Solkane®-
Pocket Manual

Refrigeration and Air-Conditioning Technology

Solvay
Fluor und Derivate

SOLVAY

Solkane®-Pocket Manual
Refrigeration and Air-Conditioning Technology

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Foreword

This Solkane-Pocket Manual covers the principal areas of refrigeration. The text is supported by abundant physical, chemical and technical data, as well as thermodynamic equations for thermophysical properties calculation of Solkane refrigerants, which serve to help in the planning and design of refrigerating plants. The data and information contained in the Solkane-Pocket Manual also cover other areas of application where Solkane has proved itself, e.g. as blowing agents for plastic foams (PU, XPS) and propellants in the pharmaceutical field.

This manual is intended for the person who uses refrigeration equipment, to assist in day-to-day tasks. If you have particular problems outside the scope of this manual, please do not hesitate to get in touch with us for further information and advice.

Solvay Fluor und Derivate GmbH

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1 The Solvay Group – an overview

Solvay, headquartered in Brussels, Belgium, is an international group of chemical and pharmaceutical industry. It employes over 33,000 people in 50 countries around the world, its business is split into the four sectors: chemicals, plastics, processing and pharma, each of which is organized internally in strategic, regional and operative business units.

The Group is represented in Germany by Solvay Deutschland GmbH with headquarters in Hanover. It controls an entire range of subsidiaries and affiliates. The German Group employs around 7,000 people.

A short historical review

The story of the Solvay Group began in 1863, when Ernest Solvay (1838 – 1922) started up industrial production of synthetic soda using a new method developed by him, in contrast to the then-used Leblanc method. The Leblanc soda was very expensive due to high energy costs and was environmentally harmful. The Solvay process on the other hand, applies – in addition to salt and limestone as raw materials – ammonia as a process chemical which is recovered and reused in the manufacturing process. With his inexpensive soda, which furthermore may be produced without harming the environment, Solvay accommodated the huge demand in the course of rapid industrialization. After barely 20 years, he owned a network of soda factories throughout Europe, in every place where sufficient raw materials could be found, and by the first quarter of the 20th century, the Leblanc method had already disappeared from the scene. Even today, every ton of synthetic soda is produced according to the Solvay process, and the Solvay Group continues to be the world market leader.

Soon Solvay expanded the production program to other inorganic chemicals, such as sodium bicarbonate and caustic soda, which he first produced indirectly through the causticization of soda. And in 1898, he already operated the first chlorine-alkali electrolysis which directly provided him with sodium hydroxide solution.

In this process, chlorine and hydrogen arise as byproducts. But Solvay even found a use for that. From chlorine came first the production of hydrochloric acid, for which there were markets, and sodium hypochlorite, and later also organic chlorine derivatives.

The broader diversification of the Solvay Group continuing on to today's business areas accelerated after the Second World War, primarily due to an increase in chlorine chemistry. At that time as well as today the goal was growth in those areas in which Solvay has competitive advantages in technology and marketing. Using this strategy, Solvay became the market leader in numerous product fields. The four sectors can be summarized as follows:

Chemicals Sector

The most important product groups in the chemicals sector today are: salt for any and every use, chlorine/sodium hydroxide solution, soda/sodium bicarbonate/precipitated calcium carbonate, chlorine derivatives/allyl products/glycerine, fluorine chemicals, barium and strontium compounds, hydrogen peroxide/persalts, insoluble sulphur.

Within this sector of the international Solvay Group, the Strategic Business Unit Fluorine plays a significant part. With five competent partners, the unit operates worldwide from its headquarters in Hannover. Its regional subdivisions are Solvay Fluor und Derivate GmbH (Germany), Solvay Fluorides Inc. (USA), Solvay Fluor (Mexico), Solvay Fluor Iberica S.A. (Spain) and Solvay Fluores France (France).

There are production plants in Bad Wimpfen and Frankfurt a.M. (Germany), Tavaux (France), Tarragona (Spain), Juarez (Mexico), Catoosa (USA), St. Louis (USA) and Otjiwarongo (Namibia).

In recent years this Strategic Business Unit has successfully integrated not only products but also the main commodities, including a fluorspar mine as source of the raw material for manufacturing hydrofluoric acid, needed for the production of fluorinated blowing agents and refrigerants. Since not all producers of blowing agents and refrigerants have kept pace with new developments in the field of third generation substitutes, Solvay now also plays a pioneering role here.

Fluorochemistry by profession

Due to our long experience in product development, manufacture and application technology, we have attained great expertise around the world. Especially when it comes to solving technical problems with new ideas, Solvay turns out as a dependable, flexible partner with an extraordinarily wide range of fluorine compounds and specialties.

Alternative blowing agents and refrigerants

We are developing and marketing – under the name Solkane – refrigerants, solvents and blowing agents for plastic foams. Conventional fully chlorinated hydro-fluorocarbons are currently being replaced by ecofriendly alternatives – in particular the highly successful refrigerant Solkane® 134a, and 227 pharma, a propellant for medical sprays in metered dose inhalers.

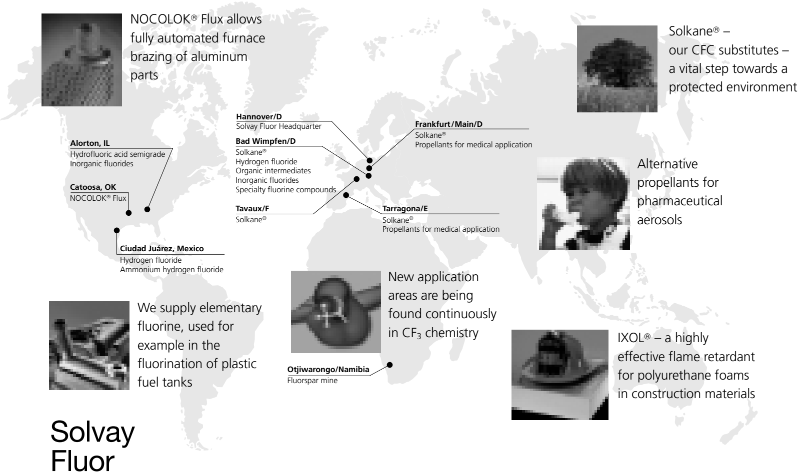
The transition process is simplified for clients by our professional support service, comprising application know- how and many decades of experience.

Elementary fluorine is our speciality

Permeability inhibition, abrasion resistance, improved painting surfaces – elemental fluorine noticeably upgrades the surface properties of plastics. Enables fluorinated plastics successfully to replace far more expensive materials. Remember: we not only supply elemental fluorine but also the vital application-oriented know-how.

Inorganic fluorides are invaluable components

As one of the leading producers of inorganic fluorides you can expect a lot from us: quality, innovation, know- how and a broad, successful product range. Almost all branches of industry benefit from our professionalism. Grinding, brazing and welding are almost impossible without fluorides; they are also indispensable in the production and processing of special types of glass. The use of NOCOLOK® Flux is currently revolutionising the brazing of aluminum components, for example in the automotive industry and in refrigeration.



Growing market for fluoro-specialties

Our fluoro-specialties are the basic building blocks for organic synthesis. For example, CF_3/CF_2 components upgrade the reactivity of active ingredients: a fact utilised in the pharmaceuticals and agricultural chemicals sector.

Plastics Sector

The most significant step on the path toward utilization of chlorine began in the 1950s, when it first became possible to produce polyvinyl chloride (PVC) using ethylene. Solvay, as a major chlorine manufacturer, seized the opportunity. That was the start of the plastics sector.

The 1960s were outstanding in the sudden development of the plastics industry, in which Solvay also wanted to take part. Consequently, the group also started the production of polyolefins, such as polyethylene – specializing in high density polyethylene (HDPE) – and polypropylene (PP). Furthermore, Solvay was strongly involved in the development of catalysts for polymerization in the plastics industry.

Simultaneous to these basic plastics, the Group developed technical polymers with particular characteristics for special purposes, such as polyarylamide (PA), polyvinylidene fluoride (PVDF) and polyvinylidene chloride (PVDC).

Today the Solvay Group is one of the most important plastics manufacturers in the world.

Processing Sector

At some point it became obvious that the experience in the manufacture of plastics would also be useful for their processing. By constructing its own production plants, but also through acquisitions and participations, the Solvay Group today controls a wide network of processing operations. The focus is on precision parts, systems and modules for the automotive industry, foils for the automotive and construction industry, for wood and metal lamination, for office products, for packaging and decorative foils as well as pipe systems for gas and water supply.

Pharmaceuticals Sector

The significant position which Solvay had attained in organic chemistry already led the Group to biochemistry in the 1950s, i.e. also to the area of pharmaceuticals. But it was only at the beginning of the 1980s that Solvay decided to further develop this sector. The result was additional acquisitions, participations and strategic alliances in relatively rapid succession, primarily in Germany, the Netherlands and the USA. Today, the pharmaceutical business enjoys a high priority concerning research and development, but also commercial and regional expansion.

As in all other sector, Solvay also concentrates on certain core competences in the pharmaceuticals business. These are the areas of cardiology, gastroenterology, psychiatry and gynecology. Furthermore, the Group has made itself a name with a series of nonprescription medications.

With a tightly organized and efficient international division of responsibilities in research and development, production, marketing and distribution under the umbrella of the Pharmaceuticals Strategic Business Unit headquartered in Brussels, Solvay is meeting new challenges emerging in the field of health care, in particular.

Equipped for the future

From its beginnings as a small soda factory in the Belgian town of Couillet, Solvay has developed into a worldwide group in the chemical and pharmaceutical industry. Its corporate philosophy is by tradition to concentrate on those areas in which it has special experience and expertise. The widely diversified program is a result of systematic product development. The diversification is borne by all four sector, which follow a unified corporate strategy.

Solvay deserves to be trusted.

2 History of Refrigerants

When Carl von Linde built his first ammonia-compression refrigerator in 1876, his landmark development settled the matter of centuries of efforts and experiments undertaken since classical antiquity for producing cold.

The problem of refrigeration is the production and maintenance of a temperature lower than the ambient.

Since a lowering of temperature can be produced only by the withdrawal of heat, refrigeration is thus equivalent to heat removal.

However, no material of a sufficiently low temperature is available for this purpose, so that even in antiquity certain physical and chemical processes were utilized for the purpose of lowering the temperature.

For example, drinks were cooled already in the past by taking advantage of the evaporative cooling effect and in the 17th century, ice cream was produced in Paris with the aid of freezing mixtures.

200 years later, the Americans and Scandinavians began to export natural ice in large quantities for cooling purposes. This was not, however, a satisfactory solution since the temperatures achieved were not below +4 to +2°C and also since natural ice is not entirely germ-free and cannot therefore be used without restrictions for the cooling of foods.

At the same time, considerable efforts were made to design and construct equipments for the purpose of withdrawing heat from the surroundings through evaporation of liquids and thus to produce low temperatures.

While it was originally assumed that heat was a substance which could not be measured, Robert Mayer was the first to realize that heat may be equivalent to mechanical work or in other words, to a form of energy.

Joule, without knowing of Mayer's theories, was able to confirm them experimentally in the year 1843. He incorporated a stirrer into a vessel filled with water and then rotated this stirrer by means of a descending weight. He measured the increase in temperature of the water equivalent to a given descent of the weight. The ratio of thermal energy to mechanical work which he found in this way is now described as the "mechanical equivalent of heat".

Heat, however, never moves automatically from a colder to a warmer body unless mechanical energy is applied at the same time. For this reason, the body to be cooled is brought into contact with a material, the refrigerant, which has previously been brought to the desired low temperature through the application of work. A corresponding amount of heat is then taken up by the refrigerant either at constant or changing temperature.

For economical reasons, it is clearly impossible to operate all the time with fresh refrigerant. A cyclic process is therefore employed through which the refrigerant passes again and again.

Types of refrigerating machines operating by this principle are divided into absorption refrigerating machines and compression refrigeration cycles. In absorption machines, the refrigerant vapor is absorbed in another substance and then driven out by boiling. In compression refrigeration cycles, the vapors are sucked off with the aid of a compressor, compressed and then reliquified in the condenser. Fluorine-containing refrigerants were developed for the latter machines to replace dangerous refrigerants.

Refrigerants which have proven themselves over decades of use are the chlorofluorocarbons (CFCs). These were sold by Kali-Chemie AG under the tradename Kaltron. In 1974, the theory of stratospheric ozone depletion was first published by Rowland and Molina. Due to the high stability of CFCs – which was a great advantage in the use of these materials – they slowly reach the stratosphere. The stratosphere is an atmospheric zone at an altitude of approximately 15 – 50 km. Sun's radiation (UV radiation) is so powerful there that CFCs are able to be decomposed, which results in free chlorine radicals. The free chlorine radicals may react with ozone to produce molecular oxygen:

$$O_3 + Cl \rightarrow O_2 + ClO$$

$$ClO + O \rightarrow O_2 + Cl$$

$$\overline{O_3 + O \rightarrow O_2 + O_2}$$

In the 1970s, different scientific models were developed in order to confirm Rowland and Molina's theory. However, these models were still insufficient. There was also no fully developed measuring technology available to determine the ozone concentration or the concentration of chlorine-containing products in the atmosphere.

Between 1980 and 1985, using improved measuring technology, a reduction in the stratospheric ozone concentration was measured over the Antarctic. The reduction was determined every year between October and December. In the winter of ‘86/‘87, the predicted correlation between the reduction in ozone concentration and the increase in chlorine monoxide concentration was verified in flights over the Antarctic.

The many various influential factors in atmospheric chemistry hinder the drawing up of exact models. Added to this was the eruption of the volcano Pinatubo, which also influenced and polluted the atmosphere.

In the meantime, there is no longer any doubt of the correlation between ozone depletion and CFCs.

Consequently, about 70 nations met in September 1987 to discuss measures for regulating ozone-depleting substances. A step-by-step phase-out of the production and use of CFCs until the year 2000 (for developed countries) was then decided. This decision is known as the Montreal Protocol. The scenario for the phase-out was revised and strengthened during subsequent conferences (e.g.: London 1990, Copenhagen 1992, Vienna 1995).

Further legislative measures followed the Montreal Protocol, such as the EC regulation 3093/94 (regulation on substances that deplete the ozone layer) which, in comparison to the Montreal Protocol, establishes earlier phase-out deadlines.

The era of CFCs use is over in the developed countries. Solvay was the first manufacturer worldwide to cease the production of CFCs. Internationally, the development of suitable substitutes was and is being promoted. In refrigeration technology, a boost to innovation has been triggered by the CFCs phase-out. Optimized plant engineering and energy-efficient refrigerants help contribute to environmental relief.

3 The new generation of Solkane®-refrigerants

3.1 Principles

3.1.1 HFCs (hydrofluorocarbons) and HCFCs (hydrochlorofluorocarbons) as refrigerants

The long-term Solvay product range for refrigerants without ozone-depleting potential comprises the following types (with the exception of Solkane 22, ODP = 0.055 and Solkane 123, ODP = 0.02):

Type	Boiling point	Chemical name / formula	Abbreviation
Solkane 22	– 40.8 °C	Chlorodifluoromethane/$CHClF_2$	R22
Solkane 23	– 82.0 °C	Trifluoromethane/CHF_3	R23
Solkane 123	27.6 °C	1.1-dichloro-2.2.2-trifluoroethane/$CHCl_2CF_3$	R123
Solkane 134a	– 26.3 °C	1.1.1.2-tetrafluoroethane/CH_2FCF_3	R134a
Solkane 227	– 16.5 °C	1.1.1.2.3.3.3 heptafluoropropane/CF_3CHFCF_3	R227ea
Solkane 404A	– 46.4 °C	Near-azeotrope R125/R143a/R134a/ CHF_2CF_3/CH_3CF_3/CH_2FCF_3	R404A
Solkane 407C	– 43.9 °C	Zeotrope R32/R125/R134a/ CH_2F_2/CHF_2CF_3/CH_2FCF_3	R407C
Solkane 410	– 51.5 °C	Near-azeotrope R32/R125/ CH_2F_2/CHF_2CF_3	R410A
Solkane 507	– 46.5 °C	Azeotrope R125/R143a/ CHF_2CF_3/CH_3CF_3	R507

also the following components for refrigerant blends:

Solkane 32	– 51.6 °C	Difluoromethane/CH_2F_2	R32
Solkane 125	– 48.1 °C	Pentafluoroethane/CHF_2CF_3	R125
Solkane 143a	– 47.3 °C	1.1.1-trifluoroethane/CH_3CF_3	R143a
Solkane 152a	– 24.0 °C	1.1-difluoroethane/CH_3CHF_2	R152a

3.1.2 Nomenclature

The Solkane types listed above are derivatives of methane, ethane or propane, the hydrogen being partially replaced by fluorine (for the HFCs) or fluorine and chlorine for the transitional refrigerants (HCFCs) Solkane 22 and 123. As nomenclature for the above-mentioned types, the general formula applies:

$C_mH_nCl_pF_q$
in which $n + p + q = 2m + 2$.

m	=	the number of carbon atoms
n	=	the number of hydrogen atoms
p	=	the number of chlorine atoms
q	=	the number of fluorine atoms

The number of chlorine atoms (p) is not included in the nomenclature since it can be derived from the other three quantities. Therefore, the numbers of the various Solkane types are of the three-digit variety and are written in the form **HZE**. H is however omitted if it is equal to zero (for the methane derivatives).

As a general symbol for refrigerants, the prefix R (refrigerant) is used.

H	=	m – 1	related to the number of carbon atoms
Z	=	n + 1	related to the number of hydrogen atoms
E	=	q	related to the number of fluorine atoms.

Therefore,

$CHClF_2$	(where m = 1, n = 1, q = 2)	R 22
$C_2H_2F_4$	(where m = 2, n = 2, q = 4)	R 134
C_3HF_7	(where m = 3, n = 1, q = 7)	R 227

The designation of the cyclic hydrocarbons is the same as above except that a C is placed in front of the nomenclature number.
(Example: CH_2-CH_2 = RC270).
CH_2

If there are isomers, the symmetrical form does not have a suffix. Asymmetric compounds are given the suffixes a, b, c etc. The letter sequence increases with increasing asymmetry (example: R134 = CHF_2-CHF_2; Solkane134a = CH_2F-CF_3).

Further explanations are given in ASHRAE Standard 34.

3.1.3 Development status of HFC and HCFC refrigerant substitutes

3.1.3.1 Refrigerant substitutes for R11

The production and consumption (supply of virgin refrigerant to the market; use in new equipment) of R11 is no longer permitted. An exception is made for developing countries under the Montreal Protocol (see Chapter 9 "Regulations"). R123 (an HCFC) is a substitute for R11, especially for centrifugal chillers. The physical characteristics of this substance deviate only minimally from the R11 data. The energetic efficiency ratio of R123 differs in direct comparison to R11. The volumetric refrigerating capacity and the theoretical coefficient of performance of R123 are less. The difference is about 3 % for the coefficient of performance. The swept volume of a R123 compressor must be larger in comparison to a R11 compressor in order to achieve comparable coefficients of performance.

One advantage of R123 is that no new lubricants are necessary for this substitute. Mineral oils suitable for R11 are also appropriate for R123. In addition, the changeover from existing R11 centrifugal water chillers to R123 is possible. R123 and R11 are miscible.

3.1.3.2 Refrigerant substitutes for R12

The production and consumption (supply of virgin refrigerant to the market; use in new equipment) of R12 is no longer permitted. An exception is made for developing countries under the Montreal Protocol (see Chapter 9 "Regulations").

Due to the similar physical and thermodynamic properties, R134a is the suitable R12 substitute. The refrigeration industry has created the technical preconditions for the use of R134a. Appropriate components, as well as machine and plant elements are being offered. Additionally, the changeover of existing R12 refrigerating plants to R134a is possible. R134a is used commercially both in new plants as well as in converted, former R12 plants. Handling R134a is safe and easy. R134a is nonflammable.

Numerous applications in refrigeration show that R134a is the appropriate refrigerant to replace R12.

When converting former R12 plants, R22-containing blends may also be used.

3.1.3.3 Refrigerant substitutes for R13 and R13B1

The production and consumption (supply of virgin refrigerant to the market; use in new equipment) of R13 and R13B1 is no longer permitted. An exception is made for developing countries under the Montreal Protocol (see Chapter 9 "Regulations"). R410A may be used as a substitute for the low temperature refrigerant R13B1. The refrigerant R13B1 has been used for example in deep freeze plants with evaporating temperatures between –70°C and –50°C. After checking the operating conditions and the design of the plant, R13B1 may be exchanged for R410A using the retrofit method.

The refrigerant R13, which was used for evaporating temperatures between –90°C to –70°C, may be substituted by R23. The physical characteristics of R13 and R23 are very similar. Conversions of R13 cascade refrigerating plants to R23 have been done in practice and are possible without any major problem.

3.1.3.4 Refrigerant substitutes for R22

International regulations are already giving phase-out schedules and quantity limits regarding the production for HCFCs, like R22 (see Chapter 9 "Regulations" for details). Some countries, like Sweden and Germany, have even stricter national regulations, which have to be followed. For example in Germany, the use of R22 will no longer be permitted in new installations as of the year 2000. Due to the broad application range of this refrigerant, there is no single substance that can offer all the technical advantages of R22, in contrast to the situation that prevails with R134a as a substitute for R12.

For compact units, a significant trend toward R410A as an efficient high-performance refrigerant can be recognized. The use of R410A in heat pumps – after the transitional introduction of propane – may also be regarded as very promising, since here a significant system size reduction may be possible in comparison to R22 and propane. Besides an improvement in the seasonal energy efficiency ratio (SEER) – with at least an equal TEWI value – the reduced space requirement is a decisive reason here for the use of this refrigerant.

R22 applications are currently being realized also with the R502 refrigerant substitutes R404A and R507. The possibility is being pursued, particularly in the supermarket area, of using only one refrigerant in the normal and in the deep freeze temperature range, in order to attain an overall plant cost reduction.

If the use of R22 is considered in an air-conditioning relevant range with evaporating temperatures of t_0 = 0°C, significantly improved coefficients of performance and therefore reduced energy consumption can be attained in part with R134a. The disadvantage here is that R134a has a smaller refrigerating effect per unit of swept volume and therefore larger machines are required when it is used as a substitute for R22.

The zeotropic refrigerant R407C was developed to reproduce the vapor pressure curve of R22. In certain cases, it is suitable as a direct retrofit substitute for R22 if the same boundary parameters apply and the same performance data is to be achieved.

The use of the zeotropic refrigerant R407C shows an increasing tendency. This means the technical demands on the contractors and also on the component and plant manufacturers are increasing.

The near-azeotropic refrigerant R410A is remarkable due to its considerably higher working pressure. Through examples of application in heat pumps, it is seen that a higher refrigerating capacity is achieved in comparison to R22, R407C and also to propane. Here the use of R410A leads to substantially smaller sizes and to lower costs than for R22, R407C and propane. The refrigerant R410A can however not be used as a retrofit refrigerant for existing R22-systems due to the higher working pressure.

In contrast to R134a as a substitute for R12, there is no refrigerant which may be used in all installations instead of R22. This fundamental difference implies that a substitute for R22, which is to be used in existing plants which are to be preserved, is not available according to the current standard of technology.

3.1.3.5 Refrigerant substitutes for R502

The production and consumption (supply of virgin refrigerant to the market; use in new equipment) of R502 is no longer permitted. An exception is made for developing countries under the Montreal Protocol (see Chapter 9 "Regulations").

The refrigerant R502 cannot be replaced by one single substance, such as is the case for R134a as a substitute for R12. Here refrigerant mixtures are required. Substitute refrigerants for R502 with an ozone depletion potential of zero are already "state-of-the-art".

This concerns the refrigerant blends known as R404A, R407A, R407B and R507, according to the ASHRAE nomenclature, which have already been introduced on the market under these names.

However, the refrigerant market for these substitutes is divided up between the two substances R404A and R507. The strongly zeotropic blends R407A and B, which demonstrate a pronounced temperature glide, have not succeeded to the same extent.

The phase-out of R502 will soon occur, because components such as compressors, expansion devices etc. are no longer available from the manufacturers for the CFC refrigerant R502, i.e. the R502 refrigerating plants can no longer be serviced in the medium term. Furthermore, the R502 component R115 is no longer produced on the world market, so that the refrigerant R502 is now only available from warehouse stock.

3.1.4 Fluorine-containing methane derivatives

The 15 methane derivatives (including methane itself) are listed in Figure 1 with their boiling points, toxicity values (if known)* and flammability limits (if flammable and known).

As can be seen, the boiling point increases by exchanging chlorine for hydrogen from methane to carbon tetrachloride, while the exchange of fluorine for chlorine results in a lowering of the boiling point.

The substitution of hydrogen or chlorine by fluorine greatly reduces the toxicity in most cases, which applies to the commercially used products. Also the flammability, i.e. the tendency towards formation of flammable mixtures with air is more reduced the more hydrogen is replaced by fluorine or chlorine. Methane derivatives with one or two halogen atoms are still flammable, while three and four halogen atoms in the molecule mean no flammability or explosivity.

Along with increasing fluorine content, the stability of these compounds also increases, however the GWP value increases as well, while the POCP value drops. The reason for this lies in the high bonding energy of the C-F bond. As the chlorine content increases, the molecular weights and also the densities increase.

MAK: Threshold limit value (TLV-TWA) in accordance with the DFG (German Research Foundation); see remark below

SAEL: Solvay Acceptable Exposure Limit

UL6: Classification in accordance with Underwriters Laboratories (USA)

TRK: Technical reference concentration in accordance with the German Dangerous Substances Regulations (TRK)

🔥 Flammability limits, percent by volume in dry air

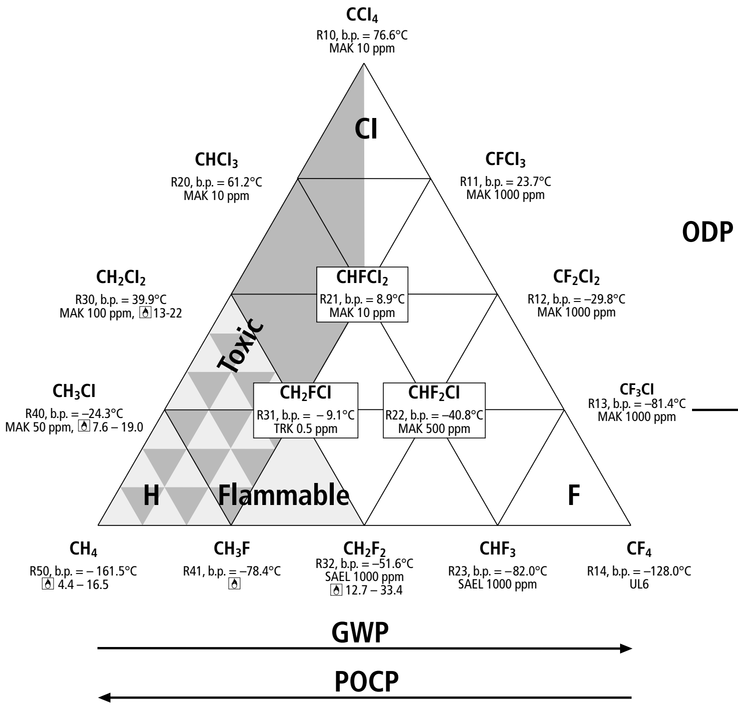


Figure 1: Fluorine-chlorine derivatives of methane

*Remarks to Figure 1; "Toxicity Values":

The MAK is the abbreviation for "Maximale Arbeitsplatz Konzentration", which corresponds to the time weighted averaged threshold limit value (TLV-TWA) for the maximum allowable occupational exposure limit of a substance. If one is exposed 8h a day and 5 days a week to this concentration, no adverse health effects are to be expected. The MAK value is officially announced by the German commitee for the evaluation of hazardous substances (DFG). At the date of printing this pocket manual, not all refrigerants have been evaluated offically by this commitee. However, the toxcity of alternate refrigerants has been studied. See also table 2, chapter 3.3 "Other refrigerants" for information. Note, that national TLVs may deviate from the German MAK.

3.1.5 Fluorine-containing ethane derivatives

The general laws regarding the different properties of methane compounds relative to the chemical structure still apply for the most part for the 28 basic compounds of ethane (including ethane itself). In Figure 2, the most important isomers with their boiling points, toxicity values* and flammability limits – if known and relevant – are listed.

Due to the numerous isomers, the number of possible combinations is even increased to 55. The boiling point also increases here when hydrogen is substituted by chlorine, and drops on the other hand when chlorine is replaced by fluorine. However, this reduction is smaller than for the methane derivatives. The influence of increasing fluorine content in regard to toxicity, flammability and environmental parameters is analogous to the methane derivatives.

*Remarks to Figure 2, "Toxicity Values":
The MAK is the abbreviation for "Maximale Arbeitsplatz Konzentration", which corresponds to the time weighted averaged threshold limit value (TLV-TWA) for the maximum allowable occupational exposure limit of a substance. If one is exposed 8h a day and 5 days a week to this concentration, no adverse health effects are to be expected. The MAK value is officially announced by the German commitee for the evaluation of hazardous substances (DFG). At the date of printing this pocket manual, not all refrigerants have been evaluated offically by this commitee. However, the toxcity of alternate refrigerants has been studied. See also table 2, chapter 3.3 "Other refrigerants" for information. Note, that national TLVs may deviate from the German MAK.

MAK: Threshold limit value (TLV-TWA) in accordance with the DFG (German Research Foundation); see remark on previous page
AEL: Acceptable Exposure Limit
SAEL: Solvay Acceptable Exposure Limit
UL6: Classification in accordance with Underwriters Laboratories (USA)
EL: Exposure Limit (PAFT)
OEL: Occupational Exposure Limit (PAFT)
TRK: Technical reference concentration in accordance with the German Dangerous Substances Regulations (TRK)
Flammability limits, percent by volume in dry air

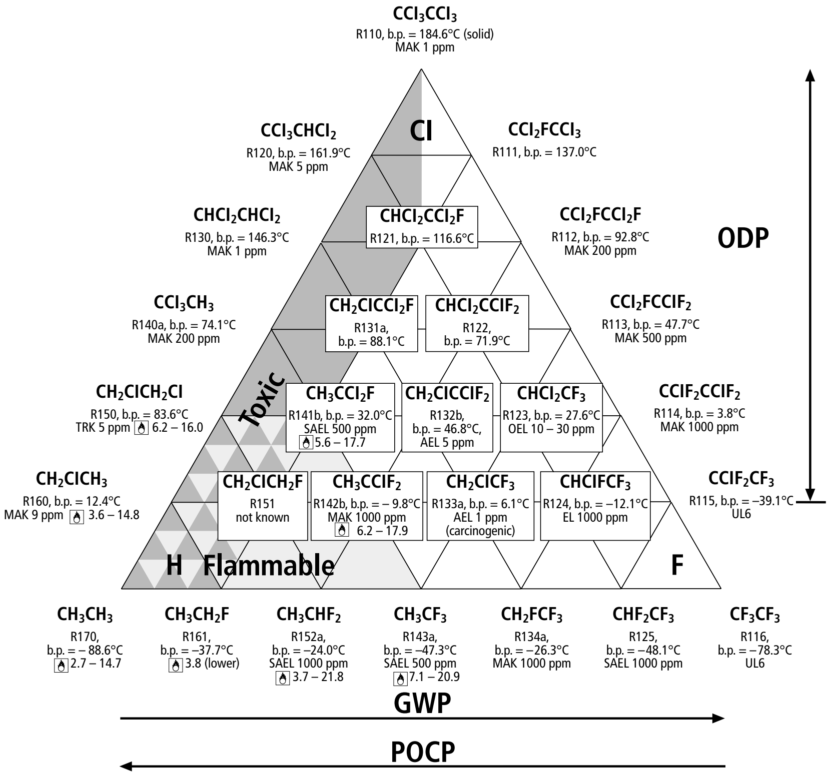


Figure 2: Fluorine-chlorine derivatives of ethane

3.1.6 Refrigerant blends

The chlorofluorocarbon refrigerants (CFCs) cannot be substituted in certain cases by single refrigerants but rather only by blends (mixtures of two or more refrigerants). A difference is made between azeotropic, nonazeotropic and near-azeotropic mixtures.

Azeotropic mixture
(short term: azeotrope; example: R502, R507): Mixture of two or more liquids in which liquid and vapor have the same composition in a state of equilibrium. The azeotropic composition itself is a function of pressure and temperature. Azeotropes have a lower or higher boiling point than the individual components of the blend. The vapor pressure of the mixture is accordingly higher or lower than that of the individual components. Azeotropes cannot be separated through distillation.

Nonazeotropic mixture
(short term: nonazeotrope or zeotrope, example: R407C): Mixture of refrigerants, the vapor and liquid of which have different compositions in the entire range of concentration. For nonazeotropic mixtures, the vapor is enriched in the components which have a lower boiling point or are more volatile. Nonazeotropic refrigerants have a temperature glide. If this glide is large, it can lead to problems in regard to the operation of the refrigerating plant (control, leakage, heat transfer, separation effects in the plant, handling).

Near-azeotropic mixture
(Example: R404A): Nonazeotrope with a small temperature glide which can be ignored in practice without consequence for a specific application.

Temperature glide
Difference between boiling (bubble) – and dew-point temperature at constant pressure.

Solvay has committed itself to offer the user the simplest possible solutions for long-term substitution of CFC refrigerants. For this reason, we are giving preference to single-component refrigerants. If the use of a single-component refrigerant is not possible due to thermodynamic properties, we then offer azeotropic refrigerant mixtures. If this is also not possible, we recommend near-azeotropic refrigerants. Here the Solvay guideline applies that the temperature glide must be smaller than 0.2 K. We only suggest nonazeotropic mixtures as the very last possibility for a solution.

3.2 Solkane® refrigerants

3.2.1 The refrigerants Solkane® 22, 23, 123, 134a, 227, 404A, 407C, 410, 507

Solkane® 22
(Chlorodifluoromethane; $CHClF_2$)

Boiling point at 1.013 bar –40.8°C / molecular weight 86.5

Solkane 22 is a medium pressure refrigerant like ammonia, although it has the advantage of a smaller pressure ratio. Thus temperatures of –60 to –75°C may be attained in two stages. Piston compressors (as well as rotary and screw compressors) are normally used for R22, with hermetics accounting for a considerable percentage. At low temperatures, where the swept volume is high, centrifugal compressors are also used. R22 is a potential transitional refrigerant in new installations as a substitute for CFC 12 and CFC 502 for low temperature applications and in blends for the entire R12 application range (existing R12 installations). It must be taken into consideration that the refrigerating effect per unit of swept volume is about 60% higher than for R12.

R22 is a very well known and extensively tested refrigerant. It is currently the most frequently used refrigerant worldwide and is implemented in a broad spectrum of applications (evaporating temperature range –40 to +5°C) such as in frozen food display cases, upright freezers, chest freezers, air-conditioners, cold rooms, refrigerated storage for scientific purposes, in transport refrigeration, commercial refrigeration (especially in supermarkets), industrial refrigeration, but also for heat pumps.

Solkane 22 is nonflammable and toxicologically safe (EC standard limit value (TLV-TWA) 1,000 vol.-ppm). The ODP value is 94.5% less than R12. Due to the remaining ODP value of 5.5%, R22 must be labelled in the EC as "Dangerous for the ozone layer". The phase-out of HCFCs is already controlled by international regulations (Montreal Protocol, EC regulation; see chapter 9).

Under refrigerating machine conditions, R22 is thermally and chemically stable. The compatibility with metals is comparable to that of R12. Standard structural materials are: copper, brass, monel metal, nickel, cast iron, steel and aluminum.

Magnesium, lead, zinc and aluminum alloys with more than 2% by weight of magnesium should not be used.

In regard to plastics and elastomers, R22 is more aggressive than R12 and leads to different degrees of increased swelling. Chloroprene rubber (CR), chlorosulfonated polyethylene (CSM) and polytetrafluoroethylene (PTFE) are utilizable, but not acrylonitrile butadiene rubber (NBR or HNBR) and fluorinated rubber types (FPM types).

R22 and mineral oils show good miscibility at higher temperatures, however at lower temperatures a miscibility gap may exist. The broad miscibility gap can lead to difficulties in oil return to the compressor in low temperature plants. An effective oil separator or the use of semisynthetic oils are therefore recommended in such cases.

Solkane® 23
(Trifluoromethane; CHF_3)

Boiling point at 1.013 bar –82.0°C / molecular weight 70.0

As an excellent high pressure refrigerant, Solkane 23 is the refrigerant substitute for R13 which is used to generate very low temperatures (about –60 to –100°C). The physical and thermodynamic properties deviate only minimally from the R13 values. The vapor pressures are similar to those of R13, at least in the lower temperature range. Energy consumption for equivalent refrigerating capacities is approximately the same. The refrigerating effect per unit of swept volume for Solkane 23 is greater than that of the R13 refrigerant. As temperatures drop, the difference becomes smaller (at –60°C about 25%, at –110°C only about 1%). The coefficients of performance for both refrigerants are about equal.

Solkane 23 is used solely in cascade systems, and then at evaporating temperatures in the low temperature range of –60 to –100°C and condensing temperatures of –10 to –40°C. It is implemented in industrial refrigerating plants (e.g. gas separation and chemical processing), pharmaceutical production plants, for medicinal purposes, in material testing, in cryomats and cryostats, high vacuum chambers, test chambers and in the conversion of existing R13 plants using the retrofit method.

R23 is nonflammable and not harmful to health with proper use (Group 6 according to the classification by Underwriters Laboratories). The Solvay AEL value for Solkane 23 is 1,000 ppm.

The thermal and chemical stability of R23 is excellent. The metals normally used in refrigeration machine construction are compatible with this refrigerant. However, zinc, magnesium, lead and aluminum alloys with more than 2% by weight of magnesium should not be used for R23.

The elastomers chloroprene rubber (CR), styrene butadiene rubber (SBR) and acrylonitrile butadiene rubber (NBR) are utilizable as sealing materials with only minimal swelling. The influence of lubricants should be tested through experiments.

Polyolester oils are suitable lubricants for use with R23.

Solkane® 123
(1.1-dichloro-2.2.2-trifluoroethane; $CHCl_2CF_3$)

Boiling point at 1.013 bar 27.6°C / molecular weight 152.9

Solkane 123 is a low pressure refrigerant and can replace R11. However, R123 is a transitional refrigerant, because it is a HCFC. The phase-out of HCFCs is already controlled by international regulations (Montreal Protocol, EC regulation; see chapter 9).

The physical and thermodynamic properties deviate only minimally from the R11 values. The refrigerating effect per unit of swept volume as well as the coefficient of performance for R 123 are somewhat smaller however. The swept volume of an R123 compressor must be larger in comparison to an R11 compressor in order to achieve comparable energy efficiencies.

Solkane 123 is usable in water chillers for industrial and commercial use, especially in centrifugal water chillers. R123 is also utilizable for heat pumps and ORC (Organic Rankine Cycle) systems.

One advantage of Solkane 123 is that no new refrigeration machine oils are necessary for this substitute. Mineral oils suitable for R11 may also be used for R123. Furthermore, the conversion of existing R11 centrifugal water chillers to R123 is possible. R123 and R11 are miscible. The exchange may therefore be carried out without any special cleaning work in the refrigeration circuit. The conversion should be discussed with the compressor or plant manufacturer to determine whether the existing compressor may be used. In addition, the sealing materials and filter dryers must be changed. Hermetic compressors are not suitable for conversion since the electrical motor winding coatings are damaged by R123. In these cases, complete conversion sets with open R123 compressors are offered.

The conversion to R123 as a transitional refrigerant is especially recommended for older R11 refrigerating plants with only a limited remaining service life.

Solkane 123 is nonflammable. The recommended TLV-TWA value of R123, from most of the companies participating in PAFT, lies between 10 and 30 ppm. Measurements of the room air concentration of R123 around centrifugal water chillers have shown that the TLV is not exceeded under normal operation conditions. Operation can be made safe through technical measures.

Due to the – though minimal – ODP value of 0.02%, R123 must be labelled in the EC as "Dangerous for the ozone layer." R123 is thermally and chemically stable under refrigeration machine conditions. In regard to carbon steel, copper and aluminum, it behaves similarly to R11, however in the presence of water, particularly at increased temperatures, corrosion could occur.

Solkane® 134a
(1.1.1.2-tetrafluoroethane; $CH_2F\ CF_3$)

Boiling point at 1.013 bar –26.3°C / molecular weight 102.0

Solkane 134a is the long-term alternative for the CFC refrigerant R12. R134a was introduced as the first refrigerant substitute and may be designated today as state-of-the-art. In its physical and refrigeration properties, R134a compares very well to R12. The refrigerating effect per unit of swept volume for R134a is equal to or higher than for R12, down to evaporating temperatures of approx. –25°C (theoretically only down to –5°C), the coefficient of performance is comparable or better (theoretically practically equal) down to evaporating temperatures of approx. –20°C.

Solkane 134a may replace R12 in practically all applications, such as in household refrigerators, automobile air conditioners, heat pumps, centrifugal water chillers for air conditioning in buildings, for transport and commercial refrigeration. The refrigeration industry has created the technical prerequisites for application. Refrigerating machines, plant parts and components are offered on a broad basis. In addition, the conversion of existing R12 refrigerating plants, particularly newer plants, as well as of plants with semihermetic or open compressors is possible, although only after some modifications of the plant (refer to the special chapter, "Retrofit").

Solkane 134a is nonflammable and toxicologically safe. Based on PAFT tests, the TLV value was determined to be 1,000 vol.-ppm.

R134a is thermally and chemically stable. Its compatibility with metals is comparable to that of R12. All metals and metal alloys standardly used in refrigerating machine construction may be utilized. Only zinc, magnesium, lead and aluminum alloys with more than 2% by weight of magnesium should be avoided. Even storage tests with humidified R134a demonstrated good hydrolysis resistance on metals such as ferritic steel, V2A stainless steel, copper, brass or aluminum.

Only low or moderate swelling occurs due to the effect of R134a on the following plastics and elastomers: polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyamide (PA), polycarbonate (PC), epoxy resin, polytetrafluoroethylene (PTFE), polyacetal (POM), chloroprene rubber (CR), acrylonitrile butadiene rubber (NBR) and hydrogenated acrylonitrile butadiene rubber (HNBR). However, any possible influence of the lubricant must also be considered. In the absence of mineral oil in the refrigeration system, contact of R134a and/or PAG as well as polyolester oils with ethylene-propylene-diene rubber (EPDM) results only in a low swelling effect. Fluorinated rubber types are not recommended for R134a. Flexible hose connections should contain a polyamide core.

Molecular sieves with 3 Angström pore diameter should be used as dryer material when using R134a. Suitable refrigerating machine oils for R134a are PAG oils (for automobile air conditioners) and particularly polyolester oils.

Solkane® 227
(1.1.1.2.3.3.3-heptafluoropropane;CF_3CHFCF_3)

Boiling point at 1.013 bar –16.5°C / molecular weight 170.0

Solkane 227 is a long-term alternative for the CFC refrigerants R114 and R12B1 as well as in special areas for the CFC refrigerant R12. Solkane 227 is especially suited for applications with high condensing temperatures. The thermodynamic properties of Solkane 227 lie between those of R12 and R114. The refrigerating effect per unit of swept volume lies about 50% above that of R114 and 40% below that of R12. The coefficient of performance for the theoretical comparison process is less than that for the refrigerants R12 and R114.

Solkane 227 is primarily used in high temperature applications such as crane cabin air conditioners in the steel industry and high temperature heat pumps. Furthermore, there are application areas for ORC systems or as a filling medium for temperature sensors. Generally, Solkane 227 is a possible alternative to Solkane 134a for applications in which the condensing temperature lies above 75°C, since a majority of available components are only designed up to 25 bar. The vapor pressure of R134a at 75°C lies at 24 bar as opposed to 17 bar for Solkane 227.

Solkane 227 is nonflammable, has a toxicity comparable to R12 and is thermally and chemically stable. The recommended TLV is 1,000 ppm.

The compatibility of Solkane 227 with metals is comparable to that of R12. All materials standardly used in refrigeration machine construction may be utilized. Only zinc, lead, magnesium and aluminum alloys with more than 2% by weight of magnesium should be avoided.

Compatibility tests with the elastomer types chloroprene rubber (CR) and acrylonitrile butadiene rubber (NBR) produced minimal swelling as well as negligible extract proportions. Fluorinated rubber (FPM) types can only be conditionally recommended, since, depending on the formula, strong swelling as well as blister formation may be observed (this also applies to other partially halogenated fluorocarbons). However, any possible influence of the lubricant must also be considered. In the absence of mineral oil in the refrigeration system, contact of R227 and/or polyolester oils with ethylene-propylene-diene rubber (EPDM) results only in a low swelling effect.

Solkane 227, like all HFC refrigerants, is practically immiscible with conventional mineral oils. Both polyolester oil as well as polyalkylene glycol (PAG) types are miscible with Solkane 227 over a wide temperature and composition range and are used.

Solkane® 404A

(Near-azeotrope $CHF_2CF_3/CH_3CF_3/CH_2FCF_3$ = 44/52/4% by weight)

Boiling point at 1.013 bar: bubble point temperature –46.4°C,
dew-point –45.7°C / molecular weight 97.6

Solkane 404A is a long-term alternative for the CFC refrigerant R502. Use of Solkane 404A in refrigeration machines may be described as state-of-the-art. The refrigerating effect per unit of swept volume is comparable to that of R502. At evaporating temperatures of –40°C, the theoretical refrigerating effect per unit of swept volume lies at approx. 5% below that of R502. The coefficient of performance for Solkane 404A is approx. 5 – 8% below that of R502. With increasing superheat, the coefficient of performance improves more for Solkane 404A than for R502.

Solkane 404A is a near-azeotropic blend of R125, R143a and R134a (44/52/4% by weight). Solkane 404A was, like Solkane 507, designed as a substitute for R502. Its applications are mainly in commercial low temperature refrigeration at evaporating temperatures between –50 and –20°C. It has however been seen that this refrigerant is also used in medium temperature refrigeration as well as in air conditioning. The reason for this is that it is possible to operate over a very wide evaporating temperature range with a single refrigerant. Moreover, the refrigerating effect per unit of swept volume for Solkane 404A and also for Solkane 507 considerably exceeds that of Solkane 134a in the medium temperature refrigeration area. These advantages are however counterbalanced by a lower coefficient of performance. The higher the evaporation temperature, the lower the coefficient of performance for Solkane 404A compared to Solkane 134a. The vapor pressure for Solkane 404A is slightly lower than that of Solkane 507. The refrigerating effect per unit of swept volume as well as the coefficient of performance for the theoretical comparison process are below those for Solkane 507. Also the surface coefficient of heat transfer for pool boiling lies below that of Solkane 507 (for plants with flooded evaporation, this effect is particularly noticeable). Existing R502 plants can be converted to Solkane 404A. The standard retrofit procedure for a conversion from CFC plants to HFC refrigerants can be used here (oil change/rinsing out mineral oil, check material compatibilities, adaptation or replacement of the expansion valve, installation of suction gas filter).

Solkane 404A is nonflammable, has a toxicity comparable to R502 and is thermally and chemically stable. The recommended TLV value for R404A is 1,000 ppm.

The compatibility of Solkane 404A with metals is comparable with that of R502. All standard materials used in refrigeration machine construction may be utilized. Zinc, lead, magnesium and aluminum alloys with more than 2% by weight of magnesium should be avoided.

Material compatibility tests with the elastomer types chloroprene rubber (CR) and acrylonitrile butadiene rubber (NBR) have resulted in low to moderate swellings as well as negligible extract proportions. Fluorinated rubber (FPM) types can only be conditionally recommended since, depending on the formula, strong swelling as well as blister formation have been observed (this also applies to other partially halogenated fluorocarbons). However, any possible influence of the lubricant must also be considered. In the absence of mineral oil in the refrigeration system, contact of R404A and/or polyolester oils with ethylene-propylene-diene rubber (EPDM) results only in a low swelling effect.

As with all HFCs or HFC blends, Solkane 404A is not miscible with mineral oil. Different polyolester oils demonstrate good solubility with Solkane 404A in the relevant temperature and composition ranges (also refer to the chapter 5.5, "Lubricant aspects").

Solkane® 407C

(Zeotrope $CH_2F_2/CHF_2CF_3/CH_2FCF_3$ = 23/25/52% by weight)

Boiling point at 1.013 bar: bubble point temperature: –43.9°C,
dew-point –36.3°C / molecular weight 86.2

As R22 replacements, neither pure substances nor azeotropic or near-azeotropic mixtures were found which match the partially halogenated hydrochlorofluorocarbon (HCFC) R22 in its properties. Solkane 407C is a zeotropic mixture of R125, R32 and R134a (25/23/52% by weight) with a temperature glide of approx. 7 K. It is a long-term alternative to R22 in certain applications. For air-conditioning applications, the refrigerating effect per unit of swept volume as well as the coefficient of performance correspond approximately to that of R22.

The choice of heat exchangers is of critical importance for the use of Solkane 407C. When an R22 plant with shell and tube heat exchangers on the condenser side and on the evaporator side is converted to Solkane 407C a reduction in refrigerating capacity by 10% and a reduction in the coefficient of performance of up to 18% may result. The reason for this can be found in the poor surface coefficient of heat transfer which zeotropic blends generally demonstrate if they are compared with the values of the components from which they consist. In air-cooled plants with plate fin heat exchangers, this effect is however hardly noticeable and the performance data are comparable or under certain conditions even better than for R22 operation.

The temperature glide can lead to problems in case of leakage. The out streaming refrigerant is rich in components with a lower boiling temperature (R32 and R125) during a vapour leakage, while the concentration of the blend circulating in the refrigerating plant shifts toward the higher boiling component (R134a). It must be absolutely certain that Solkane 407C is only filled from the liquid phase. The composition of the gas phase in the cylinder deviates from the specification.

Existing R22 plants can be converted to Solkane 407C. For this type of retrofit to Solkane 407C however, the plant parameters – especially the heat exchangers – must be precisely examined. Plants which tend towards large leakages, as well as plants with flooded evaporators, should not be converted to Solkane 407C. In general, refrigerating plants with centrifugal compressors can never be converted to Solkane 407C.

Solkane 32 is flammable, on the other hand Solkane 125 and Solkane 134a are nonflammable. Both Solkane 407C in its original composition as well as all compositions which could result from possible separations (e.g. in case of leakage) are nonflammable. Solkane 407C is thermally and chemically stable and has a comparable or lower toxicity than R22. Based on PAFT results, a TLV of 1,000 ppm is recommended. The TLV value of R134a is 1,000 ppm. The Solvay AEL values for Solkane 32 and Solkane 125 are both 1,000 ppm.

Compatibility with metals is comparable to that of R22. All standard materials used in refrigeration machine construction may be used. Zinc, lead, magnesium and aluminum alloys with more than 2 % by weight of magnesium should be avoided.

The behavior of Solkane 407C in regard to elastomers is comparable to that of other Solkane types. Chloroprene rubber (CR), acrylonitrile butadiene rubber (NBR) or hydrogenated acrylonitrile butadiene rubber (HNBR) are common elastomer types well compatible with Solkane 407C. Fluorinated rubber (FPM) types may be only conditionally recommended since, with certain formulas, stronger swellings or blister formations occur. However, any possible influence of the lubricant must also be considered. In the absence of mineral oil in the refrigeration system, contact of R407C and/or polyolester oils with ethylene-propylene-diene rubber (EPDM) results only in a low swelling effect. Before application, we recommend performing tests since there may be different formulations for individual plastics and elastomers.

Solkane 407C is immiscible with mineral oil. Different polyolester oils demonstrate good solubility with Solkane 407C in the relevant temperature and composition ranges (refer also to the chapter 5.5, "Lubricant aspects").

Solkane® 410

(Near-azeotrope CH_2F_2/CHF_2CF_3 = 50/50% by weight)

Boiling point at 1.013 bar: bubble-point temperature –51.51°C,
dew-point –51.49°C / molecular weight 72.6

Solkane 410 is preferred internationally as a long-term refrigerant substitute for R22, however it is also an alternative for R13B1. This refrigerant blend is a near-azeotrope with a very low temperature glide. It is made for use in new plants and will replace R22 as a working medium in refrigerating plants, air conditioners and heat pumps. The essential difference from R22 is the higher working pressure. R410A reaches a pressure of 25 bar already at a condensing temperature of approx. 42°C, R22 on the other hand only at approx. 62°C. A great advantage of R410A is the extremely high refrigerating effect per unit of swept volume which can be up to 50% above that of R22. In this way, smaller plant components may be used, whereby a more compact plant may be realized in comparison to R22. Refrigeration components, such as compressors, must be designed for the increased pressure. This development is already fully underway. Due to the higher working pressure, R410A is not suitable for conversion of existing R22 plants. For such a conversion with the retrofit method, we recommend the use of Solkane 407C after thorough revision of the plant design.

There are application possibilities for the refrigerant R410A in air conditioners, heat pumps, cold room storage, commercial and industrial refrigeration and as replacement for R13B1 in the low temperature range. Retrofit methods for R13B1 have already been successfully performed.

Solkane 410 is nonflammable and toxicologically safe. Based on PAFT tests, the recommended TLV is 1,000 ppm. The Solvay AEL values for Solkane 32 and Solkane 125 are both 1,000 ppm.

Solkane 410 is thermally and chemically stable. There is compatibility with the standard metals used in refrigeration machine construction such as steel, copper, aluminum and brass. However, zinc, magnesium, lead and aluminum alloys with more than 2% by weight of magnesium should also be avoided here.

Only minimal or low swelling occurred due to the effect of Solkane 410 on the following plastics or elastomers: polyamide (PA), phenol resin, polytetrafluoroethylene (PTFE), polyacetal (POM), chloroprene rubber (CR) and hydrogenated acrylonitrile butadiene rubber (HNBR). Since there may be differing formulations for individual plastics and elastomers, we recommend performing tests in every case before application. Also take into consideration here the possible influence of lubricants. Fluorinated rubber (FPM) types are not recommended. In the absence of mineral oil in the refrigeration system, contact of R410A and/or polyolester oils with ethylene-propylene-diene rubber (EPDM) results only in a low swelling effect.

Polyolester oils are suitable lubricants for use with Solkane 410.

Solkane® 507
(Azeotrope CHF_2CF_3/CH_3CF_3 = 50/50% by weight)

Boiling point at 1.013 bar –46.5°C / molecular weight 98.9

Solkane 507 is a long-term refrigerant substitute for low temperature application, where the refrigerants R502 or R22 had previously been used. It corresponds well to R502 in physical, thermodynamic, refrigeration and operational properties. Here the final compression temperature is lower than that for R502 and the refrigerating effect per unit of swept volume under certain operating conditions is above that of R502 at an only minimally lower coefficient of performance. Due to its azeotropic properties, it is the optimal substitute for R502.

Compressors for the evaporation temperature range of –45 to +10°C are offered. R507 may however also be used as a refrigerant for the normal refrigeration range instead of R134a. Advantageous here is the greater refrigerating effect per unit of swept volume for R507, which can additionally cover the low and medium temperature refrigeration range with one refrigerant. However, the smaller coefficient of performance is then a disadvantage.

Typical areas of use for R507 are: refrigerated cabinets or cold rooms, supermarket refrigerating plants, ice machines, transport refrigeration, commercial refrigerating plants and industrial refrigerating plants. R507 is utilizable in new refrigerating plants as well as in existing plants by means of the retrofit method.

As a further alternative to R502, the refrigerant blend Solkane 404A may also be considered. However, this is a nonazeotrope and therefore has certain disadvantages as compared to Solkane 507 (see Solkane 404A).

R507 is nonflammable and toxicologically safe. The Solvay AEL value for Solkane 125 is 1,000 ppm and for Solkane 143a currently 500 ppm. The determination of the TLV for R507 of at least 500 ppm may therefore be calculated.

R507 is thermally and chemically stable. Compatibility with metals is comparable to that of R134a. All metals and metal alloys standardly used in refrigeration machine construction are utilizable. Only zinc, magnesium, lead and aluminum alloys with more than 2% by weight of magnesium should be avoided. Storage tests with humid R507 display good hydrolysis resistance and no corrosive effect on metals such as ferritic steel, V2A stainless steel, copper, brass or aluminum.

Only minimal or low swelling occurs due to the effect of R507 on the following plastics or elastomers: polyamide (PA), epoxy resin, phenolic resin, polytetrafluoroethylene (PTFE), polyacetal (POM), chloroprene rubber (CR) and acrylonitrile butadiene rubber (NBR). Here too, the possible influence of lubricant must be considered. If mineral oil is absent in the refrigerating circuit, ethylene-propylene-diene rubber (EPDM) types may also be used. Fluorinated rubber types (FPM types) are only conditionally recommended.

Polyolester oils are suitable lubricants for use with R507.

3.2.2 Components for refrigerant blends: Solkane® 32, 125, 143a, 152a

Solkane® 32
(Difluoromethane; CH_2F_2)

Boiling point at 1.013 bar –51.6°C / molecular weight 52.0

Solkane 32 has excellent thermodynamic properties as a refrigerant. In its refrigeration characteristics, it is similar to the refrigerants R502 and R22. However, R32 in its pure form should not be considered, since vapor pressure and compression discharge temperature are too high. Moreover, R32 has flammability limits (12.7 – 33.4% by volume in air). For this reason, R32 must be labelled as "highly flammable." On the other hand, R32 is extremely well suited as a blend component for R22 and R13B1 refrigerant substitutes. Thus it has already found a use for such purposes in Solkane 410 and Solkane 407C.

R32 demonstrates very good heat transfer characteristics.

Solkane 32 is toxicologically safe. The results of the PAFT test anticipate a TLV of 1,000 ppm. The Solvay AEL value for Solkane 32 is 1,000 ppm.

Solkane 32 is extremely stable thermally and chemically. There is compatibility with the standard metals in refrigeration machine construction such as steel, copper, aluminum and brass. Zinc, magnesium, lead and aluminum alloys should be avoided.

The behavior of Solkane 32 in regard to plastics and elastomers is just as good as for R12 and R22. Only minimal or low swelling occurs due to its effect on the following substances: polytetrafluoroethylene (PTFE), chloroprene rubber (CR), acrylonitrile butadiene rubber (NBR), hydrogenated acrylonitrile butadiene rubber (HNBR) and chlorosulfonated polyethylene (CSM). Fluorinated rubber (FPM) types are not recommended. Since there may be different formulations for individual plastics and elastomers, we recommend performing tests in every case before application.

Solkane® 125
(Pentafluoroethane; CHF_2CF_3)

Boiling point at 1.013 bar –48.1°C / molecular weight 120.0

Solkane 125 is a refrigerant substitute for low temperature application. The physical, thermodynamic and refrigeration properties are similar to those of the refrigerant R502. However, the vapor pressures are higher. For this reason, and because of the low critical point (critical temperature = 66.3°C), the condensing temperature is limited to a maximum of approx. 35°C, which considerably limits the possible applications.

Theoretical calculations show a higher refrigerating capacity for R125 than for R502. Liquid subcooling leads to an increased refrigerating capacity compared to R502. The coefficient of performance for R125 is nevertheless smaller than that for R502.

Solkane 125 can be used as a substitute for R502, and also for R22, however with a limited application range, e.g. for water-cooled refrigerating plants at low evaporation temperatures, for commercial food storage at low temperatures and for transport. Due to the advantageous molecular weight, Solkane 125 is also used as a pure substance in refrigerating plants with centrifugal compressors.

Because of its nonflammability, Solkane 125 is a convenient component for use in refrigerant blends, e.g. in Solkane 507, Solkane 404A, Solkane 410 and Solkane 407C.

Solkane 125 is toxicologically safe. Due to PAFT tests, the recommended TLV is 1,000 ppm. The Solvay AEL value for Solkane 125 is 1,000 ppm.

R125 is thermally and chemically stable. There is compatibility with the standard metals used in refrigeration machine construction such as steel, copper, aluminum and brass. Zinc, magnesium, lead and aluminum alloys with more than 2% by weight of magnesium should be avoided.

R125 is compatible with most of the conventionally used plastics and elastomers. Fluorinated rubber (FPM) types, hydrogenated acrylnitrile-butadiene rubber (HNBR) and silicone rubber are not recommended. In any case, tests should be performed before application, since plastics and elastomers may have different formulations.

Polyolester oils are suitable lubricants for use with Solkane 125.

Solkane® 143a
(1.1.1-trifluoroethane; CH_3CF_3)

Boiling point at 1.013 bar –47.3°C / molecular weight 84.0

The thermophysical, thermodynamic and refrigeration properties of Solkane 143a are similar to those of R502. R143a fulfills the preconditions for a good R502 substitute, however it is flammable. Only this characteristic (explosion limits 7.1 – 20.9% by volume in air) contradicts the use of R143a in pure form as an R502 substitute. Because of the explosion limits, R143a must be labelled as "highly flammable." However, as a blend component, R143a has already found its application in refrigerant substitutes for R502. Thus Solkane 507 and Solkane 404A are state-of-the-art in refrigeration cabinets, cold rooms, supermarket refrigerating plants, ice machines and in transport refrigeration.

Solkane 143a is toxicologically safe. The Solvay AEL value is currently 500 volume ppm.

R143a is thermally and chemically stable. There is compatibility with the standard metals as well as plastics and elastomers used in refrigeration machine construction. Avoid the use of zinc, magnesium, lead and aluminum alloys with more than 2% by weight of magnesium as well as fluorinated rubber (FPM) types. In any case, tests should be performed before application since plastics and elastomers may have different formulations.

Solkane® 152a
(1.1-difluoroethane; CH_3CHF_2)

Boiling point at 1.013 bar –24.0°C / molecular weight 66.1

Solkane 152a is a medium pressure refrigerant for the medium temperature refrigeration range. The physical, thermodynamic and refrigeration characteristics are similar to those of the refrigerants R12 and R134a. Although Solkane 152a is a good refrigerant substitute for R12, it is not used in its pure form because of its flammability (flammability limits 3.7 – 21.8% by volume in air). For this reason, R152a must be labelled as "highly flammable." R152a is preferably used in nonflammable refrigerant blends, particularly in the Drop-In method, e.g. as an R12 substitute in R401-blends (R22/R152a/R124 blends) and R405A (R22/R152a/R142b/RC318 blend) and also as an R502 substitute in R411 (R1270/R22/R152a blends). The refrigerants R401-blends, R405A and R411 include the chlorine-containing products R22, R124 and R142b and therefore have an ODP value.

Solkane 152a is toxicologically safe. It appears in Group 6 in the classification in accordance with Underwriters Laboratories (USA). The Solvay AEL value is 1,000 ppm.

Solkane 152a is thermally and chemically stable. The standard metals used in refrigeration machine construction such as steel, copper, aluminum and brass may be used. Zinc, magnesium, lead and aluminum alloys with more than 2% by weight of magnesium should be avoided.

In conjunction with R152a, plastics and elastomers such as chloroprene rubber (CR) and acrylonitrile butadiene rubber (NBR), which are standard when using HFCs, should be used. Avoid using fluorocaoutchouc (FPM) types. We recommend performing tests before application, since there may be different formulations for the individual plastics and elastomers.

3.2.3 Packaging and storage

Table 1 summarizes the container sizes available from the factory for the various Solkane types. We recommend storing the container in a cool, dry place. Figure 3 shows a returnable bulk container with a capacity of approximately 800 kg (depending upon the density of the refrigerant).

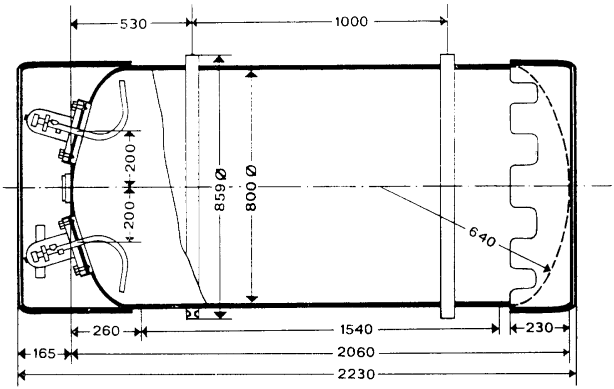
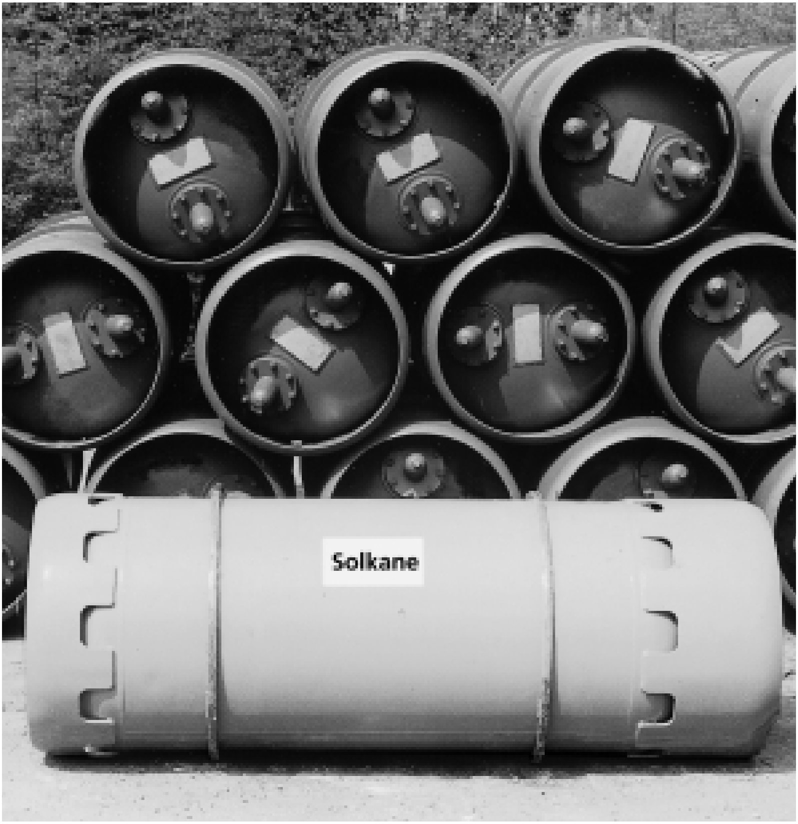


Figure 3: Loan steel container

The end is equipped with two valves which are connected to the dip-tubes in the interior. If the valves are arranged vertically one above the other, the refrigerant can then be withdrawn from the lower valve in liquid form and from the upper valve in vapor form. Containers intended for discharging should therefore always be placed in such a way that the two valves are above each other.



Loan steel containers hold up to 800 kg of Solkane

Table 1: Available container sizes[1)] for different Solkane® types
(August 1997)

	Loan steel containers	ISO-tank-containers	Road Tankers	Drums
Solkane 22	900 kg	approx. 17 t	20 t	
Solkane 23	940 kg	approx. 10 t		
Solkane 123	1000 kg	approx. 20 t		300 kg
Solkane 134a	400 and 900 kg	approx. 17 t	20 t	
Solkane 227	1050 kg	approx. 20 t		
Solkane 404A	720 kg	approx. 15 t		
Solkane 407C	800 kg			
R409A	950 kg			
Solkane 410	720 and 320 kg			
Solkane 507	720 kg	15 t		

1) other container sizes can be purchased from wholesalers

Road tanker with Solkane offer a capacity of approx. 20 t

3.3 Other refrigerants

The following table contains refrigerants already listed in the Solkane-Pocket Manual as well as other refrigerants. It represents an excerpt from the ASHRAE STANDARD 34 "Number Designation and Safety Classification of Refrigerants" (Draft dated November 15, 1996). See also page 135 (chapter 9 e)) for the classification of refrigerants according EN 378-1, which gives an identical safety group classification. It must be remembered that the use of chlorine-containing refrigerants is governed by law. The appropriate regulations must be heeded.

An explanation of the listed Standard 34 safety group: The classification consists of a letter (A or B) which indicates the toxicity class, and a number which characterizes the flammability class. Toxicity class A labels refrigerants with a low toxicity, while class B refrigerants have a high toxicity. Flammability class 1 includes refrigerants which propagate no flames in air, class 2 refrigerants with low flammability and class 3 are those with high flammability. The categorization criterion is based on the lower flammability limit and the combustion enthalpy. Non-azeotropic mixtures whose toxicity and/or flammability characteristics change if the composition is altered by fractionation, are labelled as a dual safety group, whereby the two classifications are separated from one another by a diagonal (/). The first classification applies to the initial composition, the second for the mixture composition during "worst case" fractionation (example R406A:A1/A2).

