Solkane®-
Pocket Manual

Refrigeration and Air-Conditioning Technology

Solvay
Fluor

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 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 29,000 people in 50 countries around the world, its business is split into the three sectors: pharma, chemicals and plastics, 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 4,000 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 three sectors can be summarized as follows:

Chemicals Sector

The most important product groups in the chemicals sector today are: 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.

Solvay Fluor

Solvay Fluor – the name of the international Solvay Group's globally active Strategic Business Unit – is made up of many committed companies and 11 production operations, including a fluorspar mine.

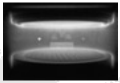
Today we rank second worldwide in the rapidly growing fluorochemicals market.

Our structure is targeted at providing rapid and flexible responses to the demands of a global market – for the benefit of our clients.

Professional Fluorochemistry

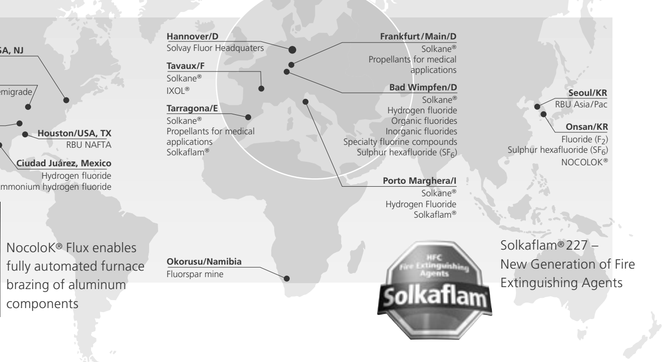
Solvay Fluor stands for a professional team of outstanding chemists and sales personal, all committed to the best in fluorochemistry. It is a name synonymous with powerful application technologies, prepared to take on any challenge, seeking to solve the problem at hand in close consultation with the client. It also means an unusually broad range of fluorocompounds and specialties, produced at 11 locations worldwide. Solvay Fluor is the only company offering a full range of fluor products using fluorspar sourced in-house.

Solkane® – our CFC substitutes – a vital step towards a protected environment



SIFREN® – etching gas for semiconductor industry

Alternative propellants for pharmaceutical aerosols



NocoloK® Flux enables fully automated furnace brazing of aluminum components

Solkaflam® 227 – New Generation of Fire Extinguishing Agents

Alternative foaming agents and refrigerants

We develop and market – under our name Solkane – refrigerants, solvents and blowing agents for plastic foams. Solvay Fluor is offering beside the complete HCFC product line, the eco-friendly HFC 3rd generation products. In particular the highly successful refrigerant Solkane 134a and our pharma propellants Solkane 134a pharma and Solkane 227 pharma for medical applications.

To ease the transition process, our clients can draw on our application know-how and many decades of professional experience.

F_2 – Elemental fluorine is our speciality

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

SIFREN® a high performance critical etching gas, is the preferred compound used in the semiconductor industry. Elemental Fluorine electronic grade is a highly efficient cleaning medium for CVD chambers.

Inorganic fluorides – vital support

We are proud of our role as one of the leading producers of inorganic fluorides: we offer 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 unthinkable without fluorides; they are absolutely 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.

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.

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 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:

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

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

$$O_3 + O \rightarrow O_2 + O_2$$

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 2037/2000 (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	– 26.1 °C	1.1.1.2-tetrafluoroethane/CH_2FCF_3	R134a
Solkane 227	– 16.4 °C	1.1.1.2.3.3.3-heptafluoropropane/CF_3CHFCF_3	R227ea
Solkane 404A	– 46.2 °C	Near-azeotrope R125/R143a/R134a/ CHF_2CF_3/CH_3CF_3/CH_2FCF_3	R404A
Solkane 407C	– 43.6 °C	Zeotrope R32/R125/R134a/ CH_2F_2/CHF_2CF_3/CH_2FCF_3	R407C
Solkane 410	– 51.4 °C	Near-azeotrope R32/R125/ CH_2F_2/CHF_2CF_3	R410A
Solkane 507	– 46.7 °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.

*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.

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)

[flame symbol] Flammability limits, percent by volume in dry air

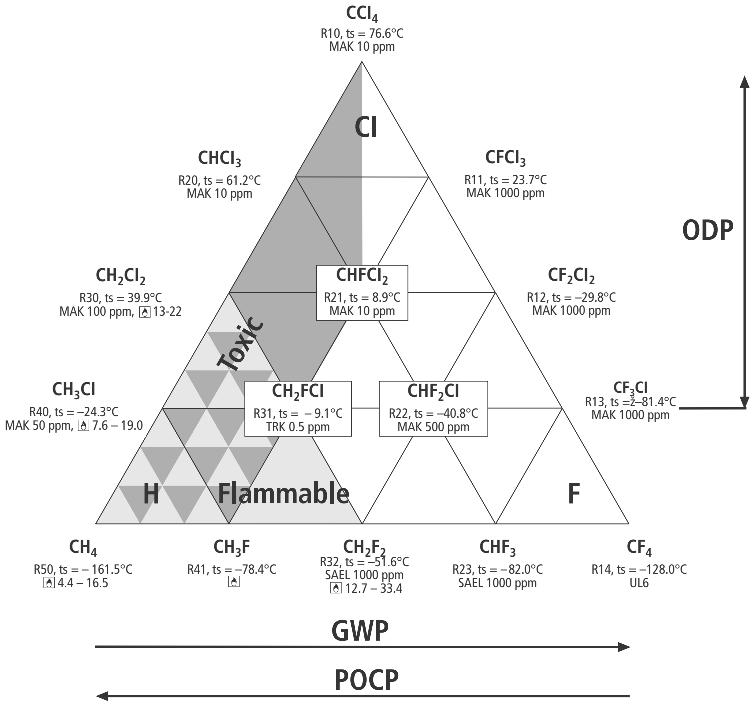


Figure 1: Fluorine-chlorine derivatives of methane

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)
[flame symbol] Flammability limits, percent by volume in dry air

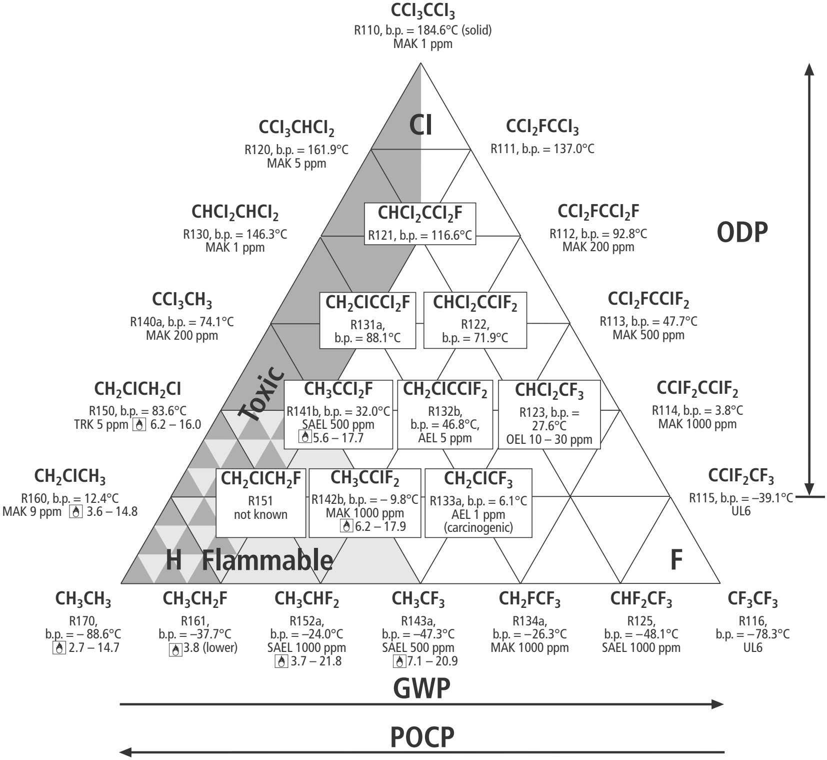


Figure 2: Fluorine-chlorine derivatives of ethane

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 86.47

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 –26.1 °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 –16.4 °C / molecular weight 170.03

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 –46.2 °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: –43.6 °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 –51.4 °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 –46.7 °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 Working fluids for high temperature applications

Higher costs for energy during the last years increased the utilization of alternative energy sources and waste heat.

Solvay offers two fluids which were developed for high temperature applications up to 225°C.

Solkane® 365mfc

Boiling point at 1.013 bar +41,4°C / Molecular weight 148.07

Solkane 365mfc is a liquid hydrofluorocarbon which is mainly used as a foam blowing agent. The application of R365mfc as refrigerant for high temperature heat pumps and centrifugal chillers is under development.

Solkane 365mfc is a new chemical substance and is listed in ELINCS – (no. 430-250-1).

Although Solkane 365mfc has a flash point below −27 °C, it has a high minimum ignition energy (10.4 mJ at 25 °C, 8 vol.% in air at 1 bar). This is 50 times higher than for n-Pentane and means that only strong ignition sources could ignite (at ambient conditions). The flammability limit is 3.6 – 13.3 vol.% in air.

R365mfc is compatible with all the metals which are usually used in refrigeration systems. At high temperatures and/or at high pressures reactions can occur with reactive metals like zinc, aluminum, alloy and magnesium.

R365mfc is compatible with Neoprene, EPDM, PVC, PP and PE.

Solkatherm® SES36

Normal boiling point 1.013 bar +35,6°C / Molecular weight 184.85

Solkatherm SES36 is a liquid azeotrope consisting out of R365mfc ($CF_3CH_2CF_2CH_3$) and a perfluoropolyether (HT55). It is mainly used in high temperature applications like high temperature heat pumps or in Organic Rankine Cycles and in cooling systems for machines and electronic parts (e.g. CPU). Due to its favorable dielectric properties, it can cool electronic parts in direct contact (Immersion cooling).

Solkatherm SES36 is compatible with most standard metals used in refrigeration systems. Only at high temperatures and pressures reactions can occur with reactive metals like zinc, aluminum and magnesium.

Suitable non metal materials for gaskets and o-rings are Neoprene, EPDM, PVC, PP and PS.

3.2.4 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).

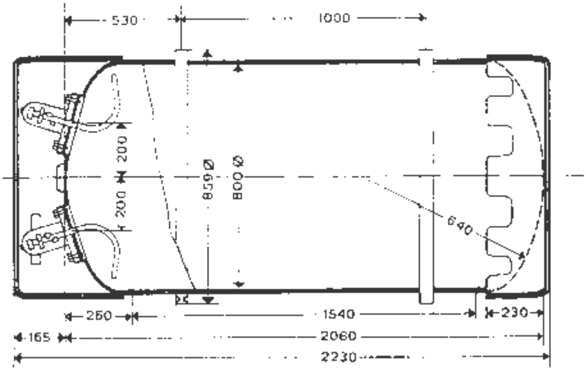


Figure 3: Loan steel container

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 sizes1) for different Solkane® types
(August 2000)

	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 / 320 kg			
Solkane 507	720 kg	approx. 15 t		

1) other container sizes can be purchased from wholesalers

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

Tankcontainer filled with Solkane ready for Railtransport in front of Frankfurt plant

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 34-2004 "Number Designation and Safety Classification of Refrigerants". 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 34-2004 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.

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	137.40	23.9	198.0	4.40
R12	CCl_2F_2	120.90	– 29.5	112.0	4.14
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	148.93	– 58.1	67.0	3.96
R14	CF_4	88.00	– 127.9	–45.7	3.75
R22	$CHClF_2$	86.47	– 40.8	90.1	4.99
R23	CHF_3	70.00	– 82.0	26.3	4.87
R32	CH_2F_2	52.00	– 51.6	78.1	5.78
R41	CH_3F	34.03	– 78.4	44.3	5.88
R50	CH_4-Methan	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	$CHCl_2CF_3$	152.90	27.6	183.7	3.66
R124	$CHClFCF_3$	136.48	– 12.0	122.3	3.62
R125	CHF_2CF_3	120.00	– 48.1	66.2	3.63
R134	CHF_2CHF_2	102.03	– 23.0	118.7	4.62
R134a	CH_2FCF_3	102.00	– 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	84.00	– 47.3	72.9	3.78
R152a	CH_3CHF_2	66.10	– 24.0	113.3	4.52
R161	CH_3CH_2F	48.06	– 37.1	102.2	4.70
R170	CH_3CH_3-Ethan	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	– 16.4	101.8	2.93

Safety data			Environmental data	
TLV-TWA (ppm)	UEG (Vol.-%)	Std. 34 Safety group	ODP	GWP_{100}
C1000	none	A1	1.000	4000
1000	none	A1	0.900	8500
	none		5.000	
1000	none	A1	1.000	11700
1000	none	A1	13.000	5600
	none	A1	0	6500
1000	none	A1	0.050	1700
1000	none	A1	0	11700
1000	12.7	A2	0	650
			0	150
1000	5	A3	0	21
1000	none	A1	0.900	5000
1000	none	A1	0.850	9200
1000	none	A1	0.400	9300
1000	none	A1	0	9200
10-30	none	B1	0.020	93
1000	none	A1	0.030	480
1000	none	A1	0	2800
1000	none		0	1000
1000	none	A1	0	1300
500	6.4		0.100	630
1000	9.0	A2	0.066	2000
500	7.1	A2	0	3800
1000	3.1	A2	0	140
	3.8		0	low
1000	3.2	A3	0	3
1000	3.3		0	<1
1000	none	A1	0	7000
1000	none		0	2900

Table 2: Information on refrigerants (2)

Refrigerant			Physical data			
Num-ber	Chem. formula or blend composition (% by weight)		Molar mass	Boiling point at 1.013 bar(°C)	Critical properties t_c (°C)	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	– 46.2	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	– 43.6	86.0	4.63
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)	72.60	– 51.4	71.4	4.90
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)	UEG (Vol.-%)	Std. 34 Safety group	ODP	GWP_{100}
	2.4		0	
p2500	2.3	A3	0	3
	none	A1	0	8700
	none	A1	0.875	8850
	none	A1	0.880	8780
800	none	A1	0.037	1080
840	none	A1	0.039	1190
	none	A1	0.032	830
	none		0.033	910
	none	A1	0.019	2330
	none	A1	0.030	2080
1000	none	A1	0.038	2680
1000	none	A1	0.028	3680
500	none	A1	0	3260
1000	none	A1	0.026	4580
	wff	A2	0.055	1760
	wff		0.051	1680
1000	none	A1	0	1770
1000	none	A1	0	2290
1000	none	A1	0	1530
1000	none	A1	0	1430
	none	A1	0.024	2740
	none	A1	0.047	1440
	none	A1	0.047	1430
1000	none	A1	0	1730
	none	A1	0	
	none		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)	Critical properties 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		
R414B	R22/124/600a/142b	(50/39/1.5/9.5)	101.59	– 34.3	118.2	
R414A	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)	98.90	– 46.7	70.7	3.71
R508A	R23/116	(39/61)	100.10	– 85.7	23.1	4.06

Safety data			Environmental data	
TLV-TWA (ppm)	UEG (Vol.-%)	Std. 34 Safety group	ODP	GWP_{100}
1000	wff	A2	0.044	1500
1000	wff	A2	0.047	1600
1000	none		0.048	1630
1000	wff	A2	0.052	2040
	wff	A2	0	1770
	none		0.043	1230
			0.045	1330
1000	none		0.040	1970
1000	none		0.045	2120
	none		0	1630
	none		0	3330
	none		0	2850
1000	none	A1	0.664	6310
	none	A1	0.263	3400
1000	none	A1	0.229	5590
1000	none		0.599	11700
	none		0.207	5130
	none		0.704	
	none		0.387	
500	none	A1	0	3300
1000	none	A1	0	10200

Table 2: Information on refrigerants (4)

Refrigerant		Physical Data			
Num-ber	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-Butan	58.12	– 0.5	152.0	3.80
R600a	$CH(CH_3)_2$-CH_3-Isobutan	58.12	– 11.8	135.0	3.65
R601	CH_3-CH_2-CH_2-CH_2-CH_3-Pentan	72.15	36.2	196.4	3.36
R601a	$(CH_3)_2CH$-CH_2-CH_3-Isopentan	72.15	27.8	187.4	3.37
R601b	$(CH_3)_4C$-Neopentan	72.15	9.5	160.6	3.20
R610	CH_3-CH_2-O-CH_2-CH_3-Ethylether	74.12	34.6	214.0	6.00
R611	$HCOOCH_3$-Methylformiat	60.05	31.8	214.0	5.99
R630	$CH_3(NH_2)$-Methylamin	31.06	– 6.7	156.9	7.46
R631	CH_3-$CH_2(NH_2)$-Ethylamin	45.10	16.6	183.0	5.62
R717	NH_3-Ammoniak	17.03	– 33.3	133.0	11.42
R718	H_2O-Wasser	18.02	100.0	374.2	22.10
R744	CO_2-Kohlendioxid	44.01	– 78.4	31.1	7.38
R7146	SF_6-Schwefelhexafluorid	146.05	– 63.8	45.6	3.76
R1130	CHCl=CHCl	96.94	47.8	243.3	5.48
R1150	CH_2=CH_2-Ethylen	28.05	– 109.4	9.3	5.11
R1270	CH_3CH=CH_2-Propylen	42.08	– 47.7	92.4	4.62

Safety data			Environmental data	
TLV-TWA (ppm)	UEG (Vol.-%)	Std. 34 Safety group	ODP	GWP_{100}
1000	none	A1/A1	0	10400
1000	none	A1	0.022	4670
800	1.9	A3	0	<1
800	1.8	A3	0	
600	1.5		0	11
600	1.4		0	
600			0	
400	1.9		0	
100	5.1	B2	0	
5	4.9		0	
5	3.5		0	
25	14.8	B2	0	<1
	none	A1	0	<1
5000	none	A1	0	1
1000	none		0	23900
200	5.6			
1000	2.7	A3	0	
1000	2.0	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	$F_3CH_2CHF_2$	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	ca. 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,

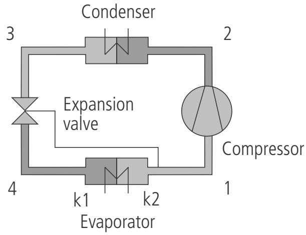


Figure 4: Single-stage compression refrigeration cycle

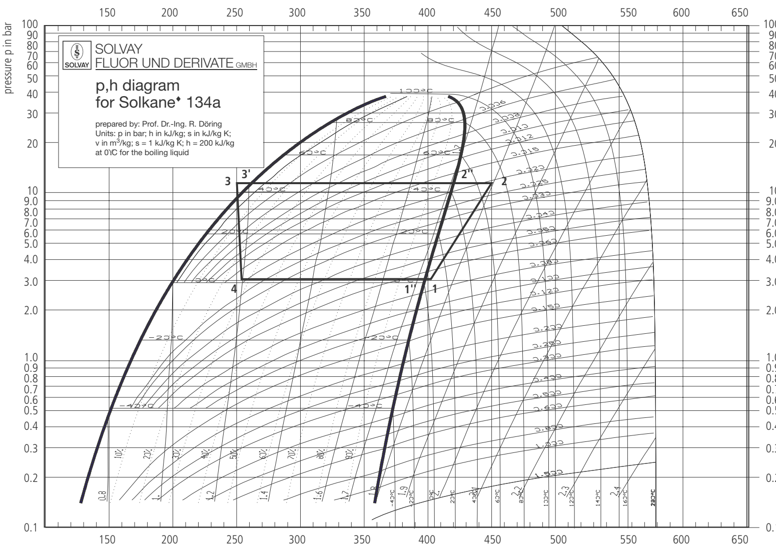


Figure 5: Mollier(-lg p, h-)diagram of a single-stage compression refrigeration cycle for Solkane 134a

chapter 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.

$$q_{ov} = \frac{\dot{Q}_O}{\dot{m}_R \cdot V_{v1}}$$

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	$\frac{W}{m^2K}$	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

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

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:

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

and

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

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:

$$\frac{dp}{dT} = \frac{1}{T} \cdot \frac{h'' - h'}{v'', - v'} \quad (7)$$

Transformation of equation (7) gives:

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

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

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

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 (‘‘).

Table 3: Constants for the thermodynamic calculation bases (1)

const.	Unit	R22 [a, b]	R32	R123
Saturated [TR=T/Tc]		0.60 – 0.95	0.69 – 0.95	0.56 – 0.97
Superheated p [Mpa]/Tmax [K]		0.05 – 2.5 / 420	0.05 – 0.5 / 455	0.05 – 2.5 / 500
A_1	[–]	–7.1180E+00	–7.5756E+00	–7.6830E+00
A_2	[–]	2.3300E+00	3.0907E+00	4.3623E+00
A_3	[–]	–3.9257E+00	–5.9497E+00	–1.0067E+01
A_4	[–]	6.3012E+00	9.4120E+00	1.5277E+01
A_5	[–]	–6.3919E+00	–8.2233E+00	–1.2065E+01
A_6	[–]	–9.2010E–06	1.3937E–04	5.4113E–04
B_1	[–]	1.5000	1.5000	1.5000
B_2	[–]	2.0000	2.0000	2.0000
B_3	[–]	2.5000	2.5000	2.5000
B_4	[–]	3.0000	3.0000	3.0000
C_1	[–]	1.65	1.800263	1.743412
C_2	[–]	1.27	1.355916	1.210301
C_3	[–]	–1.06	–0.980629	–1.269500
C_4	[–]	0.91	0.879826	1.142949
D_1	[kJ/kg K]	2.62795E–01	1.24207E+00	1.10920E–01
D_2	[kJ/kg K^2	1.22539E–03	–4.30444E–03	2.64730E–03
D_3	[kJ/kg K^3]	6.25581E–07	1.49037E–05	–3.03990E–06
D_4	[kJ/kg K^4]	–1.49815E–09	–1.30550E–08	1.53676E–09
D_5	[kJ/kg K^5]	0	0	0
D_6	[kJ/kg]	1.66484E+00	–3.34252E+01	2.35112E–02
E_1	[–]	–1.49669E–03	–3.48463E–03	–1.09399E–03
E_2	[–]	1.83231E–06	–8.46896E–07	9.92069E–07
E_3	[–]	1.20294E–10	9.54425E–10	4.39233E–10
E_4	[–]	–4.66754E–12	–7.19661E–11	–4.51951E–12
F_1	[–]	1.74608E–06	6.74996E–06	1.39387E–06
F_2	[–]	–2.39315E–09	1.73316E–09	–1.59353E–09
F_4	[–]	8.15538E–15	1.74923E–13	8.27068E–15
G_1	[–]	–2.24897E–02	–7.40687E–02	–1.37139E–02
G_2	[–]	1.53942E–05	–2.69804E–05	–2.66296E–05
G_4	[–]	1.72572E–10	4.59565E–09	1.47297E–10
b	[m^3/kg]	2.23593E–04	–1.23088E–03	–2.61126E–04
k	[–]	5.475	5.475	5.475
R	[bar m^3/(kJ K)]	9.61549E–04	1.59821E–03	5.43677E–04
Tc	[K]	369.30	351.26	456.83
pc	[bar]	49.90	57.82	36.62
rc	[kg/m^3]	523.84	424.00	550.00
M	[kg/kmol]	86.47	52.00	152.90

Applicable acc. ISO/DIS 17584* (12/2003)

R125	R134a	R143a	R152a
	0.60 – 0.96	0.59 – 0.95	0.56 – 0.97
	0.05 – 2.5 / 500	0.05 – 2.0 / 475	0.05 – 2.5 / 500
–7.7226E+00	–7.7069E+00	–7.5556E+00	–7.7213E+00
3.6331E+00	2.4932E+00	3.7588E+00	4.5614E+00
–7.0409E+00	–2.9212E+00	–7.7972E+00	–1.0393E+01
1.0112E+01	–3.8684E+00	1.1445E+01	1.5212E+01
–9.1166E+00	4.6898E–01	–9.1198E+00	–1.1241E+01
6.2974E–05	–8.3360E–05	7.3763E–05	4.5324E–04
1.5000	1.5158	1.5000	1.5000
2.0000	1.9907	2.0000	2.0000
2.5000	4.3798	2.5000	2.5000
3.0000	1.7461	3.0000	3.0000
1.692899	1.732277	1.834762	1.750819
1.380434	1.348322	1.086108	1.306798
–1.266397	–1.251446	–0.768969	–1.059488
0.991319	1.056144	0.756214806	0.910847
4.43550E–01	2.49202E–01	2.84634E–01	4.18642E–01
9.89241E–04	2.45251E–03	2.25435E–03	1.40396E–03
2.05444E–06	–1.65650E–06	5.55068E–07	3.09703E–06
–3.01960E–09	8.91048E–10	–2.18660E–09	–3.46140E–09
0	0	0	0
–1.61960E+01	–6.96764E+00	–5.68048E+00	2.35978E–01
–7.60920E–04	–1.40114E–03	–1.87726E–03	–3.38549E–03
–6.11070E–07	2.19433E–06	1.78850E–07	1.77559E–06
–2.04710E–09	–6.73580E–10	1.71317E–09	1.30470E–09
–6.33460E–12	–4.66800E–12	–3.32970E–11	–4.84868E–11
1.34481E–06	1.63714E–06	3.40317E–06	5.31125E–06
3.08935E–09	–2.78860E–09	–2.27055E–10	–2.30804E–09
2.15058E–14	1.02574E–14	7.38650E–14	9.94006E–14
–1.32304E–02	–2.69555E–02	–3.34101E–02	–5.73338E–02
–3.47650E–05	2.67772E–05	–6.23063E–05	–2.54917E–06
5.22200E–10	1.69513E–10	1.87386E–09	3.16760E–09
–7.80700E–04	2.99628E–04	–8.95779E–04	–7.73363E–04
5.166	5.475	5.475	5.475
6.92749E–04	8.14892E–04	9.89340E–04	1.25880E–03
339.33	374.21	346.04	386.41
36.29	40.59	37.76	45.17
571.30	511.90	425.73	368.00
120.00	102.00	84.00	66.10

* Except Heat Capacities

Table 3: Constants for the thermodynamic calculation bases (2)

const.	Unit	R404A [a, b]	R407C [a, b]
Saturated [TR=T/Tc]		0.62 – 0.90	0.58 – 0.95
Superheated p [Mpa]/Tmax [K]		0.05 – 2.0 / 420	0.05 – 2.5 / 420
A_1	[–]	–7.5388152 / –7.7843482	–6.6102789 / –9.1030381
A_2	[–]	3.1135196 / 4.5429514	–1.4132342 / 10.275949
A_3	[–]	–6.2846755 / –10.59339	4.7954371 / –24.268356
A_4	[–]	10.007636 / 16.350124	–3.8776663 / 32.465544
A_5	[–]	–9.016329 / –12.872483	–1.7421263 / –20.814719
A_6	[–]	8.6689E–4 / –5.51545E–4	0.010919942 / –0.01227508
B_1	[–]	1.5000	1.5000
B_2	[–]	2.0000	2.0000
B_3	[–]	2.5000	2.5000
B_4	[–]	3.0000	3.0000
C_1	[–]	1.667096	1.782668035
C_2	[–]	1.579917	1.9543224381
C_3	[–]	–1.572306	–2.34590112
C_4	[–]	1.185236	1.705800362
D_1	[kJ/kg K]	2.68898E–01	5.16830E–01
D_2	[kJ/kg K^2]	2.18304E–03	5.86760E–04
D_3	[kJ/kg K^2]	–6.45482E–08	2.94150E–06
D_4	[kJ/kg K^4]	–1.32660E–09	–3.16270E–09
D_5	[kJ/kg K^5]	0	0
D_6	[kJ/kg]	–4.83918E+00	–1.47650E+01
E_1	[–]	–1.42473E–03	1.58978E–03
E_2	[–]	–1.24141E–06	–1.85207E–06
E_3	[–]	–3.34429E–10	–2.95621E–10
E_4	[–]	–2.01320E–11	–2.92687E–11
F_1	[–]	2.91474E–06	3.30921E–06
F_2	[–]	2.95444E–09	3.96706E–09
F_4	[–]	5.39828E–14	7.29247E–14
G_1	[–]	–2.47247E–02	–3.35072E–02
G_2	[–]	–5.45329E–05	–7.28580E–05
G_4	[–]	1.46493E–09	2.05836E–09
b	[m^3/kg]	–1.09320E–03	–1.18597E–03
k	[–]	5.475	5.475
R	[bar m^3/(kJ K)]	8.51862E–04	9.64516E–04
Tc	[K]	345.20	359.18
pc	[bar]	37.29	46.30
rc	[kg/m^3]	486.53	484.23
M	[kg/kmol]	97.60	86.20

Applicable acc. ISO 17584:2005

R410A [a]	R507 [a]
0.59 – 0.94	0.61 – 0.92
0.05 – 0.5 / 440	0.05 – 2.5 / 420
–7.44346906 / –7.55263161	–7.60093772 / –7.65020846
1.777486346 / 2.317371339	3.38922434 / 3.722323831
–1.95648689 / –3.1974852	–6.97163346 / –7.9903175
3.374098233 / 4.915099639	10.82146993 / 12.37193104
–5.0656166 / –5.8902625	–9.45590737 / –10.3687047
6.9069E–4 / 2.51091E–4	0.00018596 / –2.4939E–6
1.5000	1.5000
2.0000	2.0000
2.5000	2.5000
3.0000	3.0000
2.028037	1.647704
1.755952	1.740683
–2.432390	–1.899114
1.913324	1.385889
8.26738E–01	2.65117E–01
–1.56394E–03	2.18485E–03
8.23946E–06	–1.04594E–07
–7.81040E–09	–1.29306E–09
0	0
–2.37897E+01	–4.48048E+00
–1.90321E–03	–1.35751E–03
–6.39865E–07	1.66645E–06
6.31686E–10	–4.89974E–10
–2.76115E–11	–5.24016E–12
3.64583E–06	1.78716E–06
1.59116E–09	–1.96249E–09
6.29721E–14	1.13725E–14
–4.43417E–02	–2.49293E–02
–3.14090E–05	–4.89974E–10
2.11482E–09	3.16976E–10
–8.73663E–04	1.12341E–04
5.475	5.475
1.14549E–03	8.41047E–04
344.51	343.77
49.03	37.05
459.53	490.77
72.60	98.86

* Except Heat Capacities

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	R22	R32	R123
H_0	[Pa s]	–1.55991947	–1.8646	–0.56273755
H_1	[Pa s/K]	–0.01083022	–0.0113347	–0.0130821
H_2	[Pa s/K^2]	–5.3528E–06	–2.393700E–05	4.566270E–05
H_3	[Pa s/K^3]	1.47439E–07	–2.173300E–07	–2.192300E–07
I_0	[–]	285.7	N	275.16
I_1	[–]	0.4652	N	0.5909
I_2	[–]	37.488	N	35.816
I_3	[–]	0.2736	N	0.2689
ζ	[1/Pa s]	37488	N	35816
J_0	[10^{-3}W/m K]	96.6888148	151.43	83.890607
J_1	[10^{-3}W/m K^2]	–0.436130061	–0.70375	–0.290282105
K_0	[10^{-3}N/m]	11.69554373	1.108080E+01	1.848186E+01
K_1	[10^{-3}N/m K]	–0.14976356	–1.720700E–01	–1.232125E–05
K_2	[10^{-3}N/m K^2]	0.000185225	2.085600E–04	2.559425E–05
K_3	[10^{-3}N/m K^3]	5.89052E–07	1.263800E–06	5.088261E–07
L_0	[10^{-3}W/m K]	9.503310023	1.288200E+01	8.454018E+00
L_1	[10^{-3}W/m K^2]	0.060826729	1.026400E–01	6.711867E–02
L_2	[10^{-3}W/m K^3]	–0.000039977	1.392130E–03	3.968701E–05
L_3	[10^{-3}W/m K^4]	4.15695E–07	0	–4.607059E–07
L_4	[10^{-3}W/m K^5]	5.2452E–20	0	1.852623E–09
M_0	[kJ/(kg K)]	334.721	438.0707293	148.4284461
M_1	[kJ/(kg K)]	–1405.7	–1808.85382	–601.053656
M_2	[kJ/(kg K)]	2070.38	2624.069589	856.2204098
M_3	[kJ/(kg K)]	–1089.66	–1362.52461	–435.393072
M_4	[kJ/(kg K)]	91.9077	111.5079622	32.69939588

R125	R134a	R143a
–1.59881	–1.29909	–1.86345
–0.013809	–0.0129286	–0.013459
–1.408100E–05	4.922300E–06	–4.240000E–07
–2.918000E–07	–1.986000E–07	1.670300E–07
N	277.74	N
N	0.5067	N
N	39.721	N
N	0.2597	N
N	39721	N
72.06	94.21	78.39
–0.38514	–0.42784	–0.41553
6.818000E+00	1.148600E+01	7.762700E+00
–1.322500E–01	–1.426700E–01	–1.313900E–01
2.235000E–04	1.313300E–04	1.495200E–04
2.982500E–06	1.169700E–06	1.955300E–06
1.347600E+01	1.180400E+01	1.231200E+01
1.031500E–01	8.305000E–02	9.808000E–02
1.333310E–03	1.337410E–04	2.324970E–04
1.107480E–05	0	1.112810E–05
8.531950E–08	0	1.454960E–07
344.02988	395.19	273.2385559
–1417.609	–1588.637	–1128.09554
2042.5403	2233.8111	1638.813984
–1049.057	–1120.361	–851.664324
81.293348	81.2566	69.17485057

