressure imposed in the field.

For hot-water boilers, the test pressure would be 1½ times the allowable pressure for hot-water service. Therefore, a 30-psi hot-water-heating boiler can be subjected to a 45-psi hydrostatic test, a 60-psi hot-water boiler would require a 90-psi hydrostatic test, etc.

**Q** Name the types of ci boilers built today.

**A** Cast-iron boilers are built to various shapes and sizes, but can be grouped into the three following broad classifications:

1. Round ci boilers (Fig. 5-1) consist of a firepot (furnace) section with base, a crown sheet section, one or two intermediate sections, and a

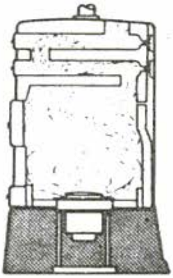

**Fig. 5-1.** Round cast-iron boiler with wall-flame rotary oil burner.

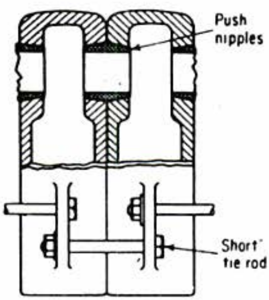


**Fig. 5-2.** Details of push nipple and short tie-rod construction.

top or dome section. The sections are held together by tie rods or bolts with push nipples (Fig. 5-2) interconnecting the waterside of the sections. Thus water circulates freely through the nipples from section to section. Fuel is burned in the center furnace, with the flue gases rising and flowing through the various gas passages of the water-filled sections, then out to the stack. The round ci boiler used to be popular for hw-supply service, and was often stamped "hy-test" to indicate an allowable pressure of 100 psi for domestic hot-water service. But it is rapidly being replaced by fired steel-welded water heaters or by electrically heated water heaters.

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2. Sectional boilers (vertical) consisting of sections assembled front-to-back, with sections standing vertically and assembled by means of push nipples or screwed nipples. See Figs. 5-3 and 5-4.

3. Sectional boilers (horizontal) consisting of assembled sections stacked like pancakes. Here each section is laid flat in relation to the base. This type of vertical stacking may be supplemented by having three vertically stacked boilers side by side and interconnected to gain additional capacity. In this arrangement a common supply and return header is used with no intervening valves between the vertically stacked boilers. These units are usually gas-fired, with a burner for each vertical stacking.

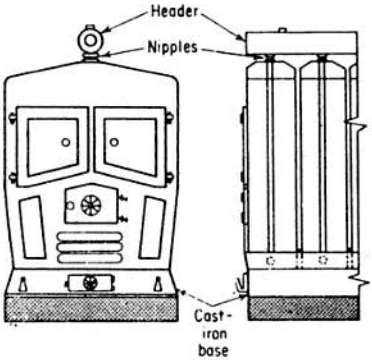


**Fig. 5-3. Vertical-sectional horizontal-stacked cast-iron boiler of the screwed-nipple type.**

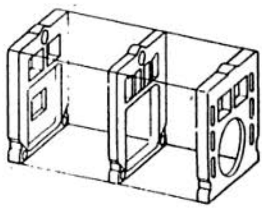

**Fig. 5-4. Assembling vertical sectional cast-iron boiler of push-nipple type.**

**Q** Name the two design features used to aid in assembly of vertical ci boilers.

**A** 1. Internal, tapered push nipples inserted into holes of the vertical section. Then by means of through tie rods, or short tie rods (Fig. 5-2), the sections are pulled together by tightening nuts against washers on the tie rod. That interconnects the sections on the waterside, enabling them to withstand pressure as assembled sections.

2. External header type (Fig. 5-5) where the sections are individually assembled to headers (supply drum and return drums) by means of threaded nipples, locknuts, and gaskets. This type assembly allows replacing an intermediate section, because only the locknuts, gaskets, and threaded nipple have to be removed on each header to slide a section out. In contrast, with through tie-rod construction, all the sections in front of the intermediate section to be replaced have to be removed first to get at the affected section.

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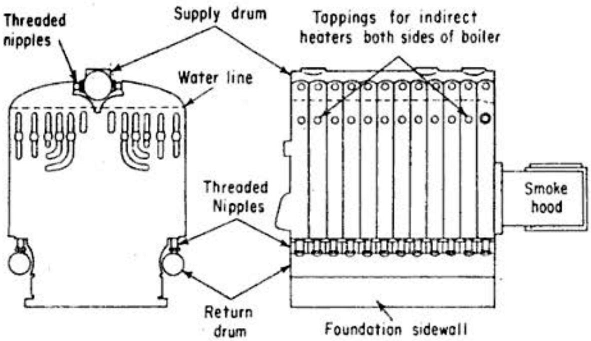


**Fig. 5-5. Header-drum and screwed-nipple construction.**

**Q** How does the flue gas travel through a ci boiler?

**A** In the design shown in Fig. 5-6, flue gases rise from the combustion area into uptakes between each boiler section at the right and left side. The gases are directed through the two outside flue passages to the front of the boiler and then back through the center flue ways to the smoke collar. The uptakes between each section expose more radiant-heat-absorbing surfaces and divide the hot gas volume into small gas streams. These gas streams are directed to the cooler sides of the firebox. Multiple uptakes combined with three-pass design prevent gases taking shortcuts to the chimney. Thus longer flue-gas travel and higher velocities increase heat absorption of the secondary heating surfaces.

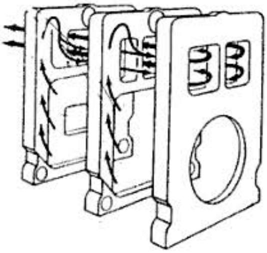

**Fig. 5-6. Gas travel through tie-rod assembled-type cast-iron boiler.**

Today ci boilers are also built for forced-draft firing. This is possible by sealing the space between sections with asbestos rope seals. The advantages claimed are that the pressurized furnace can use a shorter chimney and less boiler-room space because the unit is smaller and more efficient. Flame-retention-type burners are used which hold the flame in front of the nozzle, guiding it in a shape-controlled pattern.

The sections of these boilers have a newly designed, grooved, seal strip which receives the asbestos rope. When installed, the outer edge of the rope is accessible between sections so that the boiler can be visually checked for furnace tightness. The rope is compressible, thus allowing for contraction and expansion of the boiler. The assembled boiler, partially illustrated in

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Fig. 5-6, requires no combustion chamber. The bottom and sides of the assembled sections form the furnace. Note this arrangement's similarity to a wt boiler with waterwalls and bottom furnace tubes. Here also, flame retention burners limit the flame travel and avoid flame impingement on the sections.

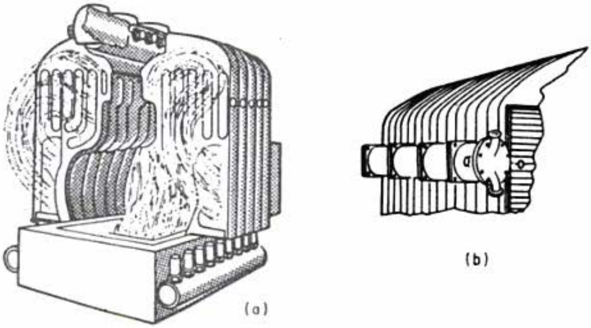


**Fig. 5-7. (a) Gas travel in header-type cast-iron boiler. (b) Manifold for heating domestic hot water.**

Figure 5-7*a* shows the external-header boiler and its gas travel. This unit has two half-sections for each vertical row, sometimes referred to as pork chop sections. The design shown may also be provided with a manifold on both sides (Fig. 5-7*b*) to obtain domestic hot water.

**Fig. 5-8. Official symbol for stamps to denote ASME Standard Heating Boilers, Section IV.**

**Q** What is the minimum-size safety valve (sv) allowed indicate that it is built under ASME rules?
**A** The first stamping to note is the ASME Heating Boiler Code symbol shown in Fig. 5-8. The other stamping required is one indicating allowable pressures and capacities, and whether the boiler is for water or steam usage.

**Q** What is the minimum-size safety valve (sv) allowed on a ci steam boiler? Is the same true for a hot-water ci boiler?
**A** ASME requires a minimum ¾-in. sv for both steam and hot-water ci boilers.

**Q** What is meant by an officially rated ASME pressure-relief valve?
**A** An officially rated ASME pressure-relief valve is meant for hot-water boilers. It must be stamped for its pressure setting and its Btu-per-hr re-

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lieving capacity. Also, it must be equipped with a hand test lever, be spring-loaded, and must not be of the adjustable screw-down type. A typical sv ASME symbol is shown in Fig. 5-9.

**Q** Does a ci boiler require a bottom blow-off pipe and valve?

**A** Yes. The ASME Code requires each boiler to have a blow-off pipe connection fitted with a valve or cock, of not less than ¾-in. pipe size. It must be connected with the lowest water space practicable.


**Fig. 5-9. ASME standard symbol for safety relief valves.**

**Q** What is the minimum size of pipe required for connecting a water column to a steam-heating boiler?

**A** The minimum size of ferrous or nonferrous pipe must be of 1 in. diam.

**Q** Does the ASME Code require a low-water fuel cutoff on a ci steam-heating boiler?

**A** Yes. Each automatically fired steam or vapor system ci boiler (or low-pressure steel steam boiler) must be equipped with an automatic low-water fuel cutoff. It must be so located as to automatically cut off the fuel supply when the water level drops to the lowest safe waterline. The safe waterline cannot be lower than the lowest visible part of the water gage glass.

**Q** Can ci boilers explode, or do they merely crack?

**A** When controls are not operating properly, or if the safety relief valve is stuck or of the wrong size, a ci boiler will explode. Many have. The big difference between a shell-type steel boiler explosion and a ci boiler explosion is that a ci boiler will usually fragmentize into smaller pieces of the affected sections. A steel boiler, on the other hand, rips and tears along the sheet of a drum or shell. Then it flies apart in the form of curved panels of steel. But in each explosion, the danger to life and property is very great.

**Q** Name the most frequent failure on a ci boiler.

**A** Cracking of a section or sections, permitting steam and water to gush out of the cracks, and thus making the boiler inoperable.

**Q** Does a cracked section require a complete replacement of all sections on a ci boiler?

**A** Only if the model and type of boiler section are obsolete and no longer available. The reason is that cast sections made from a pattern to be built and then cast in a foundry are too expensive a repair. Therefore, the obsolescence of a ci boiler can be very rapid if the model owned, or operated, is no longer stocked by the manufacturer with replacement sections. On steel boilers, especially welded boilers, repairs can be made

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more readily by replacing defective areas of sheets, veeing out and rewelding cracks, etc.

If sections are available, and one or two sections are cracked, the defective section or sections can be removed and the replacement installed without too much difficulty (see Fig. 5-10). On older through-tie-rod construction, this may mean first removing good sections in front of the defective section. But on the external header type with screwed nipples, only the defective section has to be removed.

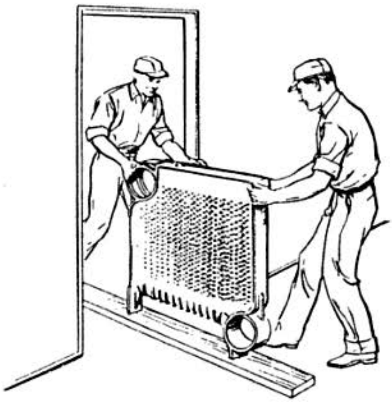

**Fig. 5-10. Replacement section of cast-iron boiler.**

**Q** Cannot cracks in cast iron sections be repaired by welding?

**A** Yes, but the work must be done by a firm, or weldor, very experienced in welding cast iron. At times, depending on the location and length of the crack, economics will dictate a cheaper repair. Thus a more reliable one may be to replace the cracked section. For example, if of through-tie-rod construction and the section is cracked in an intermediate inaccessible area, the unit will have to be dismantled. Then the area of the crack will have to be thoroughly cleaned on the fireside (also waterside, if possible), followed by slow and careful welding.

But if the crack is small and in an accessible area, it may be possible to repair the crack in position, if done properly by an experienced weldor. Fusion welding of the *cold-welding* type is recommended, using iron, steel, stainless steel, nickel, or bronze electrodes. But the experience of the weldor may dictate the electrode.

**Q** What is mant by cold welding?

**A** Cold welding is a method of fusion welding that has been used for

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years in the repair of castings such as ci boilers, cylinder blocks, and stationary ci objects. Basically, cold welding is done by keeping the heat input to the casting at a minimum while keeping the casting and repair area at a low temperature until welding is completed. While no preheating is used, it is best to have the casting at room (ambient) temperature. Of course any foreign matter should be removed before welding.

**Q** Name at least seven causes of ci boilers cracking.

**A** Cast iron boilers of different poured shapes, with unpredictable stress concentration areas, geometry, service factors, waterside fouling, soot and carbon accumulation on the fireside, and rapid temperature changes are all causes for cracking. Thus they may never fail twice in an identical manner. Careful investigation will usually point to one or more of the following causes:

1. Rapid introduction of cold water into a hot boiler, as may occur with poorly operated manual makeup or an automatic feed device.
2. Makeup line connected to a section instead of to the return line to temper the cold water with the returning condensate or hot water (the Code requires makeup to *enter return lines*).
3. Controls not functioning and thus overstressing the boiler either by pressure or temperature.
4. Insufficient water in the boiler.
5. Internal concentrated deposits, blanking off proper heat transfer or obstructing circulation from section to section.
6. Defective material or casting which does not become noticeable until after several years of service.
7. Poor assembly or workmanship, or improper installation of the boiler as to pitch, alignment, tie-rod tightening, screwed-nipple fitting, etc.

**Q** What should be checked on section connections?

**A** When checking new boilers, always check the type of nuts securing the tie rods. If solid steel or brass nuts are used, make sure they are only hand-tight, or backed off a few threads. The first choice on new boilers is collapsible washers, with shallow split brass nuts. The second choice is split shallow nuts backed off hand-tight (or cloverleaf-type nuts that fail when a slight expansion takes place). On an older unit idle during summer months and located in a damp basement, make sure the holding nuts are not tight. Also determine whether the tie rods are rusted into their holes, which may have the same binding effect as tight securing nuts. Obviously, if the rods are free and nuts slacked off, there should be no problem of expansion cracking. If rust growth plus tight tie rods are the cause of cracking, the boiler must be dismantled and the rust buildup removed by chipping.

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Header-type boilers have no tie rods nor tapered nipples, so nothing can be adjusted to allow for abnormal expansion. In addition to rust depositing between the sections, rapid start-up can cause serious damage to these units. Make sure older boilers without good blowdown facilities do not develop scale buildup, because it results in cracking. Restriction of water supply and circulation can also be caused by scale buildup in these units, resulting in overheating.

**Q** What are the ASME recommendations for connecting steam-heating boilers in battery?

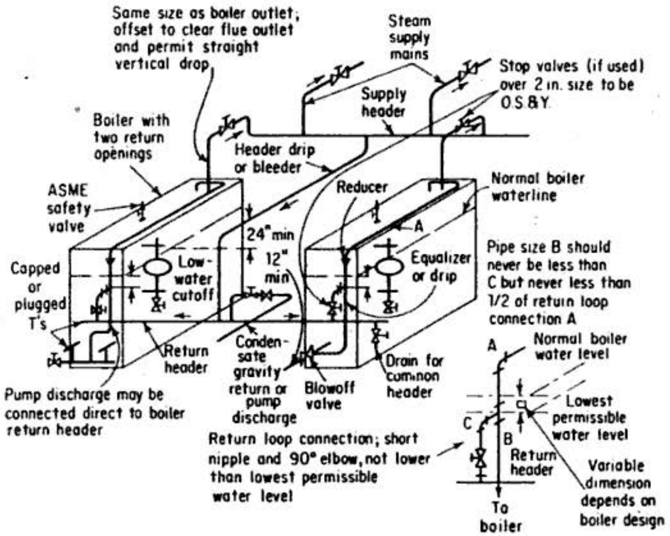


**Fig. 5-11. ASME recommendations for connecting steam-heating boilers in battery.**

**A** See Fig. 5-11 and note the following:

1. Return-loop connection shown eliminates the need of check valves on gravity-return systems, but in some localities a check valve is a legal requirement.

2. When pump discharge piping exceeds 25 ft, install a swing check valve as shown and at the pump discharge.

3. If pump discharge is looped above normal boiler waterline, install a spring-loaded check valve at the return header and at the pump discharge.

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4. Where supply pressures are adequate, feedwater may be introduced directly to a boiler through an independent connection (see the latest ASME Code).

5. The return connections shown for a multiple-boiler installation may not always ensure that the system will operate properly. Thus in order to maintain proper water levels in multiple-boiler installations, it may be necessary to install supplementary controls or other suitable devices.

**Q** Name the four ASME recommendations for return-pipe connections to steam-heating boilers.

**A** 1. The return-pipe connections of each boiler supplying a gravity-return steam-heating system shall be arranged to form a loop as shown in Fig. 5-11. Then the water in each boiler cannot be forced out below the safe water level.

2. For hand-fired boilers with a normal grate line, the recommended pipe sizes detailed as A in Fig. 5-11 are 1½ in. for 4 sq ft or less of firebox area at the normal grate line, 2½ in. for areas more than 4 sq ft and up to 14.9 sq ft, and 4 in. for 15 sq ft or more.

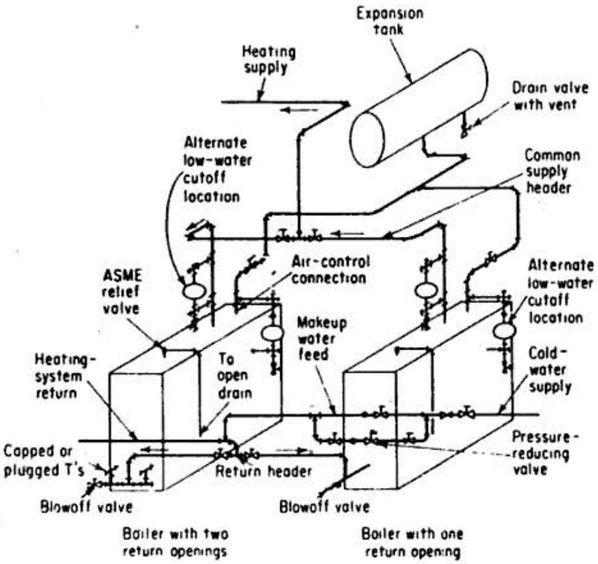


**Fig. 5-12. ASME recommendations for connecting hot-water-heating boilers in battery.**

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3. For automatically fired boilers which do not have a normal grate line, the recommended pipe sizes detailed as A in Fig. 5-11 are 1½ in. for boilers with a minimum sv relieving capacity of 250 lb per hr or less, 2½ in. for boilers with minimum sv relieving capacity from 251 to 2,000 lb per hr, inclusive, and 4 in. for boilers with more than 2,000 lb per hr minimum sv relieving capacity.

4. Provision shall be made for cleaning the interior of the return piping at, or close to, the boiler.

**Q** What are the ASME recommendations for connecting hot-water-heating boilers in battery?

**A** See Fig. 5-12. The pipe size can usually be obtained from the boiler manufacturer if the model and type are identified. Also see the ASME and the local Code. Note that acceptable shut-off valves, or cocks, in the connecting piping may be installed for convenience of control testing and service.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

- *Power Handbook*, 64 pages
- *Steam Generation*, 48 pages
- *Fuels and Firing*, 48 pages
- *Gaskets*, 20 pages

Books

- Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.
- Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.
- *ASME Boiler and Pressure Vessel Code*, Section IV, Low-pressure Heating Boilers, American Society of Mechanical Engineers, New York.

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# 6

# SPECIAL BOILERS

**Q** What are special boilers?
**A** Any of the better-known designs that have unusual features and therefore cannot be labeled as a conventional ft, wt, or ci design.

### COIL-TYPE BOILERS

**Q** Are controlled-circulation boilers (see Chap. 4) built in smaller sizes?
**A** Yes, they are popular in sizes of 15 to 300 hp (500 lb per hr to about 10,000 lb per hr). One design has steam generated in one continuous spiral helical-wound coil (Fig. 6-1), with no headers in between. Rapid steaming ability is a feature of several coil-type wt boilers. They have forced circulation and intense heat release from a gas or oil burner.

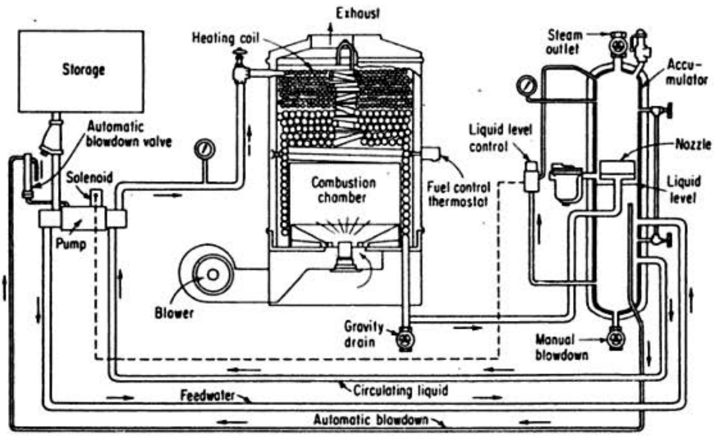


**Fig. 6-1. Coil-type unit of once-through design has accumulator.**



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Most come to full capacity and pressures within 5 min after start-up. Operation is automatic. They may generate as little as 1,500 lb per hr, although some produce 15,000 lb per hr at 900 psi.

The boiler illustrated is shipped complete, ready to operate, fully automatic at pressures to 300 psi. In addition to several units often installed in batteries, they are also used for emergency steam service, available on a rental basis, delivered where needed.

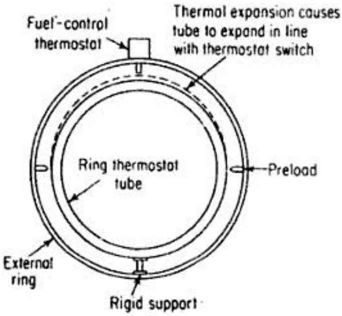


**Fig. 6-2. Expanding overheated ring-thermostat shuts off fuel.**

An unusual feature is the ring thermostat tube (Figs. 6-1 and 6-2). This tube is an integral part of the heating coil, actuated directly by combustion heat. In case of water shortage or any excessive heat condition, the thermostat control will expand beyond the set point and thus shut off the fuel supply.

Another design has three nests of coils and inlet and outlet headers. It is widely used in small sizes up to 300 hp, and pressures to 250 psig.

**Q** Name some disadvantages of coil-type boilers.

**A** Any malfunction in the loop may cause a coil failure from overheating. This could come about from pump failure, partial blockage of inlet and outlet lines, blocked tubes (scale), fireside soot accumulation in concentrated heat zones, malfunction of controls, etc. Thus it is essential to keep both the waterside and fireside of the coils clean; proper feedwater treatment is vital. A pressure differential chart is often used to show whether the difference between suction and discharge pressure on the recirculation pump exceeds a certain pressure differential. If so, it is a sign of tube or flow obstruction. In a conventional boiler of multitube design, a leaky tube can be plugged, then the boiler operated until it is convenient to replace the affected tube. With a coil-type boiler the entire coil must usually be replaced.

## WASTE-HEAT BOILERS

**Q** Where are waste-heat boilers used besides in utilizing the exhaust heat from gas turbines and internal-combustion engines?

**A** Where by-product heat of sufficient Btu content is available from a manufacturing process. With air pollution laws becoming more stringent, more waste-heat boilers will probably be installed.

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**Q** What kind of boilers are used in waste-heat applications?

**A** Depending on conditions, these types:

1. Fire-tube boilers, both the vertical and horizontal types, if waste gas is relatively clean.
2. Straight-tube wt boilers, for clean or moderately dust-laden waste gas.
3. Water-tube of the bent tube (Stirling) type, for very heavy dust loadings.
4. Positive circulation boilers, for clean, low-temperature gases.
5. Pressurized or supercharged boilers, for gas turbine exhaust (Velox type).

**Q** What is meant by the term *total energy system?*

**A** Total energy refers to the reappearance of generating plants in large apartment-house projects, office-building complexes, shopping centers, and other locations where year-round comfort cooling and heating are required. By proper design, it is possible to generate electricity by means of diesel engines or gas turbines and then use the exhaust heat (previously wasted) to heat the premises in winter. The warm engine-cooling water discharge under pressure is also used to generate hot water or steam. By means of large absorption refrigeration machines, or centrifugal compressor machines utilizing exhaust steam, the premises are cooled in summer. Other by-products of exhaust heat include hot-water supply for washing purposes. The electricity generated can be used for lighting or for driving pumps and fan motors for the air-conditioning and heating systems. Thus a very efficient heat rate can be obtained (up to 70 percent), and the energy of the fuel is spread into three directions: (1) electricity for light and power, (2) heating, and (3) cooling. Therefore the term total energy system is used, because all energy required is supplied.

**Q** What type boilers are used in incinerator plants?

**A** Four-drum Stirling-type boilers are still used in older installations, as are two-drum types. But these have a furnace designed to utilize the waste heat from a municipal incinerator. Usually the gases from the incinerator enter through an opening in the side wall of the furnace near the floor. The rear wall of the furnace may have an oil burner to supplement the waste heat when more steam is required. A convection-type superheater is used behind the water-cooled bridge wall. The garbage is not burned inside some boilers, but rather in outside ovens connected to the furnace. The flue gas is led to these boilers by means of a bricked-in tunnel. Still another type of unit has a pendant superheater suspended over the waste-gas inlet. It is a three-drum boiler, two drums on top and one on bottom. While used in large petrochemical plants for pressures up

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to 450 psig at 550°F, it can also be designed for incinerator service. And capacity is up to 112,000 lb per hr.

With tougher air pollution laws, many cities are turning to more efficient European incinerators. Figure 6-3 is one example. The boiler in the plant shown has a superheater and economizer. The refuse is burned on a barrel-grate stoker, and the steam generated is sold for district heating.

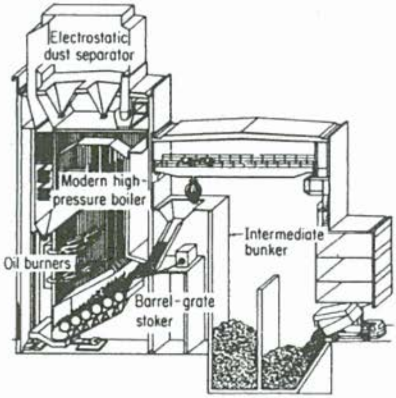


**Fig. 6-3. Incinerator plant has modern high-pressure boiler and barrel-grate stoker.**

**Q** Assume a process providing waste heat to a waste-heat boiler of a continuous nature, thus making the securing, or killing, of a fire or process extremely expensive, if not impossible. How can such a boiler be secured in case of low water to avoid burning the tubes?

**A** This is an extremely important design consideration. And if designed for, it is also a very important operating check that should be made periodically to ensure that the unit is in working condition. This test should be the same as when testing low-water fuel cutoffs on a suspended fuel-fired standard boiler. Basically the design should include a mechanism, either a heavy damper or other quick-closing mechanism. In this way in case of low water, the waste gases can be cut off from the boiler and bypassed to the stack. Then the basic process will not be interrupted, and the boiler will also be saved from serious damage due to overheating.

A preferred method is a device that automatically diverts the gases as soon as the water level drops to a predetermined dangerous level. Remember that *time* is of extreme importance in a low-water condition, so the heat input must be quickly removed.

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IMPORTANT: On waste heat boilers, the testing and duplication of a low-water condition, and actions to be taken, are often neglected by the operators. They do not realize that low water can and does happen on these units. Presumably they also fear to interrupt a process.

## WASTE-FUEL-FIRED BOILERS

**Q** From where do some gaseous waste fuels come?

**A** The steel industry has large quantities of gaseous by-product energy available. Heat content varies from less than 100 Btu per cu ft for blast-furnace gas to 525 to 600 Btu per cu ft for coke-oven gas. The main problem is getting this gas clean enough to avoid fouling the burners.

Oil refineries (catalytic cracking of crude petroleum) produce large volumes of gas as a by-product of catalyst regeneration. This gas contains 5 to 8% CO (carbon monoxide), about twice that much $CO_2$ (carbon dioxide), and air. The gas temperature is around 500°F, with a heat content of about 145 Btu per lb. Increasingly, refineries reclaim this energy by burning the gas, together with oil or gas and additional air, in a CO steam generator.

NOTE: A CO unit is also needed in any area where air pollution is a problem because it not only saves heat but burns up the CO and any unburned hydrocarbons that escape from the regenerator of a catalytic cracking unit.

**Q** From where do some liquid waste fuels come?

**A** Liquid by-products include residue from chemical processes such as tar and pitch. These can be handled in conventional oil burners, but for satisfactory results, they must be heated to maintain viscosity at the proper level. Filtration is also required to remove any solid contaminants. High moisture content can be poured off (decantation) or emulsified.

Recovery steam generators in the pulp and paper industry recover chemicals used for pulping from either the black liquor alkaline process or the red liquor acid process. In addition, they generate a high proportion of the steam needed for the plant. Black and red liquors do not burn alike; thus the steam generators used are not alike. Black liquor in the kraft process is very difficult to burn. Large furnaces are needed to keep the temperature relatively low because the liquor has a high content of low-fusion-temperature ash. Smelt collects on the refractory sloping hearth, and a reducing atmosphere must be maintained in the lower part of the furnace for chemical conversion. Also, since superheater and boiler surfaces have a tendency to coat with slag, they operate at low absorption rates. Thus frequent soot blowing and shot cleaning of heating surfaces is necessary.

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Red liquor in the MgO (Magnesia oxide) process, on the other hand, burns completely in suspension, making little or no slag. Thus a smaller steam generator can be used for an equivalent amount of steam production.

**Q** What is meant by black liquor?

**A** In the paper-making industry, wood chips are loaded into large pressure vessels (digesters). After adding water, sodium sulfide, and sodium hydroxide, live steam is introduced. Cooking turns the resultant solution black, hence the name black liquor. This strong liquor is withdrawn from the digester (the remaining pulpy mass is used for making paper) and is stored in tanks where it is joined by a weaker liquor solution used to wash the pulpy mass from the digester. In this state the liquor from the digesters cannot be burned, so it is concentrated by evaporating some of the water. Crushed salt is also added until it becomes over 50 percent solid. The resultant liquor is so viscous that it must be heated to around 220°F before it can be pumped. Heating is by direct steam, or the heat exchangers would soon plug from the viscous liquor. The high solid concentration also makes the liquor abrasive.

## SOLID-WASTE FUEL

**Q** From where do some solid-waste fuels come?

**A** Solid by-product fuels are many. Among them are wood chips, sawdust, hulls from coffee and nuts, corn cobs, bagasse (waste product from sugar cane), coal char (residue from low-temperature carbonization of coal), and petroleum coke (final solid residue from a refinery). Each product must be handled in a special manner because of differences in moisture content, consistency, specific weight, and heat content.

The furnace rather than the steam generator is affected when these special fuels are used. Products like bagasse, which has about 50 percent moisture, require a Dutch oven. The Ward furnace is a popular design for bagasse, both in the United States and abroad. Here bagasse fuel is partly dried and burned in refractory cells below a radiant arch. The combustion of gases is completed above the arch. Spreader stokers can also be used.

In refining sugar from cane, the juice squeezed out of the cane eventually is processed into sugar. The remaining fibrous, tenacious, and bulky crushed cane is called bagasse. It is also moist. Depending on where it is grown and the efficiency of the juice extractor, bagasse contains 30 to 50 percent wood fiber and 40 to 60 percent water. Heating value is 8000 to 8700 Btu per lb as a dry solid, with a yield of about 4500 Btu per lb at around 45 percent moisture content.

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The art of burning wood refuse (ranging from hogged wood to sawdust) has progressed to a point where a spreader stoker or a cyclone burner does an efficient job, generally in combination with some coal.

## HIGH-TEMPERATURE HOT-WATER BOILERS

**Q** When does a boiler become a high-temperature hot-water (hthw) unit?

**A** According to the ASME Code, when the temperature exceeds 250°F or the pressure exceeds 160 psi. In practice, 350 to 450°F is considered high-temperature water, 250 to 350°F is medium temperature.

**Q** What are some of the advantages claimed for hthw systems?

**A** A basic advantage is that the heat storage capacity of water per cubic foot is considerably greater than steam at equivalent saturation pressures (see table, Fig. 6-4). This inherent reserve (flywheel effect) permits

**Comparison of Relative Heat Content of Water and Steam**

| Abs. pressure, psi | Saturated temp, °F | Return temp, °F | Density | | Heat content | | Heat content ratio |
|---|---|---|---|---|---|---|---|
| | | | Lb/cu ft water | Lb/cu ft steam | Btu/cu ft water | Btu/cu ft steam | Water/steam |
| 14.7 | 212 | 180 | 59.8 | 0.0373 | 1,923 | 37.4 | 51.5/1 |
| 29.8 | 250 | 200 | 58.9 | 0.0724 | 2,972 | 72.1 | 41.2/1 |
| 67.0 | 300 | 200 | 57.3 | 0.1547 | 5,820 | 156.7 | 37.2/1 |
| 134.6 | 350 | 200 | 55.6 | 0.299 | 8,550 | 306.5 | 27.9/1 |
| 247.3 | 400 | 200 | 53.5 | 0.537 | 11,090 | 555 | 20.0/1 |
| 343.7 | 430 | 200 | 52.4 | 0.741 | 12,570 | 768 | 16.4/1 |
| 566.1 | 480 | 200 | 50 | 1.222 | 14,820 | 1268 | 11.7/1 |

Fig. 6-4. Water has higher heat ratio than steam.

closer temperature control and more rapid response to changing load demands. The claim is also that substantial savings in capital investment and operating and maintenance costs are possible. For example, steam traps, valves, condensate tanks, and expansion tanks are not always needed. But in an hthw system of the forced-circulation type, a pump is required to circulate the hot water. However, the pump can be located near the boiler and not elsewhere in the condensate system.

Since a closed hot-water system is under constant pressure, very little makeup is required because of flashing. Losses occur chiefly at the pumps and amount to 0.5 percent of the total system content per day. This compares with up to 15 percent per day makeup needed for steam sys-

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tems. The heat storage capacity of an hthw unit and the elimination of flashing and losses due to leaks permit a smaller heat generator. And smaller-diameter distribution lines can be used, thus exposing less circumference for heat loss. The heat storage of an hthw pipeline is 18.4 times greater than the Btu content of a comparable steam line.

**Q** What kind of boilers are generally used in hthw applications?

**A** Many types, burning coal, oil, gas, or other fuels. Forced-circulation boilers, such as the LaMont type (Fig. 6-5), are very popular. But regardless of design, they produce a mixture of water and steam which flows from the heater exit to the expansion drum (Fig. 6-6). Not all boilers have a steam drum. The basic idea is that for a given output a smaller combustion space and thus a smaller boiler can be used, if the waterwall subjected to high gas temperature can absorb larger heat quantities per unit area. (See Fig. 4-25 for a flow diagram.)

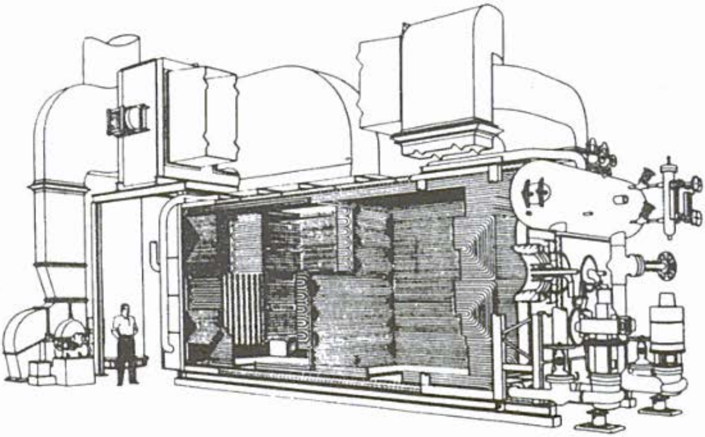

**Fig. 6-5. High-temperature hot-water boiler of forced-circulation LaMont type.**

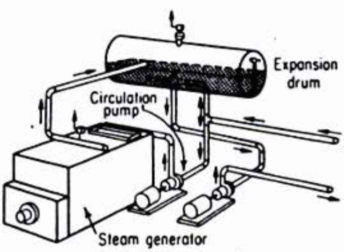


**Fig. 6-6. Steam cushion method for high-temperature hot-water system.**

**Q** Name one method used for pressurizing hthw systems.

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**A** A steam-cushioned system (Fig. 6-6) is generally used because of its simplicity. Here the hthw discharges directly from one or more generators into a common expansion drum. Steam is flashed to maintain constant pressure within the drum. To permit free vapor release, the expansion drum is located above the generator, with enough height to furnish a reasonable net positive suction head (npsh) for the circulation pump.

**Q** How is circulation through the boiler tubes controlled in forced-circulation boilers of hthw systems?
**A** The pump-circulation direction must not buck the natural circulation of the heated water in the boiler. In the LaMont design, each tube or bank of parallel tubes has an orifice. These create an artificial pressure drop to induce flow from higher to lower pressure through the tubes. A carefully designed natural recirculation system is also used to support the forced circulation, especially in high furnace-absorption zones. This is done by proportioning the flow through the tubes to match the varying furnace-heat-absorption zones. Thus downcomer tubes are used outside the heated zone toward the lower, or water, section. This affects, or restores, upward circulation to the hotter-water zone.

**Q** What kind of valves should be used for hthw application?
**A** Valve seats, plugs, and bodies should be made only of cast steel, forged steel, or steel alloys. Valve seats should be stainless chrome nickel steel, to avoid corrosion and erosion by flow of water. Pressure ratings should follow the Power Boiler Code rating on stop valves, feed valves, and blowdown valves, which is 125 percent of boiler AWP.

**Q** Do hthw generators require a water and gage glass?
**A** Only if a natural-circulation boiler has a drum, which is used as an expansion tank. If the boiler is completely filled with water under pressure and has an external expansion tank, the Power Boiler Code does not require a water gage glass, nor gage cocks.

**Q** On forced-circulation boilers for hthw, what provision should be made to prevent hot spots, or lack of circulation, in case the pump fails?
**A** A pressure differential or flow switch should be installed to shut off the fuel-burning equipment in case no water is flowing.

WARNING: This is very important for automatically operated boilers.

**Q** Should a low-water fuel cutout be used on an hthw generator of the suspended fuel-fired type?
**A** Some states now require a low-water fuel cutout on low-pressure hot-water heating systems. Thus it follows that this safety device is even more necessary on an hthw boiler. It should be installed on the boiler to shut off the fuel in case the water level drops below a dangerous level.

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## THERMAL LIQUID HEATERS AND VAPORIZERS

**Q** What is a thermal-liquid heater?

**A** As heat equipment was developed, high temperatures at moderate pressures were recognized as having potential uses in process work. For example, to obtain 705°F with water, the saturation pressure is 3,206 psi (critical pressure). So special fluids were developed to obtain high temperatures at moderate pressures. Thus the term *thermal-liquid heater* means a closed vessel in which a heat-transfer medium other than water is heated without vaporization, and the heated fluid gives up its heat or does useful work outside the closed vessel.

**Q** What is a fluid-vaporizer generator?

**A** This also is a closed vessel in which a heat-transfer medium, other than water, is vaporized under pressure by the application of heat. Here also, the heat-transfer medium is used externally to the closed vessel.

**Q** Why are high-temperature fluids used instead of water?

**A** These fluids can be used as heat-transfer media at temperatures and pressures that could make water or steam uneconomical. The allowable temperature range varies all the way from −100 to 1000°F, and a uniform temperature is obtained over the entire heat-transfer surface.

Economy is the big advantage because at moderate pressures, higher temperatures can be obtained with these media.

> EXAMPLE: Up to the 350 or 360°F temperature level, steam around 150 psi is satisfactory. But if temperatures from 450 to 1000°F are needed, the corresponding steam pressure may be excessive for economic operation.

**Q** Illustrate a thermal-liquid system for process.

**A** Figure 6-7 shows an application for the plastics industry. Thermal liquid at 550°F supplies plant process and space heating in this system. A calender temperature control valving system and recirculating pumps are part of the circuit. Liquid-type heaters are generally of the wt type, whereas vaporizers may be either ft or wt design.

**Q** Do fire insurance companies and local fire regulations have requirements on liquid-phase heaters or on vapor-phase heaters?

**A** Yes. Because a distinct fire hazard may exist with some of the organic fluids, including mineral oils, fire regulations are in effect.

**Q** How is the discharge capacity of svs determined on liquid- and vapor-phase heaters?

**A** The pressure setting of the sv should be based on the maximum allowable working pressure of the unit. The capacity of the sv should be

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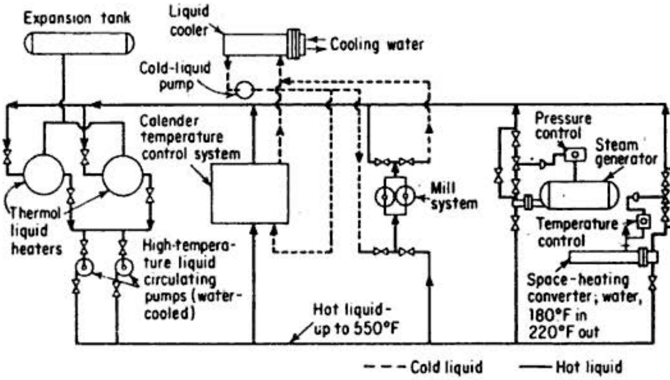


**Fig. 6-7. Thermal liquid system for plastics industry.**

based on the maximum Btu-per-hour output of the heat generator, whether for liquid- or vapor-phase heaters.

## ELECTRIC BOILERS

**Q** Is there any other type of boiler in competition with the fired vt boiler?

**A** Yes, the electric boiler is popular in areas where electric utilities are promoting electric heating. Basically, all electric boilers have the same efficiency, nearly 98 percent. Power consumption, which is proportional to the steam generated, is figured at 10 kilowatt hours (kwhr) of 220-volt (or higher) current for 1 boiler horsepower (boiler hp) or 34.5 lb of steam per hour. But this is roughly three times the cost of steam generated in a small boiler fired with No. 2 oil. Models today have capacities of up to 60 boiler hp, which is about 2,000 lb of steam per hour. Small, portable units for cleaning go down to as little as 1 boiler hp. Steam pressures go as high as 600 psi, although 100 to 150 psig is average.

**Q** How are electric boilers classified?

**A** There are two basic types:

1. Units with heating elements constantly submerged in water (Fig. 6-8). These elements do not depend on conductivity or resistance of the water for heating and steam generation.

2. Units with electrical electrodes located in a central generating chamber (Fig. 6-9). The water level recedes as the demand for steam decreases. Thus at no load, the electrodes are entirely out of water, and there is no electrical consumption.

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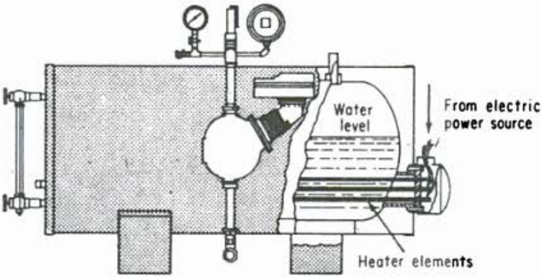


Fig. 6-8. Resistance-type electric steam generator.

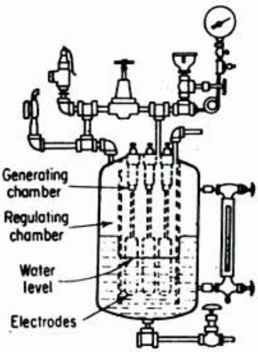


Fig. 6-9. Electrode-type electric steam generator.

While low-water-level controls are required for the boilers shown in Fig. 6-8, they are not needed for the second type. The reason is that they cannot generate steam when the water is low or when no steam is required. To ensure that the boiler carries the proper salinity, a conductivity control is generally supplied. This means that salts are added, or the unit is blown down, depending on the condition of the water. All electric boilers should be built in accordance with the ASME Boiler Code and also approved by Underwriters Laboratories.

**Q** Explain how the electrode principle works.

**A** Figure 6-9 shows a cylinder, open at the bottom, welded to the inside of the upper head of a pressure tank. This cylinder divides the tank into two concentric chambers. The outer is the regulating, the inner the generating chamber. Suspended within the generating chamber are the three electrodes with electric power connected to them.

To operate, a prescribed quantity of electrolyte is dissolved in water and poured into the generator through the hand fill. (In larger steam generators, it is added with the feedwater pump.) This electrolyte remains in the generator until drawn off with the water through the drain valve. Electric power is switched on, and heat is generated by the resistance of the water to the passage of current between the solid electrodes. Thus steam generated in the chamber flows through the outlet pipe and through the steam header, then through the pressure regulator and out the regulating chamber.

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**Q** Do state boiler code laws requiring boilers of over 15 psi pressure to be opened annually for internal inspection also apply to electric boilers?
**A** Most states include electric-type boilers in their rulings. The ASME Boiler Code states that electric boilers of a design employing a removable cover which will permit access for inspection and cleaning of the shell, and having a normal water content not exceeding 100 gal, need not be fitted with washout or inspection openings.

The usual access for inspection and cleaning is the electrode cover connection to the inside of the boiler. This must be pulled out to check the internal conditions of the boiler. At the same time, check the condition of the electrical resistance elements.

**Q** How is the sv capacity determined on an electric boiler if there are no typical heating surfaces?
**A** The capacity of the sv is determined by the kilowatt input. The minimum sv capacity must be at least 3.5 lb per hr per kw input. This is true whether it is a high- or low-pressure boiler. On a Btu-per-hour basis, the requirement is 3500 Btu per hr for each kilowatt input.

## SPECIAL CHEMICAL-TYPE STEAM GENERATORS

**Q** Besides nuclear power, what other means are under investigation or research to provide steam for process or power generation?
**A** Two units have recently been developed that could possibly affect steam generation.

1. The 30-in.-high Hyprox generator that occupies about 4 sq ft of floor space. It generates steam at a rate of up to 40,000 lb per hr. The 150,000-lb model takes only 6 sq ft of floor space.

A Hyprox generator uses hydrogen peroxide, hydrogen, and water to make virtually instantaneous steam. Obviously, it is not intended to supplant conventional steam boilers. At today's price for 90 percent hydrogen peroxide (about 42 cents per pound), sustained operation would prove to be much too costly. But Hyprox is a very handy standby generator knocking at the door of any number of industrial possibilities where high-pressure high-temperature steam is needed intermittently but immediately.

2. The LOX-hydrocarbon unit is another instantaneous steam generator, but instead of using hydrogen peroxide, hydrogen, and water, this unit uses liquid oxygen (LOX), a hydrocarbon such as propane or isopropyl alcohol, and water.

While the Hyprox generator supplies pure steam, the steam from the LOX-hydrocarbon unit contains about 20 percent noncondensable gas, mostly $CO_2$ from hydrocarbon combustion. Tremendous steam out-

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puts, for example 2 million lb per hr of steam at 300 psi and 600°F, may be obtained from an extremely small package within seconds of start-up, and the water used requires no treatment.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook*, 64 pages

*Steam Generation*, 48 pages

*Air Pollution*, 48 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

*ASME Boiler and Pressure Vessel Code*, Sections I to IV, American Society of Mechanical Engineers, New York.

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# 7

# CONSTRUCTION: METHODS OF JOINING

**Q** What are the three main methods of joining boiler elements?
**A** Welding, forge welding, and riveting. Forge welding of joints is limited by the Power Boiler Code to an ultimate strength of 35,000 lb per sq in., with steel plates manufactured in accordance with SA-285 Grades A & B steel. Welding is the predominant method of joining boiler pressure parts. But riveting on numerous existing boilers will continue to require repair and alterations. Refer to the ASME Boiler and Pressure Vessel Code, Power Boilers, Section I, for detailed requirements on old riveted boiler joints.

**Q** Are threaded connections allowed on high-pressure boilers?
**A** The Code states that threaded connections larger than 3-in. pipe size shall *not* be used when the maximum allowable pressure exceeds 100 psi. But this 3-in. pipe size restriction does not apply to (1) plug closures used for inspection openings and (2) end closures used for similar purposes. The number of threads that must be engaged and the minimum plate thickness required are shown in Fig. 7-1.

**Q** Are expanded connections allowed on high-pressure boilers?
**A** Yes, provided the pipe, tube, or forging does not exceed a 6-in. OD, so that the opening meets all reinforcement requirements. Also, the expanded connections must meet all requirements on expanded tubes described in Chaps. 3 and 4 for fire tubes and water tubes expanded into tube sheets.

## WELDING

**Q** How is welding defined?
**A** Welding is a localized coalescence (fusing together) or consolidation of metal where joining is produced by heating to fusion temperatures, with or without the application of pressure, and with or without



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| Minimum Number of Threads for Connections on High-pressure Boilers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Pressures up to and including 300 psi:** | | | | | | | | |
| Size of pipe connection, in. | 1, 1¼ | 1½, 2 | 2½–4 | 4½–6 | 7, 8 | 9, 10 | | 12 |
| Threads engaged | 4 | 5 | 7 | 8 | 10 | 12 | | 13 |
| Min plate thickness required, in. | 0.348 | 0.435 | 0.875 | 1.0 | 1.25 | 1.5 | | 1.625 |
| **Pressures above 300 psi:** | | | | | | | | |
| Size of pipe connection, in. | ½, ¼ | 1–1½ | 2 | 2½, 3 | 4–6 | 8 | 10 | 12 |
| Threads engaged | 6 | 7 | 8 | 8 | 10 | 12 | 13 | 14 |
| Min plate thickness required, in. | 0.43 | 0.61 | 0.70 | 1.0 | 1.25 | 1.5 | 1.62 | 1.75 |

Fig. 7-1. Thread and plate thickness required by Power Boiler Code.

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the use of a filler metal. The filler metal (when used) has a melting point of approximately that of the pieces (base metal) joined together. The weld is that portion which has been melted during welding. And the welded joint is the union of two or more members produced by the welding process.

**Q** What is the most common method of welding?
**A** The most common method of welding pressure parts is by *fusion* (melting) of the metal, the heat being supplied in one of several different ways. In fusion welding, no pressure is applied between the pieces being welded. Arc welding, gas welding, and Thermit welding are classified as fusion welding, but arc welding is the most common.

**Q** Define arc welding.
**A** Arc welding is a localized progressive melting and flowing together of adjacent edges of the base metal parts, caused by heat produced by an electric arc between a metal electrode, or rod, and the base metal. Both the welding material (welding rod or electrode) and the adjacent base metal are melted. On cooling they solidify, thus joining the two pieces with continuous material.