Table 2: Information on refrigerants (1)

Refrigerant		Physical data			
Number	Chem. formula or blend composition (% by weight)	Molar mass	Boiling point at 1.013 bar(°C)	Critical properties t_c (°C)	p_c (MPa)
R11	CCl_3F	137.37	23.8	198.0	4.47
R12	CCl_2F_2	120.91	– 29.6	112.0	4.13
R12B1	$CBrClF_2$-Halon 1211	165.36	– 4.0	153.8	4.10
R13	$CClF_3$	104.46	– 81.4	28.8	3.87
R13B1	$CBrF_3$-Halon 1301	148.91	– 55.2	67.0	3.96
R14	CF_4	88.00	– 127.9	–45.7	3.75
R22	$CHClF_2$	86.47	– 40.8	96.2	4.99
R23	CHF_3	70.01	– 82.1	26.3	4.87
R32	CH_2F_2	52.02	– 51.7	78.1	5.78
R41	CH_3F	34.03	– 78.4	44.3	5.88
R50	CH_4-methane	16.04	– 161.5	– 82.5	4.64
R113	CCl_2FCClF_2	187.38	47.6	214.1	3.44
R114	$CClF_2CClF_2$	170.92	3.8	145.9	3.25
R115	$CClF_2CF_3$	154.47	– 39.1	79.9	3.15
R116	CF_3CF_3	138.01	– 78.4	19.9	3.04
R123	$CHCl_2CF_3$	152.93	27.5	183.8	3.67
R124	$CHClFCF_3$	136.48	– 12.0	122.5	3.63
R125	CHF_2CF_3	120.02	– 48.2	66.3	3.63
R134	CHF_2CHF_2	102.03	– 23.0	118.7	4.62
R134a	CH_2FCF_3	102.03	– 26.1	101.1	4.06
R141b	CH_3CCl_2F	116.95	32.2	204.4	4.25
R142b	CH_3CClF_2	100.50	– 9.8	137.2	4.12
R143a	CH_3CF_3	84.04	– 47.4	72.8	3.78
R152a	CH_3CHF_2	66.05	– 24.1	113.3	4.52
R161	CH_3CH_2F	48.06	– 37.1	102.2	4.70
R170	CH_3CH_3-ethane	30.07	– 88.8	32.2	4.89
E170	CH_3-O-CH_3-DME	46.07	– 24.8	128.8	5.32
R218	$CF_3CF_2CF_3$	188.02	– 36.7	71.9	2.68
R227ea	CF_3CHFCF_3	170.03	– 16.5	101.8	2.93

Safety data		Environmental data	
TLV-TWA (ppm)	Std. 34 Safety group	ODP	GWP_{100}
C1000	A1	1.000	3800[1)]
1000	A1	0.900	8100[1)]
		5.000	
1000	A1	1.000	11700
1000	A1	13.000	5400[1)]
	A1	0	6500
1000	A1	0.050	1500[1)]
1000	A1	0	11700
1000	A2	0	650
		0	150
1000	A3	0	21
1000	A1	0.900	4800[1)]
1000	A1	0.850	9200
1000	A1	0.400	9300
1000	A1	0	9200
10-30	B1	0.020	90[1)]
1000	A1	0.030	470[1)]
1000	A1	0	2800
1000		0	1000
1000	A1	0	1300
500		0.100	600[1)]
1000	A2	0.066	1800[1)]
500	A2	0	3800
1000	A2	0	140
		0	low
1000	A3	0	3
1000		0	<1
1000	A1	0	7000
1000		0	2900

Table 2: Information on refrigerants (2)

Refrigerant			Physical data			
Number	Chem. formula or blend composition (% by weight)		Molar mass	Boiling point at 1.013 bar(°C)	Critical properties t_c (°C)	Critical properties p_c (MPa)
RC270	$-CH_2-CH_2-CH_2-$		42.08	– 33.5	125.2	5.58
R290	$CH_3CH_2CH_3$-Propan		44.10	– 42.1	96.8	4.25
RC318	$-CF_2-CF_2-CF_2-CF_2-$		200.03	– 7.0	115.4	2.78
R400	R12/114	(50/50)	141.63	– 20.5	136.5	
R400	R12/114	(60/40)	136.94	– 22.9	133.0	
R401A	R22/152a/124	(53/13/34)	94.44	– 33.1	108.0	4.60
R401B	R22/152a/124	(61/11/28)	92.84	– 34.7	106.1	4.68
R401C	R22/152a/124	(33/15/52)	101.03	– 28.4	112.7	4.37
—-	R22/152a/124	(40/17/43)	96.61	– 28.8	121.6	
R402A	R125/290/22	(60/2/38)	101.55	– 49.2	75.5	4.13
R402B	R125/290/22	(38/2/60)	94.71	– 47.4	82.6	4.45
R403A	R290/22/218	(5/75/20)	91.99	– 50.0	93.3	5.08
R403B	R290/22/218	(5/56/39)	103.26	– 49.5	90.0	5.09
R404A	R125/143a/134a	(44/52/4)	97.60	– 45.9	72.1	3.73
R405A	R22/152a/142b/C318	(45/7/5.5/42.5)	111.91	– 27.3	106.1	4.26
R406A	R22/600a/142b	(55/4/41)	89.86	– 32.4	114.5	4.58
—-	R22/600a/142b	(65/4/31)	88.57	– 37.5	118.9	
R407A	R32/125/134a	(20/40/40)	90.11	– 45.5	82.8	4.54
R407B	R32/125/134a	(10/70/20)	102.94	– 47.3	75.8	4.16
R407C	R32/125/134a	(23/25/52)	86.20	– 43.8	86.8	4.62
R407D	R32/125/134a	(15/15/70)	90.96	– 39.5	102.4	
R408A	R125/143a/22	(7/46/47)	87.02	– 43.5	83.5	4.34
R409A	R22/124/142b	(60/25/15)	97.43	– 35.1	106.9	4.62
R409B	R22/124/142b	(65/25/10)	96.67	– 36.6	116.0	4.70
R410A	R32/125	(50/50)	72.59	– 51.6	71.8	4.89
R410B	R32/125	(45/55)	75.57	– 51.3	71.0	4.78
—-	R32/125	(48/52)	73.75	– 51.4	84.5	

Safety data		Environmental data	
TLV-TWA (ppm)	Std. 34 Safety group	ODP	GWP_{100}
		0	
p2500	A3	0	3
	A1	0	8700
	A1/A1	0.875	8850
	A1/A1	0.880	8780
800	A1/A1	0.037	1080
840	A1/A1	0.039	1190
	A1/A1	0.032	830
		0.033	910
	A1/A1	0.019	2330
	A1/A1	0.030	2080
1000	A1/A1	0.038	2680
1000	A1/A1	0.028	3680
500	A1/A1	0	3260
1000	A1/A1	0.026	4580
	A1/A2	0.055	1760
		0.051	1680
1000	A1/A1	0	1770
1000	A1/A1	0	2290
1000	A1/A1	0	1526[1)]
1000	A1/A1r	0	1430
	A1/A1	0.024	2740
	A1/A1	0.047	1288[1)]
	A1/A1	0.047	1430
1000	A1/A1	0	1725[1)]
	A1/A1	0	
		0	1770

Table 2: Information on refrigerants (3)

Refrigerant			Physical data			
Number	Chem. formula or blend composition (% by weight)		Molar mass	Boiling point at 1.013 bar(°C)	Critical properties t_c (°C)	p_c (MPa)
R411A	R1270/22/152a	(1.5/87.5/11.0)	82.36	– 39.4	98.6	4.88
R411B	R1270/22/152a	(3/94/3)	83.07	– 41.6	96.5	4.92
—-	R1270/22/152a	(3.0/95.5/1.5)	83.44	– 42.6	96.5	4.92
R412A	R22/218/142b	(70/5/25)	92.17	– 38.5	104.8	
R413A	R218/134a/600a	(9/88/3)	103.95	– 35.0		
—-	R22/124/600a/142b	(50/39/1.5/9.5)	101.59	– 34.3	118.2	
—-	R22/124/600a/142b	(51/28.5/4/16.5)	96.93	– 35.1	118.3	
—-	R23/22/152a	(5/80/15)	81.72	– 45.4	111.3	5.66
—-	R23/22/152a	(5/90/5)	84.18	– 46.7	105.8	5.70
—-	R23/32/134a	(4.5/21.5/74)	83.14	– 42.2	89.0	4.90
—-	R32/125/143a	(10/45/45)	90.69	– 48.4	72.0	4.05
—-	R32/125/143a/134a	(10/33/36/21)	94.50	– 49.4	77.5	4.01
R500	R12/152a	(73.8/26.2)	99.30	– 33.5	105.5	4.42
R501	R22/12	(75/25)	93.10	– 41.4	103.8	
R502	R22/115	(48.8/51.2)	111.63	– 45.3	82.2	4.08
R503	R23/13	(40.1/59.9)	87.25	– 88.7	19.5	4.36
R504	R32/115	(48.2/51.8)	79.25	– 57.2	66.4	4.76
R505	R12/31	(78/22)	103.48	– 30.0	117.8	4.73
R506	R31/114	(55.1/44.9)	93.69	– 12.3	142.2	5.16
R507A	R125/143a	(50/50)	98.86	– 46.6	70.8	3.72
R508A	R23/116	(39/61)	100.10	– 85.7	23.1	4.06

Safety data		Environmental data	
TLV-TWA (ppm)	Std. 34 Safety group	ODP	GWP_{100}
1000	A1/A2	0.044	1500
1000	A1/A2	0.047	1600
1000		0.048	1630
1000	A1/A2	0.052	2040
	A1/A2r	0	1770
		0.043	1230
		0.045	1330
1000		0.040	1970
1000		0.045	2120
		0	1630
		0	3330
		0	2850
1000	A1	0.664	6310
	A1	0.263	3400
1000	A1	0.229	5590
1000		0.599	11700
		0.207	5130
		0.704	
		0.387	
500	A1	0	3300
1000	A1	0	10200

Table 2: Information on refrigerants (4)

Kältemittel		Physical Data			
Number	Chem. formula or blend composition (% by weight)	Molar mass	Boiling point at 1.013 bar(°C)	Critical properties t_c (°C)	p_c (MPa)
R508B	23/116 (46/54)	95.39	– 88.3	14.0	3.93
R509A	R22/218 (44/56)	123.96	– 47.1	86.9	
R600	CH_3-CH_2-CH_2-CH_3-butane	58.12	– 0.5	152.0	3.80
R600a	$CH(CH_3)_2$-CH_3-isobutane	58.12	– 11.8	135.0	3.65
R601	CH_3-CH_2-CH_2-CH_2-CH_3-pentane	72.15	36.2	196.4	3.36
R601a	$(CH_3)_2CH$-CH_2-CH_3-isopentane	72.15	27.8	187.4	3.37
R601b	$(CH_3)_4C$-neopentane	72.15	9.5	160.6	3.20
R610	CH_3-CH_2-O-CH_2-CH_3-diethyl ether	74.12	34.6	214.0	6.00
R611	$HCOOCH_3$-methyl formate	60.05	31.8	214.0	5.99
R630	$CH_3(NH_2)$-methylamine	31.06	– 6.7	156.9	7.46
R631	CH_3-$CH_2(NH_2)$-ethylamine	45.10	16.6	183.0	5.62
R717	NH_3-ammonia	17.03	– 33.3	133.0	11.42
R718	H_2O-water	18.02	100.0	374.2	22.10
R744	CO_2-carbon dioxide	44.01	– 78.4	31.1	7.38
R7146	SF_6-sulfur hexafluoride	146.05	– 63.8	45.6	3.76
R1130	CHCl=CHCl	96.94	47.8	243.3	5.48
R1150	CH_2=CH_2-ethylene	28.05	– 109.4	9.3	5.11
R1270	CH_3CH=CH_2-propylene	42.08	– 47.7	92.4	4.62

Safety data		Environmental data	
TLV-TWA (ppm)	Std. 34 Safety group	ODP	GWP_{100}
1000	A1/A1	0	10400
1000	A1	0.022	4670
800	A3	0	<1
800	A3	0	
600		0	11
600		0	
600		0	
400		0	
100	B2	0	
5		0	
5		0	
25	B2	0	<1
	A1	0	<1
5000	A1	0	1
1000		0	23900
200			
1000	A3	0	
1000	A3	0	

TLV-TWA = ACGIH Threshold Limit Value – Time – Weighted Average
C = TLV Ceiling (this concentration should never be exceeded)
wff = worst case of fractionation may become flammable
ODP = Ozone Depletion Potential
GWP_{100} = Global Warming Potential (100 year time horizon)
[1)] source: refer to table 6, page 96ff

Safety classification:
p = provisional,
r = recommendation by SSPC 34

3.4 Other possibilities

Future refrigerants should certainly have an ODP value of zero as well as a reduced atmospheric life and therefore a reduced global warming potential. In addition, nonflammability, toxicological safety and technical suitability as a refrigerant will be demanded. In consideration of these aspects, partially fluorinated propane and butane derivatives as well as fluorinated ether are currently being discussed. Products currently under scrutiny include the following compounds, either in a pure form or as components of blends:

Abbreviation	Chem. formula	Boiling point at 1.013 bar (°C)	HGWP
R245ca	$CHF_2CF_2CH_2F$	25.0	0.13
R245fa	$CF_3CH_2CHF_2$	15.3	0.24
R236ea	$CF_3CHFCHF_2$	6.5	
R236ca	$CHF_2CF_2CHF_2$	5.0	
R254cb	$CHF_2CF_2CH_3$	– 0.8	
R365mfc	$CF_3CH_2CF_2CH_3$	40.2	0.21
E245fa	$CF_3CH_2OCHF_2$	approx. 29	0.15[1)]
E125	CF_3OCHF_2	– 42.0	
E134	CHF_2OCHF_2	approx. 5	
E134a	CF_3OCH_2F	– 20	

1) Estimated value

The partially fluorinated ethers (fluorinated ether abbreviation = E) are partly characterized by a relatively short atmospheric lifetime and therefore a small HGWP value.

4 Basics of refrigeration calculations

The basis for the calculation of refrigeration processes which operate according to the compression refrigeration cycle are summarized in the following chapter. This concerns a compilation of valid definitions and terminologies according to German standards (DIN = Deutsches Institut für Normung; particularly DIN 8976 and DIN 8977). Refer to national or international standards regarding these definitions and terminologies. For a complete description of the thermodynamic principles involved, please refer to the relevant specialized literature. For example, chap-

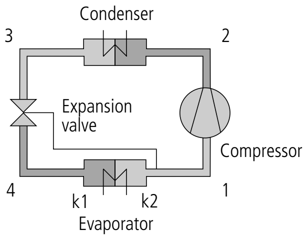


Figure 4: Single-stage compression refrigeration cycle

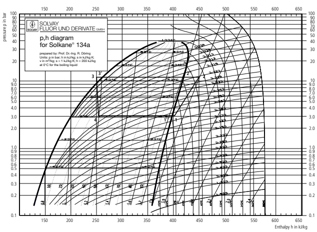


Figure 5: Mollier(-lg p, h-)diagram of a single-stage compression refrigeration cycle for Solkane 134a

ter 1 "Thermodynamics and Refrigeration Cycles" of the "1997 ASHRAE Handbook; Fundamentals (SI Edition)" published by the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N. E., Atlanta, GA 30329, USA (ISBN 1-883413-45-1) gives a good overview.

The indices of the formulas listed here relate to the single-stage compression refrigeration cycle (see Fig. 4).

The **refrigerating capacity** may be deduced from the definition of different system limits. A common form is the internal energy balance at the evaporator. By definition, the evaporator capacity is the rate of heat flow $\dot{Q}_0$ which is transfered to the refrigerant in the evaporator, i.e. the product of the refrigerant mass flow $\dot{m}_R$ and the increase in specific enthalpy Δh between the evaporator inlet and evaporator outlet $\dot{Q}_0 = \dot{m}_R \cdot (h_1 - h_4)$.

The **overall refrigerating effect** $\dot{Q}_{0t}$ is the heat flow withdrawn from the environment by the refrigerant. It is calculated from the product of the refrigerant mass flow and the enthalpy difference between the compressor inlet and condenser outlet.

$\dot{Q}_{0t} = \dot{m}_R \cdot (h_1 - h_3)$.

The enthalpy at the condenser outlet h_3 only differs from the enthalpy at the evaporator inlet h_4 due to the throttling of the refrigerant in the expansion valve, which is not isenthalpic under actual conditions. This is caused by incoming heat from the environment. In a theoretical comparative process, h_3 and h_4 are identical.

The **net refrigerating effect** $\dot{Q}_{0n}$ is the heat flow withdrawn by the refrigerant from the secondary refrigerant or a refrigeration medium in the evaporator. The net refrigerating effect therefore results from the enthalpy reduction of secondary refrigerant.

$\dot{Q}_{0n} = \dot{H}_{sr1} - \dot{H}_{sr2} + Q_a$.

The correction $\dot{Q}_a$ describes the heat flow which, due to the temperature difference between the evaporator and the environment, also reaches the secondary refrigerant as incoming heat.

$\dot{Q}_a = k \cdot A \cdot (t_a - t_m).$

The following values are represented:

- k the overall coefficient of heat transfer between the environment and secondary refrigerant
- A the outer surface of the evaporator
- t_a ambient temperature
- t_m a mean temperature (arithmetic mean of the inlet and outlet temperature of the secondary refrigerant).

The general conditional equation of net refrigerating effect for secondary refrigerants (subscript: srg – secondary refrigerant in general) is:

$\dot{Q}_{0n} = \dot{m}_{srg} (h_{srg1} - h_{srg2}) + \dot{Q}_a.$

For liquid secondary refrigerants (subscript: srl), the net refrigerating effect results from

$\dot{Q}_{0n} = \dot{m}_{srl} \cdot c_{srl} \cdot \Delta t_{srl} + \dot{Q}_a.$

Here h_{srg1} relates to the state of the secondary refrigerant at the evaporator inlet, h_{srg2} to its state at the evaporator outlet plus the solid and liquid elements of the secondary refrigerant, e.g. frost and condensation water, possibly precipitated in the evaporator.

The **compressor refrigerating effect** $\dot{Q}_{0c}$ is calculated from the product of the refrigerant mass flow and the difference between the specific enthalpy at the compressor suction inlet and the specific enthalpy of the saturated liquid of the refrigerant at the pressure existing at the outlet of the compressor.

$\dot{Q}_{0c} = \dot{m}_R \cdot (h_1 - h'_3).$

The **refrigerating effect per unit of swept volume** q_{0v} is the refrigerating effect relative to 1 m³/s of refrigerant vapor at the suction inlet of the compressor. The refrigerating effect taken as a basis must be indicated.

$$q_{0v} = \frac{\dot{Q}_0}{\dot{m}_R \cdot v_{v1}}.$$

The refrigerating effect per unit of swept volume is the influencing variable for the unit size of a refrigerating machine.

The definition of the **driving power** is also dependent upon the definition of the system limits.

A distinction is made between

- Effective power consumption of the compressor (shaft horse-power) $\mathbf{P_e}$,
- Power consumption of the entire plant $\mathbf{P_t}$
- Indicated or internal horse-power of the compressor $\mathbf{P_i}$ (shaft horse-power minus mechanical losses by the compressor) and
- Power consumption of the electric drive motor at the terminals (terminal input) $\mathbf{P_{term}}$.

The **coefficient of performance** COP is the ratio of the refrigerating capacity to the input driving power. The refrigerating capacities and driving powers taken as a basis must each be indicated (indices). The coefficient of performance for the entire plant is for example defined by

$$COP_t = \frac{\dot{Q}_{0t}}{P_t}.$$

Symbols and units

A	m^2	area
c	$\frac{J}{kg\,K}$	specific heat capacity
c_{srl}	$\frac{J}{kg\,K}$	specific heat capacity, liquid secondary refrigerant
H	J	enthalpy
$\dot{H}$	W	enthalpy flow
h	$\frac{J}{kg}$	specific enthalpy
h_{srg}	$\frac{J}{kg}$	specific enthalpy, secondary refrigerant (in general)
h_{srl}	$\frac{J}{kg}$	specific enthalpy, liquid secondary refrigerant
k	$\frac{W}{m^2 K}$	overall coefficient of heat transfer
$\dot{m}$	$\frac{kg}{s}$	mass flow
$\dot{m}_{sr}$	$\frac{kg}{s}$	secondary refrigerant mass flow
$\dot{m}_R$	$\frac{kg}{s}$	refrigerant mass flow
P	W	power
P_e	W	effective power consumption of the compressor (shaft horse-power)

P_t	W	power consumption of the entire plant
P_i	W	indicated or internal horse-power of the compressor
P_{term}	W	power consumption of the electric drive motor measured at the terminals (terminal input)
$\dot{Q}_0$	W	refrigerating capacity, evaporator capacity
$\dot{Q}_{0t}$	W	overall refrigerating effect
$\dot{Q}_{0n}$	W	net refrigerating effect
$\dot{Q}_{0c}$	W	compressor refrigerating effect
q_0	$\frac{J}{kg}$	refrigerating effect per brake horsepower (refrigerating capacity relative to mass flow)
q_{0v}	$\frac{J}{m^3}$	refrigerating effect per unit of swept volume (refrigerating capacity relative to volume flow)
t_{sr}	°C	temperature of the secondary refrigerant
Δt_{sr}	°C	temperature difference of the secondary refrigerant
t_a	°C	ambient temperature
$\dot{V}_{v1}$	$\frac{m^3}{s}$	suction volume flow
v_{v1}	$\frac{m^3}{kg}$	specific volume in suction condition

4.1 Equations for thermophysical data calculation of Solkane® refrigerants

The equations described in this chapter are valid for pure substances and also, with simplifications, for azeotropic mixtures. The mathematical description of zeotropic mixtures is considerably more complicated. Zeotropic mixtures are characterized by a temperature glide, meaning that the composition and temperature do change at a given pressure while boiling. Therefore it is not possible to derive the dew-point from the bubble-point temperature as is the case in the equational system given here. The compositions of vapor and liquid phases in equilibrium are not identical for zeotropic mixtures. An equational system for zeotropic mixtures must describe the composition shift between vapor and liquid phase in steady state. Due to these potential composition shifts, an equational system should also provide the opportunity to adapt the composition of the system. A corresponding equational system is currently being developed at Solvay.

The calculation of thermophysical properties for pure substances can be performed using the following equational system. The constants for the different refrigerants are given in Table 3.

4.1.1 Vapor pressure

Wagner's equation is well suited for representation of the vapor pressure of refrigerants. The equation consists of ten adjustable parameters in the form

$$\ln p_R = \left(A_1(1-T_R) + A_2(1-T_R)^{B_1} + A_3(1-T_R)^{B_2} + A_4(1-T_R)^{B_3} + A_5(1-T_R)^{B_4} + A_6\right)/T_R \quad (1)$$

with the reduced temperature $T_R = \frac{T}{T_c}$ the reduced pressure $p_R = \frac{p}{p_c}$ and the adjustable parameters A_i and B_i.

4.1.2 Density of saturated liquid

The density of saturated liquid can be represented by the polynomial expression

$$\rho'_R = 1 + C_1\,(1 - T_R)^{1/3} + C_2\,(1 - T_R)^{2/3} + C_3\,(1 - T_R) + C_4\,(1 - T_R)^{4/3} \qquad (2)$$

with the reduced density $\rho'_R = \dfrac{\rho'}{\rho_c}$ and the four parameters C_i .

4.1.3 Specific heat capacity

The specific heat capacity in the condition of the ideal gas may be calculated using the following polynomial expression

$$c_p^0 = D_1 + D_2 T + D_3 T^2 + D_4 T^3 + D_5/T \qquad (3)$$

with the five coefficients D_i .

4.1.4 pvT behavior

The Martin-Hou thermal equation of state is well suited to represent the pvT behavior of single-substance refrigerants or azeotropic mixtures

$$p = \frac{RT}{z} + \frac{E_1 + F_1 T + G_1 e^{-kT_R}}{z^2} + \frac{E_2 + F_2 T + G_2 e^{-kT_R}}{z^3} + \frac{E_3}{z^4} + \frac{E_4 + F_4 T + G_4 e^{-kT_R}}{z^5} \qquad (4)$$

with $z = v - b$ it contains a total of 11 adjustable parameters E_i, F_i, G_i and b as well as the constant k.

4.1.5 Specific enthalpy and specific entropy

The Martin-Hou equation of state (4) and the equation for specific heat capacity (3) form the basis of the specific enthalpy and entropy calculation. Applying generally valid thermodynamic relationships the equation is transformed to:

$$h = h_0 + (pv - RT) + D_1 T + D_2 \frac{T^2}{2} + D_3 \frac{T^3}{3} + D_4 \frac{T^4}{4} + \frac{E_1}{z} + \frac{E_2}{2z^2} + \frac{E_3}{3z^3} + \frac{E_4}{4z^4} + e^{-k \cdot T_R} \cdot (1 + k \cdot T_R) \cdot \left(\frac{G_1}{z} + \frac{G_2}{2z^2} + \frac{G_4}{4z^4}\right) \tag{5}$$

and

$$s = s_0 + R \ln\left(\frac{zp_1}{RT}\right) + D_1 \cdot \ln T + D_2 T + D_3 \frac{T^2}{2} + D_4 \frac{T^3}{3} - \left(\frac{F_1}{z} + \frac{F_2}{2z^2} + \frac{F_4}{4z^4}\right) + \frac{k}{T_c} e^{-k \cdot T_R} \cdot \left(\frac{G_1}{z} + \frac{G_2}{2z^2} + \frac{G_4}{4z^4}\right) \tag{6}$$

with p_1 = 1.01325 bar and the specific gas constant R.

The thermodynamic data for the wet vapor range were derived by using the Clausius – Clapeyron equation:

$$\frac{dp}{dT} = \frac{1}{T} \cdot \frac{h'' - h'}{v'' - v'} \tag{7}$$

Transformation of equation (7) gives:

$$h' = h'' - \frac{dp}{dT} \cdot T \cdot (v'' - v') \tag{8}$$

The integration constants h_0 and s_0 result result by letting

$h'_{(t = 0°C)}$ = 200.0 kJ/kg

$s'_{(t = 0°C)}$ = 1.000 kJ/(kgK).

4.1.6 Specific exergy

The specific exergy, while neglecting the kinetic and potential energy, is expressed by the equation

$$e = h - h_a - T_a(s - s_a) \quad (9)$$

whereby index a relates to ambient conditions. The saturation pressure of the substance at T_a = 290 K serves as the reference pressure.

Valid for equations 1 – 9 is:

- temperature T in [K]
- density ρ (in [kg/m^3]
- specific volume v in [m^3/kg]
- specific enthalpy h in [kJ/kg]
- specific entropy s in [kJ/(kgK)]

The indices show the aggregate states: liquid (‘) and gaseous (‘’).

The following table summarizes the coefficients necessary to calculate the single–substance refrigerants as well as Solkane 507.

Table 3: Constants for the thermodynamic calculation bases

const.	Unit	R404A	R407C
A_1	[-]	–7.214103 / –4.892578	–6.776073 / –9.032791
A_2	[-]	8.759989 / –3.591956	–0.310472 / 9.683701
A_3	[-]	–32.677007 / 1.774671	1.411608 / –22.491213
A_4	[-]	22.644609 / –2.063873	1.158275 / 30.286826
A_5	[-]	0	–4.451592 / –19.813675
A_6	[-]	0	1.98029E–02 / –4.59535E–03
B_1	[-]	2.116965 / 2.580478	1.5 /1.5
B_2	[-]	2.144949 / 1.77849	2 / 2
B_3	[-]	2.061007 / 0.9521610	2.5 / 2.5
B_4	[-]	0	3 / 3
C_1	[-]	1.836616	2.267417
C_2	[-]	0.841933	–2.547963
C_3	[-]	–0.497971	6.384295
C_4	[-]	0	–3.563873
D_1	[kJ/kg K]	1.157737E–01	3.398929E–01
D_2	[kJ/kg K^2]	3.334278E–03	1.292320E–03
D_3	[kJ/kg K^3]	–3.212900E–06	2.030970E–06
D_4	[kJ/kg K^4]	1.648430E–09	–2.906300E–09
D_5	[kJ/kg K^5]	0	0
D_6	[kJ/kg]	0	0
E_1	[-]	1.509020E–03	–1.873370E–03
E_2	[-]	3.359440E–07	1.301910E–06
E_3	[-]	–8.036100E–09	–1.403400E–08
E_4	[-]	–3.103200E–10	–1.201500E–09
F_1	[-]	3.805500E–06	6.034960E–06
F_2	[-]	7.197863E–13	–1.302530E–10
F_4	[-]	8.717340E–13	3.171810E–12
G_1	[-]	1.989396E–02	–2.447753E–02
G_2	[-]	–2.246500E–04	5.286100E–04
G_4	[-]	7.707570E–09	1.213160E–08
b	[m/kg]	–1.983330E–03	–3.400640E–03
k	[-]	5.475	5.475
R	[bar m/(kJ K)]	8.521810E–04	9.648824E–04
Tc	[K]	345.25	359.55
pc	[bar]	37.3	46.2
rc	[kg/m^3]	484.5	510
M	[kg/kmol]	97.6	86.2

R410A	R507	R22	R23
–6.207785 / –6.207785	–7.342584	–6.972254	–7.250472
–5.389454 / –5.389454	1.046268	0.06354301	1.020053
14.22181 / 14.22181	1.999693	4.766135	3.527447
–12.28649 / –12.28649	–9.207652	–6.381882	–7.372329
0	0	0	0
0	0	0	0
1.5 / 1.5	1.5	1.5	1.5
2 / 2	3.5	2	2.5
2.5 / 2.5	4	2.5	3
0	0	0	0
3.265416	1.471297	1.571916	1.965954
–5.003160	4.060475	2.265857	–0.0073629
7.424573	–8.198662	–2.781585	1.076588
–2.486670	6.189977	1.804239	–0.062437
4.516774E–01	1.952364E–01	2.629040E–01	2.897852E–01
5.795113E–04	2.585747E–03	1.335690E–03	1.540073E–03
3.087823E–06	–9.585077E–07	1.458470E–07	–1.712401E–07
–3.319566E–09	–5.599254E–10	–9.270830E–10	0
0	0	0	0
0	0	0	0
–1.578347E–03	–1.292014E–03	Morsy	Morsy
–1.038853E–06	1.776088E–06	Morsy	Morsy
–7.414064E–10	–1.599522E–09	Morsy	Morsy
–2.775500E–12	7.197863E–13	Morsy	Morsy
1.733234E–06	1.300073E–06	Morsy	Morsy
5.034639E–09	–1.178195E–09	Morsy	Morsy
8.051215E–15	6.303072E–16	Morsy	Morsy
–4.679572E–02	–2.833159E–02	Morsy	Morsy
1.922119E–04	8.381426E–05	Morsy	Morsy
3.878531E–11	–8.149540E–11	Morsy	Morsy
6.995596E–05	5.732031E–04	Morsy	Morsy
5.475	5.475	Morsy	Morsy
1.145486E–03	8.411154E–04	0.0961536	0.11874862
344.92	343.96	369.33	299.45
48.933	37.17	49.9	48.74
487.4	494.24	513.11	526.98
72.6	98.9	86.5	70

4.1.7 Transport properties

The following calculation equations for the transport properties are valid for single–substance refrigerants, zeotropic and azeotropic refrigerant blends. The coefficients are indicated in Table 4.

4.1.7.1 Dynamic viscosity

The dynamic viscosity of the saturated liquid is expressed by the polynomial

$$\ln\left(\frac{\eta'}{10^{-3}}\right) = H_0 + H_1 t + H_2 t^2 + H_3 t^3 \qquad (10)$$

with t in °C and η' in 10^{-3} Pa s and the four coefficients H_i .

The dynamic viscosity of the saturated vapor can be calculated according to the relationship

$$\eta = \eta_0 + \eta_s \qquad (11)$$

The variable ζ represents the viscosity parameter in the following form

$$\eta_0 = 2{,}6696 \cdot 10^{-2} \frac{(M \cdot T)^{1/2}}{I_1^2 \cdot \Omega\,(T^*)} \qquad (12a)$$

$$\Omega\,(T^*) = \exp.[0{,}45667 - 0{,}53955 \cdot \ln(I_0 \cdot T) + 0{,}187265 \cdot (\ln(I_0 \cdot T))^2 - 0{,}03629 \cdot (\ln(I_0 \cdot T))^3 + 0{,}00241 \cdot (\ln(I_0 \cdot T))^4] \qquad (12b)$$

$$\eta_s = 1000 \cdot T_r^{-2,2}\,[\ln(1{,}65 + p_{r0}^{\,0,8})]^{1,6} \cdot \left[e^{\left(1-\frac{0,78}{T_r}\right)p_{r0}} - 1\right] \cdot (I_2 \cdot I_3)^{-1} \qquad (12c)$$

$$p_{r0} = \frac{p - p_{Pambient}}{p_{crit.}} \qquad (12d)$$

4.1.7.2 Thermal conductivity

The thermal conductivity of the saturated liquid as a function of the temperature follows, with sufficient accuracy, a linear regression in the form

$$\lambda' = J_0 + J_1 t. \qquad (13)$$

The thermal conductivity of the saturated vapor is calculated with a regression equation with five coefficients in the form

$$\lambda'' = L_0 + L_1 t + L_2 t^2 + L_3 t^3 + L_4 t^4 \qquad (14)$$

Valid for the equations (13) and (14):

t = temperature in °C

λ = thermal conductivity in 10^{-3}W/(mK).

J_i and L_i are the coefficients which are adapted to the particular substance.

4.1.7.3 Surface tension

The surface tension of the liquid is represented with a 3rd degree polynomial in the form

$$\sigma = K_0 + K_1 t + K_2 t^2 + K_3 t^3 \qquad (15)$$

with t in °C and σ in 10^{-3}N/m.

4.1.7.4 Specific heat capacity

The specific heat capacity of the saturated liquid is expressed by a regression equation in the form

$$c'_p = M_0 + M_1(1-T_R)^{1/9} + M_2(1-T_R)^{2/9} + M_3(1-T_R)^{3/9} + M_4(1-T_R)^{6/9} \qquad (16)$$

with c_p' in kJ/(kgK) and the five coefficients M_i in [kJ/(kgK)].

Table 4: Constants for the calculation equations of transport properties for Solkane® refrigerants (1)

const.	Unit	R32	R123	R125
H_0	[Pa s]	–1.8646	–0.56273755	–1.59881
H_1	[Pa s/K]	–0.0113347	–0.0130821	–0.013809
H_2	[Pa s/K^2]	–2.393700E–05	4.566270E–05	–1.408100E–05
H_3	[Pa s/K^3]	–2.173300E–07	–2.192300E–07	–2.918000E–07
I_0	[-]	N	275.16	N
I_1	[-]	N	0.5909	N
I_2	[-]	N	35.816	N
I_3	[-]	N	0.2689	N
ζ	[1/Pa s]	N	35816	N
J_0	[10^{-3}W/m K]	151.43	83.890607	72.06
J_1	[10^{-3}W/m K^2]	–0.70375	–0.290282105	–0.38514
K_0	[10^{-3}N/m]	1.108080E+01	1.848186E+01	6.818000E+00
K_1	[10^{-3}N/m K]	–1.720700E–01	–1.232125E–05	–1.322500E–01
K_2	[10^{-3}N/m K^2]	2.085600E–04	2.559425E–05	2.235000E–04
K_3	[10^{-3}N/m K^3]	1.263800E–06	5.088261E–07	2.982500E–06
L_0	[10^{-3}W/m K]	1.288200E+01	8.454018E+00	1.347600E+01
L_1	[10^{-3}W/m K^2]	1.026400E–01	6.711867E–02	1.031500E–01
L_2	[10^{-3}W/m K^3]	1.392130E–03	3.968701E–05	1.333310E–03
L_3	[10^{-3}W/m K^4]	0	–4.607059E–07	1.107480E–05
L_4	[10^{-3}W/m K^5]	0	1.852623E–09	8.531950E–08
M_0	[kJ/(kg K)]	352.35922	N	344.02988
M_1	[kJ/(kg K)]	–1421.286	N	–1417.609
M_2	[kJ/(kg K)]	2017.8634	N	2042.5403
M_3	[kJ/(kg K)]	–1026.8437	N	–1049.057
M_4	[kJ/(kg K)]	79.9066	N	81.293348

R134a	R143a	R152a	R227ea
−1.29909	−1.86345	−1.55872	−1.0612
−0.0129286	−0.013459	−0.0112737	−0.013945
4.922300E−06	−4.240000E−07	2.188000E−05	5.340900E−05
−1.986000E−07	1.670300E−07	−2.109700E−07	−4.056500E−07
277.74	N	322.18	300
0.5067	N	0.4695	0.5
39.721	N	46.173	38.085
0.2597	N	0.2524	0.2752
39721	N	46173	38085
94.21	78.39	116.75	59.89
−0.42784	−0.41553	−0.46025	−0.25291
1.148600E+01	7.762700E+00	1.338300E+01	9.884890E+00
−1.426700E−01	−1.313900E−01	−1.399900E−01	−1.189714E−01
1.313300E−04	1.495200E−04	9.204200E−05	8.713140E−05
1.169700E−06	1.955300E−06	1.870100E−07	9.366990E−07
1.180400E+01	1.231200E+01	1.228200E+01	1.090952E+01
8.305000E−02	9.808000E−02	7.744000E−02	7.010000E−02
1.337410E−04	2.324970E−04	9.616400E−04	7.526930E−05
0	1.112810E−05	0	−1.126800E−07
0	1.454960E−07	0	4.559410E−08
395.19	89.975386	1437.957	N
−1588.637	−273.5245	−5986.308	N
2233.8111	266.51936	8672774	N
−1120.361	−73.87896	−4470284	N
81.2566	−8.511234	348.4895	N

Table 4: Constants for the calculation equations of transport properties for Solkane® refrigerants (1)

const.	Unit	R404A	R407C	R410A
H_0	[Pa s]	–1.73999	–1.5764	–1.78743
H_1	[Pa s/K]	–0.013554	–0.012445	–0.012082
H_2	[Pa s/K^2]	–4.758900E–06	4.502900E–06	–2.090300E–05
H_3	[Pa s/K^3]	–1.095300E–07	–1.179200E–07	–2.393000E–07
I_0	[-]	279.31	339.72	317.47
I_1	[-]	0.4968	0.4538	0.4324
I_2	[-]	42.42918	39.17502	40.99075
I_3	[-]	0.2611	0.2622	0.2542
c	[1/Pa s]	42429	39175	40990
J_0	[10^{-3}W/m K]	76.009	96.197	99.926
J_1	[10^{-3}W/m K^2]	–0.4024	–0.4615	–0.5071
K_0	[10^{-3}N/m]	7.537000E+00	9.996900E+00	8.796300E+00
K_1	[10^{-3}N/m K]	–1.290000E–01	–1.444000E–01	–1.522700E–01
K_2	[10^{-3}N/m K^2]	1.616800E–04	1.644500E–04	2.174000E–04
K_3	[10^{-3}N/m K^3]	1.562400E–06	1.430400E–06	2.114700E–06
L_0	[10^{-3}W/m K]	1.270900E+01	1.251500E+01	1.306100E+01
L_1	[10^{-3}W/m K^2]	9.932000E–02	9.413000E–02	1.027900E–01
L_2	[10^{-3}W/m K^3]	6.226100E–04	8.287300E–04	1.374300E–03
L_3	[10^{-3}W/m K^4]	1.068300E–05	1.988500E–06	3.348700E–06
L_4	[10^{-3}W/m K^5]	5.733900E–08	–1.531900E–08	–2.579800E–08
M_0	[kJ/(kg K)]	48.555298	25.041436	856.35368
M_1	[kJ/(kg K)]	–122.096807	–36.33723	–3542.485
M_2	[kJ/(kg K)]	82.3680368	–23.453984	5108.0843
M_3	[kJ/(kg K)]	–1.24E–03	45.114123	–2623.47
M_4	[kJ/(kg K)]	–7.8369982	–9.2811972	203.5988

Constants for Solkane® refrigerant blend components

R507	R22	R23
–1.76262	–1.55991947	–2.38993081
–0.0136	–0.01083022	–0.01634421
–6.017700E–06	–5.35E–06	–2.35E–05
–2.212900E–08	1.47E–07	5.57E–07
294.33	285.7	N
0.4902	0.4652	N
42.17005	37.488	N
0.2601	0.2736	N
42170.05	37488	N
75.115	96.6888148	77.564172
–0.3999	–0.436130061	–0.70733
7.357300E+00	11.69554373	0.050993183
–1.320400E–01	–0.14976356	–6.91E–05
1.865200E–04	1.85E–04	–9.23E–07
2.508400E–06	5.89E–07	1.94E–09
1.279100E+01	9.503310E+00	1.767600E+01
1.001700E–01	6.082673E–02	2.103000E–01
6.858600E–04	–3.997700E–05	1.267750E–03
1.110600E–05	4.156950E–07	–2.382328E–07
5.043700E–08	5.245200E–20	2.904613E–12
1451.267	N	N
–6005.056	N	N
8645.2715	N	N
–4428.884	N	N
339.60396	N	N

4.2. Physical data

4.2.1 Physical data for Solkane® refrigerants

Physical property	Unit	Solkane 22	Solkane 23
Chemical Formula	[-]	$CHClF_2$	CHF_3
Molecular weight	[-]	86.5	70.0
Boiling point at 1.013 bar	[°C]	–40.8	–82.0
Critical temperature	[°C]	96.2	26.3
Critical pressure	[bar]	49.9	48.7
Viscosity of saturated liquid[2]	[mPas]	0.247	0.164[5]
Viscosity of saturated liquid[1]	[mPas]	0.160	0.108[6]
Viscosity of saturated vapor[1]	[mPas]	0.0130	0.0139[6]
Thermal conductivity of saturated liquid[2]	[W/(mK)]	0.103	0.106[5]
Thermal conductivity of saturated liquid[1]	[W/(mK)]	0.086	0.085[6]
Thermal conductivity of saturated vapor[1]	[W/(mK)]	0.0110	0.0157[6]
Spec. heat capacity of saturated liquid c_p[1]	[kJ/(kgK)]	1.227	1.506[6]
Spec. heat capacity of saturated vapor c_p[1]	[kJ/(kgK)]	0.779	1.365[6]
Ratio c_p/c_v (saturated vapor)[1]	[-]	1.39	1.74[6]
Density of saturated liquid[1]	[kg/m³]	1195	1106[6]
Density of saturated vapor[1]	[kg/m³]	44.11	84.99[6]
Enthalpy of evaporation[1]	[kJ/kg]	182.0	156.6[6]
Explosion limits in air[3]	[% by vol.]	none	none

1: t = 25°C
2: t = –15°C
3: t = 25°C; p = 1.013 bar
4: t = 30°C
5: t = –40°C
6: t = –10°C

Solkane 123	Solkane 134a	Solkane 227	Solkane 404A	Solkane 407C	Solkane 410	Solkane 507
$CHCl_2CF_3$	CH_2FCF_3	CF_3CHFCF_3	CHF_2CF_3/ CH_3CF_3/ CH_2FCF_3	CHF_2CF_3/ CH_2F_2/ CH_2FCF_3	CH_2F_2/ CHF_2CF_3	CHF_2CF_3/ CH_3CF_3
152.9	102.0	170.0	97.6	86.2	72.6	98.9
27.6	–26.1	–16.4	–46.6	–43.8	–51.5	–46.5
183.8	101.1	101.8	72.1	86.4	71.8	70.8
36.7	40.6	29.3	37.3	46.2	48.9	37.2
0.701	0.332	0.432	0.215	0.249	0.200	0.210
0.421	0.197	0.251	0.124	0.152	0.122	0.122
0.0109[4]	0.0120	0.0152	0.0128	0.0125	0.0136	0.0129
0.088	0.101	0.064	0.082	0.103	0.108	0.081
0.077	0.084	0.054	0.066	0.085	0.087	0.065
0.0102	0.0140	0.0127	0.0158	0.0154	0.0165	0.0159
1.074	1.423	1.188	1.530	1.520	1.690	1.638
0.708	1.079	0.880	1.200	1.124	1.303	1.234
1.11	1.24	1.13	1.36	1.32	1.50	1.37
1465	1208	1388	1045	1135	1068	1057
5.95	32.61	36.24	65.36	43.77	65.18	68.25
170.6	175.5	111.4	140.0	183.2	190.3	137.6
none	none	none	none	none	none	none

4.2.2 Physical data of refrigerant blend components

Physical property	Unit	Solkane 32
Chemical formula	[-]	CH_2F_2
Molecular weight	[-]	52.0
Boiling point ati 1.013 bar	[°C]	–51.6
Critical temperature	[°C]	78.1
Critical pressure	[bar]	57.8
Viscosity of saturated liquid[2]	[mPas]	0.183
Viscosity of saturated liquid[1]	[mPas]	0.115
Viscosity of saturated vapor[1]	[mPas]	
Thermal conductivity of saturated liquid[2]	[W/(mK)]	0.162
Thermal conductivity of saturated liquid[1]	[W/(mK)]	0.134
Thermal conductivity of saturated vapor[1]	[W/(mK)]	0.0163
Spec. heat capacity of saturated liquid c_p[1]	[kJ/(kgK)]	1.895
Spec. heat capacity of saturated vapor c_p[1]	[kJ/(kgK)]	1.626
Ratio c_p/c_v (saturated vapor)[1]	[-]	1.75
Density of saturated liquid[1]	[kg/m³]	960
Density of saturated vapor[1]	[kg/m³]	47.59
Enthalpy of evaporation[1]	[kJ/kg]	269.1
Explosion limits in air[3]	[% by vol.]	12.7 –33.4

1 : t = 25 °C
2 : t = –15 °C
3 : t = 25 °C; p = 1.013 bar

Solkane 125	Solkane 143a	Solkane 152a
CHF_2CF_3	CH_3CF_3	CH_3CHF_2
120.0	84.0	66.1
–48.1	–47.3	–24.0
66.3	72.9	113.3
36.4	37.9	45.2
0.350	0.190	0.251
0.232	0.111	0.160
		0.0103
0.087	0.085	0.124
0.076	0.068	0.105
0.0126	0.0151	0.0148
1.213	1.656	1.799
0.757	1.391	1.241
1.22	1.40	1.29
1366	930	900
30.38	57.70	18.54
140.0	159.1	278.3
none	7.1 –20.9	3.7 –21.8

4.3 Pipe Sizing

4.3.1 Introduction

Optimisation of tube design is an important issue for the design of every refrigeration unit. Important topics of the optimisation are the minimisation of the tube diameters for cost reasons while pressure losses in the lines have to be kept low to ensure energy efficient and also safe operations. Both topics take effect on each other, so it is very important to size tubes properly.This chapter is aimed to give advice for the dimensioning of refrigeration units, which will run with SOLKANE® refrigerants.

The tables serve for the dimensioning of horizontal suction-, discharge- and liquid lines and for vertical suction- and discharge-lines as well. Valves and fittings are usually incorporated into pressure drop calculations by using an equivalent length value. This equivalent length is added to the length of the tube of the calculated section. Pressure drop is then calculated for the total resulting length. The values of the equivalent length are available e.g. from the ASHRAE-Handbook[1]. For further information, especially for the data base and the dimensioning models, please contact the Technical Service Refrigerants- of Solvay.

4.3.2 Tables of line capacity

The dimensioning data are written in tables. The tables directly relate tube diameter to optimum line capacity. The calculation method is derived from the ASHRAE-Handbook[1].

The thermophysical properties, which are necessary for the calculation of the tables are calculated using SOLVAY's Ref Calc property-module[2]. The pressure loss is calculated with the Colebrook-equation[3]. The values of roughness for the tube materials are also taken from the ASHRAE-Handbook[3].

4.3.3 Suction Lines

Suction lines are more critical than liquid and discharge lines from a design and construction standpoint. Refrigeration lines should be sized to provide a minimum pressure drop at full load and to return the oil from evaporator to the compressor under minimal load conditions. Normally the suction line is designed to have a pressure drop due to friction which is equivalent to 1 K change in the saturation temperature. The table capacities are calculated with a temperature drop of 0,04 K/m and 1 K/25m respectively. Different line lengths and evaporating temperatures can be fitted with equation 1, different capacities with equation 2.

$$Q = Q_{table} \left(\frac{l_{table}}{l_{equivalent}} \times \frac{\Delta T_{actual}}{\Delta T_{table}} \right)^{0,55} \qquad (1)$$

$$\Delta T_{actual} = \Delta T_{table} \left(\frac{l_{equivalent}}{l_{table}} \right) \left(\frac{Q_{actual}}{Q_{table}} \right)^{1,8} \qquad (2)$$

The friction loss mainly depends on the vapour velocity. The values of density and viscosity, which are necessary for the velocity calculation, are calculated with the assumption of an average vapour temperature of 20∞C in the suction line.

4.3.4 Hot-Gas Discharge Lines

Pressure loss in hot-gas lines increases the required compressor power and decreases the compressor capacity. A generous design minimises the pressure loss. A minimum value of pressure loos is required to ensure proper oil return. A pressure loss, which is equivalent to 1 K change in saturation temperature, is recommended. The table capacities are calculated with a temperature change of 0,02 K/m. Since it is not possible to take a fixed value for the superheating, the capacities are calculated with a 75 % isentropic efficiency of the compressor.

4.3.5 Liquid Lines

Liquid lines should be dimensioned so that the formation of gas is prevented. A large pressure drop can lead to an insufficient liquid pressure at the liquid feed device or cause flashing so the hole system becomes inefficient. Liquid lines should be normally designed to a pressure drop not greater than an equivalent of a 1 K change in the saturation temperature. As standard values for the calculation of the table capacities a liquid velocity of 0,5 m/s and a pressure drop , which is equivalent to a saturation temperature change of 0,02 K/m, is chosen.

[1] ASHRAE Handbook 1998, Refrigeration, SI-Edition, Chapter 2
[2] REF CALC.DLL available from Internet under: www.solvay-fluor.com
[3] ASHRAE Handbook 1993, Fundamentals, SI-Edition, Chapter 2

4.3.6 Suction Risers

In suction lines the oil is separated as a liquid film on the inner walls. The oil transport in riser lines is realised by the mass flow of refrigerant, which transports the oil through friction at the oil surface. Therefore a minimum of refrigerant flow is necessary, which is directly readable as the line capacity in the tables. The calculation of these capacities is based on an equation model (Jacobs1). The simplifying assumption was made, that the hole oil is separated in the liquid phase and the gas phase consists of pure refrigerant only. The condensing temperature is fixed at 40 °C. Capacities for different condensing temperatures can be calculated by multiplying the 40 °C-values with factors, which are available in a table between the capacity table of suction- and hot-gas risers. The R22 values are generated with an ISO-VG 32 mineral oil, the values of all other refrigerants with an ISO-VG 32 ester based oil.

4.3.7 Hot-Gas Risers

Like in suction lines, the oil transport in hot-gas discharge lines is also realised by the refrigerant flow. A sufficient oil transport in hot-gas risers is only guaranteed by a minimum of refrigerant flow. The minimum refrigerant flow is readable as the minimum line capacity in the table for hot-gas-risers. The different assumption compared to those of the suction lines, is, that the fixed temperature in the evaporator outlet is –5 °C. The calculation for different temperatures at the evaporator outlet is realised through factors of a table in the same way, which is described in the suction risers chapter. The chosen oils are identical to the oils in the suction lines calculation.

4.3.8 Tube materials

Referring to the different surface roughness of materials the tables for the dimensioning of horizontal tubes are divided into copper and iron tubes. The dimensions of the copper tubes were taken from the ASTM Standard B88 / Type L, the dimensions of the steel tubes from the ASME Standard B36.10M Type ST.

The surface roughness does not influence dimensioning of riser tubes. Their design is mainly a function of refrigerant mass flow. The referring tables do not distinguish between iron and cooper tubes.

[1] Marc L. Jacobs, u. a., „Oil Transport by Refrigerant Vapor", ASHRAE Transactions, 1976

4.3.9 Dimensioning Example

The suction line of a 10 kW refrigeration unit using R134a shall be designed. The condensing temperature is 30 °C, the evaporating temperature –10 °C. As tube material copper is chosen. Because of the isolation of the tube, the actual temperature difference is 0,02 K/m. The total equivalent length (including all fittings, reductions etc.) is about 30 m.

With the capacity of 10 kW and the factor for a condensing temperature of 30 °C, a fitted capacity is calculated

Qfit.=10 kW x 1.104 = 11.04 kW

The next greater value in the –10 °C column is 11.94 kW. The nominal tube diameter is 35 mm.

The real temperature difference is calculated with equation 2 to

Tactual =1 K x (30 m/25 m) x (10.0 KW/11.04 kW)1.8= 1.09 K

A minimum superheat of 1.09 K is therefore necessary.

4.3.9.1 Pipe Sizing for Solkane® 22 Horizontal Lines

R22 Tc = 40 °C		**suction lines ΔT [K/m] 0.04 saturated suction temperatures [°C]**					**discharge lines ΔT [K/m] 0.02 with isentrop. efficiency of0.75 saturated suction temperatures [°C]**		
Tube Diameter Copper Type L*[mm]	inner Diameter [mm]	–40	–30	–20	–5	5	–40	–20	5
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		196	277	378	570	728	743		
		line capacity [kW]					line capacity [kW]		
10	8.00	0.14	0.23	0.36	0.64	0.92	1.14	1.29	1.48
12	10.92	0.33	0.53	0.82	1.48	2.10	2.61	2.96	3.38
15	13.84	0.62	1.00	1.55	2.78	3.94	4.91	5.56	6.34
19	16.92	1.07	1.72	2.65	4.74	6.72	8.37	9.46	10.80
22	19.94	1.66	2.67	4.11	7.33	10.38	12.92	14.61	16.67
28	26.04	3.38	5.44	8.36	14.87	21.02	26.16	29.57	33.69
35	32.13	5.93	9.52	14.61	25.92	36.59	45.53	51.43	58.58
42	38.23	9.42	15.11	23.15	41.00	57.82	71.95	81.24	92.50
54	50.42	19.66	31.45	48.10	84.97	119.65	148.87	168.00	191.15
67	62.61	34.91	55.75	85.14	150.10	211.11	262.65	296.28	336.95
79	74.80	55.90	89.15	135.98	239.37	336.36	418.45	471.88	536.44
92	87.00	83.33	132.75	202.29	355.65	499.36	621.20	700.32	795.89
105	99.19	117.79	187.47	285.45	501.30	703.40	874.99	986.20	1120.50

*according to ASTM Standard B88/Type L

Calculation table for different condensing temp.

Cond. Temp.[°C]	suction line	discharge line	liquid line (0.5m/s)	liquid line (DT=0.02K/m)
20	1,168	0,754	1,251	0,967
30	1,085	0,878	1,125	0,992
40	1,000	1,000	1,000	1,000
50	0,913	1,115	0,876	0,989

liquid lines saturated suction temperatures [°C]			liquid lines $\Delta T = 0.02$ K/m saturated suction temperatures [°C]		
–40	–20	5	–40	–20	5
velocity			corresponding Δp [Pa/m]		
0.5 m/s			743		
line capacity [kW]			line capacity [kW]		
3.96	4.22	4.49	5.47	5.83	6.21
7.37	7.85	8.36	12.60	13.43	14.30
11.84	12.62	13.43	23.72	25.28	26.92
17.70	18.86	20.08	40.51	43.17	45.97
24.58	26.19	27.88	62.68	66.79	71.12
41.91	44.66	47.56	127.21	135.54	144.33
63.81	67.99	72.40	221.80	236.33	251.66
90.34	96.26	102.50	351.01	374.00	398.26
157.14	167.43	178.29	727.93	775.61	825.92
242.30	258.18	274.92	1286.49	1370.77	1459.67
345.84	368.49	392.39	2052.42	2186.87	2328.71
467.85	498.50	530.83	3050.31	3250.12	3460.93
608.14	647.98	690.01	4300.69	4582.41	4879.63

Line capacity for different temperatures and equvalent lengths

$$Q = Q_{table} \left(\frac{l_{table}}{l_{equivalent}} \times \frac{\Delta T_{actual}}{\Delta T_{table}} \right)^{0,55}$$

Saturation temperatures for different capacities and equivalent lengths

$$\Delta T_{actual} = \Delta T_{table} \left(\frac{l_{equivalent}}{l_{table}} \right) \left(\frac{Q_{actual}}{Q_{table}} \right)^{1,8}$$

R22 **Tc = 40 °C**		**suction lines ΔT [K/m] 0.04** **saturated suction temperatures [°C]**					**discharge lines** **ΔT [K/m] 0.02** **with isentrop. efficiency of0.75** **saturated suction temperatures [°C]**		
Tube Diameter Steel Type 40 ST	inner Diameter [mm]	–40	–30	–20	–5	5	–40	–20	5
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		196	277	378	570	728	743		
		line capacity [kW]					line capacity [kW]		
8	9.25	0.18	0.29	0.44	0.76	1.05	1.31	1.47	1.66
10	12.52	0.41	0.65	0.98	1.69	2.35	2.92	3.28	3.71
15	15.80	0.77	1.21	1.82	3.14	4.36	5.42	6.08	6.88
20	20.93	1.64	2.56	3.84	6.61	9.17	11.39	12.79	14.47
25	26.64	3.11	4.86	7.28	12.50	17.33	21.54	24.17	27.34
32	35.05	6.44	10.05	15.02	25.76	35.69	44.36	49.78	56.29
40	40.89	9.68	15.09	22.54	38.65	53.52	66.53	74.65	84.41
50	59.20	25.70	39.98	59.66	102.15	141.38	175.73	197.14	222.87
65	62.71	29.91	46.52	69.40	118.81	164.43	204.37	229.27	259.18
80	77.93	52.97	82.31	122.72	209.95	290.49	361.05	405.01	457.82
100	102.26	108.11	167.81	250.00	427.44	591.24	734.83	824.24	931.63

liquid lines saturated suction temperatures [°C]			**liquid lines ΔT = 0.02 K/m saturated suction temperatures [°C]**		
–40	–20	5	–40	–20	5
velocity			corresponding Δp [Pa/m]		
0.5 m/s			743		
line capacity [kW]			line capacity [kW]		
5.29	5.64	6.00	6.51	6.94	7.39
9.69	10.32	10.99	14.58	15.54	16.55
15.43	16.44	17.51	27.06	28.83	30.70
27.08	28.85	30.72	56.99	60.72	64.66
43.87	46.74	49.77	107.81	114.87	122.32
75.94	80.91	86.16	222.25	236.80	252.16
103.35	110.12	117.26	333.43	355.28	378.32
216.63	230.82	245.79	881.47	939.21	1000.13
243.08	259.00	275.80	1025.25	1092.41	1163.26
375.39	399.98	425.92	1812.02	1930.72	2055.95
646.37	688.71	733.38	3689.58	3931.28	4186.26

Vertical Lines

Suction-Risers

Refrigerant R22 $T_{cond.} = 40$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	–40	–35	0.092	0.199	0.361	0.596	0.898	1.751	2.960
		–25	0.090	0.195	0.353	0.583	0.878	1.712	2.895
		–15	0.088	0.191	0.345	0.570	0.860	1.676	2.834
	–20	–15	0.145	0.315	0.570	0.941	1.419	2.766	4.678
		–5	0.142	0.308	0.557	0.921	1.388	2.705	4.575
		5	0.139	0.302	0.546	0.902	1.359	2.649	4.480
	–5	0	0.194	0.423	0.764	1.263	1.904	3.711	6.276
		10	0.190	0.413	0.747	1.234	1.861	3.627	6.133
		20	0.186	0.404	0.731	1.208	1.821	3.549	6.002
	5	10	0.232	0.504	0.911	1.506	2.271	4.426	7.485
		20	0.226	0.492	0.890	1.471	2.218	4.322	7.309
		30	0.221	0.481	0.870	1.438	2.169	4.226	7.147

*according to ASTM Standard B88/Type L

Calculation Table for different condensing Temperatures

Refrigerant	Condensing Temperature [°C]			
	20	30	40	50
R22	1.166	1.084	1.000	0.914

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
4.572	9.132	15.692	24.481	35.717	50.528
4.470	8.930	15.344	23.938	34.925	49.408
4.377	8.744	15.024	23.439	34.196	48.377
7.224	14.430	24.795	38.681	56.434	79.837
7.066	14.114	24.252	37.835	55.200	78.091
6.918	13.820	23.746	37.046	54.049	76.462
9.692	19.361	33.268	51.901	75.722	107.122
9.472	18.920	32.510	50.719	73.997	104.682
9.269	18.515	31.814	49.633	72.412	102.440
11.559	23.090	39.675	61.897	90.305	127.752
11.287	22.546	38.740	60.438	88.176	124.742
11.038	22.048	37.885	59.104	86.230	121.988

Hot-Gas-Risers

Refrigerant R22 $T_{cond.} = -5$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	20	60	0.299	0.650	1.176	1.944	2.930	5.711	9.658
		70	0.293	0.638	1.153	1.905	2.873	5.598	9.467
		80	0.287	0.626	1.132	1.870	2.819	5.495	9.292
	30	70	0.315	0.686	1.241	2.050	3.091	6.025	10.189
		80	0.309	0.672	1.216	2.009	3.029	5.903	9.983
		90	0.303	0.659	1.193	1.971	2.971	5.791	9.793
	40	80	0.328	0.713	1.289	2.131	3.212	6.260	10.587
		90	0.321	0.698	1.262	2.086	3.145	6.129	10.365
		100	0.314	0.684	1.238	2.045	3.084	6.010	10.163
	50	90	0.335	0.729	1.318	2.178	3.283	6.398	10.820
		100	0.327	0.713	1.289	2.130	3.212	6.259	10.585
		110	0.321	0.699	1.263	2.088	3.147	6.134	10.373

*according to ASTM Standard B88/Type L

Calculation Table for different evaporation Temperatures

Refrigerant	Evaporation Temperature[°C]						
	–50	–40	–30	–20	0	5	10
R22	0.874	0.905	0.934	0.962	1.012	1.022	1.033

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
14.914	29.792	51.192	79.864	116.518	164.836
14.621	29.205	50.184	78.291	114.223	161.590
14.350	28.665	49.255	76.841	112.109	158.598
15.735	31.431	54.009	84.257	122.928	173.904
15.416	30.795	52.915	82.552	120.440	170.384
15.124	30.211	51.911	80.985	118.155	167.151
16.350	32.660	56.120	87.551	127.733	180.702
16.007	31.974	54.942	85.714	125.053	176.910
15.696	31.352	53.873	84.046	122.620	173.469
16.710	33.379	57.355	89.478	130.545	184.679
16.346	32.653	56.108	87.532	127.706	180.664
16.019	31.999	54.984	85.779	125.149	177.046

4.3.9.2 Pipe Sizing for Solkane® 134a Horizontal Lines

R134a Tc = 40 °C		**suction lines ΔT [K/m] 0.04 saturated suction temperatures [°C]**					**discharge lines ΔT [K/m] 0.02 with isentrop. efficiency of0.75 saturated suction temperatures [°C]**		
Tube Diameter Copper Type L*[mm]	inner Diameter [mm]	−10	−5	0	5	10	−10	0	10
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		317	368	424	486	554	545		
		line capacity [kW] l					line capacity [kW]		
10	8.00	0.29	0.36	0.45	0.55	0.67	0.96	1.02	1.07
12	10.92	0.67	0.84	1.03	1.26	1.53	2.20	2.33	2.46
15	13.84	1.27	1.57	1.94	2.37	2.88	4.14	4.38	4.62
19	16.92	2.17	2.69	3.31	4.05	4.91	7.05	7.46	7.86
22	19.94	3.36	4.17	5.13	6.26	7.59	10.88	11.52	12.14
28	26.04	6.83	8.47	10.41	12.70	15.38	22.02	23.30	24.55
35	32.13	11.94	14.78	18.16	22.13	26.79	38.30	40.53	42.70
42	38.23	18.91	23.41	28.74	35.01	42.35	60.49	64.02	67.44
54	50.42	39.31	48.61	59.61	72.55	87.70	125.10	132.37	139.43
67	62.61	69.58	85.99	105.38	128.17	154.84	220.63	233.43	245.86
79	74.80	111.15	137.29	168.15	204.40	246.81	351.39	371.75	391.51
92	87.00	165.37	204.16	249.94	303.69	366.55	521.51	551.69	580.99
105	99.19	233.36	287.98	352.43	428.06	516.49	734.41	776.86	818.09

*according to ASTM Standard B88/Type L

Calculation table for different condensing temp.

Cond. Temp.[°C]	suction line	discharge line	liquid line (0.5m/s)	liquid line (DT=0.02K/m)
20	1.206	0.718	1.289	0.964
30	1.104	0.859	1.144	0.993
40	1.000	1.000	1.000	1.000
50	0.892	1.131	0.858	0.982

liquid lines saturated suction temperatures [°C]			**liquid lines ΔT = 0.02 K/m saturated suction temperatures [°C]**		
–10	0	10	–10	0	10
velocity			corresponding Δp [Pa/m]		
0.5 m/s			545		
line capacity [kW]			line capacity [kW]		
3.87	4.04	4.20	4.39	4.58	4.77
7.22	7.53	7.83	10.14	10.58	11.01
11.59	12.09	12.58	19.13	19.96	20.76
17.32	18.08	18.80	32.72	34.14	35.51
24.06	25.10	26.12	50.68	52.88	55.01
41.03	42.81	44.54	103.05	107.52	111.85
62.47	65.18	67.81	179.93	187.73	195.29
88.44	92.28	96.00	285.06	297.43	309.40
153.84	160.51	166.97	592.15	617.85	642.72
237.22	247.51	257.47	1047.87	1093.34	1137.34
338.58	353.27	367.49	1673.43	1746.05	1816.32
458.03	477.91	497.14	2489.14	2597.15	2701.67
595.38	621.22	646.22	3511.94	3664.34	3811.81

Line capacity for different temperatures and equvalent lengths

$$Q = Q_{table} \left(\frac{l_{table}}{l_{equivalent}} \times \frac{\Delta T_{actual}}{\Delta T_{table}} \right)^{0,55}$$

Saturation temperatures for different capacities and equivalent lengths

$$\Delta T_{actual} = \Delta T_{table} \left(\frac{l_{equivalent}}{l_{table}} \right) \left(\frac{Q_{actual}}{Q_{table}} \right)^{1,8}$$

R134a Tc = 40 °C		suction lines ΔT [K/m] 0.04 saturated suction temperatures [°C]					discharge lines ΔT [K/m] 0.02 with isentrop. efficiency of0.75 saturated suction temperatures [°C]		
Tube Diameter Steel Type 40 ST	inner Diameter [mm]	–5	0	5	10	–10	0	10	–10
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		317	368	424	486	554	545		
		line capacity [kW]					line capacity [kW]		
8	9.25	0.36	0.44	0.53	0.65	0.78	1.09	1.16	1.22
10	12.52	0.80	0.98	1.20	1.45	1.73	2.44	2.58	2.72
15	15.80	1.49	1.83	2.22	2.68	3.22	4.53	4.79	5.04
20	20.93	3.15	3.85	4.68	5.65	6.77	9.53	10.07	10.59
25	26.64	5.96	7.29	8.86	10.68	12.80	18.00	19.03	20.02
32	35.05	12.29	15.04	18.26	22.01	26.37	37.08	39.18	41.23
40	40.89	18.46	22.57	27.39	33.02	39.55	55.60	58.76	61.82
50	59.20	48.84	59.71	72.43	87.26	104.49	146.84	155.17	163.25
65	62.71	56.82	69.45	84.24	101.49	121.53	170.77	180.45	189.85
80	77.93	100.48	122.78	148.90	179.35	214.73	301.68	318.77	335.36
100	102.26	204.71	250.08	303.21	365.13	437.11	613.95	648.72	682.48

liquid lines saturated suction temperatures [°C]			**liquid lines $\Delta T = 0.02$ K/m saturated suction temperatures [°C]**		
0	10	–10	0	10	
velocity			corresponding Δp [Pa/m]		
0.5 m/s			545		
line capacity [kW]			line capacity [kW]		
5.18	5.40	5.62	5.37	5.60	5.83
9.49	9.90	10.30	12.05	12.57	13.07
15.11	15.76	16.40	22.37	23.34	24.28
26.51	27.66	28.77	47.18	49.23	51.21
42.95	44.81	46.61	89.32	93.20	96.95
74.34	77.57	80.69	184.30	192.29	200.03
101.18	105.57	109.82	276.61	288.61	300.23
212.08	221.28	230.19	731.88	763.64	794.37
237.98	248.30	258.30	851.36	888.30	924.05
367.51	383.46	398.89	1505.31	1570.64	1633.85
632.81	660.27	686.84	3066.45	3199.51	3328.28

Vertical Lines

Suction-Risers

Refrigerant R134a $T_{cond.} = 40$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	–10	–5	0.135	0.295	0.533	0.880	1.327	2.587	4.374
		5	0.132	0.288	0.520	0.860	1.296	2.526	4.272
		15	0.129	0.281	0.509	0.841	1.268	2.472	4.180
	–5	0	0.151	0.330	0.596	0.986	1.486	2.896	4.897
		10	0.148	0.322	0.582	0.962	1.451	2.827	4.781
		20	0.145	0.315	0.570	0.941	1.419	2.766	4.677
	5	10	0.187	0.408	0.738	1.219	1.838	3.583	6.059
		20	0.183	0.398	0.720	1.190	1.793	3.495	5.911
		30	0.179	0.389	0.704	1.163	1.753	3.417	5.779
	10	15	0.207	0.451	0.816	1.348	2.033	3.962	6.700
		25	0.202	0.440	0.795	1.315	1.982	3.863	6.532
		35	0.197	0.430	0.777	1.285	1.937	3.775	6.384

*according to ASTM Standard B88/Type L

Calculation Table for different condensing Temperatures

Refrigerant	Condensing Temperature [°C]			
	20	30	405	0
R134a	1.206	1.104	1.000	0.892

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
6.755	13.494	23.186	36.172	52.774	74.658
6.598	13.179	22.646	35.330	51.545	72.919
6.455	12.895	22.157	34.566	50.431	71.344
7.563	15.107	25.958	40.496	59.082	83.583
7.384	14.750	25.345	39.540	57.687	81.609
7.223	14.428	24.792	38.678	56.429	79.830
9.357	18.691	32.117	50.104	73.100	103.413
9.128	18.234	31.332	48.880	71.314	100.886
8.924	17.826	30.631	47.786	69.718	98.629
10.346	20.667	35.512	55.402	80.829	114.348
10.088	20.151	34.626	54.019	78.812	111.494
9.859	19.693	33.839	52.792	77.021	108.961

Hot-Gas-Risers

Refrigerant R134a $T_{cond.} = 40$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	20	60	0.254	0.552	0.998	1.650	2.487	4.848	8.198
		70	0.249	0.541	0.979	1.618	2.439	4.754	8.040
		80	0.244	0.532	0.961	1.589	2.395	4.669	7.895
	30	70	0.267	0.581	1.050	1.735	2.616	5.098	8.622
		80	0.261	0.569	1.029	1.701	2.564	4.998	8.452
		90	0.257	0.559	1.010	1.670	2.517	4.906	8.296
	40	80	0.275	0.598	1.081	1.787	2.695	5.251	8.881
		90	0.269	0.586	1.059	1.751	2.640	5.145	8.700
		100	0.264	0.575	1.040	1.718	2.590	5.048	8.536
	50	90	0.276	0.602	1.088	1.798	2.710	5.282	8.933
		100	0.271	0.589	1.065	1.760	2.653	5.171	8.745
		110	0.265	0.577	1.044	1.726	2.602	5.071	8.575

*according to ASTM Standard B88/Type L

Calculation Table for different evaporation Temperatures

Refrigerant	Evaporation Temperature[°C]						
	–50	–40	–30	–20	0	5	10
R134a	0.807	0.851	0.894	0.937	1.020	1.040	1.060

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
12.660	25.289	43.455	67.792	98.906	139.921
12.416	24.802	42.618	66.487	97.003	137.228
12.192	24.355	41.849	65.288	95.252	134.752
13.315	26.597	45.702	71.299	104.022	147.158
13.052	26.072	44.800	69.892	101.970	144.255
12.812	25.593	43.977	68.607	100.095	141.603
13.714	27.395	47.073	73.438	107.143	151.574
13.436	26.838	46.116	71.945	104.965	148.492
13.183	26.333	45.248	70.590	102.988	145.696
13.796	27.557	47.352	73.872	107.777	152.470
13.505	26.976	46.354	72.315	105.505	149.256
13.243	26.453	45.455	70.914	103.460	146.363

4.3.9.3 Pipe Sizing for Solkane® 404A Horizontal Lines

R404A Tc = 40 °C		**suction lines ΔT [K/m] 0.04 saturated suction temperatures [°C]**					**discharge lines ΔT [K/m] 0.02 with isentrop. efficiency of0.75 saturated suction temperatures [°C]**		
Tube Diameter Copper Type L*[mm]	inner Diameter [mm]	–40	–30	–20	–5	5	–40	–20	5
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		240	336	455	680	863	875		
		line capacity [kW]					line capacity [kW]		
10	8.00	0.12	0.19	0.31	0.58	0.84	1.04	1.23	1.46
12	10.92	0.27	0.45	0.71	1.32	1.92	2.38	2.82	3.33
15	13.84	0.51	0.85	1.34	2.48	3.60	4.45	5.27	6.24
19	16.92	0.88	1.45	2.29	4.23	6.12	7.57	8.96	10.60
22	19.94	1.36	2.25	3.54	6.53	9.45	11.67	13.82	16.33
28	26.04	2.78	4.58	7.19	13.21	19.10	23.56	27.89	32.96
35	32.13	4.87	7.99	12.55	23.00	33.21	40.91	48.43	57.21
42	38.23	7.72	12.67	19.86	36.34	52.42	64.54	76.38	90.21
54	50.42	16.08	26.33	41.20	75.20	108.31	133.19	157.59	186.08
67	62.61	28.51	46.61	72.82	132.68	190.89	234.53	277.44	327.56
79	74.80	45.60	74.46	116.20	211.39	303.86	373.09	441.28	520.92
92	87.00	67.91	110.78	172.72	313.82	450.77	553.18	654.20	772.17
105	99.19	95.92	156.33	243.54	442.04	634.55	778.37	920.42	1086.28

*according to ASTM Standard B88/Type L

Calculation table for different condensing temp.