Table 4: Constants for the calculation equations of transport properties for Solkane® refrigerants (2)

const.	Unit	R152a	R227ea	R404A
H_0	[Pa s]	–1.55872	–1.0612	–1.73999
H_1	[Pa s/K]	–0.0112737	–0.013945	–0.013554
H_2	[Pa s/K^2]	2.188000E–05	5.340900E–05	–4.758900E–06
H_3	[Pa s/K^3]	–2.109700E–07	–4.056500E–07	–1.095300E–07
I_0	[–]	322.18	300	279.31
I_1	[–]	0.4695	0.5	0.4968
I_2	[–]	46.173	38.085	42.42918
I_3	[–]	0.2524	0.2752	0.2611
ζ	[1/Pa s]	46173	38085	42429
J_0	[10^{-3}W/m K]	116.75	59.89	76.009
J_1	[10^{-3}W/m K^2]	–0.46025	–0.25291	–0.4024
K_0	[10^{-3}N/m]	1.338300E+01	9.884890E+00	7.537000E+00
K_1	[10^{-3}N/m K]	–1.399900E–01	–1.189714E–01	–1.290000E–01
K_2	[10^{-3}N/m K^2]	9.204200E–05	8.713140E–05	1.616800E–04
K_3	[10^{-3}N/m K^3]	1.870100E–07	9.366990E–07	1.562400E–06
L_0	[10^{-3}W/m K]	1.228200E+01	1.090952E+01	1.270900E+01
L_1	[10^{-3}W/m K^2]	7.744000E–02	7.010000E–02	9.932000E–02
L_2	[10^{-3}W/m K^3]	9.616400E–04	7.526930E–05	6.226100E–04
L_3	[10^{-3}W/m K^4]	0	–1.126800E–07	1.068300E–05
L_4	[10^{-3}W/m K^5]	0	4.559410E–08	5.733900E–08
M_0	[kJ/(kg K)]	378.2333496	N	272.7746241
M_1	[kJ/(kg K)]	–1569.98146	N	–1137.19404
M_2	[kJ/(kg K)]	2289.645687	N	1666.232657
M_3	[kJ/(kg K)]	–1193.68482	N	–872.727122
M_4	[kJ/(kg K)]	97.70727825	N	72.38836018

R407C	R410A	R507
–1.5764	–1.78743	–1.76262
–0.012445	–0.012082	–0.0136
4.502900E–06	–2.090300E–05	–6.017700E–06
–1.179200E–07	–2.393000E–07	–2.212900E–08
339.72	317.47	294.33
0.4538	0.4324	0.4902
39.17502	40.99075	42.17005
0.2622	0.2542	0.2601
39175	40990	42170.05
96.197	99.926	75.115
–0.4615	–0.5071	–0.3999
9.996900E+00	8.796300E+00	7.357300E+00
–1.444000E–01	–1.522700E–01	–1.320400E–01
1.644500E–04	2.174000E–04	1.865200E–04
1.430400E–06	2.114700E–06	2.508400E–06
1.251500E+01	1.306100E+01	1.279100E+01
9.413000E–02	1.027900E–01	1.001700E–01
8.287300E–04	1.374300E–03	6.858600E–04
1.988500E–06	3.348700E–06	1.110600E–05
–1.531900E–08	–2.579800E–08	5.043700E–08
309.36797	237.48544	312.9057
–1284.36142	–974.66894	–1320.8741
1873.363029	1412.81	1956.713
–977.084713	–734.81854	–1035.3755
80.36186841	60.886696	88.2952

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	[–]	86.47	70.0
Boiling point at 1.013 bar	[°C]	–40.8	– 82.0
Critical temperature	[°C]	96.1	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 cp[1]	[kJ/kg K]	1.261	1.506[6]
Spec. heat capacity of saturated vapor cp[1]	[kJ/kg K]	0.869	1.365[6]
Ratio cp/cv (saturated vapor)[1]	[–]	1.45	1.74[6]
Density of saturated liquid[1]	[kg/m/]	1191	1106[6]
Density of saturated vapor[1]	[kg/m/]	44.25	84.99[6]
Enthalpy of evaporation[1]	[kJ/kg]	182.5	156.6[6]
Explosion limits in air[3]	[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	170.03	97.6	86.2	72.6	98.9
27.8	–26.1	–16.5	–46.2	–43.6	–51.4	–46.7
183.7	101.1	101.8	72.0	86.0	71.4	70.6
36.6	40.6	29.3	37.3	46.3	49.0	37.1
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	0.0135	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
1.017	1.425	1.188	1.531	1.541	1.694	1.543
0.693	1.011	0.880	1.197	1.117	1.379	1.215
1.11	1.23	1.13	1.28	1.38	1.23	1.27
1464	1206	1388	1044	1136	1059	1048
5.87	32.35	36.24	65.27	43.76	65.93	68.86
171.6	177.5	111.4	140.1	183.2	186.0	136.4
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
Boiling point at 1.013 bar	[°C]	–51.7
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 cp[1]	[kJ/kg K]	1.939
Spec. heat capacity of saturated vapor cp[1]	[kJ/kg K]	1.516
Ratio cp/cv (saturated vapor)[1]	[–]	1.69
Density of saturated liquid[1]	[kg/m⁄]	961
Density of saturated vapor[1]	[kg/m⁄]	47.31
Enthalpy of evaporation[1]	[kJ/kg]	270.4
Explosion limits in air[3]	[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 124	Solkane 152a
CHF_2CF_3	CH_3CF_3	CF_3CHClF	CH_3CHF_2
120	84	136.48	66.1
–48.1	–47.2	–12.0	–24.0
66.2	72.9	122.3	113.3
36.3	37.8	36.2	45.2
0.248	0.190	0.423	0.251
0.141	0.111	0.257	0.160
–	–	0.0116	0.0103
0.078	0.085	0.082	0.124
0.062	0.068	0.068	0.105
0.0170	0.0151	0.0120	0.0148
1.399	1.671	1.134	1.803
1.089	1.343	0.803	1.250
1.35	1.40	1.15	1.27
1190	932	1355	899
90.57	57.63	23.62	18.47
110.3	159.6	146.5	279.1
none	7.1 – 20.9	none	3.7 – 21.8

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 Jahre Zeithorizont	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 Nr. 37 (ISBN 92-807-1449-x). Die erste Ziffer stellt die Modellberechnung dar, die zweite ist das Ergebnis der semi-empirischen Berechnung

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)

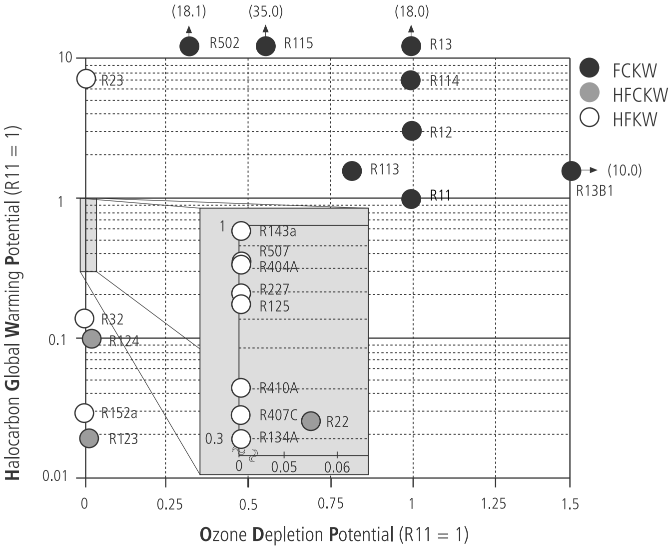


Figure 6: ODP and HGWP values of various refrigerants

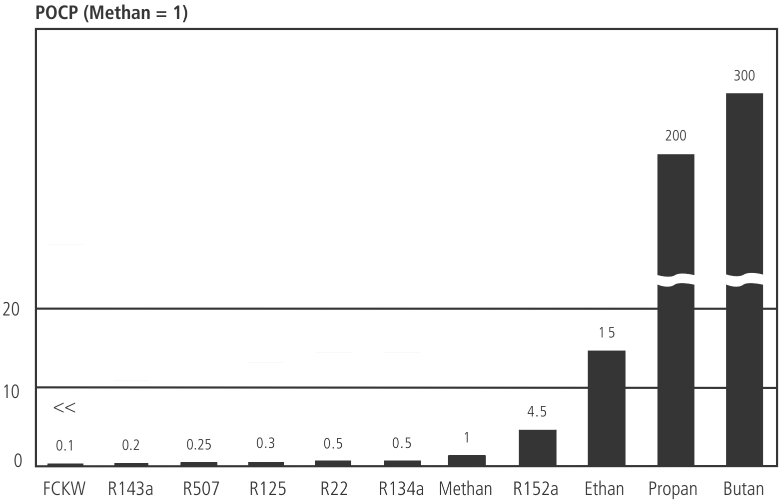


Figure 7: POCP values of various refrigerants

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.

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

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

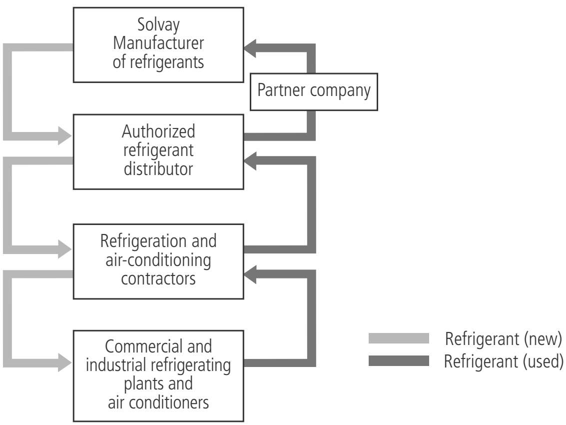


Figure 8

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.

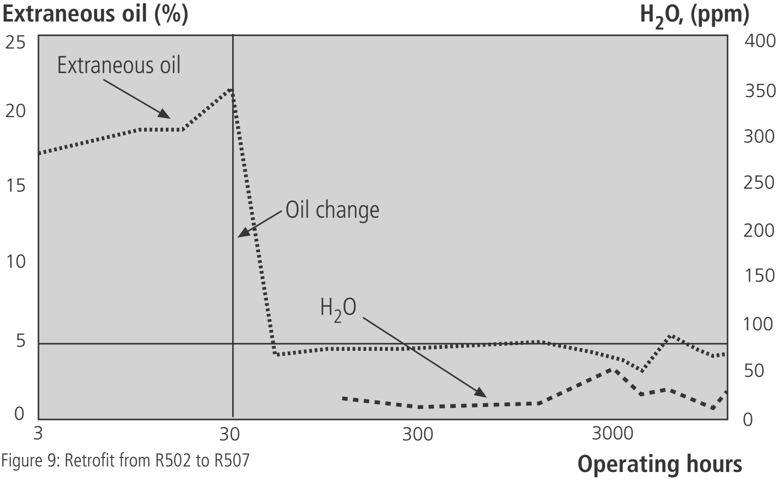


Figure 9: Retrofit from R502 to R507

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 equipment 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 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 regulations, standards, rules and guidelines for refrigeration in regard to refrigerants. Major international regulations and standards for refrigerants and refrigerating plants are:

- Montreal Protocol on substances which deplete the ozone layer
- EC Directive 2037/00 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

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 2037/00 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:

Control of the placing on the market - Cap	Cap 2.6 % of 1989 CFCs + HCFCs (ODP-tons) on		ODP-tonnes
§§ b	1.1.1999		8 079
§§ c	1.1.2001	2 % of 1989	6 678
§§ d	1.1.2002	85 % of 2001	5 676
§§ e	1.1.2003	45 % of 2001	3 005
§§ f	1.1.2004	30 % of 2001	2 003
§§ g	1.1.2008	25 % of 2001	1 669
	1.1.2010	0 %	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.

The use of HCFCs in other applications is restricted according to the following schedule

Refrigerants §§ c		
iii	From 1.1.2000 - in public and distribution cold stores and warehouses - for equipment > 150 kW	
iv	From 1.1.2001 in all other equipment, excepted: - fixed air-conditioning < 100 kW from 1.7.2002 - reversible heat pump from 1.1.2004	
v	From 1.1.2010 all use of virgin HCFCs in servicing From 1.1.2015 all HCFCs for servicing	Before 31.12.2008 the Commission shall review the date of 2015

The complete regulation can be downloaded from:

http://europa.eu.int/comm/environment/ozone/community_action.htm

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 greenhouse 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 ratifcation 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

EN 1048: 1998
Heat exchangers – Air-cooled liquid coolers “dry coolers” –
Test procedure for establishing the performance

EN 1117: 1998
Heat exchangers – Liquid cooled refrigerant condensers –
Test procedures for establishing the performance

EN 1118: 1998
Heat exchangers – Refrigerant cooled liquid coolers –
Test procedures for establishing the performance

EN 12178: 2003
Refrigerating systems and heat pumps –
Liquid level indicating devices – Requirements, testing and marking

EN 12263: 1998
Refrigerating systems and heat pumps –
Safety switching devices for limiting the pressure – Requirements and tests

EN 12900: 1999
Refrigerant compressors –
Rating conditions, tolerances and presentation of manufacturer’s performance data

EN 13136: 2001
Refrigerating systems and heat pumps –
Pressure relief devices and their associated piping –
Methods for calculation

EN 13215: 2000
Condensing units for refrigeration –
Rating conditions, tolerances and presentation of manufacturer's
performance data

EN 13313: 2001
Refrigerating systems and heat pumps – Competence of personnel

EN 13771-1: 2003
Compressors and condensing units for refrigeration –
Performance testing and test methods – Part 1: Refrigerant compressors

EN 1736: 2000
Refrigerating systems and heat pumps – Flexible pipe elements, vibration isolators and expansion joints – Requirements, design and installation

EN 1861: 1998
Refrigerating systems and heat pumps –
System flow diagrams and piping and instrument diagrams –
Layout and symbols

EN 378-1: 2000
Refrigerating systems and heat pumps –
Safety and environmental requirements –
Part 1: Basic requirements, definitions, classification and selection criteria

EN 378-2: 2000
Refrigerating systems and heat pumps – Safety and environmental requirements – Part 2: Design, construction, testing, marking and documentation

EN 378-3: 2000
Refrigerating systems and heat pumps – Safety and environmental requirements – Part 3: Installation site and personal protection

EN 378-4: 2000
Refrigerating systems and heat pumps – Safety and environmental requirements – Part 4: Operation, maintenance, repair and recovery

ISO/AWI 817
Organic refrigerants – Designation system

ISO 5149: 1993
Mechanical refrigerating systems used for cooling and heating – Safety requirements

ISO 5155: 1995
Household refrigerating appliances – Frozen food storage cabinets and food freezers – Characteristics and test methods

ISO 7371: 1995
Household refrigerating appliances – Refrigerators with or without low-temperature compartment – Characteristics and test methods

ISO 8066-2: 2001
Rubber and plastics hoses and hose assemblies for automotive air conditioning – Specification – Part 2: Refrigerant 134a (available in English only)

ISO 8187: 1991
Household refrigerating appliances – Refrigerator-freezers – Characteristics and test methods

ISO 8561: 1995
Household frost-free refrigerating appliances – Refrigerators, refrigerator-freezers, frozen food storage cabinets 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

ISO 9309: 1989

Refrigerant compressors – Presentation of performance data

ISO 9930: 1993

Green beans – Storage and refrigerated transport (available in English only)

ISO 11650: 1999

Performance of refrigerant recovery and/or recycling equipment

ISO/DIS 15502

Household refrigerating appliances – Characteristics and test methods

ISO/DIS 17584

Refrigerant properties

ISO/DIS 18132

Refrigerated light hydrocarbon fluids – Measurement of liquid levels on board ships carrying liquefied gases – General guidance

ISO/DIS 20039

Transportation refrigeration equipment –
Acoustical test methods and sound power rating procedures

ISO/DIS 23953-1

Refrigerated display cabinets – Part 1: Terms and definitions

ISO/DIS 23953-2

Refrigerated display cabinets –
Part 2: Classification, requirements and test conditions

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

The following classification is quoted from EN 378, part1. 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 separated 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.

Increasing flammability

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 mass [3)]
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 limit [4), 5)] (MM) kg/kmol	**Practical** 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**

AREA – Air conditioning and Refrigeration European Association.

Beau Site Première avenue, 88 • B - 1330 Rixensart • Belgium

Tel. : +32 2 653 88 35 • Fax : + 32 2 652 38 72

- 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**

- **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 interstage 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 sufficiently 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

* Nach Jahrbuch 1978 „Kälte-Wärme-Klima“, Verlag C. F. Müller, Karlsruhe

Weights

	Kilogramm	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

Density	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

$1\ \text{N} = 10^5\ \text{dyn}$; $1\ \text{dyn} = 1\ \text{g} \times 1\ \frac{\text{cm}}{\text{s}^2}$; $1\ \text{kp} = 1\ \text{kg} \times \text{g}$

$1\ \text{Poundal} = 1\ \text{Pound} \times \frac{\text{ft}}{\text{s}^2}$

Pressure

	1 bar $= 10^5 \frac{N}{m^2}$	1 at $= 1 \frac{kp}{cm^2}$	$\frac{\text{poundal}}{\text{sq ft}}$	$\frac{\text{poundal}^2}{\text{sq in}}$ = 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)		H_2O-column (WS) (4°C)	
	mm Hg = Torr	in Hg	m H_2O	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		ton-day of refrigeration	1 Joule = N m = W s
Metric $75 \frac{kpm}{s} h$	Imperial $550 \frac{ft \cdot lb}{s} h$		
$1.581 \cdot 10^{-3}$	$1.560 \cdot 10^{-3}$	$13.779 \cdot 10^{-6}$	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

	$1\,\frac{kcal}{h}$	$1^2\,\frac{kp\,m}{s}$	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	$\frac{kJ}{kg}$	$\frac{kcal}{kg}$	$\frac{Btu}{pound}$
1 kJ/kg	1	0.239	0.43
1 kcal/kg	4.1868	1	1.80
1 Btu/lb	2.33	0.556	1

$1\,\frac{cal}{g} = \frac{kcal}{kg}$

Entropy difference, Spec. heat capacity

Δ s	$\frac{kJ}{kg\,K}$	$\frac{kcal}{kg\,°C}$	$\frac{Btu}{pound\,°F}$
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	$\frac{J^2}{ms\,K} = \frac{W}{m\,K}$	$\frac{kJ}{m\,h\,K}$	$\frac{kcal}{m\,h\,°C}$	$\frac{Btu}{ft\,h\,°F}$	$\frac{Btu\ in}{sq\,ft\,h\,°F}$
$1\ J/m\ s\ K = \frac{W}{mK}$	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	$\frac{J^2}{m^2 s\,K} = \frac{W}{m^2 K}$	$\frac{kJ}{m^2 h\,K}$	$\frac{kcal}{m^2 h\,°C}$	$\frac{Btu}{sq\,ft\,h\,°F}$
1 J/m² s K $= \frac{W}{m^2 K}$	1	3.60	0.860	0.1761
1 kJ/m² h K	0.278	1	0.239	0.0489
1 kcal/m² h °C	1.163	4.1868	1	0.2050
1 Btu/ft² h °F	5.680	20.40	4.880	1

$$1\frac{cal}{cm^2\,s\,°C} = 41868\,\frac{J}{m^2\,s\,k} = 150725\,\frac{kJ}{m^2\,h\,k} = 36000\,\frac{kcal}{m^2\,h\,°C} = 7380\,\frac{Btu}{sq\,ft\,h\,°F}$$

Temperatures

Temperature points (also with below-zero temperatures)

a) Given t_f [deg F], wanted t_c [°C]:

$$t_c = \frac{5}{9}(t_f - 32) \quad \text{or} \quad t_c = \frac{5}{9}(t_f + 40) - 40$$

b) Given t_c [°C], wanted t_f [deg F]:

$$t_f = \frac{9}{5}t_c + 32 \quad \text{or} \quad t_f = \frac{9}{5}(t_c + 40) - 40$$

12 Vapor Tables

t = Temperature
p´ = Pressure
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´´ = Entropie des Dampfes

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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	0.10	0.659	1757.18	1.518	0.57	108.71	368.96	260.24	0.6030	1.9503
–79	0.11	0.660	1644.62	1.515	0.61	110.09	369.45	259.36	0.6102	1.9461
–78	0.12	0.661	1540.48	1.513	0.65	111.44	369.94	258.50	0.6173	1.9419
–77	0.13	0.662	1444.05	1.510	0.69	112.77	370.43	257.66	0.6243	1.9378
–76	0.14	0.663	1354.68	1.507	0.74	114.09	370.92	256.83	0.6311	1.9338
–75	0.15	0.665	1271.87	1.505	0.79	115.39	371.41	256.03	0.6378	1.9298
–74	0.16	0.666	1194.93	1.502	0.84	116.67	371.90	255.24	0.6443	1.9259
–73	0.17	0.667	1123.45	1.499	0.89	117.93	372.39	254.46	0.6507	1.9221
–72	0.18	0.668	1057.00	1.497	0.95	119.18	372.88	253.70	0.6570	1.9183
–71	0.19	0.669	995.17	1.494	1.00	120.41	373.37	252.96	0.6632	1.9146
–70	0.21	0.671	937.59	1.491	1.07	121.63	373.86	252.23	0.6693	1.9109
–69	0.22	0.672	883.94	1.488	1.13	122.84	374.35	251.51	0.6753	1.9073
–68	0.23	0.673	833.91	1.486	1.20	124.04	374.84	250.80	0.6812	1.9038
–67	0.25	0.674	787.23	1.483	1.27	125.22	375.33	250.11	0.6870	1.9003
–66	0.26	0.676	743.63	1.480	1.34	126.39	375.81	249.42	0.6928	1.8968
–65	0.28	0.677	702.89	1.478	1.42	127.56	376.30	248.74	0.6984	1.8934
–64	0.30	0.678	664.79	1.475	1.50	128.71	376.79	248.08	0.7040	1.8901
–63	0.32	0.679	629.13	1.472	1.59	129.86	377.27	247.42	0.7095	1.8868
–62	0.33	0.681	595.75	1.469	1.68	130.99	377.76	246.76	0.7149	1.8836
–61	0.35	0.682	564.46	1.466	1.77	132.12	378.24	246.12	0.7203	1.8804
–60	0.38	0.683	535.13	1.464	1.87	133.24	378.72	245.48	0.7256	1.8772
–59	0.40	0.684	507.61	1.461	1.97	134.36	379.21	244.85	0.7308	1.8742
–58	0.42	0.686	481.78	1.458	2.08	135.47	379.69	244.22	0.7360	1.8711
–57	0.44	0.687	457.51	1.455	2.19	136.58	380.17	243.59	0.7411	1.8681
–56	0.47	0.688	434.70	1.453	2.30	137.68	380.65	242.97	0.7462	1.8652
–55	0.50	0.690	413.24	1.450	2.42	138.77	381.13	242.36	0.7513	1.8622
–54	0.52	0.691	393.05	1.447	2.54	139.86	381.60	241.74	0.7563	1.8594
–53	0.55	0.692	374.04	1.444	2.67	140.95	382.08	241.13	0.7613	1.8565
–52	0.58	0.694	356.12	1.441	2.81	142.04	382.56	240.52	0.7662	1.8538
–51	0.61	0.695	339.24	1.438	2.95	143.12	383.03	239.91	0.7711	1.8510
–50	0.65	0.697	323.31	1.436	3.09	144.20	383.50	239.30	0.7759	1.8483
–49	0.68	0.698	308.28	1.433	3.24	145.28	383.98	238.70	0.7808	1.8457
–48	0.71	0.699	294.09	1.430	3.40	146.36	384.45	238.09	0.7855	1.8430
–47	0.75	0.701	280.68	1.427	3.56	147.43	384.92	237.49	0.7903	1.8404
–46	0.79	0.702	268.00	1.424	3.73	148.51	385.39	236.88	0.7951	1.8379
–45	0.83	0.704	256.01	1.421	3.91	149.58	385.85	236.27	0.7998	1.8354
–44	0.87	0.705	244.67	1.418	4.09	150.65	386.32	235.66	0.8045	1.8329
–43	0.91	0.706	233.93	1.416	4.27	151.73	386.78	235.05	0.8091	1.8305
–42	0.96	0.708	223.76	1.413	4.47	152.80	387.25	234.44	0.8138	1.8280
–41	1.00	0.709	214.12	1.410	4.67	153.88	387.71	233.83	0.8184	1.8257
–40	1.05	0.711	204.98	1.407	4.88	154.95	388.17	233.21	0.8230	1.8233
–39	1.10	0.712	196.31	1.404	5.09	156.03	388.63	232.60	0.8277	1.8210
–38	1.15	0.714	188.08	1.401	5.32	157.11	389.08	231.97	0.8322	1.8187
–37	1.21	0.715	180.27	1.398	5.55	158.19	389.54	231.35	0.8368	1.8165
–36	1.26	0.717	172.85	1.395	5.79	159.27	389.99	230.72	0.8414	1.8143
–35	1.32	0.718	165.80	1.392	6.03	160.35	390.44	230.09	0.8459	1.8121
–34	1.38	0.720	159.09	1.389	6.29	161.44	390.89	229.46	0.8504	1.8099
–33	1.44	0.721	152.72	1.386	6.55	162.52	391.34	228.82	0.8550	1.8078
–32	1.50	0.723	146.65	1.383	6.82	163.61	391.79	228.18	0.8595	1.8057
–31	1.57	0.725	140.88	1.380	7.10	164.70	392.23	227.53	0.8640	1.8036

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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	0.726	135.37	1.377	7.39	165.80	392.68	226.88	0.8685	1.8016
–29	1.71	0.728	130.13	1.374	7.68	166.89	393.12	226.22	0.8730	1.7995
–28	1.78	0.729	125.14	1.371	7.99	167.99	393.56	225.56	0.8774	1.7975
–27	1.86	0.731	120.38	1.368	8.31	169.09	393.99	224.90	0.8819	1.7956
–26	1.93	0.733	115.83	1.365	8.63	170.20	394.43	224.23	0.8864	1.7936
–25	2.01	0.734	111.50	1.362	8.97	171.31	394.86	223.56	0.8908	1.7917
–24	2.10	0.736	107.36	1.359	9.31	172.42	395.29	222.88	0.8953	1.7898
–23	2.18	0.738	103.40	1.356	9.67	173.53	395.72	222.19	0.8997	1.7879
–22	2.27	0.739	99.62	1.353	10.04	174.65	396.15	221.50	0.9041	1.7861
–21	2.36	0.741	96.01	1.350	10.42	175.76	396.57	220.81	0.9086	1.7843
–20	2.45	0.743	92.56	1.346	10.80	176.89	397.00	220.11	0.9130	1.7825
–19	2.55	0.744	89.26	1.343	11.20	178.01	397.42	219.40	0.9174	1.7807
–18	2.65	0.746	86.10	1.340	11.61	179.14	397.83	218.69	0.9218	1.7789
–17	2.75	0.748	83.08	1.337	12.04	180.27	398.25	217.97	0.9262	1.7772
–16	2.85	0.750	80.18	1.334	12.47	181.41	398.66	217.25	0.9306	1.7755
–15	2.96	0.751	77.41	1.331	12.92	182.55	399.07	216.52	0.9350	1.7738
–14	3.07	0.753	74.75	1.327	13.38	183.69	399.48	215.79	0.9394	1.7721
–13	3.19	0.755	72.21	1.324	13.85	184.83	399.89	215.05	0.9438	1.7704
–12	3.30	0.757	69.77	1.321	14.33	185.98	400.29	214.31	0.9482	1.7688
–11	3.42	0.759	67.42	1.318	14.83	187.13	400.69	213.56	0.9525	1.7672
–10	3.55	0.761	65.18	1.315	15.34	188.29	401.09	212.80	0.9569	1.7655
–9	3.67	0.763	63.02	1.311	15.87	189.45	401.48	212.04	0.9612	1.7640
–8	3.81	0.764	60.95	1.308	16.41	190.61	401.88	211.27	0.9656	1.7624
–7	3.94	0.766	58.96	1.305	16.96	191.77	402.26	210.50	0.9699	1.7608
–6	4.08	0.768	57.05	1.302	17.53	192.94	402.65	209.72	0.9743	1.7593
–5	4.22	0.770	55.22	1.298	18.11	194.11	403.04	208.93	0.9786	1.7578
–4	4.36	0.772	53.45	1.295	18.71	195.28	403.42	208.14	0.9829	1.7563
–3	4.51	0.774	51.75	1.292	19.32	196.45	403.80	207.34	0.9873	1.7548
–2	4.66	0.776	50.12	1.288	19.95	197.63	404.17	206.54	0.9916	1.7533
–1	4.82	0.778	48.55	1.285	20.60	198.81	404.54	205.73	0.9959	1.7518
0	4.98	0.780	47.04	1.281	21.26	200.00	404.91	204.91	1.0000	1.7504
1	5.14	0.782	45.59	1.278	21.94	201.19	405.28	204.09	1.0045	1.7489
2	5.31	0.785	44.19	1.275	22.63	202.38	405.64	203.26	1.0087	1.7475
3	5.48	0.787	42.84	1.271	23.34	203.57	406.00	202.43	1.0130	1.7461
4	5.66	0.789	41.54	1.268	24.07	204.76	406.36	201.59	1.0173	1.7447
5	5.84	0.791	40.29	1.264	24.82	205.96	406.71	200.75	1.0216	1.7433
6	6.03	0.793	39.08	1.261	25.59	207.16	407.06	199.89	1.0258	1.7419
7	6.22	0.795	37.91	1.257	26.38	208.37	407.40	199.04	1.0301	1.7405
8	6.41	0.798	36.79	1.254	27.18	209.57	407.74	198.17	1.0343	1.7392
9	6.61	0.800	35.71	1.250	28.01	210.78	408.08	197.30	1.0385	1.7378
10	6.81	0.802	34.66	1.247	28.85	211.99	408.42	196.43	1.0428	1.7365
11	7.02	0.804	33.65	1.243	29.72	213.20	408.75	195.54	1.0470	1.7352
12	7.23	0.807	32.68	1.240	30.60	214.42	409.07	194.66	1.0512	1.7338
13	7.45	0.809	31.74	1.236	31.51	215.64	409.40	193.76	1.0554	1.7325
14	7.67	0.812	30.83	1.232	32.44	216.86	409.72	192.86	1.0596	1.7312
15	7.89	0.814	29.95	1.229	33.39	218.08	410.03	191.95	1.0638	1.7299
16	8.12	0.816	29.10	1.225	34.37	219.31	410.34	191.03	1.0680	1.7286
17	8.36	0.819	28.28	1.221	35.36	220.54	410.65	190.11	1.0721	1.7274
18	8.60	0.821	27.48	1.217	36.39	221.77	410.95	189.18	1.0763	1.7261
19	8.85	0.824	26.71	1.214	37.43	223.00	411.25	188.25	1.0805	1.7248

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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]
20	9.10	0.826	25.97	1.210	38.50	224.24	411.54	187.30	1.0846	1.7235
21	9.36	0.829	25.25	1.206	39.60	225.48	411.83	186.35	1.0888	1.7223
22	9.62	0.832	24.56	1.202	40.72	226.72	412.11	185.39	1.0929	1.7210
23	9.89	0.834	23.88	1.199	41.87	227.96	412.39	184.43	1.0970	1.7198
24	10.16	0.837	23.23	1.195	43.05	229.21	412.66	183.46	1.1011	1.7185
25	10.44	0.840	22.60	1.191	44.25	230.46	412.93	182.47	1.1053	1.7173
26	10.72	0.843	21.99	1.187	45.48	231.71	413.20	181.48	1.1094	1.7160
27	11.01	0.845	21.39	1.183	46.75	232.97	413.45	180.49	1.1135	1.7148
28	11.31	0.848	20.82	1.179	48.04	234.23	413.71	179.48	1.1176	1.7136
29	11.61	0.851	20.26	1.175	49.36	235.49	413.95	178.46	1.1217	1.7123
30	11.92	0.854	19.72	1.171	50.71	236.75	414.19	177.44	1.1258	1.7111
31	12.23	0.857	19.19	1.167	52.10	238.02	414.43	176.41	1.1299	1.7099
32	12.55	0.860	18.69	1.163	53.52	239.30	414.66	175.36	1.1340	1.7086
33	12.88	0.863	18.19	1.159	54.97	240.57	414.88	174.31	1.1380	1.7074
34	13.21	0.866	17.71	1.154	56.46	241.85	415.10	173.25	1.1421	1.7062
35	13.55	0.869	17.25	1.150	57.98	243.14	415.31	172.17	1.1462	1.7049
36	13.89	0.873	16.80	1.146	59.54	244.43	415.51	171.09	1.1503	1.7037
37	14.24	0.876	16.36	1.142	61.14	245.72	415.71	169.99	1.1544	1.7024
38	14.60	0.879	15.93	1.137	62.77	247.02	415.90	168.88	1.1584	1.7012
39	14.96	0.883	15.52	1.133	64.45	248.32	416.08	167.76	1.1625	1.6999
40	15.34	0.886	15.11	1.129	66.17	249.63	416.26	166.63	1.1666	1.6987
41	15.71	0.890	14.72	1.124	67.92	250.94	416.42	165.48	1.1707	1.6974
42	16.10	0.893	14.34	1.120	69.73	252.26	416.58	164.32	1.1748	1.6962
43	16.49	0.897	13.97	1.115	71.57	253.59	416.74	163.15	1.1788	1.6949
44	16.89	0.900	13.61	1.111	73.47	254.92	416.88	161.96	1.1829	1.6936
45	17.29	0.904	13.26	1.106	75.41	256.26	417.01	160.76	1.1870	1.6923
46	17.70	0.908	12.92	1.101	77.40	257.60	417.14	159.54	1.1911	1.6910
47	18.12	0.912	12.59	1.097	79.44	258.95	417.25	158.30	1.1952	1.6897
48	18.55	0.916	12.27	1.092	81.53	260.31	417.36	157.05	1.1994	1.6884
49	18.98	0.920	11.95	1.087	83.67	261.68	417.46	155.78	1.2035	1.6870
50	19.43	0.924	11.64	1.082	85.88	263.05	417.54	154.49	1.2076	1.6857
51	19.88	0.928	11.35	1.077	88.14	264.44	417.62	153.18	1.2118	1.6843
52	20.33	0.932	11.06	1.072	90.45	265.83	417.69	151.86	1.2159	1.6830
53	20.80	0.937	10.77	1.067	92.84	267.23	417.74	150.51	1.2201	1.6816
54	21.27	0.941	10.50	1.062	95.28	268.65	417.78	149.14	1.2243	1.6802
55	21.75	0.946	10.23	1.057	97.79	270.07	417.81	147.74	1.2285	1.6787
56	22.24	0.951	9.96	1.052	100.38	271.50	417.83	146.33	1.2327	1.6773
57	22.74	0.955	9.71	1.047	103.03	272.95	417.84	144.89	1.2370	1.6758
58	23.24	0.960	9.46	1.041	105.76	274.41	417.83	143.42	1.2412	1.6743
59	23.75	0.965	9.21	1.036	108.57	275.88	417.80	141.93	1.2455	1.6728
60	24.27	0.971	8.97	1.030	111.46	277.36	417.77	140.41	1.2498	1.6713
61	24.80	0.976	8.74	1.025	114.43	278.86	417.71	138.86	1.2542	1.6697
62	25.34	0.981	8.51	1.019	117.50	280.37	417.64	137.28	1.2585	1.6681
63	25.89	0.987	8.29	1.013	120.66	281.90	417.56	135.66	1.2629	1.6665
64	26.45	0.993	8.07	1.007	123.91	283.44	417.45	134.02	1.2673	1.6648
65	27.01	0.999	7.86	1.001	127.27	285.00	417.33	132.34	1.2718	1.6632
66	27.59	1.005	7.65	0.995	130.74	286.57	417.19	130.62	1.2763	1.6614
67	28.17	1.011	7.45	0.989	134.32	288.16	417.03	128.87	1.2808	1.6597
68	28.76	1.018	7.25	0.983	138.02	289.78	416.85	127.07	1.2854	1.6578
69	29.36	1.024	7.05	0.976	141.84	291.41	416.65	125.24	1.2900	1.6560