## BOILER WELDING CODE

**Q** What is meant by a qualified weldor?
**A** Before a weldor is permitted to work on a job covered by a welding code or specification, he must become certified under the code that applies. Many different codes are in use today, so the specific code must be referred to when taking qualification tests. In general, these types of work are covered by codes: (1) boiler and pressure vessels and pressure piping, (2) highway and railway bridges, (3) public buildings, (4) tanks and containers for flammable or explosive materials, (5) cross-country pipelines, and (6) aircraft ordnance.

Certification differs under the various codes, thus one code may not qualify a weldor to weld under a different code. And in most cases, certification for one employer will not qualify the weldor to work for another employer. Also, if the weldor uses a different process, or if the procedure is altered drastically, recertification is required for that procedure in most codes. But if the weldor is continually employed as a weldor, recertification is not required, providing the work performed meets the quality requirements. An exception is the military aircraft code, which requires requalification every 6 months.

Qualification tests may be given by responsible manufacturers or contractors. On pressure-vessel work, the welding procedure of the fabrica-

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tor or contractor must also be qualified *before* the weldor can be qualified. Under other codes this is not necessary. To become qualified, the weldor must make specified welds using the required welding process, type of metal, thickness, electrode type, position, and joint design. Test specimens must be made to standard sizes and under the observation of a qualified person. In most government specifications, a government inspector must witness the making of welding specimens. Specimens must also be properly identified and prepared for testing. The common test is the guided-bend test. However, x-ray examinations, fracture tests, or other tests are also used. Satisfactory completion of test specimens (providing that they meet acceptability standards) will qualify the weldor for specific types of welding. Code certification, in general, is based on the range of thicknesses to be welded, the positions to be used, and the materials to be welded.

> NOTE: Qualification of weldors is too technical to be fully covered here. See Section IX of the ASME Boiler and Pressure Vessel Code.

**Q** For what five welding positions can a weldor be qualified?

**A** Figure 7-2 shows flat, horizontal, vertical, overhead, and (for groove

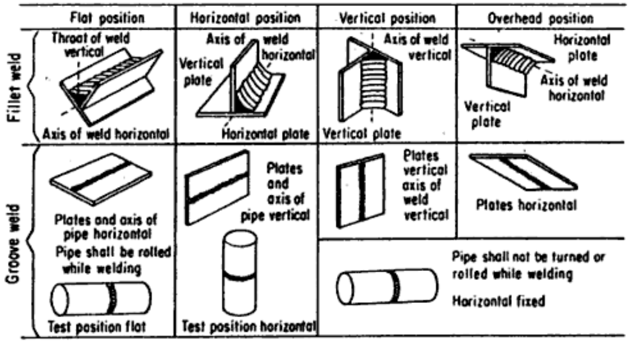


Fig. 7-2. Welding positions necessary to perform for weldor qualifications.

welds only) horizontal fixed positions. If a weldor qualifies in the horizontal, vertical, or overhead position, he automatically qualifies for the flat position For groove welds, qualifying in the fixed horizontal position automatically qualifies the weldor for the flat, vertical, and overhead positions. Qualifying in the horizontal, vertical, and overhead positions automatically qualifies the weldor for *all* positions. Angular deviations from these positions is plus-or-minus 15°.

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**Q** What is meant by welding procedure qualification?

**A** Each manufacturer or contractor who is to do Boiler Code welding is required to record in detail the procedure he is to use. Each procedure requires testing of the welds to be made by reduced-section test specimens and guided-bend specimens. The variables requiring a new procedure and new test plates are very numerous. Among these are changes in base materials, grouped in ASME Welding Qualifications (Section IX) into "P" numbers. For example, P-1 includes mostly carbon steels, P-2 consists of wrought iron, P-3 consists of chrome-moly steels with chromium content below ¾ percent, and with a total alloy content not exceeding 2 percent. The P numbers range to P-10, so the base material variable on procedure qualification is large.

The next variable is the electrode and welding rod selection which ranges from F-1 to F-7. Any change in electrode or welding rod selection requires a new set of test plates or procedure qualification. Weld m tal is classified by weld metal analysis numbers A-1 to A-8. These are related to equivalent P numbers of the base material. Again, changes of weld metal from equivalent base metal classification require a new set of test plates or procedure qualification.

The thickness of the plate, or pipe, to be welded is another variable. Classification is from 1/16 to ⅜ in., from ⅜ to ¾ in., and over ¾ in. Each classification requires new test plates as shown in the Code. The ASME Welding Code specifies other variables to consider in requiring a new procedure qualification test, and these should be consulted for specific variables.

REMEMBER: Welding boiler parts is under close control of the many variables involved in welding, so check the ASME Welding Code.

**Q** What test plates for each position must a weldor prepare and pass? And what test plates are required for procedure qualification?

**A** On groove welds, one face-bend test and one root-bend test are required for operator qualification for each position he is to weld. For fillet welds, a test plate is required according to the Code, but passing the groove-weld test will also qualify a weldor for fillet welding. Procedure qualification requires two face-bend tests, two root-bend tests, and two reduced-section tension tests, as illustrated in the Welding Qualification Code of the ASME.

**Q** What is meant by reduced-section tension test, free-bend test, root-bend test, face-bend test, and side-bend test?

**A** See ASME Code, Section IX, for typical weld test specimens. The reduced-section tension test is used for qualifying the procedure that the shop, or contractor, is to use in welding. When broken in tension, it

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must have an ultimate tensile strength at least that of the minimum range of the plate which is welded (base material), and the elongation of stretch must be a minimum of 20 percent.

The side-bend test is used for qualifying operators. The specimen is subjected to bending against the side of the weld. In the face-bend test, the specimen is subjected to bending against the surface, or face, of the weld. In the root-bend test, the specimen is subjected to bending against the bottom, or root, of the weld. The free-bend test is a shop- or contractor-qualifying procedure test. The test consists of bending the specimen cold, and the outside fibers of the weld must elongate at least 30 percent before failure occurs.

In order to pass each test, guided-bend specimens must have no cracks or other open defects exceeding ⅛ in. measured in any direction on the convex surface of the specimen *after bending*, except that cracks occurring on the corners of the specimen during testing are not considered unless these occur from slag inclusions or other welding technique defects.

**Q** 1. Who is responsible for conducting tests of welding procedures and for qualifying welding operators?

2. How long does a qualified weldor's approval test remain in effect?

3. Who keeps the records for procedure and operator's approval tests?

**A** 1. The manufacturer or contractor who is to do Code welding on boilers and pressure vessels (or nuclear vessels) is responsible for conducting procedure qualification tests, and welding operator's qualification tests for work to be done by his organization.

2. The operator's qualification remains in effect as long as he is employed by the same manufacturer or organization and does welding on a continuous basis. But if he changes employment, he is no longer considered qualified, and thus must take the test again. If he has not done any welding for a period of over 6 months in the position, material, etc., for which he is qualified, he must be requalified.

3. The manufacturer or contractor is responsible for keeping all records of procedure and operator's qualification tests. These are needed as evidence of the shop's, or weldor's, ability to do acceptable Code work. An inspector has the right, however, to ask for retests if he believes the welding is not acceptable by Code requirements. Figure 7-3 is a typical recommended ASME Welding Procedure Qualification Test recording form. Figure 7-4 is a typical recommended ASME Weldor Performance Qualification Test recording form.

**Q** Can an unqualified weldor do any welding on a boiler?

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Specification No. .......... Date ..........
Welding Process .......... Manual or Machine ..........
Material—Specification .......... to .......... of P.No. .......... to P.No. ..........
Thickness (if pipe, diameter and wall thickness) ..........
Thickness Range this test qualifies ..........
Filler Metal Group No. F- ..........
Weld Metal Analysis No. A- ..........
Describe Filler Metal ..........
..........
For oxyacetylene welding—State if Filler Metal is silicon or aluminum killed.

FLUX OR ATMOSPHERE

Flux Trade Name or Composition ..........
Inert Gas Composition ..........
Trade Name .......... Flow Rate ..........
Is Backing Strip used? ..........
Preheat Temperature Range ..........

WELDING PROCEDURE

Single or Multiple Pass .......... Postheat Treatment ..........
Single or Multiple Arc ..........
Position of Groove ..........
(Flat, horizontal, vertical, or overhead; if vertical, state whether upward or downward)

For Information Only

Filler Wire—Diameter ..........
Trade Name ..........
Type of Backing ..........
Forehand or Backhand ..........

WELDING TECHNIQUES

Joint Dimensions Accord with ..........
amps .......... volts .......... inches per min. ..........

REDUCED SECTION TENSILE TEST

| Specimen No. | Dimensions | | Area | Ultimate Total Load, lb. | Ultimate Unit Stress, psi | Character of Failure and Location |
|---|---|---|---|---|---|---|
| | Width | Thickness | | | | |
| | | | | | | |
| | | | | | | |

GUIDED BEND TESTS

| Type and Figure No. | Result | Type and Figure No. | Result |
|---|---|---|---|
| | | | |
| | | | |

Welder's Name .......... Clock No. .......... Stamp No. ..........
Who by virtue of these tests meets welder performance requirements.
Test Conducted by .......... Laboratory—Test No. ..........
per ..........

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

Signed .......... (Manufacturer)

Date .......... By ..........

(Detail of record of tests are illustrative only and may be modified to conform to the type and number of tests required by the Code.

NOTE: Any essential variables in addition to those above shall be recorded.

**Fig. 7-3. Manufacturer's record of welding-procedure qualification test.**

**A** Only if the strength of the boiler does not depend upon the weld in any way, and the effect of heating caused by welding will in no way affect the boiler component's strength or set up stresses, caused by welding, on adjoining parts.

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Welder Name.................... Clock No.................... Stamp No....................

Welding Process....................

Position (If vertical state whether upward or downward)....................
(Flat, horizontal, vertical, or overhead)

In accordance with Procedure Specification No....................

Material—Specification.......... to .......... of P-No. .......... to P-No. ..........

Diameter and Wall Thickness (if pipe) otherwise Joint Thickness....................

Thickness Range this qualifies....................

FILLER METAL

Specification No.................... Group No. F....................

Describe Filler Metal ....................

....................

Is Backing Strip used?....................

For Information Only

Filler Metal Diameter and Trade Name.................... Flux for Submerged Arc or Gas for Inert Gas Shielded Arc Welding....................

GUIDED BEND TEST RESULTS

| Type and Figure No. | Result | Type and Figure No. | Result |
|---|---|---|---|
| | | | |
| | | | |

Test Conducted by.................... Laboratory—Test No....................

per....................

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

Signed....................
(Manufacturer)

Date .................... By....................

(Detail of record of tests are illustrative only and may be modified to conform to the type and number of tests required by the Code.

NOTE: Any essential variables in addition to those above shall be recorded.

**Fig. 7-4. Manufacturer's record of weldor-performance qualification tests on groove welds.**

**Q** What welding process is used on Code boilers?

**A** Code work for arc or gas welding is restricted to shielded carbon arc, shielded metal arc, inert-gas metal arc, atomic-hydrogen metal arc, oxy-hydrogen, and oxyacetylene processes. Pressure welding is restricted to flash, induction, resistance, pressure Thermit, and oxyacetylene processes.

**Q** Is it permissible to weld any kind of steel for use on boiler pressure parts?

**A** No. Only carbon or alloy steel having a carbon content of not more than 0.35 percent can be used in welded construction or be shaped by oxygen cutting or other thermal-cutting process.

**Q** Is preheating required in Boiler Code welding?

**A** Yes, and the temperature of preheating depends on the P number of the base material to be welded. Preheating varies from 175°F in certain P-1 (low-carbon steel) materials to 450°F maximum for P-10 material

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(stainless-steel tubing and nickel-steel plate). Always consult the ASME Welding Code.

**Q** What is the maximum permissible offset of plates to be welded in the longitudinal and circumferential direction on a welded boiler drum?
**A** The maximum permissible offset of two adjoining plates in the longitudinal direction is ⅛ in.; in the circumferential direction it is ¼ in.

**Q** What is the maximum distortion permissible on a welded drum of a power boiler?
**A** The drum must be circular at any section within a limit of 1 percent of the mean diameter. If necessary to meet this requirement, plates may be reheated, rerolled, or reformed. Furnaces must be rolled (scotch marine boilers), with a maximum permissible deviation from the true circle of not more than ¼ in.

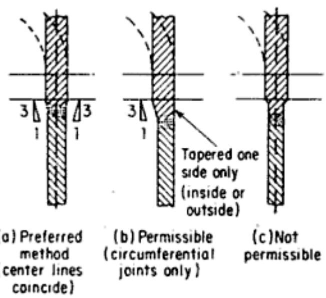


**Fig. 7-5. Butt welding of plates of unequal thickness.**

**Q** Is it permissible to weld plates of unequal thickness?
**A** Yes, provided a tapered transition section, having a length not less than three times the offset between the adjacent plate surfaces (Fig. 7-5), is provided at joints between plates that differ in thickness by more than one-fourth of the thickness of the thinner plate, or by more than ⅛ in.

**Q** Can stay bolts be welded instead of being threaded or riveted?
**A** Yes, provided they are inserted into countersunk holes through the sheets and attached by full-penetration welds according to the Code. But the face of the weld cannot be below the outside surface of the weld, and the ends of stays inserted through the plate cannot project more than ⅜ in. beyond the surfaces exposed to the products of combustion. Diagonal stays may be attached to the inner surfaces of plates (but not the head) by fillet welds as provided in the Code. Stress relieving is required of welded-in stay bolts, but not radiographing.

**Q** The intent of the welding requirements is generally to obtain good penetration and thus a good joint. Illustrate some typical nozzle and attachment welding details required by the Boiler Code to provide this full penetration.
**A** Figure 7-6 shows examples of acceptable types of welded nozzles and

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**Fig. 7-6. Some types of welded nozzles and other connections to shells, drums, and headers, acceptable by the Code.**

other connections to shells, drums, and headers. See ASME Power Boilers, Section I, for specifics.

**Q** Should weld reinforcements be removed substantially flush with the plate?
**A** On longitudinal joints of welded power boilers, weld reinforcements should be removed substantially flush with the surface of the plate. If they are not, the Code provides a penalty on the permissible longitudinal joint efficiency. But removal of weld reinforcements is not mandatory on other joints.

**Q** What is the efficiency of a welded joint, and what value does the Code allow?
**A** The efficiency of a welded joint is defined the same way it is on a riveted joint, namely, the strength of the joint divided by the strength of the solid plate. However, since a welded joint cannot be calculated the same way as a riveted joint, the Code allows the following if all Code requirements are met:

1. Ninety percent longitudinal joint efficiency if the joint is stress-relieved and radiographed but the weld reinforcement is not removed substantially flush with the surface of the plate.
2. One hundred percent longitudinal joint efficiency if it is stress-relieved, radiographed, and the weld reinforcement is removed substantially flush with the surface of the plate.

## RIVETED JOINTS

**A** What forms of riveted joints are used in boiler construction?
**A** Lap joints and butt joints. In the lap joint, edges of plates overlap. Because in the butt joint the plate edges meet or butt together, cover straps (called straps) are used.

**Q** Describe and sketch a single-riveted lap joint.
**A** In this joint, plate edges are lapped over and secured by one row of rivets. Figure 7-7*a* shows a side view and end-section view of a single-riveted lap joint.

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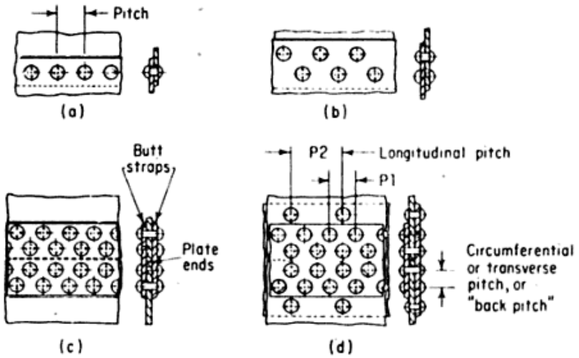


**Fig. 7-7. Riveted joints. (*a*) Single-riveted lap joint. (*b*) Double-riveted lap joint. (*c*) Double-riveted butt joint with double butt strap. (*d*) Triple-riveted butt joint with double butt straps.**

**Q** Describe and sketch a double-riveted lap joint.
**A** Figure 7-7*b* shows how plate edges of this joint are lapped and secured by two rows of rivets.

**Q** Describe and sketch a double-riveted butt joint with double straps.
**A** In this joint, plate edges are butted together and butt straps are placed inside and outside. Figure 7-7*c* shows a double-riveted double-strap joint with butt straps of equal width.

**Q** Describe and sketch a triple-riveted butt joint with double butt straps of unequal width.
**A** Figure 7-7*d* shows that this joint's plate edges butt together and butt straps are placed inside and outside. However, the outside butt strap is narrower than the one inside. Notice that the outer rows of rivets pass through the inner butt strap and shell plate, but *not* through the outer butt strap. Also, alternate rivets are omitted in these outer rows.

**Q** What are the maximum size and pressure for construction of an hp boiler with a longitudinal lap joint?
**A** Lap joints on longitudinal joints cannot be used on hp boilers over 36 in. in diameter. And the pressure is limited to a maximum of 100 psi. If the boiler is over 36 in. in diameter, or over 100 psi, a butt double-strap joint is required.

**Q** Why is a butt joint preferable to a lap joint?
**A** In the butt joint, shell plates form a true circle. Thus there is no tendency for pressure to distort the plates. In the lap joint the plates do

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not form a true circle at the lap, so internal pressure tends to pull them out of position. Also, in time this bending action creates a stress concentration at the edge of the plate. This in turn may cause grooving or cracking of the plate along the calked edge and thus create a dangerous condition. (See Chap. 16.) Properly designed butt joints have much higher efficiencies than lap joints with the same number of effective rows of rivets because in the butt joint all, or most of, the rivets pass through three plate thicknesses and so are in double shear. By contrast the rivets in lap joints are all in single shear. Rivets in double shear have twice the strength of rivets in single shear.

### RIVETED-PATCH REPAIRS

**Q** Are riveted-patch repairs still being used?

**A** Only if the boiler design is such that (1) welded patches may not be applied because of physical configuration, (2) the welded patch required is over 8 in. long with the patch in an unstayed area, which if welded requires stress relieving and radiographing, and (3) the cost of a riveted patch is more economical than a welded patch. At times, the choice of a riveted repair over a welded-repair patch might be influenced by the boiler repair firm's experience.

**Q** Will a riveted patch weaken the boiler and thus require a lowering of the allowable pressure?

**A** If the patch is designed and installed according to NBB&PVI (see index) rules, which most Code states have adopted, the riveted patch will not weaken the boiler. The rules covering the application of riveted patches are meant to restore to the weakened portion of the shell, or head, enough of its initial strength to permit the boiler to operate at its original working pressure. This involves calculations of the patch joints based on the shape and location of the patch. The rules permit the efficiency of the patch joints to be readily determined.

**Q** What kind of material must be used on patch plates?

**A** The patch material should be of *firebox* or *flange* steel boiler plate, depending upon the plate it replaces.

> CAUTION: Tank steel must *not* be used. The repair shop must produce a copy of the manufacturer's test report of the material to be used.

The boiler plate should contain the steelmaker's brand. If only part of the plate is required, and this part does not show the brand, the brand must be transferred to the patch plate in the presence of a boiler inspector or a representative of the plate manufacturer before the plate is cut.

Rivets, patch bolts, or stay bolts must be made of a material meet-

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ing the requirement of the Code. All patches must be placed inside a boiler when exposed to the products of combustion where deposits would be pocketed. An exception is where a blowoff is attached, in which case the patch should be placed on the outside. All defective material exposed to the products of combustion must be removed and properly trimmed. A distorted sheet which is to be patched must first be set back straight as much as possible before cutting out the plate. The edge of a patch shall be beveled by planing, chipping, or gas cutting before it is applied to the boiler. If possible, rivets should be driven with a pneumatic gun.

All rivet holes must be drilled full size, or they may be punched out not to exceed ¼ in. less than full size for plates over 5⁄16 in., and ⅛ in. less for plates 5⁄16 in. or less in thickness. Then holes must be reamed to full size with the patch in place. If seal welding is used, it must be laid in a single bead with a throat thickness not less than 3⁄16 in. nor more than 5⁄16 in. The patch must be tight under a hydrostatic test equal to the operating pressure *before* seal welding. Where three plates have to be lapped at the corners of a patch, the middle plate must be carefully scarfed the entire width of the lap.

**Q** What hydrostatic test pressure is required on a completed patch?
**A** Upon completion of repairs, a hydrostatic pressure test of 1½ times the allowable boiler pressure must be applied. This pressure must be held for a period of at least 30 min during which no distress or leakage must develop.

## NONDESTRUCTIVE TESTING

**Q** In what manner is the quality of a weld checked?
**A** Depending on the type of vessel, various nondestructive techniques are used. In power boiler work, besides visual examination of the weld, x-rays and gamma rays are used and required. In nuclear-vessel work, these are supplemented by magnetic-particle tests, dye checks, and ultrasonic testing. Not to be forgotten is the standard hydrostatic test of 1½ times the design pressure. The field of nondestructive testing is expanding. New methods are being perfected and are finding increasing use in boiler and pressure-vessel work, during construction and during field testing after the equipment is in use. See the suggested reading at the end of this chapter. (See also Chap. 16.)

**Q** What is meant by a nondestructive test?
**A** This is a test to check for the soundness or quality of a material or a joint of materials without affecting it physically or chemically. It includes radiography (x-rays), dye checks, and ultrasonic and hydrostatic testing.

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## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook*, 64 pages

*Nondestructive Testing*, 24 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

*ASME Boiler and Pressure Vessel Code*, Sections I and IX, American Society of Mechanical Engineers, New York.

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# 8

# PRESSURE, STRESSES, AND FORCES

**Q** What is meant by *pressure?*

**A** Pressure is that force in pounds per square inch (psi) caused by a fluid (liquids and gases are fluids) that is confined in a pressure vessel or piping. Pressure as discussed here will be confined to boiler application; it is also used in structure, soil analysis, and process flow calculations, etc. In boiler and pressure vessel strength calculations, pressure is expressed as pounds per square inch gage (psig). In physics and thermodynamic calculations involving heat flow or steam and water characteristics, *absolute pressure* (expressed as pounds per square inch absolute and abbreviated psia) is used instead of gage pressure.

**Q** How do *gage* and *absolute* pressure differ?

**A** Gage pressure, as the name implies, is the pressure noted on a pressure gage when it is installed at any opening into the pressure part of the pressure vessel. It indicates the pressure inside the vessel. But on the outside of the vessel, the atmosphere is also exerting a pressure on the outer surface of the shell. *Absolute pressure* is thus the total pressure of gage pressure *plus* atmospheric pressure. Absolute pressure is influenced by the elevation above sea level. At sea level, for example, the atmospheric pressure is 14.7 psi. Thus a 100-psi-rated boiler would show a 100-psi gage pressure and have 114.7-psi absolute pressure. In determining the heat content of steam for a boiler in Btu per pound, steam tables must be checked, and absolute pressure used.

**Q** Is there a difference between *force* and *pressure?*

**A** Yes. *Pressure* is always expressed in pounds per unit area (in Europe, kilograms per unit area). It is the force exerted on a unit area, which in the United States is expressed in pounds per square inch, abbreviated as psi. *Force* is expressed simply by the weight term, *pounds*. But there is a relationship between force and pressure.

EXAMPLE: If a plate of $10 \times 10$ in. area has 100 psi acting on it, the force on the plate is found by the following fundamental equation:



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$$F = P \times A$$

where $F$ = force
$P$ = pressure
$A$ = area (upon which pressure acts)

For the plate in this problem, force = $100 \times (10 \times 10) = 10{,}000$ lb.

**Q** What is meant by *stress?*
**A** Any body or material subject to external forces on it will resist these external forces. This resistance of the material comes from *within* the material. The internal structure of the material is subject to intercrystalline loading when an external force is applied. Thus, *stress* is defined as the internal force per unit area on the material which resists external forces on the material. It is expressed in pounds per square inch, but the notation psi is *not* used for stress as in pressure notation. Stress is always expressed by engineers with the notation lb per sq in. to differentiate it from the psi designation of pressure, which is an *external force* per unit area on the material.

**Q** Name some stresses.
**A** There are several general classifications of stresses that affect materials. A *normal stress* is a *stress* on an area of a material produced by a force at a right angle to the area acted upon. Normal stresses are further classified as *tension stresses* or *compression stresses.* In Fig. 8-1, a 1-in.

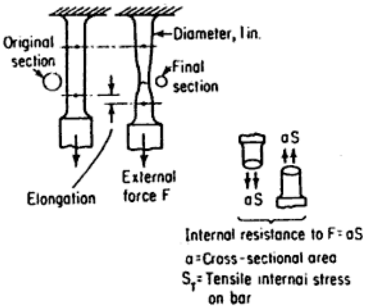


**Fig. 8-1. External force acting on bar.**

diam bar is pulled by a force $F$. This force produces a normal stress at a right angle to the cross-sectional area of the bar. Since the force tends to pull (stretch) the bar apart, it is called a *tensile* stress. Within the material, the intercrystalline structure (assuming it is steel) is also being stressed. The tensile stress of the bar is found by the following equation.

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based on the definition of stress as pounds per square inch, or internal force per unit area within the material.

$$F = a S_T$$

where $F$ = external force

$a$ = cross-sectional area of material resisting $F$

$S_T$ = tensile (internal) stress on the material

From this, the equation for stress $S_T$ is

$$S_T = \frac{F}{a}$$

This equation shows that the tensile stress $S_T$ is found by dividing the external force $F$, acting normal to the cross-sectional area, by the cross-sectional area of the material resisting the force.

If the force were acting in the opposite direction in Fig. 8-1, a compressive stress (known also as a bearing stress) would be imposed on the material. But the compressive stress would be found by the same equation:

$$F = a \times S_C$$

where $S_C$ = compressive stress.

Assume that in Fig. 8-1 the tensile force is 15,000 lb and the rod is of 1 in. diam. What would be the tensile stress on the bar?

$$S_T = \frac{F}{a}$$

$$F = 15{,}000 \text{ lb}$$

$$a = \frac{\pi\,(1)^2}{4} = 0.7854 \text{ sq in., where } \pi = 3.1416$$

Substituting,

$$S_T = \frac{15{,}000}{0.7854}$$

$$= 19{,}099 \text{ lb per sq in.}$$

**Q** What is a *shear stress?*

**A** If a force acts tangent (sideways) to the area of a material, a shear stress is produced. This is illustrated in Fig. 8-2 in which a force $F$ acts on the rivet area tangent to its cross-sectional area, thus producing a shear stress on the rivet. The shear stress is found by the equation $F = a \times s$, but $a$ is the cross-sectional area resisting shear. In Fig. 8-2, since

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only one area of the rivet is resisting the external force *F*, it is in ***single shear.***

In Fig. 8-3, a butt-riveted joint is shown with butt straps on each side of the butting plates. The rivets in this illustration are in double shear, as *two* areas of the rivet are resisting the load *F*. An example will illustrate the significance of single shear and double shear.

Assume that in Figs. 8-2 and 8-3 only one rivet is being considered for analysis, but one is in single shear, the other in doube shear. Assume the rivet to be 1 in. in each case and the load *F* to be 15,000 lb on each rivet. What is the shear stress for each rivet?

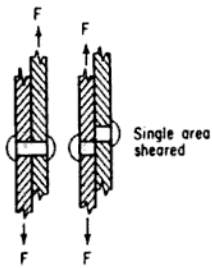


Fig. 8-2. Rivet in shear stress.

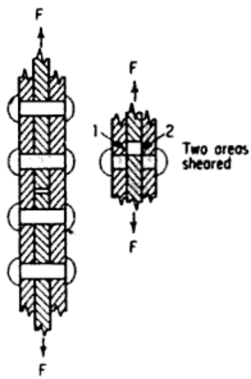


Fig. 8-3. Rivets in double shear.

Single-shear rivet

$$S_S = \frac{F}{a}$$

$$F = 15{,}000 \text{ lb}$$

$$a = \frac{\pi D^2}{4}$$

$$= \frac{\pi (1)^2}{4}$$

$$= 0.7854 \text{ sq in.}$$

$$S_S = \frac{15{,}000}{0.7854}$$

$$= 19{,}099 \text{ lb per sq in.}$$

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Double-shear rivet

$$S_s = \frac{F}{a}$$

$$F = 15{,}000 \text{ lb}$$

$$a = 2\left(\frac{\pi D^2}{4}\right)$$

$$= 2\left[\frac{\pi (1)^2}{4}\right]$$

$$= 1.5708 \text{ sq in.}$$

$$S_s = \frac{15{,}000}{1.5708}$$

$$= 9549.5 \text{ lb per sq in.}$$

This shows that a rivet in double shear is *twice* as strong as a rivet in single shear.

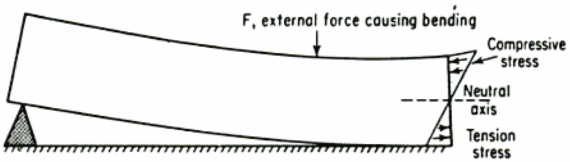


**Fig. 8-4. Compressive and tensile stresses act on supported beam.**

**Q** What is a *bending stress*?

**A** Another stress is that due to bending. A beam supported on each end and loaded in the middle will develop a bending stress. The beam, when bending, will actually be under a tension stress on one side and a compression stress on the opposite side. This is illustrated in Fig. 8-4. Flat plates and stayed surfaces in boilers are some elements that are subjected to bending stresses.

> NOTE: Stress due to torsion, such as in an axle being rotated and transmitting power, is another stress considered in an analysis of resistance of materials. Stress analysis is beyond the scope of this book. However, a knowledge of *tension*, *compression*, *shear*, and *bending* stresses is essential in understanding how pressure is contained in a pressure vessel, pipe, or any other apparatus made of material designed to confine that pressure within safe limits.

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**Q** What is *strain?*

**A** When a body or material is subjected to external forces, internal stresses resist these forces, but there is always some deformation with load. For example, a steel rod will stretch when pulled upon by an external force. The *total stretch* is expressed in a length measurement such as inches or centimeters. Strain is defined as the stretch *per unit length,* or deformation of a body per unit length, and is always expressed as inches per inch, centimeters per centimeter, etc. For example, assume that a steel rod 10 in. long stretches 0.010 in. with load; then the unit strain will be $0.010/10 = 0.001$ in. per in.

**Q** Is there any relationship between *stress* and *strain* as they apply to boiler application?

**A** Stress and strain are very important in all structural materials designed to resist dangerous forces. In the design, inspection, and operation of boilers, pressure and temperature are the key elements that create dangerous forces. There are others that will be mentioned later. These forces always create stresses and strains. But the chief relationship between stress and strain can be best understood by looking at a material that is to be used for any structural support, not only boilers.

Some of the fundamental properties of all structural materials that must be determined are found by means of *stress-strain diagrams.* From the stress-strain diagram, very important structural properties are determined, such as (1) proportional limit, (2) yield point, (3) ultimate strength, and (4) modulus of elasticity.

**Q** How are stress-strain diagrams determined?

**A** Modern engineering practice requires testing of materials so as to specify and identify their physical properties. This is particularly true for materials intended to be used in boilers, pressure vessels, and nuclear reactors. Steel manufacturers' laboratories run tests, and the Boiler Code shows sketches and requirements for preparing samples to run tensile tests and bending tests on boiler materials.

A test specimen of a specified grade of steel is cut out from a rolled stock, then machined to fit a test machine. A test specimen for a tensile

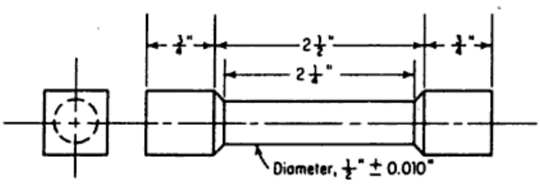


**Fig. 8-5. Tension test specimen.**

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test is shown in Fig. 8-5. The square ends are clamped in jaws of a tension-test machine. The ½-in. round center piece is marked off in a 2-in. gage length. An extensometer is attached to the 2-in. gage length. This tension-test machine has a dial gage indicating force $F$ applied to pull the rod apart. Incremental loading is applied. At each increment, the force $F$ is recorded and the total amount of length $l$ is taken at that incremental loading. This procedure is followed until rupture occurs. The data is tabulated, and then by the relationship $F/a$, where $a$ is the original ½-in. diam area, stresses are found for each increment of load.

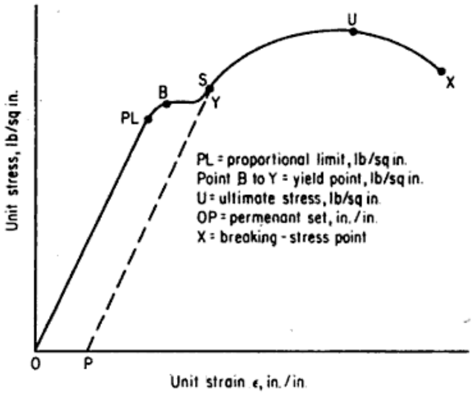


**Fig. 8-6. Stress-strain diagram (ductile material).**

The strain, or stretch, is found by calculating the amount of stretch from the original 2-in. length to obtain the unit strain $\epsilon$. These values are then plotted as in Fig. 8-6, showing a stress-strain diagram for ductile steel. The table in Fig. 8-7 shows a typical test-data recording during test. Note where a permanent set developed during this test.

**Q** How is the proportional limit determined from this chart, and what is the proportional limit?

**A** The stress-strain diagram shows a sloping straight line extending from zero upward to the point marked $PL$. The reason for this is that as the load is increased, the imposed stress $S$ increases, as does the strain $\epsilon$. The increase for both is in the same ratio, meaning that if the load is doubled, the stress is doubled, and so is the strain. This is why a straight line is drawn, not a curve. The *proportional limit* of a material is thus the maximum unit stress that can be developed in the material without causing a deviation from the law of proportionality of unit stress to unit strain. Of

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| Load, lb | Extensometer reading, in. |
|---|---|
| 500 | 0.0 |
| 1,500 | 0.0004 |
| 500 | 0.0 |
| 3,000 | 0.0008 |
| 500 | 0.0 |
| 4,400 | 0.0014 |
| 500 | 0.0 |
| 5,980 | 0.0018 |
| 500 | 0.0 |
| 7,510 | 0.0024 |
| 500 | 0.0 |
| 8,630 | 0.0029 |
| 500 | 0.0002* |
| 9,500 | 0.0075 |
| 500 | 0.004 |
| 9,600 | 0.0130 |

* Permanent set.

Fig. 8-7. Typical tension test data on 2-in. specimen of 0.5 in. diam.

even more significance, it implies that if the load is decreased, the material will return to its original length without having a permanent *set* as a result of the loading. The material will not be permanently deformed, but will return to its original shape as long as the proportional limit is not exceeded.

**Q** What is meant by *yield point*, and how is this found?

**A** As the load on our test specimen is increased further, causing a stress greater than the proportional limit, a unit stress is reached at which point the material continues to stretch *without* an increase in load, assuming it is a ductile steel. The unit stress at which this stretch-without-load occurs is called the *yield point* and is represented by the short horizontal line *B* to *Y* on the stress-strain diagram. The yield point of a material is defined as the *minimum unit stress in the material at which the material deforms or stretches appreciably without an increase of load.*

If a material is stretched or loaded slightly beyond the yield point, a permanent set or deformation occurs in the material. For example, in Fig. 8-6, if the load is reduced to zero after just passing the yield point, the extensometer will show a permanent stretch or deformation. This is found by drawing a line parallel to the proportional limit line, and the set will be length 0 to *P* per inch of test specimen.

**Q** What is the ultimate strength, and how is this determined?

**A** If the loading on our test specimen is increased, as indicated by the

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curve $S$ to $U$, a point of maximum unit stress is reached. Then the unit stress declines with slight additional loading and stretches until it breaks. This is particularly true of ductile material, which *necks down* very rapidly after reaching its maximum unit stress because of reduced area in the neck section, which requires less load to cause rapid stretching to complete breakage. See Fig. 8-8.

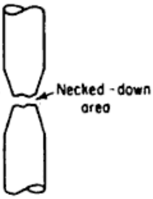


**Fig. 8.8 Necked-down ruptured test specimen.**

The *ultimate strength* of a material is defined as the maximum unit stress that can be developed in the material as determined from the *original* cross section of the material. It is point $U$ in the stress-strain diagram. The curve from $U$ to $X$ is a rapid, unstable testing condition, with point $X$ called the *breaking-load point*. The maximum unit stress is at point $U$, and this is the ultimate stress designated for the material.

**Q** A common problem involving testing is as follows. Data supplied on a tested specimen: Total length, 19 in.; sections at each end of a specimen are $1 \times 1 \times 6$ in. long; center section 7⁄16-in. diam by 7 in. long with center section concentric with the square sections at each end; center 7-in. section has a 2-in. gage length marked.

The specimen here being tested broke when the load reached a maximum of 11,274.75 lb, and the break was through the original 7⁄16-in. diam. But the diameter was now ¼ in. The cross-section area of a 7⁄16-in. diam bar is 0.15033 sq in. The length of the 2-in. gage section had stretched to 2.55 in.

1. Find the ultimate strength of the material.
2. What is the ultimate strength in pounds per square inch of the $1 \times 1$-in. section at each end?
3. What is the percentage elongation of the 2-in. gage section?

**A** 1. See Fig. 8-5. In this problem the break was in the 7⁄16-in. diam section, so the stress $S$ is

$$S = \frac{F}{a}$$

where $a$ = original cross-sectional area.

$$S = \frac{11{,}274.75}{0.15033}$$

$$= 75{,}000 \text{ lb per sq in. ultimate stress}$$

2. The ultimate stress at the $1 \times 1$-in. section is the same (75,000 lb per sq in.) because it is still the same material. It did not break at

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this section, because the cross-sectional area is larger than at the $\frac{7}{16}$-in.-diam section.

3. The percentage elongation is found as follows:

$$\frac{[\text{Final length} - \text{original length}] \times 100\%}{\text{Original length}} = \%\ \text{elongation}$$

$$\frac{[2.55 - 2] \times 100\%}{2} = \frac{55\%}{2} = 27.5\%$$

**Q** What is meant by *modulus of elasticity*, and how is this determined?

**A** This is also known as Hooke's law, which states that the unit stress in a material is proportional to the accompanying unit strain, provided that the unit stress does not exceed the proportional limit. In different words, it states that the ratio of stress to strain for a certain material is always a constant, called $E$, the modulus of elasticity, or in equation form

$$E = \frac{\text{stress}}{\text{strain}} = \frac{S}{\varepsilon} = \text{constant}$$

For steel, the modulus of elasticity is usually taken as 30,000,000 and written $30 \times 10^6$ lb per sq in. This is the modulus of elasticity for normal or axial loads. There is also a shear modulus of elasticity. For steel it is 12,000,000 lb per sq in.

**Q** How is the modulus of elasticity applied to boiler work?

**A** Designers and engineers require this for many calculations. However, one use in field and test applications involves the use of *strain gages*. Strain gages are used to determine stresses at critical areas of boilers, nuclear reactors, and pressure vessels for which exact calculations cannot be made. With the following relationship between stress, strain, and the modulus of elasticity of the material, the stress can be calculated. It is much easier to measure strain, or the deformation of a material under load, than to measure stress.

We explained that stress for normal loads is $F/a$ where $F$ = imposed load and $a$ = original area of material resisting the load.

We also explained that unit strain $\varepsilon$ is $e/l$ where $\varepsilon$ = strain in in. per in., $e$ = amount of strain from original length $l$, and $l$ = original length.

Now

$$E = \frac{\text{stress}}{\text{strain}}$$

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Substituting the above values

$$E = \frac{F/a}{e/l}$$

$$E = \frac{S}{e/l}$$

as

$$S = \frac{F}{a}$$

Rewriting this in terms of stress *S*,

$$S = \frac{Ee}{l} = E\epsilon$$

as

$$\frac{e}{l} = \epsilon$$

It can be seen that if strain is measured, stress can be calculated by knowing the modulus of elasticity of the material, which is usually a constant for the class of material being considered.

**Q** What does the modulus of elasticity reveal in a physical sense?

**A** The modulus of elasticity is a measure of the *stiffness* of a material. For example, if one material has a modulus of elasticity twice as large as another material, the elastic unit strain in the one material for a given unit stress is one-half as large as that in the other material. Thus, one material is considered twice as stiff as the other. Some common *E* values are steel, 30,000,000; cast iron, 15,000,000; aluminum, 12,000,000; concrete, 3,000,000.

**Q** What is meant by the *elastic limit* of a material?

**A** The *elastic limit* is the maximum unit stress that can be developed in the material without causing a permanent set. Test results show that for most structural metals the elastic limit of the material has about the same value as the proportional limit, and in most technical literature the elastic and proportional limits are considered identical. A small difference is apparent in testing work, but for practical purposes they can be treated as identical quantities.

**Q** The terms *longitudinal stress* and *circumferential stress* are often used with cylinders and drums. How are these determined, and what is the relationship between the two stresses?

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**A** Thin-walled cylinders, meaning those where the thickness of the shell does not exceed one-half the inside radius, have two stresses, called (1) *longitudinal* and (2) *circumferential*. The latter sometimes is called the *transverse stress*. Thick-walled cylinders have these stresses also, but they are determined differently. Both stresses are known by these names because of the loading they resist in a cylinder. Both are fundamentally tensile stresses.

Figure 8-9*a* shows a seamless cylinder with an inside diameter *D*, shell thickness at *t*, length *L*, and with a uniform pressure *P* acting in-

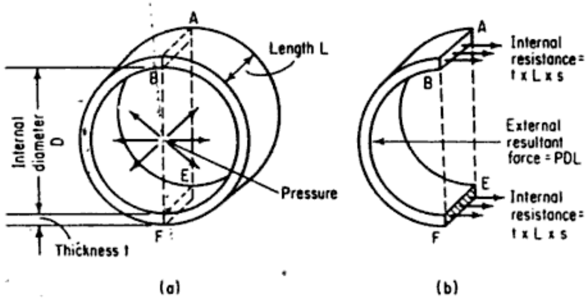


**Fig. 8-9. Longitudinal force and stress on thin-walled cylinder.**

side the cylinder. Pressure acts on the cylinder walls, so the resultant force created tends to split the cylinder along its long axis. Thus the first stress to be considered is the longitudinal stress resisting this force tending to split the cylinder along this axis. The pressure acts in all directions. But if we cut the cylinder as in Fig. 8-9*b*, which shows the external force on one side and also the internal material stress resisting this external force, the following is developed for a condition of equilibrium to exist.

The force tending to split the cylinder is area × pressure. This is:

$$D \times L \times P = \text{force acting on one side}$$

where $D \times L$ = projected effective area. The internal force of the material resisting this force is:

Stress × material area

or

$$S_L \times t \times L \times 2 = \text{resisting force}$$

where $t \times L$ = one area of the material. But since there are two material areas resisting the force, it is multiplied by 2. Equating the two forces,

$$D \times L \times P = S_L \times t \times L \times 2$$

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From this,

$$\text{Longitudinal stress } S_L = \frac{DP}{2t}$$

The force tending to split the cylinder endwise, or around its circumference, is shown in Fig. 8-10. Pressure acting on each end creates a force which is equal to the end area (circle) times the pressure, or

$$\frac{\pi D^2}{4} \times \text{pressure} = \text{end force}$$

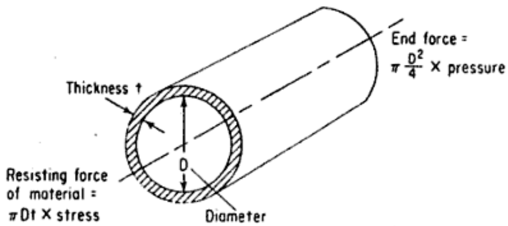


**Fig. 8-10. Circumferential stress and force on thin-walled cylinder.**

The material resists this by a force equal to the end area of the material times the stress, or

$$\pi DtS_c = \text{resisting force}$$

where $S_c$ = circumferential stress. Equating the two forces for equilibrium gives

$$\frac{\pi D^2}{4} P = \pi DtS_c$$

by elimination, and solving for $S_c$, circumferential stress, gives

$$S_c = \frac{DP}{4t}$$

If we compare this with the longitudinal stress, we find the circumferential stress is one-half the longitudinal stress.

The two equations for longitudinal and circumferential stresses are fundamental strength-of-material equations. They are modified somewhat by the Boiler & Pressure Vessel Code to take into account manufacturing and experience factors.

The equations developed are for seamless construction, meaning that no welded or riveted joint is present. Later chapters will show how the joint efficiency has to be considered to modify these equations. Note that

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equations for both longitudinal and circumferential stresses (due to pressure) are independent of the length of the vessel. But if a vessel is very long, the bending stress will have to be added to the stress due to pressure. This is especially true of a vessel filled with a substance of considerable weight.

The significance of the circumferential stress being one-half the longitudinal stress in a cylinder enters many problems in boiler design and calculation. For example, riveted circumferential joints do not have to be as strong in this direction as they do longitudinally. But in many calculations it is extremely important to check a cylinder both longitudinally and circumferentially, so as to make sure that the strength circumferentially is at least one-half the strength longitudinally. This is brought out in other chapters.

**Q** We know that pressure in a boiler causes the material confining that pressure to be stressed. What is the effect of temperature?

**A** Temperature above designed limits has the immediate effect of lowering the permissible stress on a material. For example, SA-30 Grade-A quality carbon plate firebox steel has an allowable stress of 12,000 lb per sq in. for temperatures from −20 to 400°F. At 900°F the allowable stress is only 5,000 lb per sq in. Assuming the same pressure at both temperatures, it can be seen that a boiler designed for 12,000 lb per sq in. normal stress will be weakened to 5,000/12,000 or 41.7 percent of its original strength with a temperature increase to 900°F.

Certain parts of boilers, particularly tubes, tube sheets, furnaces in scotch marine boilers, and cast parts in ci boilers are very susceptible to temperature or overheating damages. A large temperature increase in a material, with accompanying *lower permissible stress levels,* is one of the most common causes of boiler damages. Low water, poor circulation, and scale are some causes of overheating of the material beyond safe stress levels. Let us not forget that the firing side of boilers is hot enough to melt steel. And with existing pressure on the water or steam side, it does not require much overheating to cause ruptures, bulges, and other deformation. Thus if the material is stressed well beyond the yield stress at high temperatures, permanent deformation will take place. In severe cases, the ultimate stress of the material is reached at the elevated temperature level, leading to complete rupture of the affected parts of the boiler.

**Q** What effect does temperature have on boiler stresses caused by expansion and contraction resulting from temperature changes?

**A** If the boiler part is free to expand or contract, no increase in stress occurs, unless the stress is influenced by too high a temperature rise, thus lowering the permissible stress due to physical changes caused by temperature. But expansion or contraction, even if the part is free to move,

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can be considerable. This can be calculated by the following equation, in which all units must be the same:

$$e = nl\,(T_2 - T_1)$$

where $e$ = change in length
$l$ = original length
$T_1$ = original temperature, °F
$T_2$ = final temperature, °F
$n$ = coefficient of expansion (change in length per unit of length per degree change in temperature)

EXAMPLE: Steel has a coefficient of thermal expansion of 0.0000065 in. per in. per °F. To show the possible rate of expansion to be considered, assume that a stay in an hrt boiler running from tube sheet to tube sheet is 30 ft long. How much will this rod expand with a temperature change from 70 to 300°F, assuming free expansion?

Substituting in the equation,

$$e = 0.0000065\,(30)\,(12)\,(300\text{–}70)$$
$$= 0.538 \text{ in. stretch, which is over } \tfrac{1}{2} \text{ in.}$$

**Q** If we assume that the stay rod was fixed at each end and that the tube sheets would *not give*, what compressive stress would be imposed on the rod, neglecting the column effect of a long rod?

**A** This is calculated from the modulus of elasticity equation

$$S = E_\epsilon$$

where $\epsilon = \dfrac{\text{stretch}}{\text{inch}}$

$$S = 30{,}000{,}000\,\frac{0.538}{30 \times 12}$$
$$= 30{,}000{,}000\,(0.001494)$$
$$= 44{,}820 \text{ lb per sq in.}$$

This example illustrates the importance of considering temperature effects in boiler design and the rapid stress buildup when a part becomes accidentally overheated above design conditions. Remember that the stress developed is not calculated as simply as shown by the illustration. For example, we assumed that the shell and tube sheets would *not* expand because of temperature. This is obviously *not* true. If the shell is fixed or anchored, some relief will still be obtained from the expansion

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of the tube sheet. It does illustrate, however, the high stresses possible on stays and tubes. This is one of the chief reasons tubes start to leak around rolled joints or become bowed when a low-water condition develops in a boiler.

Also, on the long stay rod we ignored the column effect. But long, thin structures have to be treated as columns, involving the ratio of the length to the radius of gyration. Stay rods that bow from temperature effects are also influenced by the strength-of-material equations involving columns.

If a tube leaks at the rolled joint but does not become bowed, it is an indication that the expansion force is greater than the rolled joint's holding power. Rolled joints are equivalent to *press fits*, depending on the friction of contact areas to hold the tubes tight in a tube sheet. The exception, of course, is welded-in tubes, where a shear stress is imposed by expansion.

**Q** What is meant by *stress concentration*?

**A** If a structural material has an abrupt change in a section, for example, a flat plate containing an opening or a sharp corner as shown in the rod in Fig. 8-11, the stress distribution is not uniform over the cross-sectional area of the material. Near the abrupt change the stress is much higher than calculated. The affected section is said to have a *stress concentration* section, or area, and the ratio by which the normal stress has to be multiplied, K in Fig. 8-11, is called the *stress concentration factor*.

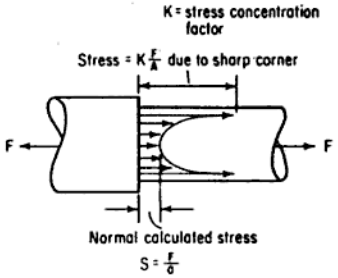


Fig. 8-11. Stress concentration factor at sharp corner loading.

Stress concentration plays an important part in structural members subject to repeated type of loadings, as the stress concentration can lead to cracks and fatigue failures. If the stress concentration is severe enough (even in normal loading), stresses may be induced far above the normal expected stress. Sharp corners in welded joints and other sharply formed shapes must be avoided. Thus openings cut into plates must be reinforced to strengthen the edges around the opening against stress concentration.

**Q** How are stress concentration factors determined?

**A** The Boiler Code specifies permissible joint connections to avoid stress concentrations. Fillet radii are specified on formed shapes. Openings must be calculated by Code rules. In analytical and design work,

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stress concentrations are determined by the *photoelastic method*, *stress-coat method*, and *strain-gage method* using the electrical resistant wire gage. In nuclear vessels one must carefully design the elements by the endurance limit and other stress-analysis methods.

**Q** What is meant by the *endurance limit* of a material?
**A** The endurance limit (also known as *fatigue limit*) is the maximum unit stress that can be imposed and repeated on a material through a definite cycle, or range of stress, for an indefinitely large number of times without causing the material to rupture.