Cond. Temp.[°C]	suction line	discharge line	liquid line (0.5m/s)	liquid line (DT=0.02K/m)
20	1.330	0.832	1.470	1.119
30	1.170	0.931	1.236	1.079
40	1.000	1.000	1.000	1.000
50	0.814	1.014	0.760	0.872

liquid lines saturated suction temperatures [°C]			**liquid lines ΔT = 0.02 K/m saturated suction temperatures [°C]**		
–40	–20	5	–40	–20	5
velocity			corresponding Δp [Pa/m]		
0.5 m/s			875		
line capacity [kW]			line capacity [kW]		
2.02	2.30	2.62	3.39	3.87	4.41
3.76	4.29	4.88	7.79	8.89	10.12
6.03	6.88	7.84	14.64	16.71	19.02
9.02	10.29	11.71	24.97	28.49	32.44
12.52	14.29	16.27	38.59	44.04	50.13
21.36	24.37	27.75	78.18	89.21	101.57
32.52	37.11	42.24	136.14	155.35	176.86
46.04	52.53	59.81	215.22	245.58	279.59
80.07	91.37	104.03	445.60	508.48	578.89
123.47	140.90	160.41	786.57	897.56	1021.85
176.23	201.10	228.95	1253.65	1430.55	1628.64
238.41	272.05	309.72	1861.69	2124.38	2418.55
309.90	353.63	402.60	2623.01	2993.13	3407.60

Line capacity for different temperatures and equvalent lengths

$$Q = Q_{table} \left(\frac{l_{table}}{l_{equivalent}} \times \frac{\Delta T_{actual}}{\Delta T_{table}} \right)^{0,55}$$

Saturation temperatures for different capacities and equivalent lengths

$$\Delta T_{actual} = \Delta T_{table} \left(\frac{l_{equivalent}}{l_{table}} \right) \left(\frac{Q_{actual}}{Q_{table}} \right)^{1,8}$$

R404A **Tc = 40 °C**		**suction lines ΔT [K/m] 0.04** **saturated suction temperatures [°C]**					**discharge lines** **ΔT [K/m] 0.02** **with isentrop. efficiency of0.75** **saturated suction temperatures [°C]**		
Tube Diameter Steel Type 40 ST	inner Diameter [mm]	–40	–30	–20	–5	5	–40	–20	5
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		240	336	455	680	863	875		
		line capacity [kW]					line capacity [kW]		
8	9.25	0.15	0.24	0.37	0.66	0.94	1.15	1.35	1.59
10	12.52	0.33	0.54	0.83	1.48	2.10	2.56	3.02	3.56
15	15.80	0.62	1.00	1.54	2.74	3.89	4.74	5.60	6.59
20	20.93	1.32	2.11	3.23	5.76	8.18	9.96	11.76	13.86
25	26.64	2.49	3.99	6.12	10.88	15.46	18.82	22.21	26.17
32	35.05	5.16	8.24	12.62	22.42	31.82	38.73	45.72	53.87
40	40.89	7.74	12.37	18.93	33.62	47.71	58.06	68.54	80.76
50	59.20	20.53	32.73	50.05	88.81	125.98	153.27	180.91	213.15
65	62.71	23.88	38.08	58.21	103.28	146.50	178.23	210.38	247.86
80	77.93	42.26	67.33	102.89	182.47	258.77	314.79	371.55	437.74
100	102.26	86.17	137.18	209.51	371.37	526.56	640.46	755.93	890.58

liquid lines saturated suction temperatures [°C]			**liquid lines $\Delta T = 0.02$ K/m saturated suction temperatures [°C]**		
–40	–20	5	–40	–20	5
velocity			corresponding Δp [Pa/m]		
0.5 m/s			875		
line capacity [kW]			line capacity [kW]		
2.70	3.08	3.50	3.93	4.49	5.11
4.94	5.63	6.41	8.80	10.04	11.43
7.86	8.97	10.22	16.31	18.61	21.19
13.80	15.75	17.93	34.33	39.17	44.60
22.35	25.51	29.04	64.90	74.05	84.31
38.70	44.16	50.27	133.70	152.57	173.70
52.67	60.10	68.42	200.53	228.83	260.51
110.39	125.97	143.41	529.79	604.55	688.27
123.87	141.35	160.92	616.16	703.10	800.46
191.29	218.28	248.51	1088.67	1242.28	1414.31
329.38	375.86	427.91	2215.98	2528.67	2878.83

Vertical Lines

Suction-Risers

Refrigerant R404A $T_{cond.} = 40$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	–40	–35	0.043	0.094	0.169	0.280	0.422	0.822	1.391
		–25	0.042	0.092	0.166	0.274	0.413	0.805	1.361
		–15	0.041	0.090	0.162	0.268	0.404	0.788	1.333
	–30	–25	0.065	0.141	0.255	0.422	0.636	1.240	2.098
		–15	0.063	0.138	0.250	0.413	0.623	1.214	2.052
		–5	0.062	0.135	0.245	0.405	0.610	1.189	2.010
	–10	–5	0.126	0.275	0.496	0.820	1.237	2.411	4.077
		5	0.123	0.268	0.485	0.802	1.208	2.355	3.983
		15	0.121	0.262	0.475	0.784	1.182	2.304	3.897
	0	5	0.165	0.359	0.649	1.073	1.618	3.154	5.333
		15	0.161	0.350	0.633	1.047	1.578	3.076	5.202
		25	0.157	0.342	0.619	1.023	1.543	3.006	5.084

*according to ASTM Standard B88/Type L

Calculation Table for different condensing Temperatures

Refrigerant	Condensing Temperature [°C]			
	20	30	40	50
R404A	1.334	1.172	1.000	0.812

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
2.148	4.290	7.371	11.500	16.777	23.735
2.101	4.197	7.213	11.252	16.416	23.224
2.058	4.112	7.065	11.022	16.080	22.748
3.239	6.471	11.119	17.347	25.308	35.803
3.170	6.332	10.880	16.973	24.763	35.031
3.105	6.202	10.657	16.626	24.256	34.315
6.296	12.576	21.609	33.712	49.185	69.581
6.151	12.286	21.111	32.935	48.052	67.978
6.018	12.022	20.658	32.227	47.018	66.516
8.236	16.452	28.269	44.102	64.342	91.024
8.033	16.046	27.573	43.016	62.758	88.783
7.851	15.683	26.948	42.041	61.336	86.771

Hot-Gas-Risers

Refrigerant R404A $T_{cond.} = 40$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	20	60	0.281	0.612	1.107	1.829	2.757	5.374	9.088
		70	0.275	0.599	1.083	1.789	2.698	5.258	8.891
		80	0.270	0.587	1.061	1.753	2.644	5.152	8.713
	30	70	0.283	0.615	1.113	1.839	2.772	5.403	9.137
		80	0.276	0.601	1.087	1.797	2.710	5.281	8.930
		90	0.271	0.589	1.065	1.760	2.653	5.171	8.745
	40	80	0.275	0.598	1.082	1.787	2.695	5.252	8.882
		90	0.268	0.584	1.056	1.745	2.631	5.128	8.671
		100	0.262	0.571	1.033	1.707	2.574	5.017	8.484
	50	90	0.254	0.554	1.001	1.654	2.494	4.861	8.221
		100	0.248	0.540	0.976	1.613	2.432	4.740	8.015
		110	0.242	0.528	0.954	1.577	2.377	4.633	7.835

*according to ASTM Standard B88/Type L

Calculation Table for different evaporation Temperatures

Refrigerant	Evaporation Temperature[°C]						
	–50	–40	–30	–20	0	5	10
R404A	0.755	0.815	0.872	0.927	1.022	1.042	1.062

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
14.035	28.035	48.173	75.154	109.647	155.115
13.731	27.428	47.129	73.525	107.270	151.753
13.455	26.877	46.183	72.048	105.116	148.706
14.110	28.185	48.431	75.556	110.233	155.945
13.791	27.548	47.336	73.848	107.741	152.419
13.504	26.976	46.353	72.313	105.503	149.253
13.717	27.400	47.082	73.451	107.162	151.601
13.391	26.750	45.965	71.708	104.620	148.004
13.102	26.172	44.972	70.160	102.361	144.808
12.696	25.360	43.577	67.983	99.184	140.314
12.378	24.726	42.487	66.283	96.705	136.806
12.100	24.170	41.531	64.791	94.528	133.727

4.3.9.4 Pipe Sizing for Solkane® 407C Horizontal Lines

R407C Tc = 40 °C		suction lines ΔT [K/m] 0.04 saturated suction temperatures [°C]					discharge lines ΔT [K/m] 0.02 with isentrop. efficiency of0.75 saturated suction temperatures [°C]		
Tube Diameter Copper Type L*[mm]	inner Diameter [mm]	–10	–5	0	5	10	–10	0	10
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		487	562	644	734	832	806		
		line capacity [kW]					line capacity [kW]		
10	8.00	0.47	0.58	0.71	0.86	1.03	1.43	1.51	1.60
12	10.92	1.08	1.33	1.62	1.97	2.37	3.27	3.46	3.65
15	13.84	2.04	2.51	3.05	3.69	4.44	6.14	6.49	6.84
19	16.92	3.49	4.28	5.21	6.29	7.56	10.44	11.05	11.63
22	19.94	5.40	6.62	8.05	9.72	11.67	16.12	17.04	17.94
28	26.04	10.95	13.42	16.31	19.69	23.61	32.57	34.44	36.24
35	32.13	19.10	23.39	28.40	34.26	41.07	56.60	59.84	62.96
42	38.23	30.24	36.99	44.91	54.14	64.86	89.35	94.45	99.37
54	50.42	62.72	76.67	93.00	112.01	134.11	184.57	195.07	205.19
67	62.61	110.88	135.45	164.18	197.63	236.46	325.25	343.69	361.48
79	74.80	176.92	216.01	261.70	314.86	376.56	517.70	546.99	575.23
92	87.00	262.98	320.95	388.66	467.42	558.80	767.93	811.31	853.13
105	99.19	370.82	452.39	547.63	658.39	786.84	1080.96	1141.93	1200.70

*according to ASTM Standard B88/Type L

Calculation table for different condensing temp.

Cond. Temp.[°C]	suction line	discharge line	liquid line (0.5m/s)	liquid line (DT=0.02K/m)
20	1.206	0.737	1.312	1.003
30	1.105	0.870	1.156	1.013
40	1.000	1.000	1.000	1.000
50	0.888	1.116	0.844	0.958

liquid lines saturated suction temperatures [°C]			**liquid lines ΔT = 0.02 K/m saturated suction temperatures [°C]**		
–10	0	10	–10	0	10
velocity			corresponding Δp [Pa/m]		
0.5 m/s			806		
line capacity [kW]			line capacity [kW]		
3.86	3.99	4.12	5.98	6.19	6.38
7.19	7.44	7.67	13.75	14.23	14.67
11.55	11.95	12.32	25.86	26.77	27.60
17.26	17.86	18.42	44.14	45.68	47.10
23.97	24.81	25.58	68.26	70.65	72.84
40.88	42.31	43.62	138.44	143.29	147.72
62.24	64.41	66.40	241.27	249.71	257.43
88.11	91.19	94.01	381.65	395.01	407.22
153.26	158.62	163.52	790.98	818.65	843.97
236.32	244.59	252.15	1397.25	1446.14	1490.86
337.30	349.10	359.90	2228.29	2306.25	2377.57
456.30	472.27	486.87	3310.71	3426.54	3532.50
593.13	613.88	632.87	4666.52	4829.79	4979.14

Line capacity for different temperatures and equvalent lengths

$$Q = Q_{table} \left(\frac{l_{table}}{l_{equivalent}} \times \frac{\Delta T_{actual}}{\Delta T_{table}} \right)^{0,55}$$

Saturation temperatures for different capacities and equivalent lengths

$$\Delta T_{actual} = \Delta T_{table} \left(\frac{l_{equivalent}}{l_{table}} \right) \left(\frac{Q_{actual}}{Q_{table}} \right)^{1,8}$$

R407C Tc = 40 °C		**suction lines ΔT [K/m] 0.04 saturated suction temperatures [°C]**					**discharge lines ΔT [K/m] 0.02 with isentrop. efficiency of0.75 saturated suction temperatures [°C]**		
Tube Diameter Steel Type 40 ST	inner Diameter [mm]	–10	–5	0	5	10	–10	0	10
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		487	562	644	734	832	806		
		line capacity [kW]					line capacity [kW]		
8	9.25	0.56	0.68	0.82	0.98	1.17	1.60	1.69	1.77
10	12.52	1.26	1.53	1.84	2.20	2.62	3.57	3.77	3.96
15	15.80	2.34	2.83	3.41	4.08	4.85	6.62	6.99	7.34
20	20.93	4.93	5.97	7.18	8.57	10.19	13.92	14.69	15.42
25	26.64	9.32	11.29	13.57	16.21	19.26	26.30	27.75	29.14
32	35.05	19.22	23.26	27.95	33.38	39.65	54.15	57.12	59.99
40	40.89	28.83	34.89	41.92	50.06	59.46	81.18	85.64	89.94
50	59.20	76.23	92.21	110.77	132.24	157.02	214.34	226.11	237.44
65	62.71	88.66	107.25	128.83	153.79	182.61	249.26	262.94	276.11
80	77.93	156.71	189.53	227.63	271.70	322.58	440.27	464.43	487.68
100	102.26	319.12	385.87	463.35	552.98	656.46	895.87	945.01	992.30

liquid lines saturated suction temperatures [°C]			liquid lines ΔT = 0.02 K/m saturated suction temperatures [°C]		
–10	0	10	–10	0	10
velocity			corresponding Δp [Pa/m]		
0.5 m/s			806		
line capacity [kW]			line capacity [kW]		
5.16	5.34	5.50	7.04	7.28	7.51
9.45	9.78	10.08	15.76	16.31	16.81
15.05	15.58	16.06	29.22	30.25	31.18
26.41	27.33	28.18	61.53	63.68	65.65
42.78	44.28	45.65	116.37	120.44	124.17
74.06	76.65	79.02	239.84	248.23	255.91
100.80	104.32	107.55	359.78	372.37	383.88
211.28	218.67	225.43	950.87	984.14	1014.57
237.08	245.37	252.96	1105.93	1144.62	1180.01
366.12	378.93	390.65	1954.36	2022.74	2085.29
630.42	652.47	672.65	3978.86	4118.07	4245.41

Vertical Lines

Suction-Risers

Refrigerant R407C $T_{cond.}$ = 40 °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	–10	–5	0.170	0.369	0.667	1.103	1.663	3.241	5.481
		5	0.166	0.360	0.652	1.077	1.624	3.165	5.352
		15	0.162	0.352	0.637	1.053	1.588	3.095	5.234
	–5	0	0.189	0.410	0.742	1.227	1.849	3.604	6.095
		10	0.184	0.401	0.724	1.197	1.805	3.517	5.948
		20	0.180	0.392	0.708	1.170	1.765	3.439	5.816
	5	10	0.230	0.501	0.906	1.498	2.258	4.400	7.441
		20	0.224	0.488	0.883	1.460	2.201	4.289	7.254
		30	0.219	0.477	0.863	1.426	2.150	4.191	7.087
	10	15	0.253	0.550	0.995	1.645	2.480	4.834	8.174
		25	0.246	0.536	0.970	1.602	2.416	4.708	7.963
		35	0.241	0.524	0.947	1.565	2.359	4.598	7.775

*according to ASTM Standard B88/Type L

Calculation Table for different condensing Temperatures

Refrigerant	Condensing Temperature [°C]			
	20	30	405	0
R407C	1.206	1.105	1.000	0.888

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
8.464	16.908	29.053	45.325	66.128	93.550
8.265	16.509	28.368	44.256	64.567	91.342
8.084	16.147	27.746	43.286	63.152	89.340
9.412	18.801	32.307	50.401	73.533	104.025
9.186	18.349	31.530	49.189	71.765	101.524
8.982	17.942	30.829	48.096	70.170	99.268
11.492	22.955	39.444	61.536	89.779	127.008
11.202	22.377	38.451	59.986	87.517	123.809
10.944	21.862	37.565	58.605	85.502	120.958
12.624	25.217	43.330	67.598	98.623	139.520
12.297	24.563	42.207	65.846	96.067	135.904
12.007	23.985	41.214	64.297	93.807	132.707

Hot-Gas-Risers

Refrigerant R407C $T_{cond.} = 40$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	20	60	0.311	0.677	1.225	2.024	3.052	5.948	10.058
		70	0.305	0.664	1.200	1.984	2.991	5.828	9.857
		80	0.299	0.651	1.178	1.946	2.935	5.719	9.672
	20	60	0.311	0.677	1.225	2.024	3.052	5.948	10.058
		70	0.305	0.664	1.200	1.984	2.991	5.828	9.857
		80	0.299	0.651	1.178	1.946	2.935	5.719	9.672
	40	80	0.335	0.730	1.319	2.180	3.287	6.406	10.834
		90	0.328	0.714	1.291	2.133	3.216	6.268	10.600
		100	0.321	0.700	1.265	2.091	3.152	6.144	10.390
	50	90	0.335	0.730	1.319	2.180	3.287	6.406	10.834
		100	0.328	0.713	1.290	2.131	3.213	6.262	10.589
		110	0.321	0.698	1.263	2.087	3.147	6.133	10.371

*according to ASTM Standard B88/Type L

Calculation Table for different evaporation Temperatures

Refrigerant	Evaporation Temperature[°C]						
	–50	–40	–30	–20	0	5	10
R407C	0.831	0.871	0.910	0.948	1.016	1.032	1.047

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
15.533	31.027	53.315	83.175	121.349	171.670
15.222	30.406	52.246	81.508	118.917	168.230
14.936	29.836	51.267	79.980	116.688	165.077
15.533	31.027	53.315	83.175	121.349	171.670
15.222	30.406	52.246	81.508	118.917	168.230
14.936	29.836	51.267	79.980	116.688	165.077
16.731	33.421	57.428	89.592	130.711	184.915
16.370	32.700	56.189	87.659	127.892	180.926
16.045	32.050	55.072	85.916	125.348	177.327
16.731	33.421	57.428	89.593	130.712	184.916
16.353	32.667	56.132	87.569	127.760	180.740
16.016	31.993	54.973	85.762	125.124	177.011

4.3.9.5 Pipe Sizing for Solkane® 410 Horizontal Lines

R410 Tc = 40 °C		**suction lines ΔT [K/m] 0.04 saturated suction temperatures [°C]**					**discharge lines ΔT [K/m] 0.02 with isentrop. efficiency of0.75 saturated suction temperatures [°C]**		
Tube Diameter Copper Type L*[mm]	inner Diameter [mm]	−40	−30	−20	−5	5	−40	−20	5
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		320	447	605	905	1152	1182		
		line capacity [kW]					line capacity [kW]		
10	8.00	0.23	0.37	0.56	1.00	1.43	1.82	2.07	2.37
12	10.92	0.53	0.85	1.30	2.30	3.27	4.17	4.74	5.42
15	13.84	1.00	1.59	2.44	4.32	6.12	7.81	8.87	10.14
19	16.92	1.71	2.73	4.16	7.36	10.42	13.28	15.08	17.23
22	19.94	2.65	4.23	6.44	11.37	16.07	20.49	23.26	26.56
28	26.04	5.41	8.59	13.07	23.01	32.46	41.38	46.95	53.58
35	32.13	9.46	15.00	22.79	40.03	56.41	71.89	81.53	93.01
42	38.23	15.01	23.77	36.06	63.23	89.03	113.44	128.61	146.66
54	50.42	31.25	49.38	74.77	130.79	183.87	234.23	265.42	302.51
67	62.61	55.39	87.38	132.13	230.68	323.96	412.60	467.37	532.49
79	74.80	88.57	139.55	210.79	367.45	515.57	656.55	743.48	846.80
92	87.00	131.89	207.58	313.25	545.39	764.69	973.68	1102.35	1255.22
105	99.19	186.25	292.88	441.62	768.09	1076.29	1370.32	1551.08	1765.81

*according to ASTM Standard B88/Type L

Calculation table for different condensing temp.

Cond.	suction	discharge	liquid line	liquid line
Temp.[°C]	line	line	(0.5m/s)	(DT=0.02K/m)
20	1.238	0.793	1.362	1.036
30	1.124	0.906	1.183	1.034
40	1.000	1.000	1.000	1.000
50	0.858	1.052	0.807	0.921

liquid lines saturated suction temperatures [°C]			liquid lines ΔT = 0.02 K/m saturated suction temperatures [°C]		
–40	–20	5	–40	–20	5
velocity			corresponding Δp [Pa/m]		
0.5 m/s			1182		
line capacity [kW]			line capacity [kW]		
3.48	3.71	3.95	6.85	7.30	7.76
6.49	6.92	7.35	15.70	16.75	17.80
10.42	11.12	11.81	29.48	31.44	33.41
15.58	16.62	17.66	50.23	53.57	56.92
21.64	23.08	24.52	77.57	82.73	87.91
36.90	39.35	41.82	156.99	167.43	177.91
56.18	59.92	63.67	273.16	291.32	309.56
79.54	84.83	90.14	431.56	460.25	489.07
138.35	147.54	156.78	892.66	952.01	1011.62
213.33	227.51	241.76	1574.58	1679.27	1784.41
304.48	324.73	345.06	2508.17	2674.93	2842.41
411.91	439.29	466.80	3722.92	3970.44	4219.03
535.42	571.02	606.77	5243.29	5591.89	5942.01

Line capacity for different temperatures and equvalent lengths

$$Q = Q_{table} \left(\frac{l_{table}}{l_{equivalent}} \times \frac{\Delta T_{actual}}{\Delta T_{table}} \right)^{0,55}$$

Saturation temperatures for different capacities and equivalent lengths

$$\Delta T_{actual} = \Delta T_{table} \left(\frac{l_{equivalent}}{l_{table}} \right) \left(\frac{Q_{actual}}{Q_{table}} \right)^{1,8}$$

R410 **Tc = 40 °C**		**suction lines ΔT [K/m] 0.04** **saturated suction temperatures [°C]**					**discharge lines** **ΔT [K/m] 0.02** **with isentrop. efficiency of0.75** **saturated suction temperatures [°C]**		
Tube Diameter Steel Type 40 ST	inner Diameter [mm]	–30	–20	–5	5	–40	–20	5	–40
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		320	447	605	905	1152	1182		
		line capacity [kW]					line capacity [kW]		
8	9.25	0.30	0.47	0.69	1.17	1.61	2.05	2.32	2.63
10	12.52	0.68	1.04	1.53	2.60	3.60	4.57	5.16	5.85
15	15.80	1.25	1.92	2.83	4.81	6.65	8.46	9.54	10.81
20	20.93	2.63	4.03	5.95	10.09	13.96	17.75	20.01	22.69
25	26.64	4.97	7.61	11.23	19.04	26.34	33.49	37.76	42.81
32	35.05	10.23	15.66	23.09	39.15	54.16	68.86	77.64	88.03
40	40.89	15.33	23.46	34.60	58.67	81.15	103.18	116.33	131.90
50	59.20	40.44	61.88	91.26	154.72	214.01	272.06	306.73	347.78
65	62.71	47.02	71.95	106.11	179.90	248.83	316.32	356.63	404.37
80	77.93	83.01	127.02	187.32	317.58	439.26	558.39	629.54	713.79
100	102.26	168.84	258.32	380.95	645.82	893.27	1135.46	1280.14	1451.46

liquid lines saturated suction temperatures [°C]			**liquid lines ΔT = 0.02 K/m saturated suction temperatures [°C]**		
–20	5	–40	–20	5	
velocity			corresponding Δp [Pa/m]		
0.5 m/s			1182		
line capacity [kW]			line capacity [kW]		
4.66	4.97	5.28	7.82	8.34	8.86
8.53	9.10	9.67	17.48	18.64	19.81
13.59	14.49	15.40	32.39	34.55	36.71
23.84	25.42	27.02	68.14	72.67	77.22
38.62	41.19	43.77	128.78	137.34	145.94
66.86	71.30	75.76	265.23	282.87	300.58
90.99	97.04	103.12	397.75	424.19	450.75
190.72	203.40	216.14	1050.50	1120.35	1190.49
214.01	228.24	242.53	1221.70	1302.92	1384.50
330.50	352.47	374.54	2158.26	2301.75	2445.87
569.08	606.92	644.92	4392.45	4684.48	4977.79

Vertical Lines

Suction-Risers

Refrigerant R410 $T_{cond.} = 40$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10,92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	–40	–35	0.117	0.256	0.462	0.764	1.152	2.245	3.796
		–25	0.115	0.249	0.451	0.745	1.123	2.189	3.702
		–15	0.112	0.244	0.441	0.728	1.098	2.139	3.617
	–30	–25	0.149	0.324	0.586	0.969	1.460	2.846	4.813
		–15	0.145	0.316	0.571	0.944	1.424	2.774	4.692
		–5	0.142	0.309	0.558	0.922	1.390	2.710	4.583
	–20	–15	0.185	0.402	0.728	1.203	1.813	3.534	5.976
		–5	0.180	0.392	0.709	1.172	1.766	3.443	5.822
		5	0.176	0.383	0.692	1.144	1.725	3.361	5.684
	5	10	0.295	0.642	1.161	1.919	2.893	5.637	9.534
		20	0.286	0.623	1.127	1.863	2.808	5.473	9.256
		30	0.279	0.607	1.098	1.814	2.735	5.331	9.016

*according to ASTM Standard B88/Type L

Calculation Table for different condensing Temperatures

Refrigerant	Condensing Temperature [°C]			
	20	30	405	0
R410A	1.240	1.126	1.000	0.857

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
5.862	11.709	20.120	31.389	45.796	64.787
5.717	11.421	19.624	30.616	44.667	63.190
5.586	11.159	19.174	29.913	43.642	61.740
7.432	14.846	25.510	39.798	58.064	82.142
7.245	14.473	24.869	38.798	56.605	80.078
7.077	14.137	24.292	37.897	55.291	78.219
9.229	18.436	31.679	49.422	72.105	102.005
8.991	17.959	30.859	48.143	70.239	99.366
8.778	17.534	30.128	47.002	68.575	97.011
14.723	29.410	50.535	78.838	115.022	162.720
14.294	28.552	49.062	76.540	111.669	157.976
13.923	27.811	47.788	74.553	108.771	153.876

Hot-Gas-Risers

Refrigerant R410 $T_{cond.} = 40$ °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	20	60	0.398	0.866	1.566	2.588	3.902	7.605	12.861
		70	0.389	0.847	1.532	2.532	3.817	7.439	12.580
		80	0.381	0.830	1.501	2.481	3.740	7.289	12.326
	20	60	0.398	0.866	1.566	2.588	3.902	7.605	12.861
		70	0.389	0.847	1.532	2.532	3.817	7.439	12.580
		80	0.381	0.830	1.501	2.481	3.740	7.289	12.326
	40	80	0.414	0.901	1.629	2.692	4.059	7.910	13.376
		90	0.404	0.879	1.590	2.627	3.961	7.720	13.055
		100	0.395	0.860	1.555	2.570	3.875	7.552	12.771
	50	90	0.400	0.870	1.573	2.600	3.920	7.640	12.920
		100	0.390	0.848	1.533	2.534	3.820	7.445	12.591
		110	0.381	0.829	1.498	2.476	3.733	7.275	12.303

*according to ASTM Standard B88/Type L

Calculation Table for different evaporation Temperatures

Refrigerant	Evaporation Temperature[°C]						
	–50	–40	–30	–20	0	5	10
R410A	0.873	0.905	0.935	0.963	1.011	1.021	1.030

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
19.861	39.673	68.171	106.352	155.163	219.507
19.427	38.806	66.682	104.028	151.773	214.711
19.035	38.023	65.335	101.928	148.709	210.376
19.861	39.673	68.171	106.352	155.163	219.507
19.427	38.806	66.682	104.028	151.773	214.711
19.035	38.023	65.335	101.928	148.709	210.376
20.657	41.264	70.904	110.616	161.384	228.307
20.162	40.274	69.203	107.962	157.512	222.830
19.722	39.396	67.695	105.609	154.079	217.973
19.952	39.856	68.485	106.841	155.877	220.516
19.445	38.842	66.742	104.123	151.911	214.906
19.000	37.954	65.216	101.742	148.438	209.992

4.3.9.6 Pipe Sizing for Solkane® 507 Horizontal Lines

R507 **Tc = 40 °C**		**suction lines ΔT [K/m] 0.04** **saturated suction temperatures [°C]**					**discharge lines** **ΔT [K/m] 0.02** **with isentrop. efficiency of0.75** **saturated suction temperatures [°C]**		
Tube Diameter Copper Type L*[mm]	inner Diameter [mm]	–40	–20	0	5	10	–40	0	10
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		249	466	781	878	982	900		
		line capacity [kW]					line capacity [kW]		
10	8.00	0.12	0.32	0.71	0.85	1.02	1.07	1.45	1.54
12	10.92	0.28	0.73	1.62	1.94	2.32	2.44	3.31	3.51
15	13.84	0.53	1.37	3.03	3.64	4.35	4.56	6.19	6.56
19	16.92	0.90	2.33	5.16	6.20	7.40	7.75	10.52	11.15
22	19.94	1.40	3.61	7.97	9.56	11.42	11.95	16.21	17.18
28	26.04	2.86	7.33	16.13	19.33	23.06	24.12	32.70	34.65
35	32.13	5.01	12.77	28.05	33.59	40.05	41.89	56.76	60.14
42	38.23	7.94	20.22	44.29	53.03	63.20	66.07	89.51	94.83
54	50.42	16.54	41.93	91.57	109.54	130.47	136.34	184.61	195.58
67	62.61	29.32	74.11	161.45	193.04	229.80	240.06	324.94	344.23
79	74.80	46.89	118.24	257.09	307.27	365.62	381.85	516.73	547.37
92	87.00	69.82	175.74	381.51	455.80	542.19	566.12	765.93	811.31
105	99.19	98.61	247.79	537.19	641.61	763.00	796.53	1077.47	1141.27

*according to ASTM Standard B88/Type L

Calculation table for different condensing temp.

Cond.	suction	discharge	liquid line	liquid line
Temp.[°C]	line	line	(0.5m/s)	(DT=0.02K/m)
20	1.297	0.805	1.427	1.083
30	1.154	0.914	1.216	1.060
40	1.000	1.000	1.000	1.000
50	0.830	1.039	0.775	0.891

liquid lines saturated suction temperatures [°C]			liquid lines $\Delta T = 0.02$ K/m saturated suction temperatures [°C]		
–40	0	10	–40	0	10
velocity			corresponding Δp [Pa/m]		
0.5 m/s			900		
line capacity [kW]			line capacity [kW]		
2.01	2.55	2.67	3.42	4.34	4.54
3.75	4.75	4.97	7.85	9.96	10.41
6.02	7.63	7.98	14.76	18.71	19.56
9.00	11.41	11.93	25.16	31.90	33.35
12.50	15.85	16.57	38.88	49.29	51.54
21.32	27.03	28.26	78.75	99.83	104.38
32.46	41.15	43.02	137.10	173.80	181.72
45.95	58.25	60.91	216.71	274.73	287.25
79.93	101.33	105.94	448.59	568.68	594.60
123.25	156.24	163.36	791.71	1003.66	1049.40
175.91	223.01	233.17	1261.68	1599.45	1672.34
237.98	301.69	315.44	1873.41	2374.94	2483.18
309.34	392.15	410.02	2639.28	3345.85	3498.34

Line capacity for different temperatures and equvalent lengths

$$Q = Q_{table} \left(\frac{l_{table}}{l_{equivalent}} \times \frac{\Delta T_{actual}}{\Delta T_{table}} \right)^{0,55}$$

Saturation temperatures for different capacities and equivalent lengths

$$\Delta T_{actual} = \Delta T_{table} \left(\frac{l_{equivalent}}{l_{table}} \right) \left(\frac{Q_{actual}}{Q_{table}} \right)^{1,8}$$

R507 Tc = 40 °C		**suction lines ΔT [K/m] 0.04 saturated suction temperatures [°C]**					**discharge lines ΔT [K/m] 0.02 with isentrop. efficiency of0.75 saturated suction temperatures [°C]**		
Tube Diameter Steel Type 40 ST	inner Diameter [mm]	–40	–20	0	5	10	–40	0	10
		corresponding Δp [Pa/m]					corresponding Δp [Pa/m]		
		249	466	781	878	982	900		
		line capacity [kW]					line capacity [kW]		
8	9.25	0.16	0.39	0.81	0.96	1.14	1.19	1.60	1.69
10	12.52	0.36	0.86	1.81	2.15	2.54	2.64	3.56	3.77
15	15.80	0.67	1.60	3.35	3.97	4.70	4.89	6.59	6.98
20	20.93	1.40	3.35	7.03	8.34	9.86	10.26	13.83	14.64
25	26.64	2.64	6.32	13.26	15.74	18.61	19.36	26.10	27.63
32	35.05	5.44	13.00	27.27	32.37	38.27	39.81	53.67	56.81
40	40.89	8.15	19.48	40.86	48.50	57.35	59.66	80.42	85.13
50	59.20	21.49	51.37	107.76	127.89	151.23	157.31	212.06	224.48
65	62.71	24.99	59.73	125.29	148.71	175.84	182.90	246.57	261.01
80	77.93	44.12	105.44	221.18	262.51	310.40	322.88	435.26	460.75
100	102.26	89.72	214.42	449.78	533.83	631.22	656.58	885.11	936.94

liquid lines saturated suction temperatures [°C]			liquid lines ΔT = 0.02 K/m saturated suction temperatures [°C]		
–40	0	10	–40	0	10
velocity			corresponding Δp [Pa/m]		
0.5 m/s			900		
line capacity [kW]			line capacity [kW]		
2.69	3.41	3.57	3.95	5.01	5.24
4.93	6.25	6.53	8.84	11.21	11.72
7.85	9.95	10.40	16.39	20.78	21.72
13.77	17.46	18.26	34.48	43.72	45.71
22.31	28.29	29.58	65.19	82.64	86.41
38.63	48.97	51.20	134.29	170.25	178.00
52.57	66.64	69.68	201.41	255.33	266.97
110.19	139.69	146.05	532.07	674.52	705.26
123.64	156.74	163.89	618.80	784.46	820.22
190.94	242.06	253.09	1093.30	1385.99	1449.16
328.78	416.80	435.80	2225.33	2821.08	2949.65

Vertical Lines

Suction-Risers

Refrigerant R507 $T_{cond.}$ = 40 °C	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	–40	–35	0.071	0.154	0.278	0.459	0.693	1.350	2.283
		–25	0.069	0.150	0.271	0.448	0.676	1.317	2.227
		–15	0.067	0.147	0.265	0.438	0.660	1.287	2.176
	–20	–15	0.119	0.258	0.467	0.771	1.163	2.266	3.832
		–5	0.115	0.251	0.455	0.751	1.133	2.208	3.733
		5	0.113	0.245	0.444	0.734	1.106	2.155	3.645
	0	5	0.183	0.398	0.720	1.190	1.794	3.497	5.914
		15	0.178	0.387	0.700	1.156	1.744	3.398	5.747
		25	0.173	0.377	0.682	1.127	1.699	3.312	5.601
	10	15	0.222	0.483	0.873	1.442	2.174	4.238	7.167
		25	0.215	0.468	0.846	1.398	2.108	4.109	6.949
		35	0.209	0.455	0.824	1.361	2.052	3.999	6.763

*according to ASTM Standard B88/Type L

Calculation Table for different condensing Temperatures

Refrigerant	Condensing Temperature [°C]			
	20	30	405	0
R507	1.322	1.167	1.000	0.816

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
3.526	7.043	12.102	18.880	27.545	38.968
3.439	6.871	11.806	18.418	26.871	38.014
3.361	6.714	11.536	17.997	26.257	37.146
5.917	11.820	20.311	31.687	46.230	65.401
5.765	11.516	19.788	30.871	45.040	63.718
5.629	11.244	19.321	30.142	43.977	62.213
9.133	18.244	31.349	48.907	71.353	100.942
8.874	17.727	30.460	47.521	69.331	98.081
8.649	17.277	29.687	46.313	67.569	95.589
11.067	22.107	37.987	59.263	86.463	122.317
10.731	21.436	36.834	57.464	83.838	118.604
10.444	20.862	35.848	55.925	81.593	115.428

Hot-Gas-Risers

Refrigerant R507 $T_{cond.} = 40\ °C$	Saturated Temp. °C	Suction Gas Temp. °C	Copper Tube Type L*						
			10	12	15	19	22	28	35
			Inner Diameter [mm]						
			8	10.92	13.84	16.92	19.94	26.04	32.13
			Minimum Refrigeration Capacity [kW]						
	20	60	0.281	0.611	1.105	1.825	2.752	5.364	9.071
		70	0.274	0.597	1.080	1.785	2.692	5.246	8.871
		80	0.269	0.585	1.058	1.749	2.637	5.139	8.691
	30	70	0.282	0.614	1.111	1.835	2.767	5.393	9.121
		80	0.276	0.600	1.085	1.793	2.704	5.269	8.911
		90	0.270	0.587	1.062	1.755	2.647	5.158	8.723
	40	80	0.274	0.597	1.079	1.783	2.689	5.240	8.861
		90	0.267	0.582	1.053	1.740	2.623	5.113	8.647
		100	0.262	0.569	1.030	1.702	2.566	5.001	8.457
	50	90	0.253	0.550	0.995	1.645	2.480	4.833	8.173
		100	0.246	0.536	0.970	1.603	2.416	4.709	7.963
		110	0.241	0.524	0.947	1.566	2.361	4.600	7.780

*according to ASTM Standard B88/Type L

Calculation Table for different evaporation Temperatures

Refrigerant	Evaporation Temperature[°C]						
	–50	–40	–30	–20	0	5	10
R507	0.760	0.816	0.871	0.924	1.024	1.047	1.069

Copper Tube Type L*					
42	54	67	79	92	105
Inner Diameter [mm]					
38.23	50.42	62.61	74.8	87	99.95
Minimum Refrigeration Capacity [kW]					
14.008	27.982	48.082	75.011	109.438	154.820
13.700	27.366	47.024	73.360	107.030	151.413
13.421	26.810	46.068	71.869	104.855	148.336
14.085	28.136	48.346	75.423	110.040	155.671
13.761	27.489	47.234	73.688	107.509	152.091
13.471	26.910	46.239	72.136	105.244	148.887
13.684	27.335	46.970	73.277	106.908	151.241
13.353	26.673	45.833	71.503	104.320	147.579
13.060	26.087	44.826	69.932	102.029	144.338
12.621	25.211	43.320	67.583	98.601	139.489
12.297	24.565	42.210	65.851	96.074	135.914
12.015	24.000	41.239	64.336	93.864	132.788

5 General properties

5.1 Stability

One of the main requirements for refrigerants is chemical stability for the temperature and pressure range occurring in the refrigerating machine. If decomposition occurs within the refrigerating circuit, it can lead to the formation of noncondensable gases (pressure increase), or even to the formation of aggressive decomposition products, e.g. halogens and hydrohalic acids which attack the oil and component parts (corrosion). The Solkane refrigerants are stable, unless they are subjected to irregular operating conditions such as temperatures or pressures which are too high. The danger of decomposition exists especially in the presence of certain metals and metal oxides which have a catalytic effect. However, breakdown of a refrigerating machine can often not be traced back to a lack in stability of the refrigerant but rather to the decomposition of the compressor lubricant. The reason for the excellent chemical stability of HFCs and HCFCs is, as already mentioned, to be found in the high bonding energy of the C-F bond. In numerous comparative tests, it was found that R134a is just as stable or even more stable than R12 or R22.

The resistance of individual Solkane types to thermal influences naturally varies and is reduced by the presence of metals, metallic oxides, oil, oxygen or moisture.

5.2 Effect on refrigerated goods

As a consequence of a leak in a refrigerating plant, the effect of gaseous refrigerants on unpackaged foodstuffs can lead to a loss of considerable value. The refrigerant absorbed by the food can generally be removed by the addition of heat or application of a vacuum. However, chemical reactions may also take place between certain refrigerants and the components of the food. Here the danger exists that substances are formed which not only harm the flavor of the food, but also make it inedible, which can for example happen when using ammonia as a refrigerant. The Solkane types have no effect on the refrigerated goods, i.e. neither the taste nor any other quality criteria for foodstuffs are influenced by Solkane refrigerants. However, the “water solubility” and “fat solubility” parameters are also significant for HFCs and HCFCs just as for the CFCs.

5.3 Compatibility with metallic materials

Regarding the effect of refrigerants on metals, dry Solkane types are utilizable with practically all metals and metal alloys, which are standardly used for construction of refrigerating machines and equipment. Only zinc, magnesium, lead and aluminum alloys with more than 2% by weight of magnesium should be avoided.

Even storage tests with humid HFC refrigerants demonstrated good resistance against hydrolysis and no corrosive effects on metals such as ferritic steel, V2A stainless steel, copper, brass or aluminum.

Concerning the selection of metallic materials, it is not sufficient to examine the reaction of refrigerant with metal alone, but more importantly the multicomponent system of refrigerant-metal-water (there is always a small amount of moisture present) -oil.

5.4 Compatibility with nonmetallic materials

Nonmetallic materials are frequently used in refrigerating machine construction. Lacquers, textile fibers and fiber materials are used as electrical insulation materials in motor windings of hermetic compressors, elastomers are used as sealing material particularly for shaft seals, fibrous materials mixed with greases, graphite or synthetics are generally common as sealing materials. The primary application area for nonmetallic materials in refrigerating machine construction is the compressor. These substances are not only subjected to increased temperatures (occasionally above 100°C) but also the effect of gaseous refrigerants or refrigerant-oil mixtures. Here, insulation materials, elastomers and sealing materials can become brittle or soft, swell or shrink, harden, stick, partially or entirely dissolve, whereby the extractable substances may then cause blockages and chemical reactions. The correct selection of materials, maintenance of low operating temperatures and good lubrication substantially contribute to avoiding malfunctions in the refrigerating machines right from the start.

Besides containing a polymer, sealing materials also contain additives like fillers, plasticizers and an entire range of materials for processing and for protection against ageing. Regarding material compatibility with refrigerants, the polymer itself is the weakest link in the chain of different components of a sealing material. That is why the selection of the correct sealing material is often solely limited to the selection of the polymer. In practice, however, the other components may also be of decisive importance. These include, for example, the degree of cross linking, the amount of plasticizer used and the type of fillers. Polymer compatibility alone is therefore no guarantee of a secure sealing material, however it is an important prerequisite.

For the reasons given above, we recommend special tests for each new application of an HFC refrigerant.

For different HFC types, usable thermoplastics are polytretrafluoroethylene (PTFE), polyacetal (POM) and polyamide (PA). Suitable elastomers are acrylonitrile butadiene rubber (NBR) and hydrogenated acrylonitrile butadiene rubber (HNBR). However, since individual HFC and HCFC refrigerants show different compatibility to plastics and elastomers, this is described in detail in the section "Solkane types."

Metal seals are also practical. If screw connections are required, the thread must then be cleanly cut and thoroughly cleaned of residual cutting oil. Minium or glycerine paste should never be used for sealing threads.

The best method for avoiding leakages is to do without screwed connections in favor of welded or soldered ones.

5.5 Lubricant aspects

Various refrigerating oils are used as lubricant and sealing media on movable parts of refrigerating machines. The parts to be lubricated are primarily the pistons, valves, stuffing-boxes and slide ring sealings of the compressors. Since practically all moving parts of a refrigerating plant are in the compressor, this is the only part of the plant where lubrication is really necessary. The presence of oil in a refrigerating circuit is always disadvantageous.

The selection of a suitable lubricant is as important for the compressor as precise observation of the operating instructions. If these points are ignored, the viscosity of the oil in the compressor may be too low so that the lubricating properties are reduced and decomposition of the oil may take place. Organic acids are formed in such a case, which may cause corrosion. Another product of oil decomposition is oil sludge. This tends to clog movable parts and increases friction. In overheated compressors, reactions between oil and refrigerant will take place readily, which creates hydrohalic acids. Outside the compressor, the oil in the refrigerating circuit can cause some difficulties. For example, as a result of oil circulation the refrigerating capacity may be decreased due to a decreased heat transfer rate in the evaporator and a reduction of the vapor pressure. The best remedy is an effective oil separator.

International and national standards establish the requirements for suitable refrigeration lubricants. Low neutralization and saponification numbers, a very low ash and water content and an appropriated viscosity are required.

For CFC refrigerants, lubricating oils on mineral oil basis were primarily used in refrigeration. For HCFC refrigerants, such as R22, alkylbenzene oils are used. The refrigerant substitutes (HFCs), in comparison to CFC refrigerants, have a higher polarity. Mineral oils and alkylbenzene oils are relatively nonpolar substances. A general rule in chemistry states that the polarity of substances has an influence on their solubility. Two polar substances dissolve well with each other, however a polar substance is either insoluble or only insufficiently soluble in a nonpolar substance. For this reason, HFC refrigerant substitutes (e.g. R134a, R507 etc.) are not soluble in lubricants on a mineral oil or alkylbenzene oil basis. In a refrigerating plant, oil is always withdrawn with the refrigerant in the circuit. For this reason, it is desirable for the oil to have a certain solubility in the refrigerant to ensure oil return to the compressor. In this way, oil deposits are avoided in the condenser or in the evaporator. Synthetic lubricants based on polyolesters (POE) and polyalkylene glycols (PAG) have been developed for HFC refrigerants by the lubricant manufacturers. These synthetic lubricants are polar and miscible with HFC refrigerants. With the known HFC refrigerants, polyolester-based oils are almost exclusively used. One exception is found in the application area of automotive air conditioning. Here, primarily polyalkylene glycols (PAG) are used. Medium-term refrigerant substitutes, such as HCFCs (R22, R123) and Drop-In refrigerants (e.g. R409A) may be used with mineral oil or alkylbenzene oil.

Polyolester oils demonstrate excellent lubricating characteristics, as well as a high thermal and chemical stability. In comparison to the classic lubricants, polyolester oils can absorb more moisture due to their chemical properties and polarity.

At water contents of more than 200 ppm in polyolester oil reaction with moisture may take place (hydrolysis reaction). In this reaction, so-called partial esters and carboxylic acids are created from the polyolester oil. The reaction products may, under certain conditions, react with the compressor parts. In order to avoid hydrolysis, the amount of water in polyolester oils should not exceed 100 ppm. For this reason, care must be taken when handling ester oils that as little moisture as possible enters the refrigerating plant. This means that, for example, polyolester oil containers which once have been opened should not be used again later. The ester oil in an open container can absorb moisture from air. In addition, the compressor should be filled with ester oil quickly and contact with air humidity should be prevented if possible. Thorough evacuation and drying of the refrigerating plant is very important when using polyolester oils. It has to be ensured that a dryer of sufficient size is installed.

Polyalkylene glycol oils (PAG) consist of both polar and nonpolar parts. They are used as lubricants, for example, with the refrigerants propane or propylene. When using drop-in refrigerants containing hydrocarbons, the oil viscosity is in some cases reduced to a great extent due to the very good solubility of the hydrocarbons, which leads to an increase of the scuffing tendency in the bearings of the compressor. Oils approved by the compressor manufacturers should always be used.

Refrigerant substitutes, such as R134a, are well soluble in PAG oils – particularly at low temperatures. In the higher temperature range, however PAG oils demonstrate a lack of miscibility. Long-term tests have shown that the thermal stability of PAG based oils is poorer in comparison to other synthetic oils or oils on a mineral oil basis. In comparison to ester oils, the hygroscopic character of PAG oils is more pronounced. Through the addition of suitable inhibitors, the hygroscopy of PAG oils may be reduced. In practice, PAG oils are used in automotive air conditioners with R134a

The use of synthetic refrigerating machine oils for refrigerant substitutes is rather critical due to the hygroscopic properties. For this reason, refrigerating machine oil manufacturers are attempting to improve the characteristics of synthetic oils through new developments. The use of polyolester oils in automotive air conditioners for example, such as for air-conditioning on buses, can lead to problems. It is possible that moisture will enter the refrigerating circuit through the long hose connections. One solution to this problem could prove to be the use of alkylbenzene oils with special additives in conjunction with R134a. The alkylbenzene oil with additives and R134a form a dispersion which leads to sufficient oil return to the compressor. Use of these newly developed oils is also possible for stationary refrigerating and air-conditioning plants. If the suitability of these special oils is confirmed in practice, conversion of R12 refrigerating plants to long-term HFC refrigerant substitutes (R134a) may be substantially simplified (also refer to the chapter "Retrofit"). Multiple ester oil changes or the use of drop-in refrigerants will then no longer be necessary.

Concerning the selection of suitable lubricants for the alternative refrigerants, we would direct you to the approvals of the compressor manufacturer or to information from the oil manufacturer.

5.6 Refrigerants and water

Prerequisite for the smooth operation of a refrigerating machine is the purity of the refrigerant. The most widespread and, in its consequences, most harmful contaminant for refrigerants is water. It is without any doubt the cause of most failures in refrigerating machines, even when working with hydrofluorocarbons. Thus water can lead to freezing of the control devices, blockages of the filter, corrosion, copper plating and burnouts in hermetic units. Water may occur in the refrigerating circuit in various forms, free (liquid or solid), dissolved in the refrigerant or oil, adsorbed on the drying agent and on the surfaces of structural materials, chemically bonded in hydrates and contained in the structure of insulating materials. A minimal water content can generally not be avoided. Even if the assembled machine is thoroughly dried, some moisture will remain. A study by refrigerating plant manufacturers, in regard to acceptable moisture content in assembled machines, showed a water content of 10 – 60 ppm for the refrigerant R12 and 50 – 200 ppm for refrigerant R22, depending on the particular application [1]. Experiences with water contents in this range should not cause any problems, however it is recommended that the water content is kept as low as possible.

In order to understand the functions of water in the refrigerating cycle, knowledge of the solubility of water in refrigerants is required. This varies among individual refrigerant types and decreases with falling temperature. It additionally depends on the aggregate state of the refrigerant. Compared to fully halogenated CFC refrigerants, water solubility in partially halogenated hydrocarbons (e.g. HCFC R22, HFC R134a) is greater. The solubility limit of water in liquid R22 at 25°C is 1,300 mg/kg and in liquid R134a, it is in the same order of magnitude. In comparison to this, the solubility limit of water in liquid R12 at 25°C is 90 mg/kg. As mentioned above, the solubility limit at lower temperatures is lower. This means, that the water contents at 25°C given above would cause, for example, at a temperature of 0°C the presence of free water. The water can freeze out in capillary tubes or expansion valves to cause blocking. Besides the actual formation of ice, this can also lead to blockages through gelatinous, voluminous hydrates which frequently persist until well above the freezing point of water. In addition, the free water content can cause corrosion in the refrigerating machine. Freezing-up of control devices when using CFC refrigerants is a warning of a too high moisture content. Due to the higher water solubility of partially halogenated fluorocarbons (HCFCs, HFCs), ice blockages in the expansion device occur less frequently. Hydrocarbon refrigerants are even less able than CFC refrigerants to dissolve water, i.e. the above described risks would occur more often when it is used in the presence of a high moisture content.

The adherence to specifications, which are standardized, by the manufacturers of refrigerants guarantees smooth functioning of a refrigerating machine, provided that the plant has been well dried and that only dry refrigerating machine oils are used. According to ISO 12810 (status: final draft February 1998), the water limit values for refrigerant substitutes are established at 10 mg/kg. At these moisture contents, neither freeze-ups nor corrosion can occur.

Water content in the vapor phase is higher than in the liquid phase for fully halogenated CFC refrigerants. For partially halogenated halocarbon refrigerants, e.g. R22, the water content in the liquid phase is higher. Between the vapor and liquid phase an equilibrium establishes itself in regard to water content. The distribution of water between the vapor and liquid phase is dependent upon the temperature and the amount of liquid in a sample container. Thus, for example, in an almost completely filled cylinder, the largest share of the water is dissolved in the liquid phase, even if the absolute water content in the liquid phase is low. On the other hand, if this cylinder is only filled with a small amount of liquid phase, the majority of the water may thus be dissolved in the vapor phase [2]. This charactaristic provides the opportunity to dry the liquid phase of CFC refrigerants through the removal of gas, provided that gas is blown off in batches and that a new equilibrium can be established each time. For partially halogenated fluorocarbons such as R22, this is not possible because the liquid phase contains more water here than the vapor phase.

In chapter 5.5 "Lubricant aspects", it is explained that synthetic refrigerating machine oils, especially polyolester oils, must be used for HFC refrigerants. It is once again pointed out that ester oils have the tendency to attract moisture. It is very important to be certain to use only dry ester oil. Water may react with ester oil (hydrolysis). The reaction products resulting thereby may attack the components of a refrigerating plant, e.g. compressor. The hydrolysis resistance of fluorocarbon refrigerants is very good in comparison to chlorinated hydrocarbons.

Due to the higher water solubility in HFCs and the hygroscopic property of polyolester oils, great care must always be taken to be sure that as little moisture as possible is present in a refrigerating plant. In chapter 6.4, the drying of refrigerating machines will be approached more closely. The use of suitable filter dryers in the liquid line of refrigerating machines is absolutely necessary. Here it must be ascertained that, in contrast to using CFC refrigerants, suitable filter dryers are used for the refrigerant substitute. The molecular structure of the refrigerant substitutes differs from that of CFC refrigerants. The molecular sieves used in filter dryers to dry refrigerant substitutes must have a pore size of 3 Angström units. In addition, care must be taken that the material of the filter dryer is compatible with the refrigerant substitute. Suitable filter dryers for the new refrigerants are offered by wholesalers. As is generally known, filter dryers can take up 15 to 20% by weight of water of their filter insert weight.

Generally, sight glasses equipped with a moisture indicator are installed in refrigerating machines. These types of sight glasses indicate if the acceptable water content in the refrigerating machine has been exceeded. To obtain a reliable indication of the water content, make certain that a sight glass is used with a moisture indicator suitable for refrigerant substitutes.

Finally, here is a tip about a device for removing large amounts of water from refrigerating circuits. Wholesalers offer "freeze-out" units which serve to remove water from refrigerating circuits by freezing it out and is to be used if drying by conventional methods (use of filter dryers, flushing with dry nitrogen) is not possible for technical and economical reasons due to the amount of water contained in the refrigerating plant. This would for example be the case after water has entered the refrigerating machine due to defective water-cooled condensers or water chillers.

The method is based upon the physical principle of temperature-dependent water solubility of refrigerants. For utilization of this effect, superheated refrigerant vapor with a high temperature level is directed through the plant parts to be dried, where it absorbs its capacity of water and transports this into a container of a lower temperature level (freeze-out unit), where the water separates owing to the lower water solubility of the refrigerant at a low temperature. A detailed description of the unit is given in [3].

References for Chapter 5.6:

[1] American Society of Heating, Refrigerating and Airconditioning Engineers, ASHRAE Systems Handbook, Atlanta, Ga.: ASHRAE (1984), Chapter 28

[2] Ralph C. Downing, "Fluorocarbon Refrigerants Handbook" Prentice -Hall, INC., Englewood Cliffs, New Jersey 07632 (1988), Chapter 7, pp 161-189

[3] Bedienungsanleitung für Ausfriergerät zur Beseitigung von Wasser aus Kältekreisläufen, Schiessl company, Kolpingring 14, Oberhaching

5.7 Electrical properties

Since the introduction of hermetic refrigerating machines, in which the electric motor is integrated into the refrigerant circuit, it has become necessary to learn the electrical properties of refrigerants. Of particular interest are the breakdown voltage, the dielectric constant and the specific resistance. The breakdown voltage of gases is usually indicated in kilovolts for a given distance of the electrodes. The dielectric strength is the breakdown voltage related to a gap of 1 cm between the electrodes. Both, breakdown voltage and dielectric strength are also frequently given in relative values, relating for example to nitrogen = 1. For the hydrocarbons, the breakdown voltage grows with the increasing number of carbon atoms and with growing substitution of fluorine for hydrogen atoms, and even more with the substitution of chlorine atoms for hydrogen atoms.

Although HFC and HCFC refrigerants have a lower breakdown voltage and, for the liquid phase, a greater dielectric constant than the old fully halogenated refrigerants, both parameters – with only a few exceptions – are, nevertheless, in the same order of magnitude as R22.

A high dielectric strength or breakdown voltage for hermetic refrigerating machines is also demanded from the lubricating oil used.

While pure liquids only have a very low electrical conductance, even the smallest amounts of contaminants and moisture increase the conductivity significantly. Generally, the refrigerants never occur in a chemically, absolutely pure state. They are almost always contaminated with some oil and small amounts of water, which is electrolytically decomposed when the current passes through and may then be the cause of further reactions.

Table 5 contains the breakdown voltage of gaseous refrigerant substitutes and the dielectric constants and specific resistances of the liquids. The values for the breakdown voltage are measured according ASTM D 2477-84. Detailed information can be requested from the technical department for Solkane-refrigerants. It is recommended to consider also the available literature as well as future publication related to electrical properties of alternate refrigerants.

Table 5: Electrical properties of refrigerants

	Breakdown voltage (gas) [kV] (electrode gap: 2.54 mm) p, t: ambient	Dielectric constant (liquid) [-] t: ambient, p: saturation	Resistance (liquid) [MΩcm] a.c. frequency= 1kHz t: ambient, p: saturation
R12	13.7 [a)]	2.04 [a)]	0.51×10^6 [a)]
R22	7.2 [a)]	6.35 [a)]	157 [a)]
R32	2.8 [a)]	14.27 [c)]	–
R123	18.1 [a)]	4.50 [a)]	147 [a)]
R124	10.4 [a)]	5.18 [a)]	289 [a)]
R125	6.4 [a)]	4.94 [e)]	–
R134a	6.6 [a)] / 6.2 [b)]	9.51 [a)] / 9.24 [b)] / 9.46 [d)]	177 [a)] / 108 [b)]
R141b	13.4 [a)]	8.07 [a)]	322 [a)]
R142b	8.7 [a)]	9.24 [a)]	1056 [a)]
R143a	5.8 [a)]	9.57 [e)]	–
R152a	5.9 [a)]	13.89 [a)]	50.0 [b)]
R404A	5.5 [b)]	7.58 [b)]	84.5 [b)]
R407C	5.3 [b)]	8.74 [b)]	74.2 [b)]
R410A	4.8 [b)]	7.78 [b)]	39.2 [b)]
R507	5.4 [b)]	6.97 [b)]	55.7 [b)]

a) Fellows B.R., Richard R.G., Shankland I.R., "Electrical Characterization of Alternate Refrigerants", Actes Congr. Int. Froid, 18th (1991), Saint-Hyacinthe, Que, Volume 2, pp 398-402.

b) Report by RWTH Aachen (Germany), Prof.-Dr. G. Pietsch, Dipl.-Ing. Haacke, "Messung von elektrischen Kenngrößen alternativer Kältemittel", February 1998 by order of Solvay Fluor und Derivate GmbH, Hannover

c) Barão M.T., Mardolcar U.V., Nieto de Castro C.A.; "Molecular Properties of Alternative Refrigerants derived from Dielectric-Constant Measurements", Journal of Thermophysics, Vol.18, No.2, March 1997, pp 419-438

d) Barão M.T., Mardolcar U.V., Nieto de Castro C.A.; "The Dielectric-Constant of lliquid HFC 134a and HCFC 142b", Journal of Thermophysics, Vol.17, No.3, May 1996, pp 573-585

e) Personal communication to Solvay by Prof. Mardolcar (Departamento de Fisica, Instituto Superior Técnico, Av. Rovisco Pais, 1096 Lisboa Codex, Portugal) of not yet published preliminary data in 11/1997

5.8 Environmental properties

For the ecological evaluation of refrigerants, various environmental influences must be quantified. Refrigerating plants must always be designed and operated in such a way that leakages are prevented or reduced according to the state of the art. Through Solvay's extensive recycling concept the reutilization and recirculation of raw materials in the economic cycle are maintained.

The **ODP** (**O**zone **D**epletion **P**otential) quantifies the contribution of a substance to ozone depletion. The ODP of R11 is by definition 1.0.

The **GWP** (**G**lobal **W**arming **P**otential) describes the contribution to the greenhouse effect relative to CO_2 = 1.0. Indication of the time horizon is required. The calculation of GWP values over a time horizon of 100 years is most common.

The **HGWP** (**H**alocarbon **G**lobal **W**arming **P**otential) expresses the contribution to the greenhouse effect, relative to R11 = 1.0. The HGWP values relate to an infinite time horizon.

The **TEWI** (**T**otal **E**quivalent **W**arming **I**mpact) takes the sum of **direct** (global warming potential of a substance) and **indirect** (contribution of the CO_2 emissions which result from energy consumption for operation of the plant) emissions of greenhouse gases. TEWI is not a product-specific indication but rather relates to a system (plant). For household refrigeration units, TEWI is practically only made up of the indirect share (CO_2 emissions from energy consumption). The refrigerant emissions are almost zero here, i.e. the direct GWP share is negligible.

In the case of transport refrigeration, the situation is different. Due to technical conditions, refrigerant leakages cannot be avoided here so that the direct GWP share is no longer negligible.

The **POCP** (**P**hotochemical **O**zone **C**reation **P**otential) is a measure of the potential of a substance for creating ozone close to the ground ("summer smog").

The direct causes of undesirable ozone concentrations close to the ground are, on the one hand, nitric oxides (NO_x) and on the other hand, highly volatile organic compounds (**VOC**), such as hydrocarbons for example.

Only a sufficient concentration of both substance groups leads to increased ozone formation.

However, the various **VOCs** contribute in extremely differing degrees to ozone formation near the ground, the decisive factor being the stability of the substance. As a general rule, the shorter the atmospheric lifetime of a substance, the greater its photochemical ozone creation potential (POCP). The values relate to methane as a reference (POCP = 1.0).

The following table presents the ODP, GWP and HGWP values of the most common refrigerants.

Table 6: Environmentally relevant values of various refrigerants

Refrigerant	ODP Montreal Protocol	ODP[1] WMO, 1994	GWP[2] 100 year time horizon	GWP[2] 500 year time horizon	HGWP[3]
R11	1.0	1.0	3800		1.0
R12	1.0	0.82/0.9	8100		3.0
R12B1	3.0	5.1/5			
R13	1.0				
R13B1	10.0	12/13	5400		1.5
R14	**0**	**0**	**6500**	**10000**	**730**
R22	0.055	0.04/0.05	1500		0.33
R23	**0**	**0**	**11700**	**9800**	**8.4**
R32	**0**	**0**	**650**	**200**	**0.15**
R113	0.8	0.90/0.9	4800		1.6
R114	1.0	0.85			7.1
R115	0.6	0.40			35
R116	**0**	**0**	**9200**	**14000**	**208**
R123	0.02	0.014/0.02	90		0.020
R124	0.022	0.03	470		0.11
R125	**0**	**0**	**2800**	**920**	**0.67**
R134a	**0**	**0**	**1300**	**420**	**0.3**
R141b	0.11	0.10/0.1	600		0.14
R142b	0.065	0.05/0.066	1800		0.41
R143a	**0**	**0**	**3800**	**1400**	**1.0**
R152a	**0**	**0**	**140**	**42**	**0.031**

Refrigerant	ODP Montreal Protocol	ODP[1] WMO, 1994	GWP[2] 100 year time horizon	GWP[2] 500 year time horizon	HGWP[3]
R218	**0**	**0**	**7000**	**10100**	**42**
R225ca	0.025	0.02/0.025			0.030
R225cb	0.033	0.02/0.03			0.11
R227ea	**0**	**0**	**2900**	**950**	**0.69**
R236fa	**0**	**0**	**6300**	**4700**	**3.8**
R245ca	**0**	**0**	**560**	**170**	**0.13**
R C318	**0**	**0**	**8700**	**12700**	**64**
R404A	**0**	**0**	**3260**	**1150**	**0.83**
R407C	**0**	**0**	**1526**	**494**	**0.36**
R409A	0.048	0.039	1288		0.29
R410A	**0**	**0**	**1725**	**560**	**0.41**
R507	**0**	**0**	**3300**	**1160**	**0.84**

1 World Meteorological Organization, Global Ozone Research and Monitoring Project, Report No. 37 (ISBN 92-807-1449-x). The first number represents the model calculation, the second is the result of semi-empirical calculation

2 Intergovernmental Panel on Climate Change, Climate Change 1995, The Science of Climate Change, Cambridge University Press, 1996 (ISBN 0-521-56436-0)

3 Intergovernmental Panel on Climate Change, Climate Change 1994, Radiative Forcing of Climate Change and an Evaluation of IPCC IS92 Emission Scenarios, Cambridge University Press, 1995 (ISBN 0-521-55962-6)

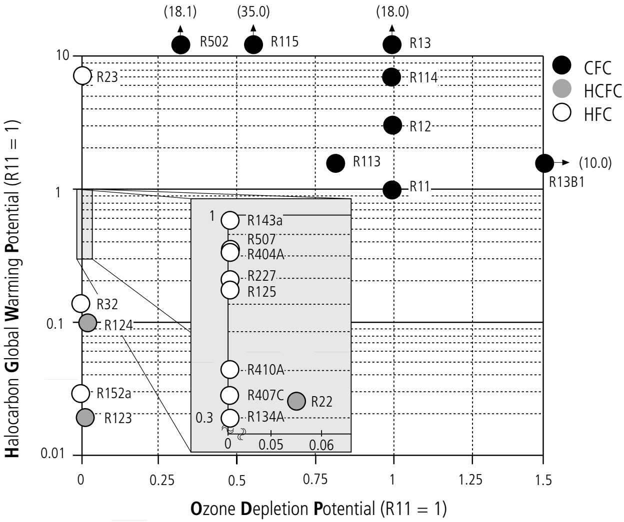


Figure 6: ODP and HGWP values of various refrigerants

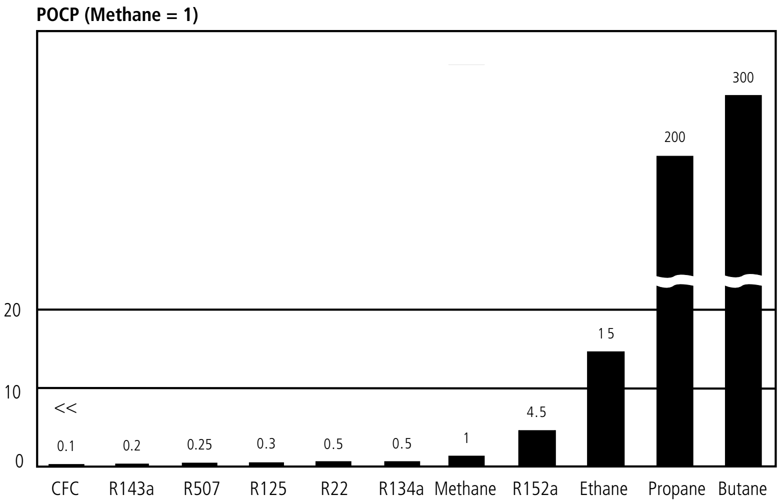


Figure 7: POCP values of various refrigerants

6 Handling of refrigerants

6.1 General information

Refrigerants are generally pressurized gases. An exception are the refrigerants R11 and R123 which are liquid at room temperature. Solkane refrigerants can be handled without risk. To ensure their safe use, recommendations are given below for safe and correct handling.

In the evaluation of safety characteristics of a refrigerant, the two factors "flammability" and "toxicity" play especially important roles. Concerning toxicity, refer to Chapters 3.1.4 and 3.1.5 in this pocket manual. The aspect of flammability is discussed in Chapter 6.2.

Information on handling is also given in the Solvay Material Safety Data Sheets.

Always prevent Solkane refrigerants from coming into contact with a flame or with red-hot metal, since the refrigerants will then decompose and form products which are corrosive, irritate the mucous membranes and are poisonous by inhalation. Rooms in which refrigerants are being used should always be well ventilated, particularly if there is a risk of refrigerant escaping from the plant. Refrigerants at high concentrations in closed rooms may have a suffocation (numbing) effect since they displace available oxygen. In addition, no smoking is allowed when handling refrigerants, since the refrigerants may decompose due to the burning cigarette ash and the decomposition products – as described above – irritate the mucous membranes and are poisonous. Refrigerants degrease the skin upon contact. Therefore protective gloves (e.g. made of PVA) should be worn during handling. Additionally, the gloves also protect from cold burns, which result if liquid refrigerant comes into contact with the skin and evaporates.

To protect the eyes, wearing safety goggles is recommended.

Perform welding work on refrigerating plants only in well ventilated rooms (after the refrigerant has been removed).

6.2 Flammability

Solkane refrigerants (with the exception of Solkane 143a, 32 and 152a, which only serve as components in blends) are nonflammable and do not form explosive mixtures with air at any mix ratio under ambient pressure. However, we point out that refrigerants containing hydrogen (HCFCs and HFCs) may form explosive mixtures with air under certain conditions. In the following, these properties and their consequences are described in greater detail.

From the literature, it is known that R134a vapor may form explosive mixtures with air under increased pressure [1]. At normal pressure, an R134a vapor/air mixture is not explosive even at a high temperature (< 250°C). The pressure limit for the formation of explosive mixtures in air is dependent upon the temperature.

The HCFC refrigerant R22 has a similar behavior [2, 3]. The refrigerant R22 may form explosive mixtures at pressures above 13 bar and an R22 concentration in air of more than 75% by mass.

Experiments have shown that no conditions exist where explosive mixtures would be created from R22 or R134a with air at ambient pressure. It is this characteristic which resulted in the fundamental difference in the safety evaluation of these refrigerants in comparison, for example, to hydrocarbons. Hydrocarbons can already form explosive mixtures with air when simply flowing out of leaks in plant sections on site. For R134a and R22 to do this, an enclosed system with air is always required in which a corresponding overpressure can develop, a situation which does not happen in refrigerating plants during proper operation.

When using HFC and HCFC refrigerants in refrigerating plants and air conditioners or heat pumps, the above discussed characteristics do not lead to safety problems or risks when the normal rules of good engineering practice are observed.

It must be emphasized in this context that today's standard practice of flushing out refrigerating plants with dry nitrogen (instead of air) before charging belongs to proper product handling.

During leak detection or pressure testing, compressed air must never be used together with refrigerants which contain hydrogen, such as R134a or R22. In an extreme case, explosive mixtures could then form in the condenser – insofar as the percentage of air there exceeds the percentage of refrigerant. Only dry nitrogen or helium may be used to increase system pressure.

Before charging a refrigerating plant, thorough evacuation is part of standard practice.

When operating a refrigerating plant in the standard range, i.e. at evaporating pressures > 1 bar absolute, the suction of air into the refrigerating plant is not possible. A precondition for this is, of course, appropriate protection by a low-pressure pressostat.

Only some large plants, primarily those with centrifugal compressors, are operated below atmospheric pressure. Sucking in air, e.g. via the rotary seal on an open compressor or through a leak in the evaporator, becomes noticeable by a drop in the capacity of the condenser, combined with a notable increase in condensation pressure. In these cases, use of a high-pressure pressostat in conjunction with an automatic purging device is recommended. Besides, a high proportion of air in plants with centrifugal compressors would mean that, due to the reduced average molecular weight of the transported vapor/air mixture, the required final pressure would no longer be attained or the compressor would reach the pumping limit.

During refrigerant recycling (on-site processing) and removal of HFC/HCFC refrigerants from plants and transfer into recycling containers, the containers must be free of air. Particularly, when put into operation for the first time. Thorough evacuation is advised here, too. It must additionally be ensured that the corresponding suction devices are also operated free of air.

Due to the aforementioned circumstances, it must be stated that the risk potential when using R134a and R22, just as for the other CFC substitutes which are nonflammable under normal pressure, must be judged as far smaller than with flammable hydrocarbons. The essential aspect here is the fact that explosive blends are not possible when this substance flows out of leaks on-site – in contrast to hydrocarbons.

Bibliography:

[1] Dekleva, Lindley, Powell, "Flammability and reactivity of select HFCs and mixtures", ASHRAE Journal, December 1993

[2] Sand, Andrjesc, "Combustibility of Chlorofluoromethane" ASHRAE Journal, May 1982

[3] Fedorko, "Flammability characteristics of R22-oxygen-nitrogen-mixtures", ASHRAE Transactions Vol. 93, No. 2, 1987

6.3 Handling refrigerant blends

HFC blends are also used as substitutes for CFC refrigerants. For these refrigerant blends, a difference must be made between azeotropic and zeotropic mixtures.

The refrigerant Solkane 507 (substitute for R502) is, for example, an azeotropic blend of R125 and R143a. Azeotropic mixtures offer several advantages over zeotropic blends. Azeotropic blends act like single-substance refrigerants in a temperature range relevant to refrigeration. This means that azeotropic refrigerant blends demonstrate practically no temperature glide and that the composition of the liquid or vapor phase only changes within the valid specification for the new product during evaporation. This extremely minimal change has no practical negative influence on the capacity of the refrigerating plant and is generally not noticeable. The refrigerant Solkane 507 can be filled into refrigerating plants either in liquid or vapor form. Detailed information on the charging of refrigerating plants as well as the properties of Solkane 507 may be seen in product information No. SFD-AK 0795.01. This information may be requested from the Technical Service Department.

In contrast to azeotropic refrigerant blends, zeotropic refrigerant blends, such as Solkane 407C, must be filled into a refrigerating plant in the liquid form. Due to the zeotropic property of blends, the compositions of the liquid and vapor phases of the refrigerant are different. In the vapor phase, the concentration of components which boil at a lower temperature increases. In addition, the change in composition is dependent upon the vapor volume present. If a zeotropic refrigerant blend is used to fill a refrigerating plant, and the charging is carried out with a blend in the vapor state, the mixture filled into the plant does not conform to the commercial composition. Smooth operation of the refrigerating plant or the required refrigerating capacity may not be achieved under certain circumstances.

Be aware that, in the case of vapor leakage from the refrigerating plant and if the refrigerant which leaks out is a zeotropic refrigerant blend, the composition of the refrigerant remaining in the plant changes. In addition, the use of zeotropic refrigerant blends in refrigerating plants with flooded evaporators is only possible with severe restrictions. In both cases, vapor leakage or use of flooded evaporators, changes in the concentration in the liquid and vapor phase will occur. The composition of the circulating refrigerant blend no longer corresponds to the original composition. The refrigerating plant is designed on the basis of thermodynamic properties for commercially available refrigerant blends. Due to the altered blend compositions, differences in capacity may occur.

In summary, it is certain that when using azeotropic refrigerant blends no fractionation problems are expected in regard to vapor leakages or vapor filling of refrigerating plants. When using zeotropic blends, make absolutely certain that the refrigerating plant is charged from the liquid phase.

6.4 Removal of water from refrigerating systems

The expression “drying of refrigerating plants” means the removal of water from the interior of such systems.

Refrigerating machines are complex units, constructed from several components, the chemical, mechanical and electrical elements of which must be harmonized to each other with particular care.

Small refrigerating units are already prepared and charged by the manufacturer, ready to operate.

For larger plants which can only be installed on site, the refrigeration engineer must fill them himself with refrigerants. Both installation and charging must be carried out with particular care while the manufacturer’s regulations must be heeded precisely.

Water is the most widespread and most harmful contaminant in refrigerating plants. It must therefore be avoided or removed from refrigeration systems.

To dry the units and parts, the following methods may be used:

1. Blowing-out with nitrogen
A uniform stream of dry nitrogen is directed through the parts to be dried. Use of dry air is not recommended, since nonflammable HFC or HCFC refrigerant/air mixtures could form explosive mixtures in closed systems under increased pressure (see chapter 6.2). This method with dry nitrogen has proven itself to be the most effective measure for drying refrigerating plants.

2. Generating a vacuum
Drying by applying a vacuum is mainly suitable for parts which can be closed and are airtight. Since water in a vacuum already evaporates at low temperatures, it

can be removed via a pump. When working at room temperature, a vacuum pump should be used which reaches 0.1 mbar absolute pressure if possible.

3. Addition of heat

The parts to be dried are heated in an oven or drying chamber. The time required for this must be sufficient to convert available water into the vapor and the applied temperatures must be high enough to also remove water adsorbed on the surfaces. The relative humidity of the air must be low. Moreover, the air enriched with water vapor must be continually suctioned off in order to prevent recondensation when the dried parts are removed from the oven. The dried parts must be sealed airtight immediately.

It is also possible to combine the three above-named methods with each other, such as adding heat and generating a vacuum. For larger systems, the method "generating a vacuum – blowing-out with nitrogen" has proven especially successful. Here the plant should be evacuated at least twice. A vacuum pump for 5 mbar absolute pressure is sufficient in this case.

6.5 Leak detection

For smooth operation of a refrigerating plant, a test for leaks is a prerequisite. Leaks in refrigerating plants are among the main reasons for breakdowns and lead to losses in refrigerant and possibly oil, and to the introduction of air and therefore humidity.

Various methods for finding leaks in refrigerating plants can be used. Leak detection methods may be divided into two groups, i.e. leak localization devices and room monitoring systems.

Room monitoring systems are used to determine the concentration of refrigerants in the ambient air in machine rooms. These devices are generally coupled with an alarm function. For example, detectors specific for refrigerants based on infrared spectroscopy are available. Using such devices, ambient air concentrations of refrigerants can be determined in a range of 1 ppm to 25 ppm.

For localization of a leak in the refrigerating plant, portable leak detectors may be used. Various types of leak detectors are available. Here a distinction is made between nonselective devices, halogen-selective devices and refrigerant-specific detectors. Nonselective and halogen-selective devices are electronic leak detectors. For the detection of refrigerants using electronic leak detectors, the ion current measurement method, for example, is suitable.

This method, commonly used in refrigeration, is based on the principle of measurement of the ion current between two electrodes. To do this, an air sample containing refrigerant is guided over an electrochemical sensor with a doped ceramic substrate. The detector is kept at a high temperature by means of a heating element. If the gas current contains refrigerant, the refrigerant is thermally decomposed on the hot surface, which releases halogen ions. The latter generate an electric current in the ceramic material to a collection electrode in the center of the detector. The electrical current caused by the refrigerant is converted into an acoustic signal. The detection limit for electronic detectors is – depending on the design – between 0.5 and 10 g per year.

The advantage of electronic leak detectors lies in their simple handling and minimal size. However, cross sensitivities, for example to chlorine-containing trace gases, may exist which could then lead to triggering of a false alarm. If it is known that other trace gases are present in the ambient air, which are sensed by the leak detector, the use of refrigerant-specific detectors is recommended. Refrigerant-specific detectors are generally expensive, however they offer the advantage of good sensitivity and disturbance-free operation. Electronic leak detectors which have been used in the past to determine CFC leaks are only conditionally, or not at all, suitable for detecting HFCs (e.g. R134a). For the new generation of Solkane refrigerants, wholesalers offer appropriate devices.