Solkane® 22

Release 1.09

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	29.97	1.031	6.86	0.970	145.80	293.06	416.42	123.36	1.2946	1.6541
71	30.60	1.039	6.67	0.963	149.90	294.73	416.17	121.44	1.2993	1.6521
72	31.23	1.046	6.49	0.956	154.16	296.42	415.89	119.46	1.3040	1.6501
73	31.87	1.054	6.31	0.949	158.57	298.14	415.58	117.44	1.3088	1.6480
74	32.52	1.062	6.13	0.942	163.15	299.88	415.24	115.36	1.3136	1.6459
75	33.18	1.070	5.96	0.934	167.92	301.64	414.88	113.23	1.3185	1.6437
76	33.85	1.079	5.78	0.927	172.88	303.43	414.47	111.04	1.3234	1.6414
77	34.53	1.088	5.62	0.919	178.06	305.25	414.04	108.79	1.3284	1.6391
78	35.22	1.098	5.45	0.911	183.46	307.09	413.56	106.47	1.3334	1.6366
79	35.92	1.108	5.29	0.902	189.11	308.96	413.04	104.08	1.3385	1.6341
80	36.64	1.119	5.13	0.894	195.03	310.86	412.48	101.62	1.3437	1.6314
81	37.36	1.130	4.97	0.885	201.24	312.79	411.87	99.08	1.3489	1.6286
82	38.10	1.142	4.81	0.875	207.78	314.75	411.20	96.45	1.3542	1.6258
83	38.85	1.155	4.66	0.866	214.67	316.75	410.48	93.73	1.3595	1.6227
84	39.61	1.169	4.51	0.855	221.96	318.78	409.69	90.92	1.3650	1.6195
85	40.38	1.184	4.35	0.845	229.71	320.84	408.83	87.99	1.3705	1.6162
86	41.16	1.200	4.20	0.834	237.97	322.94	407.88	84.94	1.3761	1.6126
87	41.96	1.217	4.05	0.822	246.83	325.08	406.84	81.76	1.3818	1.6088
88	42.77	1.236	3.90	0.809	256.40	327.25	405.68	78.43	1.3875	1.6047
89	43.59	1.257	3.75	0.795	266.85	329.47	404.38	74.91	1.3934	1.6002
90	44.42	1.281	3.59	0.780	278.46	331.73	402.89	71.16	0.0000	0.0000
91	45.27	1.309	3.43	0.764	291.70	334.03	401.13	67.10	0.0000	0.0000
92	46.14	1.342	3.25	0.745	307.72	336.37	398.88	62.51	0.0000	0.0000

12.1.2 Solkane® 23

Release 1.02

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	1.54	60.91	318.49	257.57	0.3774	1.8650
–99	0.33	0.655	604.80	1.527	1.65	62.21	318.93	256.72	0.3849	1.8590
–98	0.36	0.657	565.13	1.523	1.77	63.51	319.37	255.86	0.3923	1.8531
–97	0.39	0.658	528.54	1.519	1.89	64.81	319.81	255.00	0.3997	1.8473
–96	0.41	0.660	494.77	1.515	2.02	66.12	320.25	254.13	0.4071	1.8417
–95	0.44	0.662	463.57	1.511	2.16	67.42	320.68	253.26	0.4144	1.8361
–94	0.48	0.663	434.71	1.507	2.30	68.73	321.12	252.39	0.4217	1.8305
–93	0.51	0.665	408.00	1.504	2.45	70.03	321.54	251.51	0.4290	1.8251
–92	0.54	0.667	383.24	1.500	2.61	71.34	321.97	250.63	0.4362	1.8198
–91	0.58	0.669	359.62	1.496	2.78	73.06	322.35	249.29	0.4457	1.8143
–90	0.62	0.670	338.34	1.492	2.96	74.37	322.77	248.40	0.4528	1.8091
–89	0.66	0.672	318.57	1.488	3.14	75.68	323.19	247.51	0.4599	1.8040
–88	0.70	0.674	300.19	1.484	3.33	76.99	323.60	246.62	0.4670	1.7990
–87	0.75	0.676	283.08	1.480	3.53	78.30	324.02	245.72	0.4740	1.7940
–86	0.80	0.678	267.14	1.476	3.74	79.61	324.43	244.82	0.4810	1.7892
–85	0.85	0.679	252.05	1.472	3.97	81.12	324.81	243.69	0.4891	1.7843
–84	0.90	0.681	238.19	1.468	4.20	82.43	325.21	242.78	0.4960	1.7795
–83	0.96	0.683	225.26	1.464	4.44	83.74	325.61	241.87	0.5029	1.7749
–82	1.01	0.685	213.17	1.460	4.69	85.05	326.01	240.96	0.5097	1.7703
–81	1.08	0.687	201.86	1.456	4.95	86.36	326.40	240.04	0.5165	1.7658
–80	1.14	0.689	191.10	1.452	5.23	87.86	326.77	238.90	0.5243	1.7612
–79	1.21	0.691	181.20	1.448	5.52	89.17	327.15	237.98	0.5311	1.7568
–78	1.27	0.693	171.91	1.444	5.82	90.48	327.53	237.05	0.5378	1.7525
–77	1.35	0.695	163.15	1.439	6.13	91.85	327.91	236.05	0.5448	1.7482
–76	1.42	0.697	154.89	1.435	6.46	93.29	328.27	234.97	0.5521	1.7439
–75	1.50	0.699	147.22	1.431	6.79	94.60	328.64	234.04	0.5586	1.7398
–74	1.58	0.701	140.00	1.427	7.14	95.91	329.01	233.10	0.5652	1.7357
–73	1.67	0.703	133.18	1.423	7.51	97.28	329.36	232.09	0.5720	1.7316
–72	1.76	0.705	126.72	1.419	7.89	98.71	329.71	231.00	0.5791	1.7275
–71	1.85	0.707	120.71	1.414	8.28	100.01	330.07	230.05	0.5856	1.7236
–70	1.95	0.709	115.01	1.410	8.69	101.38	330.41	229.03	0.5923	1.7197
–69	2.05	0.711	109.61	1.406	9.12	102.81	330.74	227.93	0.5993	1.7158
–68	2.15	0.713	104.57	1.402	9.56	104.11	331.09	226.98	0.6056	1.7120
–67	2.26	0.716	99.79	1.397	10.02	105.48	331.42	225.95	0.6122	1.7082
–66	2.38	0.718	95.24	1.393	10.50	106.90	331.74	224.85	0.6190	1.7045
–65	2.49	0.720	91.00	1.389	10.99	108.20	332.08	223.88	0.6253	1.7008
–64	2.61	0.722	86.96	1.384	11.50	109.56	332.40	222.84	0.6317	1.6972
–63	2.74	0.725	83.14	1.380	12.03	110.92	332.72	221.80	0.6382	1.6936
–62	2.87	0.727	79.52	1.376	12.58	112.27	333.03	220.75	0.6446	1.6901
–61	3.00	0.729	76.09	1.371	13.14	113.63	333.34	219.71	0.6509	1.6866
–60	3.14	0.732	72.84	1.367	13.73	114.99	333.64	218.66	0.6573	1.6831
–59	3.29	0.734	69.76	1.362	14.33	116.34	333.94	217.60	0.6636	1.6797
–58	3.44	0.736	66.82	1.358	14.97	117.75	334.23	216.48	0.6701	1.6762
–57	3.59	0.739	64.04	1.353	15.61	119.10	334.52	215.42	0.6763	1.6729
–56	3.75	0.741	61.41	1.349	16.28	120.45	334.81	214.35	0.6825	1.6696
–55	3.92	0.744	58.90	1.344	16.98	121.80	335.09	213.28	0.6886	1.6663
–54	4.09	0.746	56.52	1.340	17.69	123.15	335.36	212.21	0.6947	1.6631
–53	4.27	0.749	54.26	1.335	18.43	124.50	335.64	211.14	0.7008	1.6599
–52	4.45	0.751	52.10	1.331	19.19	125.85	335.90	210.06	0.7068	1.6567
–51	4.64	0.754	50.05	1.326	19.98	127.19	336.16	208.97	0.7129	1.6535

Solkane® 23

Release 1.02

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	4.83	0.757	48.08	1.321	20.80	128.58	336.42	207.84	0.7190	1.6504
−49	5.03	0.759	46.22	1.317	21.64	129.94	336.66	206.73	0.7250	1.6473
−48	5.24	0.762	44.44	1.312	22.50	131.28	336.91	205.63	0.7309	1.6442
−47	5.45	0.765	42.74	1.307	23.39	132.63	337.15	204.52	0.7368	1.6412
−46	5.67	0.768	41.13	1.303	24.31	133.97	337.39	203.41	0.7427	1.6382
−45	5.89	0.771	39.58	1.298	25.26	135.32	337.62	202.30	0.7485	1.6352
−44	6.12	0.773	38.10	1.293	26.25	136.70	337.83	201.14	0.7545	1.6322
−43	6.36	0.776	36.69	1.288	27.26	138.04	338.05	200.01	0.7602	1.6293
−42	6.61	0.779	35.34	1.283	28.30	139.40	338.26	198.86	0.7661	1.6264
−41	6.86	0.782	34.05	1.278	29.37	140.75	338.47	197.72	0.7718	1.6235
−40	7.12	0.785	32.82	1.274	30.47	142.09	338.67	196.58	0.7775	1.6206
−39	7.39	0.788	31.63	1.269	31.61	143.46	338.86	195.40	0.7832	1.6178
−38	7.66	0.791	30.50	1.264	32.79	144.82	339.05	194.22	0.7889	1.6149
−37	7.94	0.795	29.41	1.259	34.00	146.17	339.23	193.06	0.7946	1.6121
−36	8.23	0.798	28.37	1.253	35.24	147.54	339.40	191.86	0.8003	1.6093
−35	8.53	0.801	27.38	1.248	36.53	148.89	339.56	190.68	0.8058	1.6065
−34	8.84	0.804	26.42	1.243	37.85	150.26	339.72	189.47	0.8115	1.6037
−33	9.15	0.808	25.50	1.238	39.21	151.61	339.88	188.26	0.8170	1.6010
−32	9.47	0.811	24.62	1.233	40.61	152.98	340.02	187.03	0.8226	1.5982
−31	9.80	0.815	23.78	1.228	42.06	154.34	340.16	185.81	0.8281	1.5955
−30	10.14	0.818	22.96	1.222	43.55	155.72	340.28	184.56	0.8337	1.5927
−29	10.49	0.822	22.18	1.217	45.08	157.09	340.40	183.32	0.8392	1.5900
−28	10.84	0.825	21.43	1.212	46.66	158.47	340.51	182.05	0.8447	1.5873
−27	11.21	0.829	20.71	1.206	48.28	159.84	340.62	180.78	0.8502	1.5846
−26	11.58	0.833	20.02	1.201	49.96	161.23	340.71	179.49	0.8557	1.5819
−25	11.96	0.837	19.35	1.195	51.69	162.62	340.80	178.18	0.8612	1.5792
−24	12.36	0.841	18.71	1.190	53.46	164.00	340.88	176.88	0.8666	1.5765
−23	12.76	0.845	18.09	1.184	55.29	165.40	340.94	175.54	0.8721	1.5738
−22	13.17	0.849	17.49	1.178	57.18	166.79	341.00	174.21	0.8775	1.5711
−21	13.59	0.853	16.91	1.173	59.12	168.20	341.05	172.85	0.8829	1.5684
−20	14.02	0.857	16.36	1.167	61.13	169.61	341.08	171.47	0.8884	1.5657
−19	14.47	0.861	15.82	1.161	63.19	171.03	341.11	170.08	0.8938	1.5630
−18	14.92	0.866	15.31	1.155	65.32	172.46	341.12	168.67	0.8993	1.5603
−17	15.38	0.870	14.81	1.149	67.52	173.88	341.13	167.24	0.9047	1.5576
−16	15.86	0.875	14.33	1.143	69.78	175.32	341.12	165.79	0.9101	1.5549
−15	16.34	0.879	13.87	1.137	72.12	176.77	341.09	164.32	0.9156	1.5521
−14	16.84	0.884	13.42	1.131	74.54	178.23	341.06	162.82	0.9211	1.5494
−13	17.34	0.889	12.98	1.125	77.03	179.70	341.01	161.31	0.9266	1.5466
−12	17.86	0.894	12.56	1.118	79.60	181.17	340.94	159.77	0.9320	1.5438
−11	18.39	0.899	12.16	1.112	82.25	182.65	340.87	158.21	0.9375	1.5410
−10	18.93	0.905	11.77	1.106	84.99	184.15	340.77	156.62	0.9430	1.5382
−9	19.49	0.910	11.39	1.099	87.83	185.67	340.66	154.99	0.9486	1.5353
−8	20.05	0.915	11.02	1.092	90.76	187.19	340.53	153.34	0.9541	1.5325
−7	20.63	0.921	10.66	1.086	93.79	188.73	340.39	151.66	0.9597	1.5296
−6	21.22	0.927	10.32	1.079	96.94	190.28	340.22	149.94	0.9654	1.5266
−5	21.83	0.933	9.98	1.072	100.19	191.85	340.04	148.18	0.9710	1.5236
−4	22.45	0.939	9.66	1.065	103.56	193.44	339.83	146.39	0.9767	1.5206
−3	23.08	0.946	9.34	1.058	107.05	195.05	339.60	144.55	0.9825	1.5175
−2	23.72	0.952	9.04	1.050	110.68	196.67	339.36	142.68	0.9882	1.5144
−1	24.38	0.959	8.74	1.043	114.44	198.32	339.08	140.76	0.9941	1.5113

Solkane® 23

Release 1.02

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	118.35	200.00	338.78	138.78	1.0000	1.5081
1	25.74	0.973	8.17	1.028	122.42	201.69	338.45	136.77	1.0059	1.5048
2	26.44	0.981	7.90	1.020	126.65	203.40	338.10	134.69	1.0119	1.5014
3	27.15	0.989	7.63	1.012	131.07	205.16	337.71	132.55	1.0180	1.4980
4	27.88	0.997	7.37	1.003	135.68	206.94	337.28	130.35	1.0242	1.4945
5	28.63	1.005	7.12	0.995	140.49	208.74	336.83	128.09	1.0304	1.4909
6	29.39	1.014	6.87	0.986	145.53	210.59	336.33	125.74	1.0368	1.4872
7	30.17	1.023	6.63	0.977	150.81	212.48	335.79	123.31	1.0432	1.4834
8	30.96	1.033	6.40	0.968	156.35	214.40	335.21	120.80	1.0498	1.4795
9	31.77	1.043	6.17	0.959	162.17	216.37	334.57	118.20	1.0565	1.4754
10	32.59	1.053	5.94	0.949	168.31	218.39	333.88	115.49	1.0633	1.4712
11	33.44	1.065	5.72	0.939	174.81	220.47	333.13	112.67	1.0703	1.4668
12	34.30	1.077	5.50	0.929	181.69	222.60	332.32	109.72	1.0775	1.4623
13	35.18	1.089	5.29	0.918	189.01	224.80	331.43	106.63	1.0849	1.4575
14	36.07	1.103	5.08	0.907	196.81	227.06	330.46	103.40	1.0924	1.4525
15	36.99	1.117	4.87	0.895	205.19	229.42	329.39	99.97	1.1003	1.4472
16	37.92	1.133	4.67	0.883	214.22	231.86	328.22	96.35	1.1084	1.4416
17	38.87	1.150	4.46	0.870	223.99	234.41	326.92	92.50	1.1168	1.4356
18	39.84	1.169	4.26	0.856	234.69	237.09	325.47	88.38	1.1256	1.4292
19	40.83	1.190	4.06	0.841	246.49	239.91	323.84	83.93	1.1349	1.4222
20	41.85	1.213	3.85	0.824	259.67	242.90	321.99	79.09	1.1447	1.4145
21	42.88	1.240	3.64	0.807	274.66	246.12	319.85	73.73	1.1552	1.4059
22	43.94	1.271	3.42	0.787	292.05	249.62	317.35	67.73	1.1667	1.3961
23	45.01	1.310	3.20	0.764	312.93	253.52	314.32	60.80	1.1794	1.3847

12.1.3 Solkane® 123

Release 1.02

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	0.33	0.655	446.10	1.526	2.24	200.00	381.59	181.59	1.0000	1.6652
1	0.34	0.656	427.57	1.524	2.34	200.88	382.19	181.31	1.0036	1.6649
2	0.36	0.657	409.96	1.521	2.44	201.88	382.79	180.92	1.0073	1.6647
3	0.37	0.658	393.21	1.519	2.54	202.87	383.39	180.52	1.0109	1.6645
4	0.39	0.659	377.28	1.516	2.65	203.87	384.00	180.13	1.0145	1.6644
5	0.41	0.661	362.12	1.514	2.76	204.86	384.60	179.74	1.0181	1.6642
6	0.43	0.662	347.69	1.512	2.88	205.86	385.20	179.34	1.0217	1.6640
7	0.45	0.663	333.95	1.509	2.99	206.86	385.80	178.94	1.0253	1.6639
8	0.46	0.664	320.86	1.507	3.12	207.86	386.41	178.55	1.0289	1.6638
9	0.48	0.665	308.38	1.504	3.24	208.86	387.01	178.15	1.0324	1.6637
10	0.51	0.666	296.49	1.502	3.37	209.87	387.61	177.75	1.0360	1.6636
11	0.53	0.667	285.14	1.499	3.51	210.87	388.22	177.34	1.0395	1.6635
12	0.55	0.668	274.31	1.497	3.65	211.88	388.82	176.94	1.0431	1.6634
13	0.57	0.669	263.98	1.494	3.79	212.89	389.42	176.54	1.0466	1.6634
14	0.60	0.670	254.12	1.492	3.94	213.90	390.03	176.13	1.0501	1.6633
15	0.62	0.671	244.70	1.489	4.09	214.91	390.63	175.72	1.0536	1.6633
16	0.65	0.673	235.70	1.487	4.24	215.92	391.23	175.31	1.0571	1.6633
17	0.67	0.674	227.09	1.484	4.40	216.94	391.84	174.90	1.0606	1.6633
18	0.70	0.675	218.87	1.482	4.57	217.95	392.44	174.49	1.0641	1.6633
19	0.73	0.676	211.00	1.479	4.74	218.97	393.05	174.08	1.0676	1.6633
20	0.76	0.677	203.48	1.477	4.91	219.99	393.65	173.66	1.0711	1.6633
21	0.79	0.678	196.27	1.474	5.09	221.01	394.25	173.25	1.0745	1.6634
22	0.82	0.680	189.38	1.472	5.28	222.03	394.86	172.83	1.0780	1.6634
23	0.85	0.681	182.77	1.469	5.47	223.05	395.46	172.41	1.0814	1.6635
24	0.88	0.682	176.45	1.466	5.67	224.08	396.06	171.99	1.0848	1.6636
25	0.91	0.683	170.39	1.464	5.87	225.10	396.67	171.57	1.0883	1.6636
26	0.95	0.684	164.58	1.461	6.08	226.13	397.27	171.14	1.0917	1.6637
27	0.98	0.685	159.01	1.459	6.29	227.16	397.87	170.72	1.0951	1.6638
28	1.02	0.687	153.66	1.456	6.51	228.18	398.47	170.29	1.0985	1.6639
29	1.06	0.688	148.54	1.454	6.73	229.22	399.08	169.86	1.1019	1.6641
30	1.10	0.689	143.62	1.451	6.96	230.25	399.68	169.43	1.1052	1.6642
31	1.14	0.690	138.89	1.448	7.20	231.28	400.28	169.00	1.1086	1.6643
32	1.18	0.692	134.36	1.446	7.44	232.32	400.88	168.57	1.1120	1.6645
33	1.22	0.693	130.00	1.443	7.69	233.35	401.48	168.13	1.1153	1.6646
34	1.26	0.694	125.82	1.441	7.95	234.39	402.08	167.70	1.1187	1.6648
35	1.31	0.695	121.79	1.438	8.21	235.43	402.68	167.26	1.1220	1.6650
36	1.35	0.697	117.93	1.435	8.48	236.47	403.28	166.82	1.1254	1.6651
37	1.40	0.698	114.21	1.433	8.76	237.51	403.88	166.38	1.1287	1.6653
38	1.44	0.699	110.63	1.430	9.04	238.55	404.48	165.93	1.1320	1.6655
39	1.49	0.701	107.19	1.427	9.33	239.59	405.08	165.49	1.1353	1.6657
40	1.54	0.702	103.88	1.425	9.63	240.64	405.68	165.04	1.1386	1.6660
41	1.60	0.703	100.69	1.422	9.93	241.68	406.28	164.60	1.1419	1.6662
42	1.65	0.704	97.62	1.419	10.24	242.73	406.88	164.15	1.1452	1.6664
43	1.70	0.706	94.66	1.417	10.56	243.78	407.47	163.69	1.1485	1.6666
44	1.76	0.707	91.81	1.414	10.89	244.83	408.07	163.24	1.1518	1.6669
45	1.82	0.709	89.07	1.411	11.23	245.88	408.67	162.79	1.1550	1.6671
46	1.88	0.710	86.42	1.409	11.57	246.93	409.26	162.33	1.1583	1.6674
47	1.94	0.711	83.87	1.406	11.92	247.99	409.86	161.87	1.1615	1.6676
48	2.00	0.713	81.41	1.403	12.28	249.04	410.45	161.41	1.1648	1.6679
49	2.06	0.714	79.04	1.401	12.65	250.10	411.05	160.95	1.1680	1.6682

Solkane® 123

Release 1.02

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	2.12	0.715	76.75	1.398	13.03	251.15	411.64	160.48	1.1712	1.6685
51	2.19	0.717	74.54	1.395	13.41	252.21	412.23	160.02	1.1745	1.6687
52	2.26	0.718	72.41	1.392	13.81	253.27	412.82	159.55	1.1777	1.6690
53	2.33	0.720	70.35	1.390	14.21	254.33	413.41	159.08	1.1809	1.6693
54	2.40	0.721	68.37	1.387	14.63	255.39	414.00	158.61	1.1841	1.6696
55	2.47	0.723	66.45	1.384	15.05	256.46	414.59	158.14	1.1873	1.6699
56	2.55	0.724	64.59	1.381	15.48	257.52	415.18	157.66	1.1905	1.6703
57	2.62	0.725	62.80	1.378	15.92	258.59	415.77	157.18	1.1937	1.6706
58	2.70	0.727	61.07	1.376	16.38	259.65	416.36	156.70	1.1969	1.6709
59	2.78	0.728	59.39	1.373	16.84	260.72	416.94	156.22	1.2000	1.6712
60	2.86	0.730	57.77	1.370	17.31	261.79	417.53	155.74	1.2032	1.6716
61	2.94	0.731	56.20	1.367	17.79	262.86	418.11	155.25	1.2064	1.6719
62	3.03	0.733	54.69	1.364	18.29	263.93	418.69	154.76	1.2095	1.6722
63	3.11	0.735	53.22	1.361	18.79	265.00	419.28	154.27	1.2127	1.6726
64	3.20	0.736	51.80	1.359	19.30	266.08	419.86	153.78	1.2158	1.6729
65	3.29	0.738	50.43	1.356	19.83	267.15	420.44	153.29	1.2190	1.6733
66	3.38	0.739	49.10	1.353	20.37	268.23	421.02	152.79	1.2221	1.6736
67	3.48	0.741	47.81	1.350	20.92	269.31	421.60	152.29	1.2253	1.6740
68	3.57	0.742	46.56	1.347	21.48	270.38	422.17	151.79	1.2284	1.6744
69	3.67	0.744	45.36	1.344	22.05	271.46	422.75	151.29	1.2315	1.6747
70	3.77	0.746	44.19	1.341	22.63	272.55	423.33	150.78	1.2346	1.6751
71	3.87	0.747	43.05	1.338	23.23	273.63	423.90	150.27	1.2377	1.6755
72	3.98	0.749	41.95	1.335	23.84	274.71	424.47	149.76	1.2408	1.6758
73	4.09	0.751	40.88	1.332	24.46	275.80	425.04	149.24	1.2439	1.6762
74	4.19	0.752	39.85	1.329	25.09	276.88	425.61	148.73	1.2470	1.6766
75	4.30	0.754	38.85	1.326	25.74	277.97	426.18	148.21	1.2501	1.6770
76	4.42	0.756	37.87	1.323	26.40	279.06	426.75	147.69	1.2532	1.6774
77	4.53	0.757	36.93	1.320	27.08	280.15	427.31	147.16	1.2563	1.6778
78	4.65	0.759	36.01	1.317	27.77	281.25	427.88	146.63	1.2594	1.6781
79	4.77	0.761	35.12	1.314	28.47	282.34	428.44	146.10	1.2625	1.6785
80	4.89	0.763	34.26	1.311	29.19	283.43	429.00	145.57	1.2656	1.6789
81	5.02	0.764	33.42	1.308	29.92	284.53	429.57	145.03	1.2686	1.6793
82	5.14	0.766	32.61	1.305	30.67	285.63	430.12	144.49	1.2717	1.6797
83	5.27	0.768	31.82	1.302	31.43	286.73	430.68	143.95	1.2748	1.6801
84	5.40	0.770	31.05	1.299	32.21	287.83	431.24	143.41	1.2778	1.6805
85	5.54	0.772	30.30	1.296	33.00	288.93	431.79	142.86	1.2809	1.6809
86	5.67	0.774	29.58	1.293	33.81	290.04	432.34	142.30	1.2839	1.6813
87	5.81	0.776	28.87	1.289	34.64	291.15	432.89	141.75	1.2870	1.6817
88	5.95	0.778	28.19	1.286	35.48	292.26	433.44	141.19	1.2900	1.6821
89	6.10	0.779	27.52	1.283	36.34	293.37	433.99	140.62	1.2931	1.6825
90	6.24	0.781	26.87	1.280	37.21	294.48	434.53	140.06	1.2961	1.6829
91	6.39	0.783	26.24	1.277	38.11	295.59	435.08	139.49	1.2992	1.6834
92	6.54	0.785	25.63	1.273	39.02	296.71	435.62	138.91	1.3022	1.6838
93	6.70	0.787	25.03	1.270	39.95	297.83	436.16	138.33	1.3052	1.6842
94	6.85	0.789	24.45	1.267	40.90	298.94	436.70	137.75	1.3083	1.6846
95	7.01	0.791	23.89	1.264	41.86	300.07	437.23	137.16	1.3113	1.6850
96	7.18	0.794	23.34	1.260	42.85	301.19	437.77	136.57	1.3143	1.6854
97	7.34	0.796	22.80	1.257	43.86	302.32	438.30	135.98	1.3174	1.6858
98	7.51	0.798	22.28	1.254	44.88	303.45	438.83	135.38	1.3204	1.6862
99	7.68	0.800	21.77	1.250	45.93	304.58	439.35	134.78	1.3234	1.6866

Solkane® 123

Release 1.02

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	7.86	0.802	21.28	1.247	46.99	305.71	439.88	134.17	1.3265	1.6870
101	8.03	0.804	20.80	1.243	48.08	306.84	440.40	133.55	1.3295	1.6874
102	8.21	0.806	20.33	1.240	49.19	307.98	440.92	132.94	1.3325	1.6878
103	8.39	0.809	19.87	1.237	50.33	309.12	441.43	132.31	1.3355	1.6882
104	8.58	0.811	19.42	1.233	51.48	310.27	441.95	131.68	1.3386	1.6886
105	8.77	0.813	18.99	1.230	52.66	311.41	442.46	131.05	1.3416	1.6890
106	8.96	0.816	18.57	1.226	53.86	312.56	442.97	130.41	1.3446	1.6894
107	9.16	0.818	18.15	1.223	55.09	313.71	443.48	129.77	1.3476	1.6898
108	9.35	0.820	17.75	1.219	56.34	314.87	443.98	129.12	1.3506	1.6902
109	9.56	0.823	17.36	1.215	57.61	316.02	444.48	128.46	1.3537	1.6906
110	9.76	0.825	16.97	1.212	58.91	317.18	444.98	127.80	1.3567	1.6909
111	9.97	0.828	16.60	1.208	60.24	318.35	445.47	127.13	1.3597	1.6913
112	10.18	0.830	16.24	1.204	61.59	319.51	445.97	126.45	1.3627	1.6917
113	10.39	0.833	15.88	1.201	62.97	320.68	446.45	125.77	1.3658	1.6921
114	10.61	0.835	15.53	1.197	64.38	321.85	446.94	125.09	1.3688	1.6924
115	10.83	0.838	15.19	1.193	65.82	323.03	447.42	124.39	1.3718	1.6928
116	11.06	0.841	14.86	1.190	67.29	324.21	447.90	123.69	1.3748	1.6932
117	11.28	0.843	14.54	1.186	68.79	325.39	448.38	122.98	1.3778	1.6935
118	11.52	0.846	14.22	1.182	70.31	326.58	448.85	122.27	1.3809	1.6939
119	11.75	0.849	13.91	1.178	71.87	327.77	449.32	121.54	1.3839	1.6942
120	11.99	0.852	13.61	1.174	73.47	328.97	449.78	120.81	1.3869	1.6946
121	12.23	0.854	13.32	1.170	75.09	330.17	450.24	120.07	1.3900	1.6949
122	12.48	0.857	13.03	1.166	76.75	331.37	450.70	119.33	1.3930	1.6953
123	12.73	0.860	12.75	1.162	78.45	332.58	451.15	118.57	1.3960	1.6956
124	12.98	0.863	12.47	1.158	80.18	333.79	451.60	117.81	1.3991	1.6959
125	13.24	0.866	12.20	1.154	81.94	335.00	452.04	117.03	1.4021	1.6962
126	13.50	0.869	11.94	1.150	83.75	336.23	452.48	116.25	1.4052	1.6965
127	13.76	0.873	11.68	1.146	85.59	337.45	452.91	115.46	1.4082	1.6969
128	14.03	0.876	11.43	1.142	87.48	338.68	453.34	114.66	1.4112	1.6971
129	14.30	0.879	11.19	1.138	89.40	339.92	453.77	113.85	1.4143	1.6974
130	14.58	0.882	10.94	1.134	91.37	341.16	454.18	113.03	1.4174	1.6977
131	14.86	0.886	10.71	1.129	93.38	342.40	454.60	112.20	1.4204	1.6980
132	15.14	0.889	10.48	1.125	95.44	343.65	455.01	111.35	1.4235	1.6983
133	15.43	0.892	10.25	1.120	97.54	344.91	455.41	110.50	1.4265	1.6985
134	15.72	0.896	10.03	1.116	99.69	346.17	455.81	109.64	1.4296	1.6988
135	16.02	0.900	9.81	1.112	101.89	347.44	456.20	108.76	1.4327	1.6990
136	16.32	0.903	9.60	1.107	104.14	348.71	456.59	107.87	1.4358	1.6992
137	16.62	0.907	9.39	1.102	106.45	349.99	456.96	106.97	1.4388	1.6995
138	16.93	0.911	9.19	1.098	108.81	351.28	457.34	106.06	1.4419	1.6997
139	17.25	0.915	8.99	1.093	111.22	352.57	457.70	105.13	1.4450	1.6999
140	17.56	0.919	8.80	1.088	113.70	353.87	458.06	104.19	1.4481	1.7000
141	17.88	0.923	8.60	1.084	116.23	355.17	458.41	103.24	1.4512	1.7002
142	18.21	0.927	8.42	1.079	118.83	356.49	458.75	102.27	1.4543	1.7004
143	18.54	0.931	8.23	1.074	121.49	357.80	459.09	101.29	1.4574	1.7005
144	18.88	0.936	8.05	1.069	124.22	359.13	459.42	100.29	1.4605	1.7007
145	19.22	0.940	7.87	1.064	127.03	360.46	459.74	99.27	1.4636	1.7008
146	19.56	0.945	7.70	1.059	129.90	361.81	460.05	98.24	1.4668	1.7009
147	19.91	0.949	7.53	1.053	132.85	363.15	460.35	97.19	1.4699	1.7009
148	20.26	0.954	7.36	1.048	135.89	364.51	460.64	96.13	1.4730	1.7010
149	20.62	0.959	7.19	1.043	139.00	365.87	460.92	95.04	1.4762	1.7011