**Q** How is the endurance limit determined?
**A** By testing a material through a complete reversal of stresses; when stressed nearly to its ultimate strength, the specimen will rupture after a

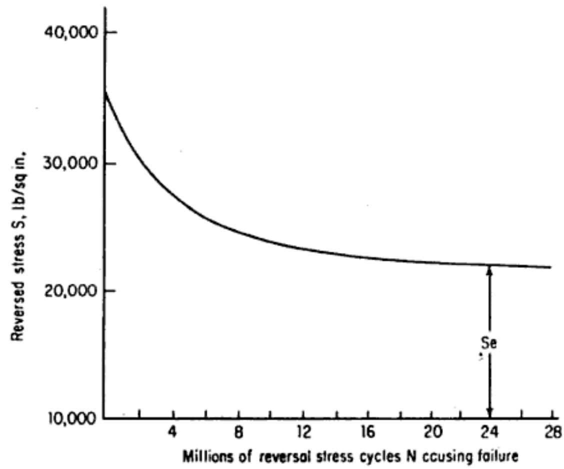


**Fig. 8-12.** *S-N* **diagram determines endurance limit.**

few cycles. If a second sample of the same material is again tested, but stressed slightly less than before, a larger number of reversals, or cycles, can be imposed. This is continued until a stress value, known as the *endurance limit*, is reached where an almost indefinite cycle of stress can be imposed without causing rupture.

Figure 8-12 shows an *S-N* diagram, where stress-to-rupture is plotted on one side and number-of-cycles-to-failure on the other. The horizontal line obtained is the endurance stress for the material. In Fig. 8-12 this is

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22,500 lb per sq in. Endurance limits are widely used in machine design work, and with the adoption of the Nuclear Vessel Code, Section III, it will receive increasing attention in the Code.

**Q** What is meant by an *allowable stress?*
**A** Sometimes called the *allowable working stress,* it is the maximum stress that is considered to be safe when the material is subjected to resisting loads that are assumed to be applied in service. In boiler applications, the term *allowable pressure* is often used. Actually, the allowable pressure is determined by applying the forces acting on a material, and then calculating the allowable pressure from the allowable stress on the material.

**Q** How is the allowable stress determined?
**A** It is determined from the ultimate strength of the material, which is divided by a safety factor to obtain the allowable stress. The safety factor used in modern boilers is 4. However, certain elements of a boiler, such as rivets, have to be designed with a safety factor of 5. Other parts have to be designed with a safety factor as high as 12.5, such as the rivets holding lugs on brackets on an hrt boiler to be suspended from a beam.

That is why the Code must always be checked regarding the part of the boiler being considered to obtain the allowable stress. Data in Fig. 8-13 is taken from ASME, Power Boiler Code, Section I, and indicates permissible allowable stress values for various temperatures. The temperature indicated is for the maximum expected steam or water temperature.

NOTE: The *specified minimum tensile strength* is the ultimate tensile strength of the material. The allowable stresses are shown under the expected temperature, and this is equal to the ultimate stress divided by the safety factor.

**Q** What is meant by *safety factor?*
**A** In boiler usage, the factor of safety is the ultimate strength divided by the allowable loadings, or the ultimate stress ($S_u$) divided by the allowable stress ($Sa$). In equation form

$$\text{Safety factor} = \frac{S_u}{Sa}$$

Another method of expressing the safety factor is by dividing the bursting pressure by the allowable pressure. This method is used on state inspection reports and on ASME data reports. In equation form, it is

$$\text{Safety factor} = \frac{\text{bursting pressure}}{\text{allowable pressure}}$$

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| Spec number and grade | | Nominal composition | Spec min tensile | Metal temperatures, max, °F | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | −20 to +400 | 500 | 600 | 650 | 700 | 750 | 800 | 850 | 900 |
| Plate steels: | | | | | | | | | | | | |
| Carbon steel: | | | | | | | | | | | | |
| SA-30 | Flange....... | ................ | 55,000 | 13,750 | 13,750 | 13,750 | 13,750 | 13,250 | 12,050 | 10,200 | 7,800 | |
| SA-30 | Firebox A.... | ................ | 55,000 | 13,750 | 13,750 | 13,750 | 13,750 | 13,250 | 12,050 | 10,200 | 7,800 | 5,000 |
| SA-30 | Firebox B.... | ................ | 48,000 | 12,000 | 12,000 | 12,000 | 12,000 | 11,650 | 10,700 | 9,000 | 7,100 | 5,000 |
| Low-alloy steel: | | | | | | | | | | | | |
| SA-202 | A.......... | Cr-Mn-Si | 75,000 | 18,750 | 18,750 | 18,750 | 18,750 | 17,700 | 15,650 | 12,000 | 7,800 | 5,000 |
| SA-202 | B.......... | Cr-Mn-Si | 85,000 | 21,250 | 21,250 | 21,250 | 21,250 | 19,800 | 17,700 | 12,000 | 7,800 | 5,000 |
| High-alloy steel: | | | | | | | | | | | | |
| SA-240 | 304........ | 18 Cr-8 Ni | 75,000 | ...... | 15,100 | 14,900 | 14,850 | 14,800 | 14,700 | 14,550 | 14,300 | 14,000 |
| SA-240 | 304........ | 18 Cr-8 Ni | 75,000 | ...... | 12,500 | 11,600 | 11,200 | 10,800 | 10,400 | 10,000 | 9,700 | 9,400 |
| SA-240 | 316........ | 18 Cr-10 Ni-2 Mo | 75,000 | ...... | 17,200 | 17,100 | 17,050 | 17,000 | 16,900 | 16,750 | 16,500 | 16,000 |
| SA-240 | 321........ | 18 Cr-8 Ni-Ti | 75,000 | ...... | 15,200 | 14,900 | 14,850 | 14,800 | 14,700 | 14,550 | 14,300 | 14,100 |
| SA-240 | 347........ | 18 Cr-8 Ni-Cb | 75,000 | ...... | 15,200 | 14,900 | 14,850 | 14,800 | 14,700 | 14,550 | 14,300 | 14,100 |

Fig. 8-13. Some maximum allowable stress values for ferrous materials, in pounds per square inch. (*Continued on next page.*)

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| Spec number and grade | Metal temperatures, max, °F | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 950 | 1000 | 1050 | 1100 | 1150 | 1200 | 1250 | 1300 | 1350 | 1400 | 1450 | 1500 |
| Plate steels: | | | | | | | | | | | | |
| Carbon steel: | | | | | | | | | | | | |
| SA-30 Flange | | | | | | | | | | | | |
| SA-30 Firebox A | | | | | | | | | | | | |
| SA-30 Firebox B | | | | | | | | | | | | |
| Low-alloy steel: | | | | | | | | | | | | |
| SA-202 A | 3,000 | 1,500 | | | | | | | | | | |
| SA-202 B | 3,000 | 1,500 | | | | | | | | | | |
| High-alloy steel: | | | | | | | | | | | | |
| SA-240 304 | 13,400 | 12,500 | 10,000 | 7,500 | 5,750 | 4,500 | 3,250 | 2,450 | 1,800 | 1,400 | 1,000 | 750 |
| SA-240 304 | 9,100 | 8,800 | 8,500 | 7,500 | 5,750 | 4,500 | 3,250 | 2,450 | 1,800 | 1,400 | 1,000 | 750 |
| SA-240 316 | 15,100 | 14,000 | 12,200 | 10,400 | 8,500 | 6,800 | 5,300 | 4,000 | 2,700 | 2,000 | 1,500 | 1,000 |
| SA-240 321 | 13,850 | 13,500 | 13,100 | 10,300 | 7,600 | 5,000 | 3,300 | 2,200 | 1,500 | 1,200 | 900 | 750 |
| SA-240 347 | 13,850 | 13,500 | 13,100 | 10,300 | 7,600 | 5,000 | 3,300 | 2,200 | 1,500 | 1,200 | 900 | 750 |

Fig. 8-13 (*Continued*). Some maximum allowable stress values for ferrous materials, in pounds per square inch.

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**Q** Why is it necessary to have a safety factor? Why can not the stresses be calculated accurately, and the allowable load based on the yield stress be used?

**A** In boiler design and usage and other critical structures where life and property may be at stake, there is a definite need for selecting working stresses and loadings considerably less than the ultimate, or the yield stress, for these reasons:

1. There is always some uncertainty in materials being used, how they were made, how they were assembled, and how they were joined or fabricated with other materials.

2. There is always some uncertainty as to the exact loading that a structure, or part of it, may have to resist and how it is abused in operation.

3. Calculations of all stresses possible in a fabricated structure are never that exact, not when one considers the variables to be encountered in service through the years.

Let us remember that the ASME Code was drawn up when yield stresses for many materials were not available. Then again, certain brittle materials like cast iron do not have a *definite* yield point. Thus it was much easier to work from ultimate stress and apply a safety factor to this so as to obtain an allowable stress. In some countries of Europe, the *yield point* is the basis of design. The Nuclear Vessel Code uses the yield stress or endurance stress or both as a basis of design. With increasing technological changes, the present Boiler Code may also be changed on this matter in time.

**Q** Can a boiler that was originally designed with a safety factor of 5 be operated with a safety factor of 4, since the latest Power Boiler Code allows a safety factor of 4?

**A** Usually, the original safety factor of 5 remains. The safety factor of 4 was drawn up principally for seamless steel or welded boilers that met stiff quality control and inspection requirements on welding. Older boilers may not meet this requirement, thus the original safety factor of 5 should govern the allowable pressure.

**Q** If a boiler is stamped for an allowable pressure of 275 psi and the sv is set at 150 psi, what is the safety factor? Assume a Code-welded boiler meeting latest Code requirements and an original design safety factor of 4.

**A** The bursting pressure of this boiler would be $4 \times 275 = 1{,}100$ psi.

$$\text{Safety factor} = \frac{\text{bursting pressure}}{\text{allowable pressure}} = \frac{1{,}100}{150} = 7.33$$

This question brings up an important consideration as to which

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pressure to use in calculating safety factors on existing boiler installations. For example, in this question, should the sv setting be used or the stamped allowable pressure? If the sv setting is *below* the stamped allowable working pressure, use the *sv setting*. If by chance the sv or svs are set *higher* than the allowable pressure (above Code limits), then a dangerous condition exists because svs must always be set at or *below* the allowable, or working, pressure stamped on the boiler.

The reason the sv setting is used where the stamped allowable pressure is above the sv setting in calculating the safety factor is that the allowable pressure on the boiler *is the sv setting*. The boiler is *not* supposed to operate above this sv setting. If an increase in pressure is needed, other items will have to be checked out first before the pressure can be raised to the maximum allowable pressure stamped for the boiler. Then, a new sv will be required. Also, Code specifications on valve ratings and water column connections will have to be checked to see if they meet the Code requirements for the new pressure.

**Q** Does the *original* safety factor continue for the *life of the boiler*?
**A** It depends on the type of boiler, the condition of the boiler, and even the state in which it is located. Assuming that internal and external inspections are satisfactory, the NB regulations state:

1. Lap-riveted longitudinal-joint boilers operating over 50 psi can be operated at this pressure for 20 years. After that, 50 psi or less is permissible but if the boiler is relocated, only low-pressure service is permitted.

2. For boilers of butt construction, at the end of 25 years, and every 5 years thereafter, the safety factor must be increased by 0.5 unless a hydrostatic test of 1½ times the allowable pressure is imposed; if this test is satisfactory, no increase in the safety factor is necessary.

The best rule to follow on any safety factor changes is to check with an insurance company boiler inspector or legal jurisdiction inspector. *Never* assume that the boiler can be operated at a higher pressure by just changing svs, even if the boiler is stamped for the higher pressure. There are other requirements to be met on feedwater, blowdown, water column connections, low-water fuel cutoff, and service valve ratings that must be considered.

**Q** Name the parts of boilers that must be considered for *stress calculations*.
**A** Any pressure vessel and parts confining pressure must be analyzed per component by carefully considering the strength of the material being used, its physical characteristics as to type and grade, allowable stress, thickness, etc. The forces acting on this material must then be analyzed. This force is usually created by pressure, but may also include tempera-

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ture, the weight it is supporting, and stress concentration such as around an opening. The problem then evolves to comparing the forces acting on the material and determining whether the material is being stressed beyond the allowable stresses governed by the Boiler Code rules. Elements to be considered depend on the type of boiler but will generally include shells or drums, tubes, tube sheets, heads, flat surfaces, stays, stay bolts, openings, furnaces, rivets, welded joints, structural supports, and connected piping and valves. Each of these is governed by Boiler Code rules as to allowable material, allowable stresses, and method of calculating forces to obtain the allowable pressure.

> NOTE: In boiler and pressure vessel application, the weakest element producing the lowest pressure then determines the *allowable pressure* for the boiler.

**Q** The term *stress corrosion* has often been applied to boiler and pressure-vessel elements that fail unexpectedly, even though *normal stresses* are within prescribed limits. What is stress corrosion?

**A** The endurance limit of a metal, when it is repeatedly stressed in the presence of a corroding agent such as water, may be greatly reduced. The result is often an unexpected failure, which is a form of fatigue failure due to corrosion. The process begins with corrosion pitting on a stressed part. As the pitting progresses, the stress in the affected part rises. This is caused by the pits serving as stress concentration points. As corrosion continues, stress continues to rise, especially if repeated, until the endurance limit of the metal is reached. Fatigue cracks start at the bottom of corrosion pits and proceed until failure occurs. The damage is primarily due to sharp pits rather than general corrosion.

Pits formed under simultaneous stress and corrosion are always sharper and deeper than pits formed in the same time under stressless conditions. The more repetitive the stress, the faster will be the pitting action. At low-cycle repetitive stress, pitting will proceed entirely by normal corrosion, and the section will fail by the normal tension failure or when the resisting area is thinned down so the stress rises proportionately, assuming a constant load.

Stress corrosion then is primarily caused by repetitive stresses of high frequency in a corroding medium, leading to pitting caused by stress and corrosion. The pitting then develops high-stress concentration points which lead to fatigue failure.

**Q** Can stress-corrosion be calculated for in design?

**A** No experimental data is available for determining the extent to which the endurance limit is reduced for most materials in combination with corroding solutions or media. But for boilers and pressure vessels

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the obvious precaution to take against stress corrosion is to make sure the water or medium being confined is free of any corrosive tendencies. This is determined by analysis of the water at regular intervals by personnel experienced in water analysis. This also points out the value of periodic internal inspections of pressure-containing parts and examination of surfaces for evidence of pitting and corrosion.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Nondestructive Testing*, 24 pages

*Steam Generation*, 48 pages

*Power Handbook*, 64 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

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# 9

# BOILER STRENGTH CALCULATIONS

## MATERIALS

**Q** How does the Boiler Code consider the various materials that are available to a designer?

**A** The Code specifies by listing permissible materials for the different components of a boiler, pressure vessel, or nuclear reactor. It also indicates the allowable stresses to be used for different temperatures. As new materials are developed, they are evaluated for strength, hardness, ductility, etc. Therefore, when replacing or reinstalling a pressure component, check the Code and use only Code-approved materials.

**Q** Describe some of the materials specified for various components on a boiler.

**A** Plate steel for any part of a boiler subject to pressure and exposed to the fire, or products of combustion, must be of firebox quality. If not exposed to fire or the products of combustion, the plate can be of flange quality. Some firebox quality steels are specification SA-201 carbon-silicon steel, specification SA-202 chromium-manganese-silicon steel, and specification SA-204 molybdenum steel. Check the Code for other firebox quality steels and refer to the ASME Material Specification, Section II, for their physical and chemical characteristics. Seamless steel drum forgings made in accordance with specifications SA-266 and SA-336 for alloy steel can be used for any part of a boiler for which either firebox or flange quality is permitted.

Pipes and tubes may be made of open hearth, electric furnace, basic oxygen, or acid deoxidized bessemer steel pipe or tubing, according to Code specifications.

Superheater pressure parts, whether the integral type or separately fired, must be of wrought steel, puddled or knobbled charcoal wrought iron, or carbon or alloy steel, according to Code specifications.

Rivets must be of steel or iron of the quality designated under specification SA-31 or SA-84 for wrought iron.

Stays and stay bolts fabricated by forge welding must be of SA-84



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stay bolt wrought iron. Threaded stay bolts must be of wrought iron of SA-84 grade, of steel complying with specification SA-31, or of annealed nickel-copper alloy of specification SB-164.

**Q** Does the Code allow cast iron to be used for nozzles or flanges attached directly to a pressure part of a high-pressure boiler?
**A** No. Cast iron cannot be used for nozzles or flanges for any pressure or temperature. But this does not apply to low-pressure boilers.

**Q** For what part of an hp boiler may cast iron be used?
**A** If the pressure does not exceed 250 psi and the temperature does not exceed 450°F, specification SA-278 gray-iron castings may be used for power boiler parts such as pipe fittings, water columns, and valves and their bonnets.

**Q** Do the above restrictions apply to malleable iron?
**A** The same pressure parts as enumerated for cast iron can be made of malleable iron, except that the pressure is limited to a maximum of 350 psi and the temperature to 450°F.

**Q** What is the minimum thickness of boiler plate permitted on a boiler, and of what tolerance for this thickness?
**A** The minimum thickness is ¼ in. for plate subjected to pressure. An exception is for miniature boilers of seamless construction, where the minimum plate thickness may be 3/16 in. The minimum thickness of tube sheets is ⅜ in., except on miniature boilers where it is 5/16 in. The plate material must be not more than 0.01 in. thinner than that required for the plate by the formula used to calculate its strength, provided the tolerance in fabrication (or when ordering the plate) also has this tolerance of not less than 0.01 in.

**Q** What is a mill test report?
**A** This is a report by the steel mill attesting to the chemistry and physical properties of the material. In the case of plate steel, it shows the heat, or slab number, from which the plate was made, which is stamped on the plate. It also gives the specification and thickness.

**Q** How are the ends of shell plates and butt straps formed for the longitudinal seam?
**A** Forming of these ends is by rolling or pressing and not by blows as with a hammer, which could weaken them.

**Q** Who is responsible for stamping or certifying the steel plate or material to be used on a boiler?
**A** The manufacturer of the plate or materials.

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NOTE: Some typical examples of Boiler Code calculations are presented in the following questions and answers. All allowable stresses shown and the formulas used are from the Code. But a word of caution. The Code does change the allowable stresses and the formulas from time to time. So always refer to the latest Code for the exact formula and stress allowed. The methods presented here show how each component of a boiler or other pressure vessel has to be considered to evaluate its strength. Refer to a good stress analysis book to ascertain the derivation of the formulas used.

## PIPE AND TUBES

**Q** What are the Code equations to be used on pipe and tube problems?

**A** There are four equations (ASME Power Boilers, Section I).

1. For wt boilers having ferrous metal economizer, superheater, and generator tubes up to 5 in. OD, use

$$P = S\left[\frac{2t - 0.01D - 2e}{D - (t - 0.005D - e)}\right]$$

or

$$t = \frac{PD}{2S + P} + 0.005D + e$$

where $P$ = maximum allowable pressure, psi
$D$ = outside diameter of tubes, in.
$t$ = minimum required thickness, in.
$S$ = maximum allowable stress, lb per sq in.
$e$ = thickness factor for expanded tube ends

NOTE: For selecting the $S$ value of *tubes*, the operating temperature of the metal shall be not less than the maximum expected mean wall temperature (the sum of the outside and inside surface temperatures divided by 2) of the tube. This in no case shall be taken as less than 700°F for tubes absorbing heat. For tubes which do not absorb heat, the wall temperature may be taken as the temperature of the fluid within the tube, but not less than the saturation temperature.

NOTE: $e$ = 0.04 over a length at least equal to the length of the seat, plus 1 in. for tubes expanded into tube seats. However, $e$ = 0 for tubes expanded into tube seats, provided that the thickness of the tube ends over a length of the seat plus 1 in. is *not* less than the following:

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0.095 in. for tubes 1¼ in. OD and smaller
0.105 in. for tubes above 1¼ in. OD and up to 2 in. OD
0.120 in. for tubes above 2 in. OD and up to 3 in. OD
0.135 in. for tubes above 3 in. OD and up to 4 in. OD
0.150 in. for tubes above 4 in. OD and up to 5 in. OD
$e = 0$ for tubes strength-welded to headers and drums.

2. For ft boilers using SA-83 and SA-178 material,

$$P = 14{,}000 \frac{(t - 0.65)}{D}$$

where $P$ = maximum allowable pressure, psi
$t$ = minimum required thickness, in.
$D$ = outside diameter of tube, in.

For ft boilers using copper tubes of SB-75 specification,

$$P = 12{,}000 \frac{(t - 0.59)}{D} - 250 \quad \text{(the symbols are the same as above)}$$

**Q** Give an example of a Code pipe and tube problem.

**A** The following specifications are for a tube strength-welded in a wt boiler: minimum thickness, 0.158 in.; outside diam, 2.5 in.; material, SA-213-T11; temperature, 700°F. What is the maximum allowable working pressure?

Using the formula

$$P = S\left[\frac{2t - 0.01D - 2e}{D - (t - 0.005D - e)}\right]$$

$S = 15{,}000$
$t = 0.158$ in.
$D = 2.5$ in.
$e = 0$ (strength-welded)

$$P = 15{,}000\left[\frac{2\,(0.158) - 0.01\,(2.5)}{2.5 - [0.158 - 0.005\,(2.5)]}\right]$$

$$P = 15{,}000\left[\frac{0.291}{2.3545}\right]$$

$$P = 15{,}000\,(0.1236) = 1{,}854 \text{ psi} \qquad \textit{Ans.}$$

## SHELLS AND DRUMS

**Q** What are the two basic equations used for shells and drums of over 24 in. diam?

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**A** The two basic equations are:

1. For plate thicknesses of ½ in. or less, or when of riveted construction, or where the weld reinforcement is not removed substantially flush, or where the backing strip on longitudinal joints is not removed, use the equation

$$P = \frac{0.8\,SEt}{R + 0.6\,t}$$

or

$$t = \frac{PR}{0.8SE - 0.6\,P}$$

where $P$ = maximum allowable pressure, psi
$S$ = maximum allowable stress, lb per sq in. for operating temperature of metal
$t$ = minimum required thickness, in.
$R$ = inside radius of cylinder, in.
$E$ = efficiency of joint

NOTE: $E$ = efficiency of longitudinal welded joints or of ligaments between openings, whichever is lower. $E = 1.00$ for seamless cylinders, and $E = 1.00$ for welded joints, provided all weld reinforcement on the longitudinal joints is removed substantially flush with the surface of the plate. $E = 0.90$ for welded joints with the reinforcement on the longitudinal joints left in place. $E$ = efficiency for riveted joints, $E$ = efficiency for ligaments between openings.

2. For plate thicknesses of over ½ in. of welded or seamless construction, with the weld reinforcement removed substantially flush and the backing strip removed, use

$$P = \frac{SE\,(t - 0.1)}{R + (1 - y)\,(t - 0.1)}$$

or

$$t = \frac{PR}{SE - (1 - y)P} + 0.1$$

$y$ = temperature coefficient, and other symbols are as shown under 1 above. (See the Code for details.)

**Q** How is the efficiency of the ligaments on the steam drums calculated?

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**A** From the equation

$$E = \frac{p - nd}{p}$$

where $E$ = efficiency
$p$ = pitch of ligament, in.
$n$ = number of tube holes in ligament pitch
$d$ = tube hole diameter, in.

**Q** Give some examples of shell and drum calculations according to the Code.

**A** EXAMPLE: A boiler is 66 in. in diameter and 16 ft long. The shell plate is 7/16 in. thick, the allowable stress is 13,750 lb per sq in. and the allowable pressure is 125 psi. What is the least permissible circumferential efficiency of the girth joint?

Using the formula

$$P = \frac{0.8\,SET}{R + 0.6t}$$

$$125 = \frac{0.8\,(13{,}750)\,(E)\,(0.4375)}{33 + 0.6\,(0.4375)}$$

$$E = \frac{125\,(33.26)}{11{,}000\,(0.4375)} = 86.6\%$$

$$\text{Circumferential } E = \frac{86.6}{2} = 43.3\% \qquad \textit{Ans.}$$

The circumferential strength of the shell must be always at least ½ that of the longitudinal joint. This was illustrated in Chap. 8.

EXAMPLE: What is the maximum OD allowed for a drum built to the following specifications: pressure, 300 psi; SA-30 flange steel; joint efficiency, 100 percent; thickness of drum plate, ¾ in.; temperature, under 650°F.

$$0.75 = \frac{300\,R}{13{,}750\,(1) - (1 - 0.4)\,300} + 0.1$$

$$0.75 - 0.1 = \frac{300\,R}{13{,}570}$$

$$R = \frac{0.65\,(13{,}570)}{300}$$

$R = 29.4$
$OD = 2(29.4) + 1.5$
$OD = 60.3$ in. *Ans.*

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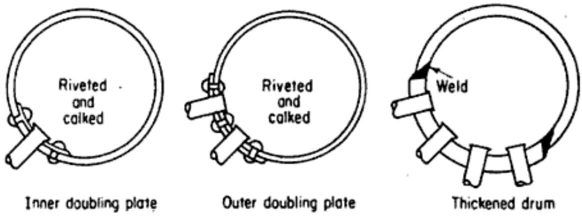


**Fig. 9-1. Three methods of reinforcing drum ligaments.**

EXAMPLE: The mud drum of a wt boiler has a 42-in. ID. The tube sheet is 5/8 in. thick and contains 3 9/32-in. diam tube holes pitched horizontally 5 5/16 in., in banks of three (Fig. 9-2) and two tubes with 6 7/8 in. between banks. The shell plate is 1/2 in. thick. The joint efficiency between tube sheet and shell is 67 percent. What is the allowable working pressure for this drum if the material is SA-285C and the maximum temperature is 650°F?

NOTE: The tube sheet is the portion of the drum where the tubes are located (Fig. 9-1).

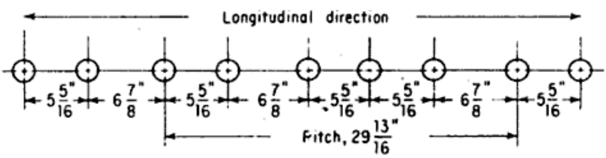


**Fig. 9-2. Tube holes forming ligament in shell or drum.**

Ligament efficiency must be calculated first.

$$E = \frac{p - nd}{p}$$

$$= \frac{29.8125 - 5\ (3.28125)}{29.8125}$$

$$= 0.448 \qquad \text{(This is lowest joint efficiency.)}$$

Using the equation in the first example (1/2 in. shell plate, riveted construction as efficiency is 67 percent) and tube sheet data,

$$P = \frac{0.8\ SEt}{R + 0.6t}$$

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$$= \frac{0.8\ (13{,}750)\ (0.448)\ (0.625)}{21 + 0.6\ (0.625)}$$

$= 145$ psi *Ans.*

EXAMPLE: What hydrostatic pressure should be made on a wt boiler, all-welded construction, of 36-in. ID, shell plate ⅝ in., tube sheet ¾ in. thick? Ligament efficiency of tube holes longitudinally is 43.5 percent, girthwise it is 20 percent; longitudinal weld efficiency is 90 percent; allowable stress is 13,750 lb per sq in.

Based on shell data, and realizing that not all welds were met, with $R = 18$, $t = 0.625$, $E = 90$ percent, $S = 13{,}750$,

$$P = \frac{0.8\ (13{,}750)\ (0.9)\ (0.625)}{18 + 6\ (0.625)}$$

$= 337$ psi *Ans.*

Based on tube sheet, with $R = 18$, $t = 0.75$, $E = 40$ percent (twice girth), $S = 13{,}750$,

$$P = \frac{0.8\ (13{,}750)\ (0.4)\ (0.75)}{18 + 0.6\ (0.75)}$$

$= 180$ psi *Ans.* (This is allowable pressure.)

Hydrostatic test required $= 1.5\ (180) = 270$ psi *Ans.*

## UNSTAYED HEADS

**Q** Name the blank unstayed heads that are allowed on power boilers.

**A** There are four: (1) segment of a sphere, (2) semiellipsoidal, (3) hemispherical, and (4) flatheads. The first three are bumped heads (Fig. 9-3). Some Code flatheads and methods of attachment are shown in Fig. 9-4. Bumped heads are flanged, with a corner radius on the concave side of the head of not less than 3 times the head thickness and in no case less than 6 percent of the diameter of the shell for which the heads are to be attached.

Flanged-in manhole openings in dished, or bumped, heads must be flanged to a depth of not less than 3 times the required thickness of the head for plate of up to 1½ in. thickness. If thicker, the depth of the flange must be the thickness of the plate plus 3 in. The minimum width of the bearing surface for a gasket on a manhole must be 11/16 in., and the gasket thickness when compressed must be less than ¼ in.

**Q** If a dished head is not designed according to Code rules and is found to be too thin, must the head be replaced?

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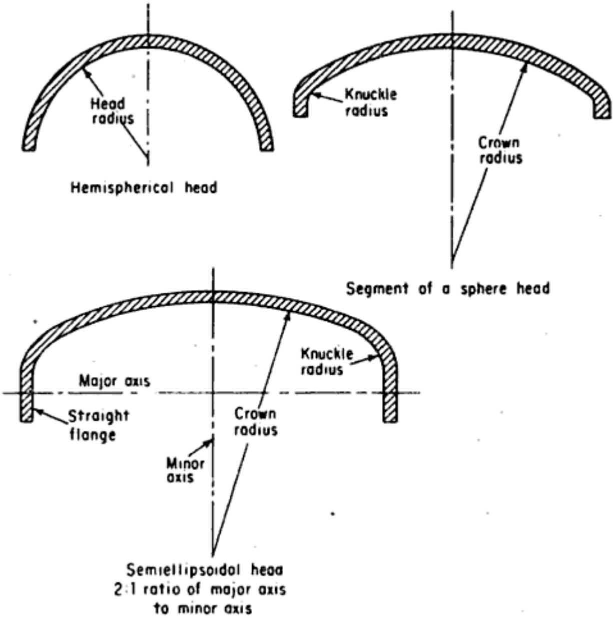


**Fig. 9-3. Dished heads come in these three shapes.**

**A** Not if it is stayed for additional strength, providing other requirements of the Code are met.

**Q** What formulas are used for the various heads?
**A** For segments of a sphere head without a manhole use the formula

$$t = \frac{5\ PL}{4.8\ SE}$$

where $S$ = maximum allowable stress, lb per sq in.
$t$ = thickness of head, in.
$P$ = maximum allowed pressure, psi
$L$ = radius on concave side to which head is dished, in.
$E$ = efficiency of weakest joint, but *not* head-to-shell joint

For semiellipsoidal heads with pressure on the concave side (without a manhole), use the shell formula for cylinders over 24 in. in diameter, but assume that the shell is seamless (no joint efficiency). For hemispherical

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heads with no manhole and pressure on the concave side, use the following formula:

$$t = \frac{PL}{1.6\,SE} \qquad (1)$$

or

$$t = \frac{PL}{2\,SE} + 0.1 \qquad (2)$$

where $t$ = required thickness, in.
$P$ = maximum allowable pressure, psi
$S$ = maximum allowable stress, lb per sq in.
$L$ = radius to which head was formed, in.
$E$ = efficiency of weakest joint, including head-to-shell joint

Formula (1) is for heads up to ½ in. thick. Formula (2) is for heads over ½ in. integrally formed with the shell, or welded head-to-shell joints, provided that all the welding meets Code requirements, including the weld reinforcement being removed substantially flush with the plate (same as for shells over ½ in. thick).

**Q** Are the same equations used for dished heads with flanged-in manholes?
**A** When any of the heads, either segment of a sphere, semiellipsoidal, or hemispherical, has a flanged-in manhole or an access opening that exceeds 6 in. in any dimension, it is computed on the following basis:

1. By the formula for a segment of a sphere head.
2. The thickness of the head must be increased by 15 percent but in no case less than ⅛ in. after the thickness is obtained by the formula.
3. If the radius to which a head is dished is less than 80 percent of the diameter of the shell, the thickness of the head with a flanged-in manhole opening must be found (or calculated) by making the dish radius equal to 80 percent of the diameter of the shell.

**Q** To what percentage may the knuckle of a dished head be thinned in forming?
**A** Not over 10 percent.

**Q** What formula is used for calculating flatheads?
**A** Consult the Code because there are several variations, depending on whether the flathead is round, square, rectangular, etc. The typical round flathead is calculated by this formula:

$$t = d\sqrt{\frac{CP}{S}}$$

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where $t$ = minimum required thickness, in.
$d$ = diameter, measured as indicated in Code
$C$ = a factor, depending on method of attachment (Fig. 9-4)
$S$ = maximum allowable stress value, lb per sq in.
$P$ = maximum allowable pressure, psi

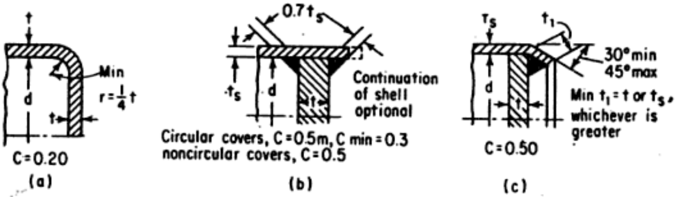


**Fig. 9-4. Some unstayed Code-approved flatheads and covers.**

**Q** Illustrate some typical head calculations.

**A** EXAMPLE: A blank, unstayed dished head (segment of a sphere) with a flanged-in manhole and with pressure on the concave side is ⅞ in. thick. The radius of the dished head is 36 in., the material is SA-285C, the temperature is under 650°F. What is the allowable pressure on this head?

Using the following formula, with $S = 13{,}750$, $L = 36$, $E = 1$, $t = 0.875/1.15 = 0.761$,

$$t = \frac{5\,PL}{4.8\,SE}$$

$$0.761 = \frac{5\,(P)\,(36)}{4.8\,(13{,}750)\,(1)}$$

$$P = \frac{(0.761)\,(4.8)\,(13{,}750)}{(5)\,(36)}$$

$$= 279 \text{ psi} \qquad \textit{Ans.}$$

NOTE: At times it is necessary to calculate the dish radius based only on chord data and depth of bump. This will be illustrated by the following to show how the radius of the dish is 47.1 in. for a chord length of 38 in. and a bump of 4 in. See Fig. 9-5.

Refer to triangle $ABO$

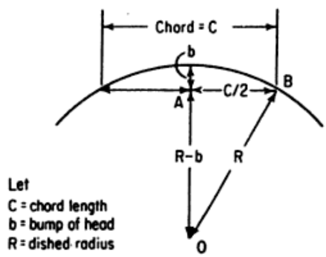


**Fig. 9-5. Method of finding a dish radius, given chord length and bump of head.**

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R = hypotenuse of right triangle

$$R^2 = \left(\frac{C}{2}\right)^2 + (R - b)^2$$

$$2Rb = \frac{C^2}{4} + b^2$$

$$R = \frac{C^2}{8b} + \frac{b}{2}$$

Substituting

$$R = \frac{(38)^2}{8\,(4)} + \frac{4}{2}$$

$$= 45.1 + 2$$
$$= 47.1 \text{ in.} \qquad \textit{Ans.}$$

EXAMPLE: An unstayed flathead is attached as in Fig. 9-4*b*. All welding meets Code requirements. The head is circular with a 16-in. diam and thickness of 1½-in., the material is SA-285-C, the temperature is under 650°F. The shell to which the head is attached is ⅜ in., and the required shell thickness is 5⁄16 in. What is the allowable pressure on this flathead?

Using the formula below and with $S = 13{,}750$, $d = 16$, $t = 1.5$, $C = 0.5m$, $m = 0.3125/0.375 = 0.833$, $C = 0.5\ (0.833) = 0.4165$ or $0.417$,

$$t = d\sqrt{\frac{CP}{S}}$$

$$1.5 = 16\sqrt{\frac{0.417P}{13{,}750}}$$

$$\left[\frac{1.5}{16}\right]^2 = \frac{0.417P}{13{,}750}$$

$$P = \left[\frac{1.5}{16}\right]^2 \left[\frac{13.750}{0.417}\right]$$

$$= 289 \text{ psi} \qquad \textit{Ans.}$$

## STAYED SURFACES

**Q** Explain the method of calculating stayed surfaces on Code boilers.

**A** The Code has various rules (Fig. 9-6) on pitch, thickness of plate

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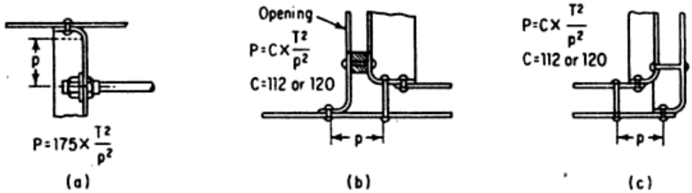


**Fig. 9-6. Stayed boiler components must adhere to the Code.**

for the pitch, and factors to be used for various constructions. Two fundamentals should be understood: (1) Figure 9-7 shows pressure acting on a square-pitch flat plate, with a stay bolt in the middle to brace the plate. The force acting on the plate from pressure is the pitch squared minus the stay bolt area times the pressure.

In equation form, we have

$$(p^2 - a)\,P = F$$

where $p$ = pitch, in.
$P$ = pressure, psi
$a$ = stay bolt area, sq in.
$F$ = force on plate, lb

This force is resisted by the strength of the stay bolt. Assume that the stay bolt is threaded with a telltale hole of ³⁄₁₆-in. diam (the area of a ³⁄₁₆-in. diam hole is 0.027 sq in.) as shown in Fig. 9-8*b*. The symbol $a$ is the net area of the stay bolt at the bottom of the threads. The strength of the stay bolt is then the net sectional area of the stay bolt times the allowable stress, or

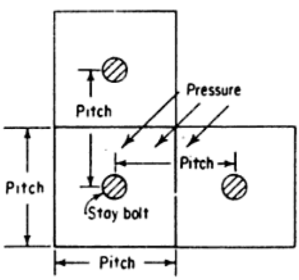


**Fig. 9-7. Square pitch plate under pressure.**

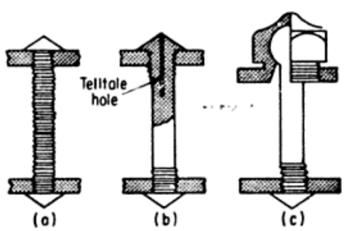


**Fig. 9-8. Types of stay bolts, with and without a telltale hole.**

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$(a - 0.027)\ S$

where $S$ equals the allowable stress on the stay bolt (Fig. 9-13).

For equilibrium to exist, obviously the two forces must be equal, or

$$(p^2 - a)\ P = (a - 0.027)\ S$$

In addition to the strength of the stay bolt, the strength of the plate between the stay bolts must be adequate, or the plate might buckle between the stay bolts. The Code requires this to be checked by one of the following equations:

$$T = p\sqrt{\frac{P}{C}} \qquad \text{or} \qquad P = \frac{T^2C}{p^2}$$

where $T$ = required thickness of plate, in sixteenths of an inch
$p$ = maximum pitch, in.
$P$ = maximum allowable pressure, psi
$C$ = factor, depending on construction (112 for stays screwed through plates of not over 7/16 in. thickness; 120 for stays screwed through plates of over 7/16 in. thickness)

NOTE: The Code shows other values of $C$, based on different stay construction.

**Q** Why are stays necessary in boiler construction?

**A** Since flat surfaces exposed to pressure tend to bulge outward, they must be supported by stays, as otherwise the flat plate required would be very thick. Because cylindrical or spherical surfaces do not tend to change their shape under pressure, they do not require staying.

**Q** Illustrate some typical Code stay bolt calculations.

**A** EXAMPLE: How many and what size of threaded stay bolts (12 V threads per in.) are required to adequately support 374 sq in. of a stayed surface in a Code boiler, if the stay bolts are pitched 5¼ × 5½ in., drilled with telltale holes of 3/16 in. (area of hole 0.027 sq in.), and the working pressure is 150 psi?

$$\text{Number of stay bolts required} = \frac{374}{5.25 \times 5.5} = 13 \qquad \textit{Ans.}$$

Let $a$ = net area of stay bolt; then

$$(5.25 \times 5.5) - a = \text{net area pressure is acting on}$$

Resisting force of stay bolt = $(a - 0.27)$ 7,500 (where 7,500 = allowable stress on stay bolt)

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Equating forces we have:

$$(28.875 - a)\ 150 = 7{,}500\ (a - 0.027)$$
$$4{,}331.25 - 150\,a = 7{,}500\,a - 202.5$$
$$4{,}533.75 = 7{,}650\,a$$
$$a = 0.592 \text{ sq in.} \qquad \textit{Ans.}$$

NOTE: Use 1¹⁄₁₆-in. stay bolt with root area of 0.662 sq in. *Ans.*

EXAMPLE: The stay bolts in the firebox of a locomotive firebox boiler (lfb) are spaced 7 in. horizontally and 6½ in. vertically; the diameter of the threaded stay bolts (12 V threads) is 1½ in.; the plate thickness is ½ in.; the telltale hole area in the stay bolts is 0.027 sq in. What is the allowable pressure, based on stay bolt data?

Based on plate thickness, and C = 120 from the Code

$$P = \frac{120 \times 8^2}{7 \times 6\frac{1}{2}} = 168.8 \text{ psi} \qquad \textit{Ans.}$$

Based on stay bolt, where the root area of a 1½-in. stay bolt is 0.960

$$(45.5 - 0.960) \times P = (0.960 - 0.027)\ 7{,}500$$
$$44.55 \times P = 6{,}997.5$$
$$P = 157.1 \text{ psi} \qquad \textit{Ans.}$$

Lowest pressure of 157.1 is awp (allowable working pressure)

## DIAGONAL STAYS

**Q** Sketch and describe a diagonal stay and explain where it is used.

**A** To stay the flat portions of heads that are not supported by tubes, diagonal stays are used above the tubes. This stay is not as direct as the through stay, and it throws stress on the shell plates as well. But the diagonal stay leaves more room above the tubes for inspection, repair, and cleaning. A common form of diagonal stay is shown in Fig. 9-9.

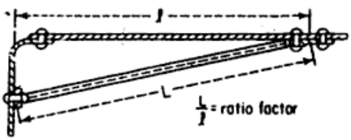

Fig. 9-9. Diagonal stay; measurements for determining stresses.

**Q** Explain how diagonal stays are installed.

**A** When the crowfoot is against the head, the holes in the shell should be so placed that the holes in the palm of the stay are about ¹⁄₃₂ in. shy of lining up. Often, the crowfoot is bolted to the head, and the shell or palm holes are marked off and drilled to meet this requirement. The crowfoot is then riveted to the head. The stay is elongated so that the shell and palm holes line up. This effect may be accomplished by heat-

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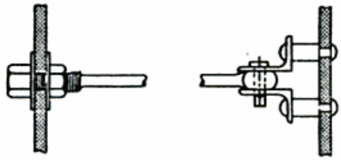

**Fig. 9-10. Method of attaching a through stay.**

ing, but a driftpin is often sledged in one hole instead. After the palm is riveted in position, the stay becomes in tension to support the head. Diagonal stays are installed before the tube is in place. The tube sheet must be held by a strong back to prevent buckling, until the tubes are inserted. Figures 9-10 and 9-11 illustrate diagonal- and through-stay details on an hrt boiler.

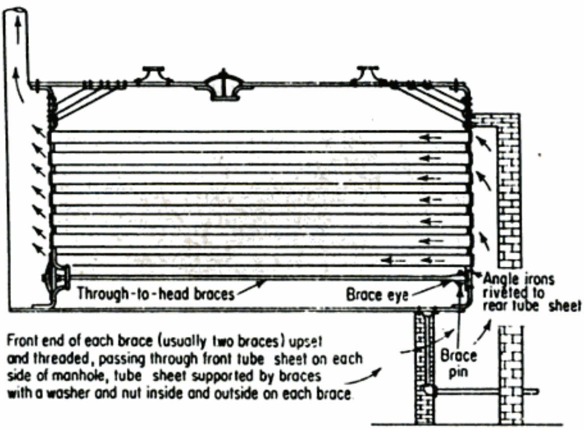


**Fig. 9-11. Methods of bracing an hrt boiler.**

**Q** How are diagonal stays calculated for holding power to resist the force caused by pressure?

**A** Three important factors to consider on diagonal stays are:

1. What is the slant of the diagonal or its angle to the flat surface being supported?
2. Is it welded or riveted to the shell and head?
3. What is the construction on the ends of the stay where it is fastened to the shell or head: riveted, pins, split palms, or blades (crowfoot type)? See Fig. 9-12.

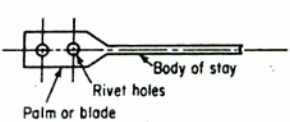


**Fig. 9-12. Elements of a riveted diagonal stay.**

The Code permits most diagonal stays to be calculated as straight stays

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similar to the stay bolt method. This method calls for multiplying pressure times area on one side, with the holding power of the stay on the other side of the equation. For example, in Fig. 9-9 if the ratio of $L/l$ is 1.15 or less (on an hrt boiler), the body of the stay is calculated as a straight stay. But the allowable stress to be used is 90 percent of that allowed for a straight stay. If the ratio of $L/l$ is over 1.15, the body of the stay is calculated by increasing the area required on the body of the stay by the ratio of $L/l$. In equation form, this is expressed as follows:

$$A = \frac{aL}{l}$$

where $a$ = cross-sectional area of direct stay body
$A$ = cross-sectional area of diagonal stay body
$l$ = length of right angles to area to be supported (see Fig. 9-9)
$L$ = diagonal length of stay

The Code rules on palms that are riveted on diagonal stays require the cross-sectional area of this part of the stay to be at least 25 percent greater than the body of the stay. Figure 9-13 gives maximum allowable stresses for stay bolts and stays or braces.

| Description of stay bolts and stays or braces | Stresses, lb/sq in. | |
|---|---|---|
| | For lengths between supports not exceeding 120 diam* | For lengths between supports exceeding 120 diam* |
| Unwelded or flexible stay bolts less than 20 diam* long, screwed through plates with ends riveted over | 7,500 | |
| Hollow steel stay bolts less than 20 diam* long, screwed through plates with ends riveted over | 8,000 | |
| Unwelded stays or braces and unwelded portions of welded stays or braces | 9,500 | 8,500 |
| Steel through stays or braces exceeding 1½ in. diam* | 10,400 | 9,000 |
| Welded portions of stays or braces† | 6,000 | 6,000 |
| Threaded rigid nickel-copper alloy stay bolt (annealed) | 9,500 | |

* Diameters taken at body of stay or brace.

† Refers to the method of fabrication by forge welding of the part itself and not to the attachment of the stays or braces to the sheets.

Fig. 9-13. Maximum allowable stresses for stay bolts and stays or braces.

**Q** Illustrate some typical Code calculations on diagonal stays.

**A** EXAMPLE: The area of a segment to be stayed is 504 sq in. This area is supported by seven 1¼-in. diam round diagonal braces (the

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area of the brace is 1.227 sq in.). The length of the brace is less than 1.15 times the length of a direct stay. What pressure is allowed on the segment if the stays are welded?

Deducting area of stays method, with allowable stress on welded stays being 6,000, the area stayed by one stay = 504/7 = 72 sq in.

$$(72 - 1.227) \times P = 1.227 \times 6{,}000 \times 0.9$$
$$70.773 \times P = 6{,}625.3$$
$$P = 92.2 \text{ psi} \qquad \textit{Ans.}$$

EXAMPLE: The area to be stayed on the front tube sheet of an lft boiler is 136 sq in. It is braced with two diagonal stays, weldless type, where $L = 29\frac{1}{4}$ in., $l = 28\frac{5}{8}$ in. What diameter of brace is required to carry 165 psi? (Do not deduct the area of the stays.)

$$136 \times P = \text{area of stays } (2a) \times \text{allowable stress}$$
$$136 \times 165 = 0.9 \times 9{,}500 \times 2a$$
$$a = \frac{22{,}440}{17{,}100} = 1.312 \text{ sq in.}$$
(Use $1\frac{5}{16}$ in. diam round stays)

NOTE: $L/l$ is less than 1.15.

**Q** How is the area to be stayed calculated on an hrt boiler for the part of the tube sheet above the tubes?

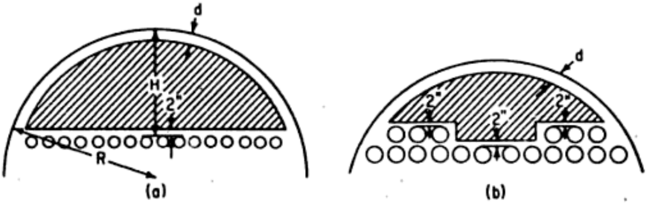


**Fig. 9-14. Method of determining net area of (a) regular segment of a head and (b) irregular segment of a head.**

**A** This area is illustrated in Fig. 9-14*a* and *b*. Two equations can be used. Let $A_s$ = area to be stayed.

1. For flanged heads:

$$A_s, \text{ sq in.} = \frac{4(H - d - 2)^2}{3} = \sqrt{\frac{2(R - d)}{(H - d - 2)} - 0.608}$$

2. For unflanged heads:

$$A_s, \text{ sq in.} = \frac{4(H - 2)^2}{3}\sqrt{\frac{2R}{H - 2} - 0.608}$$

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where $H$ = distance from tubes to shell, in.

$d$ = outer radius of flange, not exceeding 8 times thickness of head, in.

or $d = \frac{80\,t}{\sqrt{P}}$ (use largest value of $d$)

or $d = 0$ for unflanged heads

$t$ = thickness of head, in.

$P$ = maximum allowable pressure, psi

$R$ = radius of boiler head, in.

NOTE: If $d = 3$ in., the Code has a table for the area to be stayed for various lengths of $H$.

**Q** Sketch and describe a girder stay.

**A** The girder stay (Fig. 9-15) was formerly used very extensively to support flat crown sheets in lfb units. But it has been largely superseded by the radial stay (Fig. 9-17) for this purpose. It is still used to support the tops of combustion chambers in boilers of the scotch marine (sm) type. The girder stay consists of a cast steel or built-up girder with its ends resting on the side, or end sheets, of the firebox or combustion chamber. It supports the flat crown sheet (the top of the combustion chamber) by means of bolts.

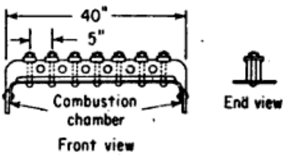


Fig. 9-15. Girder stay for supporting crown sheet of locomotive firebox and scotch marine boilers.

**Q** If the girder stay (Fig. 9-15) has a span of 40 in. from tube sheet to back connection plate, the bolts in each girder are pitched 5 in., the center distance from girder to girder is 7½ in., what is the allowable pressure if the depth of the girder is 7½ in. and the thickness of the girder is 2 in?