A further method of detecting refrigerant leaks is the use of light-intensive ultraviolet search lamps. For this method, a fluorescent additive ("dye") is introduced into the refrigerating machine oil. If the suspicious spot on the refrigerating plant is illuminated with this light, the additive/oil blend escapes with the refrigerant in the case of a leak and a bright light (fluorescence) can be seen at the leakage point. This method too is characterized by simple handling, however it has only limited use for plant sections to which access is difficult. The detection limit for the fluorescent leak detection system lies at a leak rate of approx. 4 g per year.

6.6 Recycling and disposal

The term **Recycling** here means both the reprocessing of used fluorinated refrigerant back to original quality through the manufacturer as well as its disposal as waste through chemical recovery, as opposed to waste disposal through elimination of, for example, non-reprocessable refrigerants, primarily through a unique thermal cleavage process gaining new chemical raw materials at Solvays production site in Frankfurt.

Solvay Fluor und Derivate GmbH and its recycling partners take back all used CFCs. This offer has the following restriction: refrigerants which contain a high content of bromine and/or contain some atypical impurities have to undergo a special pretreatment before recycling. The take-back guarantee also applies to mixtures of CFC, which are not always avoidable, and HFC or HCFC refrigerants as CFC substitutes such as Solkane 134a.

For further information, please ask for our special booklet for refrigerant recycling.

The central statutory regulations for all German participants in the recycling and disposal of refrigerants are the German CFC-Halon Prohibition Ordinance (see Chapter 9 “Regulations”) and the German Recycling and Waste Law dated September 27, 1994, (effective since October 7, 1996). The latter considers waste according to the definition in § 3 to be both waste for reutilization as well as waste for disposal. In accordance with §§ 5 and 11, waste producers are obliged to prevent, utilize and eliminate waste always by their own responsibility, whereby the utilization of waste has priority above its elimination. The waste code in accordance with the waste catalogue for chlorofluorocarbon refrigerants is 55205.

6.6.1. Recycling logistics

The sequence of the recycling system implemented by Solvay Fluor und Derivate GmbH and its partner companies is best clarified using Figure 8 for commercial and industrial refrigeration.

Solvay produces refrigerants and supplies these via authorized distributors to contractors. The contractors use them to charge the refrigerating plants and air conditioners which they assemble and service.

The Recycling System (Solvay) in the commercial and industrial refrigeration field

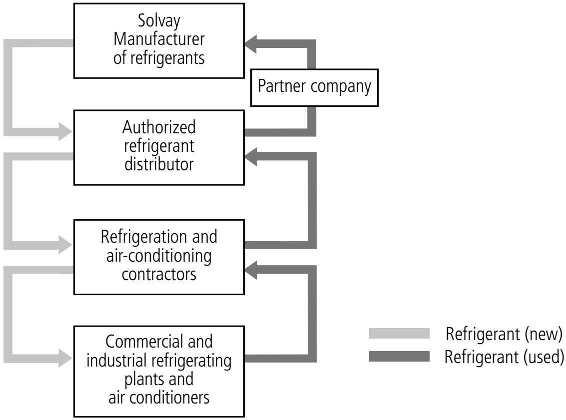


Figure 8

If such a plant is shut down or converted (retrofit), the refrigerant must be properly removed and recycled.

In the commercial and industrial refrigeration area, the Solvay Recycling System is comprised of the following substeps in particular:

- Removal of the refrigerant from the plant
- Transport to an authorized Solvay refrigerant distributor
- Incoming analyses
- Refilling into bulk containers (900 l) at the authorized refrigerant distributor
- Transport of the bulk containers to the recycling partner
- Analysis of the container contents and decision regarding how to proceed:
  a) Recycling
  b) Waste disposal via our partner company with final treatment
  at our separation unit in Frankfurt

In the case of a) recycling:

- Environmentally safe separation of the oil and other operationally relevant impurities at the partner company

- Transport in container or road tankers to Solvay, Frankfurt production site
- Primary recycling at Solvay (only for refrigerants that are in production) or
- Secondary recycling of used CFC refrigerants (refer to the corresponding chapter)

In the case of b) waste disposal via our partner company with final treatment at our separation unit in Frankfurt:

- Disposal of nonprocessable and nonutilizable refrigerants/refrigerant blends

In the Recycling System for Refrigerants, Solvay therefore offers the customer the opportunity to **remove waste** either by **reutilization** or by **disposal**.

6.6.2 Duties of the refrigeration and air-conditioning contractors

The contractor fulfills one of the most important duties in the Recycling System:

He is responsible for the proper, emission-free removal of refrigerants from the plants that he services, keeping each type of refrigerant separate.

The technical removal procedure always remains the same for all refrigerants. This also concerns the new, chlorine-free Solkane refrigerants. Although these have no influence on the ozone, recycling is also a matter of course here in order to reduce direct contribution to the greenhouse effect.

The recovery of refrigerants:
If a refrigerating plant or air conditioner is shut down or converted (retrofit), proper refrigerant removal must proceed in principle as follows: To remove the refrigerant from the plant, special recycling equipment, which shall comply with ISO/DIS 11650 or similar standards, is available. The equipment primarily consists of a condensing unit with an air-cooled condenser and a liquid pump.

The liquid phase of the refrigerant may be filled directly into the recycling cylinder using the liquid pump. Refrigerant vapor must then be suctioned out via the compressor and condensed in the recovery equipment to transfer it into the recycling cylinders.

Using appropriate level controls (e.g. twice weighing), it must be ensured that a filling factor of 0.75 kg per liter container volume is not exceeded. To avoid mixing, use a separate, appropriately labelled recycling cylinder for every refrigerant type.

For the new Solkane refrigerant generation, the demand for separation of different types is even more important because these products make higher demands on recycling in comparison to CFCs. The recycling cylinders available from authorized distributors for Solvay refrigerants must only be filled with the refrigerant for which they are intended. One single incorrectly marked recycling cylinder can make the contents of an entire bulk container unusable for processing back to original quality (primary recycling).

Besides the proper removal of refrigerants from refrigerating plants, there are further important duties for the refrigeration and air-conditioning contractors. In the future, for example, plants must be designed for refrigerant recycling – for example by attaching valves for the removal of refrigerants, even to small plants.

Of course, it is also one of the duties of the contractor to regularly control the leak-tightness of the plants serviced. Therefore the contractor shall inform the operator about the necessity of regular leak-tightness controls already during the installation of a plant.

6.6.3 Duties of the authorized distributor

The authorized wholesaler of refrigerants and refrigeration component not only plays an important distributor function by the sale of new refrigerants. Also within the Recycling System, the distributor contributes fundamentally to the functioning of logistics.

- He provides the contractor and the disposal industry with the recycling cylinders.
- He offers the recovery equipment and accessories without which the emissionfree and separate collection of refrigerants would not be possible.
- In addition, our authorized trade partners fulfill the function of collection control and distribution points in the Recycling System.

The refrigerants which are returned by contractors and refrigerator recyclers must be refilled into bulk containers. Here the authorized refrigerant distributors make sure that different refrigerant types are not mixed in the bulk container.

6.6.4 Recycling methods

For recycling used refrigerants, two different methods have been developed.

6.6.4.1 Primary recycling

So-called “primary recycling” for refrigerants, which are not mixed, on a large technical scale means the processing of used refrigerant back to original quality. Primary recycling is integrated into the production process for new refrigerants.

Since the final shutdown of CFC production, the reprocessing of old CFC refrigerant types (e.g. R11, R12, R502) back to original quality is no longer performed. Primary recycling continues to be done for Solkane 22 and for all chlorine-free refrigerants of the new Solkane generation.

Consequences of mixing different refrigerants
An essential precondition for primary recycling is that different types of refrigerant must be kept separate. Primary recycling of refrigerant blends is not possible in most cases. Every additional impurity, atypical for use as a refrigerant, makes processing more difficult and means considerable additional expense.

The quality of the reprocessed refrigerants is monitored by analyses. For all criteria they must meet Solvay’s requirements for newly produced refrigerants:

- Compliance with the boiling range
- Content of high-boiling residue
- Content of noncondensable gases
- Moisture content
- Acidity
- Impurities including other refrigerants

The relevant standards (see chapter 9) must be observed. Using our method, we make certain that only reprocessed refrigerants which have the quality of new products are offered to our customers.

Something known as “internal recycling” which has established itself in the trade sector must be differentiated from the described, large-scale primary recycling. This is the cleaning of refrigerants on site by using mobile recycling equipment. The refrigerants recovered in this way do not generally conform to the strict quality requirements of the standards or those of the refrigerant manufacturer and shall only be used in the same system again, after passing the acid-test (see also prEN 378-4).

6.6.4.2 Secondary recycling

After shutdown of CFC production, Solvay's offer to take back these refrigerants continues to apply. For the future, a return of mixtures of refrigerants from the new Solkane generation with old refrigerants cannot be avoided. These mixtures cannot really be reprocessed. Our Recycling System is prepared for this challenge.

Solvay guarantees its partners, now and in the future, to take back and reutilize used single refrigerants, commercial blends and mixtures of different refrigerants. For this procedure a special, internationally patented method based on thermal cleavage and reutilization of refrigerants is used by Solvay.

We call it secondary recycling. To us this means the recovery of valuable hydrofluoric and hydrochloric acids, which form by the thermal cleavage of refrigerants. This follows the specifications of the German recycling law, since these valuable substances will be reused as raw materials in chemical production.

The cleavage products are reintroduced into the production cycle, while solid wastes for landfill disposal and poisonous waste gases are avoided, and valuable industrial chemicals are produced.

Secondary recycling offers our customers two major advantages. For one, they can be certain that these substances can be returned to Solvay even after the production and primary recycling of CFCs has stopped. Statutory obligations will therefore always be fulfilled. Secondly, refrigerant mixtures, which may no longer be considered for primary recycling, may also be reutilized through secondary recycling.

6.6.5 A future free of CFCs

The Recycling System and the new CFC-free Solkane refrigerant generation from Solvay are important steps toward protection of the environment.

Only a closed production cycle of environmentally-friendly manufacturing, of distribution, return and recycling comprehensively protects our environment.

7 Retrofit/Drop-In: Conversion of CFC refrigerating plants to replacement refrigerants

The terms "Retrofit" and "Drop-In" are used to designate two methods for conversion of existing CFC refrigerating plants to refrigerant substitutes. In the following, these two terms are defined.

Retrofit:
During retrofit, the lubricant as well as the refrigerant is replaced. In addition, refrigeration plant components, such as the expansion valve, filter dryer or sealing materials need to be adapted or replaced. For retrofit, long-term substitutes based on HFCs are used. These refrigerants have no ozone depletion potential.

Drop-In:
During drop-in, only the refrigerant is replaced. The substitute must be similar enough to the refrigerant to be replaced in its characteristics, particularly in regard to miscibility with mineral or alkylbenzene oils, that no further changes to the plant components are required. Checking the superheat after the conversion and, if necessary, adjustment of the expansion valve is recommended. The substitutes are zeotropic refrigerant blends mainly based on HCFC (e.g. R22).

7.1 The Retrofit method

As defined above, the conversion of existing CFC refrigerating plants to long-term substitutes requires certain changes in refrigeration plants. Solvay favors the use of long-term refrigerants, such as Solkane 134a or Solkane 507, which have no ozone depletion potential, for the retrofit of existing refrigerating plants.

The basic idea of retrofit is to replace the refrigerant and refrigerating machine oil [1]. Due to the polarity of alternative refrigerants based on fluorocarbons, such as R134a, R507 etc., the use of ester oils is necessary. HFC refrigerants are not miscible with conventional lubricants based on mineral oil or with alkylbenzene oils.

In the following, retrofit methods are briefly introduced and several noteworthy points are presented. It is pointed out that oil manufacturers have developed retrofit methods. Corresponding experiences are available in the form of information sheets from oil manufacturers [1, 2] and compressor manufacturers [3].

A retrofit should only be carried out on refrigerating plants which – regardless of age – are in good condition.

As mentioned previously, the lubricant found in the old plant must be exchanged for a polyolester oil during a retrofit. Here the mineral oil or alkylbenzene oil should be removed as completely as possible from the plant in order to avoid deposits of the insoluble oil in the evaporator and thereby prevent associated capacity reductions due to reduced heat transfer. Upon completion of the retrofit, the amount of foreign substances (deposits and old oil) in the polyolester oil should not exceed 5%. In order to achieve this, several ester oil changes are necessary. Depending on the size of the refrigerating plant and the evaporating temperature, generally two to three oil changes are required.

Semihermetic and open compressors are particularly suited for conversion. Under certain conditions, an exchange of the compressor may be necessary. This depends on the application area of the plant and must be clarified with the compressor manufacturer.

Refrigerating plants with hermetic compressors are generally not suitable for a retrofit since there is normally no possibility to remove the mineral oil or the alkylbenzene oil from the compressor. For hermetic refrigerant plants, which are converted to HFC refrigerants, the use of HFC compressors filled with ester oil is recommended.

In the following, the individual steps for a retrofit are described [1, 2, 3].

In the first retrofit step, the CFC refrigerant and the old oil are removed from the plant. If necessary, seals and O-rings in the compressor housing and the shaft exit must be replaced with ones made of special elastomers resistant to ester oil. The compressor manufacturer can provide information on the materials used. Nonproblematic sealing materials for the combination of ester oil / R134a are, for example, the elastomers HNBR (hydrogenated nitrile rubber) and NBR (nitrile rubber). Information on material compatibility of elastomers and refrigerants is available from Solvay. In addition, we refer to a publication regarding the compatibility of O-ring materials with new refrigerants [4].

Filter dryers, filters and moisture indicators must be exchanged for new components compatible with ester oil and R134a. Suitable components are available from wholesalers for refrigeration equipment.

It should be checked whether the expansion valves can be adapted to the slightly differing vapor pressure curve of the refrigerant substitute compared to the CFC by changing the superheating adjustment. Otherwise the expansion valve must be replaced.

After changing the plant components and reinstalling the compressor, the refrigerating plant must be thoroughly evacuated. It is very important that air and moisture are completely removed before putting back into operation. Refer to Chapter 5.5 "Lubricant aspects," where the influence of moisture on the stability of ester oils is discussed.

To remove residues of extraneous oil, three methods are available.

1st Method: Flushing the plant with ester oil and replacement refrigerant

If rapid conversion of the refrigerating plant is required, this method should be used.

Here, after adapting or changing the plant components, the HFC refrigerant and ester oil are filled into the plant. The combination of ester oil and polar HFC refrigerant is a good "solvent" for deposits within the refrigerating plant which generally occur after several years of operation. Operation using the new refrigerants and the ester oil dissolves these deposits and circulates them in the refrigerant circuit. In order to prevent damage to the control devices or the compressor due to the dissolved deposits, installation of a suction gas filter is absolutely recommended [3]. If the contents of foreign substances (= dissolved deposits and extraneous oil) in the ester oil is below 5%, the suction gas filter may be removed.

After brief operation of the plant, the ester oil is changed once again. Experience has shown that the longer the running time of the refrigerating plant between ester oil changes, the greater the "dissolving effect" of the HFC / ester oil combination [5]. Finally the plant is put into operation. If irregularities in operation of the plant are determined, e.g. losses in capacity, the ester oil is changed again. An example of how the proportion of foreign substances changes (extraneous oil and water) over time is given in Figure 9.

The extraneous oil content in ester oil may be determined on site using test kits. These test methods are not very precise, though sufficient for determination of the 5% limit. Suitable test kits are offered by wholesalers. The lubricant manufacturer also offers an analysis service by which the foreign substance content in ester oil, among other things, can be precisely determined. It is recommended that the lubricant is analyzed by the lubricant manufacturer after approx. one third of the normal maintenance period. The result can be used to decide whether an additional oil change is required.

2nd Method: Flushing the plant with ester oil and CFC refrigerant

A second possibility is to operate the plant during a transitional phase first with CFC and ester oil. Here the ester oil is changed often enough until the content of extraneous substances is < 5%. After the necessary adaptation or change of plant components has been performed, the plant is charged with the HFC following thorough drying and evacuation. This method of proceeding can, in certain cases, be more economical since the retrofit takes place over a longer period of time. For example, necessary ester oil changes may be performed at the normal maintenance intervals. A disadvantage is that the "dissolving effect" of the HFC / ester oil combination is not utilized. Under certain circumstances, an additional oil change is required as compared to the first method.

3rd Method: Flushing of the plant with a solvent

Within the scope of a research project relating to conversion measures, a third method has been suggested [6]. In this method, the plant is flushed several times with a solvent in order to remove the old oil residues. It is an advantage that only one ester oil change is necessary. Petroleum ether or other hydrocarbons have been suggested as solvents. It is pointed out that these substances are flammable and suitable safety measures must be observed while working with these solvents. Solvay can offer the HCFC solvent R141b as rinsing fluid. However, national regulation regarding the use of ozone depleting substances for degreasing surfaces have to be observed. One obstacle is the additional equip-

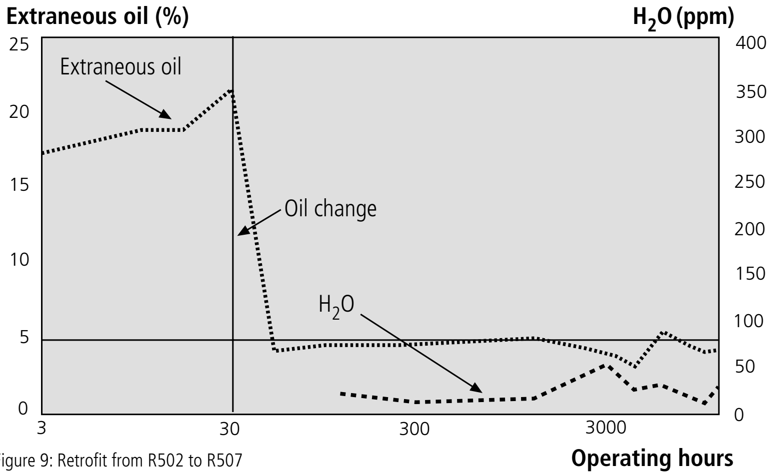


Figure 9: Retrofit from R502 to R507

ment required, since a suitable flushing apparatus must be available or supplied by the contractor.

Retrofit according to the first two named methods has been successfully used in practice for years. An existing refrigerating plant can in this way be permanently converted to a long-term refrigerant substitute.

7.2 The Drop-In method

For refrigerating plants with hermetic compressors, plants in poor overall condition, or for plants where it is not cost-efficient, a retrofit is not recommended. In such cases, Solvay offers a drop-in refrigerant. When using a drop-in refrigerant, no major modifications are required to the plant. The advantage of this method is that only the refrigerant must be replaced. Oil changes are not required. In this way the cost of conversion is reduced in comparison to retrofit procedures.

Drop-in refrigerants are generally based on mixtures of R22 with HFC and/or other HCFC refrigerants. The refrigerant R22 and other blend components have ozone depletion potentials (these are HCFCs). Therefore HCFCs are no long-term alternatives. Solvay recommends the use of drop-in refrigerants only for plants

Drop-in refrigerants are generally based on mixtures of R22 with HFC and/or other HCFC refrigerants. The refrigerant R22 and other blend components have ozone depletion potentials (these are HCFCs). Therefore HCFCs are no long-term alternatives. Solvay recommends the use of drop-in refrigerants only for plants with limited remaining service life or for plants in which the oil cannot be changed. In these cases, Solvay offers the drop-in refrigerant 409A as a substitute for R12.

Drop-in refrigerants are zeotropic blends which have several disadvantages in use (also refer to Chapter 6.3 "Handling of refrigerant blends"). Zeotropic refrigerant blends may only be filled into plants in liquid form to prevent shifts in the blend composition. Furthermore, there are further disadvantages in the application of zeotropic blends: poor heat transfer, separation during leakages and in case of service, separation in the refrigerating circuit.

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8 Contamination and its consequences

The refrigerant substitutes (HFCs and HCFCs) have proven outstandingly successful in practice. However, there may occasionally arise problems in refrigerating machines, whereby the cause may also be traced back to contaminants in the refrigerating system.

The main causes of failure are moisture, hydrofluoric and hydrochloric acids, organic acids, oil sludge, metallic contaminants, noncondensable gases and burnouts. These contaminants may be brought in, for example, during installation or servicing, and thus become the cause for chemical reactions in the refrigerating plant, which for their part may also lead to the formation of contaminants.

8.1 Water

Water is frequently the cause for failures, through blockages of filters and control valves, copper plating, corrosion, damage to bearings or shorts in the rotor windings of hermetic units. Water can get into the refrigerating system by a variety of ways. All parts must already be thoroughly dried before a refrigerating plant is assembled. Prior to filling with lubricant and the refrigerant, the system can be evacuated for an extended period of time in order to remove all traces of moisture. An extremely suitable method is flushing of the plant with dry nitrogen. However, in spite of such measures, it is never entirely avoidable that certain amounts of moisture are introduced into the refrigerating system when charging with oil and refrigerant. Additionally, in the case of machines already in operation, moisture may get into the circuit at points that are not watertight or through leaks in water-cooled condensers. Water may also be formed in the system as a result of chemical reactions, for example by atmospheric oxygen reacting with hydrogen from the refrigerating machine oil, or by reaction of the refrigerant with the oil. The simultaneously formed acids attack the insulating materials inside hermetically sealed units, which become carbonized and thus also release water.

Faults and damage caused by the presence of water in the refrigerating system vary extremely according to the differing solubility of water in individual refrigerants. They extend from blockage of the expansion valve through freezing of the water, to corrosion in machines and to the burnout of hermetic compressors.

For further details on the contaminant "Water" refer to chapter 5.6, "Refrigerants and water".

8.2 Other contaminants

8.2.1 Hydrofluoric and hydrochloric acids

Formation of these acids can in most cases be traced back to the reaction of refrigerants with water.

Decomposition of lubricants, possibly combined with sludge formation, destruction of the insulation in hermetic compressors, corrosion and copper plating may be the consequences.

Solkane refrigerants are free of mineral acids thanks to the most current purification methods. The formation of hydrofluoric and hydrochloric acid may only be prevented if the refrigerating circuit is kept as free of water as possible (refer also to Chapter 5.6, "Refrigerants and water").

8.2.2 Organic acids

Destruction of cellulose-based insulation in hermetic compressors as a result of excessive overheating causes formation of organic acids. This also promotes the formation of resinification products, oil sludge and the like. The consequences are bearing damage or scuffing. The compressor valves become leaky and cause back expansion and a decrease in the compressor displacement.

Particles of dirt may also become stuck in narrow cross-section areas and lead to blockages.

The effect of oxygen (e.g. from the air) on refrigerating machine oil at increased temperature can also lead to the development of organic acids. In order to prevent the formation of organic acids, overheating of the compressor and oxygen in the refrigerating system must be avoided.

8.2.3 Oil sludge

When selecting lubricants, particular attention must be placed on its quality and its physical properties. Not every lubricant is equally well suited for every refrigerant type. The type of compressor, operation temperature and working pressure must also be considered. For HFC refrigerants, polyolester oils have proven successful.

Heat, water, acids and refrigerants contribute primarily to the decomposition of the oil during incorrect operation and therefore to the formation of oil sludge. The consequences of oil sludge formation have already been touched on briefly in the section "Organic acids."

8.2.4 Metallic contaminants

It is well known that halogen refrigerants decompose to a greater extent at increased temperatures in the presence of metallic contaminants such as iron powder, iron oxide and copper oxides.

Apart from this, these contaminants alone suffice in damaging pistons, cylinders and bearings, to block filters and valves, and worsen the effect of higher temperatures on the refrigerant.

Furthermore, metallic particles lead to wear and corrosion. The action of the metallic particles may lead to a reduction in refrigerating capacity.

Metallic contaminants can originate from unclean transport containers or from machine parts or apparatuses in the refrigerating plant. Many refrigerants have a strong dissolving effect on oils and greases, which are used for pretreatment of metal parts. Care must therefore be taken that transport containers as well as machines and their parts are absolutely clean and dry before charging with refrigerant.

8.2.5 Noncondensable gases

A different type of contaminants are noncondensable gases which often occur in refrigerating circuits. Their presence can have different causes:

- incomplete evacuation of the system
- leaks in the system
- chemical reactions in the system during operation
- release of gases adsorbed in the refrigerant circuit

Whether these gases have a damaging effect on the function of the system or not depends on the type and concentration of the gas.

Chemically reactive gases such as HCl in CFC and HCFC refrigerants may attack the remaining components of the system and thus cause a breakdown of the plant. Inert, noncondensable gases reduce the refrigerating capacity. Their presence results in higher pressures and temperatures, whereby chemical reactions may also be triggered.

Among those gases found in hermetic systems are nitrogen and oxygen, in certain circumstances also carbon dioxide from air, hydrogen, carbon monoxide and methane.

It should nevertheless be noted here that these gases normally occur only in traces. Apart from the negative effect of noncondensable gases on the refrigerating system, their presence even in trace amounts may be seen as a measure for chemical stability.

Foreign gas may only be eliminated from refrigerants through purging, i.e. expansion into a refrigerant recycling cylinder, by suctioning off the vapor phase. At the same time, part of the foreign gas dissolved under pressure in the refrigerant is released by expansion and may escape with the evaporating refrigerant.

8.3 Burnouts

Hermetically sealed units may burn out in refrigerating plants and air conditioners due to overheating. The reasons for this are, among others, interruption of the power supply or failure of safety switches, refrigerant losses, poor oil supply, air or moisture and excessively high compressor discharge temperatures which result in chemical reactions.

The decomposition products which form during a burnout are acids, water and sludge, which often contaminate the entire system. In order to prevent further burnouts, the plant must be thoroughly cleaned before putting back into operation. This cleaning may be done advantageously by flushing with organic solvents, whereby a special cleaning device available from the refrigeration wholesalers may be used.

In certain cases, parts of the system are only subjected to a slight and brief increase in temperature, and the amount of decomposition products formed is therefore minimal.

This process, known as a “quick burnout”, may be caused by a sudden short in the motor windings or by mechanical faults.

A system which breaks down due to a “quick burnout” is not necessarily heavily contaminated. Therefore the system is not required to be cleaned to the extent of a complete cleaning procedure. Here it is sufficient to exchange the compressor and install a new filter dryer in the suction line. If there are contaminants, signs of this will be found in the expansion valve, in the condenser or in the fluid collector. If there is neither sludge nor acid in the condenser, it may be assumed that the low pressure side is free of decomposition products. An exception is the possibility of a backflow of contaminants in the suction line. This can however be determined in most cases by examining the suction line. During a “quick burnout”, no carbon deposits, little oil discoloration and practically no acid formation (acid value not greater than 0.05 mg KOH/g) can be found. To determine the further steps an oil analysis is necessary.

For “slow burnouts” the entire system must be cleaned if solid particles are found in the suction line.

In the more seldom cases of a strong burnout, the decomposition products which have collected over an extended period of time cannot be removed on site.

9 Regulations and refrigeration associations

This chapter gives information concerning ordinances, standards, rules and guidelines for refrigeration in regard to refrigerants. Important international regulations for refrigerants and refrigerating plants are:

- Montreal Protocol on substances which deplete the ozone layer
- EC Directive 3093/94 on substances that deplete the ozone layer
- ISO 817 – Refrigerants — Number designations
- ISO 5149 – Mechanical refrigeration systems used for cooling and heating – safety requirements
- ISO 12810 – Fluorocarbon refrigerants – Specifications and test methods (status: draft)
- EN 378 – Refrigerating plants and heat pumps Safety and environmental requirements
- ANSI/ASHRAE Standard 34 – Number designation and safety classification of refrigerants
- BSR/ASHRAE Standard 147P – Reducing emission of halogenated refrigerants in refrigeration and air-conditioning equipment and systems (status: draft)

a) Montreal Protocol on substances which deplete the ozone layer (valid internationally for signatory states)

Production and consumption of the CFCs R11, R12, R113, R114, R115 and R13, R111, R112, R211, R212, R213, R214, R215, R216, R217 have already been prohibited since January 1, 1996, the halon types 1211, 1301, 2402 since January 1, 1994.

Consumption of HCFCs was limited as of January 1, 1996, to a maximum amount (in ODP tons) per year (“Cap Solution”). This amount is calculated as the sum of

- 2.8 % (in contrast to 2.6 % in the EU) of the calculated total of CFC consumption in 1989 and
- the calculated total of HCFC consumption in 1989.

Consumption of HCFCs must be reduced according to the following schedule:

Beginning		Quantity (related to maximum quantity)
1.1.1996	≤	Maximum quantity
1.1.2004	≤	65%
1.1.2010	≤	35%
1.1.2015	≤	10%
1.1.2020	≤	0.5%
1.1.2030		0%

A special regulation applies to developing (Article 5) countries. As long as the annual calculated amount of consumption of controlled substances is below 0.3 kg per capita, CFCs may still be used until 2010. HCFCs are still allowed in developing countries until 2040.

b) EC Directive 3093/94 on substances that deplete the ozone layer, dated December 15, 1994

This regulation applies to the production, import, export, sale, use and recovery of chlorofluorocarbons (CFCs), other fully halogenated chlorofluorocarbons, halons, carbon tetrachloride, 1.1.1-trichloroethane, methyl bromide, partially halogenated chlorofluorobromines and partially halogenated chlorofluorocarbons (HCFC). Production and sales of CFCs are already prohibited as of January 1, 1995, of halons as of January 1, 1994.

The quantities of **HCFC** offered by manufacturers or importers in the EU are also controlled in this directive. The sale of HCFC was limited as of January 1, 1995, to a maximum quantity (in ODP tons) per year. This quantity is calculated as the sum of:

- 2.6 % of the calculated total of CFCs that manufacturers or importers brought onto the market in 1989 or used for their own purposes, and
- the calculated total of HCFCs which manufacturers or importers brought onto the market in 1989 or used for their own purposes

The quantity of HCFCs on offer must be reduced according to the following schedule:

Beginning		Quantity (related to maximum quantity)
1.1.1995	≤	Maximum quantity
1.1.2004	≤	65%
1.1.2007	≤	40%
1.1.2010	≤	20%
1.1.2013	≤	5%
1.1.2015		0%

These above given quantities relate to the quotas which the manufacturers or importers receive from the commission.

In accordance with Article 5, the **use of HCFCs** as refrigerants is prohibited with effect from January 1, 1996 in systems manufactured after December 31, 1995, for the following application purposes:

- as refrigerants in non confined direct evaporation systems,
- as refrigerants in domestic refrigerators and freezers,
- in car air-conditioning
- in road public transport air-conditioning

With effect from January 1, 1998, the use of HCFCs in systems manufactured after December 31, 1997, is prohibited for the following application purposes:

- for rail public transport air-conditioning
- as a carrier gas for sterilization substances in closed systems.

With effect from January 1, 2000, the use of HCFCs in systems manufactured after December 31, 1999, is prohibited for the following application purposes:

- as refrigerants in public and distribution cold stores and warehouses,
- as refrigerants for equipments of 150 kW and over, shaft power input

except where codes, safety regulations or other such constrains on the use of ammonia exist.

Currently a new EC directive is being prepared which will supersede the presently still valid directive 3093/94.

c) Kyoto protocol

In contrast to the Montreal protocol, which specifies general conditions for abandoning ozone-destroying substances on an international level, the Kyoto protocol is an internationally binding instrument for limiting emissions of greenhouse gases. It is based on the general climate convention of Rio de Janeiro in 1992 (Rio Convention).

- Objective of Kyoto protocol Reducing emissions of green house gases and gas groups Carbon dioxide (CO_2), methane (CH_4), nitrogen monoxide (N_2O), partially fluorinated CFC's (HCFC), perfluorated CFC's (PFCF's), sulphur hexafluoride (SF_6)

- Scale and time:

  The reduction obligations for the more important industrial nations are as follows:

EU	– 8 %
USA	– 7 %
Japan	– 6 %

In connection with the cutback obligations of other countries (emission increases have been granted to some countries) this represents a glob al average value of −5.2 %.

These emission cutbacks are to be realised within the so-called obligation period 2008 – 2012. The reference for savings are the emission of greenhouse gases CO_2, CH_4 and N_2O in 1990 and for HCFC's, per fluorised CFC's (PCFC) and SF_6 in 1995 (optionally 1990), expressed in terms of CO_2 equivalent tonnes.

- Effective date

  The Kyoto protocol comes into effect 90 days after signing and ratification by 55 states, which together represent 55 % of CO_2 emissions in 1990.

Important:

- The "shopping basket" of the 6 gases specified in the Kyoto protocol are to be considered as a unit in measures to reduce emissions, and not as the isolated application of individual gases!
- The goal of the Kyoto protocol is to achieve emission reduction and not abandonment by way of production, application or marketing prohibitions.

The EU is presently in the process of preparing actions to implement the Kyoto protocol. The cutback obligation of –8 % valid in the EU represents an average value of national cutback obligations expressed by individual EU member states and agreed within the EU. In Germany the cutback obligation is –21 %.

d) International (ISO) and European (EN) standards and ISO or EN draft standards (prEN) for Refrigeration (October 1997)

The following overview may be considered as a helpful starting point for further information. The information are derived from CEN/TC 182, which is a technical committee of the European Committee for Standardization (Central Secretariat: rue de Stassart 36, B-1050 Brussels) and ISO/TC86, which is a technical committee of the International Organization for Standardization. ISO, CEN or the national instituts for standards may provide further detailed information and can provide the standards

As it can be seen from the list below, many international standards related to refrigeration and air-conditioning are in a developmental stage.

EN or ISO No.	Status	Title
Safety		
prEN 378, part 1	Final Draft Will replace EN 378-1 (1994)	Refrigerating systems and heat pumps – Safety and environmental requirements- Part 1: Basic requirements, definitions, classification and selection criteria
prEN 378, part 2	Final Draft	Refrigerating systems and heat pumps – Safety and environmental requirements Part 2: Design, construction, testing, marking and documentation
prEN 378, part 3	Final Draft	Refrigerating systems and heat pumps – Safety and environmental requirements Part 3: Installation site and personal protection
prEN 378, part 4	Final Draft	Refrigerating systems and heat pumps – Safety and environmental requirements- Part 4: Operation, maintenance and repair
prEN 1736	3.95	Refrigerating systems and heat pumps – Flexible pipe elements, expansion joints and vibration isolators – Requirements, design and installation
prEN 1861	12.97	Refrigerating systems and heat pumps – System flow diagrams and piping and instrument diagrams – Layout and symbols
prEN 12178	1.96	Refrigerating systems and heat pumps – Liquid level indicating devices – Requirements, testing and marking

EN or ISO No.	Status	Title
prEN 12284	5.96	Refrigerating systems and heat pumps – Valves – Requirements, testing and marking
prEN 12693	4.97	Refrigeration systems and heat pumps – Safety and environmental requirements – Refrigerant compressors
ISO 5149	1993	Mechanical refrigeration systems used for cooling and heating – Safety requirements

Pressure switches

prEN 12263	9.97	Refrigerating systems and heat pumps – Safety switching devices for limiting the pressure – Requirements and test for type testing

Factory-produced refrigerating machines

prEN 12055	10.95	Liquid chillers and heat pumps with electrically driven compressors- cooling – Definition, testing and requirements
ISO 916, 1 to 3	Draft; Revision of ISO/R 916 (1968)	Testing of refrigerating systems – Test methods Part1: Testing systems for cooling liquids and gases using a positive displacement compressor Part2: Refrigerating units using a positive displacement compressor, condensing units and evaporator-compressor Part3: Systems and units for cooling liquids and gases using a turbocompressor

Cold compressed-air dryers

ISO 7183	6.90	Compressed-air dryers

Household refrigerating appliances / Domestic refrigerators

EN 153	11.95	Method for measurement of the electrical power consumption and associated characteristics for power-supply operated domestic refrigerators, deep freezers, freezers and their combinations

EN or ISO No.	Status	Title
EN 28960	10.93	Refrigerators, deep freezers and freezers for household and similar use – Measurement of emission of airborne acoustical noise
ISO 2410	1972	Household refrigerators – Method of tests for the information of the consumer
EN ISO 5155	3.96	Household refrigerating appliances - Frozen food storage, cabinets and food freezers – Characteristics and test methods
EN ISO 7371	3.96	Household refrigerating appliances – Refrigerators with or without low temperature compartments – Characteristics and test methods
ISO 8187	1991	Household refrigerating appliances – Refrigerator-freezers – Charactarestics and test methods
EN ISO 8561	3.96	Household frost-free refrigerating appliances – Refrigerators, refrigerator-freezers, frozen food storage cabinet and food freezers cooled by internal forced air circulation – Characteristics and test methods
ISO 8960	1991	Refrigerators, frozen-food storage cabinets and food freezers for household and similar use – Measurement of emission of airborne acoustical noise

Air-conditioners and heat pumps

EN 255-1	5.89	Air conditioners, liquid chillers and heat pumps with electrically driven compressors – Heating Part1: Nomenclature, definitions and marking
prEN 255, 2 to 4	5.88 – 1.89	Air conditioners, liquid chillers and heat pumps with electrically driven compressors – Heating Part2: Testing and requirements concerning the marking of devices for space heating Part3: Testing and requirements concerning the marking of devices for water heating Part4: Requirements for devices for

EN or ISO No.	Status	Title
		space and water heating Remark: Part 5 does not exist.
prEN 255, 6 to 8	10.92	Heat pumps; ready for installation heat pumps with electrically driven compressors – Heating Part6: Heating of drinking water and water for industrial use; Testing, definitions and requirements concerning marking Part7: Heating of drinking water and water for industrial use; Measurement of emission of airborne acoustical noise Part8: Heating of drinking water and water for industrial use; Requirements
prEN 810	10.92	Dehumidifiers; dehumidifiers with electrically driven compressors
EN 814, 1 to 3	6.97	Air conditioners and heat pumps with electrically driven compressors – Cooling – Part1: Nomenclature, definitions and marking Part2: Testing and requirements concerning the marking Part3: Requirements
EN 814, 4+5	10.92	Air conditioners Part4: Requirements for comfort air-conditioners Part5: Requirements for switch cabinet cooling devices
ENV 12102	5.96	Air conditioners, heat pumps and dehumidifiers with electrically driven compressors – Measurement of airborne acoustical noise
ISO 5151	1994	Non-duct air conditioners and heat pumps Testing and rating for performance
ISO 13253	1995	Ducted air conditioners and air-to-air heat pumps – Testing and rating for performance
ISO 13256	Final draft	Water-source heat pumps – Testing and rating for performance Part1: Water-to-air and brine-to-air heat pumps Part2: Water-to-water and brine-to-water heat pumps
ISO 13258	Committee draft	Air-conditioning condensing units – Testing and rating for performance

EN or ISO No.	Status	Title
ISO 13261	Final draft	Sound power rating of air-conditioning and air-source heat pump equipment Part1: Non-ducted outdoor equipment Part2: Non-ducted indoor equipment
ISO 15042	Committee draft	Multiple split-system air-conditioners and air-to-air heat pumps – Testing and rating for performance

Commercial and retail refrigerated display cabinets

EN 441, 1 to 11	1.95 – 3.96	Refrigerated display cabinets Part1: Terms and definition Part2: General mechanical and physical requirements. Part3: Linear dimensions, areas and volumes Part4: General test conditions Part5: Temperature test Part6: Temperature classes Part7: Defrosting test Part8: Water vapor condensation test Part9: Electrical energy consumption tes Part10: Test of odor and taste Part11: Installation, maintenance and requirements for the user
prEN 441, 12	7.95	Refrigerated display cabinets Part12: Measurement of heat extraction rate of the cabinets when the condensing unit is remote from the cabinet
ISO 1992, 1 to 8		Commercial refrigerated cabinets – Methods of test,
	1974	Part1: Calculation of linear dimensions, areas and volumes
	1973	Part2: General test conditions
	1973	Part3: Temperature test
	1974	Part4: Defrosting test
	1974	Part5: Water vapor condensation test
	1974	Part6: Electrical energy consumption test
	1978	Part8: Test for accidental mechanical contact Remark: Part 7 does not exist.
ISO 5160-1,-2	1979/80	Commercial refrigerated cabinets Technical specifications Part1: General requirements Part2: Parameter requirements

EN or ISO No.	Status	Title

Refrigerants

EN or ISO No.	Status	Title
ISO 817	Com. draft Revision of ISO 817:1974	Refrigerants – Number designation
ISO 12810	Draft 2.97	Fluorocarbon refrigerants – Specifications and test methods

Heat exchangers, Ventilators, Fans

EN or ISO No.	Status	Title
ENV 327	6.91	Heat exchangers – Forced circulation air-cooling condensers – Test procedures for establishing the performance
ENV 328	4.94	Heat exchangers – Forced circulation air-cooling fan coil units – Test procedures for establishing the performance
ENV 1048	2.94	Heat exchangers – Air cooled liquid coolers, "Dry cooling tower" – Test procedures for establishing the performance
ENV 1117	6.95	Heat exchangers – Liquid-cooled refrigerant condensers – Test procedures for establishing the performance
ENV 1118	6.95	Heat exchangers – Refrigerant-cooled liquid coolers – Test procedures for establishing the performance
ENV 1216	6.95	Heat exchangers – Forced circulation air-cooling and air-heating coils – Test procedures for establishing the performance
ENV 1397	5.95	Heat exchangers – Hydronic room fan coil units – Test procedures for establishing the performance
ISO 5801	1997	Industrial fans – Performance testing using standardized airways
ISO 6580	1981	General purpose industrial fans – Circular flanges – Dimensions
ISO 9097	1991	Small craft – Electric fans
ISO 10302	1996	Acoustics – Method for the measurement of airborne noise emitted by small air moving devices
ISO 13351	1996	Industrial fans – Dimensions

EN or ISO No.	Status	Title

Refrigerant compressors

EN or ISO No.	Status	Title
prEN 12900	Draft	Refrigerant compressors – Test conditions, tolerances and presentation of performance data
ISO 917	Final draft Revision ISO 917:1989	Testing of refrigerant compressors
ISO 9309	Draft Revision ISO 9309:1989	Refrigerant compressors – Presentation of performance data

e) European and international standardization work, responsible committees (October 1997)

European standardization work

Secretariat of

CEN/TC 113/WG 2	Measurement of acoustic power level
CEN/TC 182	Refrigerating systems; Safety and environmental requirements
CEN/TC 182/WG 1	Basic requirements
CEN/TC 44	Household refrigerating appliances and refrigerated display cabinets
CEN/TC 44/WG 1	Performance rating of household refrigerators and freezers
CEN/TC 110/WG 1	Heat exchangers, refrigeration
CEN/TC 113	Heat pumps and air-conditioning units
CEN/TC 113/WG 1	Heat pumps for heating of water for industrial use
CEN/TC 113/WG 3	Requirements
CEN/TC 113/WG 4	Air-conditioning units
CEN/TC 113/WG 5	Liquid cooling units
CEN/TC 113/WG 6	Refrigerant compressors – Presentation of performance data
CEN/TC 141/WG 12	Devices for measuring and recording temperature in the cold chain
CEN/TC 153/WG 8	Milk coolers
CEN/TC 181/WG 5	Liquid gas units, refrigerating appliances
CEN/TC 182/WG 2	Design and testing
CEN/TC 182/WG 3	Installation and operation
CEN/TC 182/WG 4	Disposal and environmental aspects
JWG/CEN/TC 182/TC 54	Pressure vessels in refrigeration systems
CEN/TC 232	Compressors; Safety aspects

International standardization work

Secretariat of

ISO/TC 86	Refrigeration and air-conditioning
ISO/TC 86/WG 4	Thermodynamic and thermophysical properties of refrigerants
ISO/TC 86/SC 1	Safety of refrigeration systems
ISO/TC 86/SC 2	Terms and definitions
ISO/TC 86/SC 3	Testing and rating of factory-made refrigeration systems
ISO/TC 86/SC 4	Testing and rating of refrigerant compressors
ISO/TC 86/SC 5	Testing and rating of household refrigeration appliances
ISO/TC 86/SC 5/WG 1	Refrigerators freezers
ISO/TC 86/SC 5/WG 2	Measurement of noise emitted by refrigerators and freezers
ISO/TC 86/SC 6	Testing and rating of air-conditioners and heat pumps
ISO/TC 86/SC 6/WG 1	Unitary air conditioners and heat pumps
ISO/TC 86/SC 6/WG 2	Equipment sound ratings
ISO/TC 86/SC 6/WG 3	Water source heat pumps
ISO/TC 86/SC 6/WG 4	Air-conditioning condensing units – Testing and rating for performance
ISO/TC 86/SC 6/WG 5	Non-ducted "Multiple split" air-conditioning units and heat pumps
ISO/TC 86/SC 7	Testing and rating of commercial refrigerated display cabinets
ISO/TC 86/SC 8	Refrigerants and refrigeration lubricants
ISO/TC 86/SC 8/WG 1	Technical characteristics and test methods for refrigerants
ISO/TC 86/SC 8/WG 2	Refrigerant recovery, recycling and reclaim equipment
ISO/TC 86/SC 8/WG 3	Specification for contaminant levels of fluorocarbon refrigerants
ISO/TC 86/SC 8/WG 4	Reuse of refrigerants
ISO/TC 86/SC 8/WG 5	Safety classification and requirements for refrigerants
ISO/TC 118/WG 5	Air dryers

f) Classification of refrigerants (according prEN 378, part 1, section 5.4)

The following classification is quoted from the final draft of EN 378, part1, dated October 1997. See also chapter 3.3 "other Refrigerants" (p. 51), in which the safety classification according to the ASHRAE Standard 34 is given. Basically, these classifications are identical.

5.4.1 General

Refrigerants are classified into groups according to their influence on health and safety.

5.4.2 Health and safety classification

Refrigerants are classified according to their flammability and toxicity.

5.4.2.1 Flammability classification

Refrigerants are assigned to one of the three groups 1, 2 and 3 based on the lower flammability limit at atmospheric pressure and room temperature:

group 1: Refrigerants which are not flammable in vapor form at any concentration in air;

group 2: Refrigerants whose lower flammability limit is equal to or greater than 3.5 % by volume when they form a mixture with air;

group 3: Refrigerants whose lower flammability limit is less than 3.5 % by volume when they form a mixture with air.

NOTE: The lower flammability limits are determined in accordance with an appropriate standard e.g. ANSI/ASTM E 681.

5.4.2.2 Toxicity classification

Refrigerants shall be assigned to one of the two groups A and B on toxicity:

group A: Refrigerants with a time weighted average concentration not having an adverse effect on nearly all workers who may be exposed to it day after day for a normal workday and a 40-hour workweek whose value is equal to or above 400 ml/m3 (400 ppm by volume);

group B: Refrigerants with a time weighted average concentration not having an adverse effect on nearly all workers who may be exposed to it day after day for a normal workday and a 40-hour workweek whose value is below 400 ml/m3 (400 ppm by volume)

NOTE: Toxic decomposition products may result from contact with flames or hot surfaces under certain conditions. Major decomposition products of group L1 (A1) refrigerants, with the exception of carbon dioxide, are hydrochloric acid and hydrofluoric acid. Although toxic, they provide an automatic and definite warning by their exceedingly irritant smell even at low concentrations.

5.4.2.3 Safety groups

Refrigerants are assigned to safety groups as shown in the table below.

Safety groups as determined by flammability and toxicity

Increasing flammability

Higher flammability	A3	B3
Lower flammability	A2	B2
No flame propagation	A1	B1
	Lower toxicity	Higher toxicity

Increasing toxity

For purpose of prEN378 a simplified grouping is made as follows:

L1 = A1;

L2 = A2, B1, B2;

L3 = A3, B3.

The refrigerant shall be classified in that group requiring the more stringent precautions where there is doubt under which group a refrigerant is to be classified.

5.4.2.4 Health and safety classification of refrigerant mixtures (blends)

Refrigerant mixtures, whose flammability and/or toxicity characteristics may change as the composition changes during fractionation, shall be assigned a dual safety group classification separazed by a slash (/). The first classification listed shall be the classification of the formulated composition of the mixture. The second classification listed shall be the classification of the mixture composition at the "worst case of fractionation". Each characteristic shall be considered independently.

Each of the two classifications shall be determined according to the same criteria as a single-component refrigerant.

For toxicity, “worst case of fractionation” shall be defined as the composition that results in the highest concentration of the component(s) in the vapor or liquid phase. The toxicity of a specific mixture composition shall be determined on the basis of the single components.

> NOTE 1: Since fractionation can occur as the result of a refrigerating system leak, the composition of the mixture remaining in the refrige rating system and the composition of the mixture leaking from the refrigerating system should be considered when determining the “worst case of fractionation”. The “worst case of fractionation” can be either the formulated composition or a composition that occurs during fractionation.
>
> NOTE 2: The “worst case of fractionation” for toxicity might not be the same as the “worst case of fractionation” for flammability.

Appendix 1: Information about refrigerants [1)] (Excerpt from Annex E (informative) of prEN 378, part 1)

Classification Group L	Safety group	Refrigerant number [2)]	Description (composition = % weight)	Formular
1	A1	R-11	Trichlorofluoromethane	CCl_3F
1	A1	R-12	Dichlorodifluoromethane	CCl_2F_2
1	A1	R-12B1	Bromochlorodifluoromethane	$CBrClF_2$
1	A1	R-13	Chlorotrifluoromethane	$CClF_3$
1	A1	R-13B1	Bromotrifluoromethane	$CBrF_3$
1	A1	R 22	Chlorodifluoromethane	$CHClF_2$
1	A1	R-23	Trifluoromethane	CHF_3
1	A1	R-113	1,1,2-Trichloro-1,2,2-trifluoroethane	CCl_2FCClF_2
1	A1	R-114	1,2-Dichloro-1,1,2,2-tetrafluoroethane	$CClF_2CClF_2$
1	A1	R-115	2-Chloro-1,1,1,2,2-pentafluoroethane	CF_3CClF_2
1	A1	R-124	2-Chloro-1,1,1,2-tetrafluoroethane	CF_3CHClF
1	A1	R-125	Pentafluoroethane	CF_3CHF_2
1	A1	R-134a	1,1,1,2-Tetrafluoroethane	CF_3CH_2F
1	A1	R-218	Octafluoropropane	C_3F_8
1	A1	R-C318	Octafluorocyclobutane	C_4F_8
1	A1	R-500	R-12/152a (73.8/26.2)	$CCl_2F_2 + CF_2HCH_3$
1	A1	R-501	R-12/22 (25/75)	$CCl_2F_2 + CHClF_2$
1	A1	R-502	R-22/115 (48.8/51.2)	$CHClF_2 + CF_3CClF_2$
1	A1	R-503	R-13/23 (59.9/40.1)	$CClF_3 + CHF_3$
1	A1	R-507	R-125/143a (50/50)	$CF_3CHF_2 + CF_3CH_3$
1	A1	R-508A	R-23/116 (39/61)	$CHF_3 + C_2F_6$
1	A1	R-508B	R-23/116 (46/54)	$CHF_3 + C_2F_6$
1	A1	R-509	R-22/218 (44/56)	$CHClF_2 + C_3F_8$
1	A1	R-718	Water	H_20
1	A1	R-744	Carbon dioxide	CO_2
1	A1/A1	R-401A	R-22/152a/124 (53/13/34)	$CHClF_2 + CHF_2CH_3 + CF_3CHClF$
1	A1/A1	R-401B	R-22/152a/124 (61/11/28)	$CHClF_2 + CHF_2CH_3 + CF_3CHClF$
1	A1/A1	R-401C	R-22/152a/124 (33/15/52)	$CHClF_2 + CHF_2CH_3 + CF_3CHClF$
1	A1/A1	R-402A	R-125/290/22 (60/2/38)	$CF_3CHF_2 + CH_3CH_2CH_3 + CHClF_2$
1	A1/A1	R-402B	R-125/290/22 (38/2/60)	$CF_3CHF_2 + CH_3CH_2CH_3 + CHClF_2$
1	A1/A1	R-403A	R-22/218/290 (75/20/5)	$CHClF_2 + C_3F_8 + C_3H_8$
1	A1/Al	R-403B	R-22/218/290 (56/39/5)	$CHClF_2 + C_3F_8 + C_3H_8$
1	A1/A1	R-404A	R-125/143a/134a (44/52/4)	$CF_3CHF_2 + CF_3CH_3 + CF_3CH_2F$

Molar mass [3] (MM) kg/kmol	Practical limit [4), 5)] kg/m³
137.4	0.3
120.9	0.5
165.4	0.2
104.5	0.5
148.9	0.6
86.5	0.3
70	0.68
187.4	0.4
170.9	0.7
154.5	0.6
136.5	0.11
120	0.39
102	0.25
188	1.84
200	0.81
99.3	0.40
93.1	0.38
111.7	0.45
87.3	0.35
98.8	0.49
100.1	*
95.4	*
124	0.56
18	–
44	0.1
94.4	0.30
92.8	0.34
101	0.24
101.5	0.33
94.7	0.32
92	0.33
103.2	0.41
97.6	0.48

Classification Group L	Safety group	Refrigerant number [2)]	Description (composition = % weight)	Formular
1	A1/A1	R-405A	R-22/152a/142b/C318 (45/7/5.5/42.5)	$CHClF_2 + CHF_2CH_3 + CH_3CClF_2 + C_4F_8$
1	A1/A1	R-407A	R-32/125/134a (20/40/40)	$CH_2F_2 + CF_3CHF_2 + CF_3CH_2F$
1	A1/A1	R-407B	R-32/125/134a (10/70/20)	$CH_2F_2 + CF_3CHF_2 + CF_3CH_2F$
1	A1/A1	R-407C	R-32/125/134a (23/25/52)	$CH_2F_2 + CF_3CHF_2 + CF_3CH_2F$
1	A1/A1	R-408A	R-125/143a/22 (7/46/47)	$CF_3CHF_2 + CF_3CH_3 + CHClF_2$
1	A1/A1	R-409A	R-22/124/142b (60/25/15)	$CHClF_2 + CF_3CHClF + CH_3CClF_2$
1	A1/A1	R-409B	R-22/124/142b (65/25/10)	$CHClF_2 + CF_3CHClF + CH_3CClF_2$
1	A1/A1	R-410A	R-32/125 (50/50)	$CH_2F_2 + CF_3CHF_2$
1	A1/A1	R-410B	R-32/125 (45/55)	$CH_2F_2 + CF_3CHF_2$
2	A1/A2	R-406A	R-22/142b/600a (55/41/4)	$CHClF_2 + CClF_2CH_3 + CH(CH_3)_3$
2	A1/A2	R-411A	R-22/152a/1270 (87.5/11/11.5)	$CHClF_2 + CHF_2CH_3 + C_3H_6$
2	A1/A2	R-411B	R-22/152a/1270 (94/3/3)	$CHClF_2 + CHF_2CH_3 + C_3H_6$
2	A1/A2	R-412A	R-22/218/142b (70/5/25)	$CHClF_2 + C_3F_8 + CClF_2CH_3$
2	A2	R-32	Difluoromethane	CH_2F_2
2	A2	R-141b	1,1-Dichloro-1-fluoroethane	CCl_2FCH_3
2	A2	R-142b	1-Chloro-1,1-difluoroethane	$CClF_2CH_3$
2	A2	R-143a	1,1,1-Trifluoroethane	CF_3CH_3
2	A2	R-152a	1,1-Difluoroethane	CHF_2CH_3
2	B1	R-123	2,2-Dichloro-1,1,1-trifluoroethane	CF_3CHCl_2
2	B2	R-717	Ammonia	NH_3
3	A3	R-170	Ethane	CH_3CH_3
3	A3	R-290	Propane	$CH_3CH_2CH_3$
3	A3	R-600	Butane	CH_4H_{10}
3	A3	R-600a	Isobutane	$CH(CH_3)_3$
3	A3	R-1150	Ethylene	$CH_2 = CH_2$
3	A3	R-1270	Propylene	$CH_2 = CH - CH_3$

Molar mass 3) (MM) kg/kmol	Practical limit 4), 5) kg/m³
111.9	*
90.1	0.33
102.9	0.35
86.2	0.31
87	0.41
97.5	0.16
96.7	0.17
72.6	0.44
75.5	0.43
89.9	0.13
82.4	*
83.1	*
92.2	0.18
52	0.054
117	0.053
100.5	0.049
84	0.048
66	0.027
152.9	0.10
17	0.00035
30	0.008
44	0.008
58.1	0.008
58.1	0.008
28.1	0.006
42.1	0.008

* = not known

– = not applicable

1) The table is not a complete list of substances which could be used as refrigerants. If other substances are used the appropriate practical limits are derived using the method outlined in 4) and the refrigerant is applied as appropriate to its safety group and practical limit.
2) The R-numbers are in accordance with ISO 817.
3) For comparison, the molecular mass of air is taken equal to 28.8 kg/kmol.
4) The practical limits for group L1 refrigerants are less than half the concentration of the refrigerant which can lead to suffocation due to oxygen displacement or which has narcotic (N) or cardiac sensitisation (CS) effect (80% of the effect level) after a short time, whichever is the most critical.

   For single component refrigerants of group L1, the calculation of practical limits (PL) is "PL (kg/m³) = CS or N (ppm) x 0.8 x MM x 10-6/24.45"; for blends (A/B/C), the calculation is "PL (kg/m³) = 1/{A/100/PL(A)+ B/100/PL(B)+C/100/PL(C)}" with A, B, C expressed in % weight.

   For group L2 refrigerants the practical limits refer to the toxicological and flammability characteristics, whichever is the most critical.

   For group L2-B1 value corresponding to 100% of OEL (occupational exposure limit) is taken for R-123.

   For group L2-B2 a value corresponding to 100% of IDLH (immediately dangerous concentrations for life or health) or 20% of LFL (lower flammability limit) is taken, whichever is the lower value.

   For Group L3 refrigerants 20% of LFL is used as practical limit.
5) These values are reduced to 2/3 of the listed value for altitudes higher than 2000 m above sea level and to 1/3 of the listed value for altitudes higher than 3500 m above sea level.

g) Refrigeration associations

Some European and international associations and organizations which represent refrigeration are listed below. The list is not complete and shall not be taken as an evaluation regarding importance. Any missing of further national association or organization is simply due to the lack of knowledge of the full address by the authors.

- Air-Conditioning and Refrigeration Institute, ARI
  4301 North Fairfax Drive, Suite 425., ARLINGTON, VA 22203, **USA**
- American Society of Heating Refrigerating and Airconditioning Engineers Inc., ASHRAE,
  1791 Tullie Circle, N.E., ATLANTA, GA 30329-2305, **USA**
- Asercom
  Motzstraße 91, 10779 BERLIN, **Germany**
- Association Francaise du Froid, A.F.F.
  Rue G.-Apollinaire, F-75006 PARIS, **France**
- Australian Institute of Refrigeration, Air Conditioning and Heating
  James Harrison House, 52 Rosslyn Street,
  West Melbourne 3003 Victoria, **Australia**
- Belgian Association of Refrigeration, BVK/ABF
  Rue Marianne Straat 34, B-1180 BRUSSELS, **Belgium**

- British Refrigeration Association (BRA)
  Henly Road, Medmenham,
  MARLOW, BUCKINGSHAM SL7 2ER, **England**
- Centre technique des industries aérauliques et thermiques, Cetiat
  27–29 boulevard du 11 nov. 1918, BP 6084,
  69604 VILLEURBANNE CEDEX, **France**
- Centre technique des industries mecaniques, Cetim
  52 avenue Félix Lovat, 60404 SEULIS CEDEX, **France**
- Comité européen des constructeurs de matériel aéraulique et de conditionnement d’air et Comité européen des constructeurs de matériel frigorifique, Cecomaf
  21 rue de Drapiers, 1050 BRUSSELS, **Belgium**
- Chinese Association Refrigeration, Bldg II, South No. 1 Lane,
  2nd Section of Sanlihe, 100045 BEIJING, **China**
- Danish Refrigeration Association, AKB
  Westergade 28, DK-4000 HOSKILDE, **Danmark**
- Danish Society of HVAC Engineers, DANVAK
  Ortholm vej 40 b, DK-2800 LYNGBY, **Danmark**
- DKV – Deutscher Kälte- und Klimatechnischer Verein e.V.,
  70569 STUTTGART, **Germany**

- The Finnish Societies of HVAC Engineers, FINVAC
  Sitrarori 5, SF-00420 HELSINKI, **Finland**
- Hütö-és Klimatechnikai, Vállalkozások Szövetség
  Jásberenyi ut 24-36, H-1106 BUDAPEST, **Hungaria**
- Institute of Refrigeration (IOR), Kelvin House, 76 Mill Lane,
  CARSHALTON, SURREY SM5 2JR, **England**
- **International Institute of Refrigeration (IIR) / Institut International du Froid (IIF)**, 177 bd. Malesherbes, F-75017 PARIS, **France**
- LITES, VTU 11 Sauletekio al., 2054 VILNIUS, **Lithuania**
- Nederlandes Vereniging voor Koude, NVVK,
  NL-7322 JI APELDOORN, **Netherlands**
- Norwegian Society of HVAC Engineers, NORVAC
  N-0301 OSLO, **Norway**
- Norwegian Society of Refrigeration Engineers, Sintef Energy
  Kolbjorn Hejes vei 1, N-7034 TRONDHEIM, **Norway**
- Österreichischer Kälte- und Klimatechnischer Verein,ÖKKV,
  Elisabeth Allee 95b-13, A-1130 WIEN, **Austria**
- Romanian General Ass. for Refrigeration
  66, B-dul Carol 1, RO-73232 BUCHAREST 2, **Romania**
- RACCA-IRASE Queensland Inc.,
  GLASSHOUSE MOUNTAINS QLD. 4518, **Australia**

- Schweizerischer Verein für Kältetechnik SVK, Industriestr. 7,
  CH-6312 STEINHAUSEN, **Switzerland**
- Slovak Union for Cooling and Air Conditioning
  Hlavná 325, 90041 ROVINKA, **Slovakia**
- South African Institute of Refrigeration & Air Conditioning (S.A.I.R.A.C.)
  P.O. Box 175, ISANDO 1600, **South Africa**
- South African Refrigerated Distribution Association (SARDA)
  P.O. Box 517, MILNERTON 7435, **South Africa**
- Spanish Association for Refrigeration
  Ciudad Universitaria, Instituto del Frio
  E-28040 MADRID, **Spain**
- SVAZ Chladici a Klimatizacni Techniky, Ostrovského 34
  CZ-15128 PRAHA 5 Smichov, **Czech Republic**
- Svenska Kyltekniska Föreningen
  -17504 JÄRFÄLLA, **Sweden**
- The Swedish Society of HVAC Engineers, SWEDVAC
  Hantverkargatan 40 b, S-11221 STOCKHOLM, **Sweden**
- Underwriters Laboratories Inc., UL
  333 Pfingsten Road, NORTHBROOK, IL 60062-2096, **USA**

10 Glossary

A

Absolute zero – Zero point of the absolute temperature scale corresponding to –273.15°C or –459.67°F; absolute temperature is indicated in Kelvin (K).

Absorbent – A substance that is capable, while undergoing chemical or physical change, of absorbing one or more components from mixtures of gases and/or liquids.

Absorber – Apparatus in the low pressure side of an absorption refrigerating machine, in which the refrigerant vapor is absorbed by a solution with low refrigerant concentration, whilst heat is removed.

Absorption (refrigerating) machine – Refrigerating machine in which the refrigerant vapor is absorbed by a solid or liquid substance from which it is subsequently expelled by heating at a higher partial pressure.

ACGIH – Abbreviation for the American Conference of Governmental Industrial Hygienists.

Activated alumina – Consists essentially of aluminum oxide and is used as a desiccant.

Adiabatic process – Thermodynamic process in which heat is neither supplied nor removed.

Adsorbent – A substance with large internal surface, which has the abilitiy of taking up molecules of gases or liquids by surface adhesion. The adsorbent itself does not undergo physical or chemical change.

AEL – Abbreviation for Acceptable Exposure Limit = recommended average concentration of a substance in air at the workplace, at which an employee's health is generally not harmed (based on 8 hours per day and 5 days per week).

AFEAS – Abbreviation for Alternative Fluorocarbons Environmental Acceptability Study. In the AFEAS study, CFC substitutes (HFCs and HCFCs) were and are examined in relation to their influence on the environment (notably ODP, GWP and decomposition products of the substitutes).

Air, saturated – Air, in which the partial pressure of the water vapor at a specific temperature is equal to the vapor pressure of water at this temperature.

Azeotropic mixture (also: azeotrope) – Mixture of two or more fluids whose vapor and liquid phases in equilibrium have identical compositions.

B

Bimetallic element – Consists of 2 metals with different coefficients of thermal expansion; used for temperature control.

Blowing off – Blowing off vapor from a container filled with refrigerant, formerly common method for reducing the amount of noncondensable gases. Today only expansion into a refrigerant recycling cylinder is permissible.

British Thermal Unit (BTU) – Quantity of heat required to raise the temperature of 1 lb. of water by 1°F.

C

Calorimeter – Instrument for the measurement of heat quantities.

Capillary tube – In refrigeration, a tube with a small bore, used as an expansion device between the high and low pressure sides.

Carbonization (also: coking) – Carbon formation as a result of decomposition of the refrigerating machine oil.

Carnot cycle – Consists of two isotherms and two isentropes. The Carnot cycle has proven highly suitable for a number of procedures. With this process, the maximum value for the ratio between the generated refrigerating capacity and the energy input is obtained. Comparison to this cycle characterizes the efficiency of a refrigerating machine. The ideal cycle is independent of the nature of the refrigerant.

Cascade refrigerating system – A system composed of more than one refrigerating circuit in which the condenser of the one system is cooled by the evaporator from the other system.

CFC – Abbreviation for chlorofluorocarbons, e.g. R12 (formula).

Changes in state – Characteristic for the state of a gas are its volume, the pressure to which it is subjected and its temperature.

The following changes in state can be differentiated in the case of gases:

1. Change at constant volume (isochor). Heating or cooling of a gas in a closed container, no external work is performed.
2. Change at constant pressure (isobaric).
3. Change at constant temperature (isothermal). All the heat supplied is converted into work. It does not serve to increase the temperature. If a gas is compressed isothermally, then Q must be withdrawn and work must be supplied.
4. Change at constant entropy (isentropic) S = const. No supply or withdra wal of heat, no particle friction in the medium.
5. Polytropic change of state. The temperature changes, heat is supplied or withdrawn and external work is performed.

Charging valve – A valve used to charge the system with refrigerant or add oil to the compressor, i.e. the crankcase.

Check valve – An automatic valve, which prevents return flow of a fluid.

Clearance volume – Space existing after completion of compression stroke between the top of the piston and the cylinder head.

Coefficient of performance (for a heat pump) – The ratio of heat output to power input. The heat output and drive capacity on which it is based must each be indicated.

Coefficient of performance (for a refrigerating system; COP) – The ratio of refrigerating capacity to power input. The refrigerating and drive capacities on which it is based must each be indicated.

Coefficient of thermal conductivity – is described by λ and expressed in W/mK. It depends on the properties of the material and expresses the amount of heat that flows per unit of time through two opposing surfaces of a cube from the material concerned, the cube having an edge length of 1 m and the temperature difference between the two surfaces being 1 K. The remaining sides of the cube are protected against the dissipation of heat. The coefficient of thermal conductivity of materials plays a considerable role in insulating technology.

Compound – Substance formed by the combination of two or more chemical elements at a specific mass ratio.

Compound compressor – Compression takes place in two stages, e.g. in one or more cylinders per stage. Used for extreme temperature changes, i.e. very low evaporating temperature or very high condensating temperature with inter-stage cooling of the vapors between two compression stages.

Compression ratio – The quotient of the absolute pressure after compression by the absolute pressure before compression.

Compressor heat output – The heat output of a refrigerant compressor is the product of the refrigerant mass flow passing through the compressor and the difference between the specific enthalpy of the refrigerant gas at the compressor outlet and the specific enthalpy of the saturated liquid of the refrigerant at the pressure at the compressor outlet.

Compressor refrigerating capacity – The refrigerating capacity of a refrigerant compressor is the product of the refrigerant mass flow through the compressor and the difference between the specific enthalpy at the compressor inlet and the specific enthalpy of the saturated liquid of the refrigerant at the pressure at the compressor outlet.

Compressor refrigerating machine – Refrigerating machine in which the refrigerant vapor is raised to the condensing pressure by positive displacement or centrifugal compressors.

Compressor unit – An assembly of compressor and motor.

Compressor unit, hermetic – Compressor with a gas-tight welded casing which encloses the motor windings and rotor without any movable parts passing through the casing.

Compressor unit, open type – A compressor driven by an external power unit, which has no contact with the refrigerant. A drive shaft penetrating the refrigerant-tight housing, which requires a stuffing box or shaft seal..

Compressor unit, pressure gas cooled – Hermetic or semi-hermetic compressor unit with compressed refrigerant vapor passing through its drive motor.

Compressor unit, semi-hermetic – Compresser directly coupled to an electrical motor and contained within a gas-tight bolted casing.

Compressor unit, suction gas cooled – Hermetic or semi-hermetic compressor unit with suctioned-in refrigerant vapor passing through the drive motor.

Compressor, positive displacement – A compressor in which the compression is obtained by sucking in the refrigerant by an increase of internal volume of the compression chamber and compressed by reduction of the internal volume of the compression chamber and delivered into the discharge line.

Condensation – Conversion of vapors into liquids through the withdrawal of heat.

Condensation heat – Latent heat emitted during the change from the gas phase to the liquid phase.

Condenser – Heat exchanger in which the refrigerant vapor is liquified by emitting heat to an external cooling medium.

Condenser heat – The heat flow withdrawn from the refrigerant in the condenser.

Condensing unit – An assembly including compressor with motor, condenser and receiver.

Convector fluid – A fluid by the movement of which heat is transfered.

Cooling brine – is obtained by dissolving salts that greatly depress the freezing point in water. The brine is cooled by a refrigerating system and is used for heat transfer.

Cooling coil – Used for transferring the heat absorbed from the goods being cooled to the refrigerant or the cooling brine.

Cooling tower – Apparatus in which water is cooled, by partial evaporation in air. Warm cooling water is continuously distributed as finely as possible through channels, splash plates etc. in many layers. A counterflow of outside air entering laterally at the base of the tower flows with great force toward the top due to the strong tower draft. Cooling is effected primarily through evaporation, and only to a small extent by heating of the air and by the cold water required to balance the losses.

Cooling water regulator – Automatic valve for control of the cooling water flow rate in the condenser.

Copper plating – The deposition of copper, especially onto iron surfaces moved against each other in bearings, pistons and valves. The results are inadequate lubrication, seizing up or scuffing of the sliding surfaces and leaky valves.

Critical point – The state point at which the properties of liquid and vapor are identical. Critical temperature, pressure and volume coincide at the critical point. Above the critical temperature or the critical pressure, it is not possible to distinguish between liquid or vapor.

Critical pressure – The pressure of a substance prevailing at the critical point.

Critical temperature – The temperature above which it is no longer possible to liquify a gas regardless of the pressure used.

Critical volume – The specific volume prevailing at the critical point.

Cryohydrates – Mixtures of ice and salt precipitated during the freezing of aqueous salt solutions.

Cycles (thermodynamic); also closed cycle or process – A series of changes of state in a system at the termination of which the system is reverted to its original state. The changes of state describe a closed curve in a state diagram. These so called closed processes have numerous applications in thermodynamics.

D

Desiccant – Adsorption or absorption agent, solid or liquid, which is capable of absorbing water or water vapor. The desiccant must be insoluble in the refrigerant in the refrigerating circuit.

Dew-point – The temperature at which water begins to condense from moist air under constant pressure and without moisture being supplied to or withdrawn from the air.

Direct expansion refrigeration – A system of refrigeration in which the evaporator is placed directly in contact with the material or space to be cooled, or incorporated into an air circuit which is in direct contact with the space to be cooled.

Discharge pressure – The pressure of compressed fluid discharged from the compressor; measured in the discharge line of the compressor.

Discharge valve – In a compressor, the valve which allows compressed fluid to flow from the compressor cylinder into the discharge line and prevents return flow.

Dry evaporation – Dissipation of heat into a refrigerant in an dry expansion evaporator. Is controlled by a control element (expansion valve) on the evaporator which is dependent on pressure or temperature or both. The controll is realised by the pressure difference between the high and low pressure side. The total volume of refrigerant vaporizes.

Dry ice – CO_2, solid carbon dioxide.

E

Efficiency – The ratio of the energy output to the energy input of a process or a machine.

Emulsion – Fine, though nonmolecular distribution of a substance in a liquid, e.g. oil droplets in water or water droplets in oil. Emulsions frequently tend to separate, the heavier components settling out.

Enthalpy – Heat energy at constant pressure. A variable of state used primarily to describe flowing fluids. Enthalpy is defined as the sum of internal energy plus the product of pressure and volume.

Enthalpy of evaporation – The amount of heat used to change 1 kg of a liquid into vapor at constant temperature and constant pressure. The same amount of heat is released on condensation of the vapor.

Entropy – A thermodynamic function of state. Expresses the ratio of the quantity of heat supplied to a substance to the absolute temperature at which it is supplied for a reversible process. The unit of entropy is kJ/kg K.

Eutectic mixture or solution – Mixture or solution that melts or solidifies at constant temperature without changing its composition. Its melting point is always lower than the melting point of the components.

Evaporation – The change from the liquid into the vapor phase.

Evaporator – A heat exchanger in which the liquid refrigerant is vaporized by absorbing heat from the substance to be cooled.

Evaporator capacity – The heat flow rate supplied to the refrigerant in the evaporator.

Exergy – The maximum fraction of energy in a system which, in the presence of a medium at a given temperature T_0 , can be converted into useful work during a process at the end of which the system temperature is T_0.

The nonusable fraction of energy is described as anergy. Mechanical and electrical energies are theoretically convertible without loss into other forms of energy and therefore consist of pure exergy. In contrast, heat can only be partially converted into other energy forms. It always contains a proportion of anergy. The smaller the difference between the temperature of the heat source and the ambiemt temperature, the greater the anergy. The proportion of exergy is therefore the true measure for the value of a given heat quantity.