Solkane® 123

Release 1.02

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	20.99	0.964	7.03	1.037	142.21	367.25	461.19	93.94	1.4793	1.7011
151	21.36	0.969	6.87	1.031	145.51	368.63	461.44	92.81	1.4825	1.7011
152	21.73	0.975	6.72	1.026	148.90	370.02	461.69	91.67	1.4857	1.7011
153	22.11	0.980	6.56	1.020	152.40	371.42	461.92	90.51	1.4888	1.7010
154	22.49	0.986	6.41	1.014	156.00	372.82	462.14	89.32	1.4920	1.7010
155	22.88	0.992	6.26	1.008	159.72	374.24	462.35	88.11	1.4952	1.7009
156	23.27	0.998	6.11	1.002	163.55	375.67	462.54	86.88	1.4984	1.7007
157	23.67	1.004	5.97	0.996	167.51	377.10	462.72	85.62	1.5016	1.7006
158	24.08	1.011	5.83	0.989	171.61	378.55	462.88	84.33	1.5048	1.7004
159	24.49	1.018	5.69	0.983	175.85	380.00	463.02	83.02	1.5080	1.7002
160	24.90	1.025	5.55	0.976	180.25	381.47	463.14	81.68	1.5112	1.6999
161	25.32	1.032	5.41	0.969	184.80	382.94	463.25	80.30	1.5145	1.6996
162	25.75	1.039	5.28	0.962	189.54	384.43	463.33	78.90	1.5177	1.6993
163	26.18	1.047	5.14	0.955	194.46	385.93	463.39	77.46	1.5210	1.6989
164	26.62	1.056	5.01	0.947	199.59	387.43	463.42	75.99	1.5242	1.6985
165	27.06	1.064	4.88	0.940	204.94	388.95	463.43	74.47	1.5275	1.6980
166	27.51	1.073	4.75	0.932	210.53	390.49	463.40	72.92	1.5308	1.6975
167	27.97	1.083	4.62	0.924	216.39	392.03	463.34	71.31	1.5341	1.6968
168	28.43	1.093	4.49	0.915	222.54	393.58	463.25	69.67	1.5374	1.6962
169	28.90	1.104	4.37	0.906	229.02	395.15	463.12	67.96	1.5407	1.6954
170	29.37	1.115	4.24	0.897	235.86	396.73	462.94	66.21	1.5440	1.6945
171	29.85	1.127	4.11	0.887	243.12	398.33	462.71	64.38	1.5473	1.6935
172	30.34	1.140	3.99	0.877	250.84	399.93	462.42	62.49	1.5507	1.6925
173	30.83	1.154	3.86	0.866	259.10	401.55	462.07	60.52	1.5540	1.6912
174	31.34	1.169	3.73	0.855	267.99	403.19	461.64	58.45	1.5574	1.6898
175	31.85	1.186	3.60	0.843	277.62	404.83	461.12	56.28	1.5607	1.6883
176	32.36	1.204	3.47	0.830	288.15	406.49	460.48	53.99	1.5641	1.6864
177	32.89	1.225	3.34	0.816	299.79	408.17	459.72	51.55	1.5675	1.6843
178	33.42	1.248	3.20	0.801	312.83	409.86	458.78	48.92	1.5709	1.6819
179	33.96	1.276	3.05	0.784	327.70	411.57	457.62	46.05	1.5743	1.6789

12.1.4 Solkane® 134a

Release 1.05

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	0.29	0.691	606.17	1.447	1.65	135.75	367.70	231.95	0.7409	1.7808
−49	0.31	0.692	574.14	1.444	1.74	136.99	368.33	231.34	0.7463	1.7790
−48	0.33	0.694	544.11	1.441	1.84	138.24	368.96	230.73	0.7518	1.7772
−47	0.35	0.695	515.95	1.438	1.94	139.49	369.60	230.11	0.7572	1.7755
−46	0.37	0.697	489.51	1.436	2.04	140.73	370.23	229.50	0.7626	1.7738
−45	0.39	0.698	464.68	1.433	2.15	141.98	370.86	228.89	0.7681	1.7722
−44	0.41	0.699	441.35	1.430	2.27	143.22	371.50	228.27	0.7735	1.7706
−43	0.44	0.701	419.41	1.427	2.38	144.47	372.13	227.66	0.7789	1.7690
−42	0.46	0.702	398.76	1.424	2.51	145.71	372.76	227.05	0.7842	1.7674
−41	0.49	0.704	379.33	1.421	2.64	146.96	373.39	226.43	0.7896	1.7659
−40	0.51	0.705	361.01	1.418	2.77	148.21	374.02	225.81	0.7950	1.7645
−39	0.54	0.706	343.76	1.415	2.91	149.46	374.66	225.20	0.8003	1.7630
−38	0.57	0.708	327.49	1.413	3.05	150.71	375.29	224.58	0.8057	1.7616
−37	0.60	0.709	312.13	1.410	3.20	151.96	375.92	223.95	0.8110	1.7602
−36	0.63	0.711	297.64	1.407	3.36	153.21	376.54	223.33	0.8163	1.7589
−35	0.66	0.712	283.95	1.404	3.52	154.47	377.17	222.70	0.8217	1.7576
−34	0.70	0.714	271.01	1.401	3.69	155.73	377.80	222.08	0.8270	1.7563
−33	0.73	0.715	258.78	1.398	3.86	156.98	378.43	221.45	0.8322	1.7551
−32	0.77	0.717	247.20	1.395	4.05	158.24	379.06	220.81	0.8375	1.7538
−31	0.80	0.718	236.25	1.392	4.23	159.51	379.68	220.18	0.8428	1.7526
−30	0.84	0.720	225.88	1.389	4.43	160.77	380.31	219.54	0.8480	1.7515
−29	0.88	0.721	216.05	1.386	4.63	162.04	380.93	218.89	0.8533	1.7503
−28	0.93	0.723	206.73	1.383	4.84	163.31	381.56	218.25	0.8585	1.7492
−27	0.97	0.725	197.90	1.380	5.05	164.58	382.18	217.60	0.8637	1.7481
−26	1.02	0.726	189.51	1.377	5.28	165.85	382.80	216.94	0.8689	1.7471
−25	1.06	0.728	181.56	1.374	5.51	167.13	383.42	216.29	0.8741	1.7460
−24	1.11	0.729	174.00	1.371	5.75	168.41	384.04	215.63	0.8793	1.7450
−23	1.16	0.731	166.82	1.368	5.99	169.69	384.66	214.96	0.8845	1.7440
−22	1.22	0.733	160.00	1.365	6.25	170.98	385.28	214.30	0.8896	1.7431
−21	1.27	0.734	153.51	1.362	6.51	172.27	385.89	213.62	0.8948	1.7421
−20	1.33	0.736	147.33	1.359	6.79	173.56	386.51	212.95	0.8999	1.7412
−19	1.39	0.738	141.46	1.356	7.07	174.85	387.12	212.27	0.9050	1.7403
−18	1.45	0.739	135.86	1.353	7.36	176.15	387.73	211.58	0.9101	1.7394
−17	1.51	0.741	130.54	1.349	7.66	177.45	388.34	210.90	0.9152	1.7385
−16	1.57	0.743	125.46	1.346	7.97	178.75	388.95	210.20	0.9203	1.7377
−15	1.64	0.744	120.62	1.343	8.29	180.06	389.56	209.51	0.9254	1.7369
−14	1.71	0.746	116.00	1.340	8.62	181.36	390.17	208.81	0.9304	1.7361
−13	1.78	0.748	111.60	1.337	8.96	182.68	390.77	208.10	0.9355	1.7353
−12	1.85	0.750	107.39	1.334	9.31	183.99	391.38	207.39	0.9405	1.7346
−11	1.93	0.752	103.38	1.331	9.67	185.31	391.98	206.67	0.9455	1.7338
−10	2.01	0.753	99.54	1.327	10.05	186.63	392.58	205.95	0.9505	1.7331
−9	2.09	0.755	95.88	1.324	10.43	187.95	393.18	205.23	0.9555	1.7324
−8	2.17	0.757	92.38	1.321	10.82	189.28	393.78	204.50	0.9605	1.7317
−7	2.25	0.759	89.03	1.318	11.23	190.61	394.37	203.77	0.9655	1.7310
−6	2.34	0.761	85.83	1.315	11.65	191.94	394.97	203.03	0.9705	1.7304
−5	2.43	0.763	82.76	1.311	12.08	193.27	395.56	202.29	0.9754	1.7297
−4	2.53	0.765	79.83	1.308	12.53	194.61	396.15	201.54	0.9804	1.7291
−3	2.62	0.766	77.02	1.305	12.98	195.95	396.74	200.79	0.9853	1.7285
−2	2.72	0.768	74.33	1.301	13.45	197.30	397.32	200.03	0.9902	1.7279
−1	2.82	0.770	71.75	1.298	13.94	198.64	397.91	199.27	0.9951	1.7273

Solkane® 134a

Release 1.05

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	2.93	0.772	69.28	1.295	14.43	200.00	398.49	198.49	1.0000	1.7267
1	3.04	0.774	66.91	1.291	14.95	201.35	399.07	197.72	1.0049	1.7262
2	3.15	0.776	64.64	1.288	15.47	202.70	399.65	196.95	1.0098	1.7256
3	3.26	0.778	62.46	1.285	16.01	204.06	400.22	196.16	1.0146	1.7251
4	3.38	0.780	60.36	1.281	16.57	205.42	400.80	195.38	1.0195	1.7246
5	3.50	0.782	58.35	1.278	17.14	206.79	401.37	194.58	1.0243	1.7241
6	3.62	0.785	56.42	1.275	17.72	208.15	401.94	193.78	1.0292	1.7236
7	3.75	0.787	54.57	1.271	18.33	209.52	402.50	192.98	1.0340	1.7231
8	3.88	0.789	52.79	1.268	18.94	210.90	403.07	192.17	1.0388	1.7226
9	4.01	0.791	51.08	1.264	19.58	212.27	403.63	191.36	1.0436	1.7221
10	4.15	0.793	49.43	1.261	20.23	213.65	404.19	190.54	1.0484	1.7217
11	4.29	0.795	47.84	1.257	20.90	215.03	404.74	189.71	1.0532	1.7212
12	4.43	0.798	46.32	1.254	21.59	216.42	405.30	188.88	1.0580	1.7208
13	4.58	0.800	44.85	1.250	22.29	217.80	405.85	188.04	1.0627	1.7204
14	4.73	0.802	43.44	1.247	23.02	219.19	406.39	187.20	1.0675	1.7200
15	4.88	0.804	42.08	1.243	23.76	220.58	406.94	186.35	1.0723	1.7196
16	5.04	0.807	40.77	1.240	24.53	221.98	407.48	185.50	1.0770	1.7192
17	5.21	0.809	39.51	1.236	25.31	223.38	408.02	184.64	1.0818	1.7188
18	5.37	0.811	38.30	1.232	26.11	224.78	408.55	183.77	1.0865	1.7184
19	5.54	0.814	37.12	1.229	26.94	226.18	409.08	182.90	1.0912	1.7180
20	5.72	0.816	35.99	1.225	27.78	227.59	409.61	182.02	1.0960	1.7176
21	5.90	0.819	34.91	1.221	28.65	229.00	410.14	181.14	1.1007	1.7172
22	6.08	0.821	33.85	1.218	29.54	230.41	410.66	180.25	1.1054	1.7169
23	6.27	0.824	32.84	1.214	30.45	231.83	411.18	179.35	1.1101	1.7165
24	6.46	0.826	31.86	1.210	31.39	233.25	411.69	178.44	1.1148	1.7162
25	6.65	0.829	30.91	1.206	32.35	234.67	412.20	177.53	1.1195	1.7158
26	6.85	0.832	30.00	1.202	33.33	236.09	412.71	176.61	1.1242	1.7155
27	7.06	0.834	29.12	1.199	34.34	237.52	413.21	175.69	1.1289	1.7151
28	7.27	0.837	28.27	1.195	35.38	238.96	413.71	174.75	1.1336	1.7148
29	7.48	0.840	27.44	1.191	36.44	240.39	414.20	173.81	1.1383	1.7144
30	7.70	0.842	26.65	1.187	37.53	241.83	414.69	172.86	1.1429	1.7141
31	7.93	0.845	25.88	1.183	38.64	243.27	415.18	171.91	1.1476	1.7138
32	8.15	0.848	25.13	1.179	39.79	244.72	415.66	170.94	1.1523	1.7134
33	8.39	0.851	24.41	1.175	40.96	246.17	416.14	169.97	1.1570	1.7131
34	8.63	0.854	23.72	1.171	42.16	247.62	416.61	168.99	1.1616	1.7128
35	8.87	0.857	23.04	1.167	43.40	249.08	417.07	168.00	1.1663	1.7124
36	9.12	0.860	22.39	1.163	44.66	250.54	417.54	167.00	1.1710	1.7121
37	9.37	0.863	21.76	1.159	45.96	252.01	417.99	165.99	1.1757	1.7118
38	9.63	0.866	21.15	1.155	47.29	253.48	418.44	164.97	1.1804	1.7114
39	9.90	0.869	20.55	1.150	48.66	254.95	418.89	163.94	1.1850	1.7111
40	10.17	0.872	19.98	1.146	50.06	256.43	419.33	162.90	1.1897	1.7107
41	10.44	0.876	19.42	1.142	51.49	257.91	419.76	161.85	1.1944	1.7104
42	10.72	0.879	18.88	1.138	52.97	259.40	420.19	160.79	1.1991	1.7100
43	11.01	0.882	18.36	1.133	54.48	260.90	420.61	159.72	1.2038	1.7097
44	11.30	0.886	17.85	1.129	56.03	262.40	421.03	158.63	1.2085	1.7093
45	11.60	0.889	17.36	1.125	57.62	263.90	421.44	157.54	1.2132	1.7090
46	11.90	0.893	16.88	1.120	59.25	265.41	421.84	156.43	1.2179	1.7086
47	12.21	0.896	16.41	1.116	60.92	266.93	422.24	155.31	1.2226	1.7082
48	12.53	0.900	15.96	1.111	62.64	268.45	422.63	154.17	1.2273	1.7078
49	12.85	0.904	15.53	1.107	64.40	269.98	423.01	153.02	1.2320	1.7075

Solkane® 134a

Release 1.05

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	13.18	0.908	15.10	1.102	66.21	271.52	423.38	151.86	1.2367	1.7071
51	13.51	0.911	14.69	1.097	68.07	273.07	423.75	150.68	1.2415	1.7066
52	13.85	0.915	14.29	1.093	69.98	274.62	424.10	149.49	1.2462	1.7062
53	14.20	0.919	13.90	1.088	71.94	276.18	424.45	148.28	1.2510	1.7058
54	14.55	0.923	13.52	1.083	73.95	277.74	424.79	147.05	1.2557	1.7053
55	14.92	0.928	13.15	1.078	76.02	279.32	425.12	145.81	1.2605	1.7049
56	15.28	0.932	12.80	1.073	78.15	280.90	425.44	144.54	1.2653	1.7044
57	15.66	0.936	12.45	1.068	80.34	282.49	425.76	143.26	1.2701	1.7039
58	16.04	0.941	12.11	1.063	82.59	284.10	426.06	141.96	1.2749	1.7034
59	16.42	0.945	11.78	1.058	84.90	285.71	426.35	140.64	1.2797	1.7029
60	16.82	0.950	11.46	1.053	87.28	287.33	426.63	139.30	1.2845	1.7024
61	17.22	0.955	11.15	1.047	89.72	288.96	426.90	137.94	1.2894	1.7018
62	17.63	0.960	10.84	1.042	92.24	290.60	427.15	136.55	1.2942	1.7012
63	18.04	0.965	10.54	1.037	94.84	292.26	427.40	135.14	1.2991	1.7006
64	18.47	0.970	10.26	1.031	97.51	293.92	427.63	133.71	1.3040	1.7000
65	18.90	0.975	9.97	1.026	100.27	295.60	427.84	132.25	1.3089	1.6994
66	19.34	0.980	9.70	1.020	103.11	297.29	428.05	130.76	1.3138	1.6987
67	19.78	0.986	9.43	1.014	106.04	298.99	428.24	129.25	1.3188	1.6980
68	20.24	0.992	9.17	1.008	109.06	300.71	428.41	127.70	1.3237	1.6973
69	20.70	0.998	8.91	1.002	112.19	302.44	428.57	126.13	1.3287	1.6965
70	21.17	1.004	8.66	0.996	115.41	304.18	428.71	124.52	1.3337	1.6957
71	21.65	1.010	8.42	0.990	118.75	305.94	428.83	122.88	1.3387	1.6949
72	22.13	1.016	8.18	0.984	122.20	307.72	428.93	121.21	1.3438	1.6940
73	22.63	1.023	7.95	0.978	125.77	309.51	429.01	119.50	1.3489	1.6931
74	23.13	1.030	7.72	0.971	129.47	311.32	429.07	117.76	1.3539	1.6921
75	23.64	1.037	7.50	0.964	133.30	313.14	429.11	115.97	1.3590	1.6911
76	24.16	1.044	7.28	0.958	137.28	314.99	429.13	114.14	1.3642	1.6901
77	24.69	1.052	7.07	0.951	141.42	316.85	429.12	112.27	1.3693	1.6890
78	25.23	1.060	6.86	0.944	145.71	318.73	429.08	110.35	1.3745	1.6878
79	25.78	1.068	6.66	0.936	150.19	320.64	429.02	108.38	1.3797	1.6866
80	26.33	1.077	6.46	0.929	154.85	322.56	428.93	106.37	1.3850	1.6852
81	26.90	1.086	6.26	0.921	159.71	324.50	428.80	104.30	1.3903	1.6839
82	27.47	1.095	6.07	0.913	164.79	326.47	428.64	102.17	1.3955	1.6824
83	28.06	1.105	5.88	0.905	170.11	328.46	428.44	99.98	1.4009	1.6809
84	28.65	1.116	5.69	0.896	175.69	330.47	428.19	97.72	1.4062	1.6792
85	29.26	1.127	5.51	0.888	181.54	332.51	427.91	95.40	1.4116	1.6775
86	29.87	1.138	5.33	0.879	187.71	334.57	427.57	93.01	1.4170	1.6756
87	30.50	1.151	5.15	0.869	194.22	336.66	427.19	90.53	1.4225	1.6736
88	31.14	1.164	4.97	0.859	201.11	338.77	426.74	87.97	1.4280	1.6715
89	31.78	1.178	4.80	0.849	208.42	340.91	426.23	85.31	1.4335	1.6692
90	32.44	1.193	4.63	0.838	216.21	343.08	425.64	82.56	1.4391	1.6667
91	33.11	1.210	4.45	0.827	224.56	345.28	424.97	79.69	1.4447	1.6641
92	33.79	1.228	4.28	0.814	233.54	347.52	424.20	76.69	1.4503	1.6611
93	34.49	1.248	4.11	0.801	243.26	349.78	423.33	73.55	1.4560	1.6579
94	35.19	1.270	3.94	0.788	253.90	352.07	422.31	70.24	1.4617	1.6544
95	35.91	1.295	3.76	0.772	265.66	354.40	421.13	66.73	1.4675	1.6504
96	36.64	1.324	3.59	0.755	278.91	356.76	419.73	62.96	1.4733	1.6459
97	37.39	1.358	3.40	0.736	294.32	359.16	417.99	58.84	1.4791	1.6405

12.1.5 Solkane® 227

Release 1.02

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	0.605	1068.18	1.652	0.94	137.89	285.75	147.85	0.7447	1.4383
−59	0.103	0.606	1003.38	1.650	1.00	138.84	286.37	147.53	0.7491	1.4380
−58	0.110	0.607	943.08	1.648	1.06	139.80	286.99	147.19	0.7536	1.4377
−57	0.118	0.608	887.08	1.645	1.13	140.76	287.61	146.85	0.7580	1.4374
−56	0.126	0.609	834.97	1.643	1.20	141.72	288.24	146.52	0.7624	1.4372
−55	0.134	0.610	786.45	1.641	1.27	142.68	288.86	146.19	0.7668	1.4370
−54	0.143	0.610	741.22	1.638	1.35	143.64	289.49	145.85	0.7712	1.4368
−53	0.152	0.611	699.05	1.636	1.43	144.61	290.12	145.51	0.7756	1.4366
−52	0.162	0.612	659.69	1.633	1.52	145.58	290.75	145.17	0.7800	1.4365
−51	0.172	0.613	622.93	1.631	1.61	146.55	291.38	144.83	0.7844	1.4364
−50	0.183	0.614	588.58	1.628	1.70	147.52	292.01	144.49	0.7888	1.4363
−49	0.194	0.615	556.46	1.626	1.80	148.50	292.64	144.14	0.7932	1.4362
−48	0.206	0.616	526.40	1.623	1.90	149.48	293.28	143.79	0.7975	1.4362
−47	0.218	0.617	498.26	1.621	2.01	150.47	293.91	143.44	0.8019	1.4362
−46	0.231	0.618	471.89	1.618	2.12	151.46	294.55	143.09	0.8062	1.4362
−45	0.245	0.619	447.17	1.616	2.24	152.45	295.18	142.74	0.8106	1.4362
−44	0.259	0.620	423.98	1.613	2.36	153.44	295.82	142.38	0.8149	1.4363
−43	0.274	0.621	402.21	1.610	2.49	154.44	296.46	142.02	0.8193	1.4363
−42	0.290	0.622	381.76	1.608	2.62	155.44	297.10	141.66	0.8236	1.4364
−41	0.307	0.623	362.54	1.605	2.76	156.44	297.74	141.30	0.8279	1.4366
−40	0.324	0.624	344.48	1.603	2.90	157.44	298.38	140.93	0.8322	1.4367
−39	0.342	0.625	327.47	1.600	3.05	158.45	299.02	140.57	0.8365	1.4369
−38	0.361	0.626	311.47	1.597	3.21	159.46	299.66	140.20	0.8408	1.4370
−37	0.380	0.627	296.39	1.594	3.37	160.48	300.30	139.82	0.8451	1.4372
−36	0.401	0.628	282.18	1.592	3.54	161.49	300.94	139.45	0.8494	1.4375
−35	0.422	0.629	268.78	1.589	3.72	162.51	301.59	139.07	0.8537	1.4377
−34	0.444	0.630	256.14	1.586	3.90	163.53	302.23	138.70	0.8580	1.4379
−33	0.467	0.631	244.20	1.584	4.09	164.56	302.87	138.31	0.8623	1.4382
−32	0.491	0.633	232.93	1.581	4.29	165.59	303.52	137.93	0.8666	1.4385
−31	0.517	0.634	222.28	1.578	4.50	166.62	304.17	137.54	0.8708	1.4388
−30	0.543	0.635	212.21	1.575	4.71	167.66	304.81	137.15	0.8751	1.4391
−29	0.570	0.636	202.69	1.572	4.93	168.70	305.46	136.76	0.8793	1.4395
−28	0.598	0.637	193.67	1.570	5.16	169.74	306.10	136.37	0.8836	1.4398
−27	0.628	0.638	185.14	1.567	5.40	170.78	306.75	135.97	0.8878	1.4402
−26	0.658	0.639	177.05	1.564	5.65	171.83	307.40	135.57	0.8920	1.4406
−25	0.690	0.641	169.39	1.561	5.90	172.87	308.05	135.17	0.8963	1.4410
−24	0.723	0.642	162.12	1.558	6.17	173.93	308.70	134.77	0.9005	1.4414
−23	0.757	0.643	155.23	1.555	6.44	174.98	309.34	134.36	0.9047	1.4418
−22	0.792	0.644	148.68	1.552	6.73	176.04	309.99	133.95	0.9089	1.4423
−21	0.829	0.646	142.47	1.549	7.02	177.10	310.64	133.54	0.9131	1.4427
−20	0.867	0.647	136.57	1.546	7.32	178.16	311.29	133.13	0.9173	1.4432
−19	0.906	0.648	130.96	1.543	7.64	179.23	311.94	132.71	0.9215	1.4437
−18	0.947	0.649	125.63	1.540	7.96	180.30	312.59	132.29	0.9257	1.4442
−17	0.989	0.651	120.56	1.537	8.29	181.37	313.24	131.87	0.9299	1.4447
−16	1.033	0.652	115.73	1.534	8.64	182.44	313.89	131.45	0.9340	1.4452
−15	1.078	0.653	111.14	1.531	9.00	183.52	314.54	131.02	0.9382	1.4458
−14	1.125	0.655	106.76	1.528	9.37	184.60	315.19	130.59	0.9424	1.4463
−13	1.173	0.656	102.59	1.525	9.75	185.68	315.84	130.16	0.9465	1.4469
−12	1.223	0.657	98.62	1.521	10.14	186.77	316.49	129.72	0.9507	1.4474
−11	1.274	0.659	94.83	1.518	10.54	187.86	317.14	129.28	0.9548	1.4480

Solkane® 227

Release 1.02

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	1.328	0.660	91.22	1.515	10.96	188.95	317.79	128.84	0.9590	1.4486
−9	1.383	0.661	87.77	1.512	11.39	190.04	318.44	128.40	0.9631	1.4492
−8	1.439	0.663	84.48	1.509	11.84	191.14	319.09	127.95	0.9672	1.4498
−7	1.498	0.664	81.33	1.505	12.29	192.24	319.74	127.50	0.9714	1.4504
−6	1.558	0.666	78.33	1.502	12.77	193.34	320.38	127.05	0.9755	1.4510
−5	1.620	0.667	75.46	1.499	13.25	194.44	321.03	126.59	0.9796	1.4517
−4	1.684	0.669	72.72	1.495	13.75	195.55	321.68	126.13	0.9837	1.4523
−3	1.750	0.670	70.09	1.492	14.27	196.66	322.33	125.67	0.9878	1.4530
−2	1.818	0.672	67.58	1.489	14.80	197.77	322.98	125.21	0.9919	1.4537
−1	1.888	0.673	65.18	1.485	15.34	198.89	323.63	124.74	0.9960	1.4543
0	1.960	0.675	62.88	1.482	15.90	200.00	324.27	124.27	1.0000	1.4550
1	2.035	0.676	60.68	1.479	16.48	201.13	324.92	123.79	1.0041	1.4557
2	2.111	0.678	58.56	1.475	17.08	202.25	325.57	123.32	1.0082	1.4564
3	2.190	0.680	56.54	1.472	17.69	203.38	326.21	122.83	1.0123	1.4571
4	2.270	0.681	54.60	1.468	18.31	204.51	326.86	122.35	1.0163	1.4578
5	2.353	0.683	52.74	1.465	18.96	205.64	327.50	121.86	1.0204	1.4585
6	2.439	0.684	50.96	1.461	19.62	206.77	328.15	121.37	1.0244	1.4592
7	2.526	0.686	49.25	1.457	20.31	207.91	328.79	120.88	1.0285	1.4600
8	2.616	0.688	47.60	1.454	21.01	209.05	329.43	120.38	1.0325	1.4607
9	2.709	0.690	46.03	1.450	21.73	210.19	330.07	119.88	1.0366	1.4615
10	2.804	0.691	44.51	1.446	22.47	211.33	330.71	119.38	1.0406	1.4622
11	2.901	0.693	43.05	1.443	23.23	212.48	331.36	118.87	1.0446	1.4630
12	3.001	0.695	41.65	1.439	24.01	213.63	332.00	118.36	1.0486	1.4637
13	3.104	0.697	40.31	1.435	24.81	214.79	332.63	117.85	1.0526	1.4645
14	3.209	0.699	39.01	1.432	25.63	215.94	333.27	117.33	1.0566	1.4653
15	3.317	0.700	37.77	1.428	26.48	217.10	333.91	116.81	1.0606	1.4660
16	3.428	0.702	36.57	1.424	27.34	218.26	334.55	116.28	1.0646	1.4668
17	3.542	0.704	35.42	1.420	28.23	219.42	335.18	115.76	1.0686	1.4676
18	3.658	0.706	34.31	1.416	29.15	220.59	335.81	115.22	1.0726	1.4684
19	3.777	0.708	33.24	1.412	30.09	221.76	336.45	114.69	1.0766	1.4692
20	3.899	0.710	32.21	1.408	31.05	222.93	337.08	114.15	1.0806	1.4700
21	4.024	0.712	31.22	1.404	32.03	224.11	337.71	113.60	1.0845	1.4707
22	4.152	0.714	30.26	1.400	33.05	225.29	338.34	113.05	1.0885	1.4715
23	4.284	0.716	29.34	1.396	34.09	226.47	338.97	112.50	1.0925	1.4723
24	4.418	0.718	28.45	1.392	35.15	227.65	339.59	111.94	1.0964	1.4732
25	4.555	0.720	27.59	1.388	36.24	228.84	340.22	111.38	1.1004	1.4740
26	4.696	0.723	26.76	1.384	37.37	230.03	340.84	110.81	1.1043	1.4748
27	4.840	0.725	25.96	1.380	38.52	231.22	341.46	110.24	1.1083	1.4756
28	4.987	0.727	25.19	1.376	39.70	232.42	342.08	109.67	1.1122	1.4764
29	5.138	0.729	24.45	1.371	40.91	233.61	342.70	109.09	1.1162	1.4772
30	5.292	0.732	23.73	1.367	42.15	234.82	343.32	108.50	1.1201	1.4780
31	5.449	0.734	23.03	1.363	43.42	236.02	343.93	107.91	1.1240	1.4788
32	5.610	0.736	22.36	1.358	44.72	237.23	344.55	107.32	1.1280	1.4796
33	5.774	0.739	21.71	1.354	46.06	238.44	345.16	106.72	1.1319	1.4805
34	5.942	0.741	21.08	1.349	47.43	239.65	345.77	106.11	1.1358	1.4813
35	6.114	0.744	20.48	1.345	48.84	240.87	346.37	105.50	1.1397	1.4821
36	6.289	0.746	19.89	1.340	50.28	242.09	346.98	104.88	1.1436	1.4829
37	6.468	0.749	19.32	1.336	51.76	243.32	347.58	104.26	1.1475	1.4837
38	6.651	0.751	18.77	1.331	53.28	244.55	348.18	103.63	1.1514	1.4845
39	6.838	0.754	18.24	1.327	54.83	245.78	348.78	103.00	1.1554	1.4853

Solkane® 227

Release 1.02

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	17.72	1.322	56.43	247.01	349.37	102.36	1.1593	1.4861
41	7.223	0.759	17.22	1.317	58.07	248.25	349.96	101.71	1.1632	1.4869
42	7.422	0.762	16.74	1.312	59.75	249.49	350.55	101.06	1.1671	1.4877
43	7.625	0.765	16.27	1.308	61.47	250.74	351.14	100.40	1.1710	1.4885
44	7.832	0.768	15.81	1.303	63.24	251.99	351.72	99.73	1.1749	1.4893
45	8.043	0.771	15.37	1.298	65.05	253.24	352.30	99.06	1.1788	1.4901
46	8.258	0.773	14.95	1.293	66.91	254.50	352.88	98.38	1.1826	1.4909
47	8.478	0.776	14.53	1.288	68.82	255.76	353.45	97.69	1.1865	1.4917
48	8.702	0.780	14.13	1.283	70.78	257.03	354.02	96.99	1.1904	1.4925
49	8.930	0.783	13.74	1.278	72.79	258.30	354.59	96.29	1.1943	1.4932
50	9.163	0.786	13.36	1.272	74.85	259.58	355.15	95.57	1.1982	1.4940
51	9.401	0.789	12.99	1.267	76.97	260.86	355.71	94.85	1.2021	1.4947
52	9.643	0.792	12.64	1.262	79.14	262.14	356.26	94.12	1.2060	1.4955
53	9.890	0.796	12.29	1.257	81.38	263.43	356.81	93.38	1.2099	1.4962
54	10.141	0.799	11.95	1.251	83.67	264.72	357.36	92.63	1.2138	1.4970
55	10.398	0.803	11.62	1.246	86.03	266.02	357.90	91.87	1.2177	1.4977
56	10.659	0.806	11.31	1.240	88.46	267.33	358.43	91.10	1.2216	1.4984
57	10.925	0.810	11.00	1.234	90.95	268.64	358.96	90.32	1.2255	1.4991
58	11.196	0.814	10.69	1.229	93.51	269.95	359.49	89.53	1.2295	1.4998
59	11.472	0.818	10.40	1.223	96.14	271.28	360.01	88.73	1.2334	1.5005
60	11.754	0.822	10.12	1.217	98.85	272.60	360.52	87.92	1.2373	1.5012
61	12.040	0.826	9.84	1.211	101.64	273.94	361.03	87.09	1.2412	1.5019
62	12.332	0.830	9.57	1.205	104.51	275.28	361.53	86.25	1.2452	1.5025
63	12.629	0.834	9.31	1.199	107.46	276.63	362.02	85.40	1.2491	1.5031
64	12.932	0.838	9.05	1.193	110.51	277.98	362.51	84.53	1.2530	1.5038
65	13.240	0.843	8.80	1.187	113.64	279.34	362.99	83.65	1.2570	1.5044
66	13.554	0.847	8.56	1.180	116.88	280.71	363.46	82.75	1.2610	1.5049
67	13.873	0.852	8.32	1.174	120.21	282.08	363.92	81.84	1.2649	1.5055
68	14.198	0.857	8.09	1.167	123.65	283.47	364.37	80.91	1.2689	1.5061
69	14.529	0.862	7.86	1.160	127.20	284.86	364.82	79.96	1.2729	1.5066
70	14.866	0.867	7.64	1.154	130.87	286.26	365.25	78.99	1.2769	1.5071
71	15.209	0.872	7.43	1.147	134.67	287.67	365.68	78.00	1.2809	1.5076
72	15.557	0.877	7.22	1.140	138.59	289.09	366.09	77.00	1.2850	1.5080
73	15.913	0.883	7.01	1.133	142.65	290.52	366.49	75.97	1.2890	1.5085
74	16.274	0.889	6.81	1.125	146.85	291.96	366.88	74.92	1.2931	1.5089
75	16.642	0.895	6.61	1.118	151.21	293.41	367.26	73.84	1.2971	1.5092
76	17.016	0.901	6.42	1.110	155.73	294.88	367.62	72.74	1.3012	1.5096
77	17.396	0.907	6.23	1.102	160.43	296.35	367.96	71.61	1.3054	1.5099
78	17.784	0.914	6.05	1.094	165.31	297.84	368.29	70.45	1.3095	1.5101
79	18.178	0.921	5.87	1.086	170.39	299.34	368.61	69.27	1.3137	1.5104
80	18.579	0.928	5.69	1.078	175.68	300.85	368.90	68.04	1.3179	1.5105
81	18.987	0.935	5.52	1.069	181.20	302.38	369.17	66.79	1.3221	1.5107
82	19.402	0.943	5.35	1.061	186.97	303.93	369.42	65.49	1.3263	1.5107
83	19.824	0.951	5.18	1.052	193.01	305.50	369.65	64.16	1.3306	1.5108
84	20.253	0.959	5.02	1.042	199.35	307.08	369.85	62.77	1.3349	1.5107
85	20.690	0.968	4.85	1.033	206.00	308.68	370.02	61.34	1.3393	1.5106
86	21.135	0.978	4.69	1.023	213.01	310.30	370.16	59.86	1.3437	1.5104
87	21.587	0.988	4.54	1.012	220.41	311.95	370.27	58.32	1.3482	1.5101
88	22.047	0.998	4.38	1.002	228.24	313.62	370.33	56.71	1.3527	1.5097
89	22.516	1.009	4.23	0.991	236.57	315.32	370.35	55.03	1.3572	1.5092