**A** Use the following equation:

$$P = \frac{Cd^2t}{(W - p)\,D_1W}$$

where, with seven supporting bolts, as shown in Fig. 9-15,

$C$ = 11,500 (see Code)

$d$ = depth of girder, 7½ in.

$t$ = thickness of girder, 2 in.

$W$ = distance from tube sheet support to back plate, 40 in.

$D_1$ = distance from center of girders, 7½ in.

$p$ = pitch of supporting bolts, 5 in.

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Then

$$P = \frac{11{,}500\,(7.5)^2\,(2)}{(40-5)\,(7.5)\,(40)}$$

$= 123$ psi *Ans.*

**Q** Does not the girder stay resting on the tube sheet affect the tube sheet's strength?

**A** Yes. This must be calculated according to the Code, using the equation

$$P = \frac{27{,}000\,t\,(D-d)}{WD}$$

where $P$ = maximum allowable working pressure, psi
$t$ = thickness of tube plate, in.
$d$ = inside diameter of tube, in.
$W$ = distance from tube sheet to opposite combustion chamber sheet, in.
$D$ = least horizontal distance between tube centers on horizontal row, in.

This equation applies only to tube sheets where the crown sheet is not supported from the shell of the boiler, which is the case with girder stays.

**Q** Give an example by using the above equation.

What pressure is allowed on the rear tube sheet of an sm boiler where the crown is not stayed to the shell, the tubes are 6 in. center-to-center horizontally, 4 in. OD, 0.16 in. thick, the tube sheet is 7/16 in. thick, and the depth of the combustion chamber is 30 in.?

Substituting, with $d = 4 - 0.32, = 3.68$, $D = 6$, $W = 30$, $t = 0.4375$,

$$P = \frac{27{,}000\,(0.4375)\,(6-3.68)}{30\,(6)}$$

$= 165$ psi *Ans.*

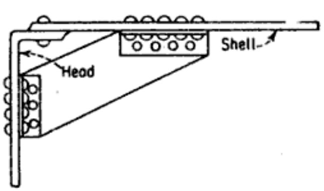

Fig. 9-16. Gusset stay.

**Q** Sketch and describe a gusset stay.

**A** This is a form of diagonal stay (Fig. 9-16) in which a plate is used instead of a bar. It consists of a heavy plate fastened by welding (or rivets) and angle bars to the head and shell. It is more rigid than the

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diagonal stay, takes up more room, and interferes to a greater extent with water circulation. Gusset stays are used very little in modern boiler construction. The gusset plate requires a cross-sectional area 10 percent greater than a typical diagonal stay.

**Q** How are curved locomotive-boiler crown sheets usually supported?

**A** By long threaded rods called *radial stays* (Fig. 9-17). These rods are screwed through both crown sheet and wrapper sheet and the ends are riveted over.

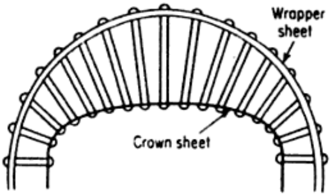


Fig. 9-17. Radial stays.

**Q** What are the advantages and disadvantages of radial stays and girder stays?

**A** The radial stays are more flexible and tend to hold less scale from circulation than do girders. About the only advantage of the girder stays is that they pass straight through the sheet rather than at an angle.

## COMBUSTION CHAMBERS

**Q** Why must furnace and combustion chambers be calculated for strength against pressure since only the products of combustion flow against them?

**A** There is pressure acting on the furnace from the waterside or steam side which might collapse the furnace inward.

**Q** Name four ways of supporting a circular furnace subjected to external pressure.

**A** The circular furnace may be (1) self-supporting, (2) stay-bolted, (3) corrugated, or (4) equipped with Adamson rings.

**Q** Give some typical Code calculations for combustion chambers.

**A** EXAMPLE: What pressure is allowed on a seamless flue 16 in. ID, thickness $\frac{13}{32}$ in.?

Where the thickness of the wall is greater than 0.023 times the diameter,

$$P = \frac{17{,}300\,t}{D} - 275$$

where $P$ = maximum allowable working pressure, psi
$D$ = outside diameter of flue, in.
$t$ = thickness of wall of flue, in.

$OD = 16 + \frac{13}{16} = 16.8125$
$16.8125\,(0.023) = 0.387$
$\frac{13}{32} = 0.40625$, so the formula applies

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$$P = \frac{17{,}300\ (0.40625)}{16.8125} - 275$$

$$= 418 - 275 = 143 \text{ psi} \qquad \textit{Ans.}$$

EXAMPLE: An sm dry-back boiler has a cylindrical furnace which is 10 ft between rivet seams and has an Adamson ring midway between its length; OD is 42 in., pressure is 125 psi. What thickness of furnace is required?

Where the length does not exceed 120 times the thickness of the plate,

$$P = \frac{57.6\ (300t - 1.03L)}{D}$$

where $P$ = maximum allowable working pressure, psi
$D$ = OD of furnace, in.
$L$ = length of furnace section, in.
$t$ = thickness of furnace wall, in.

$$125 = \frac{57.6\ (300t - 1.03 \times 60)}{42}$$

$$\frac{125\ (42)}{57.6} = 300t - 61.8$$

$$\frac{5{,}250}{57.6} + 61.8 = 300t$$

$$\frac{152.946}{300} = t$$

$$t = 0.51 \text{ in.} \qquad \textit{Ans.}$$

**Q** Are openings in boiler shells of importance in the inspection of, and calculations on, boilers?

**A** Yes, because many failures start with cracks around openings. Study the Boiler Code for particulars on reinforcement calculations needed on openings exceeding 2-in. pipe size, for this is beyond the scope of this book.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less
*Power Handbook*, 64 pages
*Steam Generation*, 48 pages

Books

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

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# 10

# FUELS, FIRING, AND COMBUSTION

**Q** Name the principal forms of fuels used in boilers.
**A** The common fuels used for production of heat in commercial boilers are either in a solid, liquid, or gaseous state. The solid fuels include coal, lignite, coke, wood, wood wastes, and vegetable wastes such as bagasse. Fuels in the liquid form include petroleum oil, black liquor in kraft paper mills, and some other liquid chemical derivatives in process industries. Gas fuels include natural, blast furnace, coke oven, and waste heat gases from process industries. Other energy sources such as atomic reactors and electricity make heat, but these do not involve combustion.

**Q** Describe some of the principal classes of coal.
**A** Anthracite coal is very hard, is noncoking, and has a high percentage of fixed carbon. It ignites slowly, unless the furnace temperature is high, and requires a strong draft. The heating value is around 14,000 Btu per lb. Butuminous coal is soft, has a high percentage of volatile matter, burns with a yellow, smoky flame, and has a heating value of 11,000 to 14,000 Btu per lb. Semibituminous coal is the highest grade of bituminous. It burns with little smoke, is softer than anthracite, and has a tendency to break into small pieces when handled. The heating value is 13,000 to 14,500 Btu per lb. Subbituminous (black lignite) is a low grade of bituminous coal with a heating value between 9000 and 11,000 Btu per lb. Lignite is between peat and subbituminous coals, with a wood structure and claylike appearance. The heating value is 7000 to 11,000 Btu per lb.

**Q** What are caking coal and free-burning coal?
**A** A caking coal is one which fuses at the surface when burning to form a more or less heavy crust. The term *coking* is also used. A free-burning coal does not form a crust and is friable (easily crumbles) throughout the combustion process.

**Q** Name the two methods of analyzing coal.
**A** (1) Ultimate analysis and (2) proximate analysis. Ultimate analysis gives the percentages of the various chemical elements of which the coal



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is composed. Proximate analysis determines the percentage of moisture, volatile matter, fixed carbon, and ash with a fair degree of accuracy.

**Q** How is the ultimate analysis made?

**A** This analysis requires a laboratory and a skilled chemist. If a sample of coal is separated into its elements, certain proportions of oxygen, hydrogen, carbon, etc. will be found. These proportions are generally expressed as percentages of the weight of the original sample, the unit weight beirg 100 percent. The heating value of coal is estimated from the ultimate analysis by getting the percentages of carbon, oxygen, hydrogen, and sulfur in the coal, and by measuring the heat of combustion available in one pound of coal.

Other conditions reported in a coal analysis are (1) as-received, (2) air-dried, (3) moisture-free, (4) moisture- and ash-free, and (5) moisture- and mineral-free.

**Q** What are the mineral impurities of coal?

**A** One is ash, which is the incombustible mineral matter left behind when coal burns completely. The amount and character of the ash constitute the biggest single factor in fuel-bed and furnace problems like clinkering and slagging. An increase in ash content usually means an increase in carbon carried to waste or imperfect combustion. Next are the incombustible gases like carbon dioxide and nitrogen. When the volatile matter distills off, a solid fuel is left, consisting mainly of carbon, but containing some hydrogen, oxygen, sulfur, and nitrogen that are not driven off with the gases. Sulfur in coal burns, but is undesirable. Besides causing clinkering and slagging, it corrodes air heaters, economizers, breachings, and stacks. It also causes spontaneous combustion in stored coal.

**Q** How is the heating value of coal determined?

**A** By burning a coal sample in a calorimeter (bomb) filled with oxygen under pressure.

**Q** How is anthracite coal sized?

**A** Standard sizes are broken, $4\frac{3}{8}$ to $3\frac{1}{4}$ in.; egg, $3\frac{1}{4}$ to $2\frac{7}{16}$ in.; stove, $2\frac{7}{16}$ to $1\frac{5}{8}$ in.; chestnut, $1\frac{5}{8}$ to $\frac{13}{16}$ in.; pea, $\frac{13}{16}$ to $\frac{9}{16}$ in.; No. 1 buckwheat, $\frac{9}{16}$ to $\frac{5}{16}$ in.; No. 2 buckwheat rice, $\frac{5}{16}$ to $\frac{3}{16}$ in.; No. 3 buckwheat (barley), $\frac{3}{16}$ to $\frac{3}{32}$ in.; culm or river coal, refuse from screening anthracite into prepared sizes.

**Q** How is bituminous coal sized?

**A** There is little standardization of either screen opening or names given to sizes. Run-of-mine is unscreened coal as it comes from the mine. A 2-in. nut-and-slack normally means that all coal passes a 2-in. screen

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but the amount of different sizes present may vary widely. The so-called between-screen sizes include everything passing one screen and retained by another. This gives a closer idea unless the spread between the screens is large.

> REMEMBER: Coal size affects the nature of the fuel bed, the draft required, the density of coal formed, and the amount of unburned-carbon loss.

**Q** What do the specimen analyses of typical coals indicate?
**A** The average, or specimen, analyses (Fig. 10-1) supplied by the Bureau of Mines can only be broadly representative and hence must be used with caution. These analyses figures are condensed and cover each bed, or seam, of coal in each county, state, and district. But remember that preparation changes the coal's characteristics. Bureau of Mines figures are from run-of-mine samples. Screenings would probably show slightly more ash. Prepared coals would show slightly less ash and sulfur, higher heating values, and probably higher fusion temperatures. Grindability data Hardgrove (HG) does not relate directly to the analyses, but serves to give a general picture.

**Q** Describe some other solid fuels.
**A** Wood from lumber and woodworking industries in the form of sawdust, slabs and shavings, and hog wood. Hog wood is wood refuse cut to uniform size before burning. Bark from pine, oak, and hemlock trees is burned in special furnaces. The heating value of wood varies from 2500 to 3000 Btu per lb. Bagasse is the crushed stalks of sugarcane from which the sap has been extracted. The heating value is from 3500 to 4500 Btu per lb. Coke is the solid remains after the destructive distillation of either petroleum oils or certain bituminous coals. The heating value of petroleum coke is from 11,500 to 15,000 Btu per lb.

**Q** Name three methods of feeding coal for combustion into the furnace of a boiler.
**A** By hand shoveling, with stokers, and with pulverizers. Hand firing is inefficient and is slowly disappearing.

**Q** How are stokers classified?
**A** See Fig. 10-2. Two broad classes are (1) overfeed, in which the fuel is carried into the furnace above the stoker, and (2) underfeed, where the fuel is carried by the stoker underneath. Overfeed stokers are further classified into spreader and chain-grate stokers.

**Q** How does the underfeed stoker work?
**A** Raw coal is pushed by a ram (Fig. 10-2*c*) into the furnace along a feed trough. The fresh coal pushed in causes the coal in the furnace to

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Specimen Analyses of Some Typical Coals

| Bed or seam | State | County | % M* | % V* | % FC* | % Ash | % S* | Htg val, Btu/lb | Ash-fusion temp, °F | HG† |
|---|---|---|---|---|---|---|---|---|---|---|
| District 1: | | | | | | | | | | |
| Barton | Md. | Allegany | 2.5 | 15.8 | 68.3 | 13.4 | 2.1 | 13,020 | | |
| Brookville | Pa. | Somerset | 4.3 | 18.0 | 69.0 | 8.7 | 1.2 | 13,340 | | |
| District 2: | | | | | | | | | | |
| Brookville | Pa. | Butler | 3.7 | 37.0 | 52.4 | 6.9 | 1.6 | 13,550 | | |
| L Freeport | Pa. | Butler | 3.1 | 35.0 | 55.2 | 6.7 | 1.1 | 13,710 | | |
| District 3: | | | | | | | | | | |
| Bakerstown | W. Va. | Preston | 2.0 | 28.9 | 61.4 | 7.7 | 1.8 | 14,010 | 2200–2500 | |
| L Kittanning | W. Va. | Randolph | 2.5 | 29.5 | 57.4 | 10.6 | 1.3 | 13,410 | 2600–3000 | 51 |
| District 4: | | | | | | | | | | |
| Clarion | Ohio | Vinton | 5.5 | 39.6 | 41.9 | 13.0 | 3.7 | 11,690 | | |
| L Freeport | Ohio | Jefferson | 3.8 | 37.6 | 49.8 | 8.8 | 2.8 | 13,050 | | |
| District 7: | | | | | | | | | | |
| Beckley | W. Va. | Raleigh | 2.7 | 17.1 | 74.8 | 5.4 | 0.7 | 14,390 | 2500–3000 | 107 |
| Big Eagle | W. Va. | McDowell | 3.0 | 29.2 | 62.0 | 5.8 | 0.8 | 14,150 | .......... | 69 |
| Campbell Creek | W. Va. | Fayette | 2.6 | 32.6 | 59.4 | 5.4 | 1.2 | 14,070 | 2400–2800 | |
| District 13: | | | | | | | | | | |
| Clark | Ala. | Bibb | 2.9 | 34.8 | 56.1 | 6.2 | 0.8 | 13,830 | 2100–2400 | 59 |
| Jagger | Ala. | Fayette | 3.1 | 33.9 | 52.5 | 10.5 | 0.7 | 12,790 | | |
| Black Creek | Ala. | Jefferson | 2.9 | 31.8 | 61.5 | 3.8 | 0.7 | 14,410 | 2500–2800 | 64–70 |

* M = muisture, V = volatile matter, FC = fixed carbon, S = sulfur.

† Grindability data (Hargrove).

Fig. 10-1. Specimen analyses give only a general picture.

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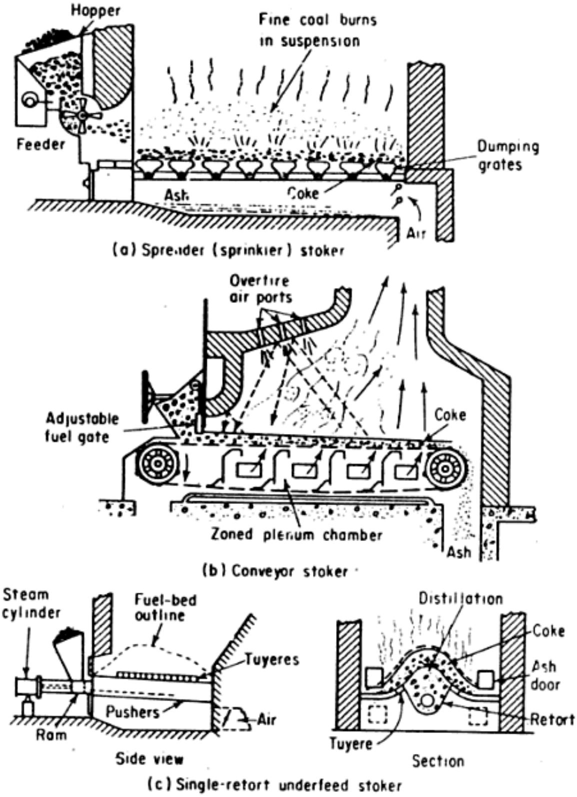


**Fig. 10-2. Spreader, conveyer, and single-retort stokers.**

rise, exposing more coal to the air coming from the tuyeres (openings) in the grate section. The raw coal is heated by the furnace heat and the incoming air, and thus ignites and burns as it moves up toward the fuel bed outline. The burning coke then moves slowly to the ash discharge end, pushed that way either by the pressure of the incoming coal or the motion of the grate.

**Q** Name some underfeed stoker types.

**A** The name of each type is determined by the mechanism used to move the coal, such as single retort, multiple retort, screw feed, or ram

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bottom protects the grate from excessive heat. Oxygen in the primary air is mostly used up a few inches above the grate (oxidation zone).

Only a little carbon monoxide is formed until all oxygen is gone, but the rate of CO formation becomes rapid at the beginning of the reduction zone. As the distance from the grate increases, CO continues to form, but at a slower rate. Thus the thicker the fuel bed, the more CO is formed. Because reduction to $CO_2$ depends on the time of contact between gas and coke, higher air velocities mean less CO. The fuel-bed temperature depends largely on the rate of firing, being higher at high rates. Usually the temperature within the bed is somewhat greater than at the surface. If this temperature is above that at which ash fuses, clinkers may form.

## PULVERIZED FIRING

**Q** Explain pulverized-coal firing.

**A** Coal is ground to almost the fineness of flour, and then flows by means of air and coal (in suspension) through ducts or pipes into the furnace to burn like gas or oil (Fig. 10-4). The grinding of the coal

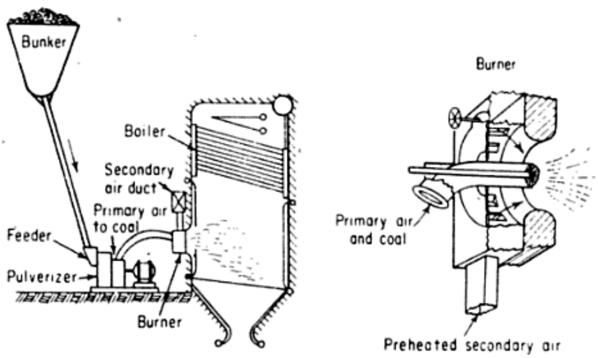


**Fig. 10-4. Pulverized coal-burning system.**

exposes the fuel elements in the coal to rapid oxidation (burning) as the ignition temperature is reached. More complete burning is thus possible than with fuel-bed burning

As these fine particles enter the furnace and become exposed to radiant heat, the temperature rises, and the volatile matter of the coal is distilled off in the form of a gas. Enough primary air is introduced at the burner to intimately mix with the stream of coal particles, which thus support combustion. The volatile matter burns first and then heats the remaining carbon to incandescence. Secondary air is introduced around

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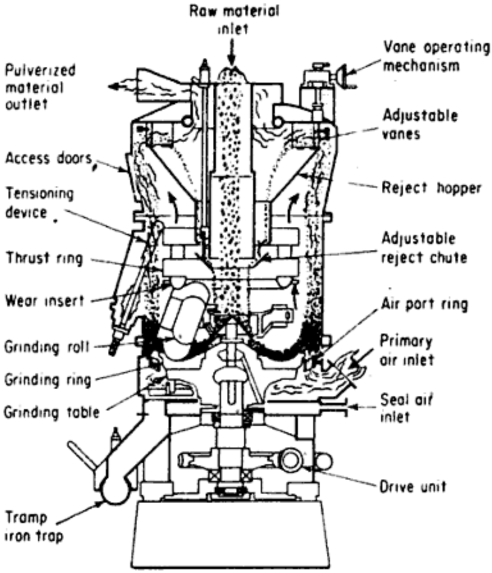


**Fig. 10-6. Bowl mill pulverizer.**

and air. The air used to transport the coal to the burner forms the primary air; secondary air may be introduced in the burner (turbulent burners) or around or near the burner (nozzle burners). The turbulent burner (Fig. 10-7) imparts a rotary motion to (1) the coal-air mixture in a central nozzle and (2) the secondary air issuing from a chamber around that nozzle, all within the burner. This gives some premixing for coal and air, and considerable turbulence. In some burners the coal-air mixture issues from a series of nozzles to mix within the furnace with secondary air admitted through separate openings.

Most burners fire into the furnace horizontally, usually from only one

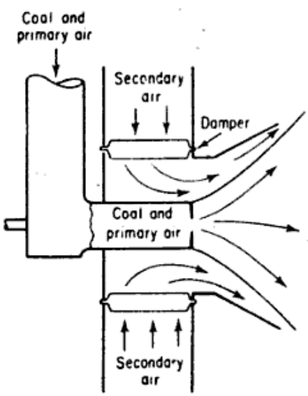


**Fig. 10-7. Turbulent burner for pulverized coal.**

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capacities and fall off at low loads, the problem of lighting off is a major one. Usually, an auxiliary oil or gas burner, electrically ignited, is used for this purpose. One design has a mechanical-atomizing oil burner. Both burner and igniting electrodes are retractable, and a safety interlocking system prevents oil flow until the burner and electrodes are extended.

**Q** Describe the cyclone burner illustrated in Fig. 10-10.

**A** In this furnace design, what might be termed deliberate slagging is used. The burner receives crushed (not pulverized) coal in a stream of high-velocity air tangent to the circular burner housing, which forms a primary water-cooled furnace. Coal thrown to the rim of the furnace by centrifugal force and held by a coating of molten ash is scrubbed by fast-moving air. Secondary air enters at high velocity also, and parallel to the path of the primary coal-air mixture. The coal in the sticky slag film burns as if it were in a fuel bed. Volatiles are distilled off, and carbon is burned out to leave ash. Combustion of volatile matter begins in the burner chamber and is completed in the secondary furnace into which the burner chamber discharges. Molten ash, under centrifugal force, clings to the burner-chamber walls and the slight inclination causes slag to discharge continuously. The nature of this burning tends to reduce greatly the amount of ash carried in suspension, and hence flyash emission is negligible.

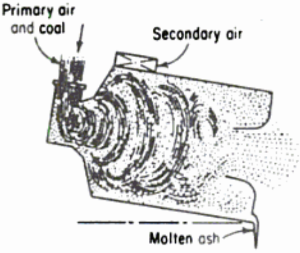

**Fig. 10-10. Cyclone burner whirls crushed coal against slagged walls.**

**Q** How is the degree of fineness of the pulverized coal checked?

**A** A sample drawn from the primary outlet is put through a stacking machine with different mesh screens stacked on top of one another. For a given weight of the sample, the amount remaining on each mesh can then be calculated as a percentage of the original weight. This can then be compared with the specification fineness required on the pulverizer and adjustments made to obtain this fineness.

## FUEL OIL

**Q** What is petroleum?

**A** Crude oil as it comes out of the ground consists of 83 to 87 percent carbon and 10 to 14 percent hydrogen, plus traces of oxygen, nitrogen, and sulfur. The hydrogen and carbon are combined as hydrocarbons. Refining consists of separating and recombining the hydrocarbons into groups or fractions having the same range of boiling points. From light

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to heavy, typical fractions are (1) naphtha, (2) gasoline, (3) kerosene, and (4) gas oil. These are the distillates; the remainder, or residual, is a straight-run.

**Q** Briefly describe fuel oils.
**A** Fuel oils are derived from petroleum, with the chief combustible ingredients being carbon and hydrogen. Their specific gravities vary with temperature and origin. The range at 60°F is from 0.84 to 0.96. The table in Fig. 10-11 gives some properties at 60°F.

| Gravity, deg API | Sp gr | Lb/gal | Btu/lb | Btu/gal | Lb/42-gal bbl | Lb/cu ft |
|---|---|---|---|---|---|---|
| 3 | 1.0520 | 8.76 | 18,190 | 159,340 | 368.00 | 65.54 |
| 5 | 1.0366 | 8.63 | 18,290 | 157,840 | 362.62 | 64.59 |
| 7 | 1.0217 | 8.50 | 18,390 | 156,320 | 357.37 | 63.65 |
| 9 | 1.0071 | 8.39 | 18,490 | 155,130 | 352.46 | 62.78 |
| 11 | 0.9930 | 8.27 | 18,590 | 153,740 | 347.71 | 61.93 |
| 13 | 0.9792 | 8.16 | 18,690 | 152,510 | 342.88 | 61.07 |
| 15 | 0.9659 | 8.05 | 18,790 | 151,260 | 338.22 | 60.24 |
| 17 | 0.9529 | 7.94 | 18,890 | 149,980 | 333.64 | 59.42 |
| 19 | 0.9402 | 7.83 | 18,980 | 148,610 | 329.23 | 58.64 |
| 21 | 0.9279 | 7.73 | 19,060 | 147,330 | 324.91 | 57.87 |
| 23 | 0.9159 | 7.63 | 19,150 | 146,110 | 320.71 | 57.12 |
| 25 | 0.9042 | 7.53 | 19,230 | 144,800 | 316.59 | 56.39 |
| 27 | 0.8927 | 7.44 | 19,310 | 143,670 | 312.60 | 55.68 |
| 29 | 0.8816 | 7.35 | 19,380 | 142,440 | 308.70 | 54.98 |
| 31 | 0.8708 | 7.26 | 19,450 | 141,210 | 304.92 | 54.31 |
| 33 | 0.8602 | 7.17 | 19,520 | 139,960 | 301.18 | 53.64 |
| 35 | 0.8498 | 7.08 | 19,590 | 138,690 | 297.57 | 53.00 |
| 37 | 0.8398 | 7.00 | 19,650 | 137,550 | 294.04 | 52.37 |
| 39 | 0.8299 | 6.92 | 19,720 | 136,400 | 290.64 | 51.76 |
| 41 | 0.8203 | 6.83 | 19,780 | 135,090 | 287.23 | 51.16 |

Fig. 10-11. Some properties of fuel oil.

In this table, the API scale is the American Petroleum Institute scale for showing specific gravity. The API scale fixes a reading of 10°F as equal to a specific gravity of 1.00. Readings greater than 10°F indicate a specific gravity of less than 1.0, or an oil which is lighter. To obtain the actual specific gravity in relation to water from the API reading, use the following equation:

$$\text{Actual specific gravity} = \frac{141.5}{131.5 + \text{API deg}}$$

**Q** How are fuel oils sold?
**A** Fuel oils are sold in six standardized grades, under the numbers or

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grades of 1, 2, 3, 4, 5, and 6. Grades 1, 2, and 3 are light, medium, and heavy domestic fuel oils. These usually do not require heating prior to burning in a furnace. Grades 4, 5, and 6 correspond to federal specifications for Bunkers *A*, *B*, and *C*, respectively. These oils are heavy and viscous, thus require heating prior to being sprayed into a furnace.

**Q** Describe some physical properties of fuel oil.

**A** Since hydrogen has a much higher heating value and lower atomic weight than the other principal elements in fuel oil, the proportions of carbon and hydrogen affect both specific gravity and heating value. Because of this, specific gravity forms a reliable guide to an oil's heating value. Some typical physical properties are:

Specific gravity in degrees API is found by dividing specific gravity with respect to water (at 60°F) into 141.5 and subtracting 131.5 from the answer. Specific gravity in degrees Baumé (°Bé) is found in the same way except that the numbers are 140 and 130, respectively. For practical purposes, the two specific gravity scales may be considered the same.

Viscosity is the relative ease, or difficulty, with which an oil flows. It is measured by the time in seconds a standard amount of oil takes to flow through a standard orifice in a device called a *viscosimeter*. The usual standard in this country is the Saybolt Universal, or the Saybolt Furol, for oils of high viscosity. Since viscosity changes with temperature, tests must be made at a standard temperature, usually 100°F for Saybolt Universal and 122°F for Saybolt Furol. Viscosity indicates how oil behaves when pumped and, more particularly, shows when preheating is required and what temperature must be held.

Flash point represents the temperature at which an oil gives off enough vapor to make an inflammable mixture with air. The results of a flash point test depend on the apparatus, so this is specified as well as temperature. Flash point measures an oil's volatility and indicates the maximum temperature for safe handling.

Pour point represents the lowest temperature at which an oil flows, under standard conditions. Including pour point as a specification ensures that an oil will not give handling trouble at expected low temperatures.

By centrifuging a sample of oil, the amounts of water and sediment present can be determined. These are impurities and while it is not economical to eliminate them, they should not occur in excessive quantities (not more than 2 percent). Incombustible impurities in oil, from natural salts, from chemicals in refining operations, or from rust and scale picked up in transit, show up as ash. Some ash-producing impurities cause rapid wear of refractories, and some are abrasive to pumps, valves, and burner parts. In the furnace, they may form slag coatings.

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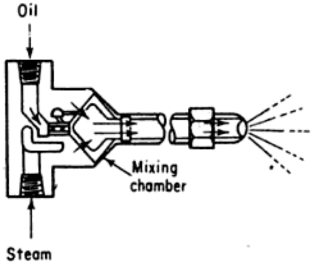


**Fig. 10-12. Steam-atomizing burner with mixing done inside.**

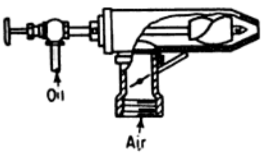


**Fig. 10-13. Air-atomizing burner uses low-pressure air.**

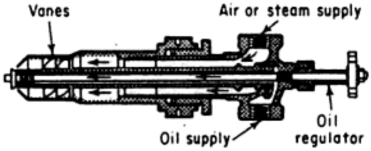


**Fig. 10-14. Steam atomizing of the external-mixing type.**

steam produced, with the average around 2 percent. The pressure required varies from about 75 to 150 psi.

In the burner of Fig. 10-14 oil reaches the tip through a central passage, flow being regulated by the screw spindle. Oil whirls out against a sprayer plate to break up at right angles to the stream of steam, or air, coming out behind it. The atomizing stream surrounds the oil chamber and receives a whirling motion from vanes in its path. When air is used for atomizing, it should be at 10 psi for lighter oils and 20 psi for

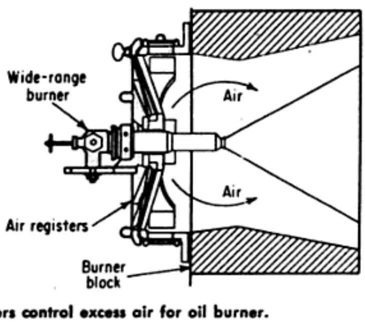


**Fig. 10-15. Air registers control excess air for oil burner.**

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Properties of Fuel Gases

| Fuel | Source | Average composition | High heat value, btu/cu ft | Remarks |
|---|---|---|---|---|
| Blast-furnace gas | By-product of iron making | 58% $N_2$ 27% CO, 12% $CO_2$, 2% $H_2$, some $CH_4$ | 90–100 | Good fuel when cleaned—used mainly at source |
| Butane .... | By-product of gasoline making, also in casing-head gas | $C_4H_{10}$ (usually has some butylene $C_4H_8$ and propane $C_3H_8$) | 3200–3260 | Liquefies under slight pressure, sold as liquid (bottled gas) |
| Casing-head gas | Oil wells | Varies, mostly butane, propane | 1200–2000 | Used mostly in oil fields |
| Carbureted water gas | Manufactured from coal, enriched with oil vapor | 34% $H_2$, 32% CO, 16% $CH_4$, 7% $N_2$, 5% $C_2H_4$, 4% $CO_2$, 2% $C_6H_6$ | 500–600 | Good fuel, but usually costly Part of most city gas |
| Coke-oven gas | By-product coke ovens | 48% $H_2$, 32% $CH_4$, 8% $N_2$, 6% CO, 3% $C_2H_4$, 2% $CO_2$, 1% $O_2$ | 500–600 | Good fuel when cleaned, often used at source |
| Natural gas | Gas wells | Varies, mostly $CH_4$, $C_2H_6$, $C_3H_8$ | 950–1150 | Ideal fuel, piped to point of use |
| Oil gas .... | Manufactured from petroleum | 54% $H_2$, 27% $CH_4$, 10% CO, 3% $N_2$, 3% $CO_2$, 3% $C_2H_4$ | 500–550 | Used on West Coast, often mixed with coke-oven gas |
| Producer gas | Manufactured from coal, coke, wood, etc. | 51% $N_2$, 25% CO, 16% $H_2$, 6% $CO_2$, 2% $CH_4$ | 135–165 | Requires cleaning |
| Propane ... | By-product of gasoline | $C_3H_8$ | 2500 | Similar to butane |
| Refinery gas | By-product of petroleum processing | Varies, mostly butane, and propane | 1200–2000 | Used mainly at refineries |
| Sewage gas | Sewage-disposal plants | 65% $CH_4$, 30% $CO_2$, 2% $H_2$, 3% $N_2$, traces of $O_2$, CO, $H_2S$ | 600–700 | Many disposal plants meet all power needs with this fuel |

Fig. 10-19. Gases used as fuel in industrial boilers.

atmospheric burner is popular, as in home gas ranges. The momentum of the incoming low-pressure gas stream is used to draw in, or aspirate, part of the air needed for combustion. A shutter or similar device regulates the amount of air so induced. Gas and air together pass through a tube leading to the burner ports, mixing in the process. The mixture burns at the ports or openings in the burner head (with a blue, nonluminous flame). Secondary air is drawn into the flame from the sur-

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rounding atmosphere. Larger counterparts of this general burner type, having ring or sectional burner heads with many ports, are used to fire small boilers and industrial equipment.

A single-port atmospheric burner is shown in Fig. 10-20. A needle valve controls the gas flow through the spud; air is drawn in around the shutter at the end. With burner-port size and shape fixed, the nature of burning depends largely on the amount of primary air, or premix. With premix low, the flame is long and pale blue. It may have a yellow tip, indicating cracking and presence of free carbon.

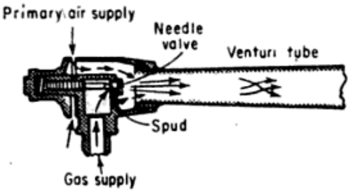

**Fig. 10-20. Single-port atmospheric gas burner.**

Operation is usually satisfactory with 30 to 70 percent premix; in some special designs 100 percent primary air is used. This premix range gives a turndown, or capacity, range of about 4:1. Usually premix and capacity ranges are somewhat narrower. Secondary air may be drawn in around the burner, the amount depending on the area of the opening and the draft. The high-pressure burner uses gas at about 20 to 30 psig and air at atmospheric pressure. Another type uses compressed air, with gas at atmospheric pressure.

**Q** Describe and illustrate refractory gas burners.

**A** For boiler firing, a slightly different type of burner is widely used. It depends on natural or fan draft to draw in all the air required for combustion; hence draft conditions are important. One design uses multiple gas jets, which discharge into the airstream to cause violent agitation in a short mixing tube or tunnel of refractory. In the burner of Fig. 10-21, turbulence vanes impart a swirling motion to the air entering the tunnel.

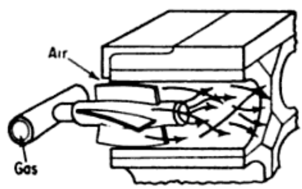

**Fig. 10-21. Tunnel gas burner uses vanes.**

**Q** What kind of gas burner is used on large steam-generating units?

**A** Large steam-generating units often use a high-pressure (2 to 25 psi) gas burner of the gas-ring, center-diffusion-tube, or turbulent, design. The gas ring has an annular manifold located between the air register and the furnace wall surrounding the burner opening. Orifices drilled in this ring spray gas angularly across an incoming air stream, controlled in quantity, velocity, and rotation by the resistor.

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**Q** Describe a gas burner where gas and air are mixed at one point and then supplied to several burners.

**A** Higher burner-head pressure to overcome variable furnace draft, high overload capacity, uniform air-gas mix at all loads, and single-valve control may be had in a system in which the mixture is made at one point and supplied to several burners (Fig. 10-22). In this low-pressure type, gas is at atmospheric pressure while air is at 1 to 2 psi. The heart of the system is the inspirator governor.

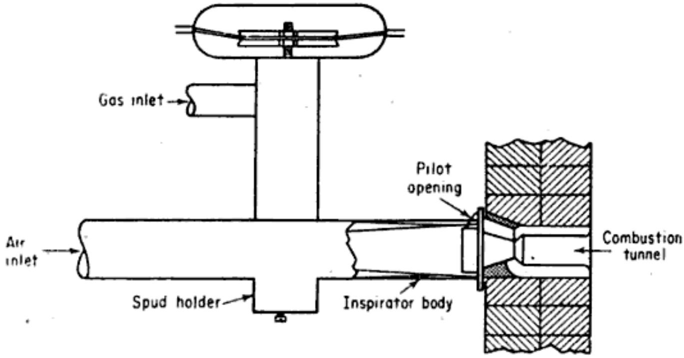


**Fig. 10-22.** Inspirator governor mixes gas and air for several burners.

## COMBUSTION

**Q** Explain how any material starts to burn.

**A** Some things burn more easily than others, depending on how easy it is to turn the substance into a gas, because nothing truly burns until it is a gas. We know it is easier to start wood burning than coal and easier to ignite a twig than a log. To make wax in a candle burn, we first turn it into a gas. With a wick, heat from a match flame lights it easily. But without a wick the wax won't light because the heat of the match is too small in comparison with the mass of wax, so no wax is vaporized. But the wick draws (by capillary action) an amount of melted wax so small in relation to the match flame that enough heat is available to raise the wax to the temperature needed for vaporization. Once wax is vaporized, or made like a gas, burning is relatively easy to start. Then the burning wax gives off enough heat to continue the process of melting, vaporizing, and igniting.

**Q** What is meant by the term *ignition temperature*?

**A** When we have a combustible gas and the exact amount of air to burn it completely, we still need another element—heat. If such a perfect mixture is heated gradually, the rate of chemical combination increases

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until a point is reached where the reaction no longer depends on heat from an outside source. The lowest temperature at which this happens is the ignition temperature, the temperature at which heat is generated by the reaction faster than it is lost to the surroundings, and combustion thus becomes self-propelling. Below this point, the gas-air mixture will not burn freely.

**Q** How is fuel converted for burning in a boiler?

**A** It is the furnace heat that does the conversion. The firing equipment puts the fuel into shape that makes the best use of this heat. For suspension firing of both oil and coal the answer is the same: fuel must be broken up into many small particles to expose as much surface as possible. With oil, atomization is obtained in a variety of ways by the burner. With coal, the pulverization is handled in a separate unit, the burner merely mixing the finely ground particles with air and injecting them into the furnace.

**Q** What three requirements are needed for the proper chemical reaction to take place in combustion?

**A** 1. Proper proportioning of fuel and oxygen (or air) with the fuel elements as shown by chemical equations.

2. Thorough mixing of fuel and oxygen (or air) so a uniform mixture is present in the combustion zone and so every fuel particle has air around it to support the combustion. Solid fuels will generally be converted to gas first by the heat and presence of air. Liquid fuels will vaporize into gases and then burn. Atomization of liquids increases the mixing with air and increases the vaporization into a gas. Pulverization of coal will have the same effect.

3. The ignition temperature must be established and monitored so that the fuel will continue to ignite itself without external heat when combustion starts.

**Q** What are the chief heat-producing elements in solid, liquid, or gaseous fuels?

**A** The chief heat-producing elements in fuels (except for atomic reaction and electricity) are carbon, hydrogen, and their compounds. Sulfur, when rapidly oxidized, is also a source of some heat energy, but its presence in a fuel has bad effects. The burning of coal, oil, or gas is a chemical reaction involving the fuel and oxygen from the air. Air is 23 percent oxygen by weight and 21 percent by volume. The remainder of air is mostly nitrogen, which takes no actual chemical part in combustion but does affect the volume of air required. The table in Fig. 10-23 represents some typical combustion reactions for various fuel constituents.

NOTE: It is always the carbon, hydrogen, or sulfur that produces the chemical reaction for heat by combining with oxygen.

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| Combustible element | Symbol | Chemical reaction | Combustion product | Volumes | Weights/lb of combustible: Oxygen, lb | Nitrogen, lb | Air, lb | Gaseous products, lb | Heating value, Btu/lb |
|---|---|---|---|---|---|---|---|---|---|
| Carbon.......... | C | $C + O_2 \rightarrow CO_2$ | Carbon dioxide | 1 vol C + 1 vol $O_2$ = 1 vol $CO_2$ | 2.67 | 8.85 | 11.52 | 12.52 | 14,600 |
| Carbon.......... | C | $2C + O_2 \rightarrow 2CO$ | Carbon monoxide | 2 vol C + 1 vol $O_2$ = 2 vol CO | 1.33 | 4.43 | 5.76 | 6.76 | 4,440 |
| Carbon monoxide. | CO | $2CO + O_2 \rightarrow 2CO_2$ | Carbon dioxide | 2 vol CO + 1 vol $O_2$ = 2 $CO_2$ | 0.57 | 1.90 | 2.47 | 3.47 | 10,160 |
| Hydrogen........ | H | $2H_2 + O_2 \rightarrow 2H_2O$ | Water | 2 vol $H_2$ + 1 vol $O_2$ = 2 vol $H_2O$ | 8 | 26.56 | 34.56 | 35.56 | 62,000 |
| Methane......... | $CH_4$ | $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ | Carbon dioxide and water | 1 vol $CH_4$ & 2 vol $CO_2$ = 1 vol $CO_2$ + 2 vol $H_2O$ | 4 | 13.28 | 17.28 | 18.28 | 23,850 |
| Ethylene......... | $C_2H_4$ | $C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$ | Carbon dioxide and water | 1 vol $C_2H_4$ + 3 vol $O_2$ = 2 vol $CO_2$ + 2 vol $H_2O$ | 3.43 | 11.38 | 14.81 | 15.81 | 21,600 |
| Ethane........... | $C_2H_6$ | $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$ | Carbon dioxide and water | 2 vol $C_2H_6$ + 7 vol $O_2$ = 4 vol $CO_2$ + 6 vol $H_2O$ | 3.73 | 12.40 | 16.13 | 17.13 | 22,230 |
| Sulfur........... | S | $S + O_2 \rightarrow SO_2$ | Sulfur dioxide | 1 vol S + 1 vol $O_2$ = 1 vol $SO_2$ | 1 | 3.32 | 4.32 | 5.32 | 4,050 |

Fig. 10-23. Combustion data needed for burning fuel efficiently.

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**A** When flue gas comes out of a stack as black smoke, it is an indication of insufficient air. Too much air usually causes a dense, white smoke. A faint, light-brown haze coming from the stack is a sign of a reasonably good air/fuel ratio. Of course a more exact analysis is made with a flue-gas analyzer, such as an Orsat apparatus. From this analysis, the percentage of either excess or insufficient air can be determined.

**Q** What does a flue-gas analyzer measure?

**A** It measures the percentages of volume of carbon dioxide, carbon monoxide, and oxygen. Because air contains 21 percent oxygen and 79 percent nitrogen by volume and because nitrogen goes through a combustion process unchanged, the maximum percentage of $CO_2$ in flue gases that is possible (discounting nitrogen) is 21 percent. And since one volume of carbon combining with one volume of oxygen produces one volume of carbon dioxide, any unburned oxygen (excess) will reduce the percentage of carbon dioxide in the flue gas.

EXAMPLE: 1. If there is no excess air, the flue-gas analysis will be

| | |
|---|---|
| Carbon dioxide | 21% |
| Oxygen | 0 |
| Nitrogen | 79 |
| Total | 100% |

2. If there is excess air of 100 percent

| | |
|---|---|
| Carbon dioxide | 10.5% |
| Oxygen | 10.5 |
| Nitrogen | 79.0 |
| Total | 100.0% |

NOTE: The 21 percent maximum possible is now split evenly between oxygen and carbon dioxide at 10.5 percent each (100 percent excess air).

3. If there is excess air of 50 percent

| | |
|---|---|
| Carbon dioxide | 14% |
| Oxygen | 7 |
| Nitrogen | 79 |
| Total | 100% |

In this case, carbon dioxide and oxygen percentages still add up to 21 percent, but the oxygen is 50 percent of the carbon dioxide (50 percent excess air). It is also possible to calculate the amount of air used per pound of fuel from the flue gas analysis.

**Q** Why is a high percentage of $CO_2$ in boiler flue gas efficient?

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**A** A high percentage of $CO_2$ in boiler flue gas is a good thing, within limits, and not because of perfect combustion. While carbon, completely burned, turns to $CO_2$, this does not mean that a high percentage of $CO_2$ indicates complete combustion. Actually, combustion can be complete with 6 percent $CO_2$ and incomplete with 15 percent. So what is wrong with a low percentage of $CO_2$? A low percentage of $CO_2$ is proof that the flue gas is heavily diluted with excess air. Since this excess air goes to waste up the stack at a fairly high temperature, it is a great loss in efficiency (heating the sky).

As an illustration, let us start with 100 cu ft of air. That is the amount theoretically needed to burn ⅓ lb of carbon, our fuel supply for this example. Of the 21 percent oxygen by volume in air, only the oxygen burns with the coal. The remaining 79 percent is nitrogen and goes along for a free ride. And when oxygen burns with carbon, the volume of $CO_2$ produced (figured back to room temperature) equals the volume of oxygen consumed.

**Q** What are the usual percentages of excess air in burning the various common fuels in boilers?

**A** For coal, usually 50 percent excess air is used. With oil, gas, or pulverized coal, excess air is 10 to 30 percent.

**Q** Illustrate and explain a typical Orsat flue-gas analyzer.

**A** The Orsat (Fig. 10-25) is a portable flue-gas analyzer. The leveling bottle and measuring burette contain pure water. The first pipette, A, is packed with steel wool, kept wet with caustic-potash solution from the container below. The steel wool in pipette B is wet with pyrogallic solution from the lower container. The third pipette C contains copper strips wet with cuprous (copper) chloride solution. Pipettes *A*, *B*, and *C* are for the absorption of $CO_2$, $O_2$, and CO. But other chemicals than those indicated are sometimes used for these absorptions.

The Orsat is connected to the sampling tube by rubber tubing in series with an aspirator rubber bulb to pump the gas. The gas line connects to the back side of the three-way cock that has three positions for these purposes: (1) to connect the sampling tube to the measuring burette, (2) to connect the burette to the atmosphere, and (3) to connect the sampling tube to the atmosphere.

**Q** Explain how a flue-gas analysis is made with an Orsat.

**A** Always study the instructions given with your instrument. Here are the main steps to use for this one (Fig. 10-26):

*Step 1.* With the hand aspirator, pump gas through the measuring burette. Gas bubbles out of the measuring bottle as shown. Keep pumping to displace all air.

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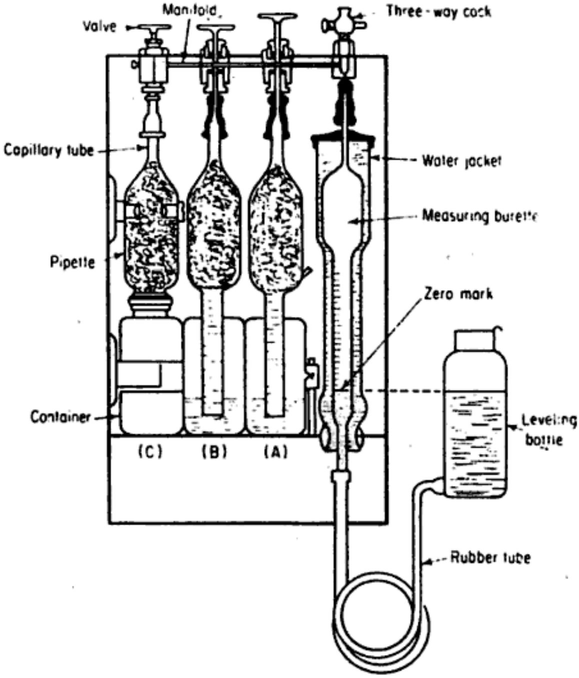


**Fig. 10-25. Orsat flue-gas analyzer.**

*Step* 2. Set three-way cock to connect the burette to the atmosphere as the leveling bottle is slowly raised until water is at the zero mark near the bottom of the burette. As this is level with the water in the bottle, the sample is measured at atmospheric pressure. (All gas measurements must be made with the water level the same in the burette as in the leveling bottle.)

*Step* 3. Lift the bottle high to absorb the $CO_2$ after closing the three-way cock. Open the valve to the $CO_2$ pipette, so that the gas displaces the liquid and contacts the caustic solution on the steel wool, which absorbs $CO_2$. Pinch the tube to check the flow when water rises to the mark in the capillary tube above the burette. Allow a few seconds for $CO_2$ absorption.

*Step* 4. With the tube pinched, lower the bottle. Then release the rubber tube slowly until the liquid rises exactly to the mark in the capillary tube on top of the pipette. After closing the pipette valve, raise or

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**Q** Can the weight of *flue gas* $W_{fg}$ be obtained per pound of fuel fired from a flue-gas analysis?

**A** Yes, use the equation

$$W_{fg} = \frac{4CO_2 + O_2 + 700}{3\,(CO_2 + CO)} \left[ \frac{W_f C_f - W_r C_r}{W_f \times 100} \right] .$$

also use the same symbols as in the previous equation.

EXAMPLE: The same coal is being burned with the same analysis as shown in the previous problem.

Substituting

$$W_{fg} = \frac{4\,(11.9) + 7.3 + 700}{3\,(11.9 + 1.0)} \left[ \frac{700\,(68) - 60\,(7.8)}{700 \times 100} \right]$$
$$= 20.06\,[0.68]$$
$$= 13.6 \text{ lb flue gas per pound of fuel fired}$$

or

$$13.6 \times 700 = 9{,}520 \text{ lb of flue gas for 700 lb of coal}$$

**Q** Can the amount of heat lost by flue gases be calculated?

**A** Yes, by using the specific heat (Btu per pound per degree temperature rise for a gas), it is possible to calculate the heat lost up the stack. Use the equation

$$H_L = W\,C_p\,(T_2 - T_1)$$

where $H_L$ = heat lost by flue gas
$W$ = weight of flue gas going up the stack, usually lb/hr
$C_p$ = mean specific heat of flue gas; can be taken as approximately 0.25 Btu/lb (°F)
$T_2$ = stack temperature, °F
$T_1$ = temperature of air entering furnace, °F

EXAMPLE: Assume that in the previous problem, 9,520 lb of flue gas per hour went up the stack. The stack temperature is 650°F and the air inlet temperature is 80°F. Then the heat lost up the stack is

$$H_L = 9520\,(0.25)\,(650 - 80)$$
$$= 1{,}356{,}600 \text{ Btu/hr}$$

Since 700 lb of coal was fired, with an assumed average of 14,500 Btu/lb, the total energy input is

$$700 \times 14{,}500 = 10{,}150{,}000 \text{ Btu/hr}$$

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The percent of heat input going up the stack is then

$$\frac{1,356,600}{10,150,000} = 13.4\% \qquad \textit{Ans.}$$

This indicates a boiler efficiency of 100 − 13.4 = 86.6%

**Q** Explain the use of charts showing excess air, $CO_2$ percentage, and heat-loss percentages.

**A** Charts are only for broad answers and are approximate percentages. See Fig. 10-27 to solve the following: What is the percentage of stack loss in hot gases for a bituminous coal if the stack-gas temperature is 580°F, the room temperature is 80°F, and the $CO_2$ in the flue gas is 14.2 percent?