Expansion valve – A regulating valve through which the refrigerant expands into the evaporator.

Expansion valve, automatic – A valve which regulates automatically the flow of liquid refrigerant to the evaporator to maintain the evaporating pressure within close limits. It reacts to pressure change in the evaporator.

Expansion valve, manual (hand expansion valve) – A needle valve which is adjusted manually and used as an expansion valve.

Expansion valve, thermostatic – see Thermostatic expansion valve.

F

Fahrenheit – Temperature scale in which the freezing point and the boiling point of water are respectively 32°F and 212°F at standard atmospheric pressure.

Float valve – Expansion valve operated by a change in liquid level.

Flooded evaporator – Evaporator in which only part of the liquid refrigerant vaporizes. Flooded evaporators comprising a low pressure receiver are called "recirculation-type evaporator". The unvaporized refrigerant returns to the evaporator inlet by gravity or by means of a pump.

Foaming – Formation of foam in the compressor crankcase. Occurs if the refrigerant dissolved in oil vaporizes as a result of a sudden pressure drop. This is the case during the start-up of the compressor and if large amounts of refrigerant are dissolved in oil. Considerable quantities of oil may then foam and be distributed in the entire refrigerating circuit.

Freeze out (to) – Ice formation in the expansion valve which disrupts the normal functioning of a refrigerating unit. Ice may be formed if the refrigerant is moist. The moisture or water freezes out. The valve may be either opened or closed due to frost formation and the movement of the valve is restricted.

G

Generator – Apparatus in the high pressure side of an absorption machine in which the refrigerant is expelled from the solution, which is concentrated with refrigerant, in the vapor state by heating.

Glide refrigerant – Refrigerant which shows a significant temperature glide.

GWP – Abbreviation for Global Warming Potential. Expresses the contribution to the greenhouse effect relative to CO_2 = 1. Indication of the time horizon is required.

H

Halocarbon – Hydrocarbon compound which contains one or more halogens (e.g. fluorine or chlorine).

HCFC – Abbreviation for hydrochlorofluorocarbons, e.g. R22 ($CHClF_2$).

Heat exchanger, internal – Heat exchanger in the refrigerating circuit which provides for the heat exchange between the refrigerant vapor coming from the evaporator and the refrigerant liquid coming from the condenser.

Heat output – The heat flow (total, net, effective) applied to the convector fluid.

Heat pump – A refrigeration system employed for heating, by using the heat given off by the condenser.

Heat radiation – In heat radiation, heat is given off by a body of higher temperature in form of electromagnetic waves (e.g. Infrared radiation).

Heat transfer – by heat conduction – Process of heat transfer through a solid by contact of particles.

Heat transfer – by convection – Heat transmission by changing location of the particles of liquid or gaseous substances.

Heat transfer fluid (see convector fluid) – Liquid or gaseous substances for heat transfer without any change of state.

Hermetic compressor – see compressor unit, hermetic

HFC – Abbreviation for hydrofluorocarbons, e.g. R134a (CF_3CH_2F)

HGWP – Abbreviation for Halocarbon Global Warming Potential. Expresses the contribution to the greenhouse effect relative to R11 = 1.0. The HGWP values relate to an infinite integration time horizon.

High pressure line – In this line, compressed refrigerant vapor is directed from the compressor to the condenser.

High pressure safety cut-out – A switch designed to stop the compressor motor should the discharge pressure reach a predetermined maximum value.

High pressure side – Parts of a refrigerating system which are at condenser pressure or higher.

Humidity – In air conditioning, water vapor within a given space. Humidity is an expression used to describe the amount of water vapor in the air (or in gases and vapors). A distinction is made between absolute humidity, relative humidity and specific humidity.

a) Absolute humidity: Number of grams of water vapor in 1 m^3 of air.
b) Relative humidity: That fraction of the saturation pressure of water that is present as partial pressure (unsaturated vapor pressure).
c) Specific humidity: Number of grams of water vapor in 1 kg of air.

Hydrocarbon – A compound (or molecule) which contains only the elements carbon and hydrogen.

Hydrolysis – Reaction of substances, for example methyl chloride, with water. Generally, hydrolysis reaction products are acids.

Hygrostat (also: humidistat) – A regulating device actuated by change in humidity.

Hygrometer – Instrument responsive to humidity conditions (usually relative humidity) of the atmosphere.

Hygroscopic – Readily absorbing and retaining moisture. If the vapor pressure of a hydrate is less than the vapor pressure of water of the ambient atmosphere, the anhydrous material takes up water from the surrounding atmosphere and converts into the hydrate. Such substances are described as hygroscopic.

I

Indirect system of refrigeration – A refrigeration system in which an intermediate fluid such as brine or water is cooled by the refrigerant and then used to cool the material or space concerned.

Intermediate (or interstage) pressure container – Container installed between the stages of a multistage compression refrigerating plant. The purpose of it is the recooling of the overheated compressed gas to the saturated state. The compressed gas is injected into liquid refrigerant in the container.

Isentrop – A graphical state line representing constant entropy in the state diagram.

Isobar – A graphical state line representing constant pressure used in thermodynamics.

Isomers – Compounds which have the same summation formula but different properties, since they have a different molecular structure or a different arrangement of atoms.

Isotherm – A graphical state line representing constant temperature.

L

Latent heat – Heat added or removed during change of phase, (temperature remains constant). Depending on the type of change of phase involved, the heat is described either as enthalpy of evaporation or as enthalpy of condensation, etc.

Leak detector – A device to facilitate detection of leaks of refrigerants.

Liquefaction – The change from the gaseous state to the liquid state.

Liquid level indicator – A device for determining a liquid level, for example a transparent tube which displays the liquid level in vessels.

Liquid line – The part of a refrigeration system in which the refrigerant is in the liquid state, i.e. from the liquid receiver or condenser to the expansion valve.

Liquid receiver – Vessel used for storage of liquid refrigerant as a reserve in the refrigerant circuit.

Liquid separator (also: suction trap or suction accumulator) – An accumulator installed in the suction line between evaporator and compressor for the purpose of trapping liquid refrigerant carry-over from the evaporator and preventing it reaching and the compressor.

Liquid, highly volatile – Liquid that evaporates at ambient temperature and under standard atmospheric pressure.

Liquid suction heat interchanger (also: superheater) – A heat exchanger in which the wet vapor leaving a flooded evaporator is superheatd and dried by the liquid refrigerant on its way to enter the evaporator.

Low pressure float valve – Float-type expansion valve operated by changes in liquid level on the low pressure side; opens at a low level and closes at a high level.

Low pressure side – That part of a refrigerating circuit in which the refrigerant is at approximately the evaporating pressure.

M

Molecular sieve – Crystallized alumino-silicates with a given pore size which is governed by composition. These products are distinguished by their high water adsorption when used as desiccants.

Molecular weight – This is the sum of atomic weights of all the elements which form a compound.

N

Near-azeotropic mixture – A nonazeotrope with a temperature glide suff-ciently small that it may disregarded without consequential error in analysis for a specific application.

Net heat output of a absorption refrigerating machine – The heat flow supplied to the convector fluid in the condenser by the refrigerant and in the absorber by the solution.

Net heat output of a refrigerating machine – The heat flow supplied to the convector fluid in the condenser by the refrigerant.

Net refrigerating effect – The rate at which heat is removed by a primary refrigerant from a secondary refrigerant in the evaporator.

Nonazeotropic mixture (also: zeotrope) – Blends comprising multiple components of different volatilities that, when used in refrigeration cycles, change composition and saturation temperatures as they evaporate (boil) or condense at constant pressure. Nonazeotropic refrigerants have a temperature glide.

Noncondensable gases – Gases that cannot be condensed under the conditions prevailing in a refrigerating circuit.

O

ODP – Abbreviation for Ozone Depletion Potential. Expresses the contribution to ozone depletion, relative to R11 = 1.0.

Oil separator – An arrangement for separating oil from refrigerant vapor. It prevents oil from reaching the evaporator, where it may separate from the vapor. This would cause a reduction in heat transfer and therefore in capacity.

Organic Rankine Cycle – Process for conversion of waste heat into mechanical or electrical energy through the use of an organic working fluid in expansion machines. In contrast to the refrigerating process, this is a clockwise thermodynamic cycle.

Overall heat output of a refrigerating machine – The heat flow supplied to the ambient by the refrigerant.

Overall heat output of an absorption refrigerating machine – The heat flow supplied to the ambient by the refrigerant and the solution.

Overall refrigerating effect – The rate at which heat is removed from outer media by a refrigerant in the low pressure side.

P

PAFT – Abbreviation for Program for Alternative Fluorocarbon Toxicity Testing. In the PAFT, various CFC substitutes (HFCs and HCFCs) were examined concerning their toxicity to allow an evaluation of risk for the use of these substitutes.

Phase – Physical state of substances; for example, solid, liquid or gaseous phase.

POCP – Abbreviation for Photochemical Ozone Creation Potential; rates the potential of a substance for creation of ozone at ground level (summer smog), relative to methane = 1.

Pressostat – A regulating or safety device actuated by change in pressure. Pressostats close the electric circuit when suction pressure increases to an adjustable upper limit and open it when suction pressure falls below the set lower limit.

Pressure gauge – Instrument for measuring pressure of liquids or gases.

Pressure loss – Spontaneous lowering of pressure in a fluid, flowing in a pipe or duct due to friction, change in direction, etc.

Pressure reducer – Valve that ensures uniform pressure on the low pressure side independent of the pressure variation on the high pressure side.

Pressure relief device – A valve or rupture member designed to relieve excessive pressure automatically.

Pressure relief valve (also: safety valve) – A valve which automatically opens in case of excessive pressure.

Psychrometer – An instrument for determining relative humidity in relation to coexistent dry bulb and wet bulb temperature (see also hygrometer).

R

Rectifier – The part of an absorption refrigerating machine in which entrained absorbent is removed from the refrigerant vapor before condensation.

Refrigerant – The working fluid in a refrigeration cycle, absorbing heat from bodies at a low temperature and rejecting heat to bodies at a higher temperature.

Refrigerant compressor – The component of a refrigeration system which, by a mechanical process, draws in refrigerant vapor and discharges it at a higher pressure.

Refrigerating effect per unit of swept volume – The ratio of the refrigerating capacity to the swept volume of the compressor per unit time.

Refrigerating machine – A generic term for thermic machines which absorb heat at a lower temperature and, using a supplied energy current, reject it again at a higher temperature.

Refrigerating plant – An assembly of components to produce refrigeration and utilize refrigeration poduced.

Refrigerating unit – A generic term designating either a compressor unit or a condensing unit or a factory assembled refrigeration system.

Refrigeration oil – Lubricant necessary for lubrication of a refrigerant compressor.

S

Secondary refrigerant – Fluid used in indirect systems of refrigeration for heat transfer from the products or spaces to be cooled to the refrigerating machine.

Separator – A device for the removal of particles from a flowing liquid or flowing gas.

Sight glass – A device installed in the liquid line or the compressor cranckcase allowing to check the presence and state of either refrigerant or oil.

Silica gel – A form of silicon dioxide which rapidly adsorbs moisture and is used as a desiccant.

Sludge – In a refrigeration systema product of decomposition of oil, resulting from impurities, moisture or chemical reactions.

Solenoid valve – On/off type valves operated by an electromagnetic coil.

Solvay AEL – Abbreviation for Solvay Acceptable Exposure Limit = recommendation by Solvay, regarding the average concentration of a substance in air at the workplace at which an employee's health is generally not harmed (based on 8 hours per day and 5 days per week).

Sorbent – A substance possessing the characteristic ability of absorption or adsorption.

Specific heat capacity – The quantity of heat needed to raise the temperature of the unit mass of a substance by 1 K (for a gas, either at constant pressure or at constant volume). Is is expressed with c and given in kJ/kg K.

Specific volume – The volume of unit mass of a substance; the reciprocal of density.

State diagrams – A diagram representing, in a system of suitable co-ordinates, the thermodynamic equilibrium of states of a substance. The following diagrams are particularly suitable for the graphic presentation of thermodynamic processes:

1. p,v diagram, indicator diagram in terms of pressure and volume; the area indicates the performed work.
2. T,s diagram, heat diagram in terms of absolute temperature and entropy; the area indicates the amount of heat.
3. h,s diagram from Mollier in terms of enthalpy and entropy. All important energy and heat values appear as straight lines.
4. h,p diagram from Mollier in terms of enthalpy and pressure, with right-angle

coordinates, also shows all energy and heat values as straight lines. It is best suited for the presentation of refrigeration cycles.

Subcooling – The reduction of temperature of liquid refrigerant to some point below the condensation temperature corresponding to its given pressure.

Suction line – The line through which refrigerant vapor flows from evaporator outlet to the compressor.

Suction pressure – The pressure at which vapor is drawn into a compressor.

Suction pressure regulator (also: constant pressure valve) – Its function is to keep the suction pressure of an evaporator or group of evaporators constant, i.e. to prevent the evaporator pressure from falling below a specific set value.

Supercooling – Cooling of a substance below the normal freezing point without solidification. The liquid can exist only in an unstable equilibrium state.

Superheated vapor – Vapor at a temperature higher than the saturation temperature at the existing pressure.

Superheater – see “Liquid suction heat interchanger”

Swept volume – The volume displaced per revolution by a reciprocating compressor.

T

Temperature glide – Difference between the boiling point and dew-point temperature at constant pressure. This term usually describes condensation or evaporation of a zeotrope.

TEWI – Abbreviation for Total Equivalent Warming Impact; expresses the sum of direct (GWP contribution of refrigerant) and **indirect** (contribution of CO_2 emissions which result from energy consumption for operation of refrigerating plants) **emissions** of greenhouse gases. TEWI is not product-specific information, but rather relates to a system (plant).

Thermocouple – A sensing element for measuring temperature based on electromotive force generated when two junctions of suitable substances are at different temperatures. (One of them being taken as the reference value.)

Thermodynamic terms – Fundamental terms such as temperature, pressure, volume, enthalpy and entropy. These terms are used to describe the state of a substance.

Thermostat – A regulating device actuated by change in temperature.

Thermostatic expansion valve – A valve which regulates automatically the flow of liquid refrigerant to the evaporator to maintain within close limits the degree of superheat of the suction vapor.

TLV – TWA – Abbreviation for Threshold Limit Value – Time-Weighted Average of the ACGIH. This is the time weighted average concentration (based on a normal 8 hour workday and 40 hour workweek), at which an employee's health is generally not harmed.

Ton of Refrigeration (US) – A capacity of 12,000 BTU/h, corresponding to 12,660 kJ/h.

Turbocompressor (or centrifugal compressor) – Compressor in which the refrigerant is compressed dynamically, basically by centrifugal forces.

The refrigerant is compressed by means of one or more rotating impellers and one or more stationary diffusers, all usually with blades or flow guides. Kinetic energy transfered to the refrigerant is converted into pressure by the turbocompressor.

U

Useful refrigerating effect – The heat flow usefully removed by the primary refrigerant or secondary refrigerant, between two specific points, taken into account the conditions of utilization.

V

Vapor – A gas in equilibrium with the liquid phase. Usually, in the case of gaseous refrigerants, it refers to refrigerant vapor. Applies generally to gases below the critical temperature and not far from the liquefaction conditions.

Vapor pressure – Basically, the pressure exerted by a vapor. Further, it is the specific pressure at which the conversion of a solid or liquid substance into its vapor takes place at a certain temperature. In the case of a chemically uniform substance, this pressure is dependent solely upon the temperature but not the amount of substance.

Viscosity – Internal friction due to molecular cohesion in fluids.

Volumetric efficiency – The ratio of volume induced, at suction conditions, by a compressor in a given time to the swept volume as measured over the same time.

W

Water or brine chiller – Refrigeration system in which heat exchange takes place between water or brine and refrigerant. Liquid refrigerant evaporates and thus removes heat from the water or brine, which is cooled.

Wax – Substance that may separate during cooling of oil-refrigerant mixtures. Wax separation may clog control valves and reduce the heat transfer.

Wet compression – Occurs when the vapor drawn into the compressor contains some portion of liquid refrigerant.

Z

Zeotrope – see nonazeotropic mixture.

11 Conversion Tables*)

Linear dimensions

	Meter	inch	foot	yard
1 m	1	39.37	3.2808	1.0936
1 in	0.0254	1	0.0833	0.0278
1 ft	0.3048	12	1	0.333
1 yd	0.9144	36	3	1

1 m = 10^{-3} km = 10 dm = 10^{2} cm = 10^{3} mm = 10^{6} µm = 10^{12} nm

Areas

	cm^2	m^2	square inch	square foot	square yard
1 cm^2	1	$1{\cdot}10^{-4}$	0.155	$1.0764{\cdot}10^{-3}$	$1.196{\cdot}10^{-4}$
1 m^2	$1{\cdot}10^{4}$	1	1550	10.764	1.196
1 sq in	6.4516	$0.64516{\cdot}10^{-3}$	1	0.00694	$0.772{\cdot}10^{-3}$
1 sq ft	929.0	0.0929	144	1	0.1111
1 sq yd	8360	0.8360	1296	9	1

1 m^2 = 10^{-6} km^2 = 10^{-4} ha = 10^{2} dm^2 = 10^{6} mm^2

Volumes

	Liter (dm^3)	m^3	cubic inch	cubic foot	Gallons US	Gallons Imperial
1 l	1	$1{\cdot}10^{-3}$	61.024	0.03531	0.2642	0.220
1 m^3	1000	1	61024	35.31	264.2	220
1 cu in	$16.387{\cdot}10^{-3}$	$16.387{\cdot}10^{-6}$	1	$0.5787 \cdot 10^{-3}$	$4.329 \cdot 10^{-3}$	$3.606 \cdot 10^{-3}$
1 cu ft	28.320	$28.320 \cdot 10^{-3}$	1728	1	7.481	6.229
1 US-gal	3.785	$3.785 \cdot 10^{-3}$	231	0.1337	1	0.8327
1 Imp-gal	4.546	$4.546 \cdot 10^{-3}$	277.3	0.1605	1.201	1

Imperial = British

* According to the 1978 annual „Kälte-Wärme-Klima“, Verlag C.F.Müller, Karlsruhe

Weights

	kilogram	pound	Tons short (US)	Tons long (Imp)
1 kg	1	2.205	$1.102 \cdot 10^{-3}$	$0.9843 \cdot 10^{-3}$
1 lb	0.4536	1	$0.500 \cdot 10^{-3}$	$0.4464 \cdot 10^{-3}$
1 short ton (US)	907.2	2000	1	0.8929
1 long ton (Imp)	1016	2240	1.12	1

1 kg = 10^3 g = 10^2 dkg

Density

Dichte	kg/ltr	kg/m³	$\frac{\text{pound}}{\text{cubic foot}}$	$\frac{\text{pound}}{\text{gallon}}$ Imperial	$\frac{\text{pound}}{\text{gallon}}$ US
1 kg/ltr	1	1000	62.43	10.022	8.345
1 kg/m³	0.001	1	0.06243	0.010022	0.008345
1 lb/cu ft	0.01602	16.02	1	0.16054	0.1337
1 lb/gal (Imp)	0.0998	99.78	6.229	1	0.8327
1 lb/gal (US)	0.1198	119.8	7.481	1.201	1

Specific volume

	ltr/kg	m³/kg	$\frac{\text{cubic foot}}{\text{pound}}$
1 ltr/kg	1	0.001	0.01602
1 m³/kg	1000	1	16.02
1 cu ft/lb	62.43	0.06243	1

Force

	Newton	kilopond	poundal
1 N	1	0.1020	7.2333
1 kp	9.80665	1	70.9344
1 pdl	0.13825	0.00141	1

1 N = 10^5 dyn; 1 dyn = 1 g x 1 $\frac{cm}{s^2}$; 1 kp = 1 kg x g

1 Poundal = 1 Pound x $\frac{ft}{s^2}$

Pressure

	1 bar $= 10^5 \frac{N}{m^2}$	1 at $= 1 \frac{kp}{cm^2}$	$\frac{\text{poundal}}{\text{sq ft}}$	$\frac{\text{poundal}}{\text{sq in}}$ = Psi
1 Pa = 1 N/m^2	$1 \cdot 10^{-5}$	$1.02 \cdot 10^{-5}$	0.0209	$1.45 \cdot 10^{-4}$
1 bar	1	1.0197	2089	14.504
1 at	0.980665	1	2048	14.22
1 pdl/sq ft	$0.4790 \cdot 10^{-3}$	$0.4882 \cdot 10^{-3}$	1	$6.944 \cdot 10^{-3}$
1 pdl/sq in = Psi	0.06895	0.07031	144	1
1 atm	1.013	1.033	2120	14.70
1 mm Hg	$1.330 \cdot 10^{-3}$	$1.360 \cdot 10^{-3}$	2.78	0.0193
1 in Hg	0.0339	0.0345	70.7	0.4910
1 m H_2O	0.0981	0.1000	205	1.4220
1 ft H_2O	0.0299	0.0305	62.4	0.4340

$1 \frac{N}{m^2}$ = Pa (Pascal) = $10 \frac{dyn}{cm^2}$

$1 \frac{kp}{m^2} = 10^{-4} \frac{kp}{cm^2}$ = 1 mm WS (bei 4°C)

Effective work, Energy, Amount of heat

	1 kcal	1 kp m	Btu = British thermal unit	1 kWh
1 kcal	1	427.0	3.968	$1.163 \cdot 10^{-3}$
1 kpm	$2.342 \cdot 10^{-3}$	1	$9.294 \cdot 10^{-3}$	$2.723 \cdot 10^{-6}$
1 Btu	0.252	107.59	1	$0.293 \cdot 10^{-3}$
1 kWh	860	$367.1 \cdot 10^3$	3412.8	1
1 PSh	632.3	$270 \cdot 10^3$	2509.3	0.7353
1 hph	641.1	$273.7 \cdot 10^3$	2545	0.7457
1 ton-day	$72.57 \cdot 10^3$	$30.99 \cdot 10^6$	$288 \cdot 10^3$	84.39
1 J	$0.239 \cdot 10^{-3}$	0.102	$0.948 \cdot 10^{-3}$	$0.278 \cdot 10^{-6}$

1 erg = 1 dyn cm = 10^{-7} Nm; 1 kJ = 10^3 J

1 atm = 760 Torr = 760 mm Hg (0°C)	Hg-column (0°C) mm Hg = Torr	Hg-column (0°C) in Hg	H_2O-column (WS) (4°C) m H_2O	H_2O-column (WS) (4°C) ft H_2O
$9.87 \cdot 10^{-6}$	0.0075	$2.95 \cdot 10^{-4}$	$1.02 \cdot 10^{-4}$	$3.35 \cdot 10^{-4}$
0.9869	750	29.5	10.20	33.5
0.96784	735.56	29.0	10.00	32.8
$0.4725 \cdot 10^{-3}$	0.359	0.0141	$4.88 \cdot 10^{-3}$	0.0160
0.06805	51.7	2.04	0.703	2.31
1	760	29.9	10.33	33.9
$1.316 \cdot 10^{-3}$	1	0.0394	0.0136	0.0446
0.0334	25.4	1	0.3450	1.133
0.0968	73.6	2.90	1	3.28
0.0295	22.4	0.883	0.3050	1

Horsepower-hour Metric $75 \frac{kpm}{s}$ h	Horsepower-hour Imperial $550 \frac{ft \cdot lb}{s}$ h	ton-day of refrigeration	1 Joule = N m = W s
$1.581 \cdot 10^{-3}$	$1.560 \cdot 10^{-3}$	$13.779 \cdot 10^{-6}$	4186.8
$3.704 \cdot 10^{-6}$	$3.653 \cdot 10^{-6}$	$32.270 \cdot 10^{-6}$	9.807
$0.398 \cdot 10^{-3}$	$0.3931 \cdot 10^{-3}$	$3.472 \cdot 10^{-6}$	1055
1.360	1.341	$11.850 \cdot 10^{-3}$	$3.6 \cdot 10^{6}$
1	0.9863	$8.713 \cdot 10^{-3}$	$2.65 \cdot 10^{6}$
1.014	1	$8.834 \cdot 10^{-3}$	$2.68 \cdot 10^{6}$
114.78	113.2	1	$304 \cdot 10^{6}$
$0.378 \cdot 10^{-6}$	$0.372 \cdot 10^{-6}$	$3.280 \cdot 10^{-9}$	1

Power, Energy flow rate, Heat flow rate

	$1\,\frac{\text{kcal}}{\text{h}}$	$1\,\frac{\text{kp m}}{\text{s}}$	British thermal unit per hour	1 kcal/s = British theor. unit of refrigeration
1 kcal/h	1	0.1186	3.968	$0.278 \cdot 10^{-3}$
1 kp m/s	8.4312	1	33.455	$2.342 \cdot 10^{-3}$
1 Btu/h	0.252	$29.89 \cdot 10^{-3}$	1	$0.07 \cdot 10^{-3}$
1 kcal/s = Br u r	3600	427.0	$14.285 \cdot 10^{3}$	1
1 kW	860.0	102.0	3414	0.2389
1 PS	632.3	75	2509.3	0.1756
1 hp	641.1	76.04	2545	0.1781
1 ton	3024	358.2	$12.0 \cdot 10^{3}$	0.831
1 Br ton	3340	396.9	$13.26 \cdot 10^{3}$	0.9277

Enthalpy difference, Latent heat

Δ h	$\frac{\text{kJ}}{\text{kg}}$	$\frac{\text{kcal}}{\text{kg}}$	$\frac{\text{Btu}}{\text{pound}}$
1 kJ/kg	1	0.239	0.43
1 kcal/kg	4.1868	1	1.80
1 Btu/lb	2.33	0.556	1

$1\,\frac{\text{cal}}{\text{g}} = \frac{\text{kcal}}{\text{kg}}$

Entropy difference, Spec. heat capacity

Δ s	$\frac{\text{kJ}}{\text{kg K}}$	$\frac{\text{kcal}}{\text{kg °C}}$	$\frac{\text{Btu}}{\text{pound °F}}$
1 kJ/kg K	1	0.239	0.239
1 kcal/kg °C	4.1868	1	1
1 Btu/lb °F	4.1868	1	1

1 kW = 1 kJ/s	Horsepower (hp) Metric $75\ \frac{kpm}{s}$	Horsepower (hp) Imperial $550\ \frac{ft \cdot lb}{s}$	Standard commercial ton of refrigeration US	British commercial ton of refrigeration
$1.163 \cdot 10^{-3}$	$1.581 \cdot 10^{-3}$	$1.560 \cdot 10^{-3}$	$0.331 \cdot 10^{-3}$	$0.299 \cdot 10^{-3}$
$9.804 \cdot 10^{-3}$	$13.333 \cdot 10^{-3}$	$13.150 \cdot 10^{-3}$	$2.792 \cdot 10^{-3}$	$2.520 \cdot 10^{-3}$
$0.293 \cdot 10^{-3}$	$0.398 \cdot 10^{-3}$	$0.393 \cdot 10^{-3}$	$0.083 \cdot 10^{-3}$	$75.310 \cdot 10^{-3}$
4.186	5.693	5.615	1.190	1.078
1	1.360	1.341	0.2846	0.2572
0.736	1	0.9863	0.2094	0.1891
0.7455	1.014	1	0.2123	0.21227
3.513	4.776	4.711	1	0.9037
3.888	5.287	5.214	1.1045	1

Volumetric refrigerating capacity (refrigerating effect per unit of swept volume)

q_{vol}	$\frac{KJ}{m^3}$	$\frac{kcal}{m^3}$	$\frac{Btu}{cubic\ foot}$	$\frac{ton\text{-}day}{cubic\ foot}$
1 kJ/m³	1	0.239	0.02685	$0.0929 \cdot 10^{-6}$
1 kcal/m³	4.1868	1	0.1123	$0.3901 \cdot 10^{-6}$
1 Btu/ft³	37.253	8.90	1	$3.473 \cdot 10^{-6}$
1 ton-day/ft³	$10.734 \cdot 10^{6}$	$2.563 \cdot 10^{6}$	$0.288 \cdot 10^{6}$	1

Thermal conductivity

λ	$\frac{J}{ms\,K} = \frac{W}{m\,K}$	$\frac{kJ}{m\,h\,K}$	$\frac{kcal}{m\,h\,°C}$	$\frac{Btu}{ft\,h\,°F}$	$\frac{Btu\ in}{sq\,ft\,h\,°F}$
$1\ J/m\ s\ K = \frac{W}{mK}$	1	3.60	0.860	0.578	6.94
1 kJ/m h K	0.278	1	0.239	0.1605	1.926
1 kcal/m h °C	1.163	4.1868	1	0.6719	8.064
1 Btu/ft h °F	1.730	6.23	1.488	1	12
1 Btu in/ft² h °F	0.144	0.519	0.124	0.0833	1

$$1\ \frac{cal}{cm\ s\,°C} = 418.68\ \frac{J}{m\ s\ k} = 1507\ \frac{kJ}{m\ h\ K} = 360\ \frac{kcal}{m\ h\ °C} = 242\ \frac{Btu}{ft\ h\ °F} = 2900\ \frac{Btu\ in}{sq\ ft\ h\ °F}$$

Overall coefficient of heat transfer, Surface coefficient of heat transfer

k, α	$\frac{J}{m^2 s K} = \frac{W}{m^2 K}$	$\frac{kJ}{m^2 h K}$	$\frac{kcal}{m^2 h\, °C}$	$\frac{Btu}{sq\, ft\, h\, °F}$
$1\ J/m^2\ s\ K = \frac{W}{m^2 K}$	1	3.60	0.860	0.1761
$1\ kJ/m^2\ h\ K$	0.278	1	0.239	0.0489
$1\ kcal/m^2\ h\ °C$	1.163	4.1868	1	0.2050
$1\ Btu/ft^2\ h\ °F$	5.680	20.40	4.880	1

$$\frac{cal}{cm^2\, s\, °C} = 41868\ \frac{J}{m^2\, s\, K} = 150725\ \frac{kJ}{m^2\, h\, K} = 36000\ \frac{kcal}{m^2\, h\, °C} = 7380\ \frac{Btu}{sq\, ft\, h\, °F}$$

Temperatures

Temperature points (also with below-zero temperatures)

a) Given t_f [°F], wanted t_c [°C]:

$$t_c = \frac{5}{9}(t_f - 32) \text{ or } t_c = \frac{5}{9}(t_f + 40) - 40$$

b) Given t_c [°C], wanted t_f deg [°F]:

$$t_f = \frac{9}{5} t_c + 32 \text{ or } t_f = \frac{9}{5}(t_c + 40) - 40$$

12 Vapor Tables

t = Temperature
p = Pressure
v´ = Specific volume of liquid
v´´ = Specific volume of vapor
ρ´ = Density of liquid
ρ´´ = Density of vapor
h´ = Enthalpy of liquid
h´´ = Enthalpy of vapor
r = Enthalpy of evaporation
s´ = Entropy of liquid
s´´ = Entropy of vapor

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t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
– 80	0.11	0.659	1753.71	1.517	0.57	114.08	367.74	253.66	0.6328	1.9461
– 79	0.11	0.660	1655.15	1.515	0.60	113.08	368.40	255.33	0.6277	1.9428
– 78	0.12	0.661	1550.31	1.512	0.65	114.06	368.91	254.85	0.6327	1.9387
– 77	0.13	0.662	1453.23	1.509	0.69	115.04	369.42	254.38	0.6378	1.9346
– 76	0.14	0.664	1363.26	1.507	0.73	116.03	369.93	253.90	0.6428	1.9307
– 75	0.15	0.665	1279.80	1.504	0.78	117.03	370.44	253.41	0.6479	1.9268
– 74	0.16	0.666	1202.32	1.502	0.83	118.03	370.95	252.92	0.6529	1.9229
– 73	0.17	0.667	1130.35	1.499	0.88	119.03	371.46	252.43	0.6579	1.9192
– 72	0.18	0.668	1060.45	1.496	0.94	120.68	371.92	251.23	0.6662	1.9152
– 71	0.19	0.670	998.36	1.494	1.00	121.69	372.42	250.73	0.6712	1.9115
– 70	0.21	0.671	940.54	1.491	1.06	122.70	372.93	250.23	0.6762	1.9079
– 69	0.22	0.672	886.67	1.488	1.13	123.72	373.44	249.72	0.6812	1.9044
– 68	0.23	0.673	836.42	1.485	1.20	124.74	373.95	249.21	0.6861	1.9009
– 67	0.25	0.674	789.54	1.483	1.27	125.76	374.46	248.70	0.6911	1.8975
– 66	0.26	0.676	747.84	1.480	1.34	126.15	375.02	248.87	0.6930	1.8944
– 65	0.28	0.677	706.82	1.477	1.41	127.18	375.53	248.35	0.6979	1.8911
– 64	0.30	0.678	668.45	1.475	1.50	128.22	376.04	247.82	0.7029	1.8878
– 63	0.32	0.679	632.55	1.472	1.58	129.26	376.54	247.29	0.7079	1.8846
– 62	0.34	0.681	598.93	1.469	1.67	130.30	377.05	246.75	0.7128	1.8814
– 61	0.36	0.682	567.43	1.467	1.76	131.35	377.55	246.21	0.7178	1.8783
– 60	0.38	0.683	537.90	1.464	1.86	132.40	378.06	245.66	0.7227	1.8752
– 59	0.40	0.684	510.19	1.461	1.96	133.45	378.56	245.11	0.7276	1.8722
– 58	0.42	0.686	484.18	1.458	2.07	134.51	379.06	244.56	0.7326	1.8692
– 57	0.45	0.687	459.75	1.456	2.18	135.57	379.57	244.00	0.7375	1.8663
– 56	0.47	0.688	436.79	1.453	2.29	136.63	380.07	243.43	0.7424	1.8634
– 55	0.50	0.690	415.19	1.450	2.41	137.70	380.57	242.87	0.7473	1.8606
– 54	0.52	0.691	394.87	1.447	2.53	138.77	381.07	242.29	0.7522	1.8578
– 53	0.55	0.692	375.73	1.445	2.66	139.84	381.56	241.72	0.7570	1.8550
– 52	0.58	0.694	357.71	1.442	2.80	140.92	382.06	241.14	0.7619	1.8523
– 51	0.61	0.695	340.72	1.439	2.94	142.00	382.56	240.55	0.7668	1.8496
– 50	0.65	0.696	324.69	1.436	3.08	143.08	383.05	239.97	0.7716	1.8470
– 49	0.68	0.698	309.57	1.433	3.23	144.17	383.54	239.37	0.7765	1.8444
– 48	0.72	0.699	295.29	1.431	3.39	145.26	384.03	238.78	0.7813	1.8418
– 47	0.75	0.700	281.80	1.428	3.55	146.35	384.52	238.17	0.7861	1.8393
– 46	0.79	0.702	269.05	1.425	3.72	147.44	385.01	237.57	0.7909	1.8368
– 45	0.83	0.703	257.24	1.422	3.89	148.34	385.52	237.18	0.7949	1.8344
– 44	0.87	0.705	245.82	1.419	4.07	149.44	386.00	236.57	0.7997	1.8320
– 43	0.91	0.706	235.01	1.416	4.26	150.54	386.49	235.95	0.8044	1.8296
– 42	0.96	0.707	224.78	1.414	4.45	151.65	386.97	235.32	0.8092	1.8273
– 41	1.01	0.709	215.08	1.411	4.65	152.75	387.45	234.70	0.8140	1.8250
– 40	1.05	0.710	205.88	1.408	4.86	153.86	387.93	234.07	0.8187	1.8227
– 39	1.10	0.712	197.17	1.405	5.07	154.97	388.40	233.43	0.8235	1.8204
– 38	1.15	0.713	188.89	1.402	5.29	156.09	388.88	232.79	0.8282	1.8182
– 37	1.21	0.715	181.04	1.399	5.52	157.21	389.35	232.15	0.8329	1.8160
– 36	1.26	0.716	173.58	1.396	5.76	158.32	389.82	231.50	0.8376	1.8138
– 35	1.32	0.718	166.54	1.393	6.00	159.38	390.30	230.92	0.8421	1.8117
– 34	1.38	0.719	159.80	1.390	6.26	160.50	390.76	230.26	0.8468	1.8096
– 33	1.44	0.721	153.39	1.387	6.52	161.63	391.23	229.60	0.8514	1.8075
– 32	1.51	0.722	147.29	1.385	6.79	162.75	391.69	228.94	0.8561	1.8054
– 31	1.57	0.724	141.49	1.382	7.07	163.88	392.15	228.27	0.8607	1.8034

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t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
– 30	1.64	0.725	135.96	1.379	7.36	165.01	392.61	227.59	0.8654	1.8014
– 29	1.71	0.727	130.69	1.376	7.65	166.14	393.06	226.92	0.8700	1.7994
– 28	1.78	0.728	125.68	1.373	7.96	167.28	393.51	226.24	0.8746	1.7975
– 27	1.86	0.730	120.89	1.370	8.27	168.41	393.96	225.55	0.8792	1.7955
– 26	1.94	0.732	116.33	1.367	8.60	169.55	394.41	224.86	0.8838	1.7936
– 25	2.02	0.733	111.97	1.364	8.93	170.69	394.85	224.17	0.8884	1.7917
– 24	2.10	0.735	107.82	1.361	9.28	171.82	395.30	223.47	0.8929	1.7899
– 23	2.18	0.737	103.85	1.358	9.63	172.96	395.74	222.77	0.8975	1.7880
– 22	2.27	0.738	100.06	1.355	9.99	174.11	396.17	222.07	0.9020	1.7862
– 21	2.36	0.740	96.40	1.352	10.37	175.31	396.60	221.29	0.9067	1.7843
– 20	2.45	0.742	92.94	1.348	10.76	176.46	397.03	220.57	0.9112	1.7826
– 19	2.55	0.743	89.63	1.345	11.16	177.60	397.46	219.86	0.9157	1.7808
– 18	2.65	0.745	86.46	1.342	11.57	178.75	397.88	219.13	0.9202	1.7791
– 17	2.75	0.747	83.43	1.339	11.99	179.90	398.30	218.41	0.9247	1.7773
– 16	2.86	0.748	80.53	1.336	12.42	181.04	398.72	217.68	0.9291	1.7756
– 15	2.96	0.750	77.72	1.333	12.87	182.25	399.13	216.88	0.9338	1.7739
– 14	3.07	0.752	75.06	1.330	13.32	183.40	399.54	216.14	0.9382	1.7722
– 13	3.19	0.754	72.49	1.327	13.80	184.62	399.94	215.33	0.9428	1.7705
– 12	3.30	0.756	70.04	1.324	14.28	185.77	400.35	214.58	0.9472	1.7689
– 11	3.42	0.757	67.70	1.320	14.77	186.92	400.75	213.83	0.9516	1.7673
– 10	3.55	0.759	65.43	1.317	15.28	188.13	401.14	213.01	0.9562	1.7656
– 9	3.68	0.761	63.27	1.314	15.81	189.29	401.54	212.25	0.9605	1.7640
– 8	3.81	0.763	61.18	1.311	16.35	190.50	401.93	211.42	0.9651	1.7624
– 7	3.94	0.765	59.19	1.308	16.90	191.66	402.31	210.66	0.9694	1.7609
– 6	4.08	0.767	57.26	1.304	17.46	192.87	402.69	209.82	0.9739	1.7593
– 5	4.22	0.769	55.42	1.301	18.04	194.03	403.07	209.04	0.9782	1.7577
– 4	4.36	0.771	53.64	1.298	18.64	195.25	403.44	208.20	0.9827	1.7562
– 3	4.51	0.772	51.95	1.295	19.25	196.41	403.82	207.41	0.9869	1.7547
– 2	4.66	0.774	50.30	1.291	19.88	197.62	404.18	206.56	0.9914	1.7531
– 1	4.82	0.776	48.73	1.288	20.52	198.80	404.54	205.74	0.9957	1.7517
0	4.98	0.778	47.21	1.285	21.18	200.00	404.90	204.90	1.0000	1.7502
1	5.14	0.781	45.74	1.281	21.86	201.22	405.25	204.03	1.0044	1.7487
2	5.31	0.783	44.35	1.278	22.55	202.38	405.61	203.23	1.0086	1.7472
3	5.48	0.785	42.99	1.274	23.26	203.60	405.95	202.35	1.0130	1.7457
4	5.66	0.787	41.69	1.271	23.99	204.78	406.30	201.51	1.0172	1.7443
5	5.84	0.789	40.42	1.268	24.74	206.00	406.63	200.63	1.0215	1.7428
6	6.02	0.791	39.21	1.264	25.50	207.20	406.96	199.76	1.0258	1.7414
7	6.21	0.793	38.04	1.261	26.29	208.43	407.29	198.86	1.0301	1.7400
8	6.40	0.795	36.92	1.257	27.09	209.61	407.62	198.01	1.0343	1.7385
9	6.60	0.798	35.83	1.254	27.91	210.81	407.94	197.12	1.0385	1.7371
10	6.80	0.800	34.78	1.250	28.76	212.04	408.25	196.21	1.0428	1.7357
11	7.01	0.802	33.76	1.247	29.62	213.26	408.56	195.30	1.0470	1.7343
12	7.22	0.804	32.79	1.243	30.50	214.45	408.86	194.42	1.0511	1.7329
13	7.43	0.807	31.84	1.240	31.41	215.67	409.16	193.49	1.0554	1.7315
14	7.65	0.809	30.93	1.236	32.33	216.88	409.46	192.58	1.0595	1.7302
15	7.88	0.811	30.04	1.232	33.28	218.10	409.75	191.65	1.0637	1.7288
16	8.11	0.814	29.19	1.229	34.26	219.33	410.03	190.70	1.0679	1.7274
17	8.34	0.816	28.37	1.225	35.25	220.54	410.31	189.78	1.0720	1.7261
18	8.58	0.819	27.57	1.221	36.27	221.75	410.59	188.84	1.0761	1.7247
19	8.83	0.821	26.80	1.218	37.31	222.98	410.86	187.88	1.0802	1.7233

Solkane® 22

Release 1.08

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
20	9.08	0.824	26.06	1.214	38.38	224.19	411.13	186.94	1.0843	1.7220
21	9.33	0.826	25.33	1.210	39.47	225.42	411.39	185.96	1.0884	1.7206
22	9.59	0.829	24.63	1.206	40.59	226.65	411.64	184.99	1.0925	1.7193
23	9.86	0.832	23.96	1.203	41.74	227.87	411.89	184.02	1.0966	1.7179
24	10.13	0.834	23.31	1.199	42.91	229.10	412.13	183.03	1.1007	1.7166
25	10.41	0.837	22.67	1.195	44.11	230.34	412.37	182.03	1.1047	1.7153
26	10.69	0.840	22.06	1.191	45.33	231.56	412.60	181.04	1.1087	1.7139
27	10.98	0.842	21.46	1.187	46.59	232.79	412.83	180.03	1.1128	1.7126
28	11.27	0.845	20.89	1.183	47.88	234.03	413.04	179.01	1.1168	1.7112
29	11.57	0.848	20.33	1.179	49.20	235.27	413.26	177.98	1.1208	1.7099
30	11.88	0.851	19.79	1.175	50.54	236.50	413.47	176.97	1.1248	1.7086
31	12.19	0.854	19.26	1.171	51.92	237.74	413.67	175.93	1.1288	1.7072
32	12.51	0.857	18.75	1.167	53.33	238.99	413.86	174.87	1.1328	1.7059
33	12.83	0.860	18.25	1.163	54.78	240.23	414.05	173.82	1.1368	1.7045
34	13.16	0.863	17.77	1.159	56.26	241.48	414.23	172.75	1.1408	1.7032
35	13.49	0.866	17.31	1.155	57.78	242.73	414.40	171.67	1.1447	1.7018
36	13.84	0.869	16.86	1.150	59.33	243.98	414.57	170.59	1.1487	1.7005
37	14.18	0.873	16.42	1.146	60.92	245.23	414.73	169.50	1.1526	1.6991
38	14.54	0.876	15.99	1.142	62.54	246.49	414.88	168.39	1.1566	1.6978
39	14.90	0.879	15.57	1.137	64.21	247.75	415.03	167.28	1.1605	1.6964
40	15.27	0.883	15.17	1.133	65.91	249.01	415.17	166.16	1.1644	1.6951
41	15.64	0.886	14.78	1.129	67.66	250.27	415.30	165.02	1.1684	1.6937
42	16.02	0.890	14.40	1.124	69.45	251.55	415.42	163.87	1.1723	1.6923
43	16.41	0.893	14.03	1.120	71.28	252.82	415.53	162.72	1.1762	1.6909
44	16.81	0.897	13.67	1.115	73.16	254.10	415.63	161.54	1.1802	1.6895
45	17.21	0.901	13.32	1.110	75.08	255.38	415.73	160.36	1.1841	1.6881
46	17.62	0.904	12.98	1.106	77.06	256.66	415.82	159.16	1.1880	1.6867
47	18.04	0.908	12.65	1.101	79.08	257.95	415.90	157.95	1.1919	1.6853
48	18.46	0.912	12.32	1.096	81.15	259.24	415.97	156.72	1.1958	1.6838
49	18.89	0.916	12.01	1.091	83.28	260.55	416.03	155.48	1.1997	1.6824
50	19.33	0.920	11.70	1.087	85.46	261.85	416.08	154.22	1.2037	1.6809
51	19.78	0.925	11.40	1.082	87.70	263.17	416.11	152.94	1.2076	1.6794
52	20.23	0.929	11.11	1.077	90.00	264.49	416.14	151.65	1.2115	1.6780
53	20.69	0.933	10.83	1.072	92.36	265.81	416.16	150.35	1.2155	1.6765
54	21.16	0.938	10.55	1.066	94.77	267.13	416.17	149.03	1.2194	1.6749
55	21.64	0.942	10.28	1.061	97.26	268.48	416.16	147.69	1.2233	1.6734
56	22.13	0.947	10.02	1.056	99.81	269.82	416.14	146.32	1.2273	1.6718
57	22.62	0.952	9.76	1.051	102.44	271.18	416.11	144.93	1.2313	1.6703
58	23.12	0.957	9.51	1.045	105.14	272.54	416.07	143.53	1.2353	1.6687
59	23.63	0.962	9.27	1.040	107.91	273.91	416.01	142.10	1.2392	1.6671
60	24.15	0.967	9.03	1.034	110.77	275.30	415.94	140.64	1.2433	1.6654
61	24.68	0.972	8.79	1.028	113.70	276.69	415.86	139.16	1.2473	1.6637
62	25.22	0.978	8.57	1.022	116.73	278.10	415.75	137.65	1.2513	1.6620
63	25.76	0.984	8.34	1.017	119.85	279.51	415.64	136.12	1.2554	1.6603
64	26.32	0.990	8.13	1.011	123.06	280.95	415.50	134.56	1.2595	1.6586
65	26.88	0.996	7.91	1.004	126.37	282.39	415.35	132.96	1.2636	1.6568
66	27.46	1.002	7.70	0.998	129.79	283.84	415.18	131.34	1.2677	1.6550
67	28.04	1.008	7.50	0.992	133.32	285.32	414.99	129.67	1.2719	1.6531
68	28.63	1.015	7.30	0.985	136.96	286.81	414.78	127.97	1.2761	1.6512
69	29.23	1.022	7.11	0.979	140.74	288.32	414.55	126.23	1.2803	1.6492

Solkane® 22

Release 1.08

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
70	29.84	1.029	6.91	0.972	144.65	289.84	414.29	124.45	1.2846	1.6472
71	30.46	1.036	6.73	0.965	148.70	291.39	414.01	122.62	1.2889	1.6452
72	31.10	1.044	6.54	0.958	152.89	292.96	413.71	120.74	1.2933	1.6431
73	31.74	1.052	6.36	0.951	157.25	294.56	413.37	118.82	1.2977	1.6409
74	32.39	1.060	6.18	0.943	161.78	296.18	413.01	116.83	1.3022	1.6387
75	33.05	1.069	6.01	0.936	166.49	297.83	412.61	114.79	1.3067	1.6364
76	33.73	1.078	5.83	0.928	171.41	299.51	412.18	112.67	1.3113	1.6340
77	34.41	1.087	5.66	0.920	176.54	301.22	411.72	110.50	1.3160	1.6316
78	35.10	1.097	5.50	0.911	181.90	302.96	411.21	108.25	1.3208	1.6290
79	35.81	1.108	5.33	0.903	187.51	304.75	410.67	105.91	1.3256	1.6264
80	36.53	1.119	5.17	0.894	193.41	306.58	410.07	103.49	1.3306	1.6236
81	37.26	1.131	5.01	0.884	199.62	308.46	409.42	100.96	1.3357	1.6207
82	38.00	1.143	4.85	0.875	206.18	310.39	408.71	98.32	1.3409	1.6177
83	38.75	1.157	4.69	0.865	213.11	312.38	407.94	95.56	1.3462	1.6145
84	39.52	1.171	4.54	0.854	220.49	314.44	407.10	92.66	1.3517	1.6112
85	40.29	1.186	4.38	0.843	228.37	316.57	406.17	89.60	1.3574	1.6076
86	41.08	1.203	4.22	0.831	236.80	318.79	405.15	86.36	1.3634	1.6038
87	41.89	1.221	4.07	0.819	245.93	321.11	404.02	82.91	1.3695	1.5998
88	42.70	1.242	3.91	0.805	255.85	323.54	402.75	79.21	1.3760	1.5953
89	43.53	1.264	3.75	0.791	266.73	326.11	401.34	75.22	1.3828	1.5905
90	44.37	1.289	3.59	0.776	278.82	328.86	399.72	70.86	1.3901	1.5853
91	45.23	1.319	3.42	0.758	292.50	331.82	397.86	66.04	1.3980	1.5793
92	46.10	1.353	3.24	0.739	308.29	335.07	395.67	60.60	1.4065	1.5725
93	46.99	1.395	3.06	0.717	327.15	338.72	393.00	54.28	1.4162	1.5644
94	47.88	1.451	2.85	0.689	350.93	342.98	389.59	46.61	1.4275	1.5544
95	48.80	1.531	2.60	0.653	384.38	348.40	384.76	36.36	1.4418	1.5406
96.18	49.90	1.949	1.95	0.513	513.11	366.80	366.80	0.00	1.4912	1.4912

12.1.2 Solkane® 23

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–100	0.31	0.653	647.87	1.531	1.544	60.77	318.50	257.73	0.3766	1.8651
–99	0.33	0.655	604.80	1.527	1.653	62.06	318.95	256.89	0.3840	1.8591
–98	0.36	0.657	565.13	1.523	1.770	63.44	319.38	255.94	0.3919	1.8532
–97	0.39	0.658	528.54	1.519	1.892	64.83	319.81	254.98	0.3998	1.8473
–96	0.41	0.660	494.77	1.515	2.021	66.11	320.25	254.14	0.4071	1.8417
–95	0.44	0.662	463.57	1.511	2.157	67.45	320.68	253.23	0.4146	1.8360
–94	0.48	0.663	434.71	1.508	2.300	68.84	321.11	252.27	0.4223	1.8305
–93	0.51	0.665	408.00	1.504	2.451	70.22	321.53	251.31	0.4300	1.8250
–92	0.54	0.667	383.24	1.500	2.609	71.51	321.95	250.44	0.4372	1.8197
–91	0.58	0.669	359.62	1.496	2.781	72.90	322.37	249.47	0.4448	1.8144
–90	0.62	0.670	338.34	1.492	2.956	74.22	322.79	248.57	0.4520	1.8092
–89	0.66	0.672	318.57	1.488	3.139	75.58	323.20	247.62	0.4594	1.8041
–88	0.70	0.674	300.19	1.484	3.331	76.91	323.61	246.70	0.4666	1.7990
–87	0.75	0.676	283.08	1.480	3.533	78.30	324.02	245.72	0.4740	1.7941
–86	0.80	0.678	267.14	1.476	3.743	79.68	324.42	244.74	0.4814	1.7891
–85	0.85	0.679	252.05	1.472	3.967	81.02	324.82	243.80	0.4885	1.7843
–84	0.90	0.681	238.19	1.468	4.198	82.37	325.22	242.85	0.4957	1.7796
–83	0.96	0.683	225.26	1.464	4.439	83.74	325.61	241.87	0.5029	1.7749
–82	1.01	0.685	213.17	1.460	4.691	85.07	326.00	240.93	0.5099	1.7703
–81	1.08	0.687	201.86	1.456	4.954	86.45	326.39	239.94	0.5171	1.7657
–80	1.14	0.689	191.10	1.452	5.233	87.81	326.77	238.96	0.5240	1.7613
–79	1.21	0.691	181.20	1.448	5.519	89.17	327.15	237.98	0.5311	1.7568
–78	1.27	0.693	171.91	1.444	5.817	90.53	327.53	237.00	0.5380	1.7525
–77	1.35	0.695	163.15	1.439	6.129	91.88	327.90	236.02	0.5449	1.7482
–76	1.42	0.697	154.89	1.435	6.456	93.27	328.27	235.00	0.5519	1.7439
–75	1.50	0.699	147.22	1.431	6.793	94.61	328.64	234.03	0.5587	1.7398
–74	1.58	0.701	140.00	1.427	7.143	95.97	329.00	233.03	0.5655	1.7356
–73	1.67	0.703	133.18	1.423	7.509	97.33	329.36	232.03	0.5723	1.7316
–72	1.76	0.705	126.72	1.419	7.891	98.70	329.71	231.01	0.5791	1.7275
–71	1.85	0.707	120.71	1.414	8.284	100.06	330.06	230.00	0.5858	1.7236
–70	1.95	0.709	115.01	1.410	8.695	101.43	330.41	228.98	0.5925	1.7197
–69	2.05	0.711	109.61	1.406	9.123	102.78	330.75	227.97	0.5991	1.7158
–68	2.15	0.713	104.57	1.402	9.563	104.14	331.09	226.95	0.6058	1.7120
–67	2.26	0.716	99.79	1.397	10.021	105.51	331.42	225.91	0.6124	1.7082
–66	2.38	0.718	95.24	1.393	10.500	106.87	331.75	224.88	0.6189	1.7045
–65	2.49	0.720	91.00	1.389	10.989	108.23	332.07	223.84	0.6254	1.7008
–64	2.61	0.722	86.96	1.384	11.500	109.59	332.40	222.81	0.6319	1.6972
–63	2.74	0.725	83.14	1.380	12.028	110.95	332.71	221.76	0.6383	1.6936
–62	2.87	0.727	79.52	1.376	12.575	112.30	333.03	220.73	0.6447	1.6900
–61	3.00	0.729	76.09	1.371	13.142	113.67	333.33	219.66	0.6511	1.6865
–60	3.14	0.732	72.84	1.367	13.729	115.02	333.64	218.62	0.6574	1.6831
–59	3.29	0.734	69.76	1.362	14.335	116.38	333.94	217.56	0.6637	1.6796
–58	3.44	0.736	66.82	1.358	14.966	117.74	334.23	216.49	0.6700	1.6763
–57	3.59	0.739	64.04	1.354	15.615	119.09	334.52	215.43	0.6762	1.6729
–56	3.75	0.741	61.41	1.349	16.284	120.45	334.81	214.36	0.6825	1.6696
–55	3.92	0.744	58.90	1.344	16.978	121.80	335.09	213.29	0.6886	1.6663
–54	4.09	0.746	56.52	1.340	17.693	123.16	335.36	212.20	0.6948	1.6631
–53	4.27	0.749	54.26	1.335	18.430	124.51	335.64	211.13	0.7008	1.6599
–52	4.45	0.751	52.10	1.331	19.194	125.87	335.90	210.03	0.7069	1.6567
–51	4.64	0.754	50.05	1.326	19.980	127.22	336.16	208.94	0.7130	1.6535

Solkane® 23

Release 1.01

t [°C]	p [bar]	v´ [dm^3/kg]	v´´ [dm^3/kg]	ρ´ [kg/dm^3]	ρ´´ [kg/m^3]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–50	4.83	0.757	48.08	1.322	20.799	128.57	336.42	207.85	0.7190	1.6504
–49	5.03	0.759	46.22	1.317	21.636	129.93	336.67	206.74	0.7250	1.6473
–48	5.24	0.762	44.44	1.312	22.502	131.28	336.91	205.63	0.7309	1.6442
–47	5.45	0.765	42.74	1.307	23.397	132.63	337.15	204.52	0.7369	1.6412
–46	5.67	0.768	41.13	1.303	24.313	133.99	337.39	203.40	0.7427	1.6382
–45	5.89	0.771	39.58	1.298	25.265	135.34	337.61	202.27	0.7486	1.6352
–44	6.12	0.773	38.10	1.293	26.247	136.69	337.84	201.15	0.7545	1.6322
–43	6.36	0.776	36.69	1.288	27.255	138.05	338.05	200.00	0.7603	1.6293
–42	6.61	0.779	35.34	1.283	28.297	139.41	338.26	198.85	0.7661	1.6264
–41	6.86	0.782	34.05	1.278	29.369	140.76	338.47	197.71	0.7718	1.6235
–40	7.12	0.785	32.82	1.274	30.469	142.11	338.67	196.56	0.7776	1.6206
–39	7.39	0.788	31.63	1.269	31.616	143.47	338.86	195.39	0.7833	1.6178
–38	7.66	0.791	30.50	1.264	32.787	144.83	339.05	194.22	0.7890	1.6149
–37	7.94	0.795	29.41	1.259	34.002	146.18	339.23	193.05	0.7946	1.6121
–36	8.23	0.798	28.37	1.254	35.249	147.54	339.40	191.86	0.8003	1.6093
–35	8.53	0.801	27.38	1.248	36.523	148.90	339.56	190.66	0.8059	1.6065
–34	8.84	0.804	26.42	1.243	37.850	150.26	339.72	189.46	0.8115	1.6037
–33	9.15	0.808	25.50	1.238	39.216	151.62	339.87	188.25	0.8171	1.6010
–32	9.47	0.811	24.62	1.233	40.617	152.99	340.02	187.03	0.8226	1.5982
–31	9.80	0.815	23.78	1.228	42.052	154.36	340.15	185.79	0.8282	1.5955
–30	10.14	0.818	22.96	1.222	43.554	155.73	340.28	184.55	0.8337	1.5927
–29	10.49	0.822	22.18	1.217	45.086	157.10	340.40	183.30	0.8392	1.5900
–28	10.84	0.825	21.43	1.212	46.664	158.47	340.52	182.05	0.8447	1.5873
–27	11.21	0.829	20.71	1.206	48.286	159.85	340.62	180.77	0.8502	1.5846
–26	11.58	0.833	20.02	1.201	49.950	161.24	340.71	179.47	0.8557	1.5819
–25	11.96	0.837	19.35	1.195	51.680	162.62	340.80	178.18	0.8612	1.5792
–24	12.36	0.841	18.71	1.190	53.447	164.01	340.88	176.87	0.8666	1.5765
–23	12.76	0.845	18.09	1.184	55.279	165.41	340.94	175.53	0.8721	1.5738
–22	13.17	0.849	17.49	1.178	57.176	166.81	341.00	174.19	0.8775	1.5711
–21	13.59	0.853	16.91	1.173	59.137	168.21	341.05	172.84	0.8830	1.5684
–20	14.02	0.857	16.36	1.167	61.125	169.62	341.08	171.46	0.8884	1.5657
–19	14.47	0.861	15.82	1.161	63.211	171.04	341.11	170.07	0.8939	1.5630
–18	14.92	0.866	15.31	1.155	65.317	172.46	341.12	168.66	0.8993	1.5603
–17	15.38	0.870	14.81	1.149	67.522	173.90	341.13	167.23	0.9047	1.5576
–16	15.85	0.875	14.33	1.143	69.784	175.33	341.12	165.79	0.9102	1.5549
–15	16.34	0.879	13.87	1.137	72.098	176.78	341.09	164.31	0.9156	1.5521
–14	16.84	0.884	13.42	1.131	74.516	178.24	341.06	162.82	0.9211	1.5494
–13	17.34	0.889	12.98	1.125	77.042	179.70	341.01	161.31	0.9266	1.5466
–12	17.86	0.894	12.56	1.118	79.618	181.18	340.94	159.76	0.9320	1.5438
–11	18.39	0.899	12.16	1.112	82.237	182.67	340.86	158.19	0.9376	1.5410
–10	18.93	0.905	11.77	1.106	84.962	184.17	340.77	156.60	0.9431	1.5382
–9	19.49	0.910	11.39	1.099	87.796	185.68	340.66	154.98	0.9486	1.5353
–8	20.05	0.915	11.02	1.092	90.744	187.20	340.53	153.33	0.9542	1.5325
–7	20.63	0.921	10.66	1.086	93.809	188.74	340.39	151.65	0.9598	1.5295
–6	21.22	0.927	10.32	1.079	96.899	190.29	340.22	149.93	0.9654	1.5266
–5	21.83	0.933	9.98	1.072	100.200	191.86	340.04	148.18	0.9710	1.5236
–4	22.44	0.939	9.66	1.065	103.520	193.45	339.83	146.38	0.9767	1.5206
–3	23.08	0.946	9.34	1.058	107.066	195.06	339.61	144.55	0.9825	1.5175
–2	23.72	0.952	9.04	1.050	110.619	196.68	339.36	142.68	0.9883	1.5144
–1	24.38	0.959	8.74	1.043	114.416	198.33	339.08	140.75	0.9941	1.5113

Solkane® 23

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
0	25.05	0.966	8.45	1.035	118.343	200.00	338.78	138.78	1.0000	1.5081
1	25.74	0.973	8.17	1.028	122.399	201.69	338.45	136.76	1.0059	1.5048
2	26.44	0.981	7.90	1.020	126.582	203.41	338.10	134.69	1.0119	1.5014
3	27.15	0.989	7.63	1.012	131.062	205.16	337.71	132.55	1.0180	1.4980
4	27.88	0.997	7.37	1.003	135.685	206.94	337.28	130.34	1.0242	1.4945
5	28.63	1.005	7.12	0.995	140.449	208.75	336.83	128.08	1.0304	1.4909
6	29.39	1.014	6.87	0.986	145.560	210.60	336.33	125.73	1.0368	1.4872
7	30.17	1.023	6.63	0.978	150.830	212.48	335.79	123.31	1.0433	1.4834
8	30.96	1.033	6.40	0.968	156.250	214.41	335.21	120.80	1.0498	1.4795
9	31.77	1.043	6.17	0.959	162.075	216.38	334.57	118.19	1.0565	1.4754
10	32.59	1.053	5.94	0.949	168.350	218.40	333.88	115.48	1.0634	1.4712
11	33.44	1.065	5.72	0.939	174.825	220.47	333.13	112.66	1.0703	1.4668
12	34.30	1.077	5.50	0.929	181.818	222.60	332.32	109.72	1.0775	1.4623
13	35.17	1.089	5.29	0.918	189.036	224.80	331.43	106.63	1.0849	1.4575
14	36.07	1.103	5.08	0.907	196.850	227.07	330.46	103.39	1.0925	1.4525
15	36.99	1.117	4.87	0.895	205.339	229.42	329.39	99.97	1.1003	1.4472
16	37.92	1.133	4.67	0.883	214.133	231.87	328.22	96.35	1.1084	1.4416
17	38.87	1.150	4.46	0.870	224.215	234.42	326.92	92.50	1.1168	1.4356
18	39.84	1.169	4.26	0.856	234.742	237.09	325.47	88.38	1.1256	1.4292
19	40.83	1.190	4.06	0.841	246.305	239.91	323.84	83.93	1.1349	1.4222
20	41.85	1.213	3.85	0.824	259.740	242.91	321.99	79.08	1.1447	1.4145
21	42.88	1.240	3.64	0.807	274.725	246.13	319.86	73.73	1.1552	1.4059
22	43.93	1.271	3.42	0.787	292.398	249.63	317.35	67.72	1.1667	1.3961
23	45.01	1.310	3.20	0.764	312.500	253.52	314.32	60.80	1.1794	1.3847
24	46.11	1.360	2.95	0.736	338.983	258.02	310.46	52.44	1.1940	1.3705
25	47.24	1.432	2.66	0.698	375.940	263.59	305.08	41.49	1.2122	1.3514
26.3	48.74	1.898	1.90	0.527	527.010	284.74	284.74	0.00	1.2824	1.2824

12.1.3 Solkane® 123

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
0	0.328	0.655	442.91	1.527	2.258	200.00	382.73	182.73	1.0000	1.6690
1	0.343	0.656	424.29	1.524	2.357	201.08	383.33	182.25	1.0039	1.6687
2	0.359	0.657	406.62	1.522	2.459	202.16	383.93	181.77	1.0079	1.6685
3	0.376	0.658	389.83	1.519	2.565	203.24	384.52	181.29	1.0118	1.6683
4	0.393	0.659	373.87	1.517	2.675	204.31	385.12	180.81	1.0157	1.6680
5	0.411	0.660	358.70	1.515	2.788	205.39	385.72	180.33	1.0195	1.6679
6	0.429	0.661	344.21	1.512	2.905	206.50	386.31	179.81	1.0235	1.6677
7	0.448	0.662	330.48	1.510	3.026	207.58	386.91	179.33	1.0274	1.6675
8	0.468	0.663	317.42	1.507	3.150	208.65	387.51	178.86	1.0312	1.6674
9	0.489	0.664	304.99	1.505	3.279	209.73	388.11	178.38	1.0350	1.6672
10	0.510	0.666	293.02	1.503	3.413	210.87	388.70	177.83	1.0390	1.6671
11	0.532	0.667	281.73	1.500	3.549	211.94	389.30	177.35	1.0428	1.6670
12	0.554	0.668	270.97	1.498	3.690	213.01	389.89	176.88	1.0466	1.6669
13	0.577	0.669	260.71	1.495	3.836	214.09	390.49	176.41	1.0503	1.6668
14	0.602	0.670	250.92	1.493	3.985	215.16	391.09	175.93	1.0541	1.6667
15	0.626	0.671	241.57	1.490	4.140	216.23	391.69	175.46	1.0578	1.6667
16	0.652	0.672	232.65	1.488	4.298	217.30	392.29	174.99	1.0615	1.6667
17	0.679	0.673	224.09	1.485	4.462	218.39	392.88	174.49	1.0652	1.6666
18	0.706	0.674	215.92	1.483	4.631	219.48	393.48	173.99	1.0690	1.6666
19	0.734	0.675	208.11	1.481	4.805	220.57	394.07	173.50	1.0727	1.6666
20	0.763	0.677	200.67	1.478	4.983	221.64	394.67	173.03	1.0764	1.6666
21	0.793	0.678	193.55	1.476	5.167	222.71	395.27	172.56	1.0800	1.6666
22	0.824	0.679	186.74	1.473	5.355	223.78	395.87	172.09	1.0836	1.6667
23	0.856	0.680	180.19	1.471	5.550	224.88	396.46	171.59	1.0873	1.6667
24	0.889	0.681	173.95	1.468	5.749	225.94	397.06	171.12	1.0909	1.6668
25	0.922	0.682	167.97	1.465	5.953	227.01	397.66	170.65	1.0945	1.6668
26	0.957	0.684	162.24	1.463	6.164	228.07	398.25	170.18	1.0980	1.6669
27	0.993	0.685	156.73	1.460	6.380	229.16	398.85	169.69	1.1017	1.6670
28	1.029	0.686	151.45	1.458	6.603	230.24	399.44	169.20	1.1052	1.6671
29	1.067	0.687	146.41	1.455	6.830	231.31	400.04	168.74	1.1088	1.6672
30	1.106	0.688	141.55	1.453	7.065	232.39	400.64	168.25	1.1123	1.6673
31	1.146	0.690	136.90	1.450	7.305	233.45	401.23	167.78	1.1158	1.6675
32	1.187	0.691	132.44	1.448	7.550	234.51	401.83	167.32	1.1193	1.6676
33	1.229	0.692	128.13	1.445	7.804	235.60	402.42	166.82	1.1229	1.6677
34	1.273	0.693	124.02	1.442	8.063	236.66	403.02	166.35	1.1263	1.6679
35	1.317	0.695	120.05	1.440	8.330	237.74	403.61	165.87	1.1298	1.6681
36	1.363	0.696	116.25	1.437	8.602	238.81	404.20	165.39	1.1333	1.6682
37	1.410	0.697	112.60	1.435	8.881	239.87	404.80	164.93	1.1367	1.6684
38	1.458	0.698	109.07	1.432	9.168	240.95	405.39	164.44	1.1401	1.6686
39	1.507	0.700	105.70	1.429	9.461	242.01	405.99	163.98	1.1435	1.6688
40	1.558	0.701	102.44	1.427	9.762	243.09	406.58	163.49	1.1470	1.6690
41	1.610	0.702	99.30	1.424	10.071	244.16	407.17	163.01	1.1504	1.6693
42	1.663	0.704	96.29	1.421	10.386	245.22	407.76	162.54	1.1537	1.6695
43	1.718	0.705	93.38	1.419	10.709	246.30	408.35	162.06	1.1571	1.6697
44	1.774	0.706	90.57	1.416	11.041	247.37	408.94	161.57	1.1605	1.6700
45	1.831	0.708	87.88	1.413	11.379	248.43	409.54	161.11	1.1638	1.6702
46	1.890	0.709	85.28	1.411	11.726	249.50	410.13	160.62	1.1672	1.6705
47	1.950	0.710	82.78	1.408	12.081	250.57	410.72	160.15	1.1705	1.6707
48	2.012	0.712	80.36	1.405	12.444	251.64	411.30	159.66	1.1738	1.6710
49	2.075	0.713	78.03	1.403	12.815	252.70	411.89	159.19	1.1771	1.6713

Solkane® 123

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
50	2.140	0.714	75.78	1.400	13.196	253.77	412.48	158.72	1.1804	1.6716
51	2.206	0.716	73.61	1.397	13.585	254.84	413.07	158.23	1.1837	1.6718
52	2.274	0.717	71.52	1.394	13.983	255.91	413.66	157.75	1.1870	1.6721
53	2.343	0.719	69.50	1.392	14.389	256.97	414.25	157.28	1.1902	1.6724
54	2.414	0.720	67.54	1.389	14.805	258.04	414.83	156.79	1.1935	1.6727
55	2.487	0.722	65.66	1.386	15.230	259.10	415.42	156.32	1.1967	1.6731
56	2.561	0.723	63.84	1.383	15.665	260.18	416.00	155.83	1.2000	1.6734
57	2.637	0.724	62.08	1.380	16.109	261.24	416.59	155.35	1.2032	1.6737
58	2.714	0.726	60.38	1.378	16.563	262.31	417.17	154.86	1.2064	1.6740
59	2.793	0.727	58.73	1.375	17.028	263.38	417.76	154.37	1.2096	1.6744
60	2.874	0.729	57.14	1.372	17.501	264.45	418.34	153.89	1.2128	1.6747
61	2.957	0.730	55.60	1.369	17.985	265.51	418.92	153.41	1.2160	1.6751
62	3.042	0.732	54.11	1.366	18.480	266.58	419.51	152.92	1.2191	1.6754
63	3.128	0.733	52.67	1.363	18.986	267.65	420.09	152.43	1.2223	1.6758
64	3.216	0.735	51.28	1.360	19.503	268.73	420.67	151.94	1.2255	1.6761
65	3.306	0.737	49.93	1.358	20.029	269.79	421.25	151.46	1.2286	1.6765
66	3.398	0.738	48.62	1.355	20.568	270.86	421.82	150.96	1.2318	1.6769
67	3.492	0.740	47.35	1.352	21.117	271.93	422.40	150.47	1.2349	1.6773
68	3.588	0.741	46.13	1.349	21.679	273.00	422.98	149.98	1.2380	1.6776
69	3.686	0.743	44.94	1.346	22.252	274.08	423.56	149.48	1.2411	1.6780
70	3.786	0.745	43.79	1.343	22.836	275.14	424.13	148.99	1.2442	1.6784
71	3.888	0.746	42.67	1.340	23.434	276.22	424.71	148.49	1.2473	1.6788
72	3.992	0.748	41.59	1.337	24.043	277.29	425.28	147.99	1.2504	1.6792
73	4.098	0.750	40.54	1.334	24.666	278.36	425.86	147.49	1.2535	1.6796
74	4.206	0.751	39.52	1.331	25.301	279.44	426.43	146.99	1.2566	1.6800
75	4.316	0.753	38.54	1.328	25.949	280.52	427.00	146.48	1.2596	1.6804
76	4.429	0.755	37.58	1.325	26.610	281.59	427.57	145.98	1.2627	1.6808
77	4.543	0.756	36.65	1.322	27.284	282.66	428.14	145.47	1.2658	1.6812
78	4.660	0.758	35.75	1.319	27.973	283.75	428.71	144.96	1.2688	1.6816
79	4.779	0.760	34.87	1.316	28.676	284.83	429.27	144.45	1.2719	1.6820
80	4.901	0.762	34.02	1.313	29.391	285.90	429.84	143.94	1.2749	1.6825
81	5.024	0.764	33.20	1.310	30.122	286.98	430.41	143.42	1.2779	1.6829
82	5.150	0.765	32.40	1.306	30.869	288.07	430.97	142.90	1.2809	1.6833
83	5.279	0.767	31.62	1.303	31.628	289.15	431.53	142.39	1.2840	1.6837
84	5.410	0.769	30.86	1.300	32.404	290.23	432.10	141.86	1.2870	1.6842
85	5.543	0.771	30.12	1.297	33.196	291.32	432.66	141.34	1.2900	1.6846
86	5.679	0.773	29.41	1.294	34.004	292.41	433.22	140.81	1.2930	1.6850
87	5.817	0.775	28.71	1.291	34.826	293.50	433.77	140.28	1.2960	1.6855
88	5.957	0.777	28.04	1.287	35.667	294.59	434.33	139.74	1.2990	1.6859
89	6.101	0.779	27.38	1.284	36.523	295.68	434.89	139.21	1.3020	1.6864
90	6.246	0.781	26.74	1.281	37.396	296.77	435.44	138.67	1.3049	1.6868
91	6.395	0.783	26.12	1.278	38.287	297.87	435.99	138.13	1.3079	1.6872
92	6.546	0.785	25.51	1.274	39.196	298.97	436.54	137.58	1.3109	1.6877
93	6.700	0.787	24.92	1.271	40.121	300.06	437.10	137.03	1.3139	1.6881
94	6.856	0.789	24.35	1.268	41.065	301.16	437.64	136.48	1.3168	1.6886
95	7.015	0.791	23.79	1.264	42.029	302.26	438.19	135.93	1.3198	1.6890
96	7.177	0.793	23.25	1.261	43.012	303.37	438.74	135.37	1.3228	1.6895
97	7.342	0.795	22.72	1.258	44.013	304.48	439.28	134.80	1.3257	1.6899
98	7.509	0.797	22.20	1.254	45.036	305.59	439.82	134.23	1.3287	1.6904
99	7.680	0.799	21.70	1.251	46.078	306.70	440.36	133.66	1.3316	1.6908