Solkane® 227

Release 1.02

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	22.992	1.021	4.07	0.979	245.45	317.05	370.32	53.27	1.3619	1.5086
91	23.477	1.034	3.92	0.967	254.97	318.82	370.23	51.42	1.3666	1.5078
92	23.970	1.048	3.77	0.954	265.23	320.62	370.07	49.46	1.3714	1.5068
93	24.472	1.064	3.62	0.940	276.37	322.46	369.83	47.37	1.3763	1.5057
94	24.983	1.081	3.47	0.925	288.55	324.36	369.50	45.14	1.3813	1.5043
95	25.503	1.099	3.31	0.910	302.04	326.31	369.04	42.73	1.3865	1.5025
96	26.032	1.121	3.15	0.892	317.17	328.34	368.43	40.09	1.3918	1.5004
97	26.572	1.145	2.99	0.873	334.52	330.46	367.61	37.15	1.3974	1.4977
98	27.121	1.175	2.82	0.851	355.06	332.70	366.48	33.79	1.4032	1.4943

12.1.6 Solkane® 404A

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]
–60	0.498	0.475	0.742	371.99	1.348	2.688	122.48	331.69	209.21	0.680	1.667
–59	0.526	0.502	0.744	352.96	1.345	2.833	123.72	332.30	208.58	0.686	1.665
–58	0.556	0.531	0.745	335.09	1.342	2.984	124.95	332.91	207.96	0.692	1.663
–57	0.587	0.561	0.747	318.30	1.339	3.142	126.18	333.52	207.34	0.697	1.662
–56	0.619	0.592	0.748	302.52	1.336	3.306	127.41	334.13	206.72	0.703	1.660
–55	0.652	0.625	0.750	287.67	1.333	3.476	128.63	334.74	206.10	0.709	1.658
–54	0.687	0.659	0.752	273.70	1.330	3.654	129.86	335.35	205.49	0.714	1.657
–53	0.724	0.694	0.754	260.54	1.327	3.838	131.08	335.95	204.88	0.720	1.655
–52	0.762	0.731	0.755	248.14	1.324	4.030	132.30	336.56	204.26	0.725	1.653
–51	0.801	0.770	0.757	236.45	1.321	4.229	133.52	337.17	203.65	0.731	1.652
–50	0.842	0.810	0.759	225.42	1.318	4.436	134.74	337.77	203.03	0.737	1.650
–49	0.885	0.852	0.760	215.00	1.315	4.651	135.96	338.38	202.42	0.742	1.649
–48	0.930	0.895	0.762	205.17	1.312	4.874	137.18	338.98	201.80	0.748	1.648
–47	0.976	0.940	0.764	195.87	1.309	5.105	138.40	339.58	201.18	0.753	1.646
–46	1.024	0.987	0.766	187.08	1.306	5.345	139.63	340.18	200.55	0.759	1.645
–45	1.074	1.036	0.768	178.77	1.303	5.594	140.85	340.78	199.93	0.765	1.643
–44	1.126	1.087	0.769	170.90	1.300	5.852	142.08	341.38	199.30	0.770	1.642
–43	1.179	1.140	0.771	163.44	1.297	6.118	143.32	341.98	198.66	0.776	1.641
–42	1.235	1.194	0.773	156.38	1.294	6.395	144.55	342.57	198.02	0.781	1.640
–41	1.293	1.251	0.775	149.68	1.290	6.681	145.79	343.17	197.38	0.787	1.639
–40	1.353	1.309	0.777	143.33	1.287	6.977	147.03	343.76	196.73	0.792	1.637
–39	1.415	1.370	0.779	137.31	1.284	7.283	148.28	344.35	196.07	0.798	1.636
–38	1.479	1.433	0.781	131.59	1.281	7.600	149.53	344.94	195.41	0.803	1.635
–37	1.545	1.498	0.783	126.15	1.278	7.927	150.78	345.53	194.75	0.808	1.634
–36	1.614	1.566	0.784	120.99	1.275	8.265	152.04	346.12	194.08	0.814	1.633
–35	1.685	1.636	0.786	116.08	1.272	8.615	153.30	346.71	193.40	0.819	1.632
–34	1.758	1.708	0.788	111.41	1.268	8.976	154.57	347.29	192.72	0.825	1.631
–33	1.834	1.783	0.790	106.97	1.265	9.349	155.84	347.87	192.03	0.830	1.630
–32	1.913	1.860	0.792	102.74	1.262	9.734	157.12	348.45	191.34	0.836	1.629
–31	1.994	1.940	0.795	98.71	1.259	10.131	158.40	349.03	190.63	0.841	1.628
–30	2.077	2.022	0.797	94.87	1.255	10.541	159.68	349.61	189.93	0.846	1.627
–29	2.164	2.107	0.799	91.21	1.252	10.964	160.97	350.18	189.21	0.852	1.626
–28	2.253	2.195	0.801	87.72	1.249	11.400	162.27	350.76	188.49	0.857	1.625
–27	2.345	2.285	0.803	84.39	1.246	11.850	163.57	351.33	187.76	0.862	1.625
–26	2.439	2.379	0.805	81.21	1.242	12.313	164.87	351.90	187.03	0.867	1.624
–25	2.537	2.475	0.807	78.18	1.239	12.791	166.18	352.47	186.28	0.873	1.623
–24	2.638	2.574	0.809	75.28	1.236	13.283	167.50	353.03	185.54	0.878	1.622
–23	2.741	2.676	0.812	72.51	1.232	13.790	168.81	353.59	184.78	0.883	1.621
–22	2.848	2.782	0.814	69.87	1.229	14.313	170.14	354.16	184.02	0.888	1.621
–21	2.958	2.890	0.816	67.34	1.225	14.851	171.46	354.71	183.25	0.894	1.620
–20	3.071	3.002	0.818	64.92	1.222	15.405	172.80	355.27	182.47	0.899	1.619
–19	3.187	3.117	0.821	62.60	1.219	15.975	174.13	355.82	181.69	0.904	1.618
–18	3.307	3.235	0.823	60.38	1.215	16.562	175.47	356.38	180.90	0.909	1.618
–17	3.430	3.357	0.825	58.26	1.212	17.166	176.82	356.92	180.11	0.914	1.617
–16	3.556	3.482	0.828	56.22	1.208	17.787	178.17	357.47	179.30	0.920	1.616
–15	3.686	3.610	0.830	54.27	1.205	18.427	179.52	358.01	178.49	0.925	1.616
–14	3.820	3.742	0.832	52.40	1.201	19.084	180.88	358.55	177.68	0.930	1.615
–13	3.957	3.878	0.835	50.61	1.198	19.760	182.24	359.09	176.85	0.935	1.615
–12	4.098	4.018	0.837	48.89	1.194	20.456	183.60	359.63	176.02	0.940	1.614
–11	4.243	4.161	0.840	47.23	1.191	21.171	184.97	360.16	175.19	0.945	1.613

Solkane® 404A

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]
–10	4.391	4.308	0.842	45.65	1.187	21.906	186.34	360.69	174.34	0.950	1.613
–9	4.544	4.459	0.845	44.13	1.183	22.662	187.72	361.21	173.49	0.955	1.612
–8	4.700	4.614	0.848	42.66	1.180	23.439	189.10	361.73	172.64	0.960	1.612
–7	4.861	4.773	0.850	41.26	1.176	24.237	190.48	362.25	171.77	0.965	1.611
–6	5.025	4.936	0.853	39.91	1.172	25.057	191.86	362.77	170.91	0.970	1.610
–5	5.194	5.103	0.856	38.61	1.169	25.900	193.25	363.28	170.03	0.975	1.610
–4	5.367	5.274	0.858	37.36	1.165	26.766	194.64	363.79	169.15	0.980	1.609
–3	5.544	5.450	0.861	36.16	1.161	27.656	196.04	364.29	168.26	0.985	1.609
–2	5.726	5.630	0.864	35.00	1.157	28.570	197.43	364.79	167.36	0.990	1.608
–1	5.912	5.815	0.867	33.89	1.154	29.509	198.83	365.29	166.46	0.995	1.608
0	6.102	6.004	0.870	32.81	1.150	30.474	200.00	365.78	165.78	1.000	1.607
1	6.297	6.197	0.873	31.78	1.146	31.465	201.64	366.27	164.63	1.005	1.607
2	6.497	6.395	0.876	30.79	1.142	32.482	203.05	366.76	163.71	1.010	1.606
3	6.702	6.598	0.879	29.83	1.138	33.527	204.46	367.24	162.78	1.015	1.606
4	6.911	6.806	0.882	28.90	1.134	34.600	205.87	367.71	161.84	1.020	1.605
5	7.125	7.019	0.885	28.01	1.130	35.703	207.28	368.18	160.90	1.025	1.605
6	7.344	7.236	0.888	27.15	1.126	36.835	208.70	368.65	159.95	1.030	1.604
7	7.568	7.459	0.891	26.32	1.122	37.997	210.12	369.11	158.99	1.034	1.604
8	7.797	7.687	0.894	25.52	1.118	39.191	211.55	369.57	158.02	1.039	1.603
9	8.032	7.920	0.898	24.74	1.114	40.417	212.97	370.02	157.05	1.044	1.603
10	8.271	8.158	0.901	23.99	1.110	41.676	214.40	370.46	156.06	1.049	1.603
11	8.516	8.401	0.904	23.27	1.106	42.970	215.83	370.90	155.07	1.054	1.602
12	8.766	8.650	0.908	22.57	1.102	44.298	217.27	371.34	154.07	1.059	1.602
13	9.022	8.904	0.911	21.90	1.098	45.662	218.70	371.77	153.06	1.064	1.601
14	9.283	9.164	0.915	21.25	1.093	47.063	220.14	372.19	152.04	1.069	1.601
15	9.550	9.429	0.918	20.62	1.089	48.502	221.59	372.60	151.02	1.074	1.600
16	9.823	9.701	0.922	20.01	1.085	49.980	223.04	373.01	149.98	1.079	1.600
17	10.101	9.978	0.926	19.42	1.080	51.499	224.49	373.42	148.93	1.084	1.599
18	10.385	10.260	0.929	18.85	1.076	53.060	225.94	373.81	147.87	1.088	1.599
19	10.675	10.549	0.933	18.29	1.071	54.663	227.40	374.20	146.80	1.093	1.598
20	10.972	10.844	0.937	17.76	1.067	56.311	228.87	374.58	145.72	1.098	1.598
21	11.274	11.145	0.941	17.24	1.062	58.004	230.34	374.96	144.62	1.103	1.597
22	11.582	11.452	0.945	16.74	1.058	59.745	231.81	375.33	143.52	1.108	1.597
23	11.897	11.766	0.950	16.25	1.053	61.534	233.29	375.68	142.39	1.113	1.596
24	12.218	12.085	0.954	15.78	1.048	63.374	234.77	376.03	141.26	1.118	1.596
25	12.546	12.412	0.958	15.32	1.044	65.266	236.26	376.37	140.11	1.123	1.595
26	12.880	12.745	0.963	14.88	1.039	67.212	237.76	376.71	138.94	1.128	1.594
27	13.220	13.084	0.967	14.45	1.034	69.214	239.27	377.03	137.76	1.133	1.594
28	13.568	13.430	0.972	14.03	1.029	71.274	240.78	377.34	136.56	1.138	1.593
29	13.922	13.784	0.976	13.63	1.024	73.394	242.30	377.64	135.34	1.143	1.593
30	14.283	14.144	0.981	13.23	1.019	75.577	243.83	377.93	134.10	1.148	1.592
31	14.651	14.511	0.986	12.85	1.014	77.824	245.37	378.22	132.85	1.153	1.591
32	15.026	14.885	0.991	12.48	1.009	80.139	246.92	378.48	131.57	1.158	1.591
33	15.408	15.266	0.996	12.12	1.004	82.524	248.47	378.74	130.27	1.164	1.590
34	15.798	15.655	1.002	11.77	0.998	84.982	250.04	378.99	128.94	1.169	1.589
35	16.195	16.051	1.007	11.43	0.993	87.516	251.63	379.22	127.59	1.174	1.589
36	16.599	16.455	1.013	11.10	0.987	90.129	253.22	379.44	126.22	1.179	1.588
37	17.011	16.866	1.018	10.77	0.982	92.826	254.83	379.64	124.81	1.184	1.587
38	17.431	17.285	1.024	10.46	0.976	95.609	256.45	379.83	123.38	1.190	1.586
39	17.858	17.712	1.030	10.15	0.970	98.484	258.09	380.00	121.92	1.195	1.585

Solkane® 404A

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]
40	18.294	18.146	1.037	9.86	0.965	101.454	259.74	380.16	120.43	1.200	1.584
41	18.737	18.589	1.043	9.57	0.959	104.524	261.41	380.30	118.90	1.206	1.584
42	19.189	19.040	1.050	9.29	0.953	107.700	263.09	380.43	117.33	1.211	1.583
43	19.648	19.499	1.057	9.01	0.946	110.987	264.80	380.53	115.73	1.216	1.582
44	20.116	19.967	1.064	8.74	0.940	114.391	266.53	380.61	114.09	1.222	1.581
45	20.593	20.443	1.071	8.48	0.934	117.918	268.27	380.67	112.40	1.227	1.580
46	21.078	20.928	1.079	8.23	0.927	121.578	270.04	380.71	110.67	1.233	1.578
47	21.572	21.422	1.086	7.98	0.920	125.376	271.83	380.73	108.90	1.238	1.577
48	22.074	21.925	1.095	7.73	0.914	129.323	273.65	380.72	107.07	1.244	1.576
49	22.586	22.436	1.103	7.49	0.907	133.428	275.49	380.69	105.19	1.250	1.575
50	23.107	22.957	1.112	7.26	0.899	137.702	277.36	380.62	103.26	1.255	1.573
51	23.637	23.488	1.121	7.03	0.892	142.157	279.26	380.53	101.26	1.261	1.572
52	24.176	24.027	1.131	6.81	0.884	146.808	281.19	380.40	99.21	1.267	1.570
53	24.725	24.577	1.141	6.59	0.877	151.669	283.15	380.24	97.09	1.273	1.569
54	25.283	25.136	1.151	6.38	0.869	156.758	285.14	380.04	94.89	1.279	1.567
55	25.852	25.706	1.162	6.17	0.860	162.096	287.17	379.79	92.62	1.285	1.565
56	26.430	26.285	1.174	5.96	0.852	167.706	289.23	379.51	90.27	1.291	1.563
57	27.019	26.875	1.187	5.76	0.843	173.614	291.33	379.17	87.84	1.297	1.561
58	27.618	27.476	1.200	5.56	0.833	179.853	293.48	378.78	85.31	1.303	1.559
59	28.228	28.088	1.214	5.36	0.824	186.460	295.66	378.33	82.67	1.309	1.557
60	28.849	28.711	1.229	5.17	0.814	193.480	297.88	377.82	79.93	1.316	1.554
61	29.481	29.345	1.246	4.98	0.803	200.967	300.15	377.23	77.07	1.322	1.551
62	30.124	29.991	1.263	4.78	0.792	208.987	302.47	376.56	74.08	1.328	1.549
63	30.779	30.649	1.283	4.60	0.780	217.626	304.84	375.79	70.95	1.335	1.545
64	31.445	31.320	1.304	4.41	0.767	226.989	307.26	374.90	67.65	1.342	1.542
65	32.125	32.003	1.328	4.22	0.753	237.216	309.73	373.89	64.16	1.348	1.538
66	32.817	32.700	1.355	4.02	0.738	248.497	312.25	372.72	60.47	1.355	1.534
67	33.522	33.411	1.386	3.83	0.722	261.092	314.84	371.36	56.52	1.362	1.529
68	34.241	34.138	1.422	3.63	0.703	275.382	317.48	369.75	52.26	1.369	1.523

12.1.7 Solkane® 407C

Release 1.04

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	0.738	0.502	0.714	418.06	1.400	2.392	132.44	381.96	249.52	0.728	1.866
–49	0.777	0.531	0.716	396.66	1.397	2.521	133.73	382.56	248.83	0.733	1.863
–48	0.817	0.561	0.717	376.57	1.394	2.656	135.02	383.16	248.14	0.739	1.861
–47	0.859	0.593	0.719	357.69	1.391	2.796	136.31	383.76	247.44	0.745	1.858
–46	0.903	0.626	0.720	339.93	1.388	2.942	137.61	384.35	246.75	0.751	1.856
–45	0.948	0.660	0.722	323.23	1.385	3.094	138.90	384.95	246.05	0.757	1.854
–44	0.995	0.696	0.724	307.50	1.382	3.252	140.20	385.54	245.34	0.762	1.851
–43	1.044	0.734	0.725	292.69	1.379	3.417	141.50	386.14	244.64	0.768	1.849
–42	1.095	0.773	0.727	278.72	1.376	3.588	142.80	386.73	243.93	0.774	1.847
–41	1.147	0.814	0.728	265.56	1.373	3.766	144.10	387.32	243.22	0.779	1.844
–40	1.202	0.857	0.730	253.14	1.370	3.950	145.40	387.90	242.50	0.785	1.842
–39	1.259	0.901	0.732	241.41	1.367	4.142	146.71	388.49	241.78	0.791	1.840
–38	1.318	0.947	0.733	230.33	1.363	4.342	148.02	389.07	241.06	0.796	1.838
–37	1.379	0.995	0.735	219.86	1.360	4.548	149.33	389.66	240.33	0.802	1.836
–36	1.442	1.045	0.737	209.96	1.357	4.763	150.65	390.24	239.59	0.808	1.834
–35	1.508	1.097	0.739	200.60	1.354	4.985	151.96	390.82	238.85	0.813	1.832
–34	1.575	1.150	0.740	191.73	1.351	5.216	153.28	391.39	238.11	0.819	1.830
–33	1.645	1.206	0.742	183.33	1.348	5.455	154.61	391.97	237.36	0.825	1.828
–32	1.718	1.264	0.744	175.38	1.345	5.702	155.93	392.54	236.61	0.830	1.826
–31	1.793	1.324	0.745	167.84	1.341	5.958	157.26	393.11	235.85	0.836	1.824
–30	1.871	1.387	0.747	160.68	1.338	6.223	158.60	393.68	235.09	0.841	1.822
–29	1.951	1.452	0.749	153.90	1.335	6.498	159.93	394.25	234.32	0.847	1.820
–28	2.034	1.519	0.751	147.45	1.332	6.782	161.27	394.81	233.54	0.852	1.818
–27	2.119	1.588	0.753	141.33	1.329	7.076	162.61	395.38	232.76	0.858	1.816
–26	2.207	1.660	0.755	135.52	1.325	7.379	163.96	395.94	231.98	0.863	1.815
–25	2.299	1.735	0.756	129.99	1.322	7.693	165.31	396.49	231.19	0.869	1.813
–24	2.393	1.812	0.758	124.73	1.319	8.017	166.66	397.05	230.39	0.874	1.811
–23	2.490	1.891	0.760	119.73	1.315	8.352	168.02	397.60	229.59	0.879	1.809
–22	2.590	1.974	0.762	114.97	1.312	8.698	169.38	398.15	228.78	0.885	1.808
–21	2.693	2.059	0.764	110.43	1.309	9.055	170.74	398.70	227.96	0.890	1.806
–20	2.799	2.147	0.766	106.11	1.306	9.424	172.11	399.25	227.14	0.896	1.805
–19	2.908	2.238	0.768	101.99	1.302	9.805	173.47	399.79	226.31	0.901	1.803
–18	3.021	2.332	0.770	98.07	1.299	10.197	174.85	400.33	225.48	0.906	1.801
–17	3.137	2.429	0.772	94.32	1.296	10.602	176.22	400.87	224.64	0.912	1.800
–16	3.256	2.529	0.774	90.75	1.292	11.019	177.60	401.40	223.80	0.917	1.798
–15	3.379	2.632	0.776	87.34	1.289	11.450	178.99	401.93	222.95	0.922	1.797
–14	3.505	2.738	0.778	84.08	1.285	11.894	180.37	402.46	222.09	0.927	1.795
–13	3.635	2.848	0.780	80.97	1.282	12.351	181.76	402.98	221.22	0.933	1.794
–12	3.768	2.961	0.782	77.99	1.279	12.822	183.15	403.51	220.35	0.938	1.792
–11	3.906	3.078	0.784	75.15	1.275	13.307	184.55	404.03	219.48	0.943	1.791
–10	4.047	3.198	0.786	72.43	1.272	13.807	185.95	404.54	218.60	0.948	1.790
–9	4.191	3.322	0.789	69.82	1.268	14.322	187.35	405.05	217.71	0.954	1.788
–8	4.340	3.449	0.791	67.33	1.265	14.852	188.75	405.56	216.81	0.959	1.787
–7	4.493	3.580	0.793	64.95	1.261	15.397	190.16	406.07	215.91	0.964	1.785
–6	4.650	3.715	0.795	62.66	1.258	15.958	191.57	406.57	215.00	0.969	1.784
–5	4.811	3.853	0.797	60.47	1.254	16.536	192.99	407.07	214.09	0.974	1.783
–4	4.976	3.996	0.800	58.38	1.251	17.131	194.40	407.57	213.17	0.980	1.782
–3	5.145	4.143	0.802	56.36	1.247	17.742	195.82	408.06	212.24	0.985	1.780
–2	5.319	4.293	0.804	54.43	1.243	18.371	197.25	408.55	211.30	0.990	1.779
–1	5.497	4.448	0.807	52.58	1.240	19.018	198.67	409.03	210.36	0.995	1.778

Solkane® 407C

Release 1.04

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	4.607	0.809	50.81	1.236	19.683	200.00	409.51	209.51	1.000	1.776
1	5.866	4.771	0.811	49.10	1.232	20.366	201.53	409.99	208.46	1.005	1.775
2	6.058	4.938	0.814	47.46	1.229	21.069	202.97	410.46	207.50	1.010	1.774
3	6.254	5.111	0.816	45.89	1.225	21.792	204.40	410.93	206.53	1.015	1.773
4	6.455	5.288	0.819	44.38	1.221	22.534	205.84	411.40	205.55	1.020	1.772
5	6.661	5.469	0.821	42.92	1.218	23.298	207.29	411.86	204.57	1.025	1.770
6	6.872	5.655	0.824	41.53	1.214	24.082	208.73	412.31	203.58	1.030	1.769
7	7.087	5.846	0.826	40.18	1.210	24.887	210.18	412.76	202.58	1.035	1.768
8	7.308	6.042	0.829	38.89	1.206	25.715	211.63	413.21	201.58	1.041	1.767
9	7.534	6.243	0.832	37.64	1.202	26.566	213.09	413.65	200.57	1.046	1.766
10	7.765	6.449	0.834	36.44	1.199	27.439	214.55	414.09	199.54	1.051	1.764
11	8.001	6.660	0.837	35.29	1.195	28.337	216.01	414.52	198.52	1.056	1.763
12	8.243	6.876	0.840	34.18	1.191	29.258	217.47	414.95	197.48	1.061	1.762
13	8.490	7.097	0.843	33.11	1.187	30.205	218.94	415.37	196.44	1.066	1.761
14	8.742	7.324	0.845	32.07	1.183	31.177	220.41	415.79	195.38	1.071	1.760
15	9.000	7.557	0.848	31.08	1.179	32.175	221.88	416.20	194.32	1.076	1.759
16	9.264	7.794	0.851	30.12	1.175	33.200	223.36	416.61	193.25	1.081	1.758
17	9.533	8.038	0.854	29.19	1.171	34.253	224.84	417.01	192.17	1.086	1.757
18	9.808	8.287	0.857	28.30	1.167	35.334	226.32	417.41	191.09	1.091	1.756
19	10.089	8.542	0.860	27.44	1.163	36.444	227.81	417.80	189.99	1.096	1.754
20	10.376	8.803	0.863	26.61	1.159	37.584	229.30	418.18	188.88	1.101	1.753
21	10.669	9.070	0.866	25.80	1.154	38.754	230.80	418.56	187.76	1.106	1.752
22	10.969	9.343	0.869	25.03	1.150	39.956	232.30	418.93	186.63	1.111	1.751
23	11.274	9.623	0.873	24.28	1.146	41.190	233.80	419.30	185.50	1.116	1.750
24	11.585	9.908	0.876	23.55	1.142	42.457	235.31	419.65	184.35	1.121	1.749
25	11.903	10.200	0.879	22.85	1.137	43.758	236.82	420.01	183.19	1.126	1.748
26	12.228	10.498	0.883	22.18	1.133	45.094	238.34	420.35	182.01	1.131	1.747
27	12.558	10.803	0.886	21.52	1.129	46.466	239.86	420.69	180.83	1.136	1.746
28	12.896	11.115	0.889	20.89	1.124	47.875	241.39	421.02	179.63	1.141	1.745
29	13.240	11.433	0.893	20.27	1.120	49.323	242.92	421.34	178.42	1.146	1.743
30	13.591	11.759	0.897	19.68	1.115	50.809	244.46	421.66	177.20	1.151	1.742
31	13.948	12.091	0.900	19.11	1.111	52.336	246.00	421.97	175.96	1.156	1.741
32	14.313	12.430	0.904	18.55	1.106	53.905	247.55	422.26	174.71	1.161	1.740
33	14.685	12.777	0.908	18.01	1.102	55.517	249.11	422.56	173.45	1.166	1.739
34	15.063	13.131	0.912	17.49	1.097	57.173	250.67	422.84	172.16	1.171	1.738
35	15.449	13.492	0.916	16.99	1.092	58.874	252.24	423.11	170.87	1.176	1.737
36	15.842	13.861	0.920	16.50	1.087	60.623	253.82	423.38	169.55	1.181	1.736
37	16.243	14.237	0.924	16.02	1.083	62.421	255.41	423.63	168.22	1.186	1.734
38	16.651	14.621	0.928	15.56	1.078	64.269	257.00	423.87	166.87	1.191	1.733
39	17.066	15.013	0.932	15.11	1.073	66.170	258.60	424.11	165.50	1.196	1.732
40	17.489	15.413	0.937	14.68	1.068	68.124	260.22	424.33	164.12	1.201	1.731
41	17.920	15.821	0.941	14.26	1.063	70.135	261.84	424.55	162.71	1.207	1.730
42	18.359	16.237	0.946	13.85	1.058	72.203	263.47	424.75	161.28	1.212	1.729
43	18.805	16.662	0.950	13.45	1.052	74.331	265.11	424.94	159.83	1.217	1.727
44	19.260	17.095	0.955	13.07	1.047	76.522	266.76	425.12	158.36	1.222	1.726
45	19.722	17.536	0.960	12.69	1.042	78.778	268.42	425.29	156.86	1.227	1.725
46	20.193	17.987	0.965	12.33	1.037	81.101	270.10	425.44	155.34	1.233	1.723
47	20.672	18.446	0.970	11.98	1.031	83.493	271.79	425.58	153.79	1.238	1.722
48	21.159	18.914	0.975	11.63	1.026	85.959	273.49	425.71	152.22	1.243	1.721
49	21.655	19.391	0.981	11.30	1.020	88.501	275.20	425.82	150.62	1.248	1.720

Solkane® 407C

Release 1.04

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	22.159	19.878	0.986	10.97	1.014	91.123	276.93	425.92	148.99	1.254	1.718
51	22.672	20.374	0.992	10.66	1.008	93.827	278.67	426.00	147.33	1.259	1.717
52	23.194	20.879	0.998	10.35	1.002	96.618	280.43	426.06	145.64	1.264	1.715
53	23.724	21.394	1.004	10.05	0.996	99.500	282.20	426.11	143.91	1.270	1.714
54	24.264	21.919	1.010	9.76	0.990	102.477	283.99	426.14	142.15	1.275	1.712
55	24.812	22.455	1.016	9.47	0.984	105.554	285.80	426.15	140.35	1.281	1.711
56	25.370	23.000	1.023	9.20	0.978	108.736	287.63	426.15	138.52	1.286	1.709
57	25.937	23.556	1.029	8.93	0.971	112.029	289.47	426.12	136.65	1.292	1.708
58	26.513	24.122	1.036	8.66	0.965	115.438	291.34	426.07	134.73	1.297	1.706
59	27.098	24.699	1.044	8.41	0.958	118.971	293.22	425.99	132.77	1.303	1.704
60	27.693	25.287	1.051	8.15	0.951	122.635	295.13	425.90	130.77	1.308	1.702
61	28.298	25.886	1.059	7.91	0.944	126.438	297.06	425.77	128.72	1.314	1.701
62	28.912	26.497	1.067	7.67	0.937	130.388	299.01	425.62	126.61	1.319	1.699
63	29.537	27.119	1.076	7.44	0.930	134.496	300.98	425.44	124.46	1.325	1.697
64	30.171	27.753	1.084	7.21	0.922	138.772	302.98	425.23	122.25	1.331	1.695
65	30.815	28.399	1.094	6.98	0.914	143.229	305.01	424.99	119.98	1.337	1.693
66	31.469	29.058	1.103	6.76	0.906	147.880	307.06	424.71	117.65	1.342	1.691
67	32.134	29.729	1.113	6.55	0.898	152.740	309.15	424.40	115.25	1.348	1.688
68	32.809	30.414	1.124	6.34	0.890	157.827	311.26	424.04	112.78	1.354	1.686
69	33.494	31.111	1.135	6.13	0.881	163.161	313.40	423.64	110.24	1.360	1.684
70	34.189	31.823	1.147	5.93	0.872	168.765	315.57	423.19	107.62	1.366	1.681
71	34.896	32.548	1.159	5.73	0.862	174.666	317.77	422.69	104.91	1.372	1.678
72	35.613	33.289	1.173	5.53	0.853	180.894	320.01	422.13	102.12	1.378	1.676
73	36.340	34.044	1.187	5.33	0.842	187.487	322.28	421.50	99.22	1.384	1.673
74	37.079	34.815	1.202	5.14	0.832	194.488	324.59	420.81	96.21	1.390	1.669
75	37.828	35.602	1.219	4.95	0.820	201.951	326.94	420.03	93.09	1.397	1.666
76	38.588	36.405	1.237	4.76	0.809	209.940	329.32	419.16	89.84	1.403	1.662
77	39.359	37.227	1.257	4.58	0.796	218.536	331.75	418.19	86.44	1.409	1.658
78	40.141	38.067	1.278	4.39	0.782	227.843	334.21	417.09	82.88	1.416	1.654
79	40.935	38.927	1.303	4.20	0.768	237.994	336.72	415.85	79.14	1.422	1.650
80	41.739	39.808	1.330	4.01	0.752	249.166	339.27	414.44	75.17	1.429	1.645
81	42.554	40.711	1.362	3.82	0.734	261.605	341.87	412.82	70.96	1.435	1.639
82	43.380	41.640	1.400	3.63	0.714	275.663	344.51	410.94	66.43	1.442	1.633