First, a given $CO_2$ analysis means there is one specific percentage of excess air when burning anthracite coal, less for bituminous coal, and still less for fuel oil. For 12 percent $CO_2$, Fig. 10-27*a* shows 61 percent excess air for anthracite, 53 percent for bituminous, and 24 percent for fuel oil. The actual stack loss in the hot gases depends on both the excess air and the stack temperature.

The scale on this chart for bituminous coal shows that the excess air is 30 percent for 14.2 percent $CO_2$. The temperature rise is the stack temperature minus the room temperature, or 580°F − 80°F = 500°F. Now to find the loss from the chart in Fig. 10-27*b*.

Run a straightedge from 500 on the left scale through 30 on the center scale (dotted line). It cuts the right scale at 12.2 percent. This means that 12.2 percent of the coal's heat is wasted in heating the sky.

**Q** How does the furnace provide for proper combustion?

**A** For fuel to be burned efficiently, the furnace must have adequate combustion space to ensure a thorough mixing of air and fuel. The furnace must also maintain a high enough temperature for complete combustion. The furnace must be tight so that air cannot leak into, or out of, the casing and thus affect the air/fuel ratio. Too high a furnace temperature must also be avoided, as this can lead to rapid deterioration of linings (if installed), or possible overheating of vital pressure parts such as tubes or combustion furnaces in scotch marine boilers. Also, the reaction of combustion should be completed before the flue gases leave the combustion chamber so as to avoid flame impingement on tubes and possible overheating.

**Q** What causes soot and smoke?

**A** With either coal or oil, some carbon formerly associated in hydrocarbon compounds breaks away as free carbon. Thus we always have the problem of burning carbon particles, which proves difficult even when

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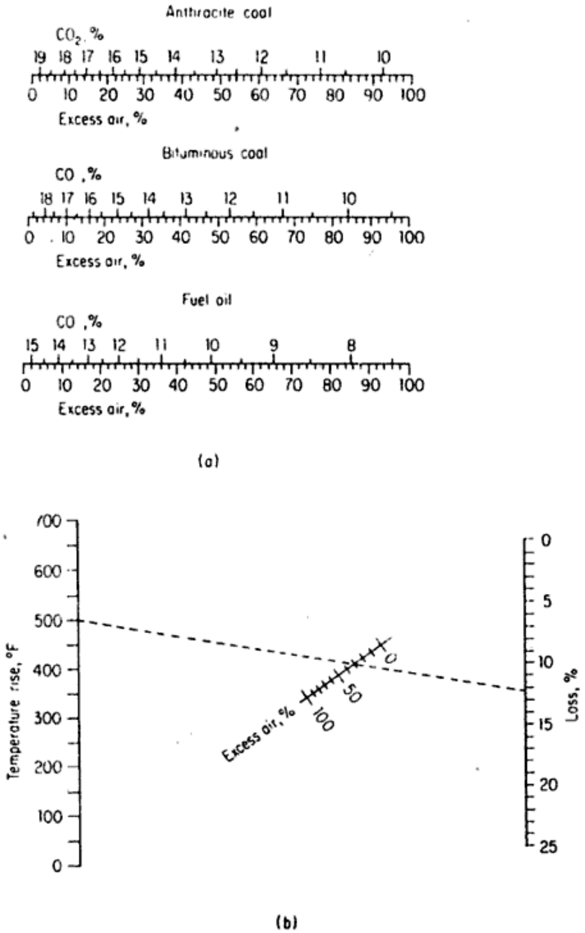


**Fig. 10-27. (a) For any values of $CO_2$, these scales give corresponding values in percentage of excess air involved. (b) For hard and soft coal and for fuel oil this chart gives percentages of fuel's heat wasted in hot flue gas.**

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they have ample time to pass through the furnace. Incomplete combustion of carbon is the germ of smoke and soot. If the furnace is small and the relatively cold areas (boiler tubes and other heating surfaces) are badly located, carbon cannot possibly burn to completion. So all these steps, bringing air and fuel together, raising the mixture to ignition temperature, sweeping away successive layers of gas from fuel particles, and burning carbon as far as possible, occur while the fuel and air travel from burner to furnace outlet. But this is an extremely short time, thus complete combustion also depends on the distance traveled, the speed, and whether or not the flow is turbulent.

**Q** What are primary and secondary air in combustion of fuels in a boiler?

**A** See Fig. 10-28. Primary air is the air mixed with the fuel at or in the burner. Secondary air is air usually brought in around the burner or through the openings in a furnace wall or floor. The primary air ensures instant combustion as the fuel enters the furnace. The secondary air provides the oxygen to complete the combustion in the furnace.

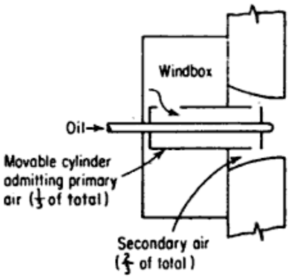


**Fig. 10-28. Primary and secondary air for oil-burning furnace.**

**Q** What is the harmful effect of sulfur in a fuel?

**A** Sulfur burns to sulfur dioxide, which when mixed with water or water vapor, forms sulfurous acid which is corrosive to tubes, breechings, and economizer sections on larger boilers. The dew point (temperature at which water vapor condenses) of the flue gas has to be watched (especially with high-sulfur-content fuel) as the gas becomes cooler and cooler while going through a furnace, so as to prevent the combination of water vapor with sulfur dioxide. Recent air pollution laws are tough on high-sulfur-content fuels, because sulfur dioxide is known to pollute the air. Percentages of permissible sulfur content in fuels are slowly being lowered from the previous 4 percent maximum to 1 percent in the near future.

Sulfur in oil-fired boilers leads to fireside corrosion of tubes, especially in those boilers cycling on and off. In cooling on the off-cycle, the sulfur dioxide combines with water vapor and with water from leaks to attack the tubes by means of the resultant acid formed.

**Q** What are ash and slag? What problems do they cause?

**A** Ash and slag are impurities that do not burn to a gas and usually

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trouble coal-fired boilers. The solid particles at high velocity are carried through the boiler with gas in suspension. The general term *flyash* is used for this slag and ash. Ash and slag can be very abrasive to tube sections if flow distribution is concentrated in the convection passages of a boiler.

**Q** What function does draft play in the combustion of fuel?

**A** Draft provides the differential pressure in a furnace to ensure the flow of gases. Without draft, stagnation in the burning process would result, and the fire or process of combustion would die from lack of air. Draft pushes or pulls air and the resultant flue gas through a boiler and up into the stack. The draft overcomes the resistance to flow of the tubes, furnace walls, baffles, dampers, and the chimney lining (also slag).

Natural draft is produced by a chimney into which the boiler exhausts. The cool air admitted to a furnace (by means of damper openings) rushes in to displace the lighter hot gases in the furnace. Thus the hot gases rise (chimney effect), causing a natural draft.

Mechanical draft is produced artificially by means of forced- or induced-draft fans. The chimney is still necessary on mechanical draft installations for venting the products of combustion high enough not to be offensive to the surroundings. Most modern boilers, including the domestic type, use some form of mechanical draft. Domestic burners may have a fan built into the burner unit.

**Q** How does a forced-draft fan differ from an induced-draft fan?

**A** A forced-draft fan pushes, or forces, air into the furnace, usually at a pressure higher than atmospheric pressure, whereas an induced-draft fan draws the air out of the furnace by creating a partial vacuum on the suction side of the fan. The blades of induced-draft fans are prone to rapid wear because they have to handle hot, corrosive gases, possibly hot unburned cinders or flyash. Thus they require periodic cleaning and dynamic balancing to prevent excessive vibration.

**Q** What is meant by balanced draft?

**A** A boiler using both forced-draft fans and induced-draft fans can be regulated and balanced in the amount of air and flue gas handled so that furnace pressure is almost atmospheric. This results in better control of air leakage from the furnace and thus control of the fuel/air ratio in the furnace.

**Q** How is draft *measured*?

**A** Air and gas under flow conditions are measured in *inches of water* (balanced by air or gas pressure) usually with a U tube (manometer). One side of the tube is connected to the chimney or furnace. The other side is open to the atmosphere. Thus the difference in the water level in the two columns indicates the inches of water, which is a measure of

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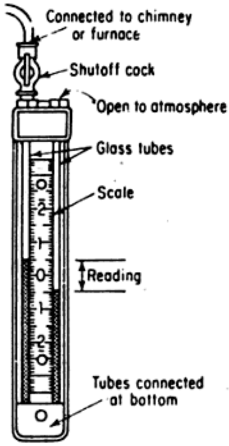


**Fig. 10-29. U tube draft gage.**

the difference in pressure (Fig. 10-29). If the furnace pressure is greater than atmospheric, the water in the column connected to the furnace will be pushed down, and on the column connected to the atmosphere, the water will rise the same amount. If the pressure is less than atmospheric, the reverse will take place.

**Q** Convert 3 in. of draft into pounds per square inch or into ounces per square in.

**A** Since water at normal temperature weighs 62.4 lb per cu ft, dividing this by the number of cubic inches in a cubic foot gives

$$\frac{62.4}{1{,}728} = 0.036 \text{ psi per cu in. of water}$$

Thus for 3 in., pressure = 3 × 0.036 = 0.108 psi. And since there are 16 oz in a pound, the ounces per square inch = 0.108 × 16 = 1.73 oz pressure per square inch. *Ans.*

**Q** Explain the term *heating value of fuel.*

**A** The heat liberated by the complete and rapid burning of a fuel per unit weight or volume of the fuel is the heating, or calorific, value of the fuel. For solid and liquid fuels, this is usually expressed in Btu per pound. For gaseous fuels, it is expressed in Btu per cubic foot at a standard temperature and pressure, usually atmospheric pressure at 68°F.

**Q** What is meant by the higher and lower heating values of a fuel?

**A** Fuels which contain hydrogen have two heating values, higher and lower. The reason for this is that the burning of hydrogen produces superheated water vapor, which escapes at the temperature of the chimney gases. The lower heating value is the net heat liberated per pound of fuel after the heat necessary to vaporize and superheat the steam formed

| Gas | Symbol | Heating value, Btu/cu ft | |
|---|---|---|---|
| | | Higher | Lower |
| Carbon monoxide | $CO$ | 318 | 318 |
| Hydrogen | $H_2$ | 320 | 269 |
| Methane | $CH_4$ | 985 | 886 |
| Ethylene | $C_2H_4$ | 1551 | 1451 |
| Ethane | $C_2H_6$ | 1721 | 1571 |

**Fig. 10-30. Higher and lower heating values of typical fuels.**

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from the hydrogen (and from the fuel) has been deducted. The higher heating value is the one indicated by a fuel calorimeter and is usually used in engineering work. See Fig. 10-30.

A fuel calorimeter is a meter (also called oxygen bomb) to determine the heating value of 1 lb of fuel by burning a sample of the fuel under controlled conditions.

**Q** Can the heating value of a fuel be determined by calculations?
**A** Yes, but the following must first be established. We know that the main combustible elements in a fuel are carbon, hydrogen, and sulfur, which combine with oxygen. When each is burned separately, the following heating values are obtained for 1 lb of the element: carbon, 14,600 Btu; hydrogen, 62,000 Btu; sulfur, 4050 Btu.

The heating value of 1 lb of fuel can be calculated by Dulong's formula:

$$HV = 14{,}000C + 62{,}000\left(H - \frac{O}{8}\right) + 4{,}050S$$

where $HV$ = heating value, Btu/lb of fuel
$C$ = weight of carbon per lb of fuel
$H$ = weight of hydrogen per lb of fuel
$O$ = weight of oxygen per lb of fuel
$S$ = weight of sulfur per lb of fuel

EXAMPLE: An ultimate analysis of a coal shows the following percentages:

Carbon 82% = 0.82 lb per lb of coal
Hydrogen 4.5% = 0.045 lb per lb of coal
Oxygen 2.2% = 0.022 lb per lb of coal
Sulfur 1.8% = 0.018 lb per lb of coal
Ash 9.5% = 0.095 lb per lb of coal

Substituting

$$HV = 14{,}600\ (0.82) + 62{,}000\left(0.045 - \frac{0.022}{8}\right) + 4{,}050\ (0.018)$$

$$= 11{,}972 + 2635 + 729$$
$$= 15{,}336\ \text{Btu/lb}$$

**Q** Illustrate some common heating values of fuels.
**A** The ASME Power Boiler Code permits the values shown in Fig. 10-31 to be used in calculating sv capacities where the exact heating value of the fuel is not known. $H$ is the heating value.

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| | H = Btu/lb |
|---|---|
| Semibituminous coal | 14,500 |
| Anthracite | 13,700 |
| Screenings | 12,500 |
| Coke | 13,500 |
| Wood, hard or soft, kiln dried | 7700 |
| Wood, hard or soft, air dried | 6200 |
| Wood shavings | 6400 |
| Peat, air dried, 25% moisture | 7500 |
| Lignite | 10,000 |
| Kerosene | 20,000 |
| Petroleum, crude oil, Pennsylvania | 20,700 |
| Petroleum, crude oil, Texas | 18,500 |
| | H = Btu/cu ft |
| Natural gas | 960 |
| Blast-furnace gas | 100 |
| Producer gas | 150 |
| Water gas, uncarbureted | 290 |

**Fig. 10-31. Heating values of fuel for safety valve capacities allowed by ASME.**

**Q** Explain how steam properties may be used for calculating boiler efficiencies.

**A** A book of steam tables is necessary for computing boiler efficiency. The standard in America is *Thermodynamic Properties of Steam* by Keenan and Keyes, published by John Wiley & Sons Inc., New York. For data based on temperature, use Table 1 in Fig. 10-32. Use Table 2 if you know the pressure. All pressures in these tables are absolute. To get absolute pressure, just add 14.7 psi to the gage pressure (15 psi is close enough).

For properties of superheated steam, use Table 3 in Fig. 10-32. This table of superheated steam must be entered with the absolute pressure (gage pressure plus 15) and with the *total* steam temperature, not the degrees of superheat. This total temperature is the saturation temperature (also given in the table) plus the degrees of superheat.

**Q** Explain *enthalpy.*

**A** At one time, the expressions *heat in the water,* and *heat in the vapor* were used for the modern term *enthalpy.* Thus enthalpy means the heat content of the fluid. In dealing with water and steam, three enthalpies are to be noted as follows:

1. Enthalpy of saturated liquid (Btu), which is the heat content of the water at a certain pressure and temperature under consideration.

2. Enthalpy of evaporation (Btu), which is the heat required to evaporate 1 lb of water to steam at that pressure and temperature.

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**Table 1. Saturation, Temperatures**

| Temp, °F | Abs press, psi | Specific vol | | Enthalpy (heat) | | |
|---|---|---|---|---|---|---|
| | | Sat liquid | Sat vapor | Sat liquid | Evap | Sat vapor |
| 32 | 0.08859 | 0.01602 | 3304.7 | 0.01 | 1075.5 | 1075.5 |
| 40 | 0.12170 | 0.01602 | 2444 | 8.05 | 1071.3 | 1079.3 |
| 50 | 0.17811 | 0.01603 | 1703.2 | 18.07 | 1065.6 | 1083.7 |
| 60 | 0.2563 | 0.01604 | 1206.7 | 28.06 | 1059.9 | 1088.0 |
| 70 | 0.3631 | 0.01606 | 867.9 | 38.04 | 1054.3 | 1092.3 |
| 80 | 0.5069 | 0.01608 | 633.1 | 43.02 | 1048.6 | 1096.6 |
| 90 | 0.6982 | 0.01610 | 468.0 | 57.99 | 1042.9 | 1100.9 |
| 100 | 0.9492 | 0.01613 | 350.4 | 67.97 | 1037.2 | 1105.2 |
| 110 | 1.2748 | 0.01617 | 265.4 | 77.94 | 1031.6 | 1109.5 |
| 120 | 1.6924 | 0.01620 | 203.27 | 87.92 | 1025.8 | 1113.7 |
| 130 | 2.2225 | 0.01625 | 157.34 | 97.90 | 1020.0 | 1117.9 |
| 140 | 2.8886 | 0.01629 | 123.01 | 107.9 | 1014.1 | 1122.0 |
| 150 | 3.718 | 0.01634 | 97.07 | 117.9 | 1008.2 | 1126.1 |
| 160 | 4.741 | 0.01639 | 77.29 | 127.9 | 1002.3 | 1130.2 |
| 170 | 5.992 | 0.01645 | 62.06 | 137.9 | 996.3 | 1134.2 |
| 180 | 7.510 | 0.01651 | 50.23 | 147.9 | 990.2 | 1138.1 |
| 190 | 9.339 | 0.01657 | 40.96 | 157.9 | 984.1 | 1142.0 |
| 200 | 11.526 | 0.01663 | 33.64 | 168.0 | 977.9 | 1145.9 |
| 212 | 14.696 | 0.01672 | 26.80 | 180.0 | 970.4 | 1150.4 |
| 220 | 17.186 | 0.01677 | 23.15 | 188.1 | 965.2 | 1153.4 |
| 240 | 24.969 | 0.01692 | 16.323 | 208.3 | 952.2 | 1160.5 |
| 280 | 49.203 | 0.01726 | 8.645 | 249.1 | 924.7 | 1173.8 |
| 300 | 67.013 | 0.01745 | 6.466 | 269.6 | 910.1 | 1179.7 |
| 340 | 118.01 | 0.01787 | 3.788 | 311.1 | 879.0 | 1190.1 |
| 380 | 195.77 | 0.01836 | 2.335 | 353.5 | 844.6 | 1198.1 |
| 400 | 247.31 | 0.01864 | 1.8633 | 375.0 | 826.0 | 1201.0 |

**Table 2. Saturation, Pressures**

| Abs press, psi | Temp, F | Specific vol | | Enthalpy (heat) | | |
|---|---|---|---|---|---|---|
| | | Sat liquid | Sat vapor | Sat liquid | Evap | Sat vapor |
| 0.50 | 79.58 | 0.01608 | 641.4 | 47.6 | 1048.8 | 1096.4 |
| 1.0 | 101.74 | 0.01614 | 333.6 | 69.7 | 1036.3 | 1106.0 |
| 5.0 | 162.24 | 0.01640 | 73.52 | 130.1 | 1001.0 | 1131.1 |
| 10 | 193.21 | 0.01659 | 38.42 | 161.2 | 982.1 | 1143.3 |
| 14.7 | 212.00 | 0.01672 | 26.80 | 180.0 | 970.4 | 1150.4 |
| 15 | 213.03 | 0.01672 | 26.29 | 181.1 | 969.7 | 1150.8 |
| 20 | 227.96 | 0.01683 | 20.089 | 196.2 | 960.1 | 1156.3 |
| 25 | 240.07 | 0.01692 | 16.303 | 208.5 | 952.1 | 1160.6 |
| 30 | 250.33 | 0.01701 | 13.746 | 218.8 | 945.3 | 1164.1 |
| 40 | 267.25 | 0.01715 | 10.498 | 236.0 | 933.7 | 1169.7 |
| 50 | 281.01 | 0.01727 | 8.515 | 250.1 | 924.0 | 1174.1 |
| 60 | 292.71 | 0.01738 | 7.175 | 262.1 | 915.5 | 1177.6 |
| 70 | 302.92 | 0.01748 | 6.206 | 272.6 | 907.9 | 1180.6 |
| 80 | 312.03 | 0.01757 | 5.472 | 282.0 | 901.1 | 1183.1 |
| 90 | 320.27 | 0.01766 | 4.896 | 290.6 | 894.7 | 1185.3 |
| 100 | 327.81 | 0.01774 | 4.432 | 298.4 | 888.8 | 1187.2 |
| 110 | 334.77 | 0.01782 | 4.049 | 305.7 | 883.2 | 1188.9 |
| 120 | 341.25 | 0.01789 | 3.728 | 312.4 | 877.9 | 1190.4 |
| 130 | 347.32 | 0.01796 | 3.455 | 318.8 | 872.9 | 1191.7 |
| 140 | 353.02 | 0.01802 | 3.220 | 324.8 | 868.2 | 1193.0 |
| 150 | 358.42 | 0.01809 | 3.015 | 330.5 | 863.6 | 1194.1 |
| 200 | 381.79 | 0.01839 | 2.288 | 355.4 | 843.0 | 1198.4 |
| 250 | 400.95 | 0.01865 | 1.8438 | 376.0 | 825.1 | 1201.1 |
| 300 | 417.33 | 0.01890 | 1.5433 | 393.8 | 809.0 | 1202.8 |
| 350 | 431.72 | 0.01913 | 1.3260 | 409.7 | 794.2 | 1203.9 |
| 400 | 444.59 | 0.0193 | 1.1613 | 424.0 | 780.5 | 1204.5 |

Fig 10-32. Use Table 1 for data based on temperature, Table 2 for data based on pressure, Table 3 for superheated steam.

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| Abs pressure, psi (sat temp) | * | Sat liquid | Sat vapor | Temperature, °F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 15 | v | 0.016 | 26.29 | 29.91 | 33.97 | 37.99 | 41.99 | 45.98 | 49.97 | 53.95 | 57.93 |
| (213.03) | h | 181.1 | 1150.8 | 1192.8 | 1239.9 | 1287.1 | 1334.8 | 1383.1 | 1432.3 | 1482.3 | 1533.1 |
| 20 | v | 0.016 | 20.09 | 22.36 | 25.43 | 28.46 | 31.47 | 34.47 | 37.46 | 40.45 | 43.44 |
| (227.96) | h | 196.2 | 1156.3 | 1191.6 | 1239.2 | 1286.6 | 1334.4 | 1382.9 | 1432.1 | 1482.1 | 1533.0 |
| 40 | v | 0.017 | 10.498 | 11.040 | 12.628 | 14.168 | 15.688 | 17.198 | 18.702 | 20.20 | 21.70 |
| (267.25) | h | 236.0 | 1169.7 | 1186.8 | 1236.5 | 1284.8 | 1333.1 | 1381.9 | 1431.3 | 1481.4 | 1532.4 |
| 60 | v | 0.017 | 7.175 | 7.259 | 8.357 | 9.403 | 10.427 | 11.441 | 12.449 | 13.452 | 14.454 |
| (292.71) | h | 262.1 | 1177.6 | 1181.6 | 1233.6 | 1283.0 | 1331.8 | 1380.9 | 1430.5 | 1480.8 | 1531.9 |
| 80 | v | 0.018 | 5.472 | ... | 6.220 | 7.020 | 7.797 | 8.562 | 9.322 | 10.077 | 10.830 |
| (312.03) | h | ... | 282.10 | 1183.1 | 1230.7 | 1281.1 | 1330.5 | 1379.9 | 1429.7 | 1480.1 | 1531.3 |
| 100 | v | 0.018 | 4.432 | ... | 4.937 | 5.589 | 6.218 | 6.835 | 7.446 | 8.052 | 8.656 |
| (327.81) | h | 298.4 | 1187.2 | ... | 1227.6 | 1279.1 | 1329.1 | 1378.9 | 1428.9 | 1479.5 | 1530.8 |
| 150 | v | 0.018 | 3.015 | ... | 3.223 | 3.681 | 4.113 | 4.532 | 4.944 | 5.352 | 5.758 |
| (358.42) | h | 330.5 | 1194.1 | ... | 1219.4 | 1274.1 | 1325.7 | 1376.3 | 1426.9 | 1477.8 | 1529.4 |
| 200 | v | 0.018 | 2.288 | ... | 2.361 | 2.726 | 3.060 | 3.380 | 3.693 | 4.002 | 4.309 |
| (381.79) | h | 355.4 | 1198.4 | ... | 1210.3 | 1268.9 | 1322.1 | 1373.6 | 1424.8 | 1476.2 | 1528.0 |
| 300 | v | 0.0189 | 1.5433 | ... | | 1.7675 | 2.005 | 2.227 | 2.442 | 2.652 | 2.859 |
| (417.33) | h | 393.8 | 1202.8 | ... | | 1257.6 | 1314.7 | 1368.3 | 1420.6 | 1472.8 | 1525.2 |
| 400 | v | 0.0193 | 1.1613 | ... | ... | 1.2851 | 1.4770 | 1.6508 | 1.8161 | 1.9767 | 2.134 |
| (444.59) | h | 424.0 | 1204.5 | ... | ... | 1245.1 | 1306.9 | 1362.7 | 1416.4 | 1469.4 | 1522.4 |
| 500 | v | 0.0197 | 0.9278 | ... | ... | 0.9927 | 1.1591 | 1.3044 | 1.4405 | 1.5715 | 1.6996 |
| (467.01) | h | 449.4 | 1204.4 | ... | ... | 1231.3 | 1298.6 | 1357.0 | 1412.1 | 1466.0 | 1519.6 |
| 600 | v | 0.0201 | 0.7698 | ... | ... | 0.7947 | 0.9463 | 1.0732 | 1.1899 | 1.3013 | 1.4096 |
| (486.21) | h | 471.6 | 1203.2 | ... | ... | 1215.7 | 1289.9 | 1351.1 | 1407.7 | 1462.5 | 1516.7 |
| 800 | v | 0.0209 | 0.5687 | ... | ... | ... | 0.6779 | 0.7833 | 0.8763 | 0.9633 | 1.0470 |
| (518.23) | h | 509.7 | 1198.6 | ... | ... | ... | 1270.7 | 1338.6 | 1398.6 | 1455.4 | 1511.0 |
| 1000 | v | 0.0216 | 0.4456 | ... | ... | ... | 0.5140 | 0.6084 | 0.6878 | 0.7604 | 0.8294 |
| (544.61) | h | 542.4 | 1191.8 | ... | ... | ... | 1248.8 | 1325.3 | 1389.2 | 1448.2 | 1505.1 |
| 1200 | v | 0.0223 | 0.3619 | ... | ... | ... | 0.4016 | 0.4909 | 0.5617 | 0.6250 | 0.6843 |
| (567.22) | h | 571.7 | 1183.4 | ... | ... | ... | 1223.5 | 1311.0 | 1379.3 | 1440.7 | 1499.2 |
| 1400 | v | 0.0231 | 0.3012 | ... | ... | ... | 0.3174 | 0.4062 | 0.4714 | 0.5281 | 0.5805 |
| (587.10) | h | 598.7 | 1173.4 | ... | ... | ... | 1193.0 | 1295.5 | 1369.1 | 1433.1 | 1493.2 |

Table 3. Superheated Steam

* V = specific volume, cu ft/lb; h = enthalpy, Btu/lb.

**Fig. 10-32 (*Continued*). Use Table 1 for data based on temperature, Table 2 for data based on pressure, Table 3 for superheated steam.**



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water temperature is 180°F. Table 1 in Fig. 10-32 shows that the heat in the water is 148 Btu. Then the heat supplied to turn this water into steam is merely the difference, or 1194 − 148 = 1046 Btu.

It is easy from this to figure the boiler efficiency. Let us say the boiler generates 10 lb steam per pound of coal burned and the coal contains 13,000 Btu per lb. Then, for every 13,000 Btu put in as fuel, there is delivered in steam 10 × 1046 = 10,460 Btu.

The efficiency of any power unit is its output divided by its input, so here 10,460 ÷ 13,000 = 0.805, or 80.5 percent efficiency. *Ans.*

For most purposes Table 1 in Fig. 10-32 is not needed to get a close value of the heat of the liquid. Just subtract 32 from the water temperature. For example, the enthalpy of water at 180°F is the heat required to raise it from 32 to 180°F, or a difference of 148°F. This takes about 148 Btu. But it will not work out so closely for very high temperatures. Take water at 300°F. Table 1 in Fig. 10-32 gives 269.7 Btu, while our simple method gives 300 − 32 = 268 Btu, close enough for most purposes.

Below 212°F the rule is extremely accurate, never out by more than 1/10 Btu. Just remember that condensing of steam in a condenser, heater, radiator, or process is nothing but heating the evaporation, worked backward.

**Q** Explain how to use the steam tables for superheated steam.

**A** The first column of Table 3 in Fig. 10-32 gives the absolute pressure and (directly below it in parentheses) the corresponding saturation temperature, or boiling temperature. In the next column *v* and *h* stand for volume of 1 lb and its heat content. For example, at 150 psia the volume of 1 lb is 0.018 cu ft for liquid water and 3.015 cu ft for the saturated steam. The corresponding heat contents of 1 lb are 330.5 Btu and 1194.1 Btu.

The temperature columns give the volume and heat content per pound for superheated steam at the indicated temperature. Take steam at 150 psi, superheated to a total temperature of 600°F. Look in the 600°F column opposite 150 psi. The volume is 4.113 cu ft, as against 3.015 cu ft for saturated steam at the same pressure. This is natural because steam expands like a gas when superheated. Also, the heat content is naturally higher, 1325.7 Btu instead of 1194.1 Btu. Note that this table gives the actual temperature of the superheated steam rather than the degrees of superheat, which is a different thing. If the steam has been superheated from a saturation temperature of 358 to 600°F, the superheat is

600 − 358 = 242°F

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These superheat tables are used similarly to the saturation tables described in the previous question. Let us take a problem. How much heat does it take to convert 1 lb of feedwater at 205°F into superheated steam at 150 psia and 600°F? The heat in the steam is 1325.7 (1326 Btu). The heat in the water is 205 − 32 = 173 Btu. Then the heat required to convert 1 lb of steam is 1326 − 173 = 1153 Btu.

**Q** Name two methods of calculating boiler efficiency.

**A** To calculate boiler efficiency the method is the same as that for finding the efficiency of practically any other piece of power equipment; namely, efficiency is the useful energy output divided by the energy input. For example, if we get out three-quarters of what we put in, the efficiency is ¾, or 0.75 percent. In the case of a boiler unit, we feed in Btu in the form of coal, oil, or gas, and we get out useful Btu in the form of steam. Thus, the first method states that boiler efficiency can be figured directly from the total fuel burned in a given period and the total water evaporated into steam in the same period. It is more common to figure, first, the evaporation per pound of fuel fired and then from this, the efficiency. Another method is from data on heat lost up the stack. Figuring this way,

$$\text{Boiler efficiency} = \frac{\text{fuel energy input} - \text{energy lost up stack}}{\text{fuel energy input}}$$

**Q** Calculate boiler efficiency using the steam generated versus the fuel consumed. Assume that for one calendar month of regular operation, the coal consumed is 682,000 lb and the steam generated is 6,400,000 lb at 179 psig and superheated to a total temperature of 520°F.

**A** First, the actual evaporation per pound of coal fired is

$$\frac{6{,}400{,}000}{682{,}000} = 9.40 \text{ lb}$$

For rough estimates of efficiency the heat content of the coal may be taken from the statement of the company supplying the coal. For accurate work the operator must collect a good average sample of the coal and send it to a laboratory for testing. Assume that the figure is 13,260 Btu per lb of coal as fired. Remember that this pound of coal produces 9.4 lb of steam.

The absolute steam pressure is

$$170 + 15 = 194 \text{ lb abs}$$

Then, the steam tables show that the total heat of 1 lb of steam at 194 lb abs temp and 520°F is 1280.4 Btu. Assuming that the feedwater temperature is 208°F, its heat content above water at 32°F is merely 208 − 32 = 176 Btu. Thus the heat put into each pound of steam pro-

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duced by the boiler is 1280.4 − 176.0 = 1104.4 Btu. The heat put into 9.4 lb of steam will be 10,381 Btu. Then, boiler efficiency equals heat put into 9.4 lb steam divided by the heat in 1 lb of coal, or

$$\frac{10{,}381}{13{,}260} \times 100\% = 78.3\% \text{ efficiency} \qquad \textit{Ans.}$$

**Q** What are some average small-boiler efficiencies?

**A** Figure 10-33 gives some average boiler efficiencies as found under tests by a consulting engineering firm.

| Type of boiler | Percent of rating | Gas | Oil | Coal (stoker-fired) | Coal (hand-fired) |
|---|---|---|---|---|---|
| SBI steel heating | 100 | 75 | 78 | 75 | 60 |
| | 125 | 73 | 76 | 73 | 58 |
| | 150 | 70 | 73 | 70 | 55 |
| Horizontal return tube, 4-in. tubes | 100 | 73 | 76 | 73 | 58 |
| | 125 | 70 | 73 | 70 | 55 |
| | 150 | 65 | 68 | 65 | 50 |
| Horizontal return tube, 3-in. tubes | 100 | 75 | 78 | 75 | 60 |
| | 125 | 72 | 75 | 72 | 57 |
| | 150 | 67 | 70 | 67 | 52 |
| Scotch marine | 100 | 76 | 79 | 76 | 61 |
| | 125 | 74 | 77 | 74 | 59 |
| | 150 | 71 | 74 | 71 | 56 |
| Water tube | 100 | 77 | 80 | 77 | |
| | 125 | 76 | 79 | 76 | |
| | 150 | 75 | 78 | 75 | |
| Low head water tube | 100 | 75 | 78 | 75 | |
| | 125 | 74 | 77 | 74 | |
| | 150 | 73 | 76 | 73 | |

NOTE: The above efficiencies apply to boilers of 500 hp and under, without preheaters and superheaters. Where the larger-capacity boilers and steam generators are to be considered, efficiencies will increase for all fuels in approximately the same ratios. Where powdered coal is used with preheaters, efficiencies can go as high as 87% plus, while gas is limited to 84% plus.

Fig. 10-33. Average overall efficiencies of boilers of 500 hp and under.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

- *Air Pollution*, 48 pages
- *Steam Generation*, 48 pages
- *Handbook on Fans*, 16 pages
- *Fuel Handling and Storage*, 24 pages

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# 11

# COMBUSTION SAFEGUARDS AND CONTROLS

**Q** What is a furnace explosion?

**A** The ignition and almost instantaneous combustion of explosive or highly inflammable gas, vapor, or dust accumulated in a boiler setting. Often it is of greater expansive force than the boiler setting can withstand. In minor explosions, called puffs, flarebacks, or blowbacks, flames may blow suddenly for a distance of many feet from all firing and observation doors. Thus anyone in the flame path may be seriously or fatally burned. Such minor explosions indicate dangerous conditions, even if no real damage is done. Heavier explosions may shatter gas baffles, bulge setting walls, loosen refractory, blow brick tops of boiler settings through roofs, blow the sidewalls out from under the boiler, break connecting piping, and even demolish boiler housings.

**Q** What conditions are necessary to cause a furnace explosion?

**A** Usually three (Fig. 11-1): (1) Accumulation of unburned fuel, (2) air and fuel in an explosive mixture, and (3) a source of ignition, such as hot furnace walls, improper ignition timing, faulty torch, and dangerous light-off procedures on manually started boiler combustion systems.

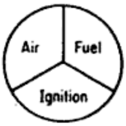


**Fig. 11-1. Elements for combustion.**

**Q** Name the common types of furnace explosions.

**A** Gas explosions and coal dust explosions; each results from the presence of unburned fuel and its delayed ignition. Furnace explosions are of the primary and secondary types. For example, a quantity of unburned fuel in the primary combustion chamber, or furnace, may distill off a large volume of gas during a period of interrupted ignition. If this gas does not ignite promptly, it may fill the furnace and circulate back to a secondary pass.

Continued ignition delay may cause the volatile content of the unburned fuel to be exhausted and the major part of the gas to pocket in



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the second or third pass of the setting. When the diluted gas mixture remaining in the furnace ignites (because the burner is relighted or for some other reason), a furnace explosion of minor intensity occurs in the primary chamber. The blast of flame may then follow through to ignite the gas in the succeeding passes, resulting in a secondary, and more violent, explosion.

**Q** Today there is an increase in furnace explosions in modern boilers. Why?

**A** The four main reasons are:

1. Boilers are larger, calling for higher burner capacity and more efficient boiler operation.
2. Boiler capacity has been increased while furnace size has been held to a minimum. Thus firing conditions are more critical.
3. Many boilers of the waterwall type are now being used, and the firebox temperatures are lower.
4. More installations are using mixtures of natural and plant process gases.

The steam and water pressure parts of boilers are required by state law to have periodic standard inspections. But few standards for periodic legal inspections have been developed for fireboxes and their controls. This has resulted in a wide difference of opinion as to what is considered necessary to prevent furnace explosions. The maintenance and inspection of boiler combustion safety controls are often left to the discretion of the boiler owner. Thus there is an increase in firebox explosions.

The current trend toward automatic boiler control, with fewer operating personnel, has created a strong need for reliable safety controls. Legal requirements, such as exist for the construction and inspection of the boiler pressure parts, have not been adopted as widely for the construction, installation, and inspection of controls needed to prevent furnace explosions.

**Q** What are the main causes of firebox explosions?

**A** Statistics show there are nine major causes:

1. Flame failure due to liquids or inert gases entering the boiler fuel system.
2. Insufficient purge before lighting the first burner.
3. Human error.
4. Faulty automatic fuel regulating controls.
5. Fuel shutoff valve leakage.
6. Unbalanced fuel/air ratio.
7. Faulty fuel supply systems.
8. Loss of furnace draft.
9. Faulty pilot igniters.

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Most of these causes, such as insufficient purge, leaking fuel valves, or improper pilots, have long been known. Liquids or inert gases in fuel systems (as cause of explosions) have increased in frequency as more plants have begun using mixtures of process and natural gas for boiler fuel. Plant process upsets, or equipment failures, allow inert or excessively rich gases to enter the fuel system. Many installations are being equipped to burn both gas and liquid fuels. But each fuel has its own peculiar safety problems.

Faulty automatic fuel-regulating controls can immediately create a dangerous condition in a modern high-efficiency boiler because of lower temperatures of fireboxes, mixed fuels, high capacity burners, and rapid load swings.

Faulty oil or coal fuel-burner systems also cause explosions. But most explosions are on gas-fired units, usually caused by incorrect limits or stops on the combustion controls, or a control component failure or malfunction.

Forced or induced draft or both in modern boilers are necessary to achieve complete combustion of the fuel being burned. Failure of fan drives, dampers, or damper controls causes an accumulation of unburned gases in the firebox. Failure or partial failure of combustion air may starve the burner flames, creating conditions for firebox explosions. Human error is a factor in many furnace explosions. Faulty ignition includes inadequate torches, torches held in the wrong position, or pilot lights incorrectly adjusted.

**Q** How does human error contribute to furnace explosions?

**A** Human error causes are primarily due to incompetent or poorly trained operators.

> EXAMPLE: Forgetting to purge the firebox before light-off; trying to light one burner from an adjacent burner, or worse still, from hot refractory; incorrectly adjusting combustion and safety controls; also, not recognizing a dangerous condition because of not understanding the equipment.

Operating today's complex, modern boilers is too difficult for an untrained operator. The only answer is well-trained personnel, backed up by adequate safety controls. The quality and quantity of safety control system maintenance are as important as any other phase of its design and use. The annual cost of maintaining the control system should be from one to five percent of the equipment's original cost. If the system is selected on cost alone, maintenance can go much higher. Worse still, the reliability of the system will suffer.

**Q** List the operating precautions needed to prevent furnace explosions.

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**A** Seven basic precautions are:

1. Check the operation of the boiler periodically.

2. If a burner goes out accidentally, shut off the igniter and fuel supply and thoroughly scavenge the furnaces and gas passes before again attempting ignition. Always, always determine and remedy the cause of the stoppage.

3. Keep burners and all allied equipment clean.

4. On boilers using both forced- and induced-draft fans, test the interlock periodically.

5. Do not attempt to secure excessively high $CO_2$ by using too rich a fuel/air ratio or by an inadequate secondary air supply.

6. Keep the temperatures and pressures for preheated air, drying air fuel oil, etc. at the right levels.

7. Never allow an unstable flame condition to continue uncorrected.

**Q** How may burner firing controls be classified as to manual, semi-automatic, automatic, and degree of operator participation on larger industrial and utility-type boilers?

**A** Here is one classification:

Manual control. An operator watches the burner and boiler, then adjusts the burner manually. Adjustments on operating conditions are made by the operator. But to properly coordinate the start-up and shutdown of burner equipment, good communication is required between the operator and the control room. Today manual supervision and control are found mostly on older boilers.

Manual control with lighter-flame-proving system. This system provides a semi-automatic lighter control, including a flame proving and interlock system. Starting is from a control board with firing and purge interlocks first satisfied. Then the lighter will be started and proved continuously, thus providing a "go" signal for the introduction of main fuel to that burner. The National Fire Protection Association (NFPA) now recommends that flame detectors or other means be provided to prove igniters in service. For this limited system, the fuel equipment should be operated similarly to manual control.

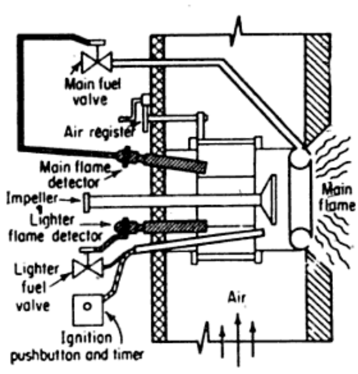


**Fig. 11-2. Manual control with lighter and main-flame-proving systems.**

Manual control with lighter- and main-flame-proving systems (Fig. 11-2). Many industrial boilers

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with gas or oil firing or both in multiple burners are protected by a burner interlock and safety system, using individual supervisory cocks and individual burner trip valves from main-flame detection. The lighter is initiated from a local panel with manual operation of the air registers and supervisory cocks. If a short ignition-time delay occurs, the individual burner valve will trip on the loss of the main flame. Normally no other monitoring is provided at each burner, except by the operator's judgment. This is a local manual system because such systems have limited, or no, burner interlocks and trips, except from lighter and main-flame detectors, but also no, or limited, cross-interlocks between burners.

Remote manual sequence control. For remote manual operation and for proper evaluation, this system should use instrumentation systems and

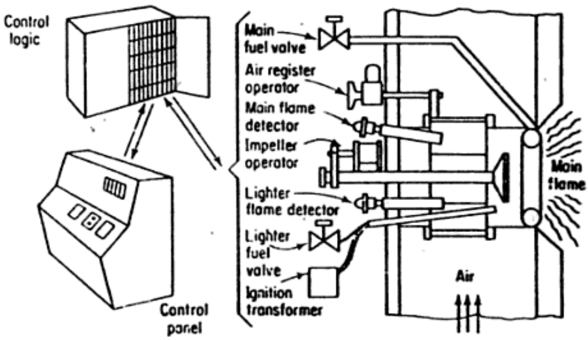


**Fig. 11-3. Automatic sequence control system.**

position switches in the control room. Besides flame detection, such a system needs various burner permissives, interlocks, and trips that sense the position of fuel valve and air registers, in addition to main-flame detection. With this system, the operator still participates in the operation of the fuel equipment. He controls each sequence of the burner-operating procedure from the control room, and no steps are taken except by his initiation.

Automatic sequence control (Fig. 11-3). This system automates the sequence control, thus permitting initiation of burner equipment from a single push button or switch control. Automation then replaces the operator in control of the operating sequences. The operator still initiates the demand for each fuel equipment unit, so he must monitor the operating sequence, as indicated by signal lights and instrumentation signals, as the start-up process proceeds to completion of service on automatic control.

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This category has been widely applied to gas, oil, and coal burning systems.

Fuel management (same equipment as in Fig. 11-3). This system will permit fuel equipment to be placed in service without supervision by the operator. The system will recognize the level of fuel demand to the boiler, sense the operating range of the fuel equipment in service, make a decision concerning the need for starting up or shutting down the next increment of fuel equipment, and then select the next increment based on the firing pattern of burners in service. Demands for the start-up or shutdown of fuel preparation and burning equipment can be initiated by this system without the immediate knowledge of the operator.

**Q** Some large-city ordinances cover operator functions with manual and automatic boiler controls. How do they relate to the degree of automation?

**A** The ordinances usually refer to the terms *manual* and *automatic*. There are four classifications, two manual and two automatic:

1. Manual. A boiler which is purged, started, modulated, and stopped manually.
2. Supervised manual. A boiler which is purged and started manually, modulated automatically, and stopped manually.
3. Automatic nonrecycling. A boiler which, when actuated manually by a push button, is purged, started, modulated, and stopped automatically, but does not recycle automatically.
4. Automatic recycling. A boiler which is purged, started, modulated, and stopped automatically, and which recycles on a preset pressure or temperature range automatically.

**Q** Are furnace explosions more common with suspension firing?

**A** While furnace explosions may occur with any type of fuel or firing, they occur far more frequently when fuels burn in suspension than in solid form on grates. This means that the risk is greater with boilers fired with pulverized coal, oil, gas, and waste gas.

**Q** What characteristic of coal is responsible for furnace explosions?

**A** During light-load periods, a cold furnace has little igniting tendency, and with pulverized coal low in volatiles, the flame may be unstable, thus may go out. The drop in steam pressure will cause the automatic controls to increase coal feed, filling the furnace with an unburned mixture of pulverized coal and oxygen. A dust explosion may result, or the coal may settle to distill off the volatiles, resulting in a gas explosion before the burner comes on again, or when it does come on. Use of a smaller burner for low-load periods, or burning higher-volatile coal, will prevent explosions of this type.

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Good starting pilots are necessary to ignite pulverized coal reliably. A relatively large, stable pilot flame is needed. Either gas or oil may be used, but oil is preferable because its flame is hotter and more stable. Under strong draft conditions, it is possible to pull a gas flame away from the pilot burner.

Pulverized-coal-burning equipment should be mechanically or electrically interlocked so the units can be placed in operation only in the following order: (1) induced-draft fan to purge furnace and passes, (2) forced-draft fan, (3) primary-air blower, (4) coal pulverizer, and (5) coal feeder. Where natural draft is used instead of induced draft, make provision to ensure the wide opening of the flue damper if the forced-draft fan should stop. Failure of any one of the units should automatically shut down all the equipment, following it in the above *reverse* order. An alarm to warn of any interruption in the flow of coal to the pulverizer feed is valuable.

**Q** How can a burner-igniter malfunction cause an explosion?
**A** Burners using an auxiliary pilot to ignite a main burner always present the hazard of the pilot going out accidentally before the main burner goes on. By then the entire setting may be filled with fuel. Fire departments and insurance company requirements usually stipulate that pilots be equipped with automatic shutoffs to stop the fuel flow if the flame on the pilot goes out. Pilot-proving flame detectors are now becoming mandatory on larger boilers and also on smaller gas-fired units.

**Q** Name three types of gas pilot ignition for industrial boilers.
**A** 1. Interrupted gas-electric ignition. This type uses a pilot for seconds only. The burner fires after ignition without the pilot. Use is mostly for firing residual fuel oil, but also for natural gas, depending upon gas-line valving and vent line to prevent leakage of gas into the furnace during off-firing cycle.

2. Intermittent pilot. This type uses a pilot to ignite fuel and continues to burn during the firing cycle. The burner and pilot go off simultaneously.

3. Continuous pilot. Once ignited, this type of pilot burns continuously whether the burner is firing or is off. Thus protection is provided against unburned gases entering the furnace. This pilot will ignite and burn off any leakage of gas that may enter the furnace.

**Q** Can fan and damper malfunction contribute to furnace explosions?
**A** Accidental stoppage of the induced-draft fan, with continued operation of the forced-draft fan, results in fuel being fed to the furnace faster than combustion products leave. Mechanical or electrical interlocks prevent this condition and also prevent the possibility of starting the forced-draft fan unless the induced unit is running. A tightly closed damper

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creates a situation similar to the stoppage of an induced-draft fan. Cutting back dampers, so there is always an opening at the bottom and top edges (even in the closed position), allows gas movement at all times.

Mechanical and electrical interlocks play a vital role in operating equipment in proper sequence. They immediately shut down a unit if any of the components in a combustion system is not operating within set limits.

**Q** Explain how a purge interlock system functions.

**A** Interlocks are used for purging a boiler before lighting off or for shutting down equipment in case of fan failure. The purge interlock (Fig. 11-4) is actuated by a differential pressure that is proportional to

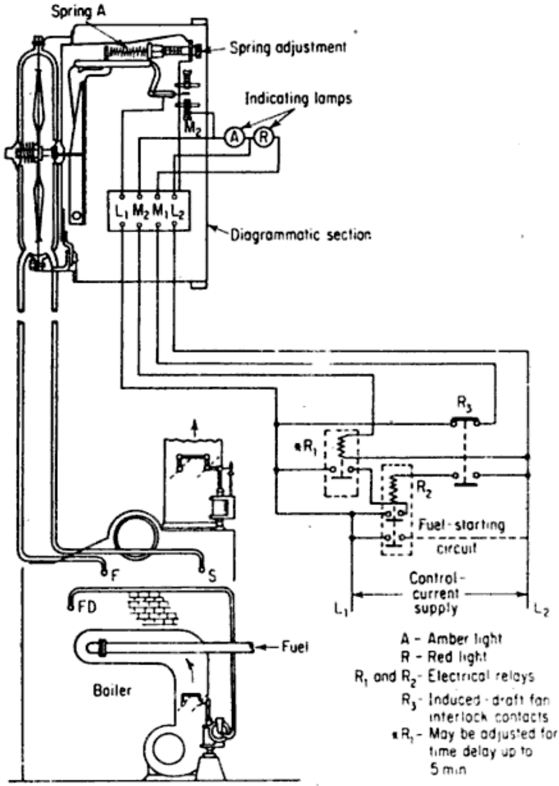


**Fig. 11-4. Purge interlock wiring diagram.**

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the airflow through the boiler. This is usually the differential across the boiler tubes. When the boiler is out of service, no differential is applied to the interlock measuring element (diaphragm), thus contact *M2* is open. Contact *R3* (closed) may be auxiliary fingers on a fan-motor breaker [on whichever, or both, of the induced-draft (id) or forced-draft (fd) fans that will be used for purging], or may be a relay actuated by contact *M1* of a fan interlock. With contact *M2* open and the top contact of *R3* closed, the time-delay relay *R1* is deenergized and contact *R1* is open, thus opening the fuel-starting circuit to prevent the supply of fuel. Also, the red signal light (if furnished) is energized.

Before fuel may be supplied to the furnace, the fan motors must be started to open the top contact of *P3* and close the bottom contact, and the airflow through the furnace must be increased to about 60 percent of capacity. This high rate of airflow differential closes contact *M2* to complete the circuit from *L1* through *M2* and the *R1* coil to *L2*. The amber signal light (if installed) is energized. The time-delay relay *R1* allows the high rate of flow through the furnace for several minutes to purge the boiler of any explosive mixture before contact *R1* is made to energize the fuel-starting circuit to permit fuel supply. When contact *R2* is made, it sustains itself through one of its own contacts and the lower contact of *R3*. The airflow can then be reduced for lighting off. Upon a boiler shutdown, the lower contact of *R3* will open to deenergize the relay *R2* and bring about the same conditions as mentioned above when the boiler is out of service.