Solkane® 123

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
100	7.853	0.802	21.21	1.248	47.140	307.81	440.90	133.09	1.3346	1.6912
101	8.029	0.804	20.74	1.244	48.224	308.93	441.43	132.51	1.3375	1.6917
102	8.208	0.806	20.27	1.241	49.329	310.04	441.97	131.92	1.3405	1.6921
103	8.390	0.808	19.82	1.237	50.456	311.17	442.50	131.34	1.3434	1.6926
104	8.576	0.811	19.38	1.234	51.606	312.29	443.03	130.74	1.3464	1.6930
105	8.764	0.813	18.95	1.230	52.778	313.42	443.56	130.15	1.3493	1.6935
106	8.955	0.815	18.53	1.227	53.975	314.55	444.09	129.54	1.3523	1.6939
107	9.150	0.818	18.12	1.223	55.194	315.68	444.61	128.93	1.3552	1.6944
108	9.347	0.820	17.72	1.219	56.438	316.81	445.13	128.32	1.3581	1.6948
109	9.548	0.823	17.33	1.216	57.708	317.95	445.65	127.70	1.3611	1.6952
110	9.752	0.825	16.95	1.212	59.002	319.09	446.17	127.08	1.3640	1.6957
111	9.959	0.828	16.58	1.208	60.324	320.24	446.68	126.44	1.3670	1.6961
112	10.170	0.830	16.21	1.205	61.672	321.39	447.19	125.81	1.3699	1.6965
113	10.384	0.833	15.86	1.201	63.046	322.54	447.70	125.16	1.3728	1.6970
114	10.601	0.835	15.52	1.197	64.450	323.70	448.21	124.51	1.3758	1.6974
115	10.822	0.838	15.18	1.193	65.882	324.86	448.71	123.86	1.3787	1.6978
116	11.047	0.841	14.85	1.190	67.343	326.02	449.21	123.20	1.3817	1.6982
117	11.274	0.843	14.53	1.186	68.834	327.19	449.71	122.53	1.3846	1.6987
118	11.506	0.846	14.21	1.182	70.356	328.36	450.21	121.85	1.3876	1.6991
119	11.740	0.849	13.91	1.178	71.910	329.53	450.70	121.17	1.3905	1.6995
120	11.979	0.852	13.61	1.174	73.497	330.71	451.19	120.47	1.3935	1.6999
121	12.221	0.855	13.31	1.170	75.117	331.90	451.67	119.77	1.3964	1.7003
122	12.467	0.858	13.03	1.166	76.771	333.09	452.15	119.06	1.3994	1.7007
123	12.716	0.861	12.75	1.162	78.459	334.28	452.63	118.35	1.4024	1.7011
124	12.969	0.864	12.47	1.158	80.185	335.48	453.11	117.62	1.4053	1.7015
125	13.226	0.867	12.20	1.154	81.947	336.69	453.58	116.89	1.4083	1.7019
126	13.487	0.870	11.94	1.150	83.747	337.90	454.04	116.15	1.4113	1.7023
127	13.752	0.873	11.68	1.145	85.587	339.11	454.50	115.39	1.4143	1.7026
128	14.021	0.876	11.43	1.141	87.467	340.33	454.96	114.63	1.4172	1.7030
129	14.294	0.879	11.19	1.137	89.388	341.56	455.42	113.86	1.4202	1.7034
130	14.570	0.883	10.95	1.133	91.353	342.79	455.87	113.08	1.4232	1.7037
131	14.851	0.886	10.71	1.128	93.361	344.03	456.31	112.28	1.4262	1.7041
132	15.136	0.890	10.48	1.124	95.416	345.27	456.75	111.48	1.4293	1.7044
133	15.425	0.893	10.25	1.120	97.517	346.52	457.18	110.66	1.4323	1.7047
134	15.718	0.897	10.03	1.115	99.666	347.78	457.61	109.83	1.4353	1.7051
135	16.015	0.900	9.82	1.111	101.865	349.04	458.04	108.99	1.4383	1.7054
136	16.317	0.904	9.60	1.106	104.117	350.31	458.45	108.14	1.4414	1.7057
137	16.623	0.908	9.40	1.101	106.422	351.59	458.87	107.28	1.4444	1.7060
138	16.933	0.912	9.19	1.097	108.783	352.87	459.27	106.40	1.4475	1.7063
139	17.248	0.916	8.99	1.092	111.201	354.17	459.67	105.50	1.4506	1.7065
140	17.567	0.920	8.80	1.087	113.680	355.47	460.06	104.59	1.4536	1.7068
141	17.891	0.924	8.60	1.082	116.219	356.78	460.45	103.67	1.4567	1.7070
142	18.219	0.928	8.42	1.077	118.823	358.09	460.83	102.73	1.4598	1.7073
143	18.552	0.932	8.23	1.072	121.494	359.42	461.20	101.78	1.4629	1.7075
144	18.889	0.937	8.05	1.067	124.234	360.75	461.56	100.81	1.4661	1.7077
145	19.231	0.941	7.87	1.062	127.048	362.10	461.91	99.82	1.4692	1.7079
146	19.578	0.946	7.70	1.057	129.936	363.45	462.26	98.81	1.4724	1.7081
147	19.930	0.951	7.52	1.052	132.905	364.81	462.60	97.78	1.4755	1.7083
148	20.286	0.956	7.36	1.047	135.955	366.19	462.92	96.74	1.4787	1.7084
149	20.648	0.961	7.19	1.041	139.091	367.57	463.24	95.67	1.4819	1.7085

Solkane® 123

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
150	21.014	0.966	7.03	1.036	142.319	368.96	463.55	94.58	1.4851	1.7087
151	21.385	0.971	6.87	1.030	145.640	370.37	463.84	93.47	1.4884	1.7087
152	21.762	0.976	6.71	1.024	149.061	371.79	464.13	92.34	1.4916	1.7088
153	22.143	0.982	6.55	1.019	152.587	373.22	464.40	91.18	1.4949	1.7088
154	22.530	0.988	6.40	1.013	156.226	374.66	464.66	89.99	1.4982	1.7089
155	22.921	0.993	6.25	1.007	159.980	376.12	464.90	88.78	1.5015	1.7089
156	23.318	0.999	6.10	1.001	163.858	377.59	465.13	87.54	1.5048	1.7088
157	23.721	1.006	5.96	0.994	167.868	379.07	465.34	86.27	1.5082	1.7088
158	24.129	1.012	5.81	0.988	172.019	380.57	465.54	84.97	1.5116	1.7087
159	24.542	1.019	5.67	0.981	176.318	382.09	465.72	83.63	1.5150	1.7085
160	24.960	1.026	5.53	0.975	180.778	383.62	465.88	82.26	1.5184	1.7083
161	25.385	1.033	5.39	0.968	185.407	385.17	466.02	80.85	1.5219	1.7081
162	25.815	1.041	5.26	0.961	190.221	386.74	466.13	79.40	1.5254	1.7079
163	26.250	1.049	5.12	0.954	195.234	388.33	466.23	77.90	1.5290	1.7076
164	26.692	1.057	4.99	0.946	200.462	389.94	466.29	76.36	1.5325	1.7072
165	27.139	1.065	4.86	0.939	205.925	391.57	466.33	74.76	1.5362	1.7068
166	27.592	1.074	4.72	0.931	211.647	393.23	466.34	73.11	1.5398	1.7063
167	28.051	1.084	4.59	0.923	217.649	394.91	466.31	71.40	1.5435	1.7058
168	28.516	1.094	4.46	0.914	223.969	396.62	466.24	69.62	1.5473	1.7051
169	28.987	1.104	4.34	0.906	230.640	398.36	466.13	67.77	1.5511	1.7044
170	29.464	1.115	4.21	0.897	237.709	400.14	465.97	65.83	1.5550	1.7036
171	29.948	1.127	4.08	0.887	245.231	401.95	465.76	63.80	1.5590	1.7027
172	30.438	1.140	3.95	0.877	253.279	403.81	465.48	61.67	1.5631	1.7016
173	30.935	1.153	3.82	0.867	261.943	405.71	465.12	59.40	1.5672	1.7003
174	31.438	1.168	3.69	0.856	271.348	407.67	464.67	56.99	1.5715	1.6989
175	31.947	1.184	3.55	0.844	281.671	409.70	464.10	54.40	1.5758	1.6972
176	32.464	1.202	3.41	0.832	293.171	411.80	463.38	51.58	1.5804	1.6952
177	32.987	1.222	3.26	0.818	306.303	414.01	462.46	48.45	1.5852	1.6928
178	33.518	1.245	3.11	0.803	321.905	416.36	461.21	44.86	1.5902	1.6897
179	34.056	1.271	2.92	0.787	342.254	418.94	459.35	40.41	1.5958	1.6852
180	34.601	1.302	2.85	0.768	351.494	420.79	459.17	38.38	1.5997	1.6844
181	35.153	1.341	2.72	0.746	368.053	423.19	457.98	34.80	1.6049	1.6815
182	35.714	1.393	2.55	0.718	391.389	426.07	455.95	29.88	1.6110	1.6767
183	36.283	1.478	2.34	0.677	427.350	429.85	452.42	22.57	1.6192	1.6686
183.79	36.74	1.819	1.82	0.550	549.900	438.95	438.95	0.00	1.6390	1.6390

12.1.4 Solkane® 134a

Release 1.04

t [°C]	p [bar]	v´ [dm^3/kg]	v´´ [dm^3/kg]	ρ´ [kg/dm^3]	ρ´´ [kg/m^3]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–50	0.293	0.693	607.09	1.443	1.647	135.75	366.14	230.39	0.7409	1.7748
–49	0.311	0.694	574.82	1.440	1.740	137.00	366.77	229.77	0.7463	1.7730
–48	0.329	0.696	544.61	1.437	1.836	138.24	367.40	229.15	0.7518	1.7712
–47	0.349	0.697	516.26	1.435	1.937	139.49	368.03	228.54	0.7572	1.7694
–46	0.369	0.698	489.66	1.432	2.042	140.73	368.65	227.92	0.7626	1.7677
–45	0.390	0.700	464.69	1.429	2.152	141.98	369.28	227.30	0.7681	1.7660
–44	0.412	0.701	441.25	1.426	2.266	143.23	369.91	226.68	0.7735	1.7644
–43	0.435	0.702	419.20	1.424	2.385	144.47	370.53	226.06	0.7789	1.7628
–42	0.459	0.704	398.46	1.421	2.510	145.72	371.16	225.44	0.7842	1.7612
–41	0.485	0.705	378.94	1.418	2.639	146.97	371.78	224.82	0.7896	1.7597
–40	0.511	0.707	360.57	1.415	2.773	148.21	372.41	224.20	0.7950	1.7582
–39	0.538	0.708	343.24	1.413	2.913	149.46	373.03	223.57	0.8003	1.7567
–38	0.567	0.709	326.91	1.410	3.059	150.71	373.66	222.94	0.8057	1.7553
–37	0.597	0.711	311.51	1.407	3.210	151.96	374.28	222.31	0.8110	1.7539
–36	0.628	0.712	296.98	1.404	3.367	153.22	374.90	221.68	0.8163	1.7525
–35	0.660	0.714	283.25	1.401	3.530	154.47	375.52	221.05	0.8217	1.7512
–34	0.694	0.715	270.28	1.399	3.700	155.73	376.14	220.41	0.8270	1.7499
–33	0.729	0.716	258.03	1.396	3.876	156.99	376.76	219.77	0.8322	1.7486
–32	0.766	0.718	246.44	1.393	4.058	158.25	377.38	219.13	0.8375	1.7473
–31	0.804	0.719	235.47	1.390	4.247	159.51	378.00	218.49	0.8428	1.7461
–30	0.843	0.721	225.08	1.387	4.443	160.78	378.61	217.84	0.8480	1.7449
–29	0.884	0.722	215.24	1.384	4.646	162.04	379.23	217.19	0.8533	1.7438
–28	0.926	0.724	205.92	1.382	4.856	163.31	379.85	216.53	0.8585	1.7426
–27	0.970	0.725	197.08	1.379	5.074	164.58	380.46	215.87	0.8637	1.7415
–26	1.016	0.727	188.70	1.376	5.299	165.86	381.07	215.21	0.8689	1.7404
–25	1.063	0.728	180.74	1.373	5.533	167.14	381.68	214.55	0.8741	1.7394
–24	1.112	0.730	173.19	1.370	5.774	168.42	382.29	213.88	0.8793	1.7383
–23	1.163	0.732	166.01	1.367	6.024	169.70	382.90	213.20	0.8845	1.7373
–22	1.216	0.733	159.20	1.364	6.282	170.98	383.51	212.53	0.8896	1.7363
–21	1.271	0.735	152.72	1.361	6.548	172.27	384.12	211.85	0.8948	1.7353
–20	1.327	0.736	146.55	1.358	6.824	173.56	384.72	211.16	0.8999	1.7344
–19	1.385	0.738	140.68	1.355	7.108	174.86	385.33	210.47	0.9050	1.7335
–18	1.446	0.740	135.10	1.352	7.402	176.15	385.93	209.78	0.9101	1.7326
–17	1.508	0.741	129.78	1.349	7.705	177.45	386.53	209.08	0.9152	1.7317
–16	1.573	0.743	124.72	1.346	8.018	178.75	387.13	208.38	0.9203	1.7308
–15	1.639	0.745	119.89	1.343	8.341	180.06	387.73	207.67	0.9254	1.7300
–14	1.708	0.746	115.28	1.340	8.674	181.37	388.33	206.96	0.9304	1.7292
–13	1.779	0.748	110.89	1.337	9.018	182.68	388.93	206.25	0.9355	1.7284
–12	1.853	0.750	106.70	1.334	9.372	183.99	389.52	205.53	0.9405	1.7276
–11	1.928	0.752	102.70	1.331	9.737	185.31	390.11	204.80	0.9455	1.7268
–10	2.006	0.753	98.88	1.328	10.113	186.63	390.71	204.07	0.9505	1.7261
–9	2.087	0.755	95.23	1.324	10.500	187.96	391.30	203.34	0.9555	1.7254
–8	2.170	0.757	91.75	1.321	10.900	189.28	391.89	202.60	0.9605	1.7247
–7	2.255	0.759	88.41	1.318	11.311	190.61	392.47	201.86	0.9655	1.7240
–6	2.343	0.760	85.22	1.315	11.734	191.94	393.06	201.11	0.9705	1.7233
–5	2.434	0.762	82.17	1.312	12.170	193.28	393.64	200.36	0.9754	1.7227
–4	2.528	0.764	79.25	1.309	12.618	194.62	394.22	199.61	0.9804	1.7220
–3	2.624	0.766	76.46	1.305	13.079	195.96	394.80	198.85	0.9853	1.7214
–2	2.723	0.768	73.78	1.302	13.554	197.30	395.38	198.08	0.9902	1.7208
–1	2.824	0.770	71.22	1.299	14.042	198.65	395.96	197.31	0.9951	1.7202

Solkane® 134a

Release 1.04

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
0	2.929	0.772	68.76	1.296	14.544	200.00	396.53	196.53	1.0000	1.7196
1	3.037	0.774	66.40	1.292	15.060	201.35	397.11	195.75	1.0049	1.7191
2	3.147	0.776	64.14	1.289	15.591	202.71	397.68	194.97	1.0098	1.7185
3	3.261	0.778	61.97	1.286	16.136	204.07	398.25	194.18	1.0146	1.7180
4	3.378	0.780	59.89	1.282	16.696	205.43	398.81	193.39	1.0195	1.7174
5	3.498	0.782	57.90	1.279	17.272	206.79	399.38	192.59	1.0243	1.7169
6	3.621	0.784	55.98	1.276	17.864	208.16	399.94	191.78	1.0292	1.7164
7	3.748	0.786	54.14	1.272	18.472	209.53	400.50	190.97	1.0340	1.7160
8	3.877	0.788	52.37	1.269	19.096	210.90	401.06	190.16	1.0388	1.7155
9	4.011	0.790	50.67	1.265	19.737	212.28	401.62	189.34	1.0436	1.7150
10	4.147	0.792	49.03	1.262	20.395	213.66	402.17	188.52	1.0484	1.7146
11	4.288	0.795	47.46	1.259	21.071	215.04	402.72	187.69	1.0532	1.7141
12	4.432	0.797	45.95	1.255	21.764	216.42	403.27	186.85	1.0580	1.7137
13	4.579	0.799	44.49	1.252	22.477	217.81	403.82	186.01	1.0627	1.7133
14	4.730	0.801	43.09	1.248	23.207	219.20	404.37	185.17	1.0675	1.7129
15	4.885	0.804	41.74	1.245	23.957	220.59	404.91	184.32	1.0723	1.7125
16	5.044	0.806	40.44	1.241	24.727	221.99	405.45	183.46	1.0770	1.7121
17	5.206	0.808	39.19	1.237	25.516	223.38	405.98	182.60	1.0818	1.7117
18	5.373	0.811	37.99	1.234	26.326	224.78	406.52	181.73	1.0865	1.7113
19	5.544	0.813	36.82	1.230	27.157	226.19	407.05	180.86	1.0912	1.7110
20	5.718	0.815	35.70	1.226	28.009	227.60	407.58	179.99	1.0960	1.7106
21	5.897	0.818	34.62	1.223	28.883	229.01	408.11	179.10	1.1007	1.7103
22	6.080	0.820	33.58	1.219	29.780	230.42	408.63	178.21	1.1054	1.7099
23	6.267	0.823	32.57	1.215	30.699	231.83	409.15	177.32	1.1101	1.7096
24	6.459	0.825	31.60	1.212	31.642	233.25	409.67	176.42	1.1148	1.7093
25	6.655	0.828	30.67	1.208	32.609	234.68	410.18	175.51	1.1195	1.7090
26	6.855	0.831	29.76	1.204	33.600	236.10	410.70	174.59	1.1242	1.7086
27	7.060	0.833	28.89	1.200	34.617	237.53	411.20	173.67	1.1289	1.7083
28	7.269	0.836	28.04	1.196	35.659	238.96	411.71	172.75	1.1336	1.7080
29	7.483	0.839	27.23	1.192	36.728	240.40	412.21	171.81	1.1383	1.7077
30	7.702	0.841	26.44	1.189	37.823	241.83	412.71	170.87	1.1429	1.7074
31	7.926	0.844	25.68	1.185	38.946	243.28	413.20	169.92	1.1476	1.7071
32	8.154	0.847	24.94	1.181	40.098	244.72	413.69	168.97	1.1523	1.7069
33	8.388	0.850	24.23	1.177	41.278	246.17	414.18	168.01	1.1570	1.7066
34	8.626	0.853	23.54	1.173	42.489	247.63	414.66	167.04	1.1616	1.7063
35	8.869	0.856	22.87	1.169	43.729	249.08	415.14	166.06	1.1663	1.7060
36	9.118	0.859	22.22	1.164	45.002	250.55	415.62	165.07	1.1710	1.7057
37	9.372	0.862	21.60	1.160	46.306	252.01	416.09	164.07	1.1757	1.7055
38	9.631	0.865	20.99	1.156	47.643	253.48	416.55	163.07	1.1804	1.7052
39	9.895	0.868	20.40	1.152	49.014	254.96	417.01	162.06	1.1850	1.7049
40	10.165	0.871	19.83	1.148	50.420	256.44	417.47	161.03	1.1897	1.7046
41	10.440	0.875	19.28	1.143	51.862	257.92	417.92	160.00	1.1944	1.7044
42	10.721	0.878	18.75	1.139	53.340	259.41	418.37	158.96	1.1991	1.7041
43	11.007	0.881	18.23	1.135	54.856	260.90	418.81	157.91	1.2038	1.7038
44	11.299	0.885	17.73	1.130	56.411	262.40	419.25	156.84	1.2085	1.7035
45	11.597	0.888	17.24	1.126	58.007	263.91	419.68	155.77	1.2132	1.7032
46	11.901	0.892	16.77	1.121	59.643	265.42	420.11	154.69	1.2179	1.7030
47	12.211	0.895	16.31	1.117	61.322	266.94	420.53	153.59	1.2226	1.7027
48	12.527	0.899	15.86	1.112	63.044	268.46	420.94	152.48	1.2273	1.7024
49	12.849	0.903	15.43	1.108	64.812	269.99	421.35	151.36	1.2320	1.7021

Solkane® 134a

Release 1.04

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
50	13.177	0.907	15.01	1.103	66.626	271.53	421.75	150.22	1.2367	1.7018
51	13.511	0.910	14.60	1.098	68.488	273.07	422.14	149.07	1.2415	1.7015
52	13.852	0.914	14.20	1.094	70.400	274.62	422.53	147.91	1.2462	1.7011
53	14.199	0.919	13.82	1.089	72.362	276.18	422.91	146.73	1.2510	1.7008
54	14.552	0.923	13.44	1.084	74.378	277.75	423.28	145.53	1.2557	1.7005
55	14.913	0.927	13.08	1.079	76.449	279.32	423.65	144.32	1.2605	1.7001
56	15.279	0.931	12.73	1.074	78.577	280.91	424.00	143.10	1.2653	1.6998
57	15.653	0.936	12.38	1.069	80.763	282.50	424.35	141.85	1.2701	1.6994
58	16.034	0.940	12.05	1.064	83.011	284.10	424.69	140.59	1.2749	1.6990
59	16.421	0.945	11.72	1.059	85.322	285.71	425.02	139.31	1.2797	1.6986
60	16.815	0.949	11.40	1.053	87.699	287.34	425.34	138.01	1.2845	1.6982
61	17.217	0.954	11.09	1.048	90.144	288.97	425.65	136.69	1.2894	1.6978
62	17.626	0.959	10.79	1.043	92.661	290.61	425.95	135.34	1.2942	1.6974
63	18.042	0.964	10.50	1.037	95.251	292.26	426.24	133.98	1.2991	1.6969
64	18.465	0.969	10.21	1.032	97.919	293.93	426.52	132.59	1.3040	1.6964
65	18.896	0.975	9.93	1.026	100.668	295.61	426.79	131.18	1.3089	1.6959
66	19.335	0.980	9.66	1.020	103.501	297.30	427.04	129.74	1.3138	1.6954
67	19.781	0.986	9.40	1.014	106.423	299.00	427.28	128.28	1.3188	1.6949
68	20.236	0.992	9.14	1.009	109.437	300.72	427.51	126.79	1.3237	1.6943
69	20.698	0.997	8.89	1.003	112.549	302.45	427.72	125.27	1.3287	1.6937
70	21.168	1.004	8.64	0.996	115.762	304.19	427.91	123.72	1.3337	1.6931
71	21.646	1.010	8.40	0.990	119.083	305.95	428.09	122.14	1.3387	1.6924
72	22.132	1.016	8.16	0.984	122.518	307.73	428.26	120.53	1.3438	1.6917
73	22.627	1.023	7.93	0.977	126.072	309.52	428.40	118.88	1.3489	1.6910
74	23.130	1.030	7.71	0.971	129.753	311.33	428.52	117.20	1.3539	1.6902
75	23.642	1.037	7.49	0.964	133.568	313.15	428.63	115.47	1.3590	1.6894
76	24.163	1.045	7.27	0.957	137.525	315.00	428.71	113.71	1.3642	1.6885
77	24.692	1.052	7.06	0.950	141.635	316.86	428.77	111.91	1.3693	1.6876
78	25.230	1.060	6.85	0.943	145.908	318.74	428.80	110.06	1.3745	1.6866
79	25.778	1.069	6.65	0.936	150.354	320.64	428.81	108.16	1.3797	1.6856
80	26.334	1.078	6.45	0.928	154.987	322.57	428.78	106.22	1.3850	1.6845
81	26.901	1.087	6.26	0.920	159.822	324.51	428.73	104.22	1.3903	1.6833
82	27.476	1.096	6.07	0.912	164.876	326.48	428.64	102.16	1.3955	1.6821
83	28.061	1.106	5.88	0.904	170.166	328.47	428.52	100.05	1.4009	1.6807
84	28.657	1.117	5.69	0.895	175.716	330.48	428.35	97.87	1.4062	1.6793
85	29.262	1.128	5.51	0.887	181.550	332.52	428.14	95.62	1.4116	1.6778
86	29.877	1.140	5.33	0.878	187.698	334.58	427.88	93.30	1.4170	1.6761
87	30.503	1.152	5.15	0.868	194.195	336.67	427.56	90.90	1.4225	1.6743
88	31.139	1.165	4.97	0.858	201.083	338.78	427.19	88.41	1.4280	1.6724
89	31.786	1.179	4.80	0.848	208.412	340.92	426.74	85.82	1.4335	1.6703
90	32.444	1.195	4.62	0.837	216.247	343.09	426.21	83.12	1.4391	1.6680
91	33.114	1.211	4.45	0.826	224.665	345.29	425.60	80.30	1.4447	1.6654
92	33.795	1.229	4.28	0.813	233.769	347.53	424.87	77.35	1.4503	1.6626
93	34.487	1.249	4.10	0.801	243.694	349.79	424.02	74.23	1.4560	1.6595
94	35.192	1.271	3.93	0.787	254.627	352.08	423.01	70.92	1.4617	1.6560
95	35.910	1.296	3.75	0.771	266.837	354.41	421.79	67.38	1.4675	1.6519
96	36.640	1.325	3.56	0.755	280.745	356.77	420.32	63.54	1.4733	1.6472
97	37.384	1.359	3.37	0.736	297.074	359.17	418.46	59.29	1.4791	1.6415

12.1.5 Solkane® 227

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–60	0.097	0.628	1067.46	1.591	0.937	137.92	285.62	147.69	0.7448	1.4377
–59	0.104	0.628	1002.80	1.591	0.997	138.86	286.25	147.38	0.7492	1.4374
–58	0.111	0.629	942.71	1.591	1.061	139.80	286.88	147.07	0.7536	1.4372
–57	0.118	0.629	886.82	1.591	1.128	140.75	287.50	146.75	0.7580	1.4369
–56	0.126	0.629	834.80	1.590	1.198	141.70	288.13	146.44	0.7624	1.4367
–55	0.134	0.629	786.34	1.590	1.272	142.66	288.77	146.12	0.7668	1.4365
–54	0.143	0.629	741.18	1.589	1.349	143.61	289.40	145.79	0.7711	1.4364
–53	0.152	0.629	699.05	1.589	1.431	144.57	290.04	145.47	0.7755	1.4363
–52	0.162	0.630	659.74	1.588	1.516	145.54	290.68	145.13	0.7799	1.4362
–51	0.172	0.630	623.01	1.588	1.605	146.51	291.31	144.81	0.7842	1.4361
–50	0.183	0.630	588.69	1.587	1.699	147.47	291.94	144.47	0.7886	1.4360
–49	0.194	0.630	556.59	1.586	1.797	148.44	292.58	144.15	0.7929	1.4360
–48	0.206	0.631	526.55	1.585	1.899	149.42	293.23	143.81	0.7973	1.4360
–47	0.218	0.631	498.41	1.584	2.006	150.40	293.87	143.47	0.8016	1.4360
–46	0.231	0.631	472.05	1.584	2.118	151.38	294.50	143.12	0.8059	1.4360
–45	0.245	0.632	447.33	1.583	2.235	152.37	295.14	142.78	0.8103	1.4361
–44	0.259	0.632	424.14	1.582	2.358	153.36	295.80	142.44	0.8146	1.4362
–43	0.275	0.633	402.37	1.581	2.485	154.35	296.44	142.09	0.8189	1.4363
–42	0.290	0.633	381.92	1.580	2.618	155.35	297.07	141.72	0.8232	1.4364
–41	0.307	0.634	362.70	1.578	2.757	156.35	297.73	141.38	0.8275	1.4365
–40	0.324	0.634	344.63	1.577	2.902	157.35	298.37	141.01	0.8318	1.4367
–39	0.342	0.635	327.62	1.576	3.052	158.36	299.01	140.66	0.8361	1.4368
–38	0.361	0.635	311.61	1.575	3.209	159.36	299.65	140.29	0.8404	1.4370
–37	0.380	0.636	296.53	1.573	3.372	160.38	300.31	139.93	0.8447	1.4373
–36	0.401	0.636	282.31	1.572	3.542	161.40	300.95	139.56	0.8490	1.4375
–35	0.422	0.637	268.90	1.571	3.719	162.42	301.61	139.19	0.8533	1.4377
–34	0.444	0.637	256.25	1.569	3.902	163.43	302.25	138.81	0.8576	1.4380
–33	0.467	0.638	244.31	1.568	4.093	164.46	302.89	138.44	0.8619	1.4383
–32	0.492	0.639	233.03	1.566	4.291	165.49	303.55	138.06	0.8661	1.4386
–31	0.517	0.639	222.37	1.564	4.497	166.52	304.19	137.68	0.8704	1.4389
–30	0.543	0.640	212.29	1.563	4.710	167.56	304.85	137.28	0.8747	1.4393
–29	0.570	0.641	202.76	1.561	4.932	168.59	305.50	136.91	0.8789	1.4396
–28	0.598	0.641	193.74	1.559	5.162	169.63	306.14	136.51	0.8831	1.4400
–27	0.628	0.642	185.20	1.557	5.400	170.68	306.80	136.12	0.8874	1.4404
–26	0.658	0.643	177.10	1.555	5.646	171.73	307.44	135.72	0.8916	1.4408
–25	0.690	0.644	169.43	1.553	5.902	172.78	308.10	135.31	0.8959	1.4412
–24	0.723	0.645	162.16	1.551	6.167	173.83	308.75	134.91	0.9001	1.4416
–23	0.757	0.645	155.26	1.549	6.441	174.89	309.39	134.50	0.9043	1.4420
–22	0.793	0.646	148.71	1.547	6.724	175.94	310.05	134.10	0.9085	1.4425
–21	0.829	0.647	142.49	1.545	7.018	177.01	310.69	133.69	0.9128	1.4429
–20	0.867	0.648	136.59	1.543	7.321	178.07	311.35	133.28	0.9169	1.4434
–19	0.907	0.649	130.97	1.541	7.635	179.15	312.00	132.85	0.9212	1.4439
–18	0.948	0.650	125.64	1.539	7.960	180.22	312.65	132.44	0.9253	1.4444
–17	0.990	0.651	120.56	1.536	8.295	181.30	313.31	132.00	0.9296	1.4449
–16	1.033	0.652	115.73	1.534	8.641	182.37	313.95	131.59	0.9337	1.4454
–15	1.079	0.653	111.13	1.531	8.998	183.45	314.61	131.16	0.9379	1.4460
–14	1.125	0.654	106.75	1.529	9.367	184.54	315.25	130.72	0.9421	1.4465
–13	1.174	0.655	102.58	1.526	9.748	185.62	315.90	130.28	0.9463	1.4471
–12	1.224	0.656	98.60	1.524	10.141	186.71	316.56	129.84	0.9504	1.4476
–11	1.275	0.657	94.81	1.521	10.547	187.81	317.20	129.40	0.9546	1.4482

Solkane® 227

Release 1.01

t [°C]	p [bar]	v′ [dm^3/kg]	v″ [dm^3/kg]	ρ′ [kg/dm^3]	ρ″ [kg/m^3]	h′ [kJ/kg]	h″ [kJ/kg]	r [kJ/kg]	s′ [kJ/kg·K]	s″ [kJ/kg·K]
–10	1.329	0.659	91.20	1.518	10.965	188.90	317.86	128.96	0.9588	1.4488
–9	1.384	0.660	87.75	1.516	11.396	189.99	318.50	128.50	0.9629	1.4494
–8	1.440	0.661	84.45	1.513	11.841	191.09	319.14	128.06	0.9670	1.4500
–7	1.499	0.662	81.31	1.510	12.299	192.20	319.80	127.59	0.9712	1.4506
–6	1.559	0.663	78.30	1.507	12.771	193.31	320.44	127.14	0.9753	1.4512
–5	1.621	0.665	75.43	1.504	13.257	194.42	321.10	126.67	0.9795	1.4519
–4	1.686	0.666	72.69	1.501	13.758	195.52	321.74	126.22	0.9836	1.4525
–3	1.752	0.667	70.06	1.498	14.273	196.64	322.38	125.75	0.9877	1.4532
–2	1.820	0.669	67.55	1.495	14.804	197.75	323.02	125.28	0.9918	1.4538
–1	1.890	0.670	65.15	1.492	15.350	198.88	323.68	124.80	0.9959	1.4545
0	1.962	0.672	62.84	1.489	15.912	200.00	324.31	124.31	1.0000	1.4551
1	2.036	0.673	60.64	1.486	16.491	201.13	324.96	123.83	1.0041	1.4558
2	2.113	0.675	58.53	1.482	17.085	202.25	325.61	123.36	1.0082	1.4565
3	2.191	0.676	56.51	1.479	17.697	203.38	326.25	122.86	1.0123	1.4572
4	2.272	0.678	54.57	1.476	18.326	204.51	326.88	122.38	1.0163	1.4579
5	2.355	0.679	52.71	1.472	18.973	205.64	327.52	121.89	1.0204	1.4586
6	2.441	0.681	50.92	1.469	19.637	206.78	328.17	121.39	1.0245	1.4593
7	2.528	0.682	49.21	1.465	20.320	207.92	328.81	120.89	1.0285	1.4600
8	2.618	0.684	47.57	1.462	21.022	209.07	329.44	120.38	1.0326	1.4607
9	2.711	0.686	45.99	1.458	21.743	210.21	330.08	119.88	1.0366	1.4615
10	2.806	0.688	44.48	1.455	22.484	211.35	330.71	119.36	1.0406	1.4622
11	2.903	0.689	43.02	1.451	23.244	212.51	331.36	118.84	1.0447	1.4629
12	3.004	0.691	41.62	1.447	24.026	213.66	331.99	118.33	1.0487	1.4637
13	3.106	0.693	40.28	1.443	24.828	214.82	332.62	117.81	1.0527	1.4644
14	3.212	0.695	38.98	1.439	25.651	215.97	333.25	117.28	1.0567	1.4652
15	3.320	0.697	37.74	1.435	26.497	217.13	333.88	116.75	1.0607	1.4659
16	3.430	0.699	36.54	1.432	27.364	218.29	334.51	116.22	1.0647	1.4667
17	3.544	0.700	35.39	1.428	28.255	219.46	335.14	115.69	1.0687	1.4674
18	3.660	0.702	34.28	1.424	29.169	220.61	335.76	115.16	1.0727	1.4682
19	3.779	0.705	33.22	1.419	30.107	221.79	336.39	114.61	1.0767	1.4690
20	3.902	0.707	32.19	1.415	31.069	222.95	337.01	114.06	1.0806	1.4697
21	4.027	0.709	31.20	1.411	32.056	224.13	337.64	113.52	1.0846	1.4705
22	4.155	0.711	30.24	1.407	33.068	225.31	338.26	112.95	1.0886	1.4713
23	4.286	0.713	29.32	1.403	34.107	226.48	338.88	112.41	1.0925	1.4721
24	4.420	0.715	28.43	1.398	35.172	227.67	339.50	111.83	1.0965	1.4728
25	4.558	0.717	27.57	1.394	36.265	228.84	340.12	111.28	1.1004	1.4736
26	4.698	0.720	26.75	1.390	37.386	230.03	340.74	110.70	1.1043	1.4744
27	4.842	0.722	25.95	1.385	38.535	231.21	341.35	110.14	1.1082	1.4752
28	4.989	0.724	25.18	1.381	39.713	232.40	341.95	109.56	1.1122	1.4760
29	5.139	0.727	24.44	1.376	40.921	233.59	342.56	108.97	1.1161	1.4767
30	5.293	0.729	23.72	1.371	42.160	234.79	343.18	108.39	1.1200	1.4775
31	5.450	0.732	23.03	1.367	43.430	235.99	343.79	107.80	1.1239	1.4783
32	5.611	0.734	22.36	1.362	44.732	237.18	344.38	107.20	1.1278	1.4791
33	5.775	0.737	21.71	1.357	46.067	238.38	344.99	106.61	1.1317	1.4799
34	5.943	0.739	21.08	1.353	47.436	239.59	345.58	106.00	1.1356	1.4807
35	6.115	0.742	20.48	1.348	48.840	240.80	346.19	105.39	1.1395	1.4815
36	6.290	0.745	19.89	1.343	50.279	242.00	346.77	104.78	1.1433	1.4822
37	6.469	0.747	19.32	1.338	51.754	243.22	347.38	104.16	1.1472	1.4830
38	6.652	0.750	18.77	1.333	53.267	244.43	347.96	103.53	1.1511	1.4838
39	6.838	0.753	18.24	1.328	54.818	245.64	348.55	102.91	1.1549	1.4846

Solkane® 227

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
40	7.029	0.756	17.73	1.323	56.408	246.87	349.13	102.27	1.1588	1.4854
41	7.223	0.759	17.23	1.318	58.038	248.09	349.71	101.62	1.1626	1.4861
42	7.421	0.762	16.75	1.313	59.710	249.31	350.30	100.98	1.1665	1.4869
43	7.624	0.765	16.28	1.308	61.425	250.55	350.88	100.33	1.1703	1.4877
44	7.830	0.768	15.83	1.303	63.183	251.77	351.44	99.67	1.1742	1.4884
45	8.041	0.771	15.39	1.297	64.987	253.01	352.01	99.00	1.1780	1.4892
46	8.256	0.774	14.96	1.292	66.836	254.25	352.58	98.33	1.1818	1.4900
47	8.476	0.777	14.55	1.287	68.734	255.48	353.14	97.67	1.1856	1.4907
48	8.699	0.780	14.15	1.281	70.680	256.73	353.70	96.97	1.1895	1.4915
49	8.927	0.784	13.76	1.276	72.678	257.98	354.26	96.28	1.1933	1.4922
50	9.160	0.787	13.38	1.270	74.727	259.24	354.82	95.58	1.1971	1.4929
51	9.397	0.791	13.02	1.265	76.830	260.48	355.37	94.89	1.2010	1.4937
52	9.639	0.794	12.66	1.259	78.989	261.75	355.92	94.17	1.2048	1.4944
53	9.885	0.798	12.31	1.254	81.205	263.01	356.45	93.44	1.2086	1.4951
54	10.136	0.801	11.98	1.248	83.481	264.28	357.00	92.72	1.2124	1.4958
55	10.392	0.805	11.65	1.243	85.817	265.55	357.52	91.97	1.2162	1.4965
56	10.653	0.809	11.34	1.237	88.218	266.83	358.06	91.22	1.2201	1.4972
57	10.919	0.812	11.03	1.231	90.683	268.10	358.57	90.47	1.2239	1.4979
58	11.190	0.816	10.73	1.225	93.217	269.39	359.10	89.70	1.2277	1.4986
59	11.466	0.820	10.44	1.219	95.821	270.69	359.62	88.92	1.2315	1.4993
60	11.747	0.824	10.15	1.214	98.498	271.98	360.12	88.14	1.2354	1.4999
61	12.033	0.828	9.88	1.208	101.252	273.28	360.62	87.34	1.2392	1.5006
62	12.324	0.832	9.61	1.202	104.084	274.58	361.12	86.53	1.2430	1.5012
63	12.621	0.836	9.35	1.196	106.998	275.90	361.61	85.70	1.2469	1.5018
64	12.924	0.841	9.09	1.190	109.997	277.22	362.10	84.88	1.2507	1.5024
65	13.232	0.845	8.84	1.184	113.086	278.54	362.56	84.03	1.2545	1.5030
66	13.545	0.849	8.60	1.177	116.268	279.87	363.04	83.17	1.2584	1.5036
67	13.864	0.854	8.36	1.171	119.546	281.21	363.50	82.28	1.2623	1.5042
68	14.189	0.858	8.13	1.165	122.926	282.56	363.95	81.39	1.2661	1.5047
69	14.520	0.863	7.91	1.159	126.412	283.91	364.40	80.50	1.2700	1.5052
70	14.857	0.868	7.69	1.152	130.010	285.27	364.83	79.56	1.2739	1.5058
71	15.200	0.873	7.48	1.146	133.724	286.64	365.26	78.62	1.2778	1.5063
72	15.549	0.877	7.27	1.140	137.562	288.02	365.69	77.67	1.2817	1.5067
73	15.904	0.883	7.07	1.133	141.528	289.40	366.10	76.69	1.2856	1.5072
74	16.265	0.888	6.87	1.127	145.632	290.80	366.50	75.69	1.2895	1.5076
75	16.633	0.893	6.67	1.120	149.879	292.21	366.88	74.67	1.2935	1.5080
76	17.008	0.898	6.48	1.113	154.279	293.63	367.25	73.62	1.2975	1.5084
77	17.389	0.904	6.30	1.106	158.841	295.06	367.62	72.56	1.3015	1.5087
78	17.776	0.910	6.11	1.099	163.575	296.49	367.96	71.47	1.3055	1.5090
79	18.171	0.915	5.93	1.092	168.493	297.95	368.31	70.36	1.3095	1.5093
80	18.572	0.921	5.76	1.085	173.607	299.42	368.62	69.20	1.3136	1.5095
81	18.981	0.928	5.59	1.078	178.931	300.90	368.93	68.03	1.3177	1.5097
82	19.397	0.934	5.42	1.071	184.482	302.41	369.21	66.81	1.3218	1.5099
83	19.820	0.941	5.26	1.063	190.276	303.92	369.48	65.56	1.3259	1.5100
84	20.250	0.948	5.09	1.055	196.335	305.46	369.73	64.27	1.3301	1.5101
85	20.688	0.955	4.93	1.047	202.681	307.01	369.94	62.94	1.3344	1.5101
86	21.133	0.962	4.78	1.039	209.341	308.60	370.14	61.55	1.3387	1.5100
87	21.586	0.970	4.62	1.031	216.347	310.20	370.31	60.12	1.3430	1.5099
88	22.047	0.979	4.47	1.022	223.735	311.83	370.45	58.62	1.3474	1.5097
89	22.516	0.988	4.32	1.012	231.549	313.48	370.56	57.08	1.3518	1.5094

Solkane® 227

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
90	22.993	0.998	4.17	1.002	239.841	315.18	370.62	55.45	1.3564	1.5091
91	23.479	1.008	4.02	0.992	248.676	316.92	370.64	53.73	1.3611	1.5086
92	23.973	1.020	3.87	0.980	258.133	318.71	370.62	51.91	1.3658	1.5080
93	24.475	1.033	3.73	0.968	268.315	320.55	370.55	49.99	1.3707	1.5072
94	24.987	1.048	3.58	0.954	279.353	322.47	370.39	47.92	1.3758	1.5063
95	25.507	1.066	3.43	0.938	291.427	324.48	370.17	45.69	1.3811	1.5052
96	26.036	1.087	3.28	0.920	304.786	326.62	369.83	43.22	1.3868	1.5038
97	26.574	1.114	3.13	0.897	319.801	328.93	369.38	40.45	1.3929	1.5021
98	27.122	1.151	2.97	0.869	337.058	331.51	368.75	37.23	1.3996	1.5000
99	27.679	1.204	2.80	0.831	357.584	334.54	367.86	33.31	1.4076	1.4971
100	28.246	1.294	2.61	0.773	383.506	338.52	366.56	28.04	1.4181	1.4932
101	28.823	1.513	2.38	0.661	420.784	345.59	364.38	18.80	1.4368	1.4871

12.1.6 Solkane® 404A

Release 1.02

t [°C]	p′ [bar]	p″ [bar]	v′ [dm^3/kg]	v″ [dm^3/kg]	ρ′ [kg/dm^3]	ρ″ [kg/m^3]	h′ [kJ/kg]	h″ [kJ/kg]	r [kJ/kg]	s′ [kJ/kg·K]	s″ [kJ/kg·K]
–60	0.510	0.487	0.742	363.14	1.348	2.754	123.13	330.65	207.52	0.6838	1.6621
–59	0.539	0.515	0.743	344.88	1.346	2.900	124.32	331.27	206.95	0.6894	1.6604
–58	0.569	0.544	0.745	327.71	1.343	3.051	125.52	331.89	206.37	0.6951	1.6586
–57	0.600	0.574	0.746	311.56	1.340	3.210	126.71	332.51	205.80	0.7007	1.6570
–56	0.632	0.605	0.748	296.35	1.337	3.374	127.91	333.13	205.22	0.7063	1.6553
–55	0.666	0.638	0.750	282.03	1.334	3.546	129.11	333.74	204.63	0.7119	1.6537
–54	0.701	0.672	0.751	268.53	1.331	3.724	130.31	334.36	204.05	0.7174	1.6522
–53	0.738	0.708	0.753	255.80	1.328	3.909	131.52	334.98	203.46	0.7230	1.6507
–52	0.776	0.745	0.755	243.79	1.325	4.102	132.73	335.59	202.87	0.7286	1.6492
–51	0.816	0.784	0.756	232.46	1.322	4.302	133.94	336.21	202.27	0.7341	1.6478
–50	0.858	0.825	0.758	221.75	1.319	4.510	135.15	336.82	201.67	0.7396	1.6464
–49	0.901	0.867	0.760	211.63	1.316	4.725	136.36	337.44	201.07	0.7451	1.6450
–48	0.946	0.910	0.762	202.06	1.313	4.949	137.58	338.05	200.47	0.7507	1.6437
–47	0.992	0.956	0.763	193.01	1.310	5.181	138.80	338.66	199.86	0.7561	1.6424
–46	1.041	1.003	0.765	184.45	1.307	5.422	140.03	339.27	199.24	0.7616	1.6411
–45	1.091	1.052	0.767	176.34	1.304	5.671	141.26	339.88	198.62	0.7671	1.6399
–44	1.143	1.103	0.769	168.65	1.301	5.929	142.49	340.49	198.00	0.7725	1.6386
–43	1.197	1.156	0.771	161.37	1.298	6.197	143.72	341.10	197.37	0.7780	1.6375
–42	1.253	1.211	0.772	154.46	1.295	6.474	144.96	341.70	196.74	0.7834	1.6363
–41	1.312	1.268	0.774	147.91	1.291	6.761	146.20	342.31	196.11	0.7888	1.6352
–40	1.372	1.327	0.776	141.69	1.288	7.058	147.45	342.91	195.46	0.7942	1.6341
–39	1.434	1.388	0.778	135.78	1.285	7.365	148.70	343.51	194.82	0.7996	1.6331
–38	1.499	1.452	0.780	130.17	1.282	7.682	149.95	344.11	194.17	0.8050	1.6320
–37	1.566	1.517	0.782	124.84	1.279	8.010	151.20	344.71	193.51	0.8103	1.6310
–36	1.635	1.585	0.784	119.77	1.276	8.350	152.46	345.31	192.85	0.8157	1.6300
–35	1.707	1.655	0.786	114.94	1.273	8.700	153.73	345.91	192.18	0.8210	1.6290
–34	1.781	1.728	0.788	110.35	1.269	9.062	154.99	346.50	191.51	0.8263	1.6281
–33	1.857	1.803	0.790	105.97	1.266	9.436	156.26	347.10	190.83	0.8316	1.6272
–32	1.936	1.881	0.792	101.81	1.263	9.822	157.54	347.69	190.15	0.8369	1.6263
–31	2.017	1.961	0.794	97.84	1.260	10.221	158.81	348.28	189.46	0.8422	1.6254
–30	2.102	2.044	0.796	94.06	1.256	10.632	160.10	348.86	188.77	0.8475	1.6246
–29	2.189	2.129	0.798	90.45	1.253	11.056	161.38	349.45	188.07	0.8527	1.6237
–28	2.278	2.217	0.800	87.01	1.250	11.493	162.67	350.03	187.37	0.8579	1.6229
–27	2.371	2.308	0.802	83.72	1.247	11.944	163.96	350.62	186.66	0.8632	1.6221
–26	2.466	2.402	0.804	80.58	1.243	12.409	165.26	351.20	185.94	0.8684	1.6213
–25	2.564	2.499	0.806	77.59	1.240	12.889	166.56	351.77	185.22	0.8736	1.6206
–24	2.665	2.599	0.809	74.72	1.237	13.383	167.86	352.35	184.49	0.8788	1.6198
–23	2.770	2.701	0.811	71.99	1.233	13.892	169.16	352.92	183.76	0.8839	1.6191
–22	2.877	2.807	0.813	69.37	1.230	14.416	170.47	353.49	183.02	0.8891	1.6184
–21	2.987	2.916	0.815	66.87	1.227	14.955	171.79	354.06	182.27	0.8942	1.6177
–20	3.101	3.028	0.818	64.47	1.223	15.511	173.10	354.63	181.52	0.8994	1.6170
–19	3.218	3.144	0.820	62.18	1.220	16.083	174.42	355.19	180.77	0.9045	1.6163
–18	3.338	3.263	0.822	59.98	1.216	16.672	175.75	355.75	180.00	0.9096	1.6157
–17	3.462	3.385	0.825	57.88	1.213	17.278	177.08	356.31	179.23	0.9147	1.6151
–16	3.589	3.511	0.827	55.86	1.209	17.902	178.41	356.87	178.46	0.9198	1.6144
–15	3.720	3.640	0.829	53.93	1.206	18.544	179.74	357.42	177.68	0.9249	1.6138
–14	3.854	3.773	0.832	52.07	1.202	19.204	181.08	357.97	176.89	0.9299	1.6132
–13	3.992	3.909	0.834	50.30	1.199	19.882	182.42	358.51	176.10	0.9350	1.6126
–12	4.134	4.049	0.837	48.59	1.195	20.580	183.76	359.06	175.30	0.9401	1.6121
–11	4.279	4.193	0.839	46.95	1.192	21.298	185.11	359.60	174.49	0.9451	1.6115

Solkane® 404A

Release 1.02

t [°C]	p′ [bar]	p″ [bar]	v′ [dm³/kg]	v″ [dm³/kg]	ρ′ [kg/dm³]	ρ″ [kg/m³]	h′ [kJ/kg]	h″ [kJ/kg]	r [kJ/kg]	s′ [kJ/kg·K]	s″ [kJ/kg·K]
–10	4.429	4.341	0.842	45.38	1.188	22.035	186.46	360.13	173.68	0.9501	1.6110
–9	4.582	4.493	0.844	43.87	1.185	22.794	187.81	360.67	172.86	0.9551	1.6104
–8	4.739	4.648	0.847	42.42	1.181	23.573	189.17	361.20	172.03	0.9602	1.6099
–7	4.900	4.808	0.849	41.03	1.177	24.374	190.52	361.73	171.20	0.9652	1.6094
–6	5.065	4.972	0.852	39.69	1.174	25.197	191.89	362.25	170.36	0.9702	1.6088
–5	5.235	5.139	0.855	38.40	1.170	26.043	193.25	362.77	169.52	0.9751	1.6083
–4	5.408	5.312	0.858	37.16	1.166	26.911	194.62	363.29	168.66	0.9801	1.6078
–3	5.586	5.488	0.860	35.97	1.162	27.804	196.00	363.80	167.80	0.9851	1.6073
–2	5.769	5.669	0.863	34.82	1.159	28.721	197.37	364.31	166.93	0.9901	1.6069
–1	5.955	5.854	0.866	33.71	1.155	29.662	198.75	364.81	166.06	0.9950	1.6064
0	6.147	6.044	0.869	32.65	1.151	30.629	200.00	365.31	165.31	1.0000	1.6059
1	6.342	6.238	0.872	31.62	1.147	31.622	201.52	365.81	164.29	1.0050	1.6054
2	6.543	6.437	0.875	30.64	1.143	32.642	202.91	366.30	163.39	1.0099	1.6050
3	6.748	6.641	0.878	29.68	1.139	33.689	204.30	366.79	162.48	1.0148	1.6045
4	6.958	6.849	0.881	28.77	1.135	34.764	205.70	367.27	161.57	1.0198	1.6041
5	7.173	7.062	0.884	27.88	1.131	35.868	207.10	367.75	160.65	1.0247	1.6036
6	7.392	7.281	0.887	27.03	1.127	37.001	208.51	368.22	159.72	1.0297	1.6032
7	7.617	7.504	0.890	26.20	1.123	38.165	209.91	368.69	158.78	1.0346	1.6027
8	7.846	7.732	0.893	25.41	1.119	39.360	211.33	369.16	157.83	1.0395	1.6023
9	8.081	7.965	0.897	24.64	1.115	40.586	212.74	369.61	156.87	1.0445	1.6018
10	8.321	8.204	0.900	23.90	1.111	41.846	214.16	370.07	155.90	1.0494	1.6014
11	8.567	8.448	0.903	23.18	1.107	43.138	215.59	370.52	154.93	1.0543	1.6009
12	8.817	8.697	0.907	22.49	1.103	44.466	217.02	370.96	153.94	1.0593	1.6005
13	9.073	8.952	0.910	21.82	1.099	45.829	218.45	371.40	152.94	1.0642	1.6000
14	9.335	9.212	0.914	21.17	1.094	47.228	219.89	371.83	151.93	1.0692	1.5996
15	9.602	9.478	0.917	20.55	1.090	48.665	221.34	372.25	150.91	1.0741	1.5992
16	9.875	9.749	0.921	19.94	1.086	50.140	222.79	372.67	149.88	1.0790	1.5987
17	10.153	10.026	0.925	19.36	1.081	51.655	224.24	373.08	148.84	1.0840	1.5983
18	10.438	10.309	0.929	18.79	1.077	53.212	225.70	373.49	147.79	1.0889	1.5978
19	10.728	10.598	0.932	18.24	1.073	54.810	227.17	373.89	146.72	1.0939	1.5973
20	11.024	10.893	0.936	17.71	1.068	56.451	228.64	374.28	145.64	1.0989	1.5969
21	11.326	11.194	0.940	17.20	1.063	58.138	230.12	374.67	144.55	1.1038	1.5964
22	11.634	11.501	0.944	16.70	1.059	59.871	231.61	375.05	143.44	1.1088	1.5959
23	11.949	11.815	0.949	16.22	1.054	61.651	233.10	375.42	142.32	1.1138	1.5954
24	12.270	12.134	0.953	15.75	1.050	63.481	234.60	375.78	141.18	1.1188	1.5949
25	12.597	12.460	0.957	15.30	1.045	65.362	236.11	376.13	140.03	1.1238	1.5944
26	12.931	12.793	0.962	14.86	1.040	67.295	237.62	376.48	138.86	1.1289	1.5939
27	13.271	13.132	0.966	14.43	1.035	69.284	239.14	376.82	137.67	1.1339	1.5934
28	13.618	13.478	0.971	14.02	1.030	71.329	240.68	377.14	136.47	1.1389	1.5928
29	13.972	13.830	0.975	13.62	1.025	73.433	242.22	377.46	135.25	1.1440	1.5923
30	14.332	14.190	0.980	13.23	1.020	75.598	243.77	377.77	134.00	1.1491	1.5917
31	14.699	14.556	0.985	12.85	1.015	77.826	245.33	378.07	132.74	1.1542	1.5911
32	15.074	14.930	0.990	12.48	1.010	80.120	246.89	378.35	131.46	1.1593	1.5905
33	15.455	15.310	0.995	12.12	1.005	82.483	248.48	378.63	130.15	1.1644	1.5899
34	15.844	15.698	1.001	11.78	0.999	84.918	250.07	378.89	128.83	1.1695	1.5893
35	16.240	16.093	1.006	11.44	0.994	87.427	251.67	379.15	127.48	1.1747	1.5886
36	16.643	16.496	1.011	11.11	0.989	90.015	253.28	379.38	126.10	1.1799	1.5879
37	17.054	16.906	1.017	10.79	0.983	92.683	254.91	379.61	124.70	1.1851	1.5872
38	17.473	17.323	1.023	10.48	0.977	95.438	256.55	379.82	123.27	1.1903	1.5864
39	17.899	17.749	1.029	10.17	0.972	98.282	258.21	380.02	121.81	1.1955	1.5857

Solkane® 404A

Release 1.02

t [°C]	p′ [bar]	p″ [bar]	v′ [dm³/kg]	v″ [dm³/kg]	ρ′ [kg/dm³]	ρ″ [kg/m³]	h′ [kJ/kg]	h″ [kJ/kg]	r [kJ/kg]	s′ [kJ/kg·K]	s″ [kJ/kg·K]
40	18.333	18.182	1.035	9.88	0.966	101.220	259.87	380.20	120.32	1.2008	1.5849
41	18.775	18.624	1.042	9.59	0.960	104.257	261.56	380.36	118.80	1.2061	1.5840
42	19.226	19.073	1.048	9.31	0.954	107.399	263.25	380.50	117.25	1.2114	1.5831
43	19.684	19.531	1.055	9.04	0.948	110.650	264.97	380.63	115.66	1.2167	1.5822
44	20.151	19.997	1.062	8.77	0.942	114.018	266.70	380.74	114.04	1.2221	1.5813
45	20.626	20.472	1.069	8.51	0.935	117.509	268.45	380.82	112.37	1.2275	1.5803
46	21.109	20.955	1.077	8.26	0.929	121.131	270.21	380.88	110.67	1.2329	1.5792
47	21.602	21.447	1.084	8.01	0.922	124.892	272.00	380.92	108.92	1.2384	1.5781
48	22.103	21.948	1.093	7.76	0.915	128.801	273.80	380.94	107.13	1.2439	1.5769
49	22.613	22.458	1.101	7.53	0.908	132.868	275.63	380.92	105.29	1.2494	1.5757
50	23.132	22.977	1.110	7.29	0.901	137.105	277.47	380.88	103.40	1.2549	1.5743
51	23.660	23.506	1.119	7.07	0.894	141.523	279.34	380.80	101.46	1.2605	1.5730
52	24.198	24.044	1.128	6.84	0.886	146.137	281.23	380.69	99.46	1.2661	1.5715
53	24.746	24.592	1.138	6.62	0.879	150.962	283.14	380.54	97.40	1.2718	1.5699
54	25.303	25.149	1.149	6.41	0.871	156.015	285.08	380.35	95.27	1.2775	1.5682
55	25.870	25.717	1.160	6.20	0.862	161.317	287.05	380.12	93.08	1.2832	1.5665
56	26.447	26.295	1.171	5.99	0.854	166.889	289.04	379.84	90.81	1.2890	1.5646
57	27.034	26.884	1.183	5.79	0.845	172.756	291.05	379.51	88.46	1.2948	1.5625
58	27.632	27.483	1.196	5.59	0.836	178.948	293.10	379.12	86.03	1.3007	1.5603
59	28.240	28.093	1.210	5.39	0.826	185.497	295.17	378.67	83.50	1.3066	1.5580
60	28.859	28.714	1.225	5.20	0.816	192.440	297.28	378.15	80.88	1.3125	1.5555
61	29.489	29.347	1.241	5.00	0.806	199.822	299.41	377.56	78.14	1.3185	1.5527
62	30.130	29.992	1.258	4.81	0.795	207.691	301.58	376.88	75.30	1.3246	1.5498
63	30.783	30.648	1.277	4.63	0.783	216.104	303.78	376.10	72.32	1.3307	1.5466
64	31.447	31.318	1.298	4.44	0.770	225.126	306.02	375.22	69.20	1.3368	1.5431
65	32.124	32.000	1.321	4.26	0.757	234.828	308.29	374.23	65.94	1.3430	1.5393
66	32.813	32.695	1.348	4.08	0.742	245.287	310.60	373.11	62.51	1.3492	1.5352
67	33.514	33.405	1.378	3.90	0.726	256.580	312.95	371.85	58.90	1.3555	1.5307
68	34.228	34.130	1.414	3.72	0.707	268.773	315.34	370.45	55.12	1.3619	1.5258

12.1.7 Solkane® 407C

Release 1.03

t [°C]	p′ [bar]	p″ [bar]	v′ [dm^3/kg]	v″ [dm^3/kg]	ρ′ [kg/dm^3]	ρ″ [kg/m^3]	h′ [kJ/kg]	h″ [kJ/kg]	r [kJ/kg]	s′ [kJ/kg·K]	s″ [kJ/kg·K]
–50	0.746	0.505	0.713	416.20	1.402	2.403	132.74	380.81	248.07	0.7305	1.8614
–49	0.785	0.534	0.715	394.95	1.399	2.532	134.02	381.42	247.41	0.7363	1.8589
–48	0.825	0.565	0.716	375.01	1.396	2.667	135.29	382.04	246.74	0.7420	1.8564
–47	0.867	0.596	0.718	356.27	1.393	2.807	136.57	382.65	246.08	0.7477	1.8540
–46	0.911	0.630	0.719	338.65	1.391	2.953	137.85	383.26	245.41	0.7534	1.8516
–45	0.957	0.664	0.721	322.05	1.388	3.105	139.13	383.87	244.74	0.7591	1.8493
–44	1.004	0.700	0.722	306.43	1.385	3.263	140.42	384.48	244.06	0.7647	1.8470
–43	1.053	0.738	0.724	291.72	1.382	3.428	141.71	385.08	243.38	0.7704	1.8447
–42	1.104	0.777	0.725	277.84	1.379	3.599	143.00	385.69	242.69	0.7760	1.8425
–41	1.157	0.818	0.727	264.76	1.376	3.777	144.29	386.29	242.00	0.7816	1.8403
–40	1.211	0.861	0.729	252.41	1.373	3.962	145.58	386.89	241.31	0.7872	1.8381
–39	1.268	0.905	0.730	240.75	1.370	4.154	146.88	387.49	240.61	0.7928	1.8360
–38	1.327	0.951	0.732	229.73	1.366	4.353	148.18	388.09	239.91	0.7984	1.8339
–37	1.388	0.999	0.733	219.32	1.363	4.560	149.49	388.69	239.20	0.8039	1.8319
–36	1.452	1.049	0.735	209.47	1.360	4.774	150.80	389.28	238.49	0.8094	1.8299
–35	1.517	1.101	0.737	200.15	1.357	4.996	152.11	389.88	237.77	0.8150	1.8279
–34	1.585	1.155	0.739	191.33	1.354	5.227	153.42	390.47	237.05	0.8205	1.8260
–33	1.655	1.211	0.740	182.97	1.351	5.465	154.74	391.06	236.32	0.8260	1.8241
–32	1.728	1.269	0.742	175.05	1.348	5.713	156.06	391.64	235.59	0.8314	1.8222
–31	1.803	1.329	0.744	167.54	1.345	5.969	157.38	392.23	234.85	0.8369	1.8203
–30	1.880	1.392	0.745	160.42	1.341	6.234	158.71	392.81	234.10	0.8424	1.8185
–29	1.960	1.457	0.747	153.66	1.338	6.508	160.04	393.39	233.36	0.8478	1.8167
–28	2.043	1.524	0.749	147.24	1.335	6.792	161.37	393.97	232.60	0.8532	1.8150
–27	2.129	1.593	0.751	141.14	1.332	7.085	162.71	394.55	231.84	0.8586	1.8132
–26	2.217	1.665	0.753	135.35	1.329	7.388	164.05	395.12	231.08	0.8640	1.8115
–25	2.308	1.740	0.755	129.84	1.325	7.702	165.39	395.69	230.30	0.8694	1.8098
–24	2.402	1.817	0.756	124.60	1.322	8.026	166.73	396.26	229.53	0.8748	1.8082
–23	2.499	1.897	0.758	119.61	1.319	8.361	168.08	396.83	228.74	0.8801	1.8066
–22	2.598	1.979	0.760	114.86	1.315	8.706	169.43	397.39	227.96	0.8855	1.8049
–21	2.701	2.064	0.762	110.34	1.312	9.063	170.79	397.95	227.16	0.8908	1.8034
–20	2.807	2.152	0.764	106.03	1.309	9.432	172.15	398.51	226.36	0.8961	1.8018
–19	2.916	2.243	0.766	101.92	1.305	9.812	173.51	399.06	225.56	0.9014	1.8003
–18	3.029	2.337	0.768	98.00	1.302	10.204	174.87	399.61	224.74	0.9067	1.7987
–17	3.144	2.434	0.770	94.26	1.298	10.609	176.24	400.16	223.92	0.9120	1.7972
–16	3.263	2.534	0.772	90.70	1.295	11.026	177.61	400.71	223.10	0.9172	1.7958
–15	3.386	2.637	0.774	87.29	1.292	11.456	178.98	401.25	222.27	0.9225	1.7943
–14	3.512	2.744	0.776	84.04	1.288	11.899	180.36	401.79	221.43	0.9277	1.7929
–13	3.641	2.853	0.778	80.93	1.285	12.356	181.74	402.33	220.59	0.9329	1.7914
–12	3.775	2.966	0.781	77.96	1.281	12.827	183.12	402.86	219.74	0.9382	1.7900
–11	3.911	3.083	0.783	75.12	1.278	13.312	184.50	403.39	218.89	0.9434	1.7887
–10	4.052	3.203	0.785	72.40	1.274	13.812	185.89	403.91	218.02	0.9486	1.7873
–9	4.196	3.326	0.787	69.80	1.271	14.326	187.28	404.43	217.15	0.9538	1.7859
–8	4.345	3.454	0.789	67.31	1.267	14.856	188.67	404.95	216.28	0.9589	1.7846
–7	4.497	3.584	0.792	64.93	1.263	15.401	190.07	405.47	215.40	0.9641	1.7833
–6	4.653	3.719	0.794	62.65	1.260	15.963	191.47	405.98	214.51	0.9692	1.7820
–5	4.813	3.858	0.796	60.46	1.256	16.540	192.87	406.49	213.62	0.9744	1.7807
–4	4.978	4.000	0.798	58.36	1.252	17.135	194.28	406.99	212.71	0.9795	1.7794
–3	5.146	4.146	0.801	56.35	1.249	17.746	195.68	407.49	211.81	0.9847	1.7782
–2	5.319	4.297	0.803	54.42	1.245	18.375	197.09	407.98	210.89	0.9898	1.7769
–1	5.497	4.452	0.806	52.57	1.241	19.022	198.51	408.47	209.97	0.9949	1.7757

Solkane® 407C

Release 1.03

t [°C]	p′ [bar]	p″ [bar]	v′ [dm³/kg]	v″ [dm³/kg]	ρ′ [kg/dm³]	ρ″ [kg/m³]	h′ [kJ/kg]	h″ [kJ/kg]	r [kJ/kg]	s′ [kJ/kg·K]	s″ [kJ/kg·K]
0	5.679	4.611	0.808	50.79	1.238	19.687	200.00	408.96	208.96	1.0000	1.7744
1	5.865	4.774	0.811	49.09	1.234	20.371	201.34	409.44	208.10	1.0051	1.7732
2	6.056	4.941	0.813	47.45	1.230	21.074	202.76	409.92	207.16	1.0102	1.7720
3	6.251	5.113	0.816	45.88	1.226	21.797	204.19	410.39	206.21	1.0153	1.7708
4	6.452	5.290	0.818	44.37	1.222	22.540	205.61	410.86	205.25	1.0203	1.7696
5	6.657	5.471	0.821	42.91	1.218	23.303	207.04	411.33	204.28	1.0254	1.7685
6	6.867	5.657	0.823	41.51	1.215	24.088	208.48	411.79	203.31	1.0305	1.7673
7	7.081	5.847	0.826	40.17	1.211	24.894	209.91	412.24	202.33	1.0355	1.7661
8	7.301	6.043	0.829	38.88	1.207	25.722	211.35	412.69	201.34	1.0406	1.7650
9	7.526	6.243	0.831	37.63	1.203	26.573	212.79	413.14	200.35	1.0456	1.7639
10	7.756	6.449	0.834	36.43	1.199	27.447	214.24	413.58	199.34	1.0507	1.7627
11	7.992	6.659	0.837	35.28	1.195	28.345	215.68	414.01	198.33	1.0557	1.7616
12	8.232	6.875	0.840	34.17	1.191	29.267	217.14	414.44	197.31	1.0607	1.7605
13	8.478	7.096	0.843	33.10	1.187	30.214	218.59	414.87	196.28	1.0658	1.7594
14	8.730	7.322	0.846	32.07	1.182	31.186	220.05	415.29	195.24	1.0708	1.7582
15	8.987	7.554	0.849	31.07	1.178	32.185	221.51	415.70	194.19	1.0758	1.7571
16	9.249	7.792	0.852	30.11	1.174	33.211	222.98	416.11	193.13	1.0808	1.7560
17	9.518	8.035	0.855	29.19	1.170	34.264	224.44	416.51	192.07	1.0859	1.7549
18	9.792	8.283	0.858	28.29	1.166	35.345	225.92	416.91	190.99	1.0909	1.7539
19	10.072	8.538	0.861	27.43	1.162	36.455	227.39	417.30	189.90	1.0959	1.7528
20	10.358	8.798	0.864	26.60	1.157	37.595	228.88	417.68	188.81	1.1009	1.7517
21	10.649	9.064	0.867	25.80	1.153	38.765	230.36	418.06	187.70	1.1059	1.7506
22	10.947	9.337	0.871	25.02	1.149	39.967	231.85	418.44	186.59	1.1109	1.7495
23	11.251	9.615	0.874	24.27	1.144	41.201	233.34	418.80	185.46	1.1159	1.7484
24	11.562	9.900	0.877	23.55	1.140	42.468	234.84	419.16	184.32	1.1210	1.7473
25	11.879	10.191	0.881	22.85	1.135	43.768	236.35	419.52	183.17	1.1260	1.7463
26	12.202	10.489	0.884	22.17	1.131	45.104	237.86	419.86	182.01	1.1310	1.7452
27	12.531	10.793	0.888	21.52	1.126	46.475	239.37	420.20	180.83	1.1360	1.7441
28	12.868	11.104	0.891	20.88	1.122	47.884	240.89	420.53	179.65	1.1410	1.7430
29	13.210	11.422	0.895	20.27	1.117	49.330	242.41	420.86	178.45	1.1460	1.7419
30	13.560	11.746	0.899	19.68	1.113	50.815	243.95	421.18	177.23	1.1511	1.7408
31	13.917	12.078	0.903	19.11	1.108	52.341	245.48	421.49	176.01	1.1561	1.7397
32	14.280	12.416	0.906	18.55	1.103	53.908	247.03	421.79	174.76	1.1611	1.7386
33	14.650	12.762	0.910	18.01	1.099	55.518	248.58	422.09	173.51	1.1662	1.7375
34	15.028	13.115	0.914	17.49	1.094	57.171	250.14	422.37	172.24	1.1712	1.7364
35	15.412	13.475	0.918	16.99	1.089	58.871	251.70	422.65	170.95	1.1763	1.7353
36	15.804	13.843	0.922	16.50	1.084	60.617	253.28	422.92	169.65	1.1813	1.7342
37	16.204	14.219	0.927	16.02	1.079	62.413	254.86	423.18	168.33	1.1864	1.7331
38	16.610	14.602	0.931	15.56	1.074	64.258	256.45	423.44	166.99	1.1915	1.7319
39	17.025	14.993	0.935	15.12	1.069	66.155	258.05	423.68	165.63	1.1965	1.7308
40	17.446	15.392	0.940	14.68	1.064	68.106	259.65	423.91	164.26	1.2016	1.7296
41	17.876	15.799	0.944	14.26	1.059	70.113	261.27	424.13	162.86	1.2067	1.7285
42	18.313	16.214	0.949	13.85	1.054	72.178	262.90	424.34	161.44	1.2118	1.7273
43	18.759	16.638	0.954	13.46	1.049	74.303	264.54	424.54	160.01	1.2169	1.7261
44	19.212	17.070	0.958	13.07	1.043	76.491	266.19	424.73	158.55	1.2221	1.7249
45	19.673	17.510	0.963	12.70	1.038	78.743	267.84	424.91	157.07	1.2272	1.7236
46	20.143	17.959	0.968	12.34	1.033	81.062	269.52	425.08	155.56	1.2323	1.7224
47	20.621	18.417	0.973	11.98	1.027	83.452	271.20	425.23	154.03	1.2375	1.7211
48	21.107	18.884	0.979	11.64	1.022	85.915	272.90	425.37	152.47	1.2427	1.7198
49	21.601	19.361	0.984	11.31	1.016	88.455	274.61	425.49	150.89	1.2478	1.7185