12.1.8 Solkane® 410

Release 1.05

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]
–70	0.357	0.356	0.711	640.63	1.407	1.561	101.06	389.26	288.20	0.586	2.004
–69	0.380	0.378	0.712	604.64	1.404	1.654	102.44	389.83	287.39	0.592	2.000
–68	0.404	0.402	0.714	571.04	1.401	1.751	103.82	390.40	286.59	0.599	1.996
–67	0.429	0.427	0.715	539.65	1.398	1.853	105.19	390.97	285.78	0.605	1.992
–66	0.456	0.453	0.717	510.30	1.395	1.960	106.56	391.54	284.98	0.612	1.988
–65	0.483	0.481	0.718	482.84	1.392	2.071	107.93	392.10	284.17	0.618	1.984
–64	0.512	0.510	0.720	457.12	1.389	2.188	109.29	392.66	283.37	0.624	1.980
–63	0.543	0.540	0.722	433.03	1.386	2.309	110.66	393.22	282.56	0.631	1.976
–62	0.575	0.572	0.723	410.45	1.383	2.436	112.02	393.78	281.76	0.637	1.973
–61	0.608	0.605	0.725	389.26	1.380	2.569	113.38	394.33	280.95	0.644	1.969
–60	0.643	0.640	0.726	369.37	1.377	2.707	114.74	394.88	280.14	0.650	1.965
–59	0.680	0.677	0.728	350.68	1.373	2.852	116.10	395.43	279.33	0.656	1.962
–58	0.718	0.715	0.730	333.12	1.370	3.002	117.46	395.98	278.52	0.663	1.958
–57	0.758	0.755	0.731	316.61	1.367	3.158	118.82	396.52	277.70	0.669	1.955
–56	0.799	0.796	0.733	301.07	1.364	3.321	120.18	397.06	276.88	0.675	1.951
–55	0.843	0.839	0.735	286.44	1.361	3.491	121.54	397.60	276.06	0.681	1.948
–54	0.888	0.885	0.736	272.66	1.358	3.668	122.90	398.13	275.24	0.688	1.945
–53	0.936	0.932	0.738	259.66	1.355	3.851	124.26	398.67	274.41	0.694	1.941
–52	0.985	0.981	0.740	247.41	1.352	4.042	125.62	399.20	273.58	0.700	1.938
–51	1.036	1.032	0.742	235.84	1.348	4.240	126.98	399.72	272.74	0.706	1.935
–50	1.090	1.086	0.743	224.92	1.345	4.446	128.35	400.25	271.90	0.712	1.932
–49	1.145	1.141	0.745	214.61	1.342	4.660	129.71	400.77	271.05	0.719	1.929
–48	1.203	1.199	0.747	204.86	1.339	4.881	131.08	401.28	270.20	0.725	1.926
–47	1.263	1.259	0.749	195.63	1.336	5.112	132.45	401.80	269.35	0.731	1.923
–46	1.326	1.321	0.751	186.91	1.332	5.350	133.82	402.31	268.49	0.737	1.920
–45	1.391	1.386	0.752	178.65	1.329	5.598	135.19	402.82	267.62	0.743	1.917
–44	1.458	1.453	0.754	170.82	1.326	5.854	136.57	403.32	266.75	0.749	1.914
–43	1.528	1.523	0.756	163.41	1.323	6.120	137.95	403.82	265.88	0.755	1.911
–42	1.601	1.595	0.758	156.38	1.319	6.395	139.33	404.32	264.99	0.761	1.908
–41	1.676	1.670	0.760	149.71	1.316	6.679	140.71	404.81	264.10	0.767	1.905
–40	1.754	1.748	0.762	143.39	1.313	6.974	142.09	405.30	263.21	0.773	1.902
–39	1.835	1.829	0.764	137.38	1.310	7.279	143.48	405.79	262.31	0.779	1.899
–38	1.919	1.912	0.766	131.67	1.306	7.595	144.87	406.27	261.40	0.785	1.897
–37	2.006	1.999	0.767	126.25	1.303	7.921	146.26	406.75	260.48	0.791	1.894
–36	2.096	2.088	0.769	121.09	1.300	8.258	147.66	407.22	259.56	0.797	1.891
–35	2.188	2.181	0.771	116.19	1.296	8.607	149.06	407.69	258.63	0.803	1.889
–34	2.285	2.276	0.773	111.53	1.293	8.967	150.46	408.16	257.70	0.809	1.886
–33	2.384	2.375	0.775	107.08	1.290	9.338	151.87	408.63	256.76	0.815	1.884
–32	2.487	2.478	0.777	102.85	1.286	9.723	153.28	409.08	255.81	0.820	1.881
–31	2.593	2.584	0.779	98.82	1.283	10.119	154.69	409.54	254.85	0.826	1.878
–30	2.702	2.693	0.782	94.98	1.280	10.528	156.10	409.99	253.89	0.832	1.876
–29	2.815	2.805	0.784	91.32	1.276	10.951	157.52	410.44	252.92	0.838	1.873
–28	2.932	2.922	0.786	87.83	1.273	11.386	158.94	410.88	251.94	0.844	1.871
–27	3.052	3.042	0.788	84.49	1.269	11.836	160.36	411.32	250.95	0.849	1.869
–26	3.177	3.166	0.790	81.31	1.266	12.299	161.79	411.75	249.96	0.855	1.866
–25	3.305	3.293	0.792	78.27	1.262	12.777	163.22	412.18	248.96	0.861	1.864
–24	3.437	3.425	0.794	75.36	1.259	13.269	164.65	412.60	247.95	0.867	1.861
–23	3.573	3.561	0.797	72.59	1.255	13.777	166.09	413.02	246.93	0.872	1.859
–22	3.713	3.700	0.799	69.93	1.252	14.300	167.53	413.44	245.91	0.878	1.857
–21	3.857	3.844	0.801	67.39	1.248	14.838	168.97	413.85	244.88	0.884	1.855

Solkane® 410

Release 1.05

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]
–20	4.006	3.992	0.803	64.96	1.245	15.393	170.42	414.26	243.84	0.889	1.852
–19	4.159	4.145	0.806	62.64	1.241	15.964	171.87	414.66	242.79	0.895	1.850
–18	4.317	4.302	0.808	60.41	1.238	16.553	173.32	415.05	241.73	0.901	1.848
–17	4.478	4.463	0.810	58.28	1.234	17.158	174.78	415.44	240.66	0.906	1.846
–16	4.645	4.629	0.813	56.24	1.230	17.782	176.24	415.83	239.59	0.912	1.843
–15	4.816	4.800	0.815	54.28	1.227	18.423	177.70	416.21	238.51	0.917	1.841
–14	4.992	4.975	0.818	52.40	1.223	19.084	179.17	416.58	237.41	0.923	1.839
–13	5.173	5.156	0.820	50.60	1.219	19.763	180.64	416.95	236.31	0.929	1.837
–12	5.359	5.341	0.823	48.87	1.216	20.461	182.11	417.32	235.20	0.934	1.835
–11	5.550	5.531	0.825	47.21	1.212	21.180	183.59	417.68	234.09	0.940	1.833
–10	5.746	5.727	0.828	45.62	1.208	21.919	185.07	418.03	232.96	0.945	1.830
–9	5.947	5.927	0.830	44.09	1.204	22.680	186.56	418.38	231.82	0.951	1.828
–8	6.154	6.133	0.833	42.62	1.201	23.461	188.04	418.72	230.68	0.956	1.826
–7	6.366	6.344	0.835	41.21	1.197	24.265	189.53	419.05	229.52	0.962	1.824
–6	6.583	6.561	0.838	39.85	1.193	25.091	191.03	419.38	228.36	0.967	1.822
–5	6.806	6.783	0.841	38.55	1.189	25.940	192.53	419.71	227.18	0.973	1.820
–4	7.035	7.011	0.844	37.29	1.185	26.813	194.03	420.03	225.99	0.978	1.818
–3	7.269	7.245	0.846	36.09	1.181	27.711	195.54	420.34	224.80	0.984	1.816
–2	7.509	7.484	0.849	34.92	1.178	28.633	197.05	420.64	223.59	0.989	1.814
–1	7.756	7.730	0.852	33.81	1.174	29.581	198.56	420.94	222.38	0.995	1.812
0	8.008	7.981	0.855	32.73	1.170	30.554	200.00	421.23	221.23	1.000	1.810
1	8.266	8.239	0.858	31.69	1.166	31.555	201.60	421.51	219.91	1.005	1.808
2	8.531	8.503	0.861	30.69	1.162	32.583	203.13	421.79	218.66	1.011	1.806
3	8.802	8.773	0.864	29.73	1.158	33.640	204.66	422.06	217.40	1.016	1.804
4	9.079	9.049	0.867	28.80	1.153	34.726	206.20	422.32	216.13	1.022	1.802
5	9.363	9.332	0.870	27.90	1.149	35.841	207.74	422.58	214.84	1.027	1.800
6	9.654	9.622	0.873	27.04	1.145	36.987	209.28	422.83	213.55	1.033	1.798
7	9.951	9.918	0.876	26.20	1.141	38.164	210.83	423.07	212.24	1.038	1.796
8	10.255	10.222	0.880	25.40	1.137	39.374	212.38	423.30	210.91	1.043	1.794
9	10.566	10.532	0.883	24.62	1.133	40.617	213.94	423.52	209.58	1.049	1.792
10	10.884	10.849	0.886	23.87	1.128	41.894	215.51	423.74	208.23	1.054	1.790
11	11.210	11.173	0.890	23.14	1.124	43.207	217.08	423.94	206.86	1.060	1.788
12	11.542	11.505	0.893	22.44	1.120	44.555	218.66	424.14	205.49	1.065	1.786
13	11.882	11.843	0.897	21.77	1.115	45.941	220.24	424.33	204.09	1.071	1.784
14	12.229	12.190	0.900	21.11	1.111	47.365	221.83	424.51	202.68	1.076	1.782
15	12.584	12.544	0.904	20.48	1.106	48.828	223.42	424.68	201.26	1.081	1.781
16	12.947	12.905	0.908	19.87	1.102	50.332	225.02	424.84	199.82	1.087	1.779
17	13.317	13.274	0.911	19.28	1.097	51.878	226.63	424.99	198.36	1.092	1.777
18	13.696	13.651	0.915	18.70	1.093	53.468	228.25	425.13	196.89	1.098	1.775
19	14.082	14.037	0.919	18.15	1.088	55.101	229.87	425.26	195.39	1.103	1.773
20	14.476	14.430	0.923	17.61	1.083	56.782	231.50	425.38	193.88	1.109	1.771
21	14.879	14.831	0.927	17.09	1.079	58.509	233.14	425.49	192.35	1.114	1.769
22	15.290	15.241	0.931	16.59	1.074	60.286	234.78	425.58	190.80	1.120	1.767
23	15.709	15.659	0.935	16.10	1.069	62.114	236.44	425.67	189.23	1.125	1.765
24	16.137	16.086	0.940	15.63	1.064	63.994	238.10	425.74	187.64	1.131	1.763
25	16.574	16.522	0.944	15.17	1.059	65.929	239.77	425.80	186.03	1.136	1.760
26	17.020	16.966	0.949	14.72	1.054	67.920	241.46	425.85	184.39	1.142	1.758
27	17.474	17.420	0.953	14.29	1.049	69.970	243.15	425.88	182.73	1.147	1.756
28	17.938	17.882	0.958	13.87	1.044	72.081	244.85	425.90	181.05	1.153	1.754
29	18.410	18.354	0.963	13.47	1.039	74.255	246.57	425.90	179.34	1.159	1.752

Solkane® 410

Release 1.05

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]
30	18.892	18.834	0.968	13.07	1.034	76.494	248.29	425.89	177.60	1.164	1.750
31	19.384	19.325	0.973	12.69	1.028	78.802	250.03	425.87	175.84	1.170	1.748
32	19.885	19.825	0.978	12.32	1.023	81.181	251.78	425.83	174.05	1.175	1.746
33	20.396	20.334	0.983	11.96	1.017	83.633	253.54	425.77	172.23	1.181	1.743
34	20.917	20.854	0.988	11.61	1.012	86.163	255.32	425.69	170.38	1.187	1.741
35	21.447	21.383	0.994	11.26	1.006	88.774	257.11	425.60	168.49	1.192	1.739
36	21.988	21.923	1.000	10.93	1.000	91.468	258.91	425.49	166.58	1.198	1.737
37	22.539	22.473	1.006	10.61	0.994	94.251	260.73	425.35	164.63	1.204	1.734
38	23.101	23.033	1.012	10.30	0.988	97.126	262.56	425.20	162.64	1.210	1.732
39	23.673	23.604	1.018	9.99	0.982	100.098	264.41	425.03	160.62	1.215	1.729
40	24.255	24.186	1.024	9.69	0.976	103.171	266.28	424.83	158.55	1.221	1.727
41	24.849	24.779	1.031	9.40	0.970	106.352	268.17	424.61	156.45	1.227	1.724
42	25.454	25.382	1.038	9.12	0.964	109.645	270.07	424.37	154.30	1.233	1.722
43	26.069	25.997	1.045	8.85	0.957	113.057	271.99	424.10	152.11	1.239	1.719
44	26.697	26.623	1.052	8.58	0.950	116.595	273.93	423.81	149.87	1.245	1.717
45	27.335	27.261	1.060	8.31	0.944	120.266	275.89	423.48	147.59	1.251	1.714
46	27.985	27.910	1.068	8.06	0.937	124.079	277.88	423.13	145.25	1.257	1.711
47	28.647	28.572	1.076	7.81	0.930	128.042	279.88	422.74	142.86	1.263	1.708
48	29.321	29.245	1.084	7.57	0.922	132.165	281.91	422.32	140.41	1.269	1.705
49	30.008	29.931	1.093	7.33	0.915	136.460	283.96	421.86	137.90	1.275	1.702
50	30.706	30.629	1.102	7.10	0.907	140.938	286.03	421.36	135.33	1.281	1.699
51	31.418	31.340	1.112	6.87	0.899	145.614	288.14	420.83	132.69	1.288	1.696
52	32.142	32.064	1.122	6.64	0.891	150.503	290.26	420.25	129.98	1.294	1.693
53	32.879	32.800	1.133	6.43	0.883	155.622	292.42	419.62	127.20	1.300	1.689
54	33.629	33.550	1.144	6.21	0.874	160.993	294.60	418.94	124.34	1.306	1.686
55	34.392	34.314	1.156	6.00	0.865	166.637	296.81	418.20	121.39	1.313	1.682
56	35.169	35.092	1.169	5.79	0.856	172.581	299.05	417.41	118.36	1.319	1.678
57	35.960	35.883	1.182	5.59	0.846	178.855	301.32	416.55	115.22	1.326	1.674
58	36.766	36.689	1.197	5.39	0.836	185.497	303.63	415.61	111.98	1.332	1.670
59	37.585	37.509	1.212	5.19	0.825	192.549	305.97	414.60	108.63	1.339	1.666
60	38.419	38.345	1.229	5.00	0.814	200.062	308.34	413.49	105.15	1.345	1.661
61	39.268	39.195	1.247	4.81	0.802	208.097	310.75	412.29	101.54	1.352	1.656
62	40.133	40.061	1.267	4.61	0.789	216.731	313.19	410.97	97.78	1.359	1.651
63	41.013	40.944	1.289	4.42	0.776	226.059	315.67	409.52	93.84	1.366	1.646
64	41.909	41.842	1.313	4.23	0.762	236.197	318.20	407.92	89.72	1.372	1.640
65	42.822	42.758	1.341	4.04	0.746	247.296	320.76	406.15	85.39	1.379	1.633
66	43.751	43.691	1.373	3.85	0.728	259.549	323.36	404.17	80.81	1.386	1.627

12.1.9 Solkane® 507

Release 1.05

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]
–70	0.284	0.284	0.721	589.52	1.387	1.696	110.46	322.09	211.63	0.626	1.666
–69	0.302	0.302	0.723	556.50	1.384	1.797	111.72	322.70	210.98	0.632	1.664
–68	0.321	0.321	0.724	525.68	1.381	1.902	112.98	323.31	210.34	0.637	1.662
–67	0.341	0.341	0.726	496.88	1.378	2.013	114.23	323.92	209.69	0.643	1.660
–66	0.362	0.362	0.727	469.95	1.375	2.128	115.47	324.53	209.06	0.649	1.658
–65	0.384	0.384	0.729	444.76	1.372	2.248	116.71	325.14	208.43	0.654	1.656
–64	0.407	0.407	0.730	421.18	1.369	2.374	117.95	325.75	207.80	0.660	1.654
–63	0.431	0.431	0.732	399.08	1.366	2.506	119.18	326.36	207.18	0.666	1.652
–62	0.457	0.457	0.733	378.36	1.363	2.643	120.41	326.97	206.55	0.672	1.650
–61	0.483	0.483	0.735	358.93	1.360	2.786	121.64	327.57	205.93	0.677	1.649
–60	0.511	0.511	0.737	340.69	1.357	2.935	122.86	328.18	205.32	0.683	1.647
–59	0.540	0.540	0.738	323.55	1.354	3.091	124.09	328.79	204.70	0.689	1.645
–58	0.570	0.570	0.740	307.44	1.351	3.253	125.31	329.39	204.08	0.694	1.644
–57	0.602	0.602	0.742	292.29	1.348	3.421	126.53	330.00	203.47	0.700	1.642
–56	0.635	0.635	0.743	278.04	1.345	3.597	127.75	330.60	202.85	0.705	1.640
–55	0.669	0.669	0.745	264.61	1.342	3.779	128.97	331.21	202.23	0.711	1.639
–54	0.705	0.705	0.747	251.97	1.339	3.969	130.19	331.81	201.62	0.717	1.637
–53	0.742	0.742	0.748	240.05	1.336	4.166	131.41	332.41	201.00	0.722	1.636
–52	0.781	0.781	0.750	228.80	1.333	4.371	132.63	333.01	200.38	0.728	1.635
–51	0.822	0.822	0.752	218.18	1.330	4.583	133.86	333.61	199.76	0.733	1.633
–50	0.864	0.864	0.753	208.16	1.327	4.804	135.08	334.21	199.13	0.739	1.632
–49	0.908	0.908	0.755	198.69	1.324	5.033	136.31	334.81	198.50	0.744	1.631
–48	0.953	0.953	0.757	189.73	1.321	5.271	137.53	335.41	197.87	0.750	1.629
–47	1.001	1.001	0.759	181.26	1.318	5.517	138.76	336.00	197.24	0.756	1.628
–46	1.050	1.050	0.761	173.25	1.315	5.772	139.99	336.60	196.61	0.761	1.627
–45	1.101	1.101	0.762	165.66	1.312	6.037	141.22	337.19	195.97	0.767	1.626
–44	1.154	1.154	0.764	158.47	1.309	6.310	142.46	337.78	195.32	0.772	1.624
–43	1.209	1.209	0.766	151.65	1.305	6.594	143.70	338.38	194.68	0.777	1.623
–42	1.266	1.266	0.768	145.19	1.302	6.888	144.94	338.97	194.03	0.783	1.622
–41	1.325	1.325	0.770	139.06	1.299	7.191	146.18	339.56	193.37	0.788	1.621
–40	1.386	1.386	0.772	133.24	1.296	7.505	147.43	340.14	192.71	0.794	1.620
–39	1.450	1.450	0.774	127.71	1.293	7.830	148.68	340.73	192.05	0.799	1.619
–38	1.516	1.515	0.775	122.46	1.289	8.166	149.93	341.31	191.38	0.805	1.618
–37	1.584	1.583	0.777	117.47	1.286	8.513	151.19	341.90	190.71	0.810	1.617
–36	1.654	1.654	0.779	112.72	1.283	8.871	152.45	342.48	190.03	0.815	1.616
–35	1.727	1.727	0.781	108.21	1.280	9.241	153.71	343.06	189.35	0.821	1.615
–34	1.802	1.802	0.783	103.91	1.277	9.624	154.97	343.63	188.66	0.826	1.614
–33	1.880	1.879	0.785	99.82	1.273	10.018	156.24	344.21	187.97	0.831	1.613
–32	1.960	1.960	0.787	95.92	1.270	10.426	157.52	344.79	187.27	0.837	1.612
–31	2.043	2.043	0.789	92.20	1.267	10.846	158.79	345.36	186.56	0.842	1.612
–30	2.129	2.128	0.792	88.66	1.263	11.279	160.07	345.93	185.86	0.847	1.611
–29	2.217	2.216	0.794	85.28	1.260	11.726	161.36	346.50	185.14	0.853	1.610
–28	2.308	2.307	0.796	82.06	1.257	12.187	162.65	347.07	184.42	0.858	1.609
–27	2.402	2.401	0.798	78.98	1.253	12.662	163.94	347.63	183.69	0.863	1.608
–26	2.499	2.498	0.800	76.04	1.250	13.151	165.23	348.19	182.96	0.868	1.608
–25	2.599	2.598	0.802	73.23	1.247	13.656	166.53	348.76	182.23	0.873	1.607
–24	2.702	2.701	0.804	70.54	1.243	14.175	167.83	349.31	181.48	0.879	1.606
–23	2.808	2.807	0.807	67.98	1.240	14.711	169.14	349.87	180.73	0.884	1.605
–22	2.917	2.916	0.809	65.52	1.236	15.262	170.45	350.43	179.98	0.889	1.605
–21	3.029	3.028	0.811	63.18	1.233	15.829	171.76	350.98	179.22	0.894	1.604

Solkane® 507

Release 1.05

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]
–20	3.145	3.144	0.813	60.93	1.230	16.413	173.08	351.53	178.45	0.899	1.603
–19	3.264	3.263	0.816	58.78	1.226	17.014	174.40	352.07	177.68	0.904	1.603
–18	3.386	3.385	0.818	56.71	1.223	17.632	175.72	352.62	176.90	0.910	1.602
–17	3.512	3.511	0.820	54.74	1.219	18.269	177.05	353.16	176.12	0.915	1.602
–16	3.642	3.640	0.823	52.84	1.216	18.923	178.38	353.70	175.32	0.920	1.601
–15	3.775	3.773	0.825	51.03	1.212	19.597	179.71	354.24	174.53	0.925	1.600
–14	3.911	3.909	0.828	49.29	1.208	20.289	181.05	354.77	173.72	0.930	1.600
–13	4.051	4.049	0.830	47.62	1.205	21.001	182.39	355.30	172.92	0.935	1.599
–12	4.196	4.193	0.833	46.01	1.201	21.733	183.73	355.83	172.10	0.940	1.599
–11	4.344	4.341	0.835	44.47	1.198	22.486	185.08	356.36	171.28	0.945	1.598
–10	4.495	4.493	0.838	42.99	1.194	23.260	186.43	356.88	170.45	0.950	1.598
–9	4.651	4.649	0.840	41.57	1.190	24.055	187.78	357.40	169.61	0.955	1.597
–8	4.811	4.808	0.843	40.21	1.187	24.872	189.14	357.92	168.77	0.960	1.596
–7	4.975	4.972	0.845	38.89	1.183	25.711	190.50	358.43	167.93	0.965	1.596
–6	5.143	5.140	0.848	37.63	1.179	26.574	191.87	358.94	167.07	0.970	1.595
–5	5.316	5.313	0.851	36.42	1.175	27.461	193.23	359.44	166.21	0.975	1.595
–4	5.493	5.489	0.854	35.25	1.172	28.371	194.60	359.95	165.34	0.980	1.595
–3	5.674	5.670	0.856	34.12	1.168	29.307	195.98	360.45	164.47	0.985	1.594
–2	5.859	5.855	0.859	33.04	1.164	30.268	197.35	360.94	163.59	0.990	1.594
–1	6.049	6.045	0.862	32.00	1.160	31.255	198.73	361.43	162.70	0.995	1.593
0	6.244	6.240	0.865	30.99	1.156	32.269	200.00	361.92	161.92	1.000	1.593
1	6.444	6.439	0.868	30.02	1.152	33.310	201.50	362.40	160.90	1.005	1.592
2	6.648	6.643	0.871	29.09	1.148	34.379	202.89	362.88	159.99	1.010	1.592
3	6.857	6.852	0.874	28.19	1.144	35.478	204.29	363.36	159.07	1.015	1.591
4	7.070	7.065	0.877	27.32	1.140	36.606	205.69	363.83	158.14	1.020	1.591
5	7.289	7.284	0.880	26.48	1.136	37.764	207.09	364.29	157.21	1.025	1.590
6	7.513	7.507	0.883	25.67	1.132	38.953	208.49	364.75	156.26	1.030	1.590
7	7.742	7.736	0.886	24.89	1.128	40.175	209.90	365.21	155.31	1.035	1.590
8	7.976	7.970	0.890	24.14	1.124	41.430	211.31	365.66	154.35	1.039	1.589
9	8.216	8.209	0.893	23.41	1.120	42.718	212.73	366.11	153.38	1.044	1.589
10	8.460	8.454	0.896	22.71	1.116	44.042	214.15	366.55	152.40	1.049	1.588
11	8.710	8.703	0.900	22.03	1.111	45.401	215.57	366.99	151.41	1.054	1.588
12	8.966	8.959	0.903	21.37	1.107	46.797	217.00	367.42	150.42	1.059	1.587
13	9.227	9.220	0.907	20.73	1.103	48.230	218.43	367.84	149.41	1.064	1.587
14	9.494	9.486	0.910	20.12	1.098	49.703	219.87	368.26	148.39	1.069	1.586
15	9.767	9.759	0.914	19.52	1.094	51.217	221.31	368.67	147.36	1.074	1.586
16	10.045	10.037	0.918	18.95	1.090	52.771	222.76	369.08	146.32	1.079	1.586
17	10.329	10.321	0.922	18.39	1.085	54.368	224.21	369.48	145.27	1.084	1.585
18	10.620	10.611	0.925	17.85	1.081	56.010	225.67	369.87	144.20	1.089	1.585
19	10.916	10.907	0.929	17.33	1.076	57.697	227.14	370.26	143.12	1.094	1.584
20	11.218	11.209	0.933	16.83	1.071	59.431	228.61	370.64	142.03	1.099	1.584
21	11.527	11.517	0.937	16.34	1.067	61.213	230.08	371.01	140.93	1.104	1.583
22	11.842	11.832	0.942	15.86	1.062	63.045	231.56	371.37	139.81	1.109	1.583
23	12.163	12.153	0.946	15.40	1.057	64.930	233.05	371.73	138.68	1.113	1.582
24	12.491	12.480	0.950	14.95	1.053	66.868	234.55	372.08	137.53	1.118	1.582
25	12.826	12.815	0.955	14.52	1.048	68.861	236.05	372.42	136.36	1.123	1.581
26	13.167	13.155	0.959	14.10	1.043	70.913	237.57	372.75	135.18	1.128	1.581
27	13.515	13.503	0.964	13.69	1.038	73.024	239.09	373.07	133.98	1.134	1.580
28	13.869	13.857	0.968	13.30	1.033	75.197	240.61	373.38	132.76	1.139	1.580
29	14.231	14.219	0.973	12.91	1.028	77.434	242.15	373.68	131.53	1.144	1.579

Solkane® 507

Release 1.05

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]
30	14.600	14.587	0.978	12.54	1.022	79.738	243.70	373.97	130.27	1.149	1.579
31	14.976	14.963	0.983	12.18	1.017	82.112	245.26	374.25	129.00	1.154	1.578
32	15.359	15.345	0.988	11.83	1.012	84.558	246.82	374.52	127.70	1.159	1.577
33	15.749	15.735	0.994	11.48	1.006	87.080	248.40	374.78	126.38	1.164	1.577
34	16.147	16.133	0.999	11.15	1.001	89.681	249.99	375.02	125.03	1.169	1.576
35	16.552	16.538	1.005	10.83	0.995	92.364	251.59	375.26	123.66	1.174	1.575
36	16.965	16.951	1.010	10.51	0.990	95.133	253.21	375.47	122.27	1.179	1.575
37	17.386	17.371	1.016	10.20	0.984	97.992	254.83	375.68	120.85	1.185	1.574
38	17.815	17.799	1.022	9.91	0.978	100.946	256.47	375.87	119.40	1.190	1.573
39	18.251	18.235	1.029	9.62	0.972	103.999	258.13	376.05	117.92	1.195	1.572
40	18.696	18.680	1.035	9.33	0.966	107.156	259.80	376.21	116.41	1.200	1.571
41	19.148	19.132	1.042	9.06	0.960	110.422	261.48	376.35	114.86	1.206	1.571
42	19.610	19.593	1.049	8.79	0.954	113.804	263.19	376.47	113.28	1.211	1.570
43	20.079	20.062	1.056	8.52	0.947	117.308	264.91	376.58	111.67	1.216	1.569
44	20.557	20.540	1.063	8.27	0.941	120.941	266.64	376.66	110.02	1.222	1.568
45	21.044	21.026	1.071	8.02	0.934	124.711	268.40	376.73	108.33	1.227	1.567
46	21.540	21.522	1.078	7.77	0.927	128.626	270.18	376.77	106.60	1.233	1.566
47	22.044	22.026	1.087	7.54	0.920	132.695	271.97	376.79	104.82	1.238	1.564
48	22.558	22.539	1.095	7.30	0.913	136.928	273.79	376.79	103.00	1.244	1.563
49	23.080	23.062	1.104	7.08	0.906	141.338	275.63	376.75	101.12	1.249	1.562
50	23.612	23.594	1.113	6.85	0.898	145.936	277.49	376.69	99.20	1.255	1.561
51	24.154	24.135	1.123	6.63	0.890	150.737	279.38	376.60	97.22	1.260	1.559
52	24.705	24.686	1.133	6.42	0.882	155.756	281.29	376.48	95.19	1.266	1.558
53	25.267	25.247	1.144	6.21	0.874	161.011	283.23	376.32	93.09	1.272	1.556
54	25.838	25.818	1.155	6.01	0.866	166.522	285.19	376.13	90.93	1.278	1.554
55	26.419	26.400	1.167	5.80	0.857	172.313	287.19	375.89	88.70	1.283	1.553
56	27.011	26.991	1.180	5.61	0.847	178.408	289.21	375.61	86.40	1.289	1.551
57	27.613	27.594	1.194	5.41	0.838	184.838	291.26	375.28	84.02	1.295	1.549
58	28.227	28.207	1.208	5.22	0.828	191.638	293.35	374.90	81.55	1.301	1.547
59	28.851	28.831	1.223	5.03	0.817	198.847	295.47	374.47	79.00	1.307	1.544
60	29.487	29.467	1.240	4.84	0.806	206.512	297.62	373.97	76.35	1.313	1.542
61	30.134	30.114	1.259	4.66	0.795	214.687	299.81	373.40	73.59	1.319	1.539
62	30.793	30.774	1.279	4.48	0.782	223.438	302.03	372.75	70.72	1.325	1.537
63	31.464	31.446	1.301	4.29	0.769	232.839	304.30	372.03	67.73	1.332	1.533
64	32.149	32.131	1.326	4.12	0.754	242.978	306.60	371.21	64.61	1.338	1.530
65	32.846	32.829	1.354	3.94	0.738	253.957	308.94	370.29	61.34	1.344	1.527
66	33.557	33.541	1.387	3.76	0.721	265.890	311.33	369.26	57.93	1.351	1.523
67	34.283	34.268	1.427	3.59	0.701	278.903	313.76	368.12	54.36	1.357	1.519

12.2.1 Solkane® 32

Release 1.02

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	0.187	0.776	1628.47	1.288	0.61	66.52	480.78	414.26	0.4469	2.5680
−79	0.201	0.778	1526.48	1.286	0.66	68.53	481.40	412.87	0.4544	2.5602
−78	0.215	0.779	1431.96	1.283	0.70	70.50	482.01	411.51	0.4618	2.5526
−77	0.230	0.781	1344.30	1.280	0.74	72.44	482.62	410.18	0.4693	2.5451
−76	0.246	0.783	1262.93	1.278	0.79	74.35	483.23	408.88	0.4768	2.5376
−75	0.263	0.784	1187.34	1.275	0.84	76.22	483.83	407.61	0.4843	2.5303
−74	0.280	0.786	1117.07	1.273	0.90	78.07	484.43	406.37	0.4917	2.5231
−73	0.299	0.787	1051.69	1.270	0.95	79.88	485.03	405.15	0.4992	2.5159
−72	0.319	0.789	990.80	1.268	1.01	81.68	485.63	403.95	0.5067	2.5089
−71	0.339	0.791	934.07	1.265	1.07	83.44	486.22	402.78	0.5141	2.5019
−70	0.361	0.792	881.17	1.262	1.13	85.19	486.81	401.62	0.5215	2.4950
−69	0.384	0.794	831.80	1.260	1.20	86.92	487.39	400.48	0.5290	2.4882
−68	0.408	0.796	785.70	1.257	1.27	88.62	487.98	399.35	0.5364	2.4815
−67	0.434	0.797	742.61	1.254	1.35	90.31	488.55	398.24	0.5438	2.4749
−66	0.460	0.799	702.32	1.252	1.42	91.98	489.13	397.15	0.5512	2.4684
−65	0.488	0.801	664.62	1.249	1.50	93.64	489.70	396.06	0.5586	2.4619
−64	0.518	0.802	629.31	1.246	1.59	95.28	490.27	394.98	0.5659	2.4556
−63	0.549	0.804	596.21	1.244	1.68	96.92	490.83	393.92	0.5733	2.4493
−62	0.581	0.806	565.19	1.241	1.77	98.53	491.39	392.86	0.5806	2.4430
−61	0.615	0.807	536.08	1.238	1.87	100.14	491.95	391.80	0.5880	2.4369
−60	0.650	0.809	508.75	1.236	1.97	101.74	492.50	390.75	0.5953	2.4308
−59	0.687	0.811	483.07	1.233	2.07	103.34	493.04	389.71	0.6026	2.4248
−58	0.725	0.813	458.94	1.230	2.18	104.92	493.59	388.67	0.6098	2.4188
−57	0.766	0.815	436.24	1.228	2.29	106.50	494.13	387.63	0.6171	2.4130
−56	0.808	0.816	414.87	1.225	2.41	108.07	494.66	386.59	0.6244	2.4072
−55	0.852	0.818	394.75	1.222	2.53	109.64	495.19	385.55	0.6316	2.4014
−54	0.898	0.820	375.80	1.219	2.66	111.21	495.72	384.51	0.6388	2.3958
−53	0.946	0.822	357.93	1.217	2.79	112.77	496.24	383.47	0.6460	2.3901
−52	0.995	0.824	341.07	1.214	2.93	114.33	496.75	382.43	0.6532	2.3846
−51	1.047	0.826	325.15	1.211	3.08	115.89	497.27	381.38	0.6604	2.3791
−50	1.101	0.828	310.13	1.208	3.22	117.44	497.77	380.33	0.6675	2.3737
−49	1.158	0.829	295.93	1.206	3.38	119.00	498.27	379.27	0.6746	2.3683
−48	1.216	0.831	282.51	1.203	3.54	120.56	498.77	378.21	0.6817	2.3630
−47	1.277	0.833	269.82	1.200	3.71	122.12	499.26	377.15	0.6888	2.3577
−46	1.340	0.835	257.81	1.197	3.88	123.68	499.75	376.07	0.6959	2.3525
−45	1.406	0.837	246.43	1.194	4.06	125.24	500.23	374.99	0.7029	2.3473
−44	1.474	0.839	235.66	1.192	4.24	126.80	500.71	373.91	0.7100	2.3422
−43	1.545	0.841	225.45	1.189	4.44	128.37	501.18	372.81	0.7170	2.3372
−42	1.619	0.843	215.77	1.186	4.63	129.94	501.64	371.71	0.7240	2.3321
−41	1.695	0.845	206.58	1.183	4.84	131.51	502.10	370.59	0.7309	2.3272
−40	1.774	0.847	197.87	1.180	5.05	133.09	502.56	369.47	0.7379	2.3223
−39	1.856	0.849	189.59	1.177	5.27	134.67	503.01	368.34	0.7448	2.3174
−38	1.941	0.851	181.73	1.174	5.50	136.25	503.45	367.20	0.7517	2.3126
−37	2.028	0.854	174.26	1.172	5.74	137.84	503.89	366.05	0.7586	2.3078
−36	2.119	0.856	167.16	1.169	5.98	139.44	504.32	364.89	0.7655	2.3031
−35	2.213	0.858	160.40	1.166	6.23	141.03	504.75	363.71	0.7723	2.2984
−34	2.311	0.860	153.97	1.163	6.49	142.64	505.17	362.53	0.7791	2.2937
−33	2.411	0.862	147.85	1.160	6.76	144.25	505.58	361.33	0.7859	2.2891
−32	2.516	0.864	142.02	1.157	7.04	145.86	505.99	360.13	0.7927	2.2846
−31	2.623	0.867	136.46	1.154	7.33	147.48	506.39	358.91	0.7995	2.2800