**Q** Are interlocks required for gas-fired utility boilers?

**A** The diagram of interlocks in Fig. 11-5 has been agreed upon and appears in the NFPA's 85-B Standards. Note that each igniter is interlocked to trip its fuel supply on loss of all flame, but that interlocking to trip the main fuel supply on loss of flame is not shown. Referring to the Standards, loss of all flame is stated as a mandatory fuel trip, but not necessarily automatic. This is because the Standards hold that the present state of development of flame detectors does not guarantee the required reliability.

The fact that some desirable interlocks have not been placed in the required automatic category does not preclude their use in this manner. Such use is encouraged by companies that have sufficient experience with certain devices to know they have the necessary reliability. The Standards hold that more and more automatic trip protection systems will be used in the future.

**Q** What controls are needed to prevent furnace explosion on large boilers firing fuel in suspension?

**A** These four basic controls:

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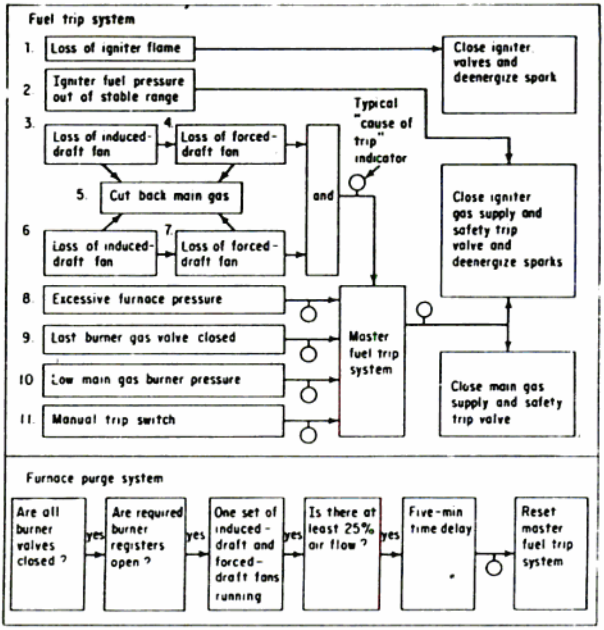


Fig. 11-5. Interlock system for a natural gas-fired public utility boiler furnace.

1. An automatic burner-control system properly programmed and composed of reliable hardware and sensitive discriminating flame detectors.

2. A fully integrated combustion-control system to maintain the correct fuel and air ratios under all operating conditions.

3. A complete safety interlock system including furnace purge, fan failure, fuel supply failure, and furnace over-pressure interlocks.

4. Communication equipment, such as furnace television, for viewing operating conditions, and combustible analyzers and interlocks to trip the fuel when approaching hazardous conditions.

**Q** Outline some causes of furnace explosions on large boilers and corrective actions to be taken by the controls.

**A** See the table in Fig. 11-6 for gas-fired boilers. Similar programs are followed for oil-fired units.

**Q** How do furnace television and combustible analyzers aid in preventing furnace explosions?

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| Causes of firebox explosions | Ways to prevent them |
|---|---|
| 1. Faulty automatic fuel and regulating controls<br>Leaking valve on fuel line<br>Unbalanced air/fuel ratios<br>Faulty fuel injection systems<br>Faulty fans and dampers | 1. Provide automatic boiler shutdown for:<br>Low fuel gas pressure<br>High fuel gas pressure<br>Loss of instrument air<br>Loss of fans<br>Loss of dependable power supply<br>Low water |
| 2. Insufficient or no purge | 2. Ensure adequate purge by performing these functions:<br>Close all pilot gas valves<br>Close all burner gas valves<br>Close main gas valve<br>Purge with airflow<br>Purge with timed airflow |
| 3. Flame failures<br>Faulty pilot light | 3. Ensure a safe light-off by taking these steps:<br>Make sure burner fuel valve is closed<br>Light and check pilot flame-failure detector<br>Extinguish pilot and check burner flame-failure detector |
| 4. Since faulty regulating controls, unbalanced fuel/air ratios, faulty fuel systems, and faulty fans and dampers also can result in flame failure, the inclusion of No. 3 in the safety system offers a double safeguard against these conditions and also a secondary source of protection against the failure of any of the components. | |

Fig. 11-6. Some firebox-explosion causes and preventive measures.

**A** Furnace television can provide the operators with the visual picture they once had when stationed at the burners and can be invaluable when placing burners in service. Combustible analyzers can be used to check the effectiveness of a furnace purge and to sound an alarm or trip the unit when approaching unsafe combustible levels.

**Q** Name four common types of combustion or oxygen analyzers.
**A** (1) Paramagnetic, (2) catalytic combustion, (3) electrochemical, and (4) inferential thermal conductivity. These four methods, unless specifically designated, are primarily suited to gas analysis. Many of them can be extended to determine dissolved oxygen in liquids by use of an auxiliary gas stream to scrub the liquid and carry the oxygen to the analyzer.

## BURNER FLAME SAFEGUARD SYSTEMS

**Q** What is meant by a flame safeguard system?
**A** A flame safeguard system is an arrangement of flame detection systems, interlocks, and relays which will sense the presence of a proper flame in a furnace and cause fuel to be shut off to the furnace if a haz-

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ardous (improper flame or combustion) condition develops. Modern combustion controls are closely interlocked with flame safeguard systems and also pressure-limit switches, low-water fuel cutoffs, and other safety controls that will stop the energy input to a boiler when a dangerous condition develops. Thus it becomes obvious that a modern flame safeguard system performs actually two functions: (1) Senses the presence of a good flame or proper combustion and (2) programs the operation of a burner system so that motors, blowers, ignition, and fuel valves are energized only when they are needed, and then in proper sequence.

**Q** What is the primary function of a flame safeguard system?

**A** Boilers are always prone to two possible types of explosions.

1. Boiler explosions. These are caused by the release of accumulated energy in the form of pressure. Then, because of structural weakness or malfunctioning of pressure and temperature controls, the vessel (or part of it) can explode from forces that are normally contained by the boiler structural elements. This type of explosion is sometimes referred to as a "steam type" explosion.

2. Furnace explosions (combustion explosions). These are caused by the sudden ignition of accumulated fuel and air in the fireside of the boiler. This can also lead to devastating property damage and loss of life. The flame safeguard system used on different boilers firing different types of fuel is designed to sense, and sometimes anticipate, this accumulation of unburned fuel and air in the fireside of the boiler. It safely shuts off the firing equipment, with purging of the furnace usually following in a time sequence so as to drive the unburned fuel-air mixture out of the furnace.[1]

**Q** What two control parameters are usually considered in a flame failure system to prevent furnace explosions?

**A** 1. Control the input composition so that it cannot accumulate to an explosive batch or mixture (Fig. 11-7). This is called *input control.*

2. Ignite in proper sequence all combustible combinations of fuel and air as they enter the furnace. This is called *ignition control.*

Input control depends on a time factor of how much fuel can be put into a furnace before combustion must ensue so no dangerous batch is present for a delayed light-off leading

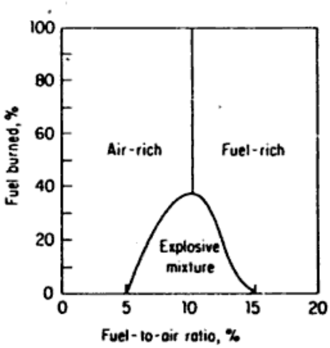


**Fig. 11-7. Methane-air mixture, showing flammability and explosive limits.**

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*b.* Infrared radiation covers most of the useful band of wavelengths and also covers most of the radiation strength. Infrared detectors are suitable for gas and oil flames. Because hot refractories also radiate infrared, scanners must avoid hot refractories. Lead sulfide cells are used in photocells to sense infrared radiation. Unlike the cadmium phototube, it does not emit electrons, but has the property of having its electrical resistance reduced while exposed to infrared radiation. The greater the strength of the radiation, the lower the resistance of the lead sulfide. If connected to a designed electronic circuit, this principle is used for flame detection purposes.

*c.* Ultraviolet radiation is the latest flame detector based on the phenomenon of sensing the strength of ultraviolet radiation in a flame. It is insensitive to visual and infrared radiation and is not affected by hot refractories, as these usually do not give off appreciable ultraviolet radiation. When radiation from a flame passes through the typical quartz viewing window of one of these detectors into the flame-sensing tube, the tube becomes electrically conductive. The strength of the detector signal, or current passed through the sensing tube, depends on the kind of fuel, size and temperature of the flame, and distance between the flame detector and the flame. Figure 11-8 shows some typical wavelengths in a flame and response percentage of total wavelengths of typical flame pickup devices.

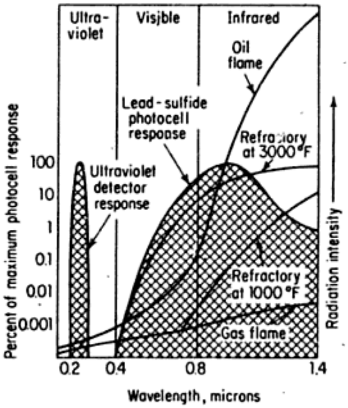


**Fig. 11-8. Percentage wavelength light response versus wavelength for flame detection systems.**

**Q** What are the principal flame detectors used on boilers?

**A** The type of flame detector depends on the fuel used, the type of burner, and the size and arrangement of the boiler. Flame detectors vary from those used on small domestic boilers to those on large boilers. Types of detectors and the task each does are:

1. Stack switch, heat sensing.
2. Rectifying flame rod, heat sensing.
3. Rectifying phototube, visible-light sensing.
4. Lead sulfide photocell, infrared-light sensing.
5. Cadmium sulfide photocell, visible-light sensing.
6. Ultraviolet flame detector tube, ultraviclet-light sensing.

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**Q** Name some limitations of flame-sensing devices.

**A** While each of the flame-sensing devices can offer a substantial amount of protection if properly installed, they are all subject to certain limitations that must be allowed for. For example, the lead sulfide cell and the photoelectric cell are subject to the following limitations (there is some variation between each type):

1. Discrimination between burners. With more than four burners in one firebox, it becomes difficult to locate the sensing cell where it will not be actuated by the flame of an adjacent burner when the burner on which it is mounted has been extinguished.

2. Ambient temperature of sensing cell. High ambient temperatures of the sensing cells (which are easily obtained at the locations where they must be mounted) can result in erratic signals, false signals, and a short

COMPARISON OF FLAME SAFEGUARDS

| Principle of Flame Detection | Rectification | | Infrared | Visible Light | Ultravision |
|---|---|---|---|---|---|
| Type of Detector | Rectifying Flame Rod | Rectifying Phototube | Lead Sulfide Photocell | Cadmium Sulfide Photocell | Ultravision Detector Tube |
| **Advantages** | | | | | |
| Same detector for gas or oil flame | | | ▨ | | ▨ |
| Can pinpoint flame in three dimensions | ▨ | | | | |
| Viewing angle can be orificed to pinpoint flame in two dimensions | | ▨ | ▨ | ▨ | ▨ |
| Not affected by hot refractory | ▨ | | | ▨ | ▨ |
| Checks own components prior to each start | ▨ | ▨ | ▨ | ▨ | ▨ |
| Can use ordinary TW plastic-covered wire for general application, no shielding needed | ▨ | ▨ | | ▨ | ▨ |
| No installation problem because of size | | | ▨ | ▨ | |
| **Disadvantages** | | | | | |
| Difficult to sight at best ignition point | | | ▨ | | |
| Exposure to hot refractory may reduce sensitivity to flame flicker and require orificing | | | ▨ | | |
| Flame rod subject to rapid deterioration and warpage under high tenperatures | ▨ | | | | |
| Not sensitive to extremely hard premixed gas flow | | | ▨ | ▨ | |
| Temperature limit too low for some applications | ▨ | ▨ | ▨ | ▨ | ▨ |
| Shimmering of hot gases in front of hot refractory may simulate flame | | | ▨ | | |
| Hot refractory background may cause flame simulation | | ▨ | | | |
| Electric ignition spark may simulate flame | | | | | ▨ |

**Fig. 11-9. Advantages and disadvantages of flame safeguard types.**

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life. Air and water cooling have been used to prevent or minimize this limitation.

The flame rod is subject to (1) short service life at high flame temperatures, (2) fouling of insulators causing short circuits and shutdowns, (3) difficulty in providing sufficient rod area to ground the flame, and (4) limitation generally to pilots and small burners. Figure 11-9 gives some comparisons of the different flame safeguard systems.

**Q** List some precautions to observe when installing flame rods.

**A** Figure 11-10 shows a typical mounting. When selecting a location, observe the following precautions:

1. Make sure that the flame rod will check the pilot flame at the desired point.

2. The unit must be clear of the fire door opening radius.

3. Locate the unit so that drafts will not blow the pilot flame away from the rod.

4. Install the unit so the flame rod is horizontal or angled upward. Use extra support for rods over 12 in. long.

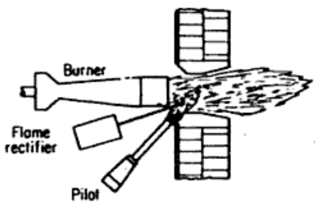


**Fig. 11-10. Correct installation for a flame rod used to prove both main and pilot flames.**

5. If the flame rod is to supervise a gas pilot for an oil burner installation, the rod must be located far enough from the oil flame to prevent oil spray from impinging and burning on the surface of the rod.

6. A horizontal or inclined flame rod should enter the pilot flame from the side.

7. Protect the lead wires from excessive radiant or reflected heat. For temperatures under 125°F, use No. 14 wire with thermoplastic insulation. Install a 2-ft flexible lead to the head of the unit to permit easy removal from the combustion chamber.

8. On an oil installation, protect the flame rod insulator from oil and soot deposits which may cause nuisance shutdowns of the burner.

**Q** Illustrate a typical gas-pilot ignition and main oil-burning flame-sensing installation.

**A** The rectified impedance system (Fig. 11-11) operates on the principle that either a flame or a photocell sighted at a flame is capable of conducting, as well as rectifying, an alternating current. This alternating current is applied to either a flame electrode inserted in the flame or to a photocell sighted at the flame. The resultant rectified current, which can be produced only when a flame is present, is in turn detected by the relay.

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The actual flame-detecting units consist of flame-electrode and photocell rectifier assemblies. The flame-electrode type is generally used for nonluminous flames, such as gas flames, whereas the photocell type is usually used for luminous flames, such as oil flames. The system shown in Fig. 11-11 provides gas-pilot flame supervision on start, and oil main-flame supervision on run, for an oil-fired burner. The flame-electrode

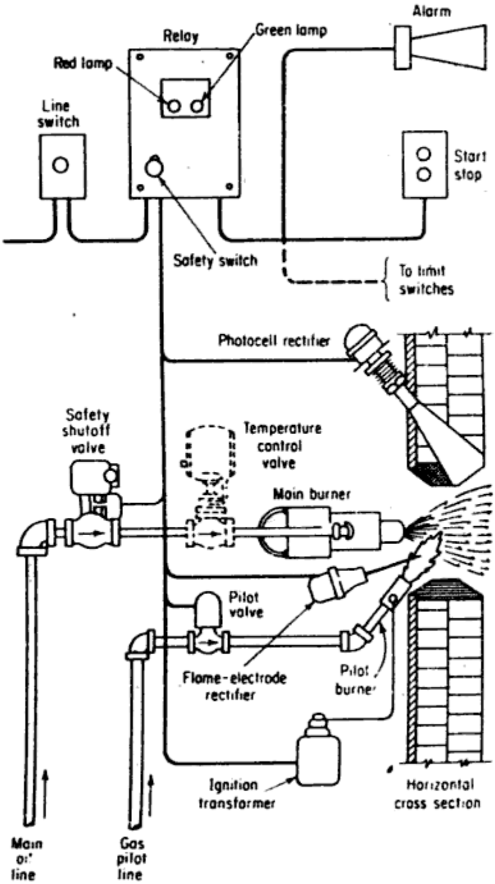


**Fig. 11-11. Combustion safeguard system based on rectified impedance principle for an oil-fired burner.**

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rectifier is used to supervise the gas-pilot flame (constant pilot) during start-up only, while the photocell rectifier is used to supervise the oil main flame. If the oil-fired burner is ignited by an intermittent pilot, the flame-electrode rectifier is not needed.

**Q** What is meant by register starting as stipulated in National Fire Prevention Association (NFPA) No. 85-B for gas firing and NFPA No. 85-T for oil firing?

**A** Open-register start-up procedure for gas firing is outlined briefly thus:

1. Set all, or most, burner-air registers in the normal firing position. Then purge the furnace and boiler setting, using not less than 25 percent of full-load airflow for 5 min.

2. Throughout the start-up period, maintain the same register settings and the same total airflow used for purge.

3. Set fuel header pressure at a value which will provide a burner fuel-flow compatible with the burner airflow.

4. Light burners one at a time as increased heat input is required, keeping the burner fuel header pressure and register settings at their initial settings. As each new burner is lit off, close the burner register to light-off position. Since the furnace is air-rich, additional burners may be cut in with no increase in airflow until the fuel flow approaches 25 percent (or whatever airflow rate was used during the purge).

**Q** What is the composition of the explosive zone in a furnace filled with a fuel-air mixture when the furnace is shut down because of a flameout?

**A** See Fig. 11-12. When there is no fire in the furnace and air is slowly

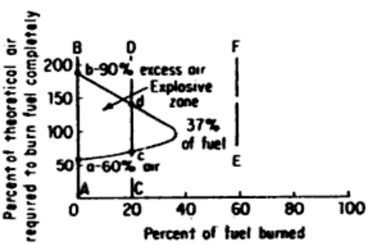


Fig. 11-12. Explosive zone in a furnace.

added to a gas-and-air mixture, conditions follow line AB. The mixture becomes explosive when about 60 percent of the air theoretically required for combustion has been supplied. It remains explosive until there is about 190 percent of total air present, from *a* to *b*; then it is too lean to

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explode. When there is a fire in an overly rich furnace and the operator tries to back out slowly, he follows, for example, line CD (assuming that 20 percent of the fuel in the furnace is burned). He is also passing through a dangerous zone from *c* to *b*, but much narrower. His hope is that the mixture is not sufficiently intimate to explode.

**Q** Describe a continuous, automatic check system of a flame safety circuit.

**A** Since it is possible to check the flame sensor by manually cutting off the flame, the same sort of check has been developed to do it automatically. Thus the flame safety circuit is automatically and continuously checked (including the sensor) by simulating flameout. See Fig. 11-13. Here the flame failure is simulated by means of a swinging shutter that intermittently interrupts the line of sight of an optical flame detector. Each time the sensor's view is blocked, a flameout is simulated long enough to prove out the sensor but not long enough to actually shut down the system. Should the sensor "see" flame while its view is blocked, the system immediately shuts down on malfunction. But if the sensor detects the intermittent flameout, its "no-go" signal (of 1-sec duration) is too brief to shut down the system, since the logic network has a time delay to prevent nuisance shutdowns. Thus, the system is a constantly repeated check, not only on the flame sensor but on the logic network as well as on the flame failure circuit.

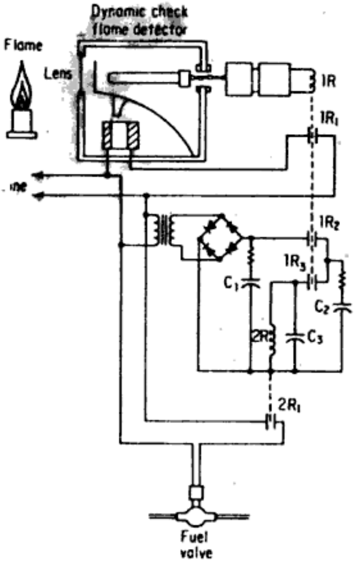


**Fig. 11-13. Automatic continuous check system of a flame safety system.**

**Q** What is the advantage of a system that checks itself so frequently?

**A** Today's flame-proving devices are composed of many resistors, capacitors, coils, tubes or transistors, etc., any one of which can fail because of vibration, aging, voltage surges, moisture damage, etc. While some of these failures will cause the relay to shut down the burner (a safe failure), others can cause the relay to keep the burner on the line, even

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to 325 Btu. And the heat energy contained in the remaining unflashed water at atmospheric pressure is 180 Btu. The difference is 145 Btu per lb. But the total flashing energy would be 6,000 × 145 = 870,000 Btu. At 778 ft-lb per Btu, the total energy resulting from the explosion would be 870,000 × 778 = 676,860,000 ft-lb. This is equivalent to the impact of a 50-ton railroad car dropping from a height of 6,760 ft.

**Q** Name some causes of overpressure on automatically fired boilers.
**A** Many causes of control malfunction can lead to overpressure by a runaway firing condition. Often the safety relief valve is the last means of preventing a dangerous overpressure. Some causes are:

1. Fused contact points on electrically operated pressure cutout switches. Then the burner keeps operating because the current to the burner motor cannot be interrupted.

2. Shorted wires to the pressure switch, thus bypassing the on-off feature of the pressure switch, permitting the burner to keep operating. A similar cause is a loose terminal connection on the electrically operated pressure switches, which might complete a circuit by shifting to the other terminal of the connection, again bypassing the on-off switch.

3. Leaking solenoid gas valves or diaphragm-operated valves on the fuel line to the burner. Thus the burner keeps operating with a resultant pressure increase, if the connected load cannot dissipate the energy input.

4. In many installations, the pressure switch (or thermostat) is electrically connected to a motor controller of the oil-burner motor. Contacts on the controller can fuse, again not permitting the oil-burner motor to stop the oil burner at the set pressure cutout setting.

5. On gas burners, manual bypass lines have been found, permitting the solenoid or diaphragm-operated gas shutoff valve to be bypassed so as to permit firing the boiler under manual control. The unattended boiler (in this condition) has no high-pressure cutout except the sv.

6. Obstructed tubing to pressure sensing switches can block the signalling of pressure to the pressure cutout switch, again permitting the burner to operate with the sv the last means of preventing overpressure.

> EXAMPLE: Consider a cock between the boiler and pressure switch (usually where the pressure switch is not mounted directly on the boiler but in a control cabinet). If the cock is inadvertently closed, the controls will sense no pressure buildup. Again the sv is the last means of preventing overpressure.

7. On closed hot-water-heating systems with only a temperature cutout switch, a water-clogged expansion tank can lead to high pressure on the boiler and piping. Again the sv is the only protection against overpressure.

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8. Low water in a boiler due to faulty feed devices, or improper interlocking between feed pumps and burner, can lead to overpressure if it is combined with a defective pressure cutout switch.

These examples show why constant checking is needed for proper control functioning on automatically fired boilers.

> REMEMBER: Never assume that the automatic features cover all possible means of failure.

**Q** What type of sv should be installed on a boiler?

**A** An ASME or NB-approved and registered direct spring-loaded pop

1. The name or identifying trademark of the manufacturer
2. Manufacturer's design or type number
3. Size, in. Seat diameter, in.
   (The pipe size of the valve inlet)
4. Pressure, lb
   (The steam pressure at which it is to blow)
5. B.D., lb
   (Blowdown—difference between me opening and closing pressure)
6. Capacity, lb per hr
7. Capacity lift, in.
   (Capacity lift—distance the valve disk rises under the action of the steam when tho valve is blowing under a pressure of 3 percent above the set pressure)

Fig. 13-1. ASME markings required on high-pressure steam safety valves.

type, properly marked as to pressure and capacity and equipped with a testing lever. The pressure setting must match either the maximum allowable pressure for which the boiler is designed or, on older boilers, the maximum pressure allowed by state or city law. The capacity of the sv should be at least equal to the maximum steam that can be generated by the boiler. Figure 13-1 gives the marking required on the sv of an hp steam boiler. Similar rules govern high-temperature hot-water (hthw) boilers and low-pressure steam and hw heating boilers.

**Q** How can one tell an ASME-approved sv, and how does one secure permission from the ASME to make approved svs?

**A** Figure 13-2 shows the official ASME stamp of approval. Permission to use the symbol is granted by the ASME to any manufacturer complying with the provisions of the Code. The manufacturer must agree (upon forms issued by the society) that any sv to which the symbol is applied

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will be constructed in accordance with the Code and that it has the capacity stamped upon the valve under the stated conditions. The manufacturer must also agree that he will not misuse, or allow others to use, the stamp by which the symbol is applied.


Fig. 13-2. Official symbol for stamp to denote the ASME standard.

**Q** Explain the difference between a relief valve and an sv. What is a safety relief valve (srv)?
**A** A relief valve is used primarily for liquid service and is an automatic relieving device actuated by the static pressure upstream of the valve, which opens farther with an increase in the pressure over the opening pressure (no pop action).

An sv is used for gas or vapor service and is an automatic pressure-relieving device, actuated by the static pressure upstream of the valve, and which opens with a full pop action once the upstream pressure activates the valve.

An srv is an automatic pressure-relieving device actuated by the pressure upstream of the valve, and which opens by pop action with further increase in lift of the valve when pressure increases over the popping pressure. It thus combines the feature of pop action and further lift with pressure increase.

**Q** What is the difference between a spring-loaded sv and a pop sv?
**A** Both valves are spring-loaded, but the pop type has a lip or slight extension on the disk of the valve which extends beyond the seat surface and provides a huddling chamber (Fig. 13-3). As the valve opens, this huddling chamber is filled with steam, thus building a static pressure on the lip because of the increased disk area exposed. This extra force upward suddenly lifts the disk against the compression spring and causes it to open wide almost instantaneously with a popping noise.

Spring-loaded valves without this pop feature open slowly, and lift is more dependent on pressure increase than sudden complete pop release. This can cause wire drawing of the disk and seat, resulting in leakage. The valve disk is held firmly on its seat by a heavy coil spring. The point at which the valve lifts and relieves the pressure is set by screwing the adjusting nut up or down and so decreasing or increasing the compression of the spring. A maximum adjustment of 10 percent from the stamped pressure is permitted. Once it is set, a lock nut keeps the adjusting nut from moving. The cap on top of the valve may be sealed, if desired, to prevent access to the adjusting nuts. A hand lever lifts the valve from its seat for testing purposes so as to make sure the valve is free. And a blowdown-adjusting arrangement regulates the number of pounds that the valve blows down before it closes.

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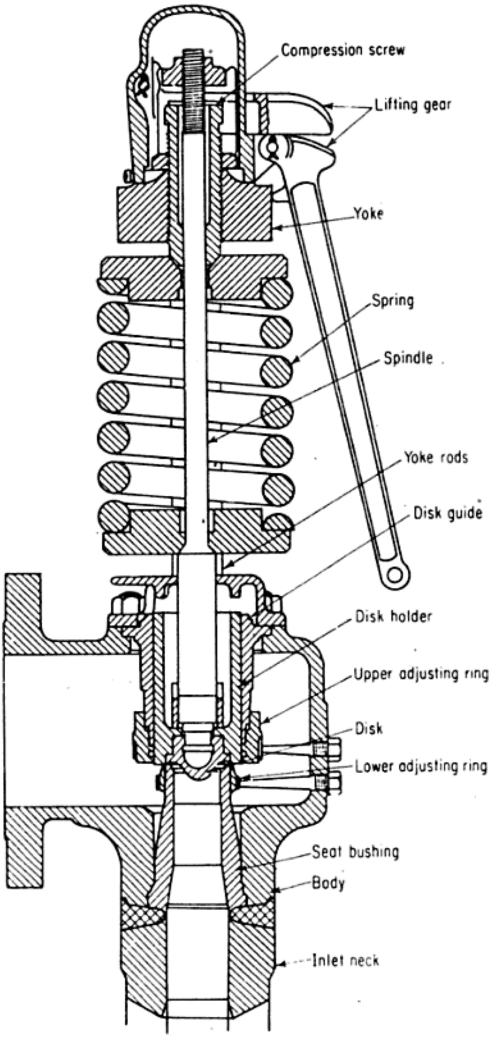


**Fig. 13-4. High-pressure, high-temperature steam safety valve.**

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**Q** Give the Code rules for range of pressure settings for two or more svs on an hp steam boiler.

**A** 1. One or more svs must be set at or below the maximum allowable pressure.

2. The highest pressure setting of any sv cannot exceed the maximum allowable working pressure by more than 3 percent.

3. The range of pressure settings of all the saturated steam svs on the boiler cannot exceed 10 percent of the highest pressure setting to which any valve is set.

**Q** Illustrate the above rule with an example.

**A** A wt boiler has a maximum allowable working pressure of 200 psi and is equipped with three svs. What is the highest permissible pressure setting? Also, at what pressure would the other valves be set according to Code rules? First, the highest setting would be $200 + 0.03\ (200) = 200 + 6 = 206$ psi. One valve would have to be set at the maximum allowable pressure or below the maximum allowable pressure. Let one valve be set at 200 psi. The lowest setting then for the third valve would be $206 - 10\%$ of $206 = 206 - 20.6 = 185.4$ psi. If we assume a range of 10 percent from the maximum allowable pressure, the lowest setting would be $200 - 10\%\ (200) = 180$ psi. The other two valves under this condition could be set between 180 and 200 psi.

**Q** When is more than one sv required on a boiler?

**A** Each boiler requires at least one sv, but if the heating surface exceeds 500 sq ft, or the boiler is electric with a power input over 500 kw, the boiler must have two or more srvs. When not more than two valves of different sizes are mounted singly on the boiler, the smaller valve must be not less than 50 percent in relieving capacity of the larger valve.

**Q** Can svs on hp boilers be attached to drums or headers by welding?

**A** Yes, providing the welding is done according to Code welding requirements, including those covering such factors as the use of qualified weldors, post-weld heat treating, and radiographing.

**Q** What is the Code rule for determining sv relieving capacity?

**A** The following rules on hp boilers must be followed:

1. The sv capacity on a boiler must be such that the sv (or valves) will discharge all the steam that can be generated by the boiler (this is assumed to be the maximum firing rate) without allowing the pressure to rise more than 6 percent above the highest pressure at which any valve is set, and in no case more than 6 percent above the maximum allowable pressure.

2. The minimum sv relieving capacity, for other than electric

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boilers, must be determined on the basis of pounds of steam generated per hour per square foot of boiler heating surface and waterwell heating surface, as given in Fig. 13-5. For electric boilers, the relieving capacity is determined by multiplying the kilowatt input by 3½ to obtain the pounds per hour of steam-relieving capacity.

3. For hthw boilers, the required steam-relieving capacity in pounds per hour is determined by dividing the maximum Btu output (for the fuel being fired) of the boiler by 1,000.

Relieving capacity rules for lp steam boilers are:

1. Low-pressure steam boilers require an sv capacity such that with the fuel-burning equipment installed, the pressure cannot rise more than 5 psi above the maximum allowable working pressure of the steam boiler.

**Minimum Pounds of Steam per Hr per Sq Ft of Surface on HP Boilers**

| Surface | Fire-tube boilers | Water-tube boilers |
|---|---|---|
| Boiler heating surface: | | |
| Hand-fired | 5 | 6 |
| Stoker-fired | 7 | 8 |
| Oil-, gas-, or pulverized-fuel-fired | 8 | 10 |
| Waterwall heating surface: | | |
| Hand-fired | 8 | 8 |
| Stoker-fired | 10 | 12 |
| Oil-, gas-, and pulverized-fuel-fired | 14 | 16 |

NOTE: When a boiler is fired only by a gas having a heat value not in excess of 200 Btu per cu ft, the minimum safety-valve relieving capacity may be based on the values given for hand-fired boilers above.

Fig. 13-5. Data used for high-pressure boiler safety valve (also lp boilers).

2. The minimum relieving capacity is determined by multiplying the heating surface by the values shown in Fig. 13-5, or by dividing by 1,000 the maximum Btu (for the fuel being fired) output of the boiler.

Relieving capacity rules for lp hot water boilers are:

1. The same rule of minimum capacity of relief valves applies to hot water boilers: The capacity is determined by taking the values shown in Fig. 13-5 times the heating surface or by dividing by 1,000 the rated Btu output of the boiler for the fuel being fired.

2. The capacity must be such that the pressure cannot rise more than 20 percent above the highest maximum allowable working pressure up to and including 30 psi, and a 10 percent rise is permitted for pressures over 30 psi.

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**Q** What area of the boiler shall be computed as heating surface?
**A** That side of the boiler surface exposed to the products of combustion, exclusive of superheating surface. The areas to be considered for this purpose are tubes, fireboxes, shells, tube sheets, and the projected area of headers. For vertical ft steam boilers, compute only the portion of the tube surface up to the middle gage cock.

**Q** Calculate the heating surface and relieving capacity of the svs required for an oil-fired, ft boiler of 100 tubes, each 2½ in. in diameter, No. 20 gage in thickness, each 15 ft long. The remaining heating surface of fire sheet and tube sheet totals 130 sq ft at a working pressure of 125 psi. How many and what size valves should be installed?
**A** Use the ID of the tubes as heating surfaces. Heat transfer is from the inside of the tube through the tube thickness to the waterside. No. 12 gage tube has a wall thickness of 0.105 in., thus the ID of the tube equals $2.5 - (2 \times 0.105) = 2.29$ in.

The area in square feet of all tubes equals the circumference times the length times the number of tubes $= \pi\ (2.29)/(12) \times 15 \times 100 =$ 897 sq ft.

Total heating surface $= 897 + 130 = 1{,}027$ sq ft.

From the table in Fig. 13-5, we see that 8 lb of steam per hour per square foot of heating surface is the minimum pounds per hour relieving capacity required for the sv. Thus, the minimum relieving capacity $= 8 \times 1{,}027 = 8{,}216$ lb per hr. Because the boiler has over 500 sq ft of heating surface, two or more svs are required. Refer to the ASME Power Code (also steam tables). It shows that for 125 psi, $V = 3.220$.

Use $A = \dfrac{HV}{420}$

where $A$ = area of opening required
$H$ = boiler heating surface, sq ft
$V$ = Specific volume of steam, cu ft per lb at allowable pressure

$$A = \frac{1{,}027 \times 3.220}{420} = 7.874 \text{ sq in.}$$

Referring to the ASME Power Boiler Code, a 2-in. and a 2½-in. diam sv are needed to give the required area of opening.

NOTE: This value must also be used to obtain the minimum size of sv connections.

**Q** If a boiler has no stamping as to capacity and there is a question as to what relieving capacity is needed on an sv, how is the proper relieving capacity for the sv determined?

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**A** 1. If the boiler has svs, the boiler can be fired at its maximum rate. Isolate the boiler from connected load, then note if the pressure rises more than 6 percent above the highest pressure to which any valve is set. If the pressure rises above 6 percent (with svs discharging), the svs are too small, and greater relieving capacity is needed. This is an accumulation test.

> WARNING: Because of the dangers of damaging the boiler from lack of circulation, this test is not permitted on boilers with superheaters or reheaters, or on ht water boilers.

2. Capacity can also be determined by measuring the maximum amount of fuel that can be burned and then working back to calculate the output of the boiler. The heating value of the fuel must be known. For example, assume that crude oil is burned with a heating value of 18,500 Btu per lb. Assume that the boiler uses 1,000 lb per hr at the maximum firing rate. Use the Code equation:

$$W = \frac{C \times H \times 0.75}{1{,}100}$$

where $W$ = weight of steam generated per hour, lb
= minimum sv capacity
$C$ = maximum weight of fuel burned per hour, lb
$H$ = heating value of fuel, Btu per lb

then

$$W = \frac{1{,}000 \times 18{,}500 \times 0.75}{1{,}100}$$

$$= 12{,}620 \text{ lb per hr minimum} \qquad \textit{Ans.}$$

3. The third method for determining the relieving capacity of the svs is based on the fact that input equals output, with respect to water and steam flow. Measure the water fed into the boiler in pounds per hour at the maximum firing rate. The maximum outlet of steam is assumed to be equal to this. The relieving capacity of the svs must at least equal this flow in pounds per hour. But do not use this method on hot-water boilers as no evaporation takes place. Also, the pump used to circulate the water through the boiler is not truly a feedwater pump.

**Q** What are the minimum diameters of svs permitted on a miniature steam boiler, a power boiler, an lp steam boiler, an hw-heating boiler, and an hw-supply boiler?

**A** The ASME Code requires the following minimum diameter srvs: Miniature steam boiler, ½ in.; power boiler, ¾ in.; lp steam boiler, ¾ in.; hw-heating boiler, ¾ in.; hw-supply boiler, ¾ in.

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**Q** When are svs required on superheaters, and can the capacity of the superheater svs be included in the total sv capacity required on a boiler?
**A** Every superheater attached to a boiler with no intervening valves between the superheater and boiler requires one or more svs on the superheater outlet header. With no intervening stop valves between the superheater and the boiler, the capacity of the svs on the superheater may be included in the total required for the boiler, provided the sv capacity in the boiler is at least 75 percent of the aggregate sv capacity required for the boiler.

**Q** Illustrate the previous answer with an example.
**A** Assume a boiler needs 50,000 lb per hr relieving capacity. A minimum of two valves is required on the boiler, with a total relieving capacity of 75% × 50,000 = 37,500 lb per hr. The superheater would then require an sv with a capacity of 50,000 − 37,500 = 12,500 lb per hr.

**Q** If there are stop valves between the boiler and the superheater, what is the Code rule for svs on the superheater?
**A** The superheater now may become an independently fired superheater or fired pressure vessel (isolated). The svs required on the superheater must be determined on the basis of 6 lb of steam per square foot of heating surface on the superheater surface exposed to the hot gases.

**Q** Which svs should blow first, the superheater or drum svs? Why?
**A** The superheater svs should always be set at a lower pressure than the drum svs so as to ensure steam flow through the superheater at all times. If the drum svs blow first, the superheater could be starved of cooling steam, leading to possible superheater tube overheating and rupture.

**Q** Do reheater svs requirements follow the rule on superheater sv requirements?
**A** No. The capacity of the reheater svs cannot be included in the total sv capacity required for the boiler and superheater. The relieving capacity of the reheater outlet sv must be not less than 15 percent of the required total on the reheater. And the total capacity on the reheater must be at least equal to the maximum steam flow for which the reheater is designed. One sv must be in the reheater outlet.

**Q** Name some points to consider when attaching an sv to a steam boiler.
**A** See the latest ASME Boiler Code, Sections I and IV. Pertinent excerpts are:

1. The sv or svs shall be connected to the boiler independent of

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any other steam connection and attached as close as possible to the boiler, without any unnecessary intervening pipe or fitting.

2. Every sv shall be connected so as to stand in an upright position, with spindle vertical.

3. The opening or connection between the boiler and the sv shall have at least the area of the valve inlet. No valve of any description shall be placed between the sv or svs and the boiler, nor on the discharge pipe between the sv and the atmosphere. When a discharge pipe is used, the cross-sectional area of the outlet pipe shall be not less than the full area of the sv outlet, or of the total of the areas of valve outlets discharging thereinto, and shall be as short and straight as possible, and so arranged as to avoid undue stresses on the valve or valves.

4. All sv discharges shall be located on pipes so as to be carried clear from running boards or platforms. Ample provision for gravity drain shall be made in the discharge pipe at or near each sv, and where water of condensation may collect. Each valve shall have an open gravity drain through the casing below the level of the valve seat. For iron and steel-bodied valves exceeding 2-in. size, the drain hole shall be tapped not less than ⅜-in. pipe size.

5. If a muffler is used on an sv it shall have sufficient outlet area to prevent backpressure from interfering with the proper operation and discharge capacity of the valve. The muffler, or plates, or other devices shall be so constructed as to avoid any possibility of restriction of the steam passages due to deposit.

**Q** What causes an sv to stick to its seat?

**A** Mostly corrosion and deposits on valve and valve seat due to the sv not having lifted for a long period. To avoid this most dangerous condition on automatic fired (especially lp) boilers, the sv should be periodically raised by using the hand lever, or preferably by raising the steam pressure to the popping point. The latter practice should be done only with constant attendance at the boiler, and then only under the supervision of trained personnel who will carefully watch boiler pressure and immediately shut the boiler down if the pressure starts exceeding the maximum allowable. The lever testing of svs should be done with at least 75 percent boiler pressure on the sv.

**Q** How often should svs be tested?

**A** 1. On lp automatic nonattendant-fired boilers, at least once a month, with a yearly test by raising the steam pressure to the popping point under the supervision of trained personnel. The same rule should be followed for the smaller package-type hp boilers that have infrequent operator attendance.

2. On large hp boilers in industrial plants with integrated and inter-

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2. The svs do not match pressure rating and capacity with that of the boiler. This is dangerous if too small a valve is installed.

3. The relief valve is installed in the wrong place (Fig. 1-3). It should be installed on the boiler proper (Fig. 1-4). Many contractors and plumbers believe the function of the relief valve on a hot-water-heating boiler is to protect the boiler against overpressure from the city water supply. Its main function is to protect the boiler against overpressure due to a runaway firing condition.

4. Hot-water-heating and hot-water-supply boilers require ASME pressure-rated, Btu-rated valves. But Btu rating should match the Btu output of the boiler for the fuel being fired. Many relief valves are installed with the Btu capacity not given, just the pressure setting and diameter of the valve.

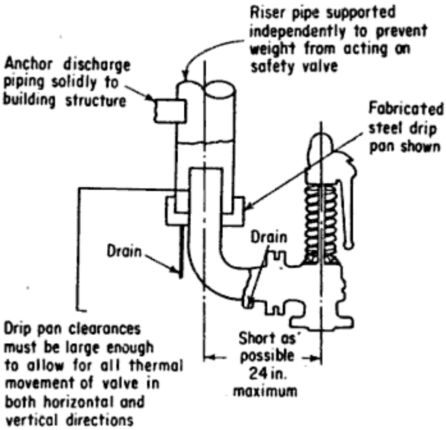


**Fig. 13-8. Correct safety valve discharge piping hookup.**

5. Undersize inlet and outlet nipple connections of the sv restricting flow. This is usually found where the outlet from the sv is piped to a safe point of discharge. And smaller diameter pipe or tubing is also often used.

> WARNING: Never use smaller inlet and outlet connections than the minimum diameter of the sv.

6. Outlet piping of svs not sufficiently braced against the reaction forces when an sv discharges (Fig. 13-8). This often leads to flanged connections breaking.

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NOTE: Excerpt from ASME Power Boiler Code 1965 states: When a discharge pipe is used, the cross-sectional area shall be not less than the full area of the valve outlet, or of the total of the areas of the valve outlets discharging therein. And it shall be as short and straight as possible and so arranged as to avoid undue stresses on the valve or valves.

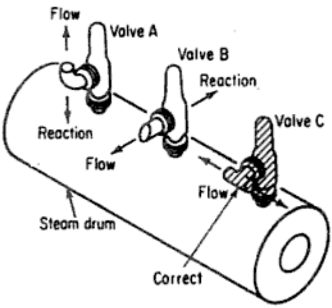

**Fig. 13-9. Reaction force on discharging safety valve.**

The usual method of handling the valve effluent, where it can be discharged directly to the atmosphere, is shown for valves A and B in Fig. 13-9. But to use less reinforcement, the tee-discharge shown for valve C is the answer. The tee produces no reaction on the valve or valve nozzle because it discharges in opposite directions, thus equalizing the thrust.

REMEMBER: Discharge of an sv should be located so there is no danger of scalding a person standing nearby.

## WATER GAGES AND WATER COLUMNS

**Q** What is the purpose of a water gage, and how should it be attached to a steam boiler?

**A** The water gage shows the proper water level that must be maintained on each boiler to avoid overheating damage. For boilers like the locomotive or vt type, it is usual to attach water gage glass fittings directly on the boiler head or shell. But in hrt and dry-back marine boilers, the setting or smokebox prevents direct attachment, so a water column is used. Water columns are also used on wt boilers where direct attachment to the drums is not convenient. The current practice is to combine water gage and water column so the water column acts as a stabilizer. That prevents water from fluctuating severely in a gage glass connected directly to a drum.

**Q** What is the first appliance to observe on a steam boiler when checking operation?

**A** The gage glass and the level of water in the gage glass. This is extremely important as most boiler damage is due to low water.

**Q** Where should the lowest visible part of the water glass be located?

**A** For hrt boilers, at least 3 in. above the highest point of the tubes,

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high and low levels by tubing connection, the water level is shown by a graduated scale on the instrument.

**Q** What is a water column, and how should it be connected to a boiler?

**A** A water column is a hollow casting, or forging, connected by pipes at top and bottom to the boiler's steam and water spaces (Fig. 13-11). The steam pipe connection to the top of the water column must not be lower than the top of the glass, and the water pipe connection to the column must not be higher than the bottom of the glass. The minimum size of these connecting pipes must not be less than 1 in. Use plugged tees or crosses at right-angle turns, so that all piping may be easily examined and cleaned by removing the plugs. Valves, if used on steam and

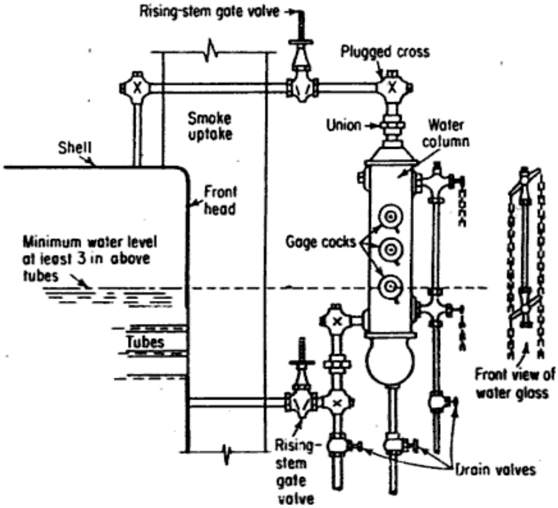


Fig. 13-11. Water column with proper connections to horizontal return-tubular boiler.

water connections to the water column, must be outside screw-and-yoke, lever-lifting gate valves or stopcocks with a level handle. Or they must be other valve types that offer a straightway passage and show by position of the operating mechanism whether they are open or closed. Always lock these valves or cocks open, or seal them open. If this is not done, the whole purpose of the water column and gage-glass connection will be destroyed, and the true level of water in the boiler cannot be determined.

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The water-gage glass with its steam, water, and drain valves is placed on the water column as shown, and also the required number of gage cocks. Damper regulators, feedwater regulators, steam gages, and other pieces of apparatus that do not require or permit escape of an appreciable amount of steam or water may be connected to the pipes leading from the water column to the boiler. Cast-iron water columns may be used for pressures not exceeding 250 psi, and malleable-iron columns for pressures not exceeding 350 psi. Above that pressure, steel columns are used.

**Q** Why is a drain required on a water column, and what should be its size?
**A** A drain is needed to remove sediment which might block the lower connection and thus cause a false water-level indication. The drain should be of at least ¾-in. diam so that it does not easily become obstructed with sediment.

**Q** Name the attachments that are permitted to pipe connections of a water column. Why limit the number of these attachments?
**A** These are pressure gage, damper regulator, feed-water regulator, drains, level indicators, and any other connections that need only a slight flow of water to operate. The reason is that a heavy flow would cause a false water-level indication in the gage glass.

**Q** Is there a desirable location for the gage glass?
**A** Yes. The gage glass should be easily seen from the operating floor, with its lowest visible point at least 2in. above the lowest safe water level in the boiler.

**Q** Why is a globe valve not desirable for water-column drain control?
**A** Because the dam or pocket in this type of valve forms a natural trap for sediment and scale.

**Q** How do you test the water column and water-gage glass to prove that all passages are clear, while the boiler is in operation?
**A** The four basic steps are:

1. Close the top valve on the column and the top valve on the glass. Then open the drain valve on the glass. If water blows freely from the drain, the water passages from the boiler to the column and from the column to the glass are clear.

2. Close the bottom valves on the column and glass, then open the top valves. If the steam blows freely from the drain valve at the bottom of the glass, the steam passages from the boiler to the column and from the column to the glass are clear.

3. Close the drain valve on the glass and open the drain valve on the column. If the steam blows freely from the column drain, the column itself is clear.

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are connected to a common steam main, the steam connection from each boiler having a manhole must have two stop valves in series, with an ample free-blowing drain between them. The discharge of the drain must be in full view of the operator when opening or closing the valves. Both valves may be of the O S & Y type, but one should be an automatic nonreturn valve. This should be placed next to the boiler so that it can be examined and adjusted or repaired when the boiler is off the line. Steam mains going into a plant from the boiler should be adequately supported.

**Q** Explain the operation of an automatic nonreturn valve.

**A** In addition to the O S & Y stop valve, automatic nonreturn valves are usually placed on the main stream outlets of boilers installed in battery with others. This valve (Fig. 13-12) is closed by screwing down the outside stem but can be opened only by boiler-steam pressure, because the outside stem is not attached to the valve. The dashpot on top of the valve spindle cushions the valve movement and prevents chattering. When a boiler is about ready to cut in, the O S & Y stop valve is opened. As soon as the boiler pressure rises a little above the pressure in the steam main, it raises the nonreturn valve disk and automatically puts the boiler on the line.

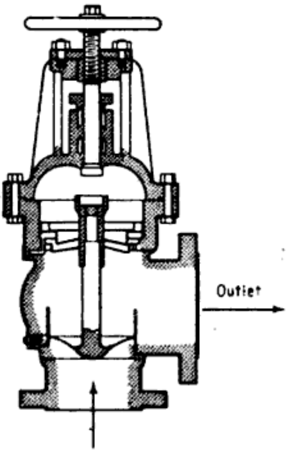

**Fig. 13-12. Automatic nonreturn valve.**

During operation, if for any reason the boiler pressure falls below the main header pressure, the nonreturn valve closes and cuts the boiler out. This valve can also be used in this way to cut out the boiler when it is being taken off the line for cleaning or repair. It really acts as a check valve, allowing steam flow from the boiler to the main, but preventing steam flow from the main to the boiler.

**Q** Does piping connected to a boiler by welding have to be radiographed? What other requirements have to be met?

**A** The welding of circumferential joints on pipes or headers is often ignored by boiler installers. The Boiler Code limits on steam pipe extends to the valves as shown in Fig. 13-13. All pipe welded within this limit must be in accord with the Boiler Code. Beyond this, it falls into the Piping Code. The contractor doing this installation of steam piping within this limit must have a PP, an A, or an S stamp for hp boilers.