Solkane® 407C

Release 1.03

t [°C]	p′ [bar]	p″ [bar]	v′ [dm³/kg]	v″ [dm³/kg]	ρ′ [kg/dm³]	ρ″ [kg/m³]	h′ [kJ/kg]	h″ [kJ/kg]	r [kJ/kg]	s′ [kJ/kg·K]	s″ [kJ/kg·K]
50	22.105	19.846	0.990	10.98	1.011	91.074	276.33	425.60	149.28	1.2530	1.7172
51	22.616	20.341	0.995	10.66	1.005	93.777	278.07	425.70	147.63	1.2582	1.7158
52	23.137	20.845	1.001	10.36	0.999	96.567	279.82	425.78	145.96	1.2635	1.7145
53	23.666	21.359	1.007	10.06	0.993	99.449	281.59	425.84	144.26	1.2687	1.7130
54	24.205	21.883	1.013	9.76	0.987	102.426	283.37	425.89	142.52	1.2740	1.7116
55	24.752	22.417	1.019	9.48	0.981	105.505	285.17	425.91	140.74	1.2792	1.7101
56	25.309	22.961	1.026	9.20	0.975	108.690	286.99	425.92	138.93	1.2845	1.7086
57	25.875	23.516	1.032	8.93	0.969	111.986	288.82	425.90	137.08	1.2898	1.7070
58	26.450	24.081	1.039	8.67	0.963	115.400	290.68	425.87	135.19	1.2951	1.7054
59	27.035	24.657	1.046	8.41	0.956	118.939	292.55	425.81	133.26	1.3005	1.7037
60	27.629	25.244	1.053	8.16	0.950	122.609	294.45	425.72	131.28	1.3058	1.7020
61	28.233	25.842	1.061	7.91	0.943	126.419	296.36	425.61	129.25	1.3112	1.7002
62	28.846	26.451	1.068	7.67	0.936	130.377	298.30	425.48	127.18	1.3166	1.6984
63	29.470	27.072	1.076	7.44	0.929	134.492	300.26	425.31	125.05	1.3220	1.6965
64	30.104	27.705	1.084	7.21	0.922	138.775	302.24	425.11	122.87	1.3275	1.6945
65	30.747	28.350	1.093	6.98	0.915	143.236	304.24	424.88	120.63	1.3330	1.6925
66	31.401	29.007	1.102	6.76	0.908	147.889	306.27	424.61	118.34	1.3384	1.6904
67	32.065	29.677	1.111	6.55	0.900	152.745	308.33	424.30	115.97	1.3440	1.6882
68	32.740	30.360	1.121	6.34	0.892	157.822	310.41	423.95	113.54	1.3495	1.6858
69	33.425	31.057	1.131	6.13	0.884	163.135	312.52	423.56	111.04	1.3551	1.6834
70	34.120	31.766	1.141	5.93	0.876	168.702	314.66	423.12	108.46	1.3606	1.6809
71	34.826	32.490	1.152	5.73	0.868	174.545	316.83	422.63	105.80	1.3663	1.6782
72	35.544	33.229	1.164	5.53	0.859	180.687	319.03	422.08	103.05	1.3719	1.6754
73	36.272	33.982	1.176	5.34	0.850	187.153	321.26	421.48	100.22	1.3776	1.6725
74	37.011	34.750	1.190	5.16	0.841	193.974	323.52	420.80	97.28	1.3833	1.6694
75	37.761	35.535	1.204	4.97	0.831	201.183	325.82	420.06	94.24	1.3890	1.6661
76	38.522	36.336	1.219	4.79	0.821	208.819	328.15	419.24	91.09	1.3948	1.6626
77	39.295	37.155	1.235	4.61	0.810	216.927	330.51	418.33	87.81	1.4005	1.6589
78	40.079	37.992	1.253	4.43	0.798	225.558	332.92	417.32	84.41	1.4064	1.6550
79	40.875	38.847	1.272	4.26	0.786	234.776	335.36	416.22	80.86	1.4122	1.6508
80	41.682	39.724	1.294	4.09	0.773	244.654	337.84	414.99	77.15	1.4181	1.6463
81	42.501	40.622	1.319	3.92	0.758	255.284	340.36	413.63	73.28	1.4240	1.6414
82	43.331	41.544	1.347	3.75	0.742	266.785	342.92	412.12	69.20	1.4300	1.6362

12.1.8 Solkane® 410

Release 1.04

t [°C]	p [bar]	v′ [dm^3/kg]	v″ [dm^3/kg]	ρ′ [kg/dm^3]	ρ″ [kg/m^3]	h′ [kJ/kg]	h″ [kJ/kg]	r [kJ/kg]	s′ [kJ/kg·K]	s″ [kJ/kg·K]
−70	0.36	0.695	640.51	1.440	1.56	100.55	390.15	289.60	0.5828	2.0083
−69	0.38	0.696	604.08	1.436	1.66	101.97	390.72	288.74	0.5898	2.0041
−68	0.40	0.698	570.34	1.433	1.75	103.30	391.29	287.99	0.5962	2.0000
−67	0.43	0.700	538.83	1.429	1.86	104.62	391.86	287.24	0.6026	1.9960
−66	0.46	0.701	509.17	1.426	1.96	106.05	392.42	286.37	0.6096	1.9920
−65	0.48	0.703	481.65	1.422	2.08	107.38	392.99	285.61	0.6159	1.9881
−64	0.51	0.705	455.89	1.419	2.19	108.71	393.56	284.85	0.6223	1.9842
−63	0.54	0.707	431.78	1.415	2.32	110.04	394.12	284.09	0.6286	1.9805
−62	0.57	0.708	409.01	1.412	2.45	111.48	394.68	283.20	0.6355	1.9767
−61	0.61	0.710	387.84	1.408	2.58	112.81	395.24	282.43	0.6417	1.9730
−60	0.64	0.712	367.96	1.405	2.72	114.15	395.80	281.65	0.6480	1.9694
−59	0.68	0.714	349.17	1.401	2.86	115.59	396.34	280.75	0.6548	1.9658
−58	0.72	0.715	331.65	1.398	3.02	116.93	396.89	279.96	0.6610	1.9622
−57	0.76	0.717	315.11	1.394	3.17	118.33	397.44	279.12	0.6674	1.9587
−56	0.80	0.719	299.63	1.391	3.34	119.67	397.99	278.32	0.6736	1.9553
−55	0.84	0.721	284.97	1.387	3.51	121.08	398.53	277.45	0.6801	1.9519
−54	0.89	0.723	271.22	1.384	3.69	122.46	399.07	276.61	0.6864	1.9486
−53	0.94	0.725	258.23	1.380	3.87	123.86	399.61	275.74	0.6928	1.9453
−52	0.99	0.727	246.05	1.376	4.06	125.21	400.14	274.93	0.6989	1.9421
−51	1.04	0.728	234.50	1.373	4.26	126.61	400.68	274.06	0.7052	1.9389
−50	1.09	0.730	223.62	1.369	4.47	128.00	401.21	273.21	0.7114	1.9357
−49	1.15	0.732	213.32	1.366	4.69	129.42	401.73	272.31	0.7177	1.9326
−48	1.21	0.734	203.62	1.362	4.91	130.81	402.25	271.45	0.7239	1.9295
−47	1.27	0.736	194.44	1.358	5.14	132.20	402.78	270.58	0.7300	1.9265
−46	1.33	0.738	185.76	1.355	5.38	133.59	403.30	269.71	0.7361	1.9235
−45	1.40	0.740	177.54	1.351	5.63	135.00	403.81	268.81	0.7423	1.9205
−44	1.46	0.742	169.75	1.348	5.89	136.41	404.32	267.91	0.7484	1.9176
−43	1.54	0.744	162.39	1.344	6.16	137.80	404.83	267.03	0.7545	1.9147
−42	1.61	0.746	155.39	1.340	6.44	139.23	405.34	266.11	0.7607	1.9119
−41	1.68	0.748	148.76	1.337	6.72	140.64	405.84	265.20	0.7667	1.9091
−40	1.76	0.750	142.48	1.333	7.02	142.04	406.34	264.30	0.7727	1.9063
−39	1.84	0.752	136.52	1.329	7.33	143.45	406.84	263.39	0.7787	1.9036
−38	1.93	0.754	130.85	1.326	7.64	144.87	407.33	262.46	0.7847	1.9009
−37	2.02	0.756	125.47	1.322	7.97	146.28	407.82	261.54	0.7907	1.8982
−36	2.11	0.759	120.35	1.318	8.31	147.70	408.31	260.61	0.7967	1.8956
−35	2.20	0.761	115.48	1.314	8.66	149.12	408.79	259.67	0.8026	1.8930
−34	2.30	0.763	110.85	1.311	9.02	150.54	409.27	258.73	0.8085	1.8904
−33	2.40	0.765	106.45	1.307	9.39	151.97	409.75	257.78	0.8145	1.8879
−32	2.50	0.767	102.25	1.303	9.78	153.40	410.22	256.82	0.8204	1.8854
−31	2.61	0.770	98.25	1.300	10.18	154.82	410.69	255.87	0.8262	1.8829
−30	2.72	0.772	94.45	1.296	10.59	156.24	411.16	254.92	0.8321	1.8804
−29	2.83	0.774	90.82	1.292	11.01	157.67	411.62	253.96	0.8379	1.8780
−28	2.95	0.776	87.35	1.288	11.45	159.11	412.08	252.97	0.8437	1.8756
−27	3.07	0.779	84.05	1.284	11.90	160.54	412.54	252.00	0.8495	1.8733
−26	3.19	0.781	80.90	1.281	12.36	161.96	412.99	251.03	0.8552	1.8709
−25	3.32	0.783	77.88	1.277	12.84	163.40	413.44	250.04	0.8610	1.8686
−24	3.45	0.786	75.01	1.273	13.33	164.84	413.89	249.05	0.8667	1.8663
−23	3.59	0.788	72.25	1.269	13.84	166.28	414.33	248.04	0.8725	1.8641
−22	3.73	0.790	69.63	1.265	14.36	167.72	414.77	247.05	0.8782	1.8618
−21	3.88	0.793	67.11	1.261	14.90	169.17	415.20	246.03	0.8839	1.8596

Solkane® 410

Release 1.04

t [°C]	p [bar]	v´ [dm^3/kg]	v´´ [dm^3/kg]	ρ´ [kg/dm^3]	ρ´´ [kg/m^3]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–20	4.03	0.795	64.70	1.258	15.46	170.61	415.63	245.02	0.8896	1.8574
–19	4.18	0.798	62.40	1.254	16.03	172.06	416.06	244.00	0.8952	1.8553
–18	4.34	0.800	60.20	1.250	16.61	173.51	416.48	242.97	0.9009	1.8531
–17	4.50	0.803	58.09	1.246	17.22	174.95	416.90	241.95	0.9064	1.8510
–16	4.67	0.805	56.06	1.242	17.84	176.41	417.31	240.91	0.9121	1.8489
–15	4.84	0.808	54.12	1.238	18.48	177.87	417.72	239.86	0.9177	1.8468
–14	5.02	0.810	52.27	1.234	19.13	179.32	418.13	238.81	0.9232	1.8447
–13	5.20	0.813	50.48	1.230	19.81	180.78	418.53	237.75	0.9288	1.8427
–12	5.38	0.815	48.77	1.226	20.50	182.24	418.93	236.68	0.9344	1.8407
–11	5.58	0.818	47.13	1.222	21.22	183.71	419.32	235.61	0.9399	1.8387
–10	5.77	0.821	45.55	1.218	21.95	185.17	419.71	234.54	0.9454	1.8367
–9	5.97	0.823	44.04	1.214	22.71	186.64	420.10	233.46	0.9509	1.8347
–8	6.18	0.826	42.58	1.210	23.48	188.11	420.47	232.36	0.9564	1.8328
–7	6.39	0.829	41.19	1.206	24.28	189.59	420.85	231.26	0.9619	1.8308
–6	6.61	0.832	39.84	1.202	25.10	191.06	421.22	230.16	0.9674	1.8289
–5	6.84	0.835	38.55	1.198	25.94	192.54	421.59	229.05	0.9728	1.8270
–4	7.07	0.837	37.31	1.194	26.81	194.03	421.95	227.92	0.9783	1.8251
–3	7.30	0.840	36.11	1.190	27.69	195.52	422.30	226.79	0.9837	1.8232
–2	7.54	0.843	34.96	1.186	28.61	197.01	422.65	225.65	0.9892	1.8213
–1	7.79	0.846	33.85	1.182	29.54	198.50	423.00	224.50	0.9946	1.8195
0	8.04	0.849	32.78	1.178	30.51	200.00	423.34	223.34	1.0000	1.8177
1	8.30	0.852	31.75	1.174	31.49	201.50	423.68	222.18	1.0054	1.8158
2	8.57	0.855	30.76	1.169	32.51	203.01	424.01	221.00	1.0108	1.8140
3	8.84	0.858	29.81	1.165	33.55	204.52	424.33	219.81	1.0162	1.8122
4	9.12	0.861	28.88	1.161	34.62	206.04	424.65	218.61	1.0216	1.8104
5	9.40	0.864	28.00	1.157	35.72	207.56	424.96	217.41	1.0270	1.8086
6	9.69	0.868	27.14	1.153	36.85	209.08	425.27	216.19	1.0324	1.8068
7	9.99	0.871	26.31	1.148	38.01	210.62	425.57	214.95	1.0378	1.8050
8	10.30	0.874	25.51	1.144	39.20	212.15	425.86	213.71	1.0431	1.8033
9	10.61	0.877	24.74	1.140	40.42	213.70	426.15	212.46	1.0485	1.8015
10	10.93	0.881	24.00	1.135	41.67	015.24	426.44	211.19	1.0539	1.7998
11	11.25	0.884	23.28	1.131	42.96	216.80	426.71	209.91	1.0593	1.7980
12	11.59	0.888	22.58	1.127	44.29	218.36	426.98	208.62	1.0647	1.7963
13	11.93	0.891	21.91	1.122	45.65	219.93	427.24	207.31	1.0701	1.7945
14	12.28	0.895	21.26	1.118	47.04	221.51	427.49	205.99	1.0754	1.7928
15	12.63	0.898	20.63	1.113	48.48	223.09	427.74	204.65	1.0808	1.7911
16	13.00	0.902	20.02	1.109	49.95	224.68	427.98	203.29	1.0862	1.7893
17	13.37	0.905	19.43	1.105	51.46	226.28	428.21	201.92	1.0917	1.7876
18	13.75	0.909	18.86	1.100	53.02	227.89	428.43	200.54	1.0971	1.7858
19	14.13	0.913	18.31	1.095	54.61	229.51	428.64	199.13	1.1025	1.7841
20	14.53	0.917	17.78	1.091	56.26	231.14	428.85	197.71	1.1079	1.7824
21	14.93	0.921	17.26	1.086	57.94	232.78	429.04	196.27	1.1134	1.7806
22	15.35	0.924	16.76	1.082	59.68	234.42	429.23	194.80	1.1189	1.7789
23	15.77	0.928	16.27	1.077	61.46	236.08	429.40	193.32	1.1243	1.7771
24	16.20	0.933	15.80	1.072	63.30	237.76	429.57	191.81	1.1298	1.7754
25	16.64	0.937	15.34	1.068	65.18	239.44	429.73	190.29	1.1354	1.7736
26	17.08	0.941	14.90	1.063	67.12	241.14	429.87	188.74	1.1409	1.7718
27	17.54	0.945	14.47	1.058	69.12	242.85	430.00	187.16	1.1465	1.7700
28	18.01	0.949	14.05	1.053	71.18	244.57	430.13	185.56	1.1520	1.7682
29	18.48	0.954	13.64	1.048	73.29	246.31	430.24	183.93	1.1577	1.7664

Solkane® 410

Release 1.04

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
30	18.97	0.958	13.25	1.043	75.47	248.06	430.33	182.27	1.1633	1.7646
31	19.46	0.963	12.87	1.039	77.72	249.83	430.42	180.59	1.1690	1.7627
32	19.96	0.968	12.50	1.034	80.03	251.61	430.49	178.88	1.1747	1.7609
33	20.48	0.972	12.13	1.028	82.41	253.41	430.54	177.13	1.1804	1.7590
34	21.00	0.977	11.78	1.023	84.87	255.24	430.58	175.35	1.1862	1.7571
35	21.53	0.982	11.44	1.018	87.40	257.07	430.61	173.54	1.1920	1.7551
36	22.08	0.987	11.11	1.013	90.02	258.94	430.62	171.68	1.1978	1.7532
37	22.63	0.992	10.79	1.008	92.72	260.82	430.61	169.79	1.2037	1.7512
38	23.20	0.998	10.47	1.002	95.51	262.72	430.58	167.86	1.2097	1.7492
39	23.77	1.003	10.16	0.997	98.40	264.64	430.54	165.89	1.2157	1.7471
40	24.36	1.008	9.86	0.992	101.38	266.60	430.47	163.87	1.2217	1.7450
41	24.95	1.014	9.57	0.986	104.46	268.57	430.38	161.81	1.2278	1.7429
42	25.56	1.020	9.29	0.981	107.66	270.57	430.27	159.70	1.2340	1.7407
43	26.18	1.026	9.01	0.975	110.97	272.60	430.14	157.54	1.2402	1.7385
44	26.81	1.032	8.74	0.969	114.40	274.66	429.98	155.32	1.2465	1.7362
45	27.45	1.038	8.48	0.963	117.96	276.75	429.79	153.04	1.2529	1.7339
46	28.10	1.045	8.22	0.957	121.66	278.88	429.58	150.70	1.2593	1.7315
47	28.76	1.051	7.97	0.951	125.50	281.04	429.34	148.30	1.2659	1.7291
48	29.44	1.058	7.72	0.945	129.51	283.23	429.06	145.83	1.2725	1.7266
49	30.13	1.065	7.48	0.939	133.68	285.46	428.75	143.28	1.2792	1.7240
50	30.83	1.072	7.24	0.932	138.03	287.74	428.40	140.66	1.2860	1.7213
51	31.54	1.080	7.01	0.926	142.58	290.06	428.01	137.95	1.2930	1.7185
52	32.26	1.088	6.79	0.919	147.34	292.42	427.58	135.15	1.3000	1.7157
53	33.00	1.096	6.56	0.912	152.33	294.84	427.09	132.26	1.3072	1.7127
54	33.74	1.105	6.35	0.905	157.57	297.30	426.56	129.26	1.3145	1.7096
55	34.50	1.114	6.13	0.898	163.10	299.83	425.97	126.14	1.3219	1.7063
56	35.28	1.123	5.92	0.890	168.92	302.42	425.32	122.90	1.3295	1.7029
57	36.06	1.133	5.71	0.882	175.10	305.07	424.60	119.52	1.3373	1.6994
58	36.86	1.144	5.50	0.874	181.66	307.80	423.79	115.99	1.3453	1.6956
59	37.67	1.155	5.30	0.866	188.65	310.60	422.90	112.30	1.3535	1.6916
60	38.49	1.167	5.10	0.857	196.15	313.50	421.91	108.41	1.3619	1.6873
61	39.32	1.180	4.90	0.848	204.24	316.49	420.79	104.30	1.3706	1.6827
62	40.17	1.193	4.69	0.838	213.02	319.60	419.54	99.94	1.3796	1.6777
63	41.03	1.209	4.49	0.827	222.65	322.83	418.11	95.28	1.3889	1.6723
64	41.90	1.225	4.29	0.816	233.34	326.22	416.48	90.26	1.3986	1.6663
65	42.78	1.244	4.07	0.804	245.40	329.79	414.57	84.78	1.4089	1.6596
66	43.67	1.265	3.86	0.790	259.36	333.59	412.28	78.70	1.4198	1.6518
67	44.57	1.290	3.62	0.775	276.17	337.69	409.44	71.75	1.4315	1.6424
68	45.48	1.321	3.36	0.757	298.03	342.25	405.63	63.38	1.4445	1.6303
69	46.39	1.360	3.00	0.735	332.86	347.66	399.38	51.72	1.4600	1.6112
70	47.31	1.415	2.52	0.707	396.88	353.49	388.44	34.95	1.4767	1.5785
71	48.23	1.512	2.41	0.661	414.58	358.08	386.50	28.41	1.4896	1.5722
71.8	48.93	2.052	2.05	0.487	487.37	375.94	375.94	0.00	1.5410	1.5410

12.1.9 Solkane® 507

Release 1.04

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–70	0.27	0.708	614.43	1.412	1.63	103.93	322.04	218.11	0.5948	1.6684
–69	0.29	0.710	578.48	1.408	1.73	105.47	322.64	217.16	0.6024	1.6661
–68	0.31	0.712	545.39	1.405	1.83	106.90	323.25	216.35	0.6093	1.6639
–67	0.33	0.714	514.56	1.401	1.94	108.31	323.86	215.54	0.6162	1.6618
–66	0.35	0.716	485.83	1.398	2.06	109.73	324.47	214.74	0.6230	1.6597
–65	0.37	0.717	459.02	1.394	2.18	111.14	325.08	213.94	0.6298	1.6576
–64	0.40	0.719	434.00	1.391	2.30	112.55	325.69	213.14	0.6366	1.6556
–63	0.42	0.721	410.44	1.387	2.44	114.04	326.29	212.25	0.6437	1.6537
–62	0.44	0.723	388.51	1.384	2.57	115.48	326.90	211.41	0.6505	1.6517
–61	0.47	0.725	368.06	1.380	2.72	116.89	327.50	210.62	0.6571	1.6499
–60	0.50	0.727	348.91	1.376	2.87	118.28	328.11	209.83	0.6637	1.6481
–59	0.53	0.728	330.96	1.373	3.02	119.68	328.72	209.04	0.6702	1.6463
–58	0.56	0.730	314.09	1.369	3.18	121.10	329.32	208.22	0.6768	1.6446
–57	0.59	0.732	298.21	1.366	3.35	122.54	329.92	207.38	0.6835	1.6429
–56	0.62	0.734	283.39	1.362	3.53	123.93	330.53	206.60	0.6899	1.6413
–55	0.66	0.736	269.45	1.359	3.71	125.31	331.13	205.82	0.6962	1.6397
–54	0.69	0.738	256.30	1.355	3.90	126.73	331.73	205.00	0.7027	1.6381
–53	0.73	0.740	243.92	1.352	4.10	128.15	332.33	204.19	0.7091	1.6366
–52	0.77	0.742	232.31	1.348	4.31	129.52	332.93	203.41	0.7153	1.6351
–51	0.81	0.744	221.32	1.345	4.52	130.94	333.53	202.59	0.7217	1.6337
–50	0.85	0.746	210.98	1.341	4.74	132.34	334.13	201.79	0.7280	1.6323
–49	0.90	0.748	201.26	1.338	4.97	133.70	334.73	201.03	0.7341	1.6309
–48	0.94	0.749	192.03	1.334	5.21	135.11	335.32	200.21	0.7404	1.6296
–47	0.99	0.751	183.34	1.331	5.45	136.50	335.91	199.42	0.7465	1.6283
–46	1.04	0.753	175.12	1.327	5.71	137.89	336.51	198.62	0.7526	1.6270
–45	1.09	0.755	167.36	1.324	5.98	139.27	337.10	197.83	0.7586	1.6257
–44	1.14	0.757	160.01	1.320	6.25	140.64	337.69	197.05	0.7646	1.6245
–43	1.20	0.759	153.06	1.317	6.53	142.02	338.28	196.27	0.7706	1.6234
–42	1.25	0.762	146.47	1.313	6.83	143.40	338.87	195.47	0.7766	1.6222
–41	1.31	0.764	140.22	1.310	7.13	144.77	339.46	194.68	0.7825	1.6211
–40	1.37	0.766	134.30	1.306	7.45	146.14	340.04	193.90	0.7883	1.6200
–39	1.44	0.768	128.67	1.303	7.77	147.52	340.63	193.10	0.7942	1.6189
–38	1.50	0.770	123.35	1.299	8.11	148.88	341.21	192.33	0.8000	1.6179
–37	1.57	0.772	118.29	1.296	8.45	150.23	341.79	191.56	0.8057	1.6169
–36	1.64	0.774	113.48	1.292	8.81	151.60	342.37	190.77	0.8115	1.6159
–35	1.71	0.776	108.90	1.288	9.18	152.97	342.95	189.98	0.8172	1.6149
–34	1.79	0.778	104.55	1.285	9.57	154.33	343.53	189.20	0.8229	1.6140
–33	1.87	0.780	100.42	1.281	9.96	155.68	344.10	188.42	0.8285	1.6131
–32	1.95	0.783	96.48	1.278	10.37	157.04	344.68	187.64	0.8341	1.6122
–31	2.03	0.785	92.73	1.274	10.79	158.39	345.25	186.86	0.8397	1.6113
–30	2.11	0.787	89.15	1.271	11.22	159.75	345.82	186.07	0.8452	1.6105
–29	2.20	0.789	85.74	1.267	11.66	161.09	346.39	185.30	0.8507	1.6097
–28	2.29	0.791	82.49	1.264	12.12	162.44	346.96	184.52	0.8562	1.6089
–27	2.39	0.794	79.39	1.260	12.60	163.79	347.52	183.73	0.8617	1.6081
–26	2.48	0.796	76.43	1.257	13.08	165.14	348.08	182.94	0.8671	1.6073
–25	2.58	0.798	73.60	1.253	13.59	166.49	348.64	182.16	0.8725	1.6066
–24	2.68	0.800	70.90	1.249	14.10	167.82	349.20	181.38	0.8779	1.6059
–23	2.79	0.803	68.32	1.246	14.64	169.17	349.76	180.59	0.8832	1.6052
–22	2.90	0.805	65.85	1.242	15.19	170.51	350.32	179.81	0.8885	1.6045
–21	3.01	0.807	63.49	1.239	15.75	171.85	350.87	179.02	0.8938	1.6038

Solkane® 507

Release 1.04

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–20	3.13	0.810	61.24	1.235	16.33	173.19	351.42	178.23	0.8991	1.6031
–19	3.24	0.812	59.07	1.231	16.93	174.53	351.97	177.44	0.9043	1.6025
–18	3.36	0.814	57.00	1.228	17.54	175.86	352.52	176.65	0.9095	1.6019
–17	3.49	0.817	55.02	1.224	18.18	177.20	353.06	175.86	0.9147	1.6013
–16	3.62	0.819	53.12	1.221	18.83	178.55	353.60	175.05	0.9199	1.6007
–15	3.75	0.822	51.30	1.217	19.49	179.88	354.14	174.26	0.9251	1.6001
–14	3.89	0.824	49.55	1.213	20.18	181.22	354.68	173.46	0.9302	1.5995
–13	4.02	0.827	47.88	1.210	20.89	182.55	355.21	172.66	0.9353	1.5990
–12	4.17	0.829	46.27	1.206	21.61	183.89	355.74	171.85	0.9404	1.5984
–11	4.31	0.832	44.72	1.202	22.36	185.23	356.27	171.04	0.9454	1.5979
–10	4.47	0.834	43.24	1.199	23.13	186.57	356.80	170.23	0.9505	1.5974
–9	4.62	0.837	41.81	1.195	23.92	187.90	357.32	169.42	0.9555	1.5969
–8	4.78	0.840	40.45	1.191	24.73	189.24	357.84	168.60	0.9605	1.5964
–7	4.94	0.842	39.13	1.187	25.56	190.58	358.36	167.78	0.9655	1.5959
–6	5.11	0.845	37.86	1.184	26.41	191.92	358.87	166.95	0.9705	1.5954
–5	5.28	0.847	36.64	1.180	27.29	193.27	359.39	166.12	0.9755	1.5950
–4	5.45	0.850	35.47	1.176	28.19	194.61	359.89	165.29	0.9804	1.5945
–3	5.63	0.853	34.34	1.172	29.12	195.95	360.40	164.44	0.9853	1.5940
–2	5.82	0.856	33.26	1.169	30.07	197.30	360.90	163.60	0.9903	1.5936
–1	6.01	0.858	32.21	1.165	31.05	198.65	361.40	162.75	0.9952	1.5932
0	6.20	0.861	31.20	1.161	32.05	200.00	361.89	161.89	1.0000	1.5927
1	6.40	0.864	30.23	1.157	33.08	201.35	362.38	161.03	1.0049	1.5923
2	6.60	0.867	29.29	1.153	34.14	202.70	362.87	160.17	1.0098	1.5919
3	6.81	0.870	28.39	1.149	35.22	204.06	363.35	159.29	1.0146	1.5915
4	7.02	0.873	27.52	1.146	36.34	205.42	363.83	158.41	1.0195	1.5910
5	7.24	0.876	26.68	1.142	37.48	206.78	364.30	157.52	1.0243	1.5906
6	7.46	0.879	25.87	1.138	38.66	208.15	364.77	156.62	1.0292	1.5902
7	7.68	0.882	25.08	1.134	39.87	209.52	365.24	155.72	1.0340	1.5898
8	7.92	0.885	24.33	1.130	41.11	210.89	365.70	154.81	1.0388	1.5894
9	8.15	0.888	23.59	1.126	42.38	212.27	366.15	153.89	1.0436	1.5890
10	8.40	0.891	22.89	1.122	43.69	213.65	366.61	152.96	1.0484	1.5886
11	8.65	0.895	22.21	1.118	45.04	215.03	367.05	152.02	1.0532	1.5882
12	8.90	0.898	21.54	1.114	46.42	216.42	367.49	151.07	1.0580	1.5878
13	9.16	0.901	20.91	1.109	47.83	217.82	367.93	150.11	1.0628	1.5874
14	9.42	0.905	20.29	1.105	49.29	219.21	368.36	149.14	1.0676	1.5870
15	9.69	0.908	19.69	1.101	50.79	220.62	368.78	148.16	1.0724	1.5866
16	9.97	0.912	19.11	1.097	52.32	222.03	369.20	147.17	1.0772	1.5862
17	10.25	0.915	18.55	1.093	53.90	223.45	369.61	146.17	1.0820	1.5858
18	10.54	0.919	18.01	1.088	55.53	224.87	370.02	145.15	1.0868	1.5854
19	10.84	0.922	17.48	1.084	57.20	226.30	370.42	144.12	1.0916	1.5849
20	11.14	0.926	16.97	1.080	58.91	227.73	370.81	143.07	1.0964	1.5845
21	11.45	0.930	16.48	1.075	60.67	229.17	371.19	142.02	1.1013	1.5841
22	11.76	0.934	16.00	1.071	62.49	230.62	371.57	140.94	1.1061	1.5836
23	12.08	0.938	15.54	1.066	64.35	232.08	371.94	139.86	1.1109	1.5831
24	12.41	0.942	15.09	1.062	66.27	233.55	372.30	138.75	1.1157	1.5827
25	12.74	0.946	14.65	1.057	68.25	235.02	372.65	137.63	1.1206	1.5822
26	13.08	0.950	14.23	1.053	70.28	236.51	373.00	136.49	1.1254	1.5817
27	13.43	0.954	13.82	1.048	72.37	238.00	373.33	135.33	1.1303	1.5812
28	13.78	0.958	13.42	1.043	74.53	239.50	373.66	134.16	1.1352	1.5807
29	14.14	0.963	13.03	1.039	76.75	241.01	373.97	132.96	1.1401	1.5801

Solkane® 507

Release 1.04

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
30	14.51	0.967	12.65	1.034	79.03	242.53	374.28	131.74	1.1450	1.5796
31	14.89	0.972	12.29	1.029	81.39	244.07	374.57	130.51	1.1499	1.5790
32	15.27	0.977	11.93	1.024	83.82	245.61	374.86	129.25	1.1549	1.5784
33	15.66	0.982	11.58	1.019	86.32	247.16	375.13	127.97	1.1598	1.5778
34	16.06	0.987	11.25	1.014	88.90	248.73	375.39	126.66	1.1648	1.5772
35	16.46	0.992	10.92	1.008	91.57	250.31	375.64	125.32	1.1698	1.5765
36	16.88	0.997	10.60	1.003	94.33	251.91	375.87	123.96	1.1749	1.5758
37	17.30	1.002	10.29	0.998	97.17	253.52	376.09	122.57	1.1799	1.5751
38	17.73	1.008	9.99	0.992	100.11	255.14	376.30	121.16	1.1850	1.5744
39	18.16	1.013	9.69	0.987	103.16	256.78	376.49	119.71	1.1901	1.5736
40	18.61	1.019	9.41	0.981	106.31	258.43	376.66	118.23	1.1953	1.5728
41	19.07	1.025	9.13	0.975	109.56	260.10	376.82	116.72	1.2004	1.5720
42	19.53	1.032	8.85	0.969	112.94	261.79	376.96	115.17	1.2057	1.5711
43	20.00	1.038	8.59	0.963	116.44	263.50	377.08	113.58	1.2109	1.5702
44	20.48	1.045	8.33	0.957	120.08	265.22	377.18	111.96	1.2162	1.5692
45	20.97	1.052	8.07	0.951	123.85	266.97	377.26	110.29	1.2215	1.5682
46	21.47	1.059	7.83	0.944	127.77	268.73	377.31	108.58	1.2269	1.5671
47	21.97	1.067	7.58	0.938	131.85	270.52	377.34	106.82	1.2323	1.5660
48	22.49	1.074	7.35	0.931	136.10	272.33	377.35	105.02	1.2378	1.5648
49	23.02	1.083	7.12	0.924	140.53	274.17	377.33	103.17	1.2433	1.5636
50	23.55	1.091	6.89	0.917	145.15	276.03	377.29	101.26	1.2489	1.5623
51	24.10	1.100	6.67	0.909	149.98	277.92	377.21	99.29	1.2546	1.5609
52	24.65	1.109	6.45	0.901	155.04	279.84	377.10	97.26	1.2603	1.5594
53	25.22	1.119	6.24	0.893	160.33	281.79	376.95	95.17	1.2661	1.5579
54	25.79	1.130	6.03	0.885	165.90	283.77	376.77	93.00	1.2720	1.5562
55	26.38	1.141	5.82	0.876	171.75	285.79	376.54	90.76	1.2779	1.5545
56	26.97	1.153	5.62	0.867	177.91	287.84	376.28	88.43	1.2840	1.5527
57	27.58	1.166	5.42	0.858	184.42	289.94	375.96	86.02	1.2901	1.5507
58	28.20	1.179	5.23	0.848	191.31	292.09	375.60	83.51	1.2964	1.5486
59	28.83	1.194	5.04	0.838	198.61	294.28	375.18	80.90	1.3028	1.5463
60	29.47	1.210	4.85	0.827	206.37	296.53	374.70	78.17	1.3093	1.5440
61	30.12	1.227	4.66	0.815	214.65	298.83	374.16	75.32	1.3160	1.5414
62	30.78	1.246	4.47	0.802	223.50	301.21	373.54	72.33	1.3228	1.5387
63	31.46	1.268	4.29	0.789	232.99	303.67	372.85	69.19	1.3299	1.5357
64	32.14	1.292	4.11	0.774	243.21	306.22	372.08	65.86	1.3372	1.5326
65	32.84	1.320	3.93	0.758	254.24	308.88	371.22	62.34	1.3448	1.5292
66	33.55	1.352	3.76	0.740	266.17	311.69	370.27	58.58	1.3529	1.5256
67	34.28	1.391	3.58	0.719	279.15	314.70	369.21	54.52	1.3614	1.5217
68	35.02	1.441	3.41	0.694	293.30	318.00	368.05	50.05	1.3708	1.5175
69	35.77	1.508	3.24	0.663	308.81	321.80	366.77	44.97	1.3816	1.5130
70	36.54	1.618	3.07	0.618	325.98	326.78	365.35	38.57	1.3958	1.5082
70.8	37.17	2.023	2.02	0.494	494.25	345.26	345.26	0	1.4491	1.4491

12.2.1 Solkane® 32

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–80	0.19	0.779	1621.22	1.284	0.62	74.05	481.53	407.48	0.4599	2.5696
–79	0.20	0.780	1519.97	1.281	0.66	75.48	482.13	406.65	0.4673	2.5618
–78	0.22	0.782	1426.03	1.279	0.70	76.93	482.72	405.80	0.4747	2.5541
–77	0.23	0.783	1338.95	1.277	0.75	78.36	483.32	404.96	0.4820	2.5466
–76	0.25	0.785	1258.04	1.274	0.79	79.81	483.90	404.09	0.4894	2.5391
–75	0.26	0.786	1182.86	1.272	0.85	81.27	484.49	403.22	0.4968	2.5317
–74	0.28	0.788	1113.00	1.269	0.90	82.71	485.07	402.36	0.5040	2.5244
–73	0.30	0.789	1047.93	1.267	0.95	84.17	485.64	401.48	0.5113	2.5172
–72	0.32	0.791	987.39	1.264	1.01	85.61	486.22	400.60	0.5185	2.5101
–71	0.34	0.793	930.87	1.262	1.07	87.10	486.78	399.69	0.5259	2.5031
–70	0.36	0.794	878.24	1.259	1.14	88.54	487.35	398.81	0.5330	2.4961
–69	0.38	0.796	829.08	1.257	1.21	90.01	487.91	397.90	0.5402	2.4893
–68	0.41	0.797	783.12	1.254	1.28	91.50	488.47	396.96	0.5475	2.4825
–67	0.43	0.799	740.21	1.252	1.35	92.98	489.02	396.04	0.5547	2.4758
–66	0.46	0.801	700.07	1.249	1.43	94.46	489.57	395.11	0.5618	2.4692
–65	0.49	0.802	662.48	1.247	1.51	95.95	490.11	394.16	0.5690	2.4626
–64	0.52	0.804	627.28	1.244	1.59	97.44	490.65	393.21	0.5761	2.4561
–63	0.55	0.806	594.30	1.241	1.68	98.93	491.19	392.25	0.5832	2.4498
–62	0.58	0.807	563.37	1.239	1.78	100.44	491.72	391.28	0.5903	2.4434
–61	0.61	0.809	534.34	1.236	1.87	101.94	492.24	390.30	0.5974	2.4372
–60	0.65	0.811	507.08	1.234	1.97	103.45	492.76	389.32	0.6045	2.4310
–59	0.69	0.812	481.48	1.231	2.08	104.96	493.28	388.32	0.6116	2.4249
–58	0.73	0.814	457.39	1.228	2.19	106.48	493.79	387.31	0.6186	2.4188
–57	0.77	0.816	434.75	1.226	2.30	107.99	494.30	386.30	0.6256	2.4128
–56	0.81	0.818	413.43	1.223	2.42	109.52	494.80	385.28	0.6327	2.4069
–55	0.85	0.819	393.37	1.220	2.54	111.04	495.30	384.26	0.6396	2.4011
–54	0.90	0.821	374.45	1.218	2.67	112.57	495.79	383.21	0.6466	2.3953
–53	0.95	0.823	356.62	1.215	2.80	114.10	496.27	382.17	0.6536	2.3895
–52	0.99	0.825	339.80	1.212	2.94	115.64	496.76	381.11	0.6605	2.3839
–51	1.05	0.827	323.92	1.210	3.09	117.18	497.23	380.05	0.6675	2.3782
–50	1.10	0.828	308.93	1.207	3.24	118.73	497.70	378.98	0.6744	2.3727
–49	1.16	0.830	294.76	1.204	3.39	120.27	498.17	377.90	0.6813	2.3672
–48	1.22	0.832	281.37	1.202	3.55	121.82	498.63	376.81	0.6881	2.3617
–47	1.28	0.834	268.71	1.199	3.72	123.38	499.08	375.71	0.6950	2.3563
–46	1.34	0.836	256.72	1.196	3.90	124.93	499.53	374.60	0.7019	2.3510
–45	1.41	0.838	245.37	1.193	4.08	126.50	499.98	373.48	0.7087	2.3457
–44	1.47	0.840	234.62	1.191	4.26	128.06	500.41	372.35	0.7155	2.3405
–43	1.54	0.842	224.44	1.188	4.46	129.63	500.85	371.22	0.7223	2.3353
–42	1.62	0.844	214.78	1.185	4.66	131.20	501.27	370.08	0.7291	2.3301
–41	1.69	0.846	205.62	1.182	4.86	132.77	501.69	368.92	0.7359	2.3250
–40	1.77	0.848	196.92	1.180	5.08	134.35	502.11	367.76	0.7426	2.3200
–39	1.85	0.850	188.67	1.177	5.30	135.93	502.52	366.59	0.7493	2.3150
–38	1.94	0.852	180.83	1.174	5.53	137.51	502.92	365.41	0.7561	2.3100
–37	2.03	0.854	173.38	1.171	5.77	139.10	503.32	364.22	0.7628	2.3051
–36	2.12	0.856	166.29	1.168	6.01	140.68	503.71	363.03	0.7694	2.3002
–35	2.21	0.858	159.56	1.165	6.27	142.28	504.10	361.82	0.7761	2.2954
–34	2.31	0.860	153.14	1.162	6.53	143.87	504.47	360.60	0.7828	2.2906
–33	2.41	0.862	147.04	1.159	6.80	145.47	504.85	359.38	0.7894	2.2859
–32	2.51	0.865	141.23	1.157	7.08	147.07	505.21	358.14	0.7960	2.2811
–31	2.62	0.867	135.69	1.154	7.37	148.68	505.58	356.90	0.8026	2.2765

Solkane® 32

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–30	2.73	0.869	130.41	1.151	7.67	150.28	505.93	355.64	0.8092	2.2718
–29	2.85	0.871	125.38	1.148	7.98	151.90	506.28	354.38	0.8158	2.2673
–28	2.97	0.874	120.58	1.145	8.29	153.51	506.62	353.11	0.8223	2.2627
–27	3.09	0.876	116.00	1.142	8.62	155.12	506.96	351.83	0.8288	2.2582
–26	3.22	0.878	111.63	1.139	8.96	156.74	507.28	350.54	0.8354	2.2537
–25	3.35	0.880	107.45	1.136	9.31	158.37	507.61	349.24	0.8419	2.2492
–24	3.48	0.883	103.47	1.133	9.67	159.99	507.92	347.93	0.8484	2.2448
–23	3.62	0.885	99.65	1.130	10.03	161.62	508.23	346.61	0.8548	2.2405
–22	3.76	0.888	96.01	1.127	10.42	163.25	508.54	345.28	0.8613	2.2361
–21	3.91	0.890	92.52	1.124	10.81	164.89	508.83	343.94	0.8677	2.2318
–20	4.06	0.892	89.19	1.121	11.21	166.52	509.12	342.60	0.8742	2.2275
–19	4.21	0.895	86.00	1.117	11.63	168.17	509.40	341.24	0.8806	2.2232
–18	4.37	0.897	82.94	1.114	12.06	169.81	509.68	339.87	0.8870	2.2190
–17	4.54	0.900	80.02	1.111	12.50	171.46	509.95	338.49	0.8934	2.2148
–16	4.71	0.902	77.21	1.108	12.95	173.11	510.21	337.10	0.8997	2.2107
–15	4.88	0.905	74.52	1.105	13.42	174.76	510.47	335.71	0.9061	2.2065
–14	5.06	0.908	71.95	1.102	13.90	176.42	510.71	334.30	0.9124	2.2024
–13	5.24	0.910	69.48	1.098	14.39	178.08	510.96	332.88	0.9188	2.1983
–12	5.43	0.913	67.11	1.095	14.90	179.74	511.19	331.45	0.9251	2.1943
–11	5.63	0.916	64.83	1.092	15.42	181.41	511.42	330.01	0.9314	2.1902
–10	5.83	0.918	62.65	1.089	15.96	183.08	511.64	328.55	0.9377	2.1862
–9	6.03	0.921	60.56	1.086	16.51	184.75	511.85	327.09	0.9440	2.1822
–8	6.24	0.924	58.54	1.082	17.08	186.43	512.05	325.62	0.9502	2.1783
–7	6.46	0.927	56.61	1.079	17.67	188.12	512.25	324.13	0.9565	2.1743
–6	6.68	0.930	54.75	1.076	18.27	189.80	512.44	322.64	0.9627	2.1704
–5	6.91	0.933	52.96	1.072	18.88	191.49	512.62	321.13	0.9690	2.1665
–4	7.14	0.936	51.24	1.069	19.52	193.18	512.79	319.61	0.9752	2.1627
–3	7.38	0.939	49.59	1.065	20.17	194.88	512.96	318.08	0.9814	2.1588
–2	7.62	0.942	48.00	1.062	20.83	196.59	513.12	316.53	0.9876	2.1550
–1	7.88	0.945	46.47	1.059	21.52	198.29	513.27	314.97	0.9938	2.1512
0	8.13	0.948	44.99	1.055	22.23	200.00	513.41	313.41	1.0000	2.1474
1	8.40	0.951	43.57	1.052	22.95	201.72	513.54	311.82	1.0062	2.1436
2	8.67	0.954	42.20	1.048	23.70	203.44	513.66	310.23	1.0123	2.1398
3	8.94	0.957	40.88	1.045	24.46	205.16	513.78	308.62	1.0185	2.1361
4	9.23	0.960	39.61	1.041	25.24	206.89	513.89	307.00	1.0247	2.1323
5	9.52	0.964	38.39	1.038	26.05	208.63	513.99	305.36	1.0308	2.1286
6	9.81	0.967	37.21	1.034	26.88	210.37	514.08	303.71	1.0369	2.1249
7	10.12	0.970	36.06	1.030	27.73	212.11	514.16	302.04	1.0431	2.1212
8	10.43	0.974	34.96	1.027	28.60	213.86	514.23	300.36	1.0492	2.1176
9	10.75	0.977	33.90	1.023	29.50	215.62	514.29	298.67	1.0553	2.1139
10	11.07	0.981	32.88	1.019	30.42	217.38	514.34	296.96	1.0615	2.1102
11	11.40	0.985	31.89	1.016	31.36	219.15	514.38	295.23	1.0676	2.1066
12	11.74	0.988	30.93	1.012	32.33	220.93	514.42	293.49	1.0737	2.1029
13	12.09	0.992	30.01	1.008	33.33	222.71	514.44	291.73	1.0798	2.0993
14	12.45	0.996	29.11	1.004	34.35	224.50	514.45	289.95	1.0859	2.0957
15	12.81	0.999	28.25	1.001	35.40	226.29	514.45	288.16	1.0921	2.0921
16	13.18	1.003	27.42	0.997	36.47	228.10	514.44	286.34	1.0982	2.0885
17	13.56	1.007	26.61	0.993	37.58	229.90	514.42	284.51	1.1043	2.0849
18	13.95	1.011	25.83	0.989	38.72	231.72	514.38	282.66	1.1104	2.0812
19	14.34	1.015	25.07	0.985	39.89	233.55	514.34	280.79	1.1165	2.0776

Solkane® 32

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
20	14.75	1.019	24.34	0.981	41.08	235.38	514.28	278.90	1.1226	2.0740
21	15.16	1.024	23.63	0.977	42.32	237.22	514.22	276.99	1.1288	2.0704
22	15.58	1.028	22.95	0.973	43.58	239.07	514.13	275.06	1.1349	2.0668
23	16.01	1.032	22.28	0.969	44.88	240.93	514.04	273.11	1.1410	2.0632
24	16.45	1.037	21.64	0.965	46.22	242.80	513.93	271.13	1.1472	2.0596
25	16.89	1.041	21.01	0.960	47.59	244.68	513.81	269.13	1.1533	2.0560
26	17.35	1.046	20.41	0.956	49.00	246.57	513.68	267.11	1.1595	2.0524
27	17.82	1.050	19.82	0.952	50.45	248.46	513.53	265.06	1.1657	2.0488
28	18.29	1.055	19.25	0.948	51.94	250.37	513.36	262.99	1.1719	2.0451
29	18.78	1.060	18.70	0.943	53.47	252.29	513.18	260.89	1.1781	2.0415
30	19.27	1.065	18.16	0.939	55.05	254.23	512.98	258.76	1.1843	2.0378
31	19.77	1.070	17.65	0.935	56.67	256.17	512.77	256.60	1.1905	2.0342
32	20.29	1.075	17.14	0.930	58.34	258.13	512.54	254.42	1.1967	2.0305
33	20.81	1.080	16.65	0.926	60.06	260.10	512.29	252.20	1.2030	2.0268
34	21.35	1.086	16.17	0.921	61.83	262.08	512.03	249.95	1.2093	2.0230
35	21.89	1.091	15.71	0.916	63.65	264.07	511.74	247.67	1.2156	2.0193
36	22.45	1.097	15.26	0.912	65.52	266.08	511.44	245.35	1.2219	2.0155
37	23.01	1.103	14.83	0.907	67.45	268.11	511.12	243.00	1.2282	2.0117
38	23.59	1.108	14.40	0.902	69.44	270.15	510.77	240.62	1.2346	2.0079
39	24.18	1.114	13.99	0.897	71.50	272.21	510.40	238.19	1.2410	2.0041
40	24.77	1.121	13.58	0.892	73.61	274.28	510.01	235.73	1.2474	2.0002
41	25.38	1.127	13.19	0.887	75.80	276.38	509.60	233.22	1.2539	1.9962
42	26.00	1.133	12.81	0.882	78.05	278.49	509.16	230.67	1.2603	1.9923
43	26.64	1.140	12.44	0.877	80.38	280.62	508.69	228.08	1.2669	1.9883
44	27.28	1.147	12.08	0.872	82.78	282.77	508.20	225.43	1.2734	1.9842
45	27.94	1.154	11.73	0.867	85.27	284.94	507.68	222.74	1.2800	1.9801
46	28.61	1.161	11.38	0.861	87.84	287.13	507.13	220.00	1.2866	1.9760
47	29.29	1.168	11.05	0.856	90.50	289.34	506.54	217.20	1.2933	1.9718
48	29.98	1.176	10.72	0.850	93.26	291.58	505.93	214.34	1.3001	1.9675
49	30.68	1.184	10.40	0.845	96.11	293.85	505.28	211.43	1.3068	1.9631
50	31.40	1.192	10.09	0.839	99.08	296.14	504.59	208.45	1.3137	1.9587
51	32.13	1.200	9.79	0.833	102.15	298.46	503.86	205.41	1.3206	1.9542
52	32.88	1.209	9.49	0.827	105.34	300.80	503.09	202.29	1.3275	1.9497
53	33.64	1.218	9.20	0.821	108.66	303.18	502.28	199.10	1.3345	1.9450
54	34.41	1.227	8.92	0.815	112.12	305.59	501.42	195.83	1.3416	1.9402
55	35.19	1.237	8.64	0.808	115.72	308.03	500.52	192.48	1.3488	1.9354
56	35.99	1.247	8.37	0.802	119.47	310.51	499.55	189.04	1.3560	1.9304
57	36.81	1.257	8.10	0.795	123.39	313.03	498.54	185.51	1.3634	1.9252
58	37.63	1.268	7.84	0.788	127.49	315.59	497.46	181.87	1.3708	1.9200
59	38.48	1.280	7.59	0.781	131.79	318.19	496.31	178.12	1.3783	1.9146
60	39.33	1.292	7.34	0.774	136.30	320.84	495.10	174.26	1.3859	1.9090
61	40.21	1.304	7.09	0.767	141.03	323.54	493.80	170.27	1.3937	1.9032
62	41.09	1.318	6.85	0.759	146.02	326.29	492.43	166.14	1.4016	1.8973
63	42.00	1.332	6.61	0.751	151.29	329.10	490.96	161.86	1.4096	1.8911
64	42.92	1.346	6.37	0.743	156.87	331.98	489.39	157.41	1.4177	1.8846
65	43.86	1.362	6.14	0.734	162.78	334.92	487.71	152.79	1.4261	1.8779
66	44.81	1.379	5.91	0.725	169.09	337.94	485.90	147.96	1.4346	1.8709
67	45.78	1.397	5.69	0.716	175.83	341.05	483.95	142.90	1.4434	1.8635
68	46.77	1.417	5.46	0.706	183.07	344.25	481.84	137.59	1.4524	1.8557
69	47.77	1.438	5.24	0.695	190.88	347.56	479.55	131.99	1.4616	1.8474

Solkane® 32

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
70	48.80	1.462	5.02	0.684	199.37	351.00	477.05	126.04	1.4712	1.8386
71	49.84	1.488	4.79	0.672	208.67	354.59	474.29	119.70	1.4813	1.8291
72	50.90	1.518	4.57	0.659	218.95	358.37	471.23	112.86	1.4918	1.8187
73	51.99	1.552	4.34	0.644	230.47	362.39	467.79	105.40	1.5029	1.8074
74	53.09	1.592	1.58	0.628	631.83	357.38	357.01	–0.37	1.4884	1.4874
75	54.21	1.642	1.62	0.609	618.31	362.55	361.57	–0.98	1.5028	1.5000
76	55.36	1.708	1.66	0.585	603.51	368.48	366.41	–2.07	1.5192	1.5133
77	56.53	1.809	1.70	0.553	587.05	376.01	371.63	–4.38	1.5402	1.5277
78.08	57.83	2.381	2.38	0.420	420.00	411.68	411.68	0.00	1.6410	1.6410

12.2.2 Solkane® 125

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–80	0.15	0.618	854.49	1.617	1.17	108.50	288.64	180.14	0.6076	1.5402
–79	0.17	0.620	800.34	1.614	1.25	109.53	289.22	179.69	0.6129	1.5384
–78	0.18	0.621	750.18	1.611	1.33	110.57	289.80	179.23	0.6182	1.5366
–77	0.19	0.622	703.66	1.608	1.42	111.62	290.37	178.75	0.6236	1.5349
–76	0.20	0.623	660.58	1.604	1.51	112.66	290.95	178.29	0.6289	1.5332
–75	0.22	0.625	620.61	1.601	1.61	113.71	291.53	177.82	0.6342	1.5316
–74	0.23	0.626	583.50	1.598	1.71	114.76	292.11	177.35	0.6395	1.5300
–73	0.25	0.627	548.96	1.595	1.82	115.83	292.69	176.86	0.6448	1.5284
–72	0.27	0.628	516.88	1.592	1.93	116.88	293.27	176.39	0.6500	1.5269
–71	0.28	0.629	487.01	1.589	2.05	117.94	293.85	175.91	0.6553	1.5254
–70	0.30	0.631	459.16	1.585	2.18	119.01	294.42	175.41	0.6605	1.5240
–69	0.32	0.632	433.23	1.582	2.31	120.07	295.00	174.93	0.6658	1.5226
–68	0.34	0.633	409.03	1.579	2.44	121.14	295.58	174.44	0.6710	1.5213
–67	0.36	0.635	386.41	1.576	2.59	122.22	296.16	173.94	0.6762	1.5200
–66	0.38	0.636	365.30	1.573	2.74	123.29	296.74	173.45	0.6814	1.5187
–65	0.41	0.637	345.55	1.569	2.89	124.37	297.32	172.95	0.6866	1.5175
–64	0.43	0.639	327.07	1.566	3.06	125.45	297.90	172.45	0.6917	1.5163
–63	0.46	0.640	309.78	1.563	3.23	126.53	298.48	171.95	0.6969	1.5151
–62	0.49	0.641	293.57	1.559	3.41	127.62	299.05	171.44	0.7020	1.5140
–61	0.51	0.643	278.38	1.556	3.59	128.70	299.63	170.93	0.7072	1.5129
–60	0.54	0.644	264.11	1.553	3.79	129.80	300.21	170.41	0.7123	1.5118
–59	0.57	0.645	250.72	1.550	3.99	130.89	300.79	169.90	0.7174	1.5108
–58	0.61	0.647	238.15	1.546	4.20	131.98	301.36	169.38	0.7225	1.5098
–57	0.64	0.648	226.33	1.543	4.42	133.08	301.94	168.86	0.7276	1.5088
–56	0.68	0.650	215.21	1.539	4.65	134.18	302.52	168.33	0.7327	1.5078
–55	0.71	0.651	204.75	1.536	4.88	135.29	303.09	167.80	0.7377	1.5069
–54	0.75	0.652	194.89	1.533	5.13	136.40	303.67	167.27	0.7428	1.5060
–53	0.79	0.654	185.61	1.529	5.39	137.50	304.24	166.74	0.7478	1.5052
–52	0.83	0.655	176.85	1.526	5.65	138.62	304.81	166.20	0.7528	1.5043
–51	0.88	0.657	168.59	1.522	5.93	139.73	305.39	165.65	0.7579	1.5035
–50	0.92	0.658	160.79	1.519	6.22	140.85	305.96	165.11	0.7629	1.5028
–49	0.97	0.660	153.43	1.516	6.52	141.97	306.53	164.56	0.7679	1.5020
–48	1.02	0.661	146.47	1.512	6.83	143.09	307.10	164.01	0.7728	1.5013
–47	1.07	0.663	139.89	1.509	7.15	144.22	307.67	163.45	0.7778	1.5006
–46	1.12	0.664	133.66	1.505	7.48	145.35	308.24	162.89	0.7828	1.4999
–45	1.18	0.666	127.77	1.502	7.83	146.48	308.81	162.33	0.7877	1.4992
–44	1.23	0.668	122.19	1.498	8.18	147.61	309.37	161.76	0.7927	1.4986
–43	1.29	0.669	116.91	1.494	8.55	148.75	309.94	161.19	0.7976	1.4980
–42	1.35	0.671	111.90	1.491	8.94	149.89	310.50	160.62	0.8025	1.4974
–41	1.42	0.672	107.14	1.487	9.33	151.03	311.07	160.04	0.8074	1.4968
–40	1.48	0.674	102.63	1.484	9.74	152.17	311.63	159.46	0.8123	1.4963
–39	1.55	0.676	98.35	1.480	10.17	153.32	312.19	158.87	0.8172	1.4957
–38	1.62	0.677	94.29	1.476	10.61	154.47	312.75	158.28	0.8221	1.4952
–37	1.70	0.679	90.42	1.473	11.06	155.62	313.31	157.69	0.8270	1.4947
–36	1.77	0.681	86.75	1.469	11.53	156.77	313.87	157.10	0.8318	1.4942
–35	1.85	0.682	83.26	1.465	12.01	157.93	314.42	156.49	0.8366	1.4938
–34	1.93	0.684	79.93	1.462	12.51	159.09	314.98	155.89	0.8415	1.4933
–33	2.01	0.686	76.77	1.458	13.03	160.25	315.53	155.28	0.8463	1.4929
–32	2.10	0.688	73.75	1.454	13.56	161.41	316.08	154.67	0.8511	1.4925
–31	2.19	0.689	70.88	1.450	14.11	162.58	316.63	154.05	0.8559	1.4921

Solkane® 125

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–30	2.28	0.691	68.14	1.447	14.68	163.75	317.18	153.43	0.8607	1.4917
–29	2.38	0.693	65.53	1.443	15.26	164.92	317.72	152.80	0.8655	1.4914
–28	2.48	0.695	63.04	1.439	15.86	166.09	318.27	152.17	0.8703	1.4910
–27	2.58	0.697	60.66	1.435	16.48	167.27	318.81	151.54	0.8750	1.4907
–26	2.68	0.699	58.39	1.431	17.12	168.45	319.35	150.90	0.8798	1.4903
–25	2.79	0.701	56.23	1.427	17.79	169.63	319.89	150.26	0.8845	1.4900
–24	2.90	0.703	54.16	1.423	18.47	170.82	320.43	149.61	0.8892	1.4897
–23	3.01	0.705	52.18	1.419	19.17	172.00	320.96	148.96	0.8940	1.4894
–22	3.13	0.706	50.28	1.415	19.89	173.19	321.49	148.30	0.8987	1.4892
–21	3.25	0.708	48.47	1.411	20.63	174.38	322.02	147.64	0.9034	1.4889
–20	3.38	0.711	46.74	1.407	21.40	175.58	322.55	146.98	0.9081	1.4887
–19	3.50	0.713	45.08	1.403	22.18	176.77	323.08	146.31	0.9128	1.4884
–18	3.64	0.715	43.49	1.399	22.99	177.97	323.60	145.63	0.9174	1.4882
–17	3.77	0.717	41.97	1.395	23.83	179.17	324.12	144.95	0.9221	1.4880
–16	3.91	0.719	40.51	1.391	24.69	180.38	324.64	144.26	0.9267	1.4878
–15	4.05	0.721	39.11	1.387	25.57	181.58	325.16	143.57	0.9314	1.4875
–14	4.20	0.723	37.77	1.383	26.48	182.79	325.67	142.88	0.9360	1.4874
–13	4.35	0.725	36.48	1.379	27.41	184.00	326.18	142.18	0.9406	1.4872
–12	4.51	0.728	35.25	1.374	28.37	185.22	326.69	141.47	0.9453	1.4870
–11	4.66	0.730	34.06	1.370	29.36	186.44	327.20	140.76	0.9499	1.4868
–10	4.83	0.732	32.92	1.366	30.38	187.66	327.70	140.04	0.9545	1.4866
–9	4.99	0.734	31.83	1.362	31.42	188.88	328.20	139.32	0.9590	1.4865
–8	5.17	0.737	30.78	1.357	32.49	190.10	328.69	138.59	0.9636	1.4863
–7	5.34	0.739	29.77	1.353	33.60	191.33	329.19	137.86	0.9682	1.4862
–6	5.52	0.742	28.79	1.348	34.73	192.56	329.68	137.12	0.9728	1.4860
–5	5.71	0.744	27.86	1.344	35.89	193.79	330.16	136.37	0.9773	1.4859
–4	5.90	0.747	26.96	1.340	37.09	195.03	330.65	135.62	0.9819	1.4857
–3	6.09	0.749	26.10	1.335	38.32	196.27	331.13	134.86	0.9864	1.4856
–2	6.29	0.752	25.26	1.330	39.58	197.51	331.60	134.10	0.9909	1.4855
–1	6.50	0.754	24.46	1.326	40.88	198.75	332.08	133.32	0.9955	1.4853
0	6.71	0.757	23.69	1.321	42.22	200.00	332.54	132.54	1.0000	1.4852
1	6.92	0.760	22.94	1.317	43.59	201.25	333.01	131.76	1.0045	1.4851
2	7.14	0.762	22.22	1.312	45.00	202.50	333.47	130.97	1.0090	1.4850
3	7.36	0.765	21.53	1.307	46.44	203.76	333.93	130.17	1.0135	1.4848
4	7.59	0.768	20.86	1.302	47.93	205.02	334.38	129.36	1.0180	1.4847
5	7.83	0.771	20.22	1.298	49.45	206.28	334.83	128.55	1.0224	1.4846
6	8.07	0.774	19.60	1.293	51.02	207.54	335.27	127.73	1.0269	1.4845
7	8.31	0.776	19.00	1.288	52.63	208.81	335.71	126.90	1.0314	1.4843
8	8.57	0.779	18.42	1.283	54.29	210.08	336.14	126.06	1.0358	1.4842
9	8.82	0.783	17.86	1.278	55.99	211.36	336.57	125.21	1.0403	1.4841
10	9.09	0.786	17.32	1.273	57.73	212.64	337.00	124.36	1.0448	1.4840
11	9.35	0.789	16.80	1.268	59.52	213.92	337.42	123.50	1.0492	1.4838
12	9.63	0.792	16.30	1.263	61.37	215.21	337.83	122.62	1.0536	1.4837
13	9.91	0.795	15.81	1.257	63.26	216.50	338.24	121.74	1.0581	1.4835
14	10.20	0.799	15.34	1.252	65.21	217.79	338.64	120.85	1.0625	1.4834
15	10.49	0.802	14.88	1.247	67.21	219.09	339.04	119.95	1.0669	1.4832
16	10.79	0.805	14.44	1.242	69.26	220.39	339.43	119.04	1.0714	1.4831
17	11.09	0.809	14.01	1.236	71.37	221.70	339.82	118.12	1.0758	1.4829
18	11.40	0.813	13.60	1.231	73.54	223.01	340.20	117.19	1.0802	1.4827
19	11.72	0.816	13.20	1.225	75.77	224.33	340.57	116.24	1.0846	1.4825

Solkane® 125

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
20	12.05	0.820	12.81	1.220	78.07	225.65	340.93	115.29	1.0891	1.4823
21	12.38	0.824	12.43	1.214	80.43	226.97	341.29	114.32	1.0935	1.4821
22	12.72	0.828	12.07	1.208	82.86	228.30	341.64	113.34	1.0979	1.4819
23	13.06	0.832	11.72	1.202	85.35	229.64	341.99	112.35	1.1023	1.4817
24	13.41	0.836	11.37	1.196	87.92	230.98	342.32	111.34	1.1068	1.4815
25	13.77	0.840	11.04	1.190	90.57	232.33	342.65	110.32	1.1112	1.4812
26	14.14	0.844	10.72	1.184	93.29	233.68	342.97	109.28	1.1156	1.4809
27	14.51	0.849	10.41	1.178	96.09	235.05	343.28	108.23	1.1201	1.4807
28	14.89	0.853	10.10	1.172	98.98	236.41	343.58	107.17	1.1245	1.4804
29	15.28	0.858	9.81	1.166	101.95	237.79	343.87	106.08	1.1290	1.4801
30	15.68	0.863	9.52	1.159	105.02	239.17	344.16	104.98	1.1334	1.4797
31	16.08	0.867	9.24	1.153	108.18	240.57	344.43	103.86	1.1379	1.4794
32	16.49	0.873	8.97	1.146	111.44	241.97	344.69	102.72	1.1424	1.4790
33	16.91	0.878	8.71	1.139	114.80	243.38	344.94	101.56	1.1469	1.4786
34	17.34	0.883	8.45	1.133	118.28	244.80	345.18	100.38	1.1514	1.4782
35	17.78	0.888	8.21	1.126	121.87	246.23	345.40	99.17	1.1559	1.4777
36	18.22	0.894	7.96	1.118	125.58	247.67	345.61	97.94	1.1604	1.4773
37	18.67	0.900	7.73	1.111	129.42	249.13	345.81	96.68	1.1650	1.4768
38	19.13	0.906	7.50	1.104	133.39	250.60	346.00	95.40	1.1696	1.4762
39	19.60	0.912	7.27	1.096	137.51	252.08	346.16	94.08	1.1742	1.4756
40	20.08	0.919	7.05	1.089	141.79	253.58	346.31	92.73	1.1789	1.4750
41	20.57	0.925	6.84	1.081	146.23	255.10	346.45	91.35	1.1836	1.4744
42	21.06	0.932	6.63	1.073	150.84	256.64	346.56	89.92	1.1883	1.4737
43	21.57	0.939	6.42	1.064	155.65	258.20	346.65	88.45	1.1931	1.4729
44	22.08	0.947	6.22	1.056	160.66	259.78	346.72	86.94	1.1980	1.4721
45	22.61	0.955	6.03	1.047	165.90	261.39	346.76	85.37	1.2029	1.4712
46	23.14	0.963	5.83	1.038	171.39	263.03	346.77	83.74	1.2079	1.4703
47	23.69	0.972	5.64	1.029	177.16	264.70	346.75	82.05	1.2129	1.4692
48	24.24	0.981	5.46	1.020	183.24	266.40	346.69	80.29	1.2181	1.4681
49	24.80	0.990	5.27	1.010	189.67	268.15	346.59	78.44	1.2233	1.4668
50	25.38	1.000	5.09	1.000	196.51	269.95	346.45	76.50	1.2287	1.4655
51	25.96	1.011	4.91	0.990	203.81	271.80	346.24	74.44	1.2343	1.4639
52	26.56	1.022	4.72	0.979	211.67	273.72	345.97	72.25	1.2400	1.4622
53	27.16	1.034	4.54	0.967	220.19	275.72	345.62	69.90	1.2459	1.4603
54	27.78	1.046	4.36	0.956	229.54	277.80	345.16	67.36	1.2521	1.4580
55	28.41	1.060	4.17	0.943	239.93	279.99	344.58	64.59	1.2586	1.4554
56	29.04	1.075	3.97	0.930	251.64	282.30	343.83	61.53	1.2654	1.4524
57	29.69	1.091	3.77	0.916	264.99	284.75	342.90	58.15	1.2726	1.4488
58	30.36	1.109	3.57	0.902	280.12	287.28	341.77	54.49	1.2801	1.4446
59	31.03	1.129	3.38	0.886	296.13	289.76	340.60	50.84	1.2873	1.4404
60	31.72	1.152	3.22	0.868	310.82	291.98	339.71	47.73	1.2938	1.4370
61	32.42	1.177	3.10	0.849	322.78	293.92	339.27	45.35	1.2993	1.4350
62	33.13	1.207	3.01	0.828	332.26	295.71	339.19	43.49	1.3044	1.4342
63	33.86	1.244	2.94	0.804	339.94	297.51	339.38	41.87	1.3095	1.4341
64	34.60	1.292	2.89	0.774	346.40	299.49	339.74	40.25	1.3151	1.4345
65	35.36	1.361	2.84	0.735	351.98	301.97	340.22	38.25	1.3222	1.4353

12.2.3 Solkane® 143a

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
– 70	0.30	0.816	656.90	1.225	1.52	102.36	345.27	242.91	0.5902	1.7859
– 69	0.32	0.818	620.55	1.223	1.61	103.74	345.90	242.16	0.5969	1.7831
– 68	0.34	0.819	586.83	1.220	1.70	105.03	346.53	241.51	0.6032	1.7804
– 67	0.36	0.821	555.29	1.218	1.80	106.32	347.17	240.85	0.6095	1.7778
– 66	0.38	0.823	525.78	1.215	1.90	107.61	347.80	240.19	0.6157	1.7752
– 65	0.40	0.825	497.84	1.213	2.01	109.04	348.42	239.38	0.6226	1.7726
– 64	0.43	0.826	471.96	1.210	2.12	110.33	349.05	238.72	0.6288	1.7702
– 63	0.45	0.828	447.69	1.208	2.23	111.63	349.68	238.05	0.6350	1.7678
– 62	0.48	0.830	424.74	1.205	2.35	113.02	350.31	237.29	0.6416	1.7653
– 61	0.50	0.832	403.36	1.203	2.48	114.32	350.94	236.62	0.6477	1.7630
– 60	0.53	0.833	383.11	1.200	2.61	115.71	351.56	235.85	0.6542	1.7607
– 59	0.56	0.835	364.24	1.197	2.75	117.02	352.19	235.17	0.6603	1.7585
– 58	0.59	0.837	346.43	1.195	2.89	118.36	352.82	234.46	0.6666	1.7563
– 57	0.63	0.839	329.62	1.192	3.03	119.72	353.44	233.72	0.6729	1.7542
– 56	0.66	0.841	313.84	1.190	3.19	121.06	354.07	233.00	0.6791	1.7521
– 55	0.69	0.842	298.93	1.187	3.35	122.44	354.69	232.25	0.6853	1.7500
– 54	0.73	0.844	284.88	1.184	3.51	123.79	355.31	231.52	0.6915	1.7480
– 53	0.77	0.846	271.64	1.182	3.68	125.15	355.93	230.78	0.6977	1.7460
– 52	0.81	0.848	259.15	1.179	3.86	126.50	356.55	230.06	0.7038	1.7441
– 51	0.85	0.850	247.32	1.176	4.04	127.87	357.17	229.30	0.7100	1.7422
– 50	0.89	0.852	236.16	1.174	4.23	129.23	357.79	228.55	0.7161	1.7403
– 49	0.94	0.854	225.59	1.171	4.43	130.61	358.40	227.79	0.7222	1.7385
– 48	0.98	0.856	215.59	1.168	4.64	131.99	359.02	227.03	0.7283	1.7367
– 47	1.03	0.858	206.13	1.166	4.85	133.37	359.63	226.26	0.7344	1.7349
– 46	1.08	0.860	197.18	1.163	5.07	134.74	360.24	225.51	0.7404	1.7332
– 45	1.13	0.862	188.71	1.160	5.30	136.10	360.86	224.75	0.7464	1.7315
– 44	1.18	0.864	180.63	1.157	5.54	137.51	361.46	223.95	0.7526	1.7299
– 43	1.24	0.866	173.01	1.155	5.78	138.88	362.07	223.19	0.7585	1.7283
– 42	1.30	0.868	165.77	1.152	6.03	140.27	362.68	222.41	0.7645	1.7267
– 41	1.36	0.870	158.89	1.149	6.29	141.65	363.28	221.63	0.7704	1.7252
– 40	1.42	0.872	152.36	1.146	6.56	143.04	363.89	220.85	0.7764	1.7236
– 39	1.48	0.874	146.15	1.144	6.84	144.43	364.49	220.05	0.7823	1.7221
– 38	1.55	0.876	140.25	1.141	7.13	145.82	365.09	219.27	0.7882	1.7207
– 37	1.62	0.879	134.63	1.138	7.43	147.22	365.69	218.47	0.7941	1.7193
– 36	1.69	0.881	129.29	1.135	7.73	148.61	366.29	217.68	0.8000	1.7179
– 35	1.76	0.883	124.20	1.132	8.05	150.01	366.88	216.87	0.8059	1.7165
– 34	1.83	0.885	119.37	1.130	8.38	151.40	367.48	216.07	0.8117	1.7152
– 33	1.91	0.887	114.74	1.127	8.72	152.82	368.06	215.25	0.8175	1.7138
– 32	1.99	0.890	110.35	1.124	9.06	154.21	368.66	214.45	0.8233	1.7126
– 31	2.07	0.892	106.15	1.121	9.42	155.61	369.24	213.63	0.8291	1.7113
– 30	2.16	0.894	102.14	1.118	9.79	157.02	369.83	212.81	0.8348	1.7100
– 29	2.25	0.897	98.32	1.115	10.17	158.42	370.41	211.99	0.8406	1.7088
– 28	2.34	0.899	94.67	1.112	10.56	159.83	370.99	211.17	0.8463	1.7076
– 27	2.43	0.901	91.18	1.109	10.97	161.25	371.57	210.33	0.8520	1.7065
– 26	2.53	0.904	87.85	1.106	11.38	162.65	372.15	209.50	0.8577	1.7053
– 25	2.62	0.906	84.67	1.104	11.81	164.07	372.73	208.66	0.8634	1.7042
– 24	2.73	0.909	81.62	1.101	12.25	165.48	373.30	207.82	0.8690	1.7031
– 23	2.83	0.911	78.71	1.098	12.71	166.90	373.87	206.97	0.8746	1.7020
– 22	2.94	0.914	75.91	1.095	13.17	168.33	374.44	206.11	0.8803	1.7010
– 21	3.05	0.916	73.25	1.092	13.65	169.74	375.00	205.27	0.8859	1.6999