Solkane® 32

Release 1.02

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	2.734	0.869	131.16	1.151	7.62	149.11	506.79	357.68	0.8062	2.2755
−29	2.849	0.871	126.11	1.148	7.93	150.74	507.18	356.44	0.8129	2.2711
−28	2.967	0.873	121.30	1.145	8.24	152.38	507.56	355.19	0.8196	2.2667
−27	3.089	0.876	116.70	1.142	8.57	154.02	507.94	353.92	0.8263	2.2623
−26	3.215	0.878	112.31	1.139	8.90	155.67	508.31	352.64	0.8330	2.2579
−25	3.345	0.880	108.12	1.136	9.25	157.32	508.67	351.35	0.8396	2.2536
−24	3.479	0.883	104.11	1.133	9.61	158.98	509.03	350.05	0.8462	2.2494
−23	3.617	0.885	100.28	1.130	9.97	160.64	509.38	348.74	0.8528	2.2451
−22	3.760	0.888	96.62	1.127	10.35	162.32	509.73	347.41	0.8594	2.2409
−21	3.906	0.890	93.12	1.124	10.74	163.99	510.06	346.07	0.8660	2.2367
−20	4.057	0.892	89.77	1.121	11.14	165.67	510.39	344.72	0.8725	2.2325
−19	4.213	0.895	86.56	1.117	11.55	167.36	510.72	343.36	0.8790	2.2284
−18	4.373	0.897	83.49	1.114	11.98	169.05	511.03	341.98	0.8856	2.2243
−17	4.537	0.900	80.55	1.111	12.41	170.75	511.34	340.59	0.8920	2.2202
−16	4.707	0.902	77.73	1.108	12.86	172.45	511.64	339.19	0.8985	2.2162
−15	4.881	0.905	75.03	1.105	13.33	174.16	511.93	337.78	0.9050	2.2122
−14	5.060	0.908	72.44	1.102	13.80	175.87	512.22	336.35	0.9114	2.2082
−13	5.244	0.910	69.96	1.098	14.29	177.58	512.50	334.91	0.9178	2.2042
−12	5.433	0.913	67.57	1.095	14.80	179.31	512.77	333.46	0.9242	2.2003
−11	5.627	0.916	65.29	1.092	15.32	181.03	513.03	332.00	0.9306	2.1963
−10	5.826	0.918	63.09	1.089	15.85	182.76	513.29	330.53	0.9370	2.1924
−9	6.031	0.921	60.98	1.085	16.40	184.50	513.54	329.04	0.9434	2.1886
−8	6.242	0.924	58.95	1.082	16.96	186.23	513.78	327.54	0.9497	2.1847
−7	6.457	0.927	57.01	1.079	17.54	187.98	514.01	326.03	0.9560	2.1809
−6	6.679	0.930	55.14	1.076	18.14	189.72	514.23	324.51	0.9623	2.1770
−5	6.906	0.933	53.34	1.072	18.75	191.47	514.44	322.97	0.9686	2.1732
−4	7.139	0.936	51.61	1.069	19.38	193.23	514.65	321.42	0.9749	2.1695
−3	7.378	0.939	49.94	1.066	20.02	194.99	514.85	319.86	0.9812	2.1657
−2	7.623	0.942	48.34	1.062	20.69	196.75	515.03	318.29	0.9875	2.1619
−1	7.874	0.945	46.79	1.059	21.37	198.51	515.21	316.70	0.9938	2.1582
0	8.131	0.948	45.31	1.055	22.07	200.00	515.38	315.38	1.0000	2.1545
1	8.395	0.951	43.88	1.052	22.79	202.05	515.54	313.49	1.0062	2.1508
2	8.665	0.954	42.50	1.048	23.53	203.83	515.69	311.87	1.0125	2.1471
3	8.942	0.957	41.17	1.045	24.29	205.61	515.84	310.23	1.0187	2.1434
4	9.225	0.960	39.89	1.041	25.07	207.39	515.97	308.58	1.0249	2.1397
5	9.515	0.964	38.66	1.038	25.87	209.17	516.09	306.92	1.0311	2.1361
6	9.812	0.967	37.46	1.034	26.69	210.96	516.20	305.24	1.0373	2.1324
7	10.115	0.970	36.31	1.031	27.54	212.75	516.30	303.55	1.0435	2.1288
8	10.426	0.974	35.21	1.027	28.40	214.54	516.40	301.85	1.0497	2.1251
9	10.744	0.977	34.14	1.023	29.30	216.34	516.48	300.13	1.0559	2.1215
10	11.069	0.981	33.10	1.020	30.21	218.14	516.55	298.40	1.0621	2.1179
11	11.402	0.984	32.10	1.016	31.15	219.95	516.60	296.66	1.0683	2.1143
12	11.742	0.988	31.14	1.012	32.11	221.76	516.65	294.90	1.0745	2.1107
13	12.090	0.992	30.21	1.008	33.10	223.57	516.69	293.12	1.0807	2.1070
14	12.445	0.995	29.31	1.005	34.12	225.38	516.71	291.33	1.0869	2.1034
15	12.808	0.999	28.44	1.001	35.17	227.20	516.72	289.52	1.0931	2.0998
16	13.179	1.003	27.59	0.997	36.24	229.03	516.72	287.70	1.0993	2.0962
17	13.559	1.007	26.78	0.993	37.34	230.86	516.71	285.86	1.1054	2.0926
18	13.946	1.011	25.99	0.989	38.47	232.69	516.69	284.00	1.1117	2.0890
19	14.342	1.015	25.23	0.985	39.63	234.53	516.65	282.12	1.1179	2.0854

Solkane® 32

Release 1.02

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	14.746	1.019	24.49	0.981	40.83	236.37	516.60	280.23	1.1241	2.0818
21	15.158	1.023	23.78	0.977	42.06	238.22	516.53	278.31	1.1303	2.0782
22	15.579	1.027	23.09	0.973	43.32	240.07	516.45	276.38	1.1365	2.0746
23	16.009	1.032	22.42	0.969	44.61	241.93	516.36	274.42	1.1428	2.0710
24	16.448	1.036	21.77	0.965	45.94	243.80	516.25	272.45	1.1490	2.0673
25	16.896	1.041	21.14	0.961	47.31	245.68	516.13	270.45	1.1553	2.0637
26	17.353	1.045	20.53	0.957	48.71	247.56	515.99	268.43	1.1616	2.0600
27	17.819	1.050	19.94	0.953	50.16	249.45	515.83	266.38	1.1679	2.0564
28	18.295	1.055	19.36	0.948	51.64	251.35	515.66	264.31	1.1742	2.0527
29	18.780	1.059	18.81	0.944	53.17	253.26	515.47	262.21	1.1805	2.0490
30	19.275	1.064	18.27	0.940	54.74	255.18	515.27	260.09	1.1868	2.0453
31	19.779	1.069	17.74	0.935	56.35	257.11	515.05	257.94	1.1932	2.0416
32	20.294	1.074	17.24	0.931	58.02	259.05	514.80	255.75	1.1996	2.0378
33	20.818	1.080	16.74	0.926	59.73	261.00	514.54	253.54	1.2060	2.0341
34	21.353	1.085	16.26	0.922	61.49	262.97	514.26	251.30	1.2124	2.0303
35	21.898	1.090	15.80	0.917	63.30	264.95	513.96	249.02	1.2188	2.0264
36	22.453	1.096	15.35	0.912	65.16	266.94	513.64	246.70	1.2253	2.0226
37	23.020	1.102	14.91	0.908	67.09	268.95	513.30	244.35	1.2318	2.0187
38	23.596	1.108	14.48	0.903	69.07	270.98	512.94	241.96	1.2383	2.0148
39	24.184	1.114	14.06	0.898	71.11	273.02	512.55	239.53	1.2449	2.0109
40	24.783	1.120	13.66	0.893	73.21	275.09	512.14	237.06	1.2515	2.0069
41	25.393	1.126	13.27	0.888	75.38	277.17	511.71	234.54	1.2581	2.0029
42	26.014	1.133	12.88	0.883	77.62	279.27	511.24	231.97	1.2648	1.9989
43	26.647	1.139	12.51	0.878	79.93	281.40	510.76	229.36	1.2714	1.9948
44	27.291	1.146	12.15	0.873	82.32	283.54	510.24	226.70	1.2782	1.9907
45	27.948	1.153	11.79	0.867	84.79	285.72	509.70	223.98	1.2849	1.9865
46	28.616	1.160	11.45	0.862	87.34	287.91	509.12	221.21	1.2917	1.9822
47	29.296	1.168	11.11	0.856	89.98	290.14	508.51	218.38	1.2986	1.9779
48	29.989	1.175	10.79	0.851	92.70	292.39	507.88	215.48	1.3055	1.9736
49	30.695	1.183	10.47	0.845	95.53	294.68	507.20	212.52	1.3124	1.9691
50	31.412	1.192	10.16	0.839	98.46	296.99	506.49	209.50	1.3194	1.9646
51	32.143	1.200	9.85	0.833	101.50	299.34	505.74	206.40	1.3264	1.9601
52	32.887	1.209	9.56	0.827	104.65	301.73	504.95	203.22	1.3334	1.9554
53	33.644	1.218	9.27	0.821	107.92	304.15	504.12	199.97	1.3406	1.9507
54	34.415	1.227	8.98	0.815	111.33	306.61	503.24	196.63	1.3477	1.9458
55	35.199	1.237	8.71	0.808	114.87	309.11	502.32	193.21	1.3550	1.9409
56	35.997	1.247	8.43	0.802	118.56	311.65	501.34	189.69	1.3622	1.9359
57	36.809	1.258	8.17	0.795	122.41	314.24	500.31	186.07	1.3696	1.9307
58	37.636	1.269	7.91	0.788	126.44	316.87	499.22	182.35	1.3770	1.9254
59	38.477	1.281	7.65	0.781	130.64	319.56	498.07	178.52	1.3844	1.9199
60	39.333	1.293	7.40	0.773	135.05	322.29	496.86	174.57	1.3919	1.9143
61	40.203	1.306	7.16	0.766	139.68	325.08	495.57	170.49	1.3995	1.9086
62	41.090	1.319	6.92	0.758	144.55	327.92	494.20	166.28	1.4072	1.9026
63	41.991	1.334	6.68	0.750	149.68	330.82	492.74	161.92	1.4149	1.8965
64	42.909	1.349	6.45	0.741	155.10	333.78	491.19	157.41	1.4227	1.8901
65	43.843	1.365	6.22	0.732	160.85	336.80	489.53	152.74	1.4305	1.8834
66	44.793	1.383	5.99	0.723	166.97	339.88	487.76	147.88	1.4384	1.8765
67	45.760	1.402	5.76	0.713	173.50	343.04	485.85	142.82	1.4464	1.8692
68	46.745	1.422	5.54	0.703	180.50	346.26	483.80	137.54	1.4545	1.8615
69	47.747	1.444	5.32	0.692	188.05	349.56	481.57	132.01	1.4627	1.8534

Solkane® 32

Release 1.02

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	48.768	1.469	5.10	0.681	196.25	352.94	479.15	126.21	1.4709	1.8448
71	49.807	1.496	4.87	0.668	205.21	356.39	476.49	120.10	1.4792	1.8355
72	50.866	1.527	4.65	0.655	215.12	359.93	473.54	113.61	1.4876	1.8255
73	51.945	1.563	4.42	0.640	226.20	363.55	470.24	106.70	1.4961	1.8146
74	53.046	1.605	4.19	0.623	238.81	367.26	466.50	99.24	1.5047	1.8024

12.2.2 Solkane® 124

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	0.265	0.643	527.58	1.554	1.90	158.02	336.35	178.33	0.8339	1.5991
−39	0.280	0.645	501.45	1.552	1.99	159.05	336.94	177.89	0.8382	1.5984
−38	0.295	0.646	476.87	1.549	2.10	160.08	337.53	177.45	0.8425	1.5977
−37	0.311	0.647	453.71	1.546	2.20	161.11	338.12	177.02	0.8468	1.5970
−36	0.328	0.648	431.89	1.543	2.32	162.14	338.72	176.58	0.8511	1.5964
−35	0.346	0.649	411.31	1.540	2.43	163.16	339.31	176.15	0.8553	1.5958
−34	0.364	0.650	391.91	1.538	2.55	164.19	339.90	175.71	0.8596	1.5952
−33	0.383	0.652	373.59	1.535	2.68	165.22	340.50	175.28	0.8639	1.5946
−32	0.403	0.653	356.29	1.532	2.81	166.25	341.09	174.84	0.8681	1.5940
−31	0.424	0.654	339.95	1.529	2.94	167.28	341.69	174.41	0.8724	1.5935
−30	0.445	0.655	324.50	1.526	3.08	168.31	342.28	173.97	0.8766	1.5930
−29	0.468	0.656	309.89	1.523	3.23	169.34	342.87	173.53	0.8808	1.5925
−28	0.491	0.658	296.07	1.520	3.38	170.37	343.47	173.10	0.8851	1.5920
−27	0.516	0.659	282.98	1.518	3.53	171.40	344.06	172.66	0.8893	1.5916
−26	0.541	0.660	270.58	1.515	3.70	172.44	344.66	172.22	0.8935	1.5911
−25	0.567	0.661	258.84	1.512	3.86	173.47	345.25	171.78	0.8977	1.5907
−24	0.595	0.663	247.70	1.509	4.04	174.51	345.84	171.34	0.9019	1.5903
−23	0.623	0.664	237.14	1.506	4.22	175.54	346.44	170.89	0.9061	1.5900
−22	0.652	0.665	227.12	1.503	4.40	176.58	347.03	170.45	0.9102	1.5896
−21	0.683	0.667	217.61	1.500	4.60	177.62	347.62	170.00	0.9144	1.5893
−20	0.714	0.668	208.57	1.497	4.79	178.66	348.22	169.55	0.9186	1.5890
−19	0.747	0.669	199.99	1.494	5.00	179.71	348.81	169.10	0.9227	1.5887
−18	0.781	0.670	191.83	1.491	5.21	180.75	349.40	168.65	0.9269	1.5884
−17	0.816	0.672	184.07	1.488	5.43	181.80	350.00	168.20	0.9310	1.5881
−16	0.853	0.673	176.69	1.486	5.66	182.85	350.59	167.74	0.9351	1.5879
−15	0.890	0.674	169.66	1.483	5.89	183.90	351.18	167.28	0.9393	1.5876
−14	0.929	0.676	162.97	1.480	6.14	184.95	351.77	166.82	0.9434	1.5874
−13	0.970	0.677	156.60	1.477	6.39	186.00	352.36	166.36	0.9475	1.5872
−12	1.011	0.679	150.52	1.474	6.64	187.06	352.96	165.89	0.9516	1.5870
−11	1.055	0.680	144.74	1.471	6.91	188.12	353.55	165.43	0.9557	1.5869
−10	1.099	0.681	139.22	1.468	7.18	189.18	354.14	164.96	0.9597	1.5867
−9	1.145	0.683	133.95	1.465	7.47	190.24	354.73	164.48	0.9638	1.5866
−8	1.192	0.684	128.92	1.462	7.76	191.31	355.32	164.01	0.9679	1.5864
−7	1.241	0.686	124.12	1.459	8.06	192.38	355.90	163.53	0.9719	1.5863
−6	1.292	0.687	119.54	1.456	8.37	193.45	356.49	163.05	0.9759	1.5862
−5	1.344	0.688	115.16	1.452	8.68	194.52	357.08	162.56	0.9800	1.5861
−4	1.398	0.690	110.97	1.449	9.01	195.59	357.67	162.07	0.9840	1.5860
−3	1.453	0.691	106.97	1.446	9.35	196.67	358.25	161.58	0.9880	1.5860
−2	1.510	0.693	103.14	1.443	9.70	197.75	358.84	161.09	0.9920	1.5859
−1	1.569	0.694	99.48	1.440	10.05	198.83	359.43	160.59	0.9960	1.5859
0	1.630	0.696	95.97	1.437	10.42	200.00	360.01	160.01	1.0000	1.5859
1	1.692	0.697	92.61	1.434	10.80	201.00	360.59	159.59	1.0040	1.5858
2	1.757	0.699	89.40	1.431	11.19	202.09	361.18	159.08	1.0079	1.5858
3	1.823	0.700	86.32	1.428	11.59	203.18	361.76	158.57	1.0119	1.5858
4	1.891	0.702	83.36	1.424	12.00	204.28	362.34	158.06	1.0159	1.5859
5	1.961	0.704	80.53	1.421	12.42	205.37	362.92	157.55	1.0198	1.5859
6	2.033	0.705	77.82	1.418	12.85	206.47	363.50	157.03	1.0237	1.5859
7	2.107	0.707	75.21	1.415	13.30	207.57	364.08	156.51	1.0276	1.5860
8	2.183	0.708	72.71	1.412	13.75	208.68	364.66	155.98	1.0316	1.5860
9	2.261	0.710	70.31	1.409	14.22	209.78	365.23	155.45	1.0355	1.5861

Solkane® 124

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	2.341	0.712	68.01	1.405	14.70	210.89	365.81	154.92	1.0394	1.5861
11	2.423	0.713	65.80	1.402	15.20	212.00	366.38	154.38	1.0433	1.5862
12	2.508	0.715	63.67	1.399	15.71	213.11	366.96	153.84	1.0471	1.5863
13	2.595	0.717	61.62	1.396	16.23	214.23	367.53	153.30	1.0510	1.5864
14	2.684	0.718	59.66	1.392	16.76	215.34	368.10	152.76	1.0549	1.5865
15	2.776	0.720	57.77	1.389	17.31	216.46	368.67	152.21	1.0587	1.5866
16	2.869	0.722	55.95	1.386	17.87	217.59	369.24	151.65	1.0626	1.5868
17	2.966	0.723	54.20	1.382	18.45	218.71	369.81	151.10	1.0664	1.5869
18	3.064	0.725	52.52	1.379	19.04	219.84	370.37	150.54	1.0702	1.5870
19	3.165	0.727	50.90	1.376	19.65	220.96	370.94	149.97	1.0741	1.5872
20	3.269	0.729	49.34	1.372	20.27	222.09	371.50	149.41	1.0779	1.5873
21	3.375	0.730	47.83	1.369	20.91	223.23	372.06	148.84	1.0817	1.5875
22	3.484	0.732	46.38	1.366	21.56	224.36	372.62	148.26	1.0855	1.5877
23	3.596	0.734	44.99	1.362	22.23	225.50	373.18	147.68	1.0893	1.5878
24	3.710	0.736	43.64	1.359	22.91	226.64	373.74	147.10	1.0930	1.5880
25	3.827	0.738	42.34	1.355	23.62	227.78	374.30	146.52	1.0968	1.5882
26	3.946	0.740	41.09	1.352	24.34	228.92	374.85	145.93	1.1006	1.5884
27	4.069	0.742	39.88	1.348	25.07	230.07	375.41	145.34	1.1044	1.5886
28	4.194	0.744	38.71	1.345	25.83	231.22	375.96	144.74	1.1081	1.5888
29	4.322	0.745	37.59	1.341	26.60	232.37	376.51	144.14	1.1119	1.5890
30	4.453	0.747	36.50	1.338	27.40	233.52	377.05	143.53	1.1156	1.5892
31	4.587	0.749	35.45	1.334	28.21	234.68	377.60	142.93	1.1193	1.5894
32	4.724	0.751	34.44	1.331	29.04	235.83	378.14	142.31	1.1231	1.5896
33	4.865	0.753	33.46	1.327	29.89	236.99	378.69	141.70	1.1268	1.5898
34	5.008	0.755	32.51	1.324	30.76	238.15	379.23	141.07	1.1305	1.5900
35	5.154	0.758	31.60	1.320	31.65	239.31	379.76	140.45	1.1342	1.5902
36	5.304	0.760	30.71	1.316	32.56	240.48	380.30	139.82	1.1379	1.5905
37	5.457	0.762	29.85	1.313	33.50	241.65	380.83	139.19	1.1416	1.5907
38	5.613	0.764	29.03	1.309	34.45	242.82	381.37	138.55	1.1453	1.5909
39	5.772	0.766	28.23	1.305	35.43	243.99	381.89	137.91	1.1490	1.5912
40	5.935	0.768	27.45	1.302	36.43	245.16	382.42	137.26	1.1527	1.5914
41	6.101	0.770	26.70	1.298	37.46	246.34	382.95	136.61	1.1564	1.5916
42	6.271	0.773	25.97	1.294	38.50	247.52	383.47	135.95	1.1601	1.5919
43	6.444	0.775	25.27	1.290	39.58	248.70	383.99	135.29	1.1638	1.5921
44	6.621	0.777	24.59	1.287	40.67	249.88	384.51	134.62	1.1674	1.5924
45	6.801	0.780	23.92	1.283	41.80	251.07	385.02	133.95	1.1711	1.5926
46	6.985	0.782	23.28	1.279	42.95	252.26	385.53	133.27	1.1748	1.5928
47	7.173	0.784	22.66	1.275	44.12	253.45	386.04	132.59	1.1784	1.5931
48	7.364	0.787	22.06	1.271	45.33	254.64	386.55	131.90	1.1821	1.5933
49	7.559	0.789	21.48	1.267	46.56	255.84	387.05	131.21	1.1858	1.5936
50	7.758	0.792	20.91	1.263	47.82	257.04	387.55	130.51	1.1894	1.5938
51	7.961	0.794	20.36	1.259	49.11	258.24	388.04	129.80	1.1931	1.5941
52	8.168	0.797	19.83	1.255	50.43	259.45	388.54	129.09	1.1967	1.5943
53	8.379	0.799	19.31	1.251	51.78	260.65	389.03	128.38	1.2004	1.5945
54	8.593	0.802	18.81	1.247	53.16	261.86	389.52	127.65	1.2040	1.5948
55	8.812	0.805	18.32	1.243	54.57	263.08	390.00	126.92	1.2077	1.5950
56	9.035	0.807	17.85	1.239	56.02	264.29	390.48	126.18	1.2113	1.5952
57	9.262	0.810	17.39	1.235	57.50	265.52	390.95	125.44	1.2150	1.5955
58	9.494	0.813	16.94	1.230	59.02	266.74	391.43	124.69	1.2187	1.5957
59	9.730	0.816	16.51	1.226	60.57	267.97	391.90	123.93	1.2223	1.5959

Solkane® 124

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	9.970	0.818	16.09	1.222	62.16	269.20	392.36	123.16	1.2260	1.5961
61	10.214	0.821	15.68	1.217	63.78	270.43	392.82	122.39	1.2296	1.5964
62	10.463	0.824	15.28	1.213	65.45	271.67	393.28	121.61	1.2333	1.5966
63	10.716	0.827	14.89	1.209	67.15	272.91	393.73	120.81	1.2369	1.5968
64	10.974	0.830	14.51	1.204	68.89	274.16	394.17	120.01	1.2406	1.5970
65	11.237	0.833	14.15	1.200	70.68	275.41	394.62	119.21	1.2443	1.5972
66	11.504	0.837	13.79	1.195	72.51	276.67	395.05	118.39	1.2479	1.5974
67	11.776	0.840	13.44	1.191	74.38	277.93	395.49	117.56	1.2516	1.5975
68	12.052	0.843	13.11	1.186	76.30	279.19	395.91	116.72	1.2553	1.5977
69	12.334	0.846	12.78	1.182	78.27	280.46	396.34	115.87	1.2590	1.5979
70	12.620	0.850	12.46	1.177	80.29	281.74	396.75	115.02	1.2627	1.5981
71	12.911	0.853	12.14	1.172	82.35	283.02	397.16	114.15	1.2663	1.5982
72	13.207	0.857	11.84	1.167	84.47	284.30	397.57	113.27	1.2700	1.5984
73	13.508	0.860	11.54	1.162	86.64	285.59	397.97	112.37	1.2737	1.5985
74	13.815	0.864	11.25	1.158	88.87	286.89	398.36	111.47	1.2774	1.5986
75	14.126	0.868	10.97	1.153	91.15	288.20	398.75	110.55	1.2812	1.5987
76	14.443	0.871	10.70	1.148	93.49	289.51	399.13	109.62	1.2849	1.5988
77	14.765	0.875	10.43	1.143	95.90	290.82	399.50	108.68	1.2886	1.5989
78	15.092	0.879	10.17	1.137	98.36	292.15	399.86	107.72	1.2924	1.5990
79	15.425	0.883	9.91	1.132	100.90	293.48	400.22	106.74	1.2961	1.5991
80	15.764	0.887	9.66	1.127	103.50	294.82	400.57	105.75	1.2999	1.5991
81	16.107	0.892	9.42	1.122	106.18	296.16	400.91	104.75	1.3036	1.5992
82	16.457	0.896	9.18	1.116	108.93	297.52	401.25	103.73	1.3074	1.5992
83	16.812	0.900	8.95	1.111	111.76	298.88	401.57	102.69	1.3112	1.5992
84	17.173	0.905	8.72	1.105	114.67	300.25	401.88	101.63	1.3150	1.5992
85	17.539	0.909	8.50	1.100	117.67	301.63	402.18	100.55	1.3188	1.5991
86	17.912	0.914	8.28	1.094	120.77	303.02	402.48	99.45	1.3226	1.5991
87	18.290	0.919	8.07	1.088	123.96	304.42	402.76	98.33	1.3264	1.5990
88	18.675	0.924	7.86	1.082	127.25	305.83	403.02	97.19	1.3303	1.5989
89	19.066	0.929	7.65	1.076	130.66	307.25	403.28	96.03	1.3341	1.5988
90	19.462	0.934	7.45	1.070	134.19	308.68	403.51	94.83	1.3380	1.5986
91	19.865	0.940	7.25	1.064	137.84	310.12	403.74	93.62	1.3419	1.5984
92	20.275	0.946	7.06	1.058	141.64	311.57	403.94	92.37	1.3458	1.5981
93	20.691	0.951	6.87	1.051	145.59	313.04	404.12	91.08	1.3497	1.5978
94	21.113	0.957	6.68	1.045	149.72	314.51	404.28	89.77	1.3536	1.5975
95	21.542	0.964	6.49	1.038	154.05	316.00	404.41	88.41	1.3576	1.5971
96	21.977	0.970	6.31	1.031	158.60	317.50	404.51	87.01	1.3615	1.5966
97	22.419	0.977	6.12	1.024	163.42	319.02	404.57	85.55	1.3655	1.5960
98	22.869	0.983	5.93	1.017	168.56	320.55	404.58	84.04	1.3695	1.5953
99	23.325	0.991	5.74	1.009	174.10	322.09	404.54	82.44	1.3735	1.5945
100	23.788	0.998	5.55	1.002	180.18	323.65	404.40	80.75	1.3775	1.5934
101	24.258	1.006	5.35	0.994	187.02	325.22	404.15	78.92	1.3816	1.5920
102	24.736	1.014	5.12	0.986	195.12	326.81	403.69	76.87	1.3857	1.5901
103	25.220	1.022	4.85	0.978	206.05	328.42	402.75	74.33	1.3897	1.5870

12.2.3 Solkane®

Release 1.02

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	0.156	0.616	849.99	1.624	1.18	107.32	288.83	181.51	0.6102	1.5392
−79	0.167	0.617	796.18	1.621	1.26	108.52	289.40	180.88	0.6153	1.5374
−78	0.179	0.618	746.38	1.618	1.34	109.71	289.97	180.26	0.6204	1.5356
−77	0.191	0.619	700.24	1.614	1.43	110.89	290.55	179.65	0.6255	1.5339
−76	0.205	0.621	657.45	1.611	1.52	112.06	291.12	179.06	0.6306	1.5322
−75	0.219	0.622	617.75	1.608	1.62	113.23	291.70	178.47	0.6357	1.5306
−74	0.234	0.623	580.87	1.604	1.72	114.38	292.27	177.89	0.6409	1.5290
−73	0.250	0.625	546.59	1.601	1.83	115.53	292.85	177.32	0.6460	1.5274
−72	0.266	0.626	514.70	1.598	1.94	116.67	293.43	176.76	0.6511	1.5259
−71	0.284	0.627	485.01	1.594	2.06	117.80	294.00	176.20	0.6562	1.5245
−70	0.302	0.629	457.35	1.591	2.19	118.93	294.58	175.65	0.6614	1.5230
−69	0.321	0.630	431.55	1.588	2.32	120.05	295.15	175.10	0.6665	1.5216
−68	0.342	0.631	407.48	1.584	2.45	121.17	295.73	174.56	0.6716	1.5203
−67	0.363	0.633	385.00	1.581	2.60	122.29	296.31	174.02	0.6767	1.5190
−66	0.386	0.634	364.00	1.578	2.75	123.40	296.88	173.49	0.6818	1.5177
−65	0.409	0.635	344.36	1.574	2.90	124.50	297.46	172.95	0.6870	1.5164
−64	0.434	0.637	325.97	1.571	3.07	125.61	298.03	172.43	0.6921	1.5152
−63	0.460	0.638	308.76	1.567	3.24	126.71	298.61	171.90	0.6972	1.5141
−62	0.487	0.639	292.63	1.564	3.42	127.81	299.19	171.37	0.7023	1.5129
−61	0.515	0.641	277.50	1.560	3.60	128.91	299.76	170.85	0.7074	1.5118
−60	0.545	0.642	263.31	1.557	3.80	130.01	300.34	170.33	0.7125	1.5108
−59	0.576	0.644	249.98	1.554	4.00	131.11	300.91	169.80	0.7175	1.5097
−58	0.608	0.645	237.46	1.550	4.21	132.21	301.49	169.28	0.7226	1.5087
−57	0.642	0.647	225.69	1.547	4.43	133.30	302.06	168.76	0.7277	1.5077
−56	0.678	0.648	214.61	1.543	4.66	134.40	302.63	168.23	0.7328	1.5068
−55	0.715	0.650	204.19	1.540	4.90	135.50	303.21	167.71	0.7378	1.5059
−54	0.753	0.651	194.37	1.536	5.14	136.60	303.78	167.18	0.7429	1.5050
−53	0.793	0.653	185.12	1.532	5.40	137.70	304.35	166.65	0.7479	1.5041
−52	0.835	0.654	176.40	1.529	5.67	138.80	304.92	166.12	0.7529	1.5033
−51	0.879	0.656	168.17	1.525	5.95	139.90	305.49	165.59	0.7580	1.5025
−50	0.924	0.657	160.40	1.522	6.23	141.01	306.06	165.06	0.7630	1.5017
−49	0.971	0.659	153.06	1.518	6.53	142.11	306.63	164.52	0.7680	1.5009
−48	1.020	0.660	146.12	1.515	6.84	143.22	307.20	163.98	0.7730	1.5002
−47	1.071	0.662	139.57	1.511	7.17	144.33	307.77	163.44	0.7780	1.4995
−46	1.124	0.663	133.36	1.507	7.50	145.45	308.34	162.89	0.7829	1.4988
−45	1.179	0.665	127.49	1.504	7.84	146.56	308.90	162.34	0.7879	1.4981
−44	1.236	0.667	121.93	1.500	8.20	147.68	309.47	161.79	0.7929	1.4975
−43	1.295	0.668	116.66	1.496	8.57	148.80	310.03	161.23	0.7978	1.4969
−42	1.357	0.670	111.66	1.493	8.96	149.92	310.60	160.67	0.8027	1.4963
−41	1.421	0.672	106.92	1.489	9.35	151.05	311.16	160.11	0.8077	1.4957
−40	1.486	0.673	102.42	1.485	9.76	152.18	311.72	159.54	0.8126	1.4952
−39	1.555	0.675	98.15	1.482	10.19	153.31	312.28	158.97	0.8175	1.4946
−38	1.626	0.677	94.10	1.478	10.63	154.45	312.84	158.39	0.8224	1.4941
−37	1.699	0.678	90.25	1.474	11.08	155.59	313.40	157.81	0.8272	1.4936
−36	1.774	0.680	86.58	1.470	11.55	156.73	313.96	157.22	0.8321	1.4932
−35	1.853	0.682	83.10	1.467	12.03	157.88	314.51	156.63	0.8370	1.4927
−34	1.934	0.684	79.78	1.463	12.53	159.03	315.07	156.04	0.8418	1.4923
−33	2.017	0.685	76.62	1.459	13.05	160.18	315.62	155.44	0.8466	1.4918
−32	2.104	0.687	73.62	1.455	13.58	161.34	316.17	154.83	0.8514	1.4914
−31	2.193	0.689	70.75	1.451	14.13	162.50	316.72	154.22	0.8562	1.4910