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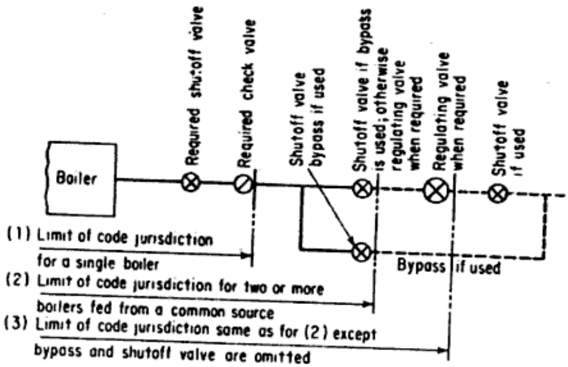


**Fig. 13-13. Code jurisdictional limits for steam piping.**

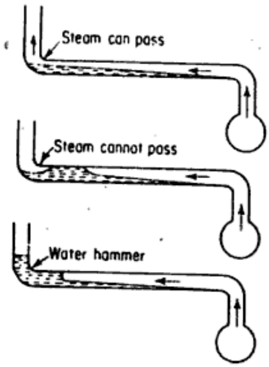


**Fig. 13-14. Water hammer is destructive.**

His weldors must be qualified for the position, material, and welding rod to be used.

If the steam piping exceeds 16 in. in nominal diameter or 1⅝ in. in wall thickness, the circumferential weld must be radiographed for the entire length. But this weld cannot be in contact with furnace gases. If they are in contact, pipe over 6 in. in diameter or ¾ in. in thickness needs radiographing. If a pipe is in contact or subjected to radiation from the furnace, radiographing is required whenever the pipe is over 4 in. in nominal diameter, or over ½ in. in wall thickness.

NOTE: Water piping need not be radiographed if it does not exceed 10 in. in nominal pipe size or 1⅛ in. in wall thickness.

**Q** What can cause water hammer in steam and condensate return lines?

**A** If the steam main is pitched incorrectly when the line is not dripped, water hammer may occur as shown in Fig. 13-14. To prevent water hammer, (1) pitch pipes properly, (2) avoid undrained pockets, and (3) choose a pipe size that prevents high steam velocity when condensate flows opposite to the steam, or where condensate has a chance to collect during idle periods.

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**Q** Why and when is a blowoff tank necessary?
**A** A blowoff tank is necessary when there is no open space available into which blowoff from the boilers can discharge without danger of accident or damage to property. For example, discharging to a sewer would probably damage the sewer by blowing hot water under high pressure directly into it. A good blowoff tank installation is always nearly full of water (Fig. 13-17).

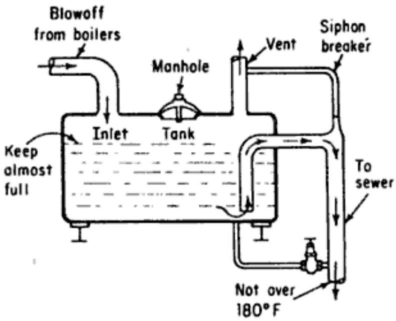


**Fig. 13-17. Blowoff tank for disposing of hot blowoff boiler water.**

**Q** When are two means of feeding water into a power boiler required?
**A** Boilers having more than 500 sq ft of heating surface require two means of feed. But the Code has been changed recently to allow one means of feed under these conditions: Boilers fired by gaseous, liquid, or solid fuel in suspension may be equipped with a single feedwater system, provided means are furnished for the immediate shutoff of heat input if the water feed is interrupted. If the boiler furnace and fuel systems retain sufficient stored heat to cause damage to the boiler if the feedwater supply is interrupted, two means of feed are still needed.

For boilers firing solid fuel not in suspension, one means of feed must be steam-operated. The source of feed must be such as to supply water to the boiler at a pressure at least 6 percent higher than any sv setting.

**Q** What is an evaporator, and why is it used for boiler operation?
**A** Evaporators are used to distill makeup water required in boilers as a result of leakage, process, or other unavoidable losses. The use of distilled water almost eliminates the formation of scale and other feedwater difficulties associated with raw water being pumped into a boiler. Evaporators are classified by the method of vaporization used as:

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1. Flash type. Hot water is pumped or injected into a chamber under vacuum, where the water flashes into steam.

2. Film type. Water in a thin film is passed over steam-filled tubes.

3. Submerged type. Steam-filled tubes are submerged in the water to be evaporated.

Deaerators are also used. Air, oxygen, carbon dioxide, or other such entrained gases are carried by water into a boiler. These may come from raw water, from leakages within a system, or by chemical reactions of water and metals in a boiler loop system. The deaerator's main function is to remove these gases from the boiler water so as to prevent corrosion of metal parts in the boiler loop. (See Chap. 15)

**Q** What is a constant potential source of oil getting into an oil-fired boiler?

**A** Oil leakage does occur in steam plants, especially during start-up. A tube failure inside the oil heater can cause a boiler to be contaminated with oil. If the oil pressure is higher than the steam pressure, oil will be forced into the steam side of the oil heater and then travel to the waterside of the boiler. To avoid this, place a check valve on the steam line to the oil heater so reverse flow cannot take place. Where condensation is returned to the boiler, it should be piped to a condensate receiver equipped with a gage glass. Then oil, if any, can be seen in the glass. Double-shell type oil heaters are often used for extra safety.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook*, 64 pages
*Pumps*, 32 pages
*Balancing Rotating Machinery*, 24 pages
*Vibration Isolation*, 16 pages
*Corrosion*, 36 pages
*Valves*, 24 pages
*Bearings and Lubrication*, 32 pages
*Mechanical Packing*, 24 pages
*Piping*, 16 pages
*Water Treatment*, 54 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

Emerick, Robert H.: *Troubleshooters' Handbook for Mechanical Systems*, McGraw-Hill Book Company, New York, 1968.

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**Q** Should new piping on a boiler installation also be cleaned?
**A** Yes. Whenever a new system is started up, not only should the boiler be boiled out, but this process should be applied to the complete system. Every piece of pipe has foreign matter deposited inside. Unless cleaned out properly by personnel familiar with boiling out and flushing piping so as to avoid undue strains on piping, trouble may develop.

> IMPORTANT: Elbows, bends, and other dead pockets in piping are dangerous spots and must be thoroughly cleaned.

**Q** What precautions must be observed in acid cleaning of boilers equipped with a superheater and other such bent tubes?
**A** Make sure all traces of acid are thoroughly cleaned out of U bends. This is critical in the neutralizing and flushing stage after soaking the tubes with an acid solution. Compressed air may have to be used to force the solution out of dead pockets. If not, the acid solution may not be completely cleared, and thinning of tubes will result. Acid cleaning of riveted boilers can be dangerous because the acid may settle under the butt straps or lapped plates and eat up these holding elements. Thus riveted boilers are usually not acid-cleaned.

**Q** What areas of a boiler may become susceptible to corrosion failures from improper acid cleaning or repetitive acid cleaning?
**A** Acid cleaning of boilers may lead to problems if the following are not considered: (1) chemical analysis of the scale, (2) the age of the boiler, and (3) construction details of the boiler. Welds with surface imperfections are a likely spot for acid attack, leading to possible stress corrosion cracks.

Areas subject to high local stress and repetitive application of stress may be affected by acid treatment. Tubes that have been repeatedly rolled and acid-cleaned may develop tube-roll leakage. Then with further rolling impossible, new tubes may be required. But the prevention of scale in a boiler is still the best method of keeping a boiler clean.

**Q** What precautions must be taken when filling an empty boiler that is hooked up in battery with other boilers?
**A** Remember that when filling, boiler pressure is near zero but the feed-line pressure is high. This causes a large quantity of water to flow with the feed valve only partly open. So make sure that steaming boilers supplied by the feed pumps are not robbed of feedwater. Also, always fill boilers with hot, deaerated or treated water. This procedure permits checking the rise of water level by the temperature rise of drums and headers. It also permits determining whether blowoff or other valves are leaking because such leakage warms up the piping.

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**A** Nondrainable superheaters, like drainable superheaters, are always prone to overheating damage due to lack of steam or water flow while the firesides of the tubes are hot. Thus start with a low fire that will limit the hot gasses to a temperature below that which might reduce the allowable stress for the pressure being carried on the boiler. This temperature is usually considered to be 900°F for steel tubes and 950°F for alloy tubes. Thermocouples should be installed on superheater tubes to pick up the temperature of the gasses.

**Q** What attention should be given the water level in a boiler when lighting off a cold boiler and also when cutting out a boiler that has been steaming?

**A** Before lighting off a cold boiler, have the water level about 1 in. from the bottom in the gage glass. As the boiler heats, the water expands and the level reaches half a glass or over by the time the boiler is ready to cut in. When the fires are extinguished, before cutting out a boiler steaming on line with other boilers, bring the water level to at least half a glass. Heat stored in hot brick walls generates steam for some time. The steam stop valve on the boiler must remain open while steam is generated with the fires out or the safety valves will lift. During this time steam flows to the main header and water drops in the glass, so feed the boiler from time to time.

When the water level in the glass stops dropping, the boiler is ready to cut out by closing the main stop. If the steam stop valve is not closed then, the water will rise in the glass because the boiler stops generating steam and condenses the steam from other boilers connected to it.

**Q** What is an operator's first duty when taking over a watch?

**A** First observe the water level in the gage glasses of all boilers. Blow down the water column and gage glass on each boiler and observe the return of water back into the glass. Then check the water level with gage cocks, if installed. Check the operating pressure and note if it is within the rated pressure of the boiler.

**Q** What action should an operating engineer take if he discovers a defect in the boiler or equipment under his charge?

**A** As most states have laws on permissible repairs, the defect should be reported to the authorized boiler inspector so he can make an inspection of the defect and advise what repairs are permissible. If the boiler is insured, contact the company. If it is not insured and is in a Code state, contact the state inspector. This procedure will assure proper repairs are made so that the strength of the boiler is in no way weakened. Remember, unauthorized repairs may be legal violations.

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**Q** Describe a test on an hp boiler which will indicate that the lower gage glass is obstructed even though the gage glass is half full of water.
**A** Open the try cocks on the water column. If all show steam it means the bottom connection is obstructed, permitting steam from the top connection to condense in the gage glass. The boiler should be shut down immediately and inspected for possible dry-firing damage. Naturally, the bottom connection of the water column and gage glass should be cleaned of all obstructions before returning the boiler to service.

**Q** What are some causes of water bobbing up and down in a boiler gage glass? How is it corrected?
**A** This condition is usually from foaming, especially in smaller boilers where contaminated condensate returns to the boiler. Foaming can also be from excessive water hardness, high water density in the boiler, or from impurities forming scum on boiler-water surface. In severe cases water boils violently and carries over into steam lines.

If the boiler is equipped with a surface blow, open it to blow scum off the water's surface.

> CAUTION: Keep your eyes on the gage glass while blowing and your hand on the valve. This habit keeps you from walking away from the boiler and forgetting to shut off the valve.

You may have to raise the water in the glass and give additional blows to stop foaming. If the test shows that the boiler-water concentration is high, raise the water to near the top of the glass and open the bottom blow valve. Repeat feeding and blowing until the water tests right and the foaming stops.

> CAUTION: Cut out fires while giving bottom blow to a wt boiler. Make a thorough check to find the source of the contamination. Grease extractors may be faulty or loaded with oil. The water should be tested by a qualified boiler-water specialist for purity. Follow his advice on how to correct the condition.

**Q** What should be done if an unusually high feedwater pressure is necessary to maintain the water in the boiler?
**A** Check the feedwater valves and lines to make sure that a valve has not broken off its seat or that there is not some obstruction in the line itself. Some methods of feedwater treatment have been known to deposit chemicals inside the feedwater line, making it impossible to get water into the boiler. Also look for leaks due to cracked or corroded piping of the feedwater (or condensate line on heating boilers) especially if it is buried anywhere in the system.

**Q** Describe the procedure to be followed in starting a vt boiler so as to

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prevent overheating the upper segments of tubes that are not surrounded by water.

**A** Two methods can be used to prevent the upper segment of the tubes from becoming overheated until steam is raised:

1. Start the boiler with a low fire until steam is raised.
2. Fill the boiler with water, operate at this level until the water temperature is near steaming, then adjust the level by blowdown.

**Q** What should be done if water is not visible in the gage glass because of failure of the feedwater supply?

**A** Immediately:

1. Shut off the fuel to the burners and secure the burners.
2. Check the water level by trying the try cocks and water-column drain. If definite low water is indicated below the gage-glass level, close the main steam valve and feedwater valve.
3. If the boiler is equipped with one, open the superheater drain.
4. Continue operating fd and id fans until the boiler cools gradually.
5. Let the pressure reduce gradually and when the furnace area is sufficiently cooled, check for leaking tubes and other signs of overheating damage. On ft boilers, look for cracked or warped tube sheets, broken and leaking stay bolts in the waterlegs. On sm boilers, check for cracked or leaking furnace-to-tube sheet welds. On ci boilers, look for cracked sections. On steel boilers, check for leaking joints on longitudinal or circumferential welds or riveted joints.
6. If no leakage is evident, give the boiler a hydrostatic test of 1½ times the allowable working pressure. Then again check for leakage at all critical parts of the boiler. If leakage is observed during the initial check or during the hydrostatic test, notify the authorized boiler inspector immediately so he can inspect the boiler and advise on permissible repairs.

**Q** What action is necessary when a tube suddenly leaks during boiler operation?

**A** Immediately extinguish the fires by cutting off the fuel. Then use all measures to protect the firing equipment. To speed cooling the unit, let the airflow remain the same. During this time, if the boiler is so equipped, partially open the superheater outlet header drain, then shut the boiler nonreturn valve.

> CAUTION: Large quantities of water may be discharged from the ruptured tube, so the feedwater supply to other units may be depleted as the automatic feed valves open on the damaged unit. Start additional feed pumps. Maintain the flow of feedwater to the damaged unit so as to keep water in the gage glass. Continue doing so until all the pressure is off and the furnace is sufficiently cooled

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to prevent overheating of pressure parts. To provide the necessary fast-cooling rate, adjust the airflow. Secure the boiler and find the damaged or leaking tube.

NOTE: Repairs should be approved by an authorized boiler inspector. After repairing the tube, hydrostatic test to 1½ times the allowable pressure and check for other weak tubes caused by corrosion, pitting, or dry firing. Replace the tubes as needed until a hydrostatic test shows no leaks. The authorized boiler inspector will also inspect the boiler for leakage or defects other than on tubes, and advise on permissible repairs.

**Q** When should boilers be blown down?

**A** Only during minimum steaming periods. The reason is that circulation in some boilers is very sensitive. Thus blowing down during maximum steaming conditions could upset the circulation so badly that some parts, especially tubes, might be seriously damaged.

CAUTION: Blowdown valves on waterwalls serve primarily as drain valves. NEVER blow down waterwalls when the boiler is in operation. If difficulties arise that require blowing down waterwalls, do this only under banked conditions (low steaming) or only in accordance with your boiler manufacturer's instructions.

**Q** What is the proper sequence in opening and closing blowoff valves?

**A** On a boiler equipped with a blowoff valve cock or a quick-opening valve in the same blowoff connection, always open the cock or the quick-opening valve first, the blowoff valve second. To close, always close the blowoff valve first and the cock or quick-opening valve second.

CAUTION: Open and close the blowoff valves and cocks slowly to reduce shocks as much as possible.

**Q** Should any special precautions be taken in blowing down a boiler where the water-gage glass is not in view of the operator blowing down the boiler?

**A** Yes. Always station another man where he can see the water-gage glass and can signal to the operator blowing down the boiler. Boiler operators must never start blowing down a boiler and then leave it to do some other job.

CAUTION: Never take your hands off the blowoff valve while it is open.

**Q** Should standby or reserve boilers not in use be full of water or empty?

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**A** Whether kept "wet" or "dry" depends. If the unit is subject to freezing, keep it dry. But if the unit will be out of service for only a few days, keep it filled with water. A boiler out of service for over 24 hr is subject to corrosion, and storing dry or filling completely with water does minimize corrosion attack. Make sure there is no suspended matter in the drum or shell when storing. And never completely empty a hot boiler because the solids will bake on the interior surfaces. When removing the boiler from service, be sure to blow down frequently to remove mud and suspended solids. And cool down gradually. Then when the boiler and setting have cooled so that residual sludge will not bake onto the metal, open the boiler.

If a boiler is to be stored dry, there is always the danger of dry firing the boiler. For example, a sudden cold spell requiring additional heat often causes someone to fire the empty boiler. Guard against damage by securing the fuel lines, tagging the switches, pulling the fuses, etc.

**Q** What is the effect of laying up heating boilers improperly during summer outages?

**A** Cast-iron and steel boilers are susceptible to corrosion damage during summer outages. Soot, if not cleaned, will form sulfuric acid in damp or sweating basements. Water, if not treated, will corrode the inside of the boiler. Burning trash intermittently in a boiler can cause dry firing if the water level is not watched and can also cause acid-type attacks in the fireside when the boiler is idle.

**Q** Can corrosion attack be minimized on heating boilers during summer lay-up?

**A** Yes. The boiler should be flushed and cleaned on the waterside. The fireside should be cleaned of all soot deposits. Then lay up the boiler either wet or dry.

**Q** Explain the wet-storage method.

**A** This method is best when freezing is not a problem and if the unit will not be needed for at least a month. After it is prepared for storage, fill the boiler to water level with deaerated water. If no deaerated water is used, open a top vent. Then build a light fire to boil the water for 8 hr so dissolved gases are driven to the atmosphere. Use 1½ lb of sodium sulfite for each 1,000 gal of water stored in the boiler to protect against oxygen. The concentration should be about 75 ppm. Use caustic soda to obtain alkalinity of 375 ppm. Keep the water temperature as low as possible and test the water weekly.

**Q** Explain the dry-storage method.

**A** The big problem with the dry method is keeping the insides dry. Air blast with independent outside hot air after draining. When dry,

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place shallow pans of quicklime inside, then close all openings tight. Place trays between tubes and one in each steam drum (wt type) and bottom of shell (ft type). Open the boiler every 30 days and if the quicklime is saturated with water, replace it (or whatever material is used).

**Q** How and why is a hydrostatic test made on a boiler?
**A** Fill the boiler with 70°F (or warmer water) until the water comes out of the highest vent. Remove the safety valves and blank their connections. Don't apply gags to the spindle because this will bend them and bind the valve. Apply the gag only to the disk of the valve. If the boiler is in battery, close both stop valves and open the drip valve between the stop valves. Leakage at the drip valve indicates that the first stop valve near the boiler is leaking. Stop the test and insert a blank in the line. Raise the pressure slowly to 1½ times the sv setting and hold this pressure until the areas to be checked can be examined. Then apply the hammer test for weaknesses.

The purpose of the hydrostatic test is to see that all welds, joints, and tube connections are tight. It is NOT a proof test. This hydrostatic test is also used on new construction, when repairs are made to a boiler (such as welding or new tubes installed), or to determine the exact source of leakage or defect suspected in some part of a boiler. It is used on heating as well as power boilers.

For example, on ci boilers for checking cracked sections, a hydrostatic test is often used. Such a test is mandatory after a major repair for checking the soundness of the repair before returning the boiler into service.

**Q** List the precautions needed with refractories on oil-fired boilers.
**A** Refractories (brickwork) are subject to damage from many causes, such as improperly adjusted fires and vanadium-contaminated oil. Impingement and the resulting carbon buildup are common. The flame should travel down the furnace on sm boilers without touching either the furnace or the refractory. Long periods of operation on low firing often cause refractory damage. The very small flame reduces the combustion chamber temperature and causes poor combustion.

Carbon builds up and intense heat is directed at the surface of the refractory, thus causing spalling (facing breaks off). Unless the oil has been specifically treated, there is no relief from the damages caused by vanadium in the oil. Moisture trapped in the refractory may develop steam, which ruptures the surface.

**Q** What size draft-air opening is needed for a packaged boiler installed in a closed machine room?

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**A** There should be a fixed opening for fresh air, an average area of 2 sq ft for each 100 boiler hp. Opening windows is not the answer because they are often closed in cold weather. Then the boiler starves for air. Remember that for each boiler horsepower, about 10 cfm of air is needed.

**Q** Explain a safe soot-blowing method to prevent furnace explosions.
**A** The boiler manufacturer provides safe soot-blowing instructions. Always follow them to prevent explosions, puffs, or blowbacks. Each boiler requires a different method, depending on its gas passage design, the type of fuel being burned, and differences in operating instructions. Here are five points to remember:

1. If possible, the boiler to be cleaned should be operated at maximum design load. If soot is blown at low boiler loads, clouds of soot may enter the gas stream to form explosive mixtures. These may ignite from hot furnace walls or from smoldering soot fires. So *all* tube surfaces and *gas* passes should be blown with the gas flow at, or near, maximum.
2. On oil- or pulverized-fuel-fired boilers, use soot blowers with burners operating at the highest possible burning rate. Check the burners during soot blowing for stability. High and stable burning rates prevent flames from being blown out by small puffs or agitation of the gas flow during soot blowing.
3. Before operating soot blowers, always increase the furnace draft to help purge combustible gas pockets.
4. If heating surfaces must be cleaned with soot blowers while burners are out of service, before blowing, make sure that the boiler is cold and that there is no smoldering soot.
5. The normal soot-blowing sequence is to follow the gas flow through the boiler. Thus the first soot blower to operate is that nearest the burners, then each unit in turn along the gas passes to keep from blowing soot on cleaned surfaces. But if back passes are heavily deposited, they may plug unless blown first.

REMEMBER: When units are banked, soot blowers are operated in reverse order, from rear to front.

**Q** How do tubes usually deteriorate from soot blowers?
**A** Steam cutting from an improperly aligned or improperly operating soot blower badly erodes tube metal. Idle soot blowers on an idle boiler with leaking soot blower valves can cause condensed steam drippage on the tubes. The drips produce external tube corrosion, especially if sulfur is present in the fuel gas deposits in the tubes. So carefully examine soot blower elements each time the boiler is out of service. Soot blower elements often warp, or a loose bearing may shift, causing misalignment, and thus erode the tubing.

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**Q** On packaged boilers, list the causes and hazards of the fire going out while the burner is running.

**A** (1) Oil supply suddenly runs out, (2) dirty or clogged oil line, (3) metering valve clogged, (4) piping or check valve clogged, (5) water is in the oil, (6) suction line springs a leak, (7) low fire set too low, (8) magnetic oil valve burned out, (9) oil is too cold, and (10) fire burns away from the nozzle. The potential hazard of each malfunction is a furnace explosion.

**Q** On packaged boilers, list the causes of the burner continually going off and on.

**A** (1) Fluctuating water level tripping low-water cutoff, (2) loose connections or defective control, (3) controls not connected properly or not properly adjusted, (4) partial electrical ground, (5) intermittent low voltage, and (6) combustion control opens the circuit when the burner goes to low fire. The potential hazards of each are overpressure and dry firing.

**Q** On a packaged boiler, what would prevent the burner from shutting off?

**A** (1) Limit controls set too high, (2) grounded control circuit wire, and (3) relays not falling out on opening of the circuit. The potential hazards of each are overpressure and dry firing.

**Q** On a packaged boiler, what would cause fire puffs when starting?

**A** (1) Starting draft poor, (2) firebox incorrect, (3) wrong burner nozzle, (4) lean fire, (5) insufficient gas pilot or excessive gas pilot, and (6) water in the oil. The potential hazard of each is a furnace explosion.

**Q** On a packaged boiler, what would cause improper combustion?

**A** 1. Fire puffs or fluctuations from the fire burning away from the nozzle (incorrect firebox, nozzle, or atomizing cup not located properly); poor draft; excessive oil temperature; water in the oil; unsteady oil pressure.

2. Carbon in the firebox from the wrong shape fire; improper firebox construction; poor draft; forcing burner; damaged atomizing cup; nozzle or cup off-center; carbonized nozzle; carbonized atomizing cup; firebox too small for the load.

3. Fire smoking from improper burner adjustment; burner too small; firebox too small; insufficient air or too much oil; poor draft; carbon in the firebox; fire room starved for air; lean fire burning at low temperatures in a large firebox.

The potential hazard of each is a furnace explosion.

**Q** On a packaged boiler, what would cause the burner to start and light but then lock out?

**A** 1. Combustion control is slow in making contact from sooted ele-

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ment; element is worn out; element is in cold-air stream or incorrectly located; element is at the end of long gas travel; auxiliary air damper opens too slowly on high-low or modulated linkage; fire is too lean; poor draft.

2. Oil supply fails or is insufficient.
3. Magnetic oil valve is defective.
4. Insufficient time for ignition.
5. Insufficient time on safety lockout switch.
6. Smothered fire due to poor draft or too little air.
7. Control contact broken or dirty.

The potential hazard of each is a furnace explosion.

**Q** On a packaged boiler, what would cause oil leaks?

**A** 1. From the furnace front, atomizing cup does not extend the proper distance beyond the nozzle.

2. From the firebox or checker work, carbon formation on the nozzle or in the firebox; poor atomization; impingement of oil on an exposed boiler surface; electric oil valve fails to shut off tightly the instant the burner is off.

3. From the rear of the burner shaft, clogged atomizing cup; leaking electric oil valve or badly leveled burner.

4. Loose pipe connections, packing glands, porous castings, defective gaskets.

5. Lubricating oil, overflow from oil filler cup caused by filling when burner is running.

The potential hazards are fire and a furnace explosion.

**Q** On a packaged boiler, what malfunctions would prevent carrying the maximum load?

**A** Oil pressure is failing, the draft is limiting maximum firing, refractory shields too great a heating surface, the burner is too small, the boiler is too small or short-circuited, the firebox is too small or improperly constructed. The potential hazards are dry firing and furnace explosions.

**Q** What safety precautions should be observed in operating and maintaining an automatic burner system?

**A** 1. Always close off all manual fuel valves before working on a burner or disconnect the wiring to automatic fuel valves or do both.

2. Never stand in *front* of a burner or boiler when starting up.

3. Never manually push in relays unless the manufacturer's instructions so advise.

4. Never permanently block in relays with rubber bands, sticks, or other devices.

5. Never change the safety switch timing of a flame supervisory control. If the system is locking out, correct the cause, NOT the symptom.

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6. Never install jumper wires or bypass any safety interlock switches.

7. Before starting a burner, visually inspect every combustion chamber to make sure there is no accumulation of combustible.

8. Regard every system lockout as a safety lockout until proved otherwise by competent personnel.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook*, 64 pages
*Steam Generation*, 48 pages
*Handbook on Fans*, 16 pages
*Water Treatment*, 54 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

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# 15

# BOILER-WATER TREATMENT

**Q** What is often neglected in maintaining heating boilers and commercial boilers in smaller plants?

**A** Usually the most damaging agent in boiler handling is either the lack of, or the improper use of, feedwater treatment. Today most sources of water are surface waters, and to make the water palatable, it is oxidized. Thus untreated boiler water ends up by being high in oxygen content, which must be eliminated so it does not combine with boiler metal. Many water sources also have high calcium or silicon contents, making treatment necessary to eliminate hard-scale forming.

Other chemical alkaline agents are found in water and all require qualified analysis. An important part of feedwater treatment is blowdown (at times continuous) because most water treatments will cause the dangerous elements to precipitate as solids. And the amount of solids in boiler water affects the quality of the steam. Each solid particle in suspension acts as the nucleus of a drop of moisture when the boiler is operated at high levels of steam production. Thus the higher the concentration of solids, the wetter the steam may be. But high concentrations of solids can also occur from over-treatment, ending up as insulation on heating surfaces, thus promoting boiler failure.

**Q** Is pure water found in a natural state?

**A** No, not chemically pure water. It always contains other substances. Nature's nearest approach to pure water is rainwater, yet this is unsuited for boiler consumption because of the foreign matter it picks up in the air. Because most of these foreign particles are harmful, they are called impurities. Their appearance in rainwater can easily be accounted for when we remember that water is the best solvent known. In fact, it is often called the universal solvent because, given time, it can dissolve almost any substance.

**Q** How do impurities get into boiler water?

**A** Besides the natural contaminants in raw water from any source, there are air, oil, and several other contaminants from plant equipment.



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Cooling water from rivers, lakes, or oceans can leak into a steam-condensing system from these sources: (1) condensers, including main or auxiliary condensers, water-cooled air-ejector condensers, distilling condensers, or water-cooled gland-exhaust condensers; (2) evaporators; (3) condensate and drain coolers; (4) leaky feed, suction, and drain lines.

**Q** How does air contaminate feedwater?

**A** Air is neither an element nor a compound, but a mixture of several gases. These gases are soluble in water to varying degrees. Thus water has a tendency to absorb and carry these gases (when the two make contact) along with it. But using a closed-feed system reduces these points of contact to a minimum. In addition to air already being present in raw feedwater, air may enter at (1) feed tanks through vent pipes, (2) pump packing and leaky packings in heating system piping and valves, and (3) open hot wells and surge tanks. But some gases in air have no effect whatever on the system or its operation.

**Q** How does oil get into feedwater?

**A** Oils and greases have a damaging effect on a boiler and offer high resistance to heat transfer. The higher the operating temperature and pressure, the more the boiler suffers from the effects of oil in the water. Fortunately, high-pressure boilers are usually used with turbines where the dangers of oil contamination are considerably reduced. Reciprocating steam engines and pumps use cylinder oil that is more detrimental than turbine oil. Oil contamination may come from (1) careless, ignorant, and excessive use of oils; (2) leaky fuel oil heater coils; (3) dirty or improperly operating grease extractors, filters in hot wells, etc.

**Q** In what state may impurities be in boiler water?

**A** No matter what the chemical characteristics of the impurity may be, three states are possible:

1. If the impurity is a soluble solid, it appears in a dissolved state or in *solution* with the water.

2. If the solid is not soluble in water, it is not in solution, but in a state of *suspension.*

3. Those impurities of a gaseous nature that are partially soluble are in an *absorbed* state in the water.

**Q** How can the state of the impurities affect the treatment of the water?

**A** The impurity classification determines the effects the impurities produce and the required methods of treatment. For example, if it is known that a certain impurity will remain in solution regardless of the temperature or concentration, then obviously it will not drop out of solution and thus not be a scale producer.

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trolled to produce high-quality feedwater. Don't compare packaged boilers with older steam generators run at much lower ratings. These older units sometimes do get by with minimum attention to feedwater treatment.

**Q** What are major treatment problems with heating boilers?
**A** Corrosion and pitting. Scale is not a problem because the same feedwater is used continuously, and initial treatment usually lasts throughout the heating season.

**Q** Are there many treatment methods available?
**A** Yes. But they all come under three broad classifications: mechanical, heat, or chemical treatment. Mechanical treatment includes filtration and boiler blowdown. Heat treatment includes makeup distillation and steam purification. But distillation is limited to boilers with small amounts of makeup. Steam purifiers are used where the process demands very dry steam. Chemical treatment, both internal and external, is most widely used. External treatment adjusts raw-water analysis before the water enters the boiler. Internal treatment adjusts the boiler-water analysis by feeding chemicals directly to the boiler.

**Q** What is the first step in any water-treatment program?
**A** Analyze the water, as chemically pure water is rare. Few water supplies are suitable for domestic or industrial use without treatment. And the chemical compositions of different water supplies vary greatly. So it is impractical to prescribe any one "ideal" treatment. Every engineer should know how to make routine water tests such as are used in the daily operation of a water-treatment system.

Remember that boiler-water treatment involves more than just scale prevention. Important are the kind and control of chemical treatment, regulating the preheating and pretreating of makeup, and regulation and control of boiler blowdown to prevent a buildup of boiler-water solids. Supervision and control of this program call for a qualified operator or a firm specializing in boiler-chemical service. Prevention of feedwater trouble usually costs far less than the repair of neglected equipment.

**Q** What is meant by a water analysis?
**A** Analyzing a water sample is the process of finding out how much of the various impurities and other chemical substances are present in the water. The results are usually expressed in parts per million (ppm) and tabulated as shown in Fig. 15-1. Parts per million is a measure of proportion by weight, such as one pound in a million pounds. Grains per gallon (gpg) is another way of expressing the amount of a substance present. One grain per gallon equals 17.1 parts per million. Individual impurities, with the possible exception of hardness, are rarely reported in grains per

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gallon. But quantities in parts per million are often converted to grains per gallon to aid in calculating the capacity of water-treating equipment.

Water usually contains a wide variety of dissolved compounds, each of which breaks down into its respective ions when dissolved. Thus atoms of the combination molecule separate. While chemists can measure the amount of each cation and anion in the solution, it is impossible to chemically analyze the amount of each individual compound. We can only assume that various ions recombine in certain ways upon evaporation or precipitation. The ionic weight of ions such as calcium, sodium,

**REPORT OF WATER ANALYSIS**

| | | | | Parts per million | Equivalents per million |
|---|---|---|---|---|---|
| Date Collected 10/30/58 | | | Silica as $SiO_2$ | 5 | |
| Source well | | | Iron as $Fe_2O_3$ | 1.2 | |
| Date analyzed 11/4/58 | | | Calcium as Ca | 62 | |
| Total dissolved mineral solids | | ppm | Magnesium as Mg | 31 | |
| Organic matter | none | ppm | Sodium and potassium as Na | 38 | |
| Suspended solids | 5 | ppm | Bicarbonate as $HCO_3$ | 250 | |
| Chloroform, extractable (oil, etc.) | none | ppm | Carbonate as $CO_3$ | 0 | |
| pH | 7.7 | | Hydroxide as OH | 0 | |
| Phenolphthalein alkalinity as $CaCO_3$ | 0 | ppm | Chloride as Cl | 11 | |
| Methyl orange alkalinity as $CaCO_3$ | 205 | ppm | Sulfate as $SO_4$ | 138 | |
| Hydroxide alkalinity as $CaCO_3$ | 0 | ppm | Nitrate as $NO_3$ | 0 | |
| Hardness as $CaCO_3$ | 282 | ppm | Carbon dioxide as $CO_2$ | 10 | |
| Specific conductance | | micromhos | Turbidity | 5 | |
| | | | | | |
| | | | Physical characteristics of sample | Clear when drawn | |

**Fig. 15-1. Water-analysis report form asks for complete information.**

sulfate, and chloride can be determined. But this doesn't tell us how much individual calcium sulfate, sodium sulfate, or sodium chloride originally went into the solution.

Since analysis measures only ions, never compounds, it is logical to use the ionic form. Usually no attempt is made to indicate hypothetical compounds. If the analyses do show them, they are figured by a chemist (from their ionic weights) by using certain arbitrary assumptions.

The combined form of analysis is best described as a rule-of-thumb attempt to put a water-analysis report into shape for practical interpretation. By adding a column for parts per million expressed as calcium

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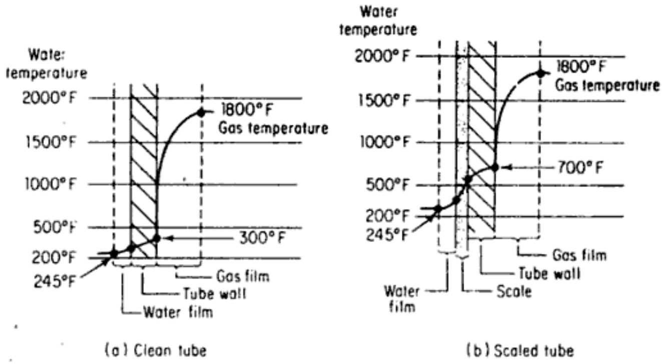


**Fig. 15-2. Effect of waterside scale in boilers.**

**Q** Give a brief rundown of external treatments for removing impurities.
**A** The table in Fig. 15-3 shows what to expect in hardness reduction when using the treatments shown. The quality of the makeup water needed depends mostly on boiler design, operating pressure, and temperature. The degree of treatment called for also depends on boiler capacity. quality of condensate returns available, and raw-water analysis. A large plant with a high percent of makeup usually justifies more elaborate external treatment than does a small installation.

| Method of treatment | Average analysis of treated water | | | | |
|---|---|---|---|---|---|
| | Hardness ppm as $CaCO_3$ | Alkalinity ppm as $CaCO_3$ | $CO_2$ in steam (potential) | Dissolved solids | Silica |
| Cold lime-soda | 30–85 | 40–100 | Medium-high | Reduced | Reduced |
| Hot lime-soda | 17–25 | 35–50 | Medium-low | Reduced | Reduced |
| Hot lime-soda phosphate | 1–3 | 35–50 | Medium-low | Reduced | Reduced |
| Hot lime-zeolite | 0–2 | 20–25 | Low | Reduced | Reduced |
| Sodium-cation exchanger | 0–2 | Unchanged | Low to high | Unchanged | Unchanged |
| Anion dealkalizer | 0–2 | 15–35 | Low | Unchanged | Unchanged |
| Split-stream dealkalizer | 0–2 | 10–30 | Low | Reduced | Unchanged |
| Demineralizer | 0–2 | 0–2 | 0–5 ppm | 0–5 ppm | Below 0.15 ppm |
| Evaporator | 0–2 | 0–2 | 0–5 ppm | 0–5 ppm | Below 0.15 ppm |

**Fig. 15-3. External treatments remove impurities from makeup water before they enter the boiler.**

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**Q** What is the difference between erosion and corrosion as it affects wearing of boiler parts?
**A** Corrosion is an electrochemical attack, whereas erosion is a mechanical action causing wear by abrasion. Improperly adjusted soot blowers, for example, can cause high-velocity steam to cut or abrade a tube. Dirty or gritty flyash travelling through a boiler at high speed can cause tube thickness to be reduced to dangerous levels by this sand-blasting effect.

**Q** What is carry-over, and how is it caused?
**A** Carry-over is entrained moisture and associated solids passing from a boiler with the steam. These slugs of moisture cause erratic superheat and mechanical troubles with engines and turbines. Carry-over also deposits solids in superheaters and on turbine blades. And it may even spoil materials in process. But the main causes of carry-over are priming, foaming, or both.

**Q** Explain priming of boiler water.
**A** Priming is the spouting or surging of water into the steam outlet. It is caused by too high a water level, uneven fire distribution, load swings, too high a steaming rate, or even faulty boiler design. Remedies range from redesigning the boiler or steam drum to installing steam purifiers, lowering the water level, improving firing distribution, or reducing the boiler load. Chemical antifoams also help.

**Q** What causes foaming?
**A** Foaming is the formation of small, stable, noncoalescing bubbles through the boiler water. Water film around each steam bubble generated at the heating surface is stabilized by an increase in dissolved and suspended solids in the boiler. Thus the bubble skin becomes tough and doesn't permit coalescence or break readily when the bubble emerges. The resulting expansion of boiler water permits carry-over and priming. The main causes of carry-over are excessive dissolved and suspended solids, high alkalinity, and the presence of oil and various organics that react with alkalinity. Steam washers and mechanical separators in boiler drums effectively control carry-over within reasonable and tolerable limits. A notable exception is silica, which at operating pressures above 600 psi passes over with steam as a vapor. Proper water treatment, including the right amount of blowdown, is the key to maintaining these limits.

**Q** What is the purpose of an electrical conductivity test of boiler water?
**A** To measure the extent to which dissolved substances are concentrated in the boiler water. This test then helps in controlling carry-over of dissolved solids, which condense in lines or equipment such as turbine blades, into the steam system.

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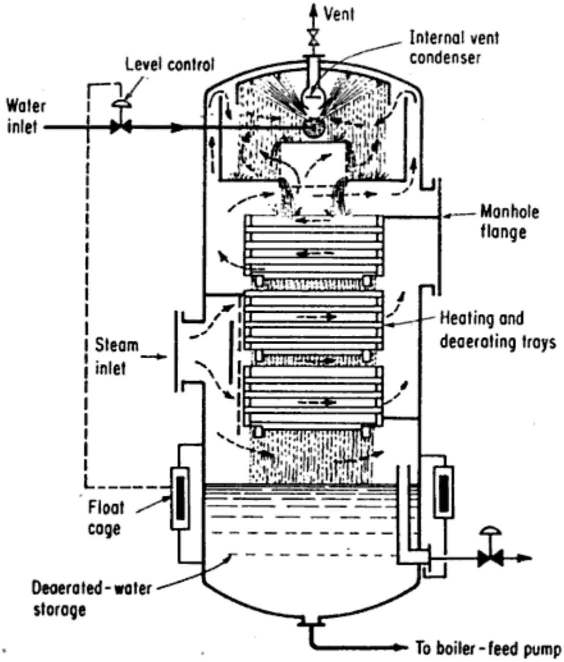


**Fig. 15-4. Deaerator of the tray-spray type.**

strong regenerating solution. The chart in Fig. 15-5 lists the capacity of the ion exchangers commonly used in water treatment.

**Q** Describe the cold, hot, and zeolite softening processes for water treatment.

**A** Four troublesome impurities in water—calcium, magnesium, silica, and oxygen—are removed by chemical reaction with combinations of lime, soda ash, and caustic. When carried out at room temperature, these reactions are termed a *cold process*. When the water is heated well above room temperature, it is called a *hot process*. The hot process is used for treating boiler feedwater. The water is heated by spraying it into the upper steam space of the softener unit. The inlet flow actuates a proportioning device to control the amount of lime and soda ash fed to the heating and mixing zone. Chemical reactions take place almost instantly. Sedimentation proceeds at a rapid pace because of the elevated temperature. The sludge-collecting cone at the bottom of the unit receives the

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trolled by blowdown. Low-pressure boilers usually permit higher sludge concentrations than are allowed for most high-pressure units.

**Q** What are organic materials?

**A** Organic materials such as tannins, lignins, starches, and seaweed derivatives are also used to keep boiler sludge fluid. Organic colloids, such as sodium mannuronate and sodium alginate, react with calcium and magnesium salts to form a floc that entangles precipitates.

**Q** Explain the phosphate treatment.

**A** The phosphate treatment to cut calcium in the boiler is almost standard practice for low-hardness feedwater. The forms commonly used include monosodium (acid), disodium (almost neutral), trisodium (alkaline), and many complex phosphates.

**Q** What is permissible boiler-water concentration?

**A** The stairstep curve in Fig. 15-7 indicates the total boiler-water con-

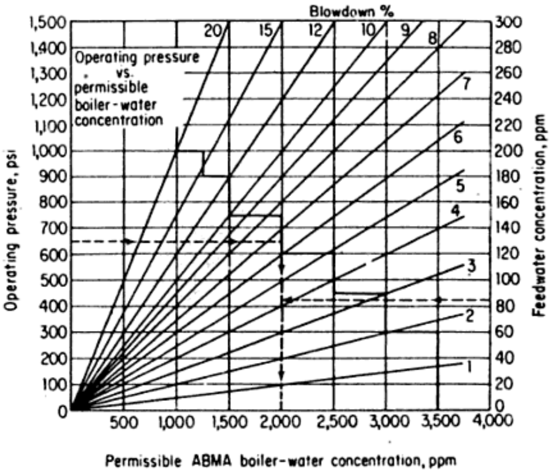


**Fig. 15-7. ABMA total boiler-water concentrations versus drum pressures.**

centrations versus the drum pressure, according to the American Boiler Manufacturers Association (ABMA). To use, assume a 650 psi operating pressure and 85 ppm feedwater concentration. To find the permissible boiler concentration and percent blowdown required, extend the drum pressure (dotted line, 650 psi) horizontally to the *pressure-versus-concentration* transfer line (stairstep curve). Now read vertically down to ***boiler-***

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*water concentration*, which is 2,000 ppm. Extend the feedwater concentration horizontally to boiler-water concentration, then read the percent blowdown required on the diagonal lines, which is 4¼ percent.

> CAUTION: This curve represents the total concentrations and does not designate the chemical constituents or physical properties of the solids. Thus do not assume that adhering to these concentrations will result in trouble-free boiler operation.

**Q** What is intermittent blowdown, and why is it necessary?
**A** Intermittent blowdown is taken from the bottom of the mud drum, waterwall headers, or lowest point in the circulation system. The blowoff valve is opened manually to remove accumulated sludge, about every 4 to 8 hr, or when the boiler is idle or on a low-steaming rate. But hot water is wasted, and control of concentrations is irregular.

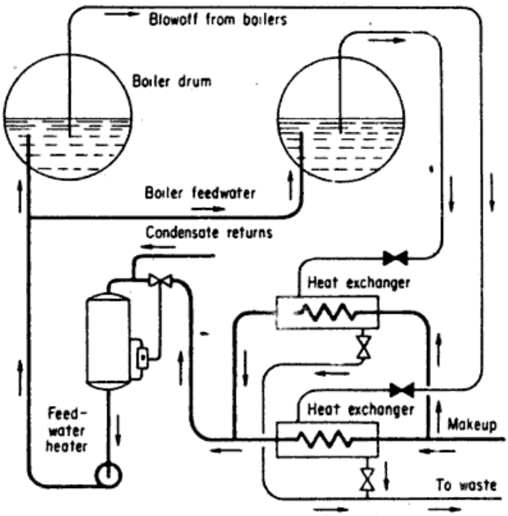


**Fig. 15-8. Continuous blowdown system keeps concentration low.**

**Q** Why is the continuous surface blowdown method used?
**A** Continuous surface blowdown automatically keeps the boiler water within desired limits. Continuously removing a small stream of boiler water keeps the concentration relatively constant. Savings by transfering heat in the blowdown to incoming makeup (Fig. 15-8) often pay for the investment.

**Q** What impurity in water requires critical attention on very hp boilers?

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**A** Silica, which in hp water volatilizes and passes over with steam to the turbine. As the steam expands and drops in pressure and temperature, the silica condenses and deposits on the turbine blades, cutting the machine's efficiency. Vaporous carry-over involving the volatilization of matter (hot gasses) increases most rapidly around 2,000 psi. Above this range, mechanical carry-over predominates, especially above the critical pressure (3,206.2 psi), as there is no longer a liquid-to-steam phase. Steam quality on these units is no longer measured by a calorimeter in percent of moisture but in parts per billion by the use of flame photometers.

**Q** What precautions must be taken when starting a systematic water treatment program for a boiler that has long been neglected?
**A** When steaming for a few days after initiating the new chemical treatment, if possible, shut down the boiler for an internal inspection. Often the new chemical treatment loosens up so much scale after the first few days, especially in hrt and sm boilers, that the scale piles up on the lower shell plates and the lower row of tubes (Fig. 16-1). Then the boiler plate and tubes bag from overheating. Scale may loosen too rapidly for removal by the usual blowdowns.

**Q** Is water treatment being automated?
**A** Yes. Today there are very sophisticated automatic controls on the market. They should be investigated and used where possible.

**Q** What are some common water-treatment tests?
**A** Titration, colorimetric, hardness, chloride, alkalinity titration, etc. Complete instructions on water testing are contained in (1) the manual on industrial water published by the American Society for Testing and Materials (ASTM) and (2) *Standard Methods for the Examination of Water, Sewerage, and Industrial Wastes,* published jointly by the American Public Health Association and the American Water Works Association.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook,* 64 pages
*Water Treatment,* 54 pages
*Waste-water Treatment,* 32 pages
*Corrosion,* 36 pages

Books

Elonka, Steve: *Plant Operators' Manual,* rev. ed., McGraw-Hill Book Company, New York, 1965.
Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers,* vols. I and II, McGraw-Hill Book Company, New York, 1959.

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# 16

# MAINTENANCE, INSPECTION, AND REPAIR

**Q** Various states and municipalities have laws pertaining to inspection of boilers. What is their purpose?

**A** The main purpose is to protect the life and limb of employees and the public, as well as protection from property damage. The legislation sets up standards for design, installation, and inspection. These are usually ASME or NB rules, made legal requirements. Most of the laws provide for periodic inspection of boilers coming within their scope, either by state, municipal, or insurance company inspectors. The owner or operator must arrange for these inspections at required, stipulated intervals. For power boilers, the requirement is usually a yearly internal inspection and an external inspection six months later. Low-pressure heating-boiler inspections may be on a yearly or biannual basis, depending on the jurisdiction.

**Q** What inspectors make the legal inspections and reports (to a jurisdiction) that a boiler is safe or unsafe to operate, or that it requires repairs before it can be operated?

**A** Three types of inspectors are:

1. State, province, or city inspectors who see that all provisions of the boiler and pressure-vessel law; and all the rules and regulations of the jurisdiction, are observed. Any order of these inspectors must be complied with, unless the owner or operator petitions (and is granted) relief or exception.

2. Insurance company inspectors qualified to make ASME Code inspections. If commissioned under the law of the jurisdiction where the unit is located, they can also make the required periodic reinspection. As commissioned inspectors, they require compliance with all the provisions of the law and rules and regulations of the authorities. In addition, they may recommend changes that will prolong the life of the boiler or pressure vessel.

3. Owner-user inspectors are employed by a company to inspect un-



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fired pressure vessels for direct use and not for resale by such a company. They must also be qualified under the rules of any state or municipality which has adopted the Code. Most states do not permit this group of inspectors to serve in lieu of state or insurance company inspectors.

**Q** What is the relationship between insurance company boiler and pressure-vessel inspectors and state laws?

**A** The relationship between authorized insurance company boiler and pressure-vessel inspectors and the enforcement officials of the various states is very close. Upon passing a required examination, the inspector is issued a certificate of competency to inspect boilers and pressure vessels by the jurisdiction in which the examination was held. Generally a person having received such a certificate then may apply for an NB commission, provided NB examinations were used by the jurisdiction. The holder of such a commission is considered as being a legal representative of the jurisdiction in which he performs inspection work.

**Q** Explain how the relationship between the commissioned insurance inspector and the legal jurisdiction is implemented.

**A** When a boiler is insured (usually by a company licensed to write boiler and machinery insurance in that state), the engineering department of the insurance company sends the state legal jurisdiction a notice that the boiler is insured. If the company has commissioned inspectors in their employ (and most companies writing boiler and machinery insurance do), the legal jurisdiction does not schedule an inspection on that boiler for which a notice was received. Why? Because it will be inspected and reported to them on a formal state report when the inspection comes due by the commissioned insurance company inspectors.

The owner must prepare the boiler for the internal inspection. On some lp boilers, internals (inspections) may be scheduled only when it is deemed advisable, depending on the state law. In others, the boiler must be drained and opened for inspection whether it is of the hp, lp, steam, or hot-water-heating type.

The commissioned inspector makes the inspection, and, if he finds conditions satisfactory, he files a report to the state, requesting the state to renew the certificate on the boiler. In some jurisdictions, the insurance company issues the certificate directly. If repairs are needed or if conditions need correction, certificates are withheld until the violation is removed. If this is not done, the inspector notifies the state of the violation and requests that no certificate be issued until the violation is removed. The state or legal jurisdiction can then use its police power to enforce the requirements.

When the insurance on a boiler is canceled or not renewed, the insurance company notifies the legal jurisdiction and gives the reasons

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for it. Many legal jurisdictions employ a numbering system on boilers. Commissioned inspectors are given state numbers to assign to boilers, and these are often stamped on the boilers.

Some legal jurisdictions have a fee for renewing certificates. The owner has to pay this when the legal jurisdiction receives a satisfactory report from the commissioned inspector when the boiler is inspected. In some states, the commissioned inspector has to collect this and send it to the state with his report. Dangerous conditions on a boiler can be reported to the state over the phone, if necessary, by the commissioned inspector. The owner will then have the full pressure of the legal jurisdiction on him to correct the condition or take the boiler out of service. Most insurance companies also have provisions for immediate suspension of insurance by the inspector under these adverse conditions.