Solkane® 143a

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
– 20	3.16	0.919	70.69	1.089	14.15	171.16	375.57	204.41	0.8915	1.6989
– 19	3.28	0.921	68.24	1.086	14.66	172.58	376.13	203.54	0.8970	1.6979
– 18	3.40	0.924	65.89	1.082	15.18	174.01	376.69	202.68	0.9026	1.6969
– 17	3.53	0.926	63.64	1.079	15.71	175.44	377.24	201.81	0.9081	1.6960
– 16	3.65	0.929	61.48	1.076	16.27	176.86	377.79	200.93	0.9136	1.6950
– 15	3.78	0.932	59.40	1.073	16.83	178.30	378.34	200.04	0.9192	1.6941
– 14	3.92	0.935	57.42	1.070	17.42	179.73	378.89	199.16	0.9246	1.6932
– 13	4.06	0.937	55.51	1.067	18.02	181.16	379.44	198.27	0.9301	1.6923
– 12	4.20	0.940	53.67	1.064	18.63	182.60	379.98	197.38	0.9356	1.6914
– 11	4.34	0.943	51.91	1.061	19.27	184.04	380.52	196.48	0.9410	1.6905
– 10	4.49	0.946	50.22	1.057	19.91	185.48	381.05	195.58	0.9464	1.6896
– 9	4.65	0.949	48.59	1.054	20.58	186.92	381.58	194.67	0.9519	1.6888
– 8	4.80	0.951	47.02	1.051	21.27	188.36	382.11	193.75	0.9573	1.6880
– 7	4.96	0.954	45.52	1.048	21.97	189.81	382.64	192.83	0.9626	1.6872
– 6	5.13	0.957	44.07	1.044	22.69	191.25	383.16	191.91	0.9680	1.6864
– 5	5.30	0.960	42.67	1.041	23.44	192.71	383.68	190.97	0.9734	1.6856
– 4	5.47	0.964	41.33	1.038	24.20	194.16	384.20	190.04	0.9787	1.6848
– 3	5.65	0.967	40.03	1.035	24.98	195.62	384.71	189.09	0.9840	1.6840
– 2	5.83	0.970	38.79	1.031	25.78	197.07	385.22	188.14	0.9894	1.6832
– 1	6.01	0.973	37.59	1.028	26.61	198.53	385.72	187.19	0.9947	1.6825
0	6.20	0.976	36.43	1.024	27.45	200.00	386.22	186.22	1.0000	1.6818
1	6.40	0.979	35.31	1.021	28.32	201.46	386.72	185.26	1.0053	1.6810
2	6.60	0.983	34.23	1.018	29.21	202.94	387.21	184.28	1.0106	1.6803
3	6.80	0.986	33.20	1.014	30.12	204.41	387.70	183.29	1.0158	1.6796
4	7.01	0.990	32.19	1.011	31.06	205.88	388.18	182.30	1.0211	1.6789
5	7.22	0.993	31.22	1.007	32.03	207.36	388.66	181.30	1.0263	1.6781
6	7.44	0.997	30.29	1.003	33.01	208.85	389.14	180.29	1.0316	1.6774
7	7.66	1.000	29.39	1.000	34.03	210.34	389.61	179.27	1.0368	1.6767
8	7.89	1.004	28.51	0.996	35.07	211.83	390.07	178.25	1.0421	1.6761
9	8.12	1.007	27.67	0.993	36.14	213.32	390.53	177.21	1.0473	1.6754
10	8.36	1.011	26.86	0.989	37.24	214.82	390.99	176.17	1.0525	1.6747
11	8.60	1.015	26.07	0.985	38.36	216.32	391.44	175.11	1.0577	1.6740
12	8.85	1.019	25.31	0.982	39.52	217.83	391.88	174.05	1.0629	1.6733
13	9.11	1.023	24.57	0.978	40.70	219.34	392.32	172.98	1.0681	1.6726
14	9.37	1.027	23.85	0.974	41.92	220.86	392.75	171.89	1.0733	1.6719
15	9.63	1.031	23.16	0.970	43.17	222.38	393.18	170.79	1.0785	1.6713
16	9.90	1.035	22.49	0.966	44.46	223.91	393.60	169.68	1.0837	1.6706
17	10.18	1.039	21.85	0.963	45.77	225.45	394.01	168.56	1.0889	1.6699
18	10.46	1.043	21.22	0.959	47.13	226.99	394.42	167.43	1.0941	1.6692
19	10.75	1.048	20.61	0.955	48.52	228.53	394.82	166.28	1.0993	1.6685
20	11.04	1.052	20.02	0.951	49.95	230.09	395.21	165.12	1.1045	1.6678
21	11.34	1.056	19.45	0.947	51.41	231.65	395.59	163.94	1.1097	1.6671
22	11.65	1.061	18.90	0.942	52.92	233.22	395.97	162.75	1.1149	1.6664
23	11.96	1.066	18.36	0.938	54.47	234.79	396.34	161.55	1.1202	1.6657
24	12.28	1.070	17.84	0.934	56.07	236.38	396.70	160.32	1.1254	1.6649
25	12.61	1.075	17.33	0.930	57.70	237.96	397.05	159.09	1.1306	1.6642
26	12.94	1.080	16.84	0.926	59.39	239.57	397.40	157.83	1.1358	1.6634
27	13.27	1.085	16.36	0.921	61.12	241.17	397.73	156.56	1.1411	1.6627
28	13.62	1.090	15.90	0.917	62.90	242.79	398.05	155.26	1.1464	1.6619
29	13.97	1.096	15.45	0.913	64.74	244.42	398.37	153.94	1.1516	1.6611

Solkane® 143a

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
30	14.33	1.101	15.01	0.908	66.62	246.06	398.67	152.61	1.1569	1.6603
31	14.69	1.107	14.58	0.904	68.57	247.71	398.96	151.25	1.1622	1.6595
32	15.07	1.112	14.17	0.899	70.57	249.37	399.24	149.87	1.1675	1.6587
33	15.45	1.118	13.77	0.894	72.63	251.04	399.51	148.46	1.1729	1.6578
34	15.83	1.124	13.38	0.890	74.76	252.73	399.76	147.03	1.1782	1.6569
35	16.23	1.130	13.00	0.885	76.95	254.43	400.00	145.58	1.1836	1.6560
36	16.63	1.136	12.62	0.880	79.21	256.14	400.23	144.09	1.1890	1.6551
37	17.04	1.143	12.26	0.875	81.55	257.86	400.45	142.58	1.1944	1.6541
38	17.46	1.149	11.91	0.870	83.96	259.61	400.64	141.04	1.1999	1.6531
39	17.88	1.156	11.57	0.865	86.44	261.36	400.83	139.46	1.2053	1.6521
40	18.32	1.163	11.23	0.860	89.02	263.14	400.99	137.85	1.2109	1.6511
41	18.76	1.170	10.91	0.855	91.68	264.93	401.14	136.21	1.2164	1.6500
42	19.21	1.177	10.59	0.849	94.43	266.74	401.27	134.53	1.2220	1.6489
43	19.66	1.185	10.28	0.844	97.28	268.57	401.38	132.81	1.2276	1.6477
44	20.13	1.193	9.98	0.838	100.24	270.42	401.46	131.04	1.2333	1.6465
45	20.60	1.201	9.68	0.833	103.30	272.29	401.53	129.24	1.2390	1.6452
46	21.09	1.209	9.39	0.827	106.48	274.19	401.57	127.38	1.2448	1.6439
47	21.58	1.218	9.11	0.821	109.79	276.11	401.59	125.48	1.2506	1.6425
48	22.08	1.227	8.83	0.815	113.22	278.05	401.58	123.52	1.2565	1.6411
49	22.59	1.236	8.56	0.809	116.80	280.02	401.54	121.51	1.2624	1.6396
50	23.11	1.246	8.30	0.803	120.53	282.02	401.47	119.44	1.2684	1.6380
51	23.64	1.256	8.04	0.796	124.42	284.06	401.36	117.31	1.2745	1.6364
52	24.18	1.267	7.78	0.789	128.49	286.12	401.23	115.10	1.2806	1.6346
53	24.73	1.278	7.53	0.783	132.75	288.22	401.05	112.82	1.2869	1.6328
54	25.29	1.289	7.29	0.776	137.21	290.36	400.83	110.47	1.2932	1.6309
55	25.85	1.301	7.05	0.768	141.89	292.54	400.57	108.03	1.2996	1.6288
56	26.43	1.314	6.81	0.761	146.83	294.76	400.26	105.49	1.3061	1.6266
57	27.02	1.328	6.58	0.753	152.04	297.03	399.89	102.86	1.3128	1.6243
58	27.62	1.342	6.35	0.745	157.54	299.35	399.46	100.11	1.3196	1.6219
59	28.23	1.357	6.12	0.737	163.38	301.72	398.97	97.25	1.3265	1.6193
60	28.85	1.373	5.90	0.728	169.60	304.16	398.41	94.25	1.3335	1.6164
61	29.48	1.391	5.67	0.719	176.24	306.66	397.76	91.10	1.3408	1.6134
62	30.12	1.410	5.45	0.709	183.37	309.24	397.02	87.78	1.3482	1.6101
63	30.77	1.430	5.23	0.699	191.06	311.90	396.17	84.28	1.3559	1.6066
64	31.44	1.452	5.02	0.689	199.39	314.65	395.21	80.56	1.3637	1.6027
65	32.11	1.477	4.80	0.677	208.51	317.51	394.09	76.58	1.3719	1.5984
66	32.80	1.504	4.58	0.665	218.53	320.49	392.82	72.32	1.3804	1.5937
67	33.50	1.535	4.35	0.651	229.69	323.62	391.34	67.72	1.3893	1.5884
68	34.22	1.571	4.13	0.637	242.21	326.92	389.62	62.70	1.3987	1.5825
69	34.94	1.614	3.90	0.620	256.45	330.44	387.62	57.18	1.4086	1.5758
70	35.68	1.666	3.67	0.600	272.81	334.25	385.28	51.03	1.4194	1.5681
71	36.43	1.736	3.43	0.576	291.67	338.50	382.57	44.07	1.4314	1.5595
72	37.19	1.842	3.20	0.543	312.97	343.65	379.59	35.94	1.4459	1.5501
72.9	37.85	2.349	2.35	0.426	425.73	360.96	360.96	0.00	1.4956	1.4956

12.2.4 Solkane® 152a

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–60	0.15	0.924	1769.01	1.082	0.57	103.28	462.37	359.09	0.6021	2.2868
–59	0.16	0.925	1667.51	1.081	0.60	104.78	463.14	358.36	0.6091	2.2826
–58	0.17	0.927	1572.65	1.079	0.64	106.31	463.91	357.59	0.6163	2.2784
–57	0.18	0.929	1484.31	1.077	0.67	107.81	464.67	356.86	0.6232	2.2742
–56	0.19	0.930	1401.63	1.075	0.71	109.36	465.44	356.08	0.6304	2.2702
–55	0.20	0.932	1324.47	1.073	0.76	110.88	466.20	355.33	0.6373	2.2662
–54	0.22	0.934	1252.26	1.071	0.80	112.41	466.97	354.56	0.6443	2.2622
–53	0.23	0.935	1184.74	1.069	0.84	113.94	467.73	353.80	0.6513	2.2584
–52	0.24	0.937	1121.46	1.067	0.89	115.48	468.50	353.02	0.6583	2.2546
–51	0.26	0.939	1062.14	1.065	0.94	117.03	469.26	352.23	0.6653	2.2508
–50	0.27	0.940	1006.59	1.064	0.99	118.57	470.02	351.46	0.6722	2.2471
–49	0.29	0.942	954.45	1.062	1.05	120.12	470.78	350.67	0.6791	2.2435
–48	0.31	0.944	905.46	1.060	1.10	121.68	471.54	349.86	0.6860	2.2399
–47	0.32	0.945	859.52	1.058	1.16	123.22	472.30	349.08	0.6929	2.2364
–46	0.34	0.947	816.31	1.056	1.23	124.78	473.06	348.28	0.6997	2.2330
–45	0.36	0.949	775.64	1.054	1.29	126.36	473.82	347.46	0.7066	2.2296
–44	0.38	0.951	737.41	1.052	1.36	127.92	474.58	346.66	0.7135	2.2263
–43	0.40	0.952	701.42	1.050	1.43	129.49	475.33	345.85	0.7203	2.2230
–42	0.42	0.954	667.51	1.048	1.50	131.05	476.09	345.03	0.7271	2.2198
–41	0.45	0.956	635.53	1.046	1.57	132.64	476.84	344.20	0.7339	2.2166
–40	0.47	0.958	605.39	1.044	1.65	134.21	477.59	343.38	0.7407	2.2134
–39	0.50	0.960	576.94	1.042	1.73	135.80	478.34	342.54	0.7474	2.2104
–38	0.52	0.961	550.10	1.040	1.82	137.38	479.09	341.71	0.7542	2.2073
–37	0.55	0.963	524.73	1.038	1.91	138.97	479.84	340.87	0.7609	2.2044
–36	0.58	0.965	500.75	1.036	2.00	140.57	480.59	340.02	0.7677	2.2014
–35	0.61	0.967	478.09	1.034	2.09	142.17	481.33	339.17	0.7744	2.1985
–34	0.64	0.969	456.67	1.032	2.19	143.76	482.08	338.32	0.7810	2.1957
–33	0.67	0.971	436.38	1.030	2.29	145.36	482.82	337.46	0.7877	2.1929
–32	0.70	0.973	417.16	1.028	2.40	146.97	483.56	336.59	0.7944	2.1901
–31	0.74	0.974	398.95	1.026	2.51	148.59	484.30	335.71	0.8010	2.1874
–30	0.77	0.976	381.70	1.024	2.62	150.20	485.04	334.84	0.8077	2.1848
–29	0.81	0.978	365.34	1.022	2.74	151.81	485.77	333.96	0.8143	2.1821
–28	0.85	0.980	349.83	1.020	2.86	153.43	486.51	333.08	0.8209	2.1795
–27	0.89	0.982	335.10	1.018	2.98	155.05	487.24	332.19	0.8275	2.1770
–26	0.93	0.984	321.11	1.016	3.11	156.68	487.97	331.29	0.8340	2.1745
–25	0.97	0.986	307.83	1.014	3.25	158.30	488.70	330.40	0.8406	2.1720
–24	1.01	0.988	295.20	1.012	3.39	159.94	489.43	329.49	0.8471	2.1696
–23	1.06	0.990	283.20	1.010	3.53	161.57	490.15	328.58	0.8537	2.1672
–22	1.11	0.992	271.78	1.008	3.68	163.21	490.88	327.67	0.8602	2.1648
–21	1.16	0.994	260.92	1.006	3.83	164.85	491.60	326.75	0.8667	2.1625
–20	1.21	0.997	250.57	1.004	3.99	166.49	492.32	325.83	0.8732	2.1602
–19	1.26	0.999	240.72	1.001	4.15	168.14	493.03	324.90	0.8796	2.1580
–18	1.31	1.001	231.33	0.999	4.32	169.79	493.75	323.96	0.8861	2.1558
–17	1.37	1.003	222.39	0.997	4.50	171.44	494.46	323.02	0.8925	2.1536
–16	1.43	1.005	213.86	0.995	4.68	173.09	495.17	322.08	0.8990	2.1514
–15	1.49	1.007	205.73	0.993	4.86	174.75	495.88	321.13	0.9054	2.1493
–14	1.55	1.009	197.96	0.991	5.05	176.42	496.59	320.17	0.9118	2.1472
–13	1.61	1.012	190.55	0.989	5.25	178.08	497.29	319.21	0.9182	2.1452
–12	1.68	1.014	183.47	0.986	5.45	179.75	497.99	318.24	0.9245	2.1432
–11	1.75	1.016	176.71	0.984	5.66	181.42	498.69	317.28	0.9309	2.1412

Solkane® 152a

Release 1.01

t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
–10	1.82	1.018	170.25	0.982	5.87	183.09	499.39	316.30	0.9372	2.1392
–9	1.89	1.020	164.07	0.980	6.09	184.77	500.08	315.32	0.9436	2.1373
–8	1.96	1.023	158.17	0.978	6.32	186.45	500.78	314.33	0.9499	2.1353
–7	2.04	1.025	152.52	0.976	6.56	188.13	501.46	313.34	0.9562	2.1335
–6	2.12	1.027	147.11	0.973	6.80	189.81	502.15	312.34	0.9625	2.1316
–5	2.20	1.030	141.93	0.971	7.05	191.50	502.84	311.34	0.9687	2.1298
–4	2.28	1.032	136.97	0.969	7.30	193.19	503.52	310.33	0.9750	2.1280
–3	2.37	1.035	132.22	0.967	7.56	194.89	504.20	309.31	0.9813	2.1262
–2	2.46	1.037	127.67	0.964	7.83	196.58	504.87	308.29	0.9875	2.1245
–1	2.55	1.039	123.31	0.962	8.11	198.28	505.55	307.26	0.9937	2.1227
0	2.64	1.042	119.12	0.960	8.39	200.00	506.22	306.22	1.0000	2.1210
1	2.74	1.044	115.11	0.958	8.69	201.69	506.89	305.19	1.0061	2.1194
2	2.84	1.047	111.26	0.955	8.99	203.40	507.55	304.15	1.0123	2.1177
3	2.94	1.049	107.56	0.953	9.30	205.12	508.21	303.10	1.0185	2.1161
4	3.04	1.052	104.02	0.951	9.61	206.83	508.87	302.04	1.0246	2.1145
5	3.15	1.054	100.61	0.948	9.94	208.55	509.53	300.98	1.0308	2.1129
6	3.26	1.057	97.33	0.946	10.27	210.27	510.18	299.91	1.0369	2.1113
7	3.37	1.060	94.19	0.944	10.62	212.00	510.83	298.84	1.0431	2.1098
8	3.49	1.062	91.16	0.941	10.97	213.72	511.48	297.76	1.0492	2.1082
9	3.61	1.065	88.25	0.939	11.33	215.46	512.12	296.67	1.0553	2.1067
10	3.73	1.068	85.46	0.937	11.70	217.19	512.77	295.58	1.0614	2.1052
11	3.86	1.070	82.76	0.934	12.08	218.93	513.40	294.48	1.0674	2.1038
12	3.99	1.073	80.17	0.932	12.47	220.67	514.04	293.37	1.0735	2.1023
13	4.12	1.076	77.68	0.929	12.87	222.41	514.67	292.25	1.0796	2.1009
14	4.25	1.079	75.28	0.927	13.28	224.16	515.30	291.14	1.0856	2.0995
15	4.39	1.082	72.97	0.925	13.70	225.91	515.92	290.01	1.0917	2.0981
16	4.53	1.084	70.74	0.922	14.14	227.67	516.54	288.87	1.0977	2.0967
17	4.68	1.087	68.59	0.920	14.58	229.43	517.16	287.73	1.1037	2.0954
18	4.83	1.090	66.52	0.917	15.03	231.19	517.77	286.58	1.1097	2.0940
19	4.98	1.093	64.53	0.915	15.50	232.96	518.38	285.43	1.1157	2.0927
20	5.13	1.096	62.60	0.912	15.97	234.73	518.99	284.26	1.1217	2.0914
21	5.29	1.099	60.75	0.910	16.46	236.50	519.59	283.09	1.1277	2.0901
22	5.46	1.102	58.95	0.907	16.96	238.28	520.19	281.91	1.1337	2.0888
23	5.62	1.105	57.22	0.905	17.47	240.06	520.78	280.72	1.1396	2.0875
24	5.79	1.108	55.56	0.902	18.00	241.85	521.37	279.53	1.1456	2.0863
25	5.97	1.112	53.94	0.900	18.54	243.64	521.96	278.32	1.1515	2.0850
26	6.15	1.115	52.39	0.897	19.09	245.43	522.54	277.11	1.1575	2.0838
27	6.33	1.118	50.88	0.895	19.65	247.23	523.12	275.89	1.1634	2.0826
28	6.52	1.121	49.43	0.892	20.23	249.03	523.69	274.66	1.1693	2.0814
29	6.71	1.124	48.02	0.889	20.82	250.84	524.26	273.42	1.1752	2.0802
30	6.90	1.128	46.66	0.887	21.43	252.65	524.83	272.18	1.1812	2.0790
31	7.10	1.131	45.35	0.884	22.05	254.47	525.39	270.92	1.1871	2.0778
32	7.31	1.135	44.08	0.881	22.69	256.29	525.94	269.65	1.1930	2.0767
33	7.51	1.138	42.85	0.879	23.34	258.12	526.50	268.38	1.1989	2.0755
34	7.73	1.142	41.66	0.876	24.00	259.95	527.04	267.09	1.2048	2.0743
35	7.94	1.145	40.51	0.873	24.69	261.78	527.58	265.80	1.2107	2.0732
36	8.16	1.149	39.39	0.871	25.38	263.63	528.12	264.49	1.2165	2.0721
37	8.39	1.152	38.31	0.868	26.10	265.47	528.65	263.17	1.2224	2.0710
38	8.62	1.156	37.27	0.865	26.83	267.33	529.17	261.85	1.2283	2.0698
39	8.86	1.160	36.25	0.862	27.58	269.18	529.69	260.51	1.2342	2.0687

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t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
40	9.10	1.164	35.27	0.859	28.35	271.05	530.21	259.16	1.2400	2.0676
41	9.34	1.167	34.32	0.857	29.14	272.92	530.71	257.80	1.2459	2.0665
42	9.59	1.171	33.40	0.854	29.94	274.79	531.22	256.42	1.2518	2.0654
43	9.85	1.175	32.50	0.851	30.77	276.68	531.71	255.04	1.2577	2.0643
44	10.11	1.179	31.64	0.848	31.61	278.56	532.20	253.64	1.2635	2.0633
45	10.37	1.183	30.79	0.845	32.47	280.46	532.68	252.23	1.2694	2.0622
46	10.64	1.187	29.98	0.842	33.36	282.36	533.16	250.80	1.2753	2.0611
47	10.92	1.191	29.19	0.839	34.26	284.27	533.63	249.36	1.2811	2.0600
48	11.20	1.196	28.42	0.836	35.19	286.19	534.10	247.91	1.2870	2.0589
49	11.49	1.200	27.67	0.833	36.14	288.11	534.55	246.44	1.2929	2.0579
50	11.78	1.204	26.94	0.830	37.11	290.04	535.00	244.96	1.2987	2.0568
51	12.07	1.209	26.24	0.827	38.11	291.98	535.44	243.46	1.3046	2.0557
52	12.38	1.213	25.55	0.824	39.13	293.92	535.88	241.95	1.3105	2.0546
53	12.69	1.218	24.89	0.821	40.18	295.88	536.30	240.42	1.3164	2.0535
54	13.00	1.222	24.24	0.818	41.25	297.84	536.72	238.88	1.3223	2.0525
55	13.32	1.227	23.61	0.815	42.35	299.81	537.13	237.32	1.3282	2.0514
56	13.65	1.232	23.00	0.812	43.47	301.79	537.53	235.74	1.3341	2.0503
57	13.98	1.237	22.41	0.809	44.62	303.78	537.92	234.14	1.3400	2.0492
58	14.32	1.242	21.83	0.805	45.80	305.78	538.30	232.52	1.3459	2.0481
59	14.66	1.247	21.27	0.802	47.02	307.79	538.68	230.89	1.3518	2.0470
60	15.01	1.252	20.72	0.799	48.26	309.81	539.04	229.23	1.3578	2.0458
61	15.37	1.257	20.19	0.795	49.53	311.83	539.39	227.56	1.3637	2.0447
62	15.73	1.263	19.67	0.792	50.84	313.87	539.73	225.86	1.3697	2.0436
63	16.10	1.268	19.17	0.789	52.17	315.92	540.06	224.14	1.3756	2.0424
64	16.47	1.273	18.67	0.785	53.55	317.99	540.38	222.40	1.3816	2.0413
65	16.86	1.279	18.20	0.782	54.96	320.06	540.69	220.63	1.3876	2.0401
66	17.25	1.285	17.73	0.778	56.40	322.14	540.99	218.84	1.3936	2.0389
67	17.64	1.291	17.27	0.775	57.89	324.24	541.27	217.03	1.3996	2.0377
68	18.04	1.297	16.83	0.771	59.41	326.35	541.54	215.19	1.4057	2.0365
69	18.45	1.303	16.40	0.768	60.98	328.47	541.80	213.32	1.4117	2.0352
70	18.87	1.309	15.98	0.764	62.59	330.61	542.04	211.43	1.4178	2.0340
71	19.29	1.315	15.57	0.760	64.24	332.76	542.27	209.50	1.4239	2.0327
72	19.73	1.322	15.16	0.756	65.94	334.93	542.48	207.55	1.4300	2.0314
73	20.16	1.329	14.77	0.753	67.69	337.11	542.68	205.57	1.4362	2.0300
74	20.61	1.335	14.39	0.749	69.49	339.31	542.85	203.55	1.4424	2.0287
75	21.06	1.342	14.02	0.745	71.34	341.52	543.02	201.50	1.4485	2.0273
76	21.52	1.350	13.65	0.741	73.24	343.75	543.16	199.41	1.4548	2.0259
77	21.99	1.357	13.30	0.737	75.21	346.00	543.29	197.29	1.4610	2.0244
78	22.47	1.365	12.95	0.733	77.23	348.26	543.39	195.13	1.4673	2.0230
79	22.95	1.372	12.61	0.729	79.31	350.55	543.47	192.92	1.4736	2.0214
80	23.44	1.380	12.28	0.725	81.46	352.85	543.54	190.68	1.4799	2.0199
81	23.94	1.388	11.95	0.720	83.68	355.18	543.57	188.39	1.4863	2.0183
82	24.45	1.397	11.63	0.716	85.97	357.53	543.59	186.06	1.4927	2.0166
83	24.96	1.406	11.32	0.711	88.33	359.90	543.58	183.68	1.4992	2.0149
84	25.49	1.414	11.02	0.707	90.78	362.29	543.54	181.25	1.5057	2.0132
85	26.02	1.424	10.72	0.702	93.31	364.71	543.47	178.76	1.5123	2.0114
86	26.56	1.433	10.42	0.698	95.93	367.15	543.38	176.22	1.5189	2.0095
87	27.11	1.443	10.14	0.693	98.64	369.62	543.25	173.62	1.5255	2.0076
88	27.67	1.453	9.86	0.688	101.46	372.12	543.08	170.96	1.5322	2.0056
89	28.24	1.464	9.58	0.683	104.38	374.65	542.88	168.23	1.5390	2.0035

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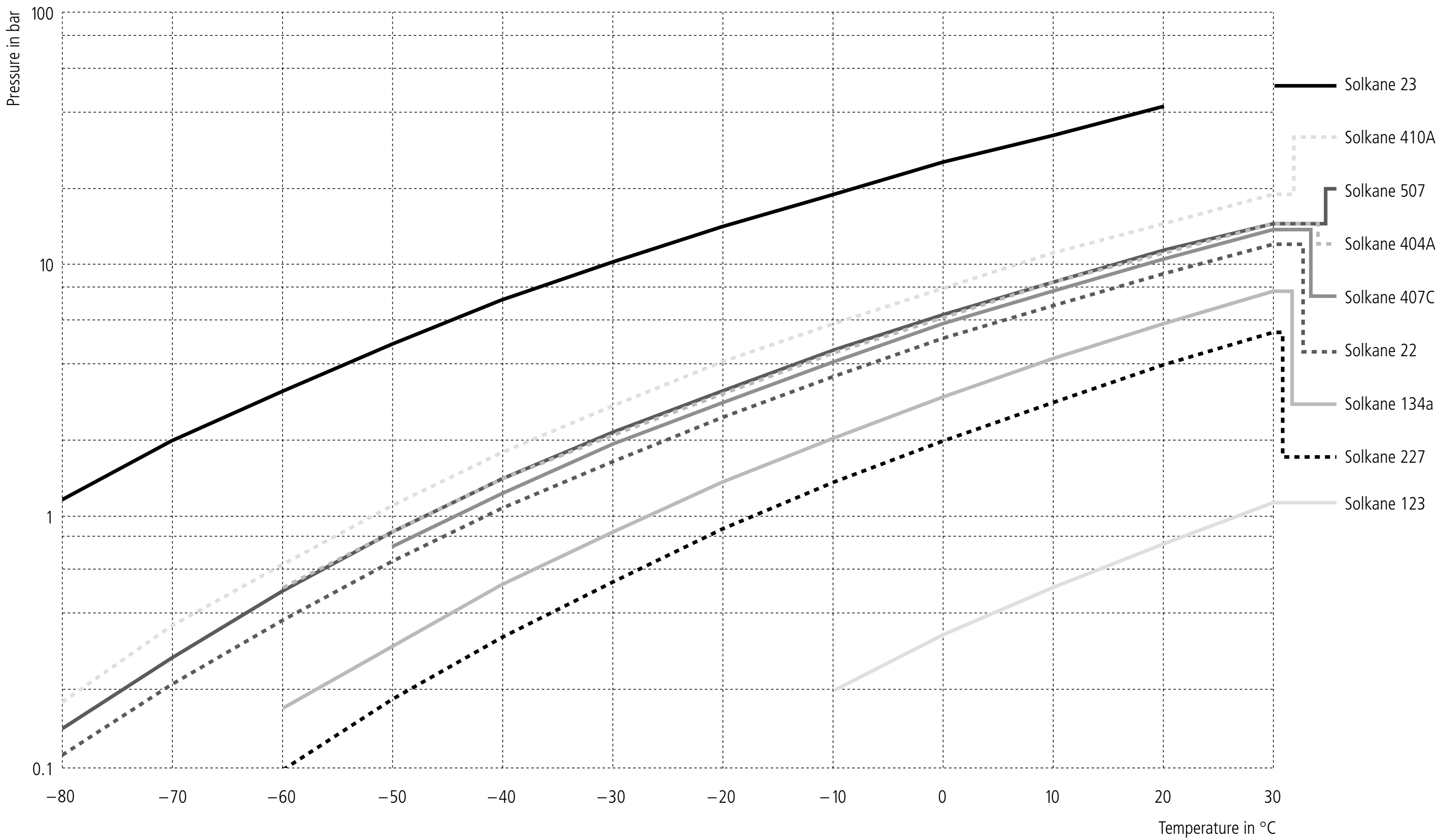
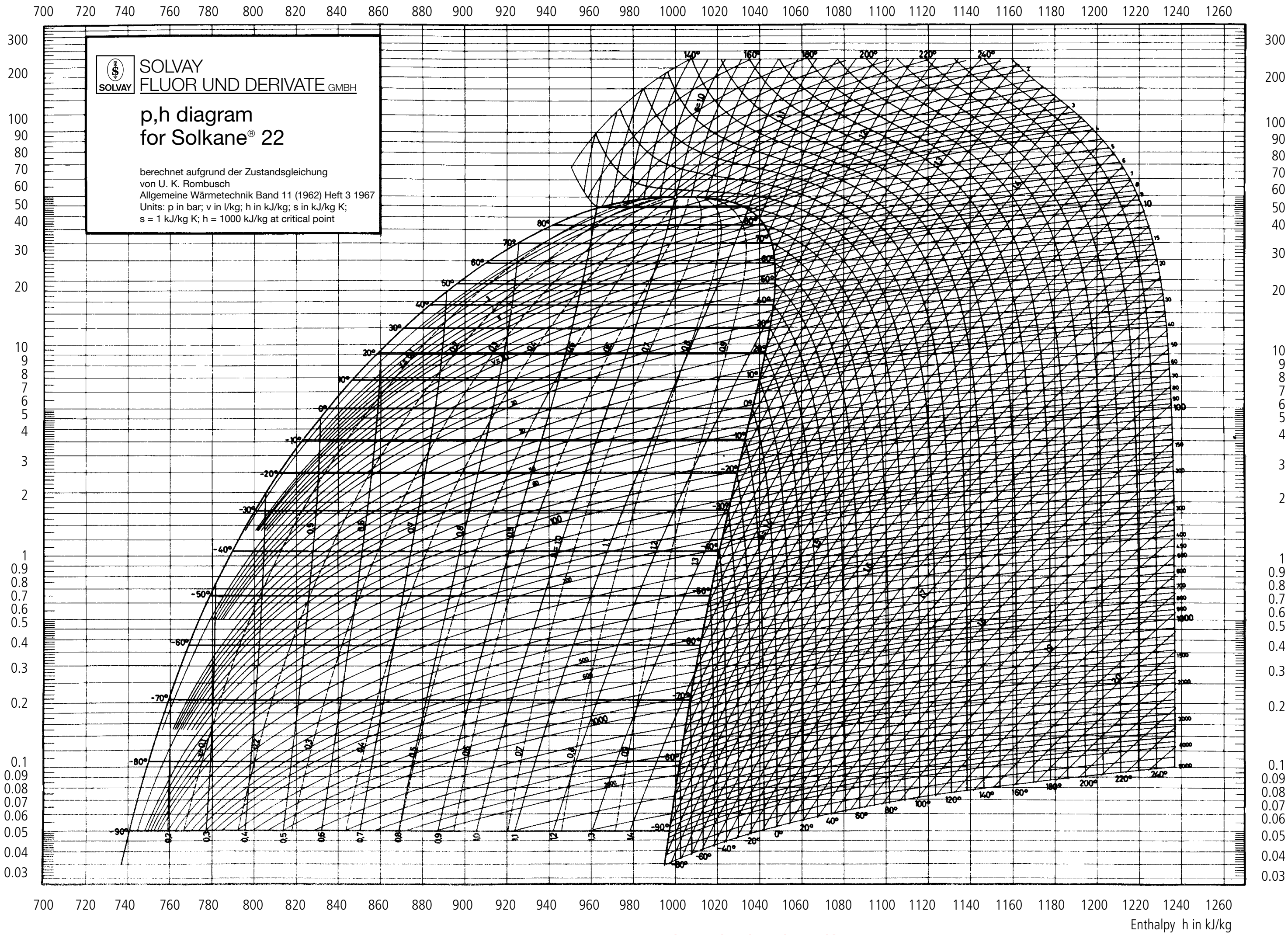
t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
90	28.82	1.475	9.31	0.678	107.42	377.21	542.64	165.43	1.5458	2.0013
91	29.40	1.486	9.04	0.673	110.58	379.81	542.36	162.55	1.5527	1.9991
92	30.00	1.498	8.78	0.667	113.88	382.44	542.04	159.60	1.5597	1.9968
93	30.60	1.511	8.52	0.662	117.31	385.11	541.66	156.55	1.5667	1.9943
94	31.22	1.524	8.27	0.656	120.90	387.82	541.24	153.42	1.5739	1.9917
95	31.84	1.537	8.02	0.651	124.66	390.57	540.76	150.18	1.5811	1.9890
96	32.48	1.551	7.78	0.645	128.60	393.37	540.21	146.84	1.5884	1.9862
97	33.12	1.566	7.53	0.638	132.74	396.22	539.60	143.38	1.5959	1.9832
98	33.77	1.582	7.29	0.632	137.11	399.13	538.91	139.79	1.6034	1.9800
99	34.44	1.599	7.06	0.625	141.72	402.09	538.14	136.05	1.6111	1.9767
100	35.11	1.617	6.82	0.618	146.60	405.12	537.28	132.16	1.6190	1.9731
101	35.80	1.636	6.59	0.611	151.79	408.23	536.32	128.09	1.6270	1.9693
102	36.50	1.657	6.36	0.604	157.34	411.42	535.23	123.82	1.6352	1.9652
103	37.20	1.679	6.12	0.596	163.29	414.70	534.01	119.31	1.6436	1.9608
104	37.92	1.703	5.89	0.587	169.73	418.08	532.63	114.55	1.6523	1.9560
105	38.65	1.729	5.66	0.578	176.73	421.60	531.06	109.46	1.6612	1.9507
106	39.40	1.759	5.42	0.569	184.44	425.26	529.25	103.98	1.6706	1.9448
107	40.15	1.792	5.18	0.558	193.05	429.12	527.14	98.02	1.6804	1.9382
108	40.92	1.830	4.93	0.547	202.84	433.22	524.63	91.42	1.6908	1.9306
109	41.70	1.874	4.66	0.534	214.38	437.65	521.54	83.89	1.7020	1.9215
110	42.49	1.928	4.37	0.519	228.91	442.60	517.43	74.83	1.7145	1.9099
111	43.30	1.998	3.97	0.500	252.01	448.68	510.33	61.65	1.7300	1.8905
112	44.12	2.099	2.05	0.476	487.36	447.96	446.44	−1.52	1.7279	1.7240
113.28	45.20	2.710	2.71	0.369	369.00	477.27	477.27	0.00	1.8031	1.8031

13 Vapor pressure diagram

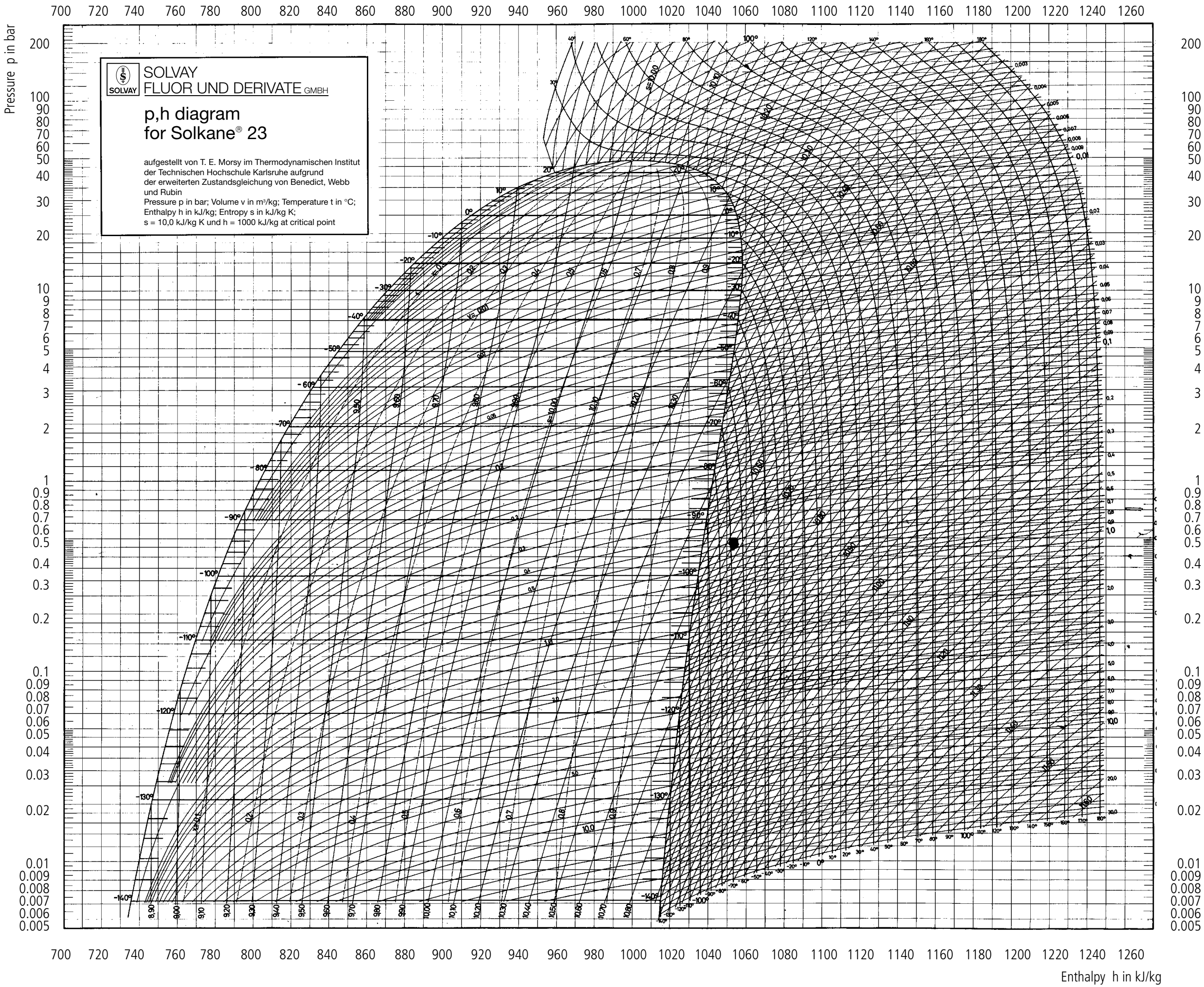


14 Mollier(-lg p, h-)diagrams

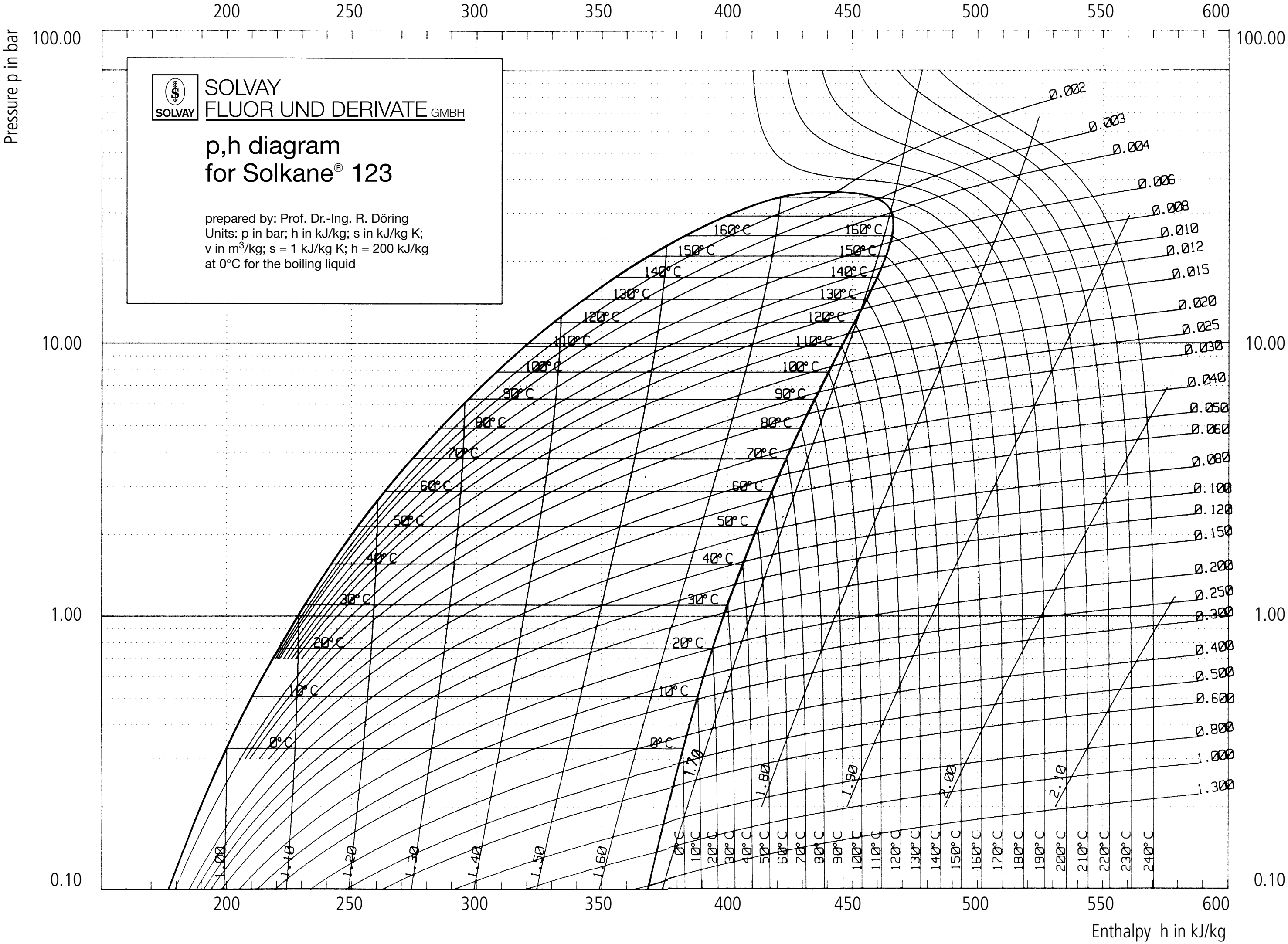
14.1.1 Solkane® 22



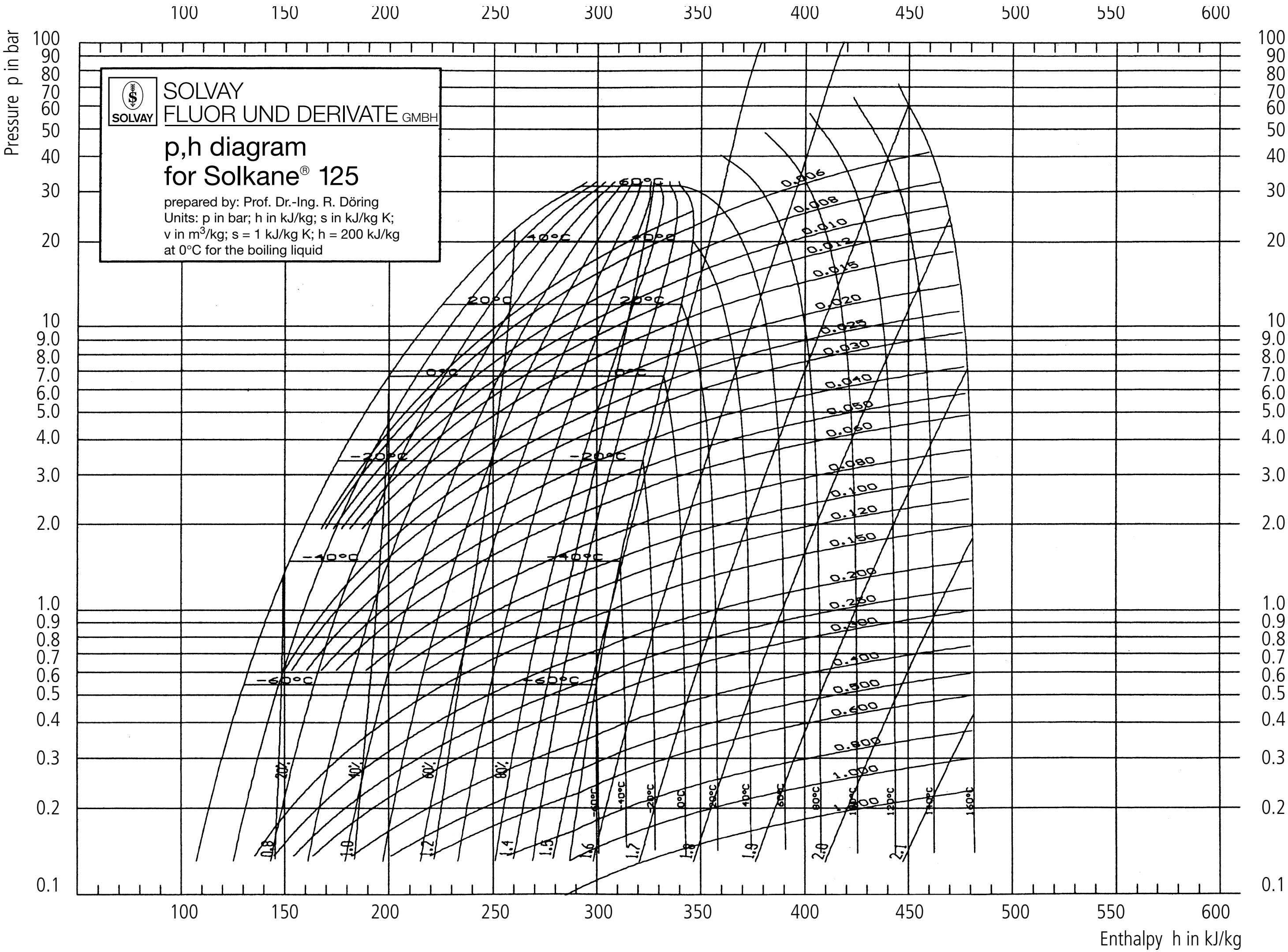
14.1.2 Solkane® 23



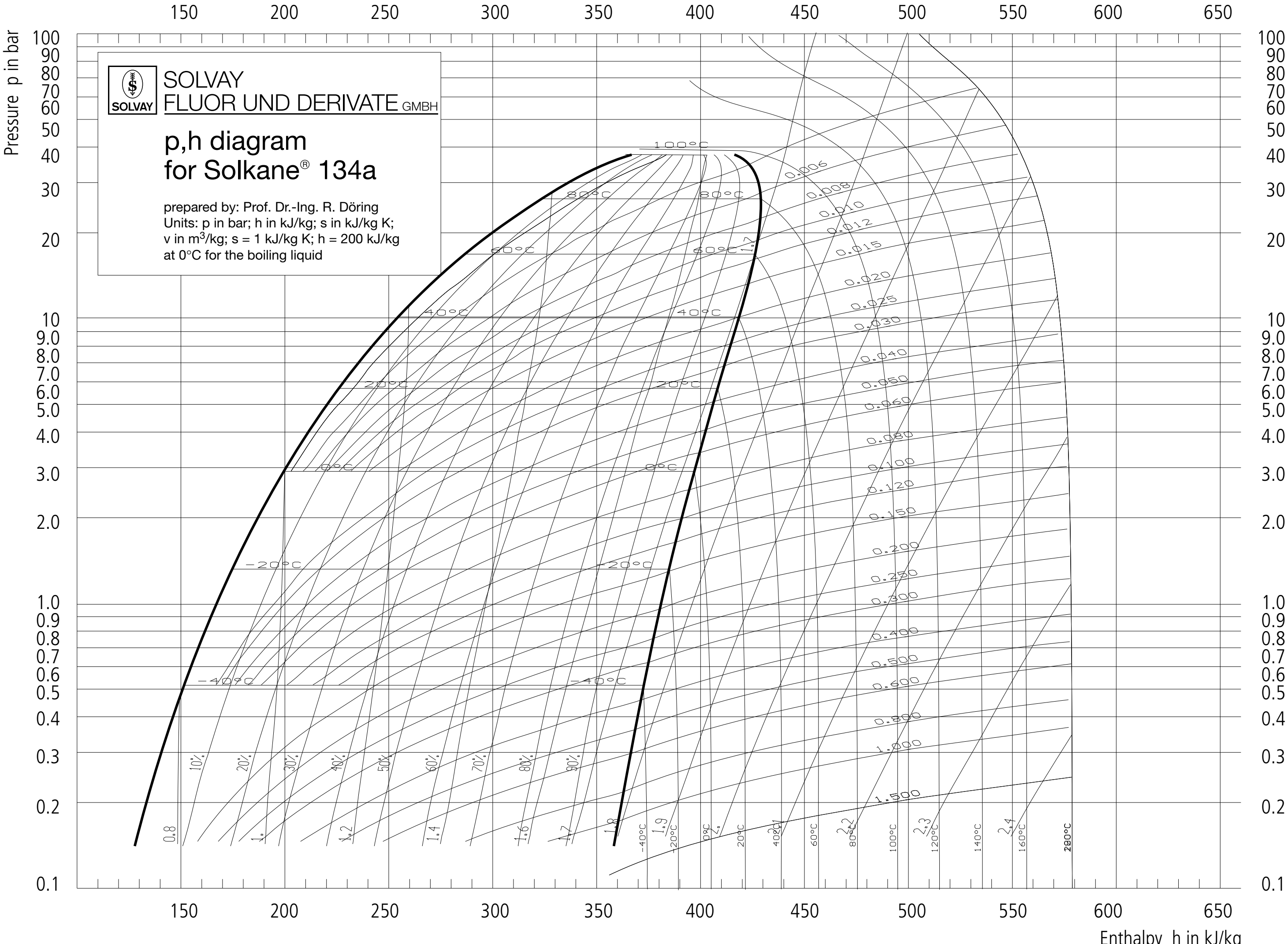
14.1.3 Solkane® 123



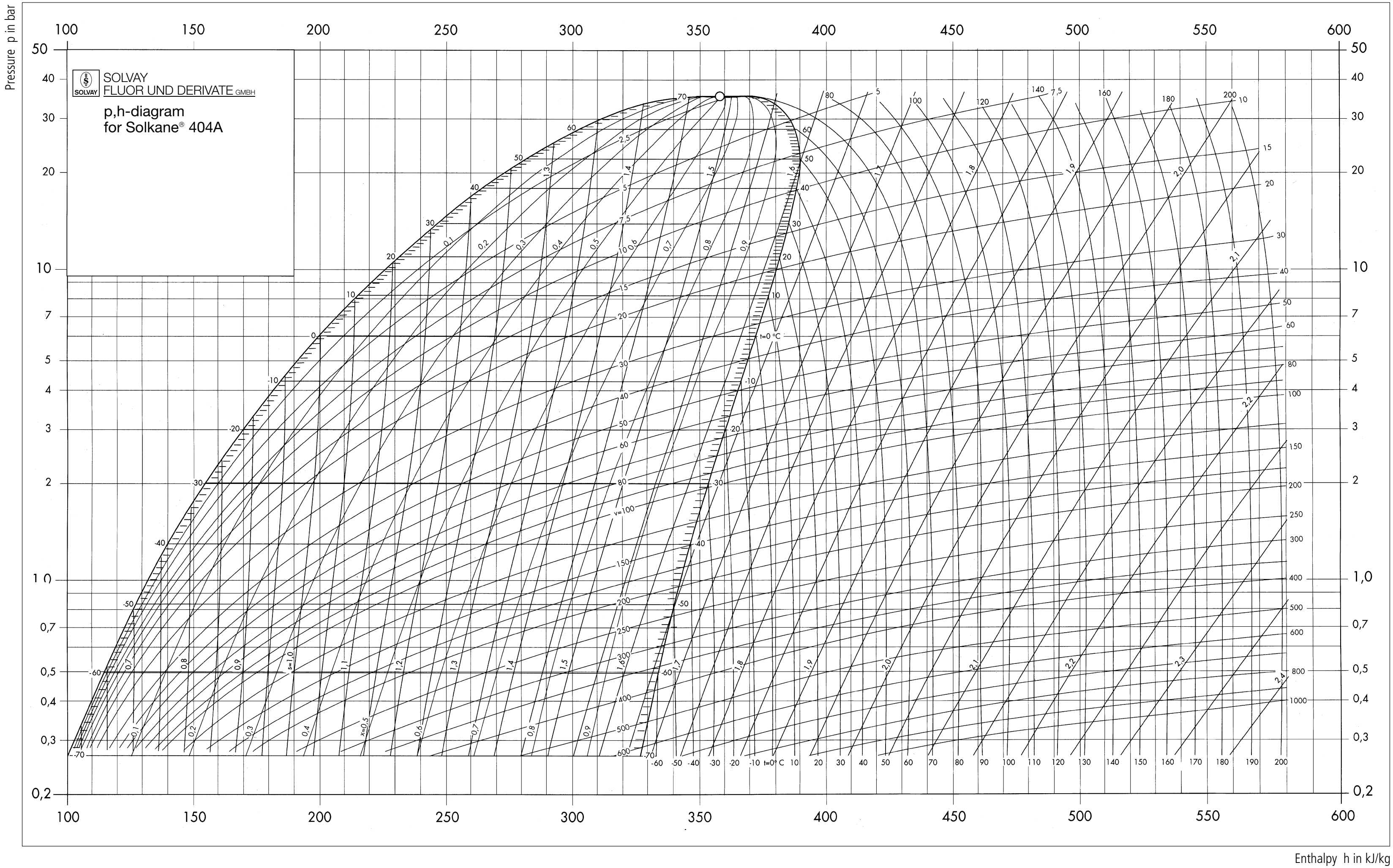
14.1.4 Solkane® 125



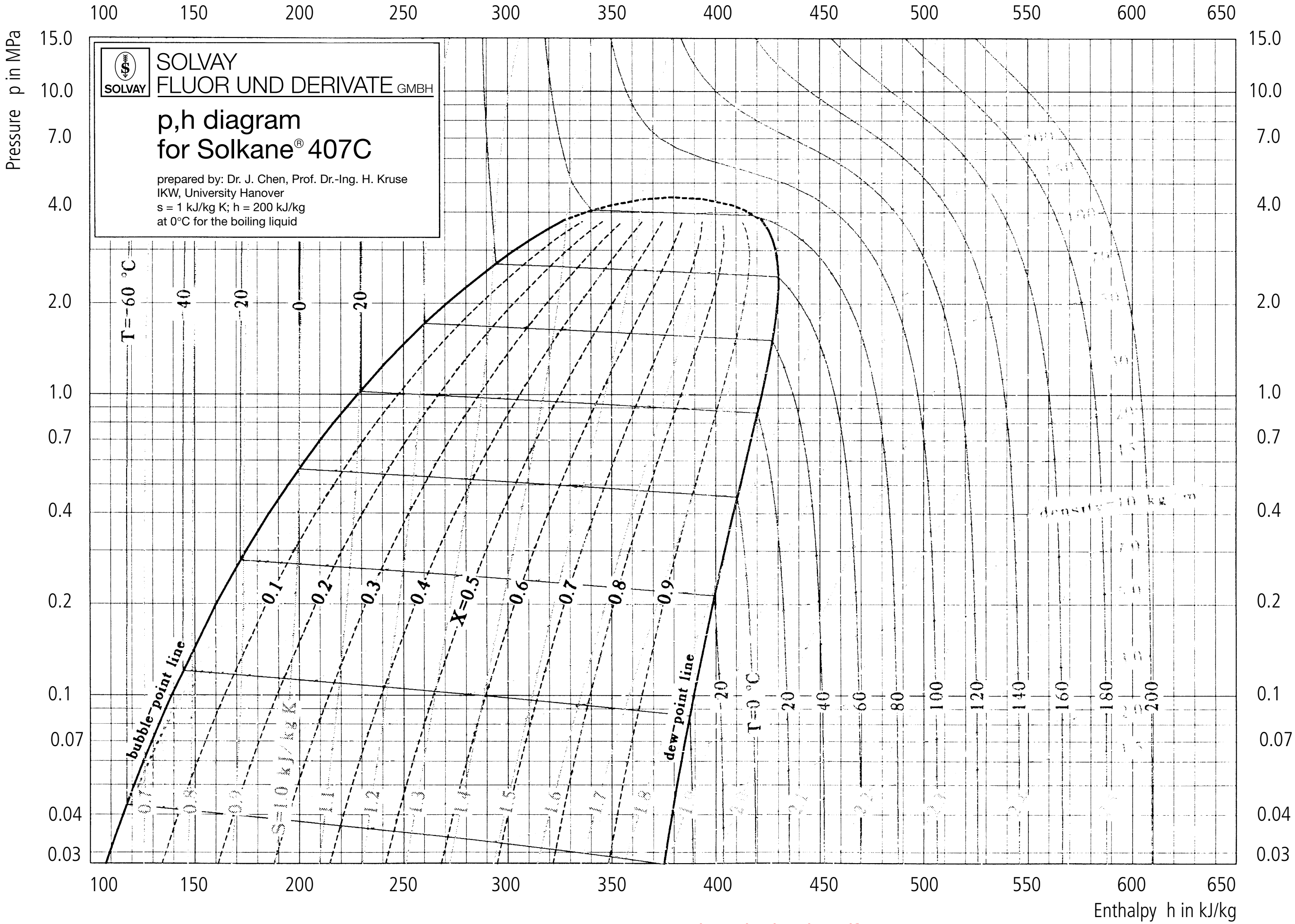
14.1.5 Solkane® 134a



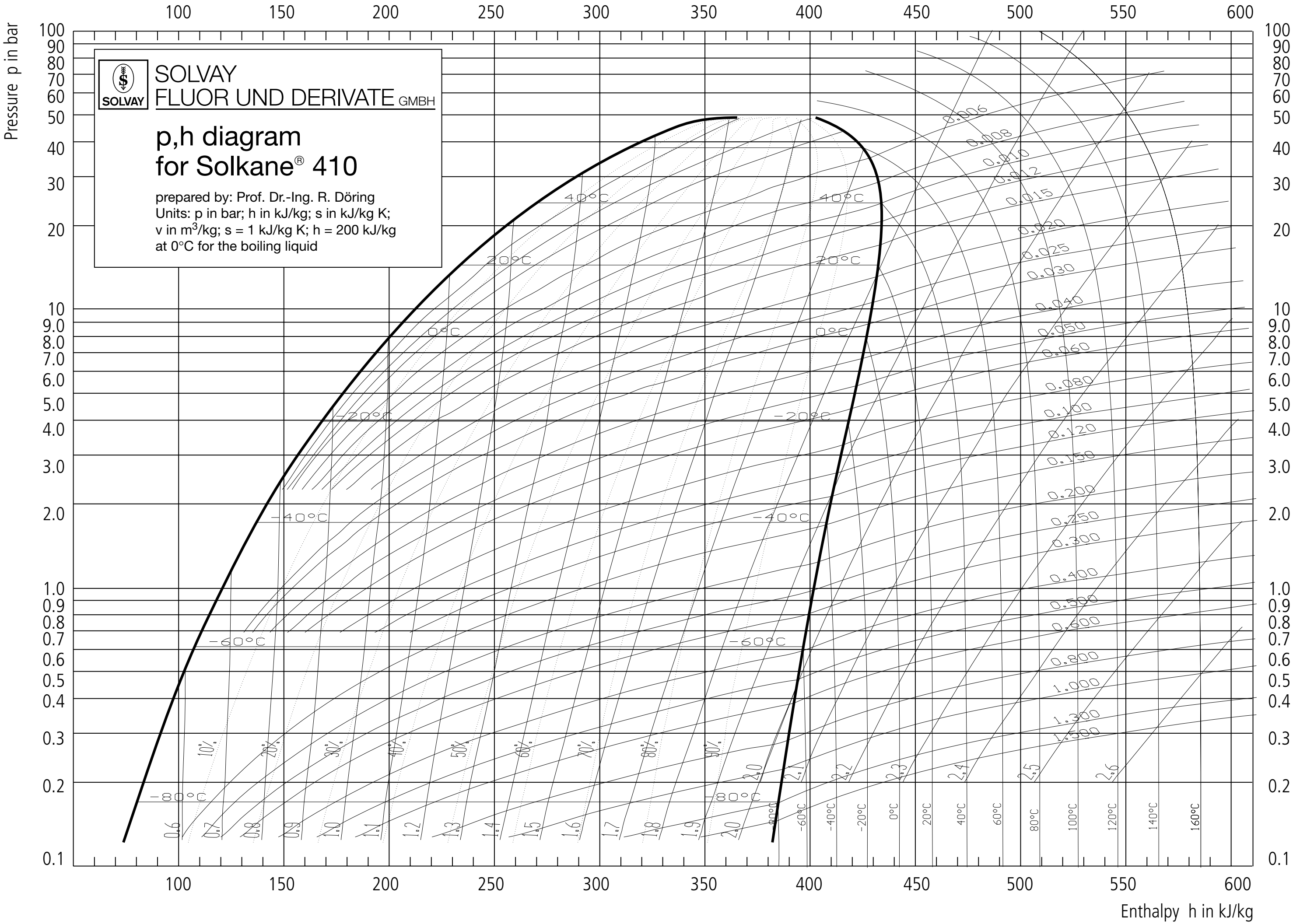
14.1.6 Solkane® 404A



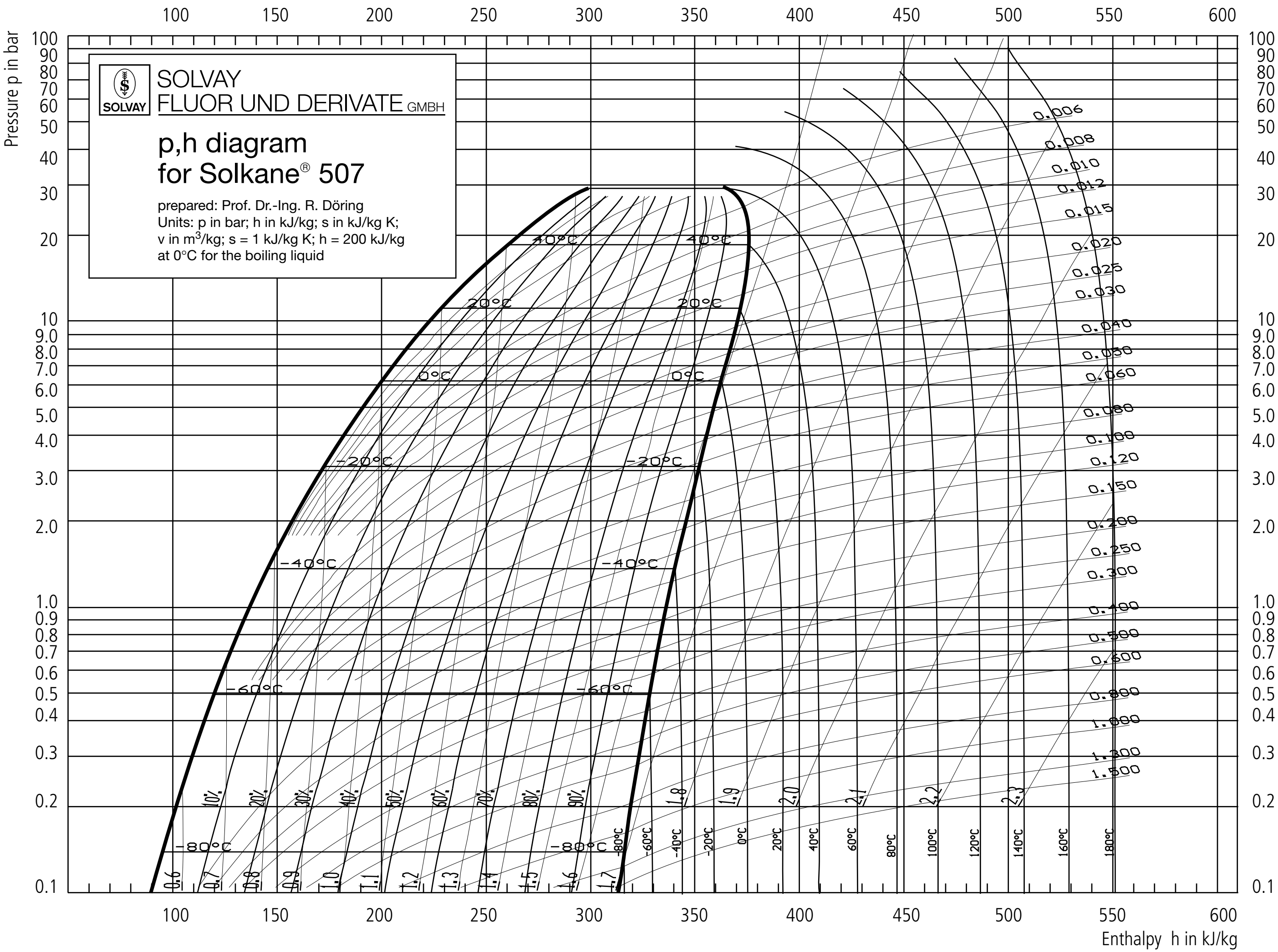
14.1.7 Solkane® 407C



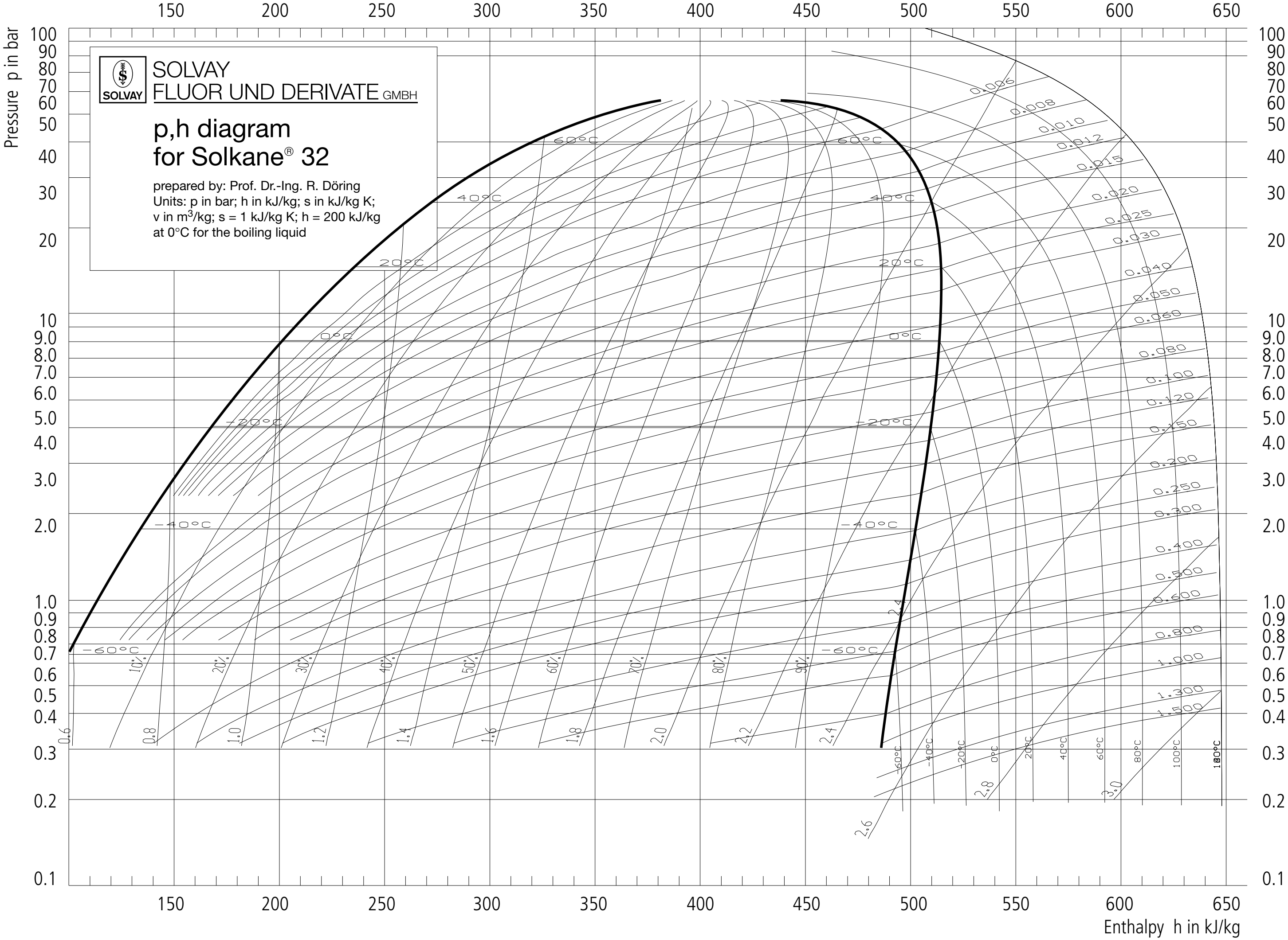
14.1.8 Solkane® 410



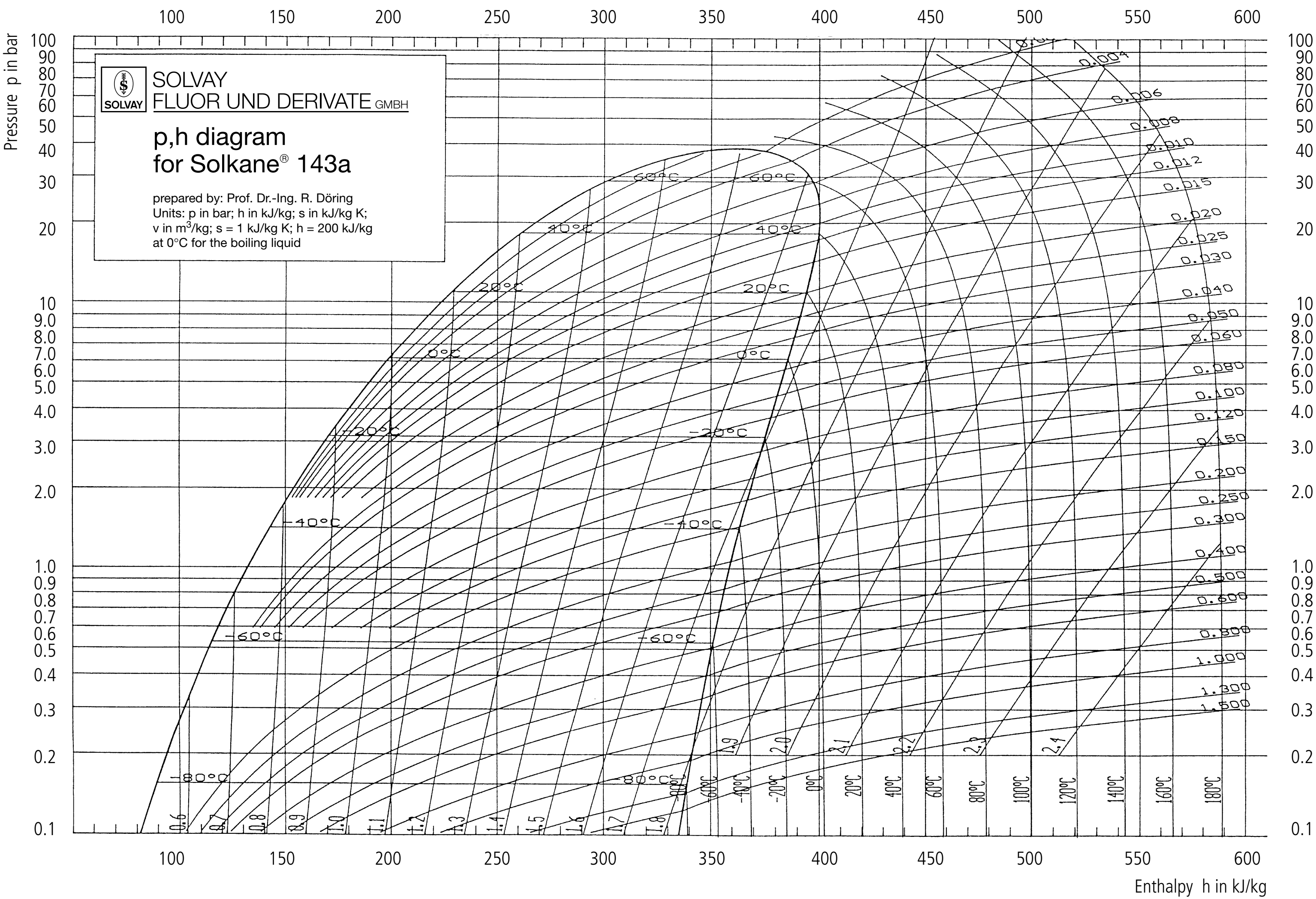
14.1.9 Solkane® 507



14.2.1 Solkane® 32



14.2.2 Solkane® 143a



14.2.3 Solkane® 152a