**Q** How is the waterside of wt boilers cleaned for internal inspection?
**A** After opening the waterside, wash out the shells and tubes with a spray of hp water. Be sure that all tubes are washed thoroughly. If it is a header-type boiler, either sectional or solid, remove all handhole caps necessary for washing and examining the tubes for scale.

> CAUTION: Wash immediately after draining the water from the boiler. This prevents any heat contained in the brick setting or furnace walls from baking the soft, muddy scale to the shell and tubes.

Examine the inner shell and tubes for scale. If it is heavier than *eggshell* thickness, remove it by hand or mechanical means. If the right feedwater treatment is used, the thin scale should peel off easily by running a hand scraper lightly over the metal. Then the tubes should be turbined. If the boiler has been neglected and is badly scaled, the drums will have to be hand-chipped. Chipping is a long and tough job. If pressed for time, several concerns remove all scale completely by acid cleaning, but this should not be done on riveted boilers.

**Q** What precaution must be observed in turbining the tubes?
**A** Turbining tubes can cause local tube wear or nicking if the turbining tool is forced through a tube or held in one position too long.

**Q** Is it safe to use portable lamps and extension cords inside boiler drums, shells, or headers?
**A** Only if low-voltage lamps, 32 volts or less, supplied by transformers or batteries, are used to avoid electrical shocks in case a lamp or bulb breaks and creates a current flow through the boiler shell. Never use extension cords without proper waterproof fittings. Make all connections outside the boiler. And light bulbs should have explosion-proof guards. Fittings, sockets, and lamp guards must be grounded.

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**Q** What is the purpose of the internal inspection, and what areas of the boiler should receive the most attention?

**A** To check on the structural soundness of the pressure-containing parts, and to note any conditions that can affect its strength to confine the pressure. Wear, deterioration, corrosion, scale, oil, cracks, grooving, thinning, and other such weakening conditions require inspection. Most boilers develop their own areas of trouble spots, depending on design, operating conditions, and maintenance practices. Check all exposed metal surfaces inside the boiler for effectiveness of water treatment and scale solvents, also for oil or other substances that enter with feedwater. Oil or scale on heating surfaces weakens the metal, causing bagging or rupture. Corrosion areas next to a seam are more serious than in a solid plate away from seams. Thinning on a joint is dangerous because the strength of a joint is less than that of a solid sheet.

Check for evidence of grooving and cracks along longitudinal seams of shells and drums. Carefully look for internal grooving in fillets of unstayed heads. Inspect stays and stay bolts for even tension, fastened ends for cracks where stays or stay bolts are punched or drilled for rivets or bolts. Manholes and other openings are subject to corrosion thinning and cracks. See that openings to water column connections, dry pipes, and svs are free of obstructions such as mud and scale.

Ligaments between tube holes in heads (of all type boilers) often crack, then leak and weaken the boiler. Also, on both wt and ft boilers the beading and flaring on tube ends need checking for erosion and corrosion, cracks and thinning. Welded nozzle and other such openings require inspections for weld washout, cracks, and evidence of deterioration of the joints.

**Q** How can the presence of oil be determined in the steam drum?

**A** Oil is usually hard to detect, especially if only a very small amount is present. Run the back of the finger along the waterline. If stained and the stain cannot be washed off with soap and water, oil is entering with the feedwater and is being distributed throughout the boiler by circulation. Oil, being lighter than water, rises gradually and forms a scum along the water level. The real danger comes from tiny solid particles sticking to the oil before it adheres to the drum sides. Then gradually this weighted oil settles to the heating surfaces, causing tubes to blister or completely fail.

**Q** What checks are made on the fireside of boilers?

**A** Carefully inspect the plate and tube surfaces that are exposed to the fire. Look for places that might become deformed by bulging or blistering during operation. Solids in the waterside of lower generating tubes cause blisters when sludge settles in tubes and water cannot carry away heat.

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The boiler must be taken out of service until the defective part or parts have been properly repaired. Blistered tubes usually must be cut out and replaced with new.

Lap-joint boilers are apt to crack where plates lap in a longitudinal or straight seam. If there is evidence of leakage or trouble at this point, remove the rivets and examine the plate carefully if cracks exist in the seam. Cracks in shell plates are usually dangerous, except fire cracks that run from the edge of the plate into the rivet holes of girth seams. Usually, a limited number of such fire cracks are not very serious.

Test stay bolts by tapping one end of each bolt with a hammer. For best results, hold a hammer or heavy tool at the opposite end while tapping. A broken bolt is indicated by a hollow sound.

Tubes in hrt boilers deteriorate faster at the ends toward the fire. Tapping the outer surface with a light hammer shows if there is serious thinness. Tubes of vt boilers usually thin at the upper ends when exposed to the products of combustion. Lack of water cooling is the cause. Tubes subject to strong draft often thin from erosion caused by impingement of fuel and ash particles. Soot blowers, improperly used, will also thin the tubes. A leaky tube spraying hot water on nearby sooty tubes will corrode them seriously from an acid condition. Short tubes or nipples joining drums or headers lodge fuel and ash, then cause corrosion if moisture is present. First clean, then thoroughly examine all such places.

Baffles in wt boilers often move out of place. Then combustion gas, short-circuiting through baffles, raises the temperature on portions of the boiler, causing trouble. Heat localization from improper or defective burners, or operation causing a blowpipe effect, must be corrected to prevent overheating.

**Q** What inspections are needed on the external fitting of boilers?

**A** Safety valves are the most important attachments on a boiler. There should be no rust, scale, or foreign matter in casings to hinder free operation. The best way to test the setting and freedom of svs is by popping the valve with pressure. If this cannot be done, test by try levers. Inspect the discharge pipe to make sure it is secure. Operators have been killed because a valve discharging into the boiler room fills the space with steam in a few seconds. The opening in the discharge line must not be plugged.

Pressure gages have to be removed to test by comparing with a standard test gage. Blow out the pipe leading to the pressure gage. Make sure water column connections are free by removing plugs, or the tees. Examine the condition of the water column and gage-glass attachments.

Examine the supports of the boiler structure. Make sure that ash and soot won't bind the boiler structure to produce excessive strains from expansion under operating conditions. Look also for evidence of corrosion

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from soot on structural supports. Check the blowdown valves to see that they work freely and are packed and that external piping and fittings are not corroded or damaged.

**Q** What assistance should the owner or operating engineer give the legal boiler inspector during inspections?

**A** It is the responsibility of the owner to prepare the boiler for the required legal internal inspection. All openings must be removed. All scale and mud must be removed so metal surfaces are exposed for inspection. Firesides must be cleaned of soot so tubes can be inspected for corrosion, thinning, erosion, and evidence of overheating.

The inspector must be given all the help he needs. Point out any known defects. Station someone immediately outside the boiler when he is making his internal inspection. If the boiler is in battery with others, make sure that all steam, water, and blowoff valves are locked and cannot be opened. Make provision for the hydrostatic test if the inspector deems it advisable. In general, assist in every way to make his examination thorough and complete.

**Q** Name some shortcomings of internal inspection on today's modern hp steam generators as compared with older boilers.

**A** As boiler size and capacity increase, the possibility of a forced outage, especially one resulting from a tube failure or explosion, takes on greater significance. The length of outage and the cost of repairs are proportionate to the size of the boiler. Thus every effort must be made to prevent failure of pressure parts by adequate inspection and maintenance. Visual inspections are still required to get as close to the parts of the boiler, both internal and external, as is practicable.

On older-type installations this was possible because a greater percentage of the surfaces of the pressure parts was accessible because of design. And more openings were provided in the setting. But with newer boilers this is not often possible. Thus inspection of large boilers should also include a review of instrumented readings so as to pinpoint areas of trouble. For example, an increase in pressure drop across a bank of tubes may indicate tube fouling in that bank, and is quicker than looking at the tubes.

**Q** How is nondestructive testing equipment being used in boiler inspection to locate potential areas of failure?

**A** There are five major nondestructive tests being used: Ultrasonics, radiography, magnetic particle, dye penetrant, and eddy current. Ultrasonic equipment is now portable for field use and is extensively used for plate and tube thickness checks. These instruments become useful as tracing instruments for determining causes of failure of a repetitive nature. For example, tube failures in waterwalls are a common problem.

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After one tube failure, adjacent tubes can be checked ultrasonically and thinned tubes replaced prior to failures.

A similar practice is followed on tubes subject to flyash erosion. The thickness of the tubes in a suspected area is checked by ultrasonic equipment, and those found thinned are replaced during normal outages. Plate thickness around manhole and handhole openings, water legs, shells, and heads, are checked ultrasonically for thickness in order to determine allowable pressure.

Flaw detection, such as checking for laminations, cracks, porosity underneath plate surfaces, or welds on inaccessible visual parts, is playing a more important role. Pulse echo instruments are now available for field testing to do flaw detection.

Radiography, so important in new construction, is extensively used in field testing. Welded repairs on hp boilers are tested by x-ray or other radiographic equipment.

Magnetic-particle inspection finds its chief use in surface crack detection. Its main use is on piping and joints of boilers.

Eddy-current testing is finding its chief use in nonmagnetic-tube searching for defects, such as condensers and heat exchangers connected to a boiler.

Nondestructive testing of nuclear reactors in service will supplement also the traditional visual internal inspection which is limited because of the radiation hazard.

**Q** Name some causes of heating-boiler failures.

**A** Heating-boiler explosions (also fireside explosions) have become very pronounced. Here are some of the causes:

1. More unattended automatic operation of boilers, with complete reliance on automatic controls for overpressure and fireside explosion prevention. Though controls can malfunction in many ways, their installation can lead to a false sense of security.

2. Failure to test srvs on a consistent, regular basis.

3. Failure to maintain boiler and auxiliaries properly. The latter includes reserve boiler feed and low-water fuel cutoff. Maintenance is often neglected on water treatment, cleaning, and checking of controls.

4. As automatic boilers become more complex in control arrangement, tampering with controls or blocking the safety controls may lead to a failure.

5. The higher firing rates with suspended fuel on today's more compact boilers can quickly lead to dry firing, or to improper fuel/air ratios that trigger fireside explosions, again if safety controls don't work fast enough.

**Q** Name the usual causes of failures on large steam generators.

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to heat up vats, tanks, etc. Low-water-cutoff operation at this time could be intermittent, causing hot-and-cold shocking of the boiler. Obviously if the low-water cutoff does not function during this draw on steam, dry firing will affect the boiler.

**Q** What causes one or more bulges in tubes in a wt boiler?

**A** Usually a piece of scale breaks away from inside the boiler and settles in a tube, causing localized overheating of tube metal (Fig 16-1). Flame or heat impingement and sludge deposits are also causes. If no evidence of scale is found after a tube bulges and leaks, it may have been blown free with the tube failure.

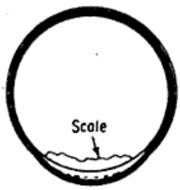


Fig. 16-1. Local bulging (blister) on water tube.

**Q** Is flame impingement on boiler parts harmful?

**A** Direct flame impingement causes local overheating of metal because water circulation may not be fast enough to keep the metal within safe limits. On ci units, flame impingement can create uneven expansion stresses that may crack a section. On wt boilers, steam pockets can form in a tube, leading to tube bulging or rupturing.

**Q** On what basis are repairs *allowed* on boilers?

**A** Repairs permitted are based on restoring the affected part or parts to as near the original strength as possible. They are governed by Code requirements for new construction, or by NB rules on permissible repairs, where the state has adopted NB rules for repairs.

**Q** Must all repairs be approved by an authorized inspector?

**A** Yes, if the strength of the vessel has been impaired in any way requiring repairs involving Code enforcement and interpretation. Repairs not affecting the strength of the boiler, or of a minor or routine nature, may not require approval. But the inspector should be consulted on the problem if there is any doubt about the safety of the boiler. Crack repairs, welding, tube replacement, sv replacement, and similar repairs or changes require approval. The best rule to follow on any structural repairs or changes on a boiler is to immediately contact an authorized boiler inspector.

**Q** Is a qualified weldor permitted to make welded repairs on any part of a boiler?

**A** Not necessarily. Because a weldor is qualified to make some welds may not mean he is qualified for welding (1) the particular thickness of plate, (2) the type of material, (3) in the position of welding to be used, or (4) the method of welding required.

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this dimension, a flush-welded patch is required, with the weld requiring full radiography and stress relieving. The repair must be approved by a qualified boiler inspector."

**Q** Can a broken stay bolt, as indicated by a leaking telltale hole, be repaired by welding?

**A** No. Repairs are not permitted because the leaking telltale hole indicates the stay bolt is cracked inside the boiler.

WARNING: Install a new stay bolt immediately.

Stay bolt heads cannot be welded to stop leakage around the heads. The heads should be recalked. If leakage persists, it may be an indication of a corroded sheet on the boiler. The old stay bolt must be removed, the sheet examined for corrosion and thinning, and if satisfactory, new stay bolts must be installed. If the sheets are corroded more than 50 percent of the original thickness, the defective section must be cut out and a flush-welded patch installed.

Threaded stays may be replaced by welded-in stays, provided that in the judgment of the qualified boiler inspector, the plate adjacent to the stay bolt has not been materially weakened by deterioration or wasting away. Stress relieving other than thermal may be used as provided in NB rules for welding.

**Q** What are the NB rules for repairing cracks on boilers?

**A** Two conditions are covered:

1. *Unstayed areas.* Cracks in unstayed shells, drums, or headers of boilers or pressure vessels may be repaired by welding, provided the cracks do not extend between rivet holes in a longitudinal riveted seam within 8 in., measured from the nearest calking edge. The total length of any one such crack shall not exceed 8 in. Cracks of greater length may be welded, provided the complete repair is radiographed and stress relieved. Cracks of any length in unstayed *furnaces* may be welded, provided the welds are thermally stress-relieved. Welds applied from both sides of the plate shall be used wherever possible. Welds applied from one side only shall be subject to the approval of the authorized inspector. Field repair of cracks at the knuckle or the turn of the flange of the furnace opening is prohibited unless approved by the enforcement authority.

2. *Stayed areas.* Cracks of any length in stayed areas may be repaired by fusion welding but multiple or star cracks (Fig. 16-3) radiating from rivet or stayed holes shall not be welded.

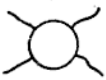

Fig. 16-3. Multiple (star) cracks.

**Q** What is a lap crack, and where would you expect to find it?

**A** Lap cracks are fatigue-type cracks (Fig. 16-4) in the longitudinal joints of lap-seam-riveted boilers. They develop because a lap seam is not part of a true cylinder. Thus a

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19. Regulate feed pumps and change-over pumps and adjust feedwater governors.
20. Regulate boiler-water level.
21. Cut in, adjust, and secure feedwater-level regulator.
22. Test svs.
23. Put a boiler on line.
24. Warm up and cut in steam lines.
25. Take a boiler off line, pull fires (for coal-burning boilers), and secure the boiler.
26. Conduct boiler-water analysis, interpret results, treat the feedwater, and adjust continuous blow according to a water treatment specialist's advice, if required.
27. Shift combustion control from manual to automatic and back again. Check the safety controls in doing this.
28. Prepare boiler logs and operating records.
29. Cut in and out superheaters properly.
30. Adjust feedwater heater pressures and temperatures.
31. Renew and repack gage glasses.
32. Remove, regasket, and replace manhole and handhole plates.
33. Inspect, repair, and set svs within Code limits.
34. Clean the fireside and waterside of the boiler.
35. Make refractory and other furnace repairs.
36. Conduct a hydrostatic test.
37. Lay up a boiler.
38. Know how to remove and replace tubes in the boiler, superheater, economizer, airheater, and feedwater heater.
39. Adjust soot blowers and lances.
40. Inspect, clean, and repair boiler gages, instruments, and controls.

In addition to the above, an operator should continuously study (1) boiler and steam system design, (2) construction, (3) operation, (4) maintenance, (5) state or city laws, (6) insurance company requirements and inspections, (7) emergency measures, (8) safety in a boiler plant, and (9) ASME Boiler and Pressure Vessel Codes.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less

*Power Handbook*, 64 pages
*Steam Generation*, 48 pages
*Fuels and Firing*, 48 pages
*Fans*, 24 pages
*Mechanical Packing*, 24 pages
*Gaskets*, 20 pages

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*Nondestructive Testing*, 24 pages
*Corrosion*, 36 pages
*Vibration Isolation*, 16 pages

Books

Elonka, Steve: *Plant Operators' Manual*, rev. ed., McGraw-Hill Book Company, New York, 1965.

Elonka, Steve, and Joseph F. Robinson: *Standard Plant Operator's Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1959.

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neutron detectors. Different types of instrumentation are provided for shutdown, start-up, and low-power and high-power operation.

For shutdown and start-up measurements, pulse counters are used, often taking the form of ionization chambers filled with boron trifluoride gas. Operating at a particular voltage, they give a pulse proportional to the incident radiation. Alternatively, fission chambers, coated with a fissile material, are capable of detecting neutrons by fissions inside the chamber. Each neutron produces an electric pulse. In either case, the output passes through a pulse amplifier to counting rate meters, logarithmically scaled since neutron flux increases exponentially. Start-up and similar low-power detectors retract into the biological shield during high-power operation. For power measurements in the normal operating range, where temperature effects on reactivity become important, instruments are linearly scaled. Ionization chambers act directly on high-impedance potentiometer recorders.

Reactor emergency tripping is based on set limits being executed for such factors as neutron density change, fuel element temperature, power

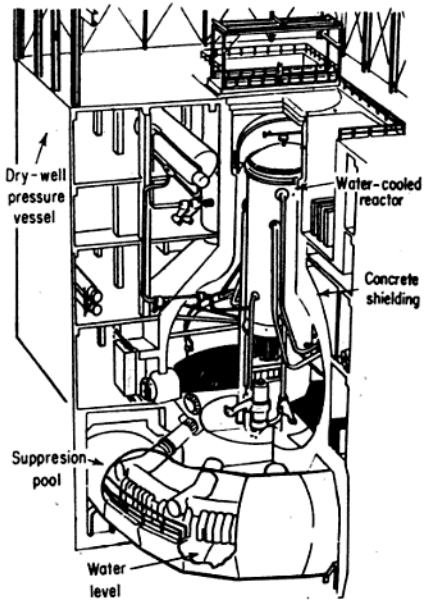


**Fig. 17-2. Suppression pool condenses steam if reactor or piping ruptures in this sodium-cooled breeder plant.**

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tion may be applied. An instrumented fuel assembly (Fig. 17-3) is used in a boiling $D_2O$ reactor to determine fuel power limits.

**Q** What is the purpose of reactor shielding?

**A** Three distinct kinds of radiation are emitted from radioactive material. Alpha and beta rays have little penetrating power, but gamma rays can penetrate great thicknesses. Neutrons, too, have great penetrating power and are the primary radiation hazard in an operating reactor.

To safeguard personnel against neutrons, gamma rays, and heat, the reactor, and much of its auxiliary equipment, must be enclosed within

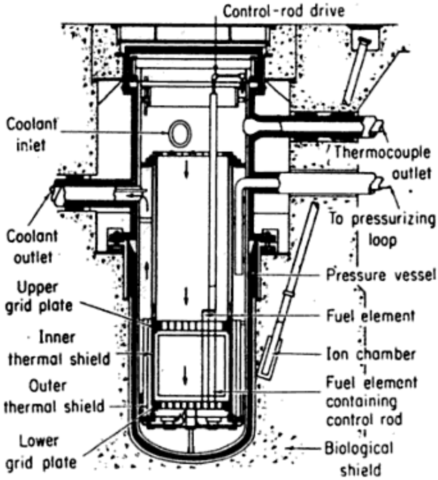


**Fig. 17-4. Detectors are placed outside the reactor in this organic cooled and moderated reactor.**

thermal and biological shielding. Gamma rays can be absorbed by a number of materials, particularly those with the greatest density, such as lead or steel. The same effect is obtained by using a much greater thickness of water or concrete. For land-based reactors space and weight limitations are not major considerations. The cost of material and construction is usually more important. The cheapest and most widely used shielding material is concrete. When several feet thick, a concrete biological shield is an excellent neutron absorber. The addition of some percentage of denser material to the mix, such as iron or barytes, will improve local gamma shielding. Alternatively, the use of more expensive magnetic concrete affords protection against both gamma rays and neutrons.

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**Q** Since a nuclear reactor is basically a pressure vessel heated by nuclear energy, why did the ASME draw up a separate Nuclear Vessel Code and not use the existing Power Boiler Code, Section I, and the Unfired Pressure Vessel Code, Section VIII?

**A** At the beginning of nuclear-reactor-vessel development, all parties involved did go to the ASME Boiler Code Committees for guidance on nuclear-reactor-vessel construction. Special rules were passed, called *cases,* as each problem of the nuclear-reactor vessel was carefully reviewed. When enough cases developed, a separate Code had to be adopted for these reasons:

1. Nuclear vessels have many unusual design considerations which require more stringent rules than are needed for boilers and other pressure vessels.

2. There are various types of nuclear vessels defined as follows:

*a. Primary vessels,* which are those subjected to the primary coolant which may be radioactive.

*b. Secondary vessels,* which are not subject to radioactivity.

*c. Pressure vessels,* which are basically containment vessels to guard against radioactive contamination in the event of failure of the primary vessels.

3. Since a nuclear-reactor vessel may be radioactive for years, periodic internal inspections in the usual sense as applied to boilers and pressure vessels are impossible. Sophisticated testing by nondestructive means has to be employed.

4. The hazard in a nuclear-reactor vessel is not only a pressure explosion, but a radioactive contamination hazard far more serious to life than a steam pressure explosion only. A whole area may be affected by radioactive fallout. Thus more stringent design and fabrication rules are required than for bodies or pressure vessels.

5. Nuclear-reactor vessels can be subjected to very sudden heating or cooling temperature changes. This creates abnormal thermal stresses and cycling fatigue stresses. The Power Boiler Code does not have enough provisions for calculating these stresses, but the Nuclear Vessel Code requires these to be calculated.

6. The material to be used on a nuclear vessel may have to withstand radiation effects which may affect its properties. Materials for nuclear vessels thus require this consideration, whereas materials for boilers and pressure vessels may not.

7. Inspection during fabrication of a nuclear-reactor pressure vessel has to be far more thorough than of a boiler because of the hazards involved. Rigid quality control must also be exercised far above the usual practice in boiler and pressure-vessel construction.

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with primary responsibility on the manufacturer for carrying out all fabrication according to Code requirements:

*Forming.* Improper layout, failure to transfer identification of material, excessive temperature during forming leading to surface scratching, shell out-of-round, scale pressed into surface, cracking.

*Heat Treatment.* Failure to maintain temperature, cooling rate too low, excessive time at temperature, and improper recording.

*Welding.* Improper choice of wire and flux, mixed electrodes, preheat variation, excessive interpass temperatures, failure to follow specifications on temporary attachments and equipment malfunction, the latter caused by (1) wire feed sticking, (2) voltage variations (power fluctuation), (3) travel speed variability (on boom welding heads), (4) walking or turning rolls, or (5) inadequate grounding; damp materials, use of unqualified weldors or procedures, failure to properly clean the weld joint preparation, excessive porosity, failure to repair undercut.

During the fabrication phase, it is important to keep complete and detailed records of all the inspections, to be sure that the inspections were made (1) at the proper time, (2) in the proper sequence and not after the fact, and (3) on all material released in fabrication.

*Testing.* Vessel test plates must be made. The welding procedure and the nondestructive examination methods used shall be the same as those used in the fabrication of the vessel. Important test specimens must be made.

A final hydrostatic test of 1¼ times the design pressure is stipulated. Pneumatic tests may be used in lieu of the hydrostatic test.

*Marking, Stamping, and Reports.* Design calculations and design specifications must be filed with the state enforcement authority responsible, at the point of the installation, for the vessel. The design specifications must be certified as to compliance on vessel classification, detailed report on operating conditions for a complete evaluation of the design, construction and inspection according to Code rules by a registered professional engineer experienced in pressure-vessel design. All necessary data sheets must be included. The vessels to be marked with the "N" symbol must be stamped with the following information: (1) class of vessel, (2) manufacturer, (3) design pressure at coincident temperature, (4) manufacturer's serial number, and (5) year built.

*Protection Against Overpressure.* Class A vessels are required to have svs. Certain other requirements on interlocking controls are detailed. See the Nuclear Code.

**Q** Does a reactor containment vessel require an *sv*?

**A** Pressure relief devices *are not* required on containment vessels de-

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signed and built to safely contain all the radioactive substances that may be released in case of a maximum credible incident affecting the reactor vessel, the primary coolant circuit, or both. If such devices are installed for any reason, adequate provision must be made for the safe disposal of the effluent escaping.

All other Class B vessels require pressure relief devices following the Unfired Pressure Vessel Code, Section VIII.

**Q** What design or requirements must be followed in Class B and Class C vessels in a nuclear installation?
**A** Generally they are designed as unfired pressure vessels, following Section VIII of the ASME Code. The Nuclear Vessel Code should be checked for the minor exception.

**Q** Do *operators* of nuclear power stations require a *license?*
**A** The Atomic Energy Commission requires by federal law all operators in a nuclear power station to be licensed. The requirements needed to secure an operator's license include a thorough knowledge of plant design and operation. An examination is given by the Atomic Energy Commission after the applicant has had suitable training.

## SUGGESTED READING

Reprints sold by *Power* magazine, costing $1 or less
*Nuclear Power Reactors*, 24 pages

Books
Elonka, Steve, and Alonzo R. Parsons: *Standard Instrumentation Questions and Answers*, vols. I and II, McGraw-Hill Book Company, New York, 1962.

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# 18

# BOILER-ROOM MANAGEMENT

## LOG SHEETS

**Q** Why should every boiler plant keep log sheets, and what should be recorded?

**A** A log sheet should record all important operating data, such as pressures and temperatures, and it should also record procedures such as the times the soot blowers and water columns are blown and when blowdown valves were operated. A continuous record of operating data and important procedures carried out is then at hand when needed. It is also important to log when testing safety appurtenances.

Any irregular operation or event should be recorded in a separate book, with a description of the irregularity and the corrective measures taken. In this book all orders should be written and initialed by the operator.

Record test each week by checking spaces.
Instructions are printed below.

Boiler No. ______________

Year ______________

| | Safety Valve Tested | | | | | Water-column Gage Glass Drained | | | | | Low-water Fuel Cutoff Tested | | | | | Pump and Return System Checked | | | | | Burner Operation Checked | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Week | | | | | Week | | | | | Week | | | | | Week | | | | | Week | | | | |
| | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Jan. | | | | | | | | | | | | | | | | | | | | | | | | | |
| Feb. | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mar. | | | | | | | | | | | | | | | | | | | | | | | | | |
| Apr. | | | | | | | | | | | | | | | | | | | | | | | | | |
| May | | | | | | | | | | | | | | | | | | | | | | | | | |
| June | | | | | | | | | | | | | | | | | | | | | | | | | |
| July | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aug. | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sept. | | | | | | | | | | | | | | | | | | | | | | | | | |
| Oct. | | | | | | | | | | | | | | | | | | | | | | | | | |
| Nov. | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec. | | | | | | | | | | | | | | | | | | | | | | | | | |

Fig. 18-1. Low-pressure heating boiler log for weekly readings.



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A fireman or shift engineer reporting for duty should read the notations made by the previous watches. Then he will know what the past operation has been, what orders have been issued for future operation, and what trouble spots to keep his eyes on. He should then initial those items for which he is responsible so as to indicate that he is familiar with the situation.

In larger plants (especially) complete records should be used to calculate the overall daily performance. Figures 18-1 and 18-2 are samples of some log sheets supplied by some insurance companies for small low-

Boiler No. ____________

Week Beginning ____________

| | | Check or Test and Record Twice Daily | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Water Level | Steam pressure | Feed-pump pressure | Feedwater temperature | Condensate temperature | Flue-gas temperature | Low-water cutoff | Water-level control | Water column | Water-gage glass | | Feed pump | Condensate tank | Burner operation | Fuel supply | | Water treatment | Boiler blowdown | | Operator on duty | Remarks |
| Mon. | A.M. | | | | | | | | | | | | | | | | | | | | | |
| | P.M. | | | | | | | | | | | | | | | | | | | | | |
| Tues. | A.M. | | | | | | | | | | | | | | | | | | | | | |
| | P.M. | | | | | | | | | | | | | | | | | | | | | |
| Wed. | A.M. | | | | | | | | | | | | | | | | | | | | | |
| | P.M. | | | | | | | | | | | | | | | | | | | | | |
| Thur. | A.M. | | | | | | | | | | | | | | | | | | | | | |
| | P.M. | | | | | | | | | | | | | | | | | | | | | |
| Fri. | A.M. | | | | | | | | | | | | | | | | | | | | | |
| | P.M. | | | | | | | | | | | | | | | | | | | | | |
| Sat. | A.M. | | | | | | | | | | | | | | | | | | | | | |
| | P.M. | | | | | | | | | | | | | | | | | | | | | |
| Sun. | A.M. | | | | | | | | | | | | | | | | | | | | | |
| | P.M. | | | | | | | | | | | | | | | | | | | | | |

**Fig. 18-2.** High-pressure power boiler log for twice-daily readings.

pressure plants and industrial hp boilers. Many plants design their own log sheets to record important data pertaining to their specific plant details and layout.

## IDENTIFYING PIPING

**Q** Should power plant piping be identified by color coding or labeling?
**A** Yes. The ASME has on sale ASA *Standard* A-13.1, which suggests identifying colors for piping to make the operator's life less confusing, especially in an unfamiliar plant.

**Q** Describe an efficient way to become familiar with a new plant.
**A** Trace out every important piping system and make a sketch of all the valves and equipment in each system. Do the same with electrical

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systems. An operator should know his plant well enough to be able to go to key valves and controls in the dark during an emergency. Make all new operators trace out and sketch each system. Keep a file of literature pertaining to machinery, instrumentation, and equipment in the plant, and study them. Also set up a filing system for blueprints of important equipment in case they are needed in a hurry. Set up an inventory of critical components so they are always on hand. This includes boiler tubes and components of equipment that would shut down the plant if not in stock and needed because of failure.

## WORK AND SHIFT SCHEDULES

**Q** Set up a power plant work schedule for a five-man crew for 24 hr per day, 7 days per week, 365 days per year, covering a 10-week period.
**A** The permanent work schedule in Fig. 18-3 shows that at the end of the 10-week period the schedule is repeated. If the pay period is 2

Permanent Work Schedule

| Days | S | S | M | T | W | T | F | S | S | M | T | W | T | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-8 | B | B | B | B | B | D | D | D | D | B | B | B | B | B |
| 8-4 | E | E | E | D | D | E | E | E | E | E | D | D | E | E |
| 4-12 | C | C | A | A | A | A | A | A | A | A | A | A | C | C |
| Maint | | | D | C | C | C | | | | C | C | C | D | |
| 12-8 | D | D | D | D | D | A | A | A | A | D | D | D | D | D |
| 8-4 | B | B | B | A | A | B | B | B | B | B | A | A | B | B |
| 4-12 | E | E | C | C | C | C | C | C | C | C | C | C | E | E |
| Maint | | | A | E | E | E | | | | E | E | E | A | |
| 12-8 | A | A | A | A | A | C | C | C | C | A | A | A | A | A |
| 8-4 | D | D | D | C | C | D | D | D | D | D | C | C | D | D |
| 4-12 | B | B | E | E | E | E | E | E | E | E | E | E | B | B |
| Maint | | | C | B | B | B | | | | B | B | B | C | |
| 12-8 | C | C | C | C | C | E | E | E | E | C | C | C | C | C |
| 8-4 | A | A | A | E | E | A | A | A | A | A | E | E | A | A |
| 4-12 | D | D | B | B | B | B | B | B | B | B | B | B | D | D |
| Maint | | | E | D | D | D | | | | D | D | D | E | |
| 12-8 | E | E | E | E | E | B | B | B | B | E | E | E | E | E |
| 8-4 | C | C | C | B | B | C | C | C | C | C | B | B | C | C |
| 4-12 | A | A | D | D | D | D | D | D | D | D | D | D | A | A |
| Maint | | | B | A | A | A | | | | A | A | A | B | |

**Fig. 18-3. Five-man permanent work schedule.**

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weeks, this schedule will cover five pay periods. During each 2-week pay period, each man works 80 hr.

This schedule is useful in plants where the operators do some maintenance work because here 8 days of maintenance out of every 50 days of work are provided. Thus overtime is not necessary.

Here is how during the 10-week period every man on every crew will receive exactly the same treatment adding up to 50 days worked and 20 days off: 14 days on a 12-to-8 shift, 14 days on an 8-to-4 shift, 14 days on a 4-to-12 shift, 8 days on maintenance, 6 weekends worked, 4 weekends off, two 4-day weekends off, one 3-day weekend off.

**Q** Prepare an 8-week shift schedule for four men, each averaging 42 hr per week.

**A** In Fig. 18-4 schedule A suitably divides the operating hours of four men with each averaging 42 hr per week. There are 21 eight-hr shifts in a week here. Thus with a four-man crew, three men will work 40 hr a

**8-week Shift – Schedule A**

| | M T W T F S S | M T W T F S S | M T W T F S S | M T W T F S S |
|---|---|---|---|---|
| 3rd shift | R R C C C C C | C R R C C C C | C C R R C C C | C C C R R C C |
| 1st shift | A A A R R A A | A A A A R R A | A A A A A R R | A A A A A A R |
| 2nd shift | B B B B B R R | B B B B B B R | R B B B B B B | R R B B B B B |
| OFF | C C R A A B B | R C C R A A B | B R C C R A A | B B R C C R A |
| 3rd | C C C C R R C | C C C C C R R | C C C C C C R | R C C C C C C |
| 1st | R A A A A A A | R R A A A A A | A R R A A A A | A A R R A A A |
| 2nd | B R R B B B B | B B R R B B B | B B B R R B B | B B B B R R B |
| OFF | A B B R C C R | A A B B R C C | R A A B B R C | C R A A B B R |

**8-week Shift – Schedule B**

| | M T W T F S S | M T W T F S S | M T W T F S S | M T W T F S S |
|---|---|---|---|---|
| 3rd shift | R R C C C C C | C R R C C C C | C C R R C C C | C C C R R C C |
| 1st shift | A A R R A A A | A A A R R A A | A A A A R R A | A A A A A R R |
| 2nd shift | B B B B R R B | B B B B B R R | B B B B B B R | R B B B B B B |
| OFF | C C A A B B R | R C C A A B B | R R C C A A B | B R R C C A A |
| 3rd | C C C C R R C | C C C C C R R | C C C C C C R | R C C C C C C |
| 1st | A A A A A A R | R A A A A A A | R R A A A A A | A R R A A A A |
| 2nd | R R B B B B B | B R R B B B B | B B R R B B B | B B B R R B B |
| OFF | B B R R C C A | A B B R R C C | A A B B R R C | C A A B B R R |

Legend. C – 3rd shift (Midnight to 8 AM.) A – 1st shift (8 AM to 4 PM.)
B – 2nd shift (4 PM to Midnight.) R – Relief shift.

Fig. 18-4. Eight-week shift schedule for four men.

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week and one will work 48 hr. This is rotated progressively among the men in an 8-week cycle. With this schedule, each man will have a complete rotation of schedule in 8 weeks and will have two Saturdays and two Sundays off. Thus, each man works 6 consecutive days (except for the swing man), and he will have 2 days off.

The swingman's week will consist of 2 days on the first shift, 24 hr off, 2 days on the second shift, 24 hr off, then 2 days on the third shift. Finally, he has 48 hr off, after which he starts over. Some plants find it preferable to assign one man in a group of four to work this swing shift. The reason is that it isn't easy to find many men who can adapt to changing shifts, but it is usually possible to find at least one in the group who does not mind the swing shift. In this case, if the labor contract calls for time and a half for the sixth consecutive work day, and double time for the seventh day, it is possible that the swing man will have to be paid the premium rate; if so, use Schedule *B* in Fig. 18-4.

In schedule *B* in Fig. 18-4 the swing shift is completed in six consecutive days. Some contracts call for time and a half on Saturdays and double time on Sundays. This would apply to the swing shift man as well, and schedule A in Fig. 18-4 would then be preferable. Most contracts call for shift premiums. Using schedule *B* in Fig. 18-4, the swing shift man will have 24 hr off at every shift change and 48 hr off at the end of his workweek. His week starts with the third shift and is completed at the end of the second shift. The other shift men work the same weekly hours in either schedule.

During the nonheating season, if experienced, licensed men are needed for the plant, most will have to be used for maintenance. If the spring and fall schedule is on a 5-day basis, the minimum crew is two men, each working 9 hr a day. But if three men are used, one man can do maintenance work for 6 hr each day and operate the two middle hours of the day, thus keeping the other two men on 8-hr shifts. But if the plant can be shut down 2 hr in the middle of the day, two men can do the work.

**Q** What is a practical work schedule for an institution-type plant (hospital, school, etc.) that is in operation around the clock? Assume five shifts, each of four operators. Such a plant might have four boilers, one turbine, several steam or diesel engines, and also refrigeration and air-conditioning equipment. Operation is 24 hr a day, 365 days a year.

**A** The work schedule in Fig. 18-5 is made up for 40 weeks, when it repeats itself. Shifts are labeled *A*, *B*, *C*, *D*, and *E*. The first four men, on a rotating schedule, perform regular duties. Shift *E* is the relief, which works as a unit to relieve the three watch shifts 1 day per week. Maintenance work is done by shift *E* on the other 3 days. To compensate

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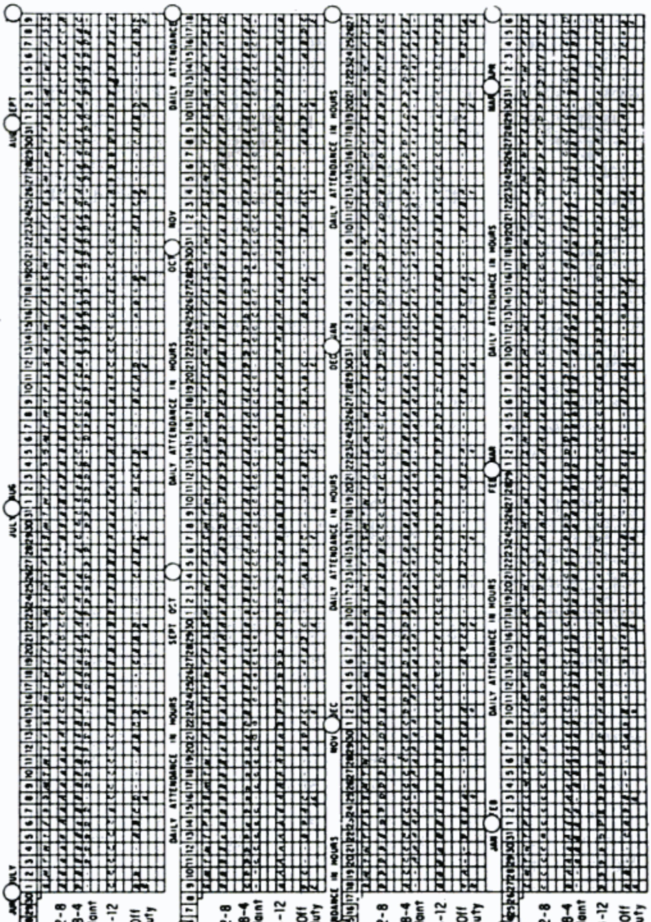

Fig. 18-5. Five-shift schedule for institution-type plant.

for the short changes during relief work and for the *cut-up* week, shift E has Sunday off the year around.

Three of the other four shifts rotate. Two weeks elapse between the changes. The fourth shift is assigned to repair and maintenance for 10 weeks, after which it replaces one of those on the rotating schedule. The relieved shift then takes its turn at maintenance and has Sunday off. While on maintenance, *no watch work* is done except for vacations or emergencies. This schedule shows that when changing from maintenance to watch work, some shifts start in the morning, some in the afternoon, and some at night. This avoids unfairness by cutting the maintenance period to 8 weeks.

To save making a new chart every 40 weeks, a set of circular tapes can be made with numbered days of the month. These can be arranged so any sequence of months, like 30-31-30-31, can be obtained. One tape can have a sequence for February, the short month, another for leap year. Tapes are tacked onto the chart as shown in Fig. 18-5, and the month tabs spotted at the proper intervals. Thus only tapes and month tabs need be shifted at the end of 40 weeks. The crew using this schedule has 52 regular days off and 20 days vacation annually. Instead of holidays, shift workers receive 10 extra days every year, a total of 82 days.

Timekeeping can be made easier by crediting 5 days off for each month worked except December and June, when 6 days can be credited. This makes 62 days off.

The advantages of this schedule are that every employee gets the same breaks in job assignment and every man has an equal number of Sundays and weekdays off in each 40-week period. Also, everyone can see at a glance just what hours and duty he will work. This schedule always provides a full shift on hand for 5 days the first week and 6 days the other 9 weeks. Then during vacations or emergencies, the man of equal title on maintenance takes the shift position of the man on leave. Notice that there is an extra shift (relief) on hand for maintenance 3 days a week throughout the year. Since duties for all with the same title are identical, except for the relief shift, the changes in schedule are easily made by transferring men from one shift to another.

**Q** Set up a *swinging* shift schedule for boiler operators and mechanics to work a 42-hr week.

**A** Figure 18-6 shows such a schedule. Each man works five shifts for 3 weeks and six shifts the fourth week. Thus his total is 21 shifts per month. The mechanics have one Sunday off in four because the maintenance work can be done on those days. To use this schedule, the pay week might start on Saturday and end on Friday.

**Q** Design a work schedule for a plant operating 24 hr a day during the

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**Boiler Operators**

| Days | S | S | M | T | W | T | F | S | S | M | T | W | T | F | S | S | M | T | W | T | F | S | S | M | T | W | T | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 3 | A | A | A | A | A | B | B | B | B | B | B | B | C | C | C | C | C | C | C | D | D | D | D | D | D | D | A | A |
| 3 11 | C | C | D | D | D | D | D | D | D | A | A | A | A | A | A | A | B | B | B | B | B | B | B | C | C | C | C | C |
| 11 7 | B | B | B | B | C | C | C | C | C | C | C | D | D | D | D | D | D | D | A | A | A | A | A | A | A | B | B | B |
| **Mechanics** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7-3 | E | E | – | – | E | E | E | E | E | E | – | – | E | E | E | – | E | E | E | E | – | – | E | E | E | E | E | E |
| 3-11 | F | F | F | – | – | F | F | F | – | F | F | F | F | F | – | F | F | F | F | F | – | – | F | – | F | F | F | F |
| 11-7 | G | – | G | G | G | G | – | – | G | G | G | G | G | – | G | G | G | G | G | – | G | G | G | G | G | G | – | – |

Fig. 18-6. Swinging-shift schedule for boiler operators.

winter months. Assume that spring and fall operation is from 4 A.M. to 1 P.M. and that there is *no* operation during the summer.

**A** Figure 18-7 is one answer. Here the plant can be shut down at night. While this schedule allows the plant to stay on line during the summer, it provides for a summer day-shift for maintenance. During shutdown periods, the operator can secure the plant around midnight. Then the scheduled midnight man can work from 5 A.M. to 1 P.M. Each operator has an equal amount of time on every shift during the 20-week period. Also, every 4 weeks there is a long weekend of almost 5 days off.

An alternate schedule for the above problem is shown in Fig. 18-8. Here, *A*, *B*, *C*, and *D* are operating engineers. *A* works from 7 A.M. to 3 P.M., *C* works from 11 P.M. to 7 A.M. *E*, *F*, *G*, and *H* are boiler tenders

**Winter Months**

| Shift Schedule | S M T W T F S | S M T W T F S | S M T W T F S | S M T W T F S | Operator |
|---|---|---|---|---|---|
| M indicates maintenance shift. | 0 0 2 2 2 2 2 | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | #1 |
| | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | 0 0 2 2 2 2 2 | 2 2 0 0 1 1 1 | #2 |
| 0 indicates day off. | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | 0 0 2 2 2 2 2 | #3 |
| The figure 1 on the shift schedule indicates day shift starting at 7:30 AM | 3 3 3 3 3 0 0 | 0 0 2 2 2 2 2 | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | #4 |
| | 0 M M 1 M M 0 | 0 M M 1 M M 0 | 0 M M 1 M M 0 | 0 M M 1 M M 0 | #5 |
| The figure 2 indicates afternoon shift starting at 3:30 PM. | 0 0 2 2 2 2 2 | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | #2 |
| | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | 0 0 2 2 2 2 2 | 2 2 0 0 1 1 1 | #3 |
| | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | 0 0 2 2 2 2 2 | #4 |
| The figure 3 indicates the graveyard shift starting at 11:30 PM the evening before the day shown. | 3 3 3 3 3 0 0 | 0 0 2 2 2 2 2 | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | #5 |
| | 0 M M 1 M M 0 | 0 M M 1 M M 0 | 0 M M 1 M M 0 | 0 M M 1 M M 0 | #1 |
| Each operator will be given a number and he will follow this schedule throut the twenty week period shown, then come back to the top and repeat. | 0 0 2 2 2 2 2 | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | #3 |
| | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | 0 0 2 2 7 2 2 | 2 2 0 0 1 1 1 | #4 |
| | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | 3 3 3 3 3 0 0 | 0 0 2 2 2 2 2 | #5 |
| | 3 3 3 3 3 0 0 | 0 0 2 2 2 2 2 | 2 2 0 0 1 1 1 | 1 1 1 0 0 3 3 | #1 |

Fig. 18-7. Work schedule for winter, no-summer operation.

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**A** The daily schedule shown in Fig. 18-9 is set up for a 44-hr week. It is for operating engineers and gives each operator the same time off weekly and also one Sunday off each month. Shifts *C* and *D* take care of the 2 hr between 12 noon and 2 P.M. Operators get 1½ days off each week. Where the schedule overlaps for 2 hr, one engineer does maintenance work for 2 hr.

**Q** Set up a monthly work schedule for a plant where pay is by the hour.

**A** In Fig. 18-10 each shift is given a number with working hours indi-

First Week

| | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|
| 12 - 8 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| 8 - 4 | 3 | 3 | 3 | 3 | 1 | 1 | 1 |
| 4 - 12 | 4 | 4 | 4 | 4 | 4 | 4 | 3 |
| Off | 2 | 2 | 1 | 1 | 3 | 3 | 4 |

Second Week

| | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|
| 12 - 8 | 2 | 2 | 4 | 4 | 4 | 4 | 4 |
| 8 - 4 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| 4 - 12 | 3 | 3 | 3 | 3 | 3 | 3 | 1 |
| Off | 4 | 4 | 2 | 2 | 1 | 1 | 3 |

Third Week

| | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|
| 12 - 8 | 4 | 4 | 3 | 3 | 3 | 3 | 3 |
| 8 - 4 | 2 | 2 | 2 | 2 | 4 | 4 | 4 |
| 4 - 12 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| Off | 3 | 3 | 4 | 4 | 2 | 2 | 1 |

Fourth Week

| | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|
| 12 - 8 | 3 | 3 | 1 | 1 | 1 | 1 | 1 |
| 8 - 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 |
| 4 - 12 | 2 | 2 | 2 | 2 | 2 | 2 | 4 |
| Off | 1 | 1 | 3 | 3 | 4 | 4 | 2 |

**Fig. 18-10. Monthly work schedule for hourly pay.**

cated. Whenever someone is given time off for sickness or other reasons, the man who would normally be off that day must take the watch. In this schedule, since everyone is paid for hours worked, there is a fair distribution of time resulting in earnings. Of course this schedule can also be used for employees who are paid weekly or monthly.

**Q** Design a 32-wk schedule for around-the-clock work.

**A** As Fig. 18-11 shows, one man on each shift works 7 days on the 12-to-8 shift, then has 2 days off. From there, he goes to the 4-to-12 shift for 7 days, then has 1 day off. After this he works 7 days on the 8-to-4 shift and has 4 days off before returning to the 12-to-8 shift.

**Q** For a plant working around the clock and 7 days a week, what kind of schedule is practical in taking care of all shift operators without requiring too much figuring and planning?

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**A** Figure 18-12 shows a schedule made for each shift to work three 40-hr periods and one 48-hr week in any one pay period. This schedule repeats itself every fourth week. The fifth and sixth days of the fourth week for any shift are worked between 8 A.M. and 4 P.M. The shift can be relieved with operators who normally work in the maintenance crew. This is a most desirable arrangement because some operators and maintenance men do both types of work in some plants and thus become familiar with the others' problems.

**Q** What kind of work schedule will give each watch stander 1 day a week off when operating 365 days a year and 7 days a week around the clock?

**A** The schedule in Fig. 18-13 gives each man one day off per week. But two spare men are needed to work this plan. Also, several other men are needed to fill in for sickness, etc. Perhaps one fireman can be used for this purpose and two men can be carried on the repair gang who can be shifted to operating duties on short notice. Carrying reserve personnel pays off when sickness and other causes of absenteeism hit a plant.

**Q** What kind of work schedule can be designed for 48-hr weeks in an 8-week cycle working around the clock?

| | Mon. | Tues. | Wed. | Thurs. | Fri. | Sat. | Sun. |
|---|---|---|---|---|---|---|---|
| DAY SHIFT | *Spare on (A off)*<br>*B*<br>*Spare on (C off)*<br>*D* | *A*<br>*Spare on (B off)*<br>*C*<br>*Spare on (D off)* | *A*<br>*B*<br>*C*<br>*D* | *A*<br>*B*<br>*C*<br>*D* | *A*<br>*B*<br>*C*<br>*D* | *A*<br>*B*<br>*C*<br>*D* | *A*<br>*B*<br>*C*<br>*D* |
| AFTER-NOON SHIFT | *E*<br>*F*<br>*G*<br>*H* | *E*<br>*F*<br>*G*<br>*H* | *E*<br>*F*<br>*G*<br>*H* | *E*<br>*F*<br>*G*<br>*H* | *Spare on (E off)*<br>*F*<br>*Spare on (G off)*<br>*H* | *E*<br>*Spare on (F off)*<br>*G*<br>*Spare on (H off)* | *E*<br>*F*<br>*G* } *Both spares off*<br>*H* |
| NIGHT SHIFT | *J*<br>*K*<br>*L*<br>*M* | *J*<br>*K*<br>*L*<br>*M* | *Spare on (J off)*<br>*K*<br>*Spare on (L off)*<br>*M* | *J*<br>*Spare on (K off)*<br>*L*<br>*Spare on (M off)* | *J*<br>*K*<br>*L*<br>*M* | *J*<br>*K*<br>*L*<br>*M* | *J*<br>*K*<br>*L*<br>*M* |

*A, E and J are shift foremen* *C, G and L are firemen*
*B, F and K are watertenders* *D, H and M are turbine operators*

**Fig. 18-13. Day-per-week-off schedule, on yearly basis.**

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