Solkane® 125

Release 1.02

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	2.285	0.691	68.02	1.447	14.70	163.66	317.27	153.61	0.8610	1.4907
−29	2.380	0.693	65.42	1.443	15.29	164.83	317.82	152.99	0.8658	1.4903
−28	2.478	0.695	62.93	1.439	15.89	166.00	318.36	152.36	0.8706	1.4900
−27	2.580	0.697	60.56	1.436	16.51	167.17	318.90	151.73	0.8754	1.4896
−26	2.684	0.699	58.30	1.432	17.15	168.35	319.45	151.10	0.8801	1.4893
−25	2.791	0.700	56.13	1.428	17.81	169.53	319.99	150.46	0.8848	1.4890
−24	2.902	0.702	54.07	1.424	18.50	170.71	320.53	149.81	0.8896	1.4887
−23	3.016	0.704	52.09	1.420	19.20	171.90	321.06	149.16	0.8943	1.4885
−22	3.134	0.706	50.20	1.416	19.92	173.09	321.60	148.50	0.8990	1.4882
−21	3.255	0.708	48.40	1.411	20.66	174.29	322.13	147.84	0.9037	1.4879
−20	3.379	0.711	46.67	1.407	21.43	175.48	322.66	147.18	0.9083	1.4877
−19	3.507	0.713	45.01	1.403	22.22	176.69	323.19	146.51	0.9130	1.4875
−18	3.639	0.715	43.43	1.399	23.03	177.89	323.72	145.83	0.9177	1.4873
−17	3.774	0.717	41.91	1.395	23.86	179.10	324.24	145.15	0.9223	1.4871
−16	3.913	0.719	40.45	1.391	24.72	180.31	324.77	144.46	0.9269	1.4869
−15	4.056	0.721	39.05	1.387	25.61	181.52	325.29	143.76	0.9316	1.4867
−14	4.203	0.723	37.72	1.382	26.51	182.74	325.80	143.07	0.9362	1.4865
−13	4.354	0.726	36.43	1.378	27.45	183.96	326.32	142.36	0.9408	1.4863
−12	4.509	0.728	35.20	1.374	28.41	185.18	326.83	141.65	0.9454	1.4862
−11	4.668	0.730	34.02	1.370	29.40	186.41	327.34	140.94	0.9500	1.4860
−10	4.831	0.732	32.88	1.365	30.41	187.64	327.85	140.22	0.9546	1.4859
−9	4.999	0.735	31.79	1.361	31.46	188.87	328.36	139.49	0.9591	1.4857
−8	5.171	0.737	30.74	1.357	32.53	190.10	328.86	138.76	0.9637	1.4856
−7	5.347	0.740	29.73	1.352	33.64	191.34	329.36	138.02	0.9683	1.4855
−6	5.528	0.742	28.76	1.348	34.77	192.58	329.86	137.27	0.9728	1.4854
−5	5.713	0.744	27.83	1.343	35.93	193.83	330.35	136.52	0.9774	1.4853
−4	5.903	0.747	26.93	1.339	37.13	195.08	330.84	135.77	0.9819	1.4852
−3	6.097	0.750	26.07	1.334	38.36	196.33	331.33	135.00	0.9864	1.4851
−2	6.297	0.752	25.24	1.330	39.63	197.58	331.82	134.23	0.9910	1.4850
−1	6.501	0.755	24.44	1.325	40.92	198.84	332.30	133.46	0.9955	1.4849
0	6.710	0.757	23.66	1.320	42.26	200.00	332.78	132.78	1.0000	1.4848
1	6.924	0.760	22.92	1.316	43.63	201.36	333.25	131.89	1.0045	1.4847
2	7.143	0.763	22.20	1.311	45.04	202.63	333.72	131.09	1.0090	1.4846
3	7.368	0.766	21.51	1.306	46.48	203.90	334.19	130.29	1.0135	1.4845
4	7.597	0.768	20.85	1.301	47.97	205.17	334.65	129.48	1.0180	1.4844
5	7.832	0.771	20.20	1.297	49.49	206.45	335.11	128.66	1.0225	1.4844
6	8.072	0.774	19.58	1.292	51.06	207.73	335.57	127.84	1.0270	1.4843
7	8.318	0.777	18.99	1.287	52.67	209.02	336.02	127.01	1.0315	1.4842
8	8.569	0.780	18.41	1.282	54.32	210.30	336.47	126.17	1.0360	1.4841
9	8.826	0.783	17.85	1.277	56.02	211.60	336.91	125.32	1.0405	1.4840
10	9.088	0.786	17.31	1.272	57.77	212.89	337.35	124.46	1.0450	1.4840
11	9.356	0.789	16.79	1.267	59.56	214.19	337.79	123.59	1.0495	1.4839
12	9.631	0.793	16.29	1.262	61.40	215.50	338.21	122.72	1.0540	1.4838
13	9.911	0.796	15.80	1.256	63.29	216.81	338.64	121.83	1.0585	1.4837
14	10.197	0.799	15.33	1.251	65.24	218.12	339.06	120.94	1.0630	1.4836
15	10.489	0.803	14.87	1.246	67.24	219.44	339.47	120.03	1.0676	1.4835
16	10.787	0.806	14.43	1.241	69.29	220.76	339.88	119.12	1.0721	1.4834
17	11.092	0.810	14.01	1.235	71.40	222.09	340.28	118.19	1.0766	1.4833
18	11.403	0.813	13.59	1.230	73.57	223.43	340.68	117.25	1.0811	1.4832
19	11.721	0.817	13.19	1.224	75.80	224.77	341.07	116.30	1.0857	1.4831

Solkane® 125

Release 1.02

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	12.045	0.821	12.81	1.219	78.09	226.11	341.45	115.34	1.0902	1.4830
21	12.376	0.824	12.43	1.213	80.45	227.47	341.83	114.37	1.0948	1.4828
22	12.713	0.828	12.07	1.207	82.87	228.83	342.20	113.38	1.0993	1.4827
23	13.058	0.832	11.71	1.201	85.37	230.19	342.57	112.37	1.1039	1.4825
24	13.409	0.836	11.37	1.196	87.93	231.57	342.92	111.36	1.1085	1.4824
25	13.767	0.841	11.04	1.190	90.57	232.95	343.27	110.32	1.1131	1.4822
26	14.132	0.845	10.72	1.184	93.29	234.34	343.61	109.27	1.1177	1.4820
27	14.505	0.849	10.41	1.178	96.09	235.74	343.95	108.21	1.1223	1.4818
28	14.885	0.854	10.10	1.171	98.97	237.14	344.27	107.13	1.1269	1.4816
29	15.273	0.858	9.81	1.165	101.94	238.56	344.59	106.03	1.1316	1.4813
30	15.667	0.863	9.52	1.159	105.00	239.99	344.89	104.91	1.1362	1.4811
31	16.070	0.868	9.25	1.152	108.16	241.42	345.19	103.76	1.1409	1.4808
32	16.480	0.873	8.98	1.146	111.41	242.87	345.48	102.60	1.1456	1.4805
33	16.899	0.878	8.71	1.139	114.77	244.33	345.75	101.42	1.1504	1.4802
34	17.325	0.883	8.46	1.132	118.23	245.80	346.02	100.21	1.1551	1.4799
35	17.759	0.889	8.21	1.125	121.81	247.28	346.27	98.98	1.1599	1.4795
36	18.201	0.894	7.97	1.118	125.51	248.78	346.51	97.73	1.1646	1.4792
37	18.652	0.900	7.73	1.111	129.33	250.29	346.73	96.45	1.1694	1.4788
38	19.111	0.906	7.50	1.104	133.28	251.81	346.95	95.13	1.1743	1.4783
39	19.579	0.912	7.28	1.096	137.37	253.35	347.15	93.79	1.1791	1.4778
40	20.056	0.918	7.06	1.089	141.61	254.90	347.33	92.42	1.1840	1.4773
41	20.541	0.925	6.85	1.081	146.00	256.47	347.49	91.02	1.1889	1.4768
42	21.036	0.932	6.64	1.073	150.56	258.06	347.64	89.58	1.1938	1.4762
43	21.539	0.939	6.44	1.065	155.29	259.67	347.77	88.11	1.1988	1.4756
44	22.052	0.947	6.24	1.056	160.22	261.29	347.88	86.59	1.2038	1.4749
45	22.574	0.954	6.05	1.048	165.34	262.93	347.97	85.04	1.2088	1.4741
46	23.106	0.962	5.86	1.039	170.68	264.60	348.03	83.44	1.2139	1.4734
47	23.647	0.971	5.67	1.030	176.25	266.28	348.07	81.79	1.2190	1.4725
48	24.199	0.980	5.49	1.021	182.08	267.98	348.08	80.10	1.2241	1.4716
49	24.761	0.989	5.31	1.011	188.19	269.71	348.07	78.35	1.2293	1.4706
50	25.333	0.999	5.14	1.001	194.60	271.47	348.01	76.55	1.2345	1.4695
51	25.915	1.009	4.97	0.991	201.34	273.24	347.92	74.68	1.2397	1.4683
52	26.508	1.021	4.80	0.980	208.46	275.05	347.79	72.75	1.2450	1.4670
53	27.112	1.032	4.63	0.969	215.99	276.87	347.62	70.74	1.2503	1.4656
54	27.728	1.045	4.46	0.957	224.00	278.73	347.39	68.66	1.2557	1.4640
55	28.355	1.059	4.30	0.945	232.55	280.62	347.10	66.48	1.2611	1.4623
56	28.993	1.073	4.14	0.932	241.73	282.53	346.74	64.21	1.2666	1.4604
57	29.644	1.090	3.97	0.918	251.66	284.48	346.30	61.81	1.2721	1.4583
58	30.307	1.107	3.81	0.903	262.50	286.46	345.75	59.29	1.2776	1.4558
59	30.984	1.127	3.64	0.887	274.48	288.48	345.08	56.60	1.2832	1.4530
60	31.673	1.150	3.47	0.870	287.93	290.52	344.24	53.71	1.2889	1.4498
61	32.377	1.175	3.30	0.851	303.42	292.61	343.17	50.56	1.2946	1.4458
62	33.095	1.206	3.11	0.829	322.02	294.73	341.74	47.01	1.3003	1.4409

12.2.4 Solkane® 143a

Release 1.02

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	0.299	0.814	657.92	1.228	1.52	103.87	346.34	242.47	0.5991	1.7908
−69	0.318	0.816	622.02	1.225	1.61	105.25	346.99	241.74	0.6052	1.7882
−68	0.337	0.818	588.45	1.223	1.70	106.61	347.63	241.02	0.6112	1.7856
−67	0.358	0.820	557.02	1.220	1.80	107.97	348.28	240.31	0.6173	1.7830
−66	0.379	0.821	527.59	1.218	1.90	109.31	348.92	239.61	0.6234	1.7805
−65	0.402	0.823	500.01	1.215	2.00	110.65	349.57	238.92	0.6294	1.7781
−64	0.425	0.825	474.15	1.213	2.11	111.97	350.21	238.24	0.6355	1.7757
−63	0.450	0.826	449.88	1.210	2.22	113.29	350.85	237.56	0.6415	1.7733
−62	0.475	0.828	427.08	1.207	2.34	114.61	351.49	236.88	0.6475	1.7710
−61	0.502	0.830	405.67	1.205	2.47	115.92	352.14	236.22	0.6536	1.7688
−60	0.530	0.832	385.53	1.202	2.59	117.23	352.78	235.55	0.6596	1.7666
−59	0.560	0.834	366.59	1.200	2.73	118.53	353.42	234.89	0.6656	1.7644
−58	0.590	0.835	348.77	1.197	2.87	119.83	354.06	234.23	0.6716	1.7623
−57	0.622	0.837	331.98	1.194	3.01	121.12	354.70	233.57	0.6776	1.7602
−56	0.656	0.839	316.15	1.192	3.16	122.42	355.33	232.91	0.6835	1.7582
−55	0.690	0.841	301.23	1.189	3.32	123.71	355.97	232.26	0.6895	1.7562
−54	0.726	0.843	287.15	1.186	3.48	125.01	356.61	231.60	0.6955	1.7542
−53	0.764	0.845	273.86	1.184	3.65	126.30	357.24	230.94	0.7014	1.7523
−52	0.803	0.847	261.31	1.181	3.83	127.59	357.88	230.29	0.7074	1.7504
−51	0.844	0.849	249.45	1.178	4.01	128.89	358.51	229.62	0.7133	1.7486
−50	0.886	0.851	238.23	1.176	4.20	130.18	359.14	228.96	0.7192	1.7468
−49	0.931	0.852	227.62	1.173	4.39	131.48	359.77	228.30	0.7251	1.7450
−48	0.976	0.854	217.57	1.170	4.60	132.78	360.40	227.63	0.7310	1.7433
−47	1.024	0.856	208.06	1.168	4.81	134.08	361.03	226.95	0.7369	1.7416
−46	1.073	0.858	199.05	1.165	5.02	135.38	361.66	226.28	0.7428	1.7399
−45	1.124	0.860	190.51	1.162	5.25	136.69	362.28	225.60	0.7487	1.7383
−44	1.177	0.863	182.40	1.159	5.48	138.00	362.91	224.91	0.7545	1.7367
−43	1.232	0.865	174.71	1.157	5.72	139.31	363.53	224.22	0.7603	1.7351
−42	1.289	0.867	167.41	1.154	5.97	140.63	364.15	223.52	0.7662	1.7336
−41	1.349	0.869	160.48	1.151	6.23	141.95	364.77	222.82	0.7720	1.7321
−40	1.410	0.871	153.89	1.148	6.50	143.27	365.39	222.11	0.7778	1.7306
−39	1.473	0.873	147.63	1.146	6.77	144.60	366.00	221.40	0.7836	1.7292
−38	1.539	0.875	141.68	1.143	7.06	145.94	366.62	220.68	0.7894	1.7277
−37	1.606	0.877	136.01	1.140	7.35	147.28	367.23	219.95	0.7951	1.7263
−36	1.676	0.879	130.61	1.137	7.66	148.62	367.84	219.22	0.8009	1.7250
−35	1.749	0.882	125.48	1.134	7.97	149.97	368.45	218.48	0.8066	1.7236
−34	1.823	0.884	120.58	1.131	8.29	151.32	369.06	217.73	0.8123	1.7223
−33	1.901	0.886	115.92	1.129	8.63	152.68	369.66	216.98	0.8180	1.7210
−32	1.980	0.888	111.47	1.126	8.97	154.04	370.26	216.22	0.8237	1.7198
−31	2.063	0.891	107.23	1.123	9.33	155.41	370.86	215.45	0.8294	1.7185
−30	2.148	0.893	103.18	1.120	9.69	156.79	371.46	214.68	0.8351	1.7173
−29	2.235	0.895	99.31	1.117	10.07	158.16	372.06	213.89	0.8407	1.7161
−28	2.326	0.898	95.62	1.114	10.46	159.55	372.65	213.10	0.8464	1.7150
−27	2.419	0.900	92.09	1.111	10.86	160.94	373.24	212.31	0.8520	1.7138
−26	2.515	0.902	88.72	1.108	11.27	162.33	373.83	211.50	0.8576	1.7127
−25	2.613	0.905	85.50	1.105	11.70	163.73	374.42	210.69	0.8633	1.7116
−24	2.715	0.907	82.41	1.102	12.13	165.14	375.00	209.87	0.8689	1.7105
−23	2.820	0.910	79.46	1.099	12.58	166.55	375.59	209.04	0.8744	1.7094
−22	2.928	0.912	76.64	1.096	13.05	167.96	376.16	208.20	0.8800	1.7084
−21	3.039	0.915	73.94	1.093	13.53	169.38	376.74	207.36	0.8856	1.7074

Solkane® 143a

Release 1.02

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	3.153	0.917	71.35	1.090	14.02	170.81	377.31	206.51	0.8911	1.7063
–19	3.270	0.920	68.86	1.087	14.52	172.24	377.88	205.65	0.8967	1.7053
–18	3.391	0.922	66.49	1.084	15.04	173.67	378.45	204.78	0.9022	1.7044
–17	3.515	0.925	64.20	1.081	15.58	175.11	379.02	203.91	0.9077	1.7034
–16	3.643	0.928	62.02	1.078	16.12	176.55	379.58	203.03	0.9132	1.7025
–15	3.774	0.930	59.92	1.075	16.69	178.00	380.14	202.14	0.9187	1.7015
–14	3.908	0.933	57.90	1.072	17.27	179.45	380.69	201.24	0.9242	1.7006
–13	4.046	0.936	55.97	1.069	17.87	180.91	381.24	200.33	0.9296	1.6997
–12	4.188	0.939	54.11	1.065	18.48	182.37	381.79	199.42	0.9351	1.6988
–11	4.334	0.941	52.32	1.062	19.11	183.84	382.34	198.50	0.9406	1.6979
–10	4.483	0.944	50.61	1.059	19.76	185.31	382.88	197.57	0.9460	1.6971
–9	4.636	0.947	48.96	1.056	20.42	186.78	383.42	196.64	0.9514	1.6962
–8	4.793	0.950	47.37	1.053	21.11	188.26	383.95	195.69	0.9569	1.6954
–7	4.954	0.953	45.85	1.049	21.81	189.74	384.48	194.74	0.9623	1.6946
–6	5.119	0.956	44.38	1.046	22.53	191.23	385.01	193.79	0.9677	1.6937
–5	5.289	0.959	42.97	1.043	23.27	192.71	385.53	192.82	0.9731	1.6929
–4	5.462	0.962	41.61	1.039	24.03	194.21	386.05	191.85	0.9785	1.6921
–3	5.640	0.965	40.30	1.036	24.82	195.70	386.57	190.86	0.9839	1.6914
–2	5.822	0.968	39.03	1.033	25.62	197.20	387.08	189.87	0.9893	1.6906
–1	6.008	0.971	37.82	1.029	26.44	198.71	387.58	188.88	0.9946	1.6898
0	6.199	0.975	36.65	1.026	27.29	200.00	388.08	188.08	1.0000	1.6890
1	6.394	0.978	35.51	1.023	28.16	201.72	388.58	186.86	1.0054	1.6883
2	6.594	0.981	34.42	1.019	29.05	203.24	389.07	185.84	1.0107	1.6875
3	6.799	0.985	33.37	1.016	29.96	204.75	389.56	184.81	1.0161	1.6868
4	7.008	0.988	32.36	1.012	30.90	206.27	390.04	183.77	1.0214	1.6860
5	7.222	0.991	31.38	1.009	31.87	207.80	390.52	182.72	1.0268	1.6853
6	7.441	0.995	30.43	1.005	32.86	209.32	390.99	181.67	1.0321	1.6846
7	7.665	0.999	29.52	1.001	33.88	210.86	391.46	180.60	1.0375	1.6838
8	7.894	1.002	28.64	0.998	34.92	212.39	391.92	179.53	1.0428	1.6831
9	8.128	1.006	27.78	0.994	35.99	213.93	392.37	178.45	1.0482	1.6824
10	8.367	1.009	26.96	0.991	37.09	215.47	392.82	177.35	1.0535	1.6816
11	8.611	1.013	26.16	0.987	38.22	217.01	393.27	176.25	1.0589	1.6809
12	8.861	1.017	25.39	0.983	39.38	218.56	393.70	175.14	1.0642	1.6802
13	9.116	1.021	24.65	0.979	40.57	220.12	394.14	174.02	1.0696	1.6795
14	9.376	1.025	23.93	0.976	41.79	221.67	394.56	172.89	1.0749	1.6787
15	9.642	1.029	23.23	0.972	43.05	223.24	394.98	171.74	1.0803	1.6780
16	9.914	1.033	22.56	0.968	44.34	224.80	395.39	170.59	1.0856	1.6773
17	10.191	1.037	21.90	0.964	45.66	226.37	395.79	169.42	1.0910	1.6766
18	10.474	1.041	21.27	0.960	47.02	227.95	396.19	168.24	1.0964	1.6758
19	10.763	1.046	20.66	0.956	48.41	229.53	396.58	167.04	1.1017	1.6751
20	11.058	1.050	20.06	0.952	49.85	231.12	396.96	165.84	1.1071	1.6743
21	11.358	1.055	19.49	0.948	51.32	232.71	397.33	164.62	1.1125	1.6736
22	11.665	1.059	18.93	0.944	52.84	234.31	397.69	163.38	1.1179	1.6728
23	11.978	1.064	18.39	0.940	54.39	235.91	398.05	162.13	1.1233	1.6720
24	12.297	1.068	17.86	0.936	55.99	237.53	398.40	160.87	1.1287	1.6712
25	12.623	1.073	17.35	0.932	57.63	239.14	398.73	159.59	1.1341	1.6705
26	12.954	1.078	16.86	0.927	59.32	240.77	399.06	158.29	1.1396	1.6697
27	13.293	1.083	16.38	0.923	61.06	242.41	399.38	156.97	1.1450	1.6688
28	13.638	1.088	15.91	0.919	62.85	244.05	399.69	155.64	1.1505	1.6680
29	13.989	1.094	15.46	0.914	64.69	245.70	399.98	154.28	1.1560	1.6672

Solkane® 143a

Release 1.02

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	14.348	1.099	15.02	0.910	66.58	247.36	400.27	152.90	1.1614	1.6663
31	14.713	1.104	14.59	0.906	68.53	249.04	400.54	151.51	1.1670	1.6654
32	15.085	1.110	14.18	0.901	70.53	250.72	400.81	150.09	1.1725	1.6645
33	15.464	1.116	13.77	0.896	72.60	252.41	401.06	148.64	1.1780	1.6636
34	15.850	1.122	13.38	0.892	74.72	254.12	401.29	147.18	1.1836	1.6627
35	16.244	1.128	13.00	0.887	76.92	255.84	401.52	145.68	1.1891	1.6617
36	16.644	1.134	12.63	0.882	79.17	257.57	401.73	144.16	1.1947	1.6607
37	17.052	1.140	12.27	0.877	81.50	259.32	401.93	142.61	1.2004	1.6597
38	17.468	1.147	11.92	0.872	83.91	261.08	402.11	141.03	1.2060	1.6587
39	17.891	1.153	11.58	0.867	86.39	262.85	402.27	139.42	1.2117	1.6576
40	18.322	1.160	11.24	0.862	88.95	264.65	402.42	137.77	1.2174	1.6565
41	18.761	1.167	10.92	0.857	91.60	266.46	402.55	136.09	1.2231	1.6554
42	19.207	1.174	10.60	0.851	94.33	268.29	402.66	134.38	1.2288	1.6542
43	19.662	1.182	10.29	0.846	97.16	270.14	402.76	132.62	1.2346	1.6530
44	20.125	1.190	9.99	0.841	100.09	272.01	402.83	130.83	1.2404	1.6518
45	20.596	1.198	9.70	0.835	103.12	273.90	402.89	128.99	1.2462	1.6505
46	21.075	1.206	9.41	0.829	106.27	275.81	402.92	127.10	1.2520	1.6492
47	21.563	1.214	9.13	0.823	109.53	277.75	402.92	125.17	1.2579	1.6478
48	22.060	1.223	8.86	0.817	112.91	279.71	402.91	123.19	1.2639	1.6463
49	22.565	1.233	8.59	0.811	116.42	281.70	402.86	121.16	1.2698	1.6448
50	23.079	1.242	8.33	0.805	120.08	283.72	402.79	119.07	1.2758	1.6432
51	23.603	1.252	8.07	0.799	123.88	285.76	402.69	116.93	1.2818	1.6416
52	24.135	1.263	7.82	0.792	127.85	287.84	402.55	114.72	1.2879	1.6399
53	24.677	1.273	7.58	0.785	131.99	289.94	402.38	112.44	1.2940	1.6381
54	25.228	1.285	7.34	0.778	136.32	292.08	402.18	110.09	1.3001	1.6362
55	25.789	1.297	7.10	0.771	140.85	294.26	401.93	107.67	1.3063	1.6342
56	26.359	1.309	6.87	0.764	145.60	296.47	401.64	105.17	1.3125	1.6321
57	26.940	1.323	6.64	0.756	150.60	298.71	401.30	102.59	1.3188	1.6299
58	27.530	1.337	6.42	0.748	155.86	301.00	400.91	99.91	1.3251	1.6275
59	28.132	1.352	6.20	0.740	161.42	303.33	400.46	97.13	1.3315	1.6250
60	28.743	1.368	5.98	0.731	167.31	305.70	399.95	94.25	1.3379	1.6224
61	29.366	1.385	5.76	0.722	173.58	308.11	399.36	91.25	1.3443	1.6195
62	30.000	1.403	5.55	0.713	180.27	310.57	398.69	88.11	1.3508	1.6164
63	30.645	1.423	5.33	0.703	187.46	313.08	397.92	84.84	1.3574	1.6131
64	31.302	1.445	5.12	0.692	195.23	315.64	397.04	81.40	1.3640	1.6095
65	31.971	1.469	4.91	0.681	203.70	318.25	396.02	77.77	1.3706	1.6055
66	32.653	1.496	4.69	0.668	213.03	320.92	394.83	73.91	1.3773	1.6010
67	33.347	1.527	4.47	0.655	223.48	323.64	393.42	69.78	1.3841	1.5959
68	34.056	1.562	4.25	0.640	235.46	326.42	391.71	65.29	1.3909	1.5900
69	34.778	1.604	4.00	0.624	249.75	329.26	389.54	60.28	1.3978	1.5827

12.2.5 Solkane® 152a

Release 1.02

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	0.150	0.923	1764.96	1.083	0.57	103.16	462.78	359.62	0.6006	2.2884
−59	0.160	0.925	1663.90	1.081	0.60	104.73	463.55	358.82	0.6077	2.2841
−58	0.170	0.927	1569.62	1.079	0.64	106.29	464.32	358.02	0.6149	2.2799
−57	0.181	0.928	1481.62	1.077	0.67	107.85	465.08	357.23	0.6220	2.2758
−56	0.193	0.930	1399.42	1.075	0.71	109.41	465.85	356.44	0.6291	2.2718
−55	0.205	0.932	1322.58	1.073	0.76	110.97	466.62	355.65	0.6362	2.2678
−54	0.217	0.933	1250.71	1.072	0.80	112.53	467.39	354.86	0.6433	2.2639
−53	0.231	0.935	1183.44	1.070	0.84	114.09	468.16	354.07	0.6503	2.2600
−52	0.245	0.937	1120.44	1.068	0.89	115.65	468.93	353.27	0.6573	2.2563
−51	0.259	0.938	1061.40	1.066	0.94	117.21	469.69	352.48	0.6644	2.2525
−50	0.274	0.940	1006.03	1.064	0.99	118.77	470.46	351.69	0.6714	2.2489
−49	0.290	0.942	954.07	1.062	1.05	120.33	471.23	350.90	0.6784	2.2453
−48	0.307	0.944	905.29	1.060	1.10	121.89	471.99	350.10	0.6853	2.2417
−47	0.325	0.945	859.46	1.058	1.16	123.45	472.76	349.31	0.6923	2.2383
−46	0.343	0.947	816.38	1.056	1.22	125.01	473.52	348.51	0.6992	2.2348
−45	0.362	0.949	775.87	1.054	1.29	126.57	474.28	347.71	0.7061	2.2315
−44	0.383	0.951	737.73	1.052	1.36	128.14	475.05	346.91	0.7130	2.2282
−43	0.404	0.952	701.82	1.050	1.42	129.71	475.81	346.10	0.7199	2.2249
−42	0.425	0.954	667.99	1.048	1.50	131.27	476.57	345.30	0.7268	2.2217
−41	0.448	0.956	636.10	1.046	1.57	132.85	477.33	344.49	0.7336	2.2186
−40	0.472	0.958	606.02	1.044	1.65	134.42	478.09	343.67	0.7405	2.2155
−39	0.497	0.960	577.63	1.042	1.73	135.99	478.85	342.86	0.7473	2.2124
−38	0.523	0.962	550.81	1.040	1.82	137.57	479.61	342.04	0.7541	2.2094
−37	0.550	0.963	525.49	1.038	1.90	139.15	480.36	341.21	0.7609	2.2065
−36	0.578	0.965	501.56	1.036	1.99	140.73	481.12	340.39	0.7676	2.2036
−35	0.607	0.967	478.92	1.034	2.09	142.32	481.87	339.55	0.7744	2.2007
−34	0.638	0.969	457.51	1.032	2.19	143.91	482.63	338.72	0.7811	2.1979
−33	0.669	0.971	437.24	1.030	2.29	145.50	483.38	337.88	0.7878	2.1951
−32	0.702	0.973	418.04	1.028	2.39	147.09	484.13	337.04	0.7945	2.1924
−31	0.736	0.975	399.85	1.026	2.50	148.69	484.88	336.19	0.8012	2.1897
−30	0.772	0.977	382.61	1.024	2.61	150.29	485.62	335.34	0.8078	2.1871
−29	0.808	0.979	366.26	1.022	2.73	151.89	486.37	334.48	0.8145	2.1845
−28	0.847	0.981	350.74	1.020	2.85	153.50	487.11	333.62	0.8211	2.1820
−27	0.886	0.983	336.01	1.018	2.98	155.11	487.86	332.75	0.8277	2.1795
−26	0.927	0.985	322.02	1.016	3.11	156.72	488.60	331.88	0.8343	2.1770
−25	0.970	0.987	308.73	1.013	3.24	158.34	489.34	331.00	0.8409	2.1746
−24	1.014	0.989	296.10	1.011	3.38	159.96	490.08	330.11	0.8474	2.1722
−23	1.060	0.991	284.09	1.009	3.52	161.59	490.81	329.23	0.8540	2.1698
−22	1.107	0.993	272.66	1.007	3.67	163.21	491.55	328.33	0.8605	2.1675
−21	1.156	0.995	261.79	1.005	3.82	164.85	492.28	327.43	0.8670	2.1652
−20	1.207	0.997	251.43	1.003	3.98	166.48	493.01	326.53	0.8735	2.1629
−19	1.259	0.999	241.57	1.001	4.14	168.12	493.74	325.62	0.8800	2.1607
−18	1.313	1.001	232.17	0.999	4.31	169.76	494.46	324.70	0.8864	2.1586
−17	1.369	1.003	223.21	0.997	4.48	171.41	495.19	323.78	0.8929	2.1564
−16	1.427	1.006	214.66	0.994	4.66	173.06	495.91	322.85	0.8993	2.1543
−15	1.487	1.008	206.51	0.992	4.84	174.71	496.63	321.92	0.9057	2.1522
−14	1.548	1.010	198.73	0.990	5.03	176.37	497.35	320.98	0.9121	2.1501
−13	1.612	1.012	191.31	0.988	5.23	178.03	498.06	320.03	0.9185	2.1481
−12	1.677	1.014	184.21	0.986	5.43	179.70	498.78	319.08	0.9248	2.1461
−11	1.745	1.017	177.43	0.984	5.64	181.37	499.49	318.12	0.9312	2.1442

Solkane® 152a

Release 1.02

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	1.815	1.019	170.96	0.981	5.85	183.04	500.20	317.16	0.9375	2.1422
−9	1.887	1.021	164.76	0.979	6.07	184.72	500.90	316.19	0.9438	2.1403
−8	1.961	1.023	158.84	0.977	6.30	186.40	501.61	315.21	0.9501	2.1385
−7	2.038	1.026	153.17	0.975	6.53	188.08	502.31	314.23	0.9564	2.1366
−6	2.116	1.028	147.75	0.973	6.77	189.77	503.01	313.24	0.9627	2.1348
−5	2.198	1.031	142.55	0.970	7.02	191.46	503.70	312.24	0.9689	2.1330
−4	2.281	1.033	137.58	0.968	7.27	193.16	504.40	311.24	0.9752	2.1312
−3	2.367	1.035	132.81	0.966	7.53	194.86	505.09	310.23	0.9814	2.1295
−2	2.455	1.038	128.24	0.964	7.80	196.56	505.77	309.21	0.9876	2.1277
−1	2.546	1.040	123.86	0.961	8.07	198.27	506.46	308.19	0.9938	2.1260
0	2.640	1.043	119.66	0.959	8.36	200.00	507.14	307.14	1.0000	2.1244
1	2.736	1.045	115.63	0.957	8.65	201.69	507.82	306.13	1.0062	2.1227
2	2.835	1.048	111.76	0.955	8.95	203.41	508.49	305.09	1.0123	2.1211
3	2.936	1.050	108.05	0.952	9.25	205.13	509.17	304.04	1.0185	2.1195
4	3.041	1.053	104.49	0.950	9.57	206.85	509.83	302.98	1.0246	2.1179
5	3.148	1.055	101.06	0.948	9.89	208.58	510.50	301.92	1.0308	2.1163
6	3.258	1.058	97.77	0.945	10.23	210.31	511.16	300.85	1.0369	2.1148
7	3.371	1.060	94.61	0.943	10.57	212.05	511.82	299.77	1.0430	2.1132
8	3.487	1.063	91.57	0.941	10.92	213.79	512.48	298.69	1.0491	2.1117
9	3.606	1.066	88.65	0.938	11.28	215.53	513.13	297.60	1.0551	2.1102
10	3.728	1.068	85.84	0.936	11.65	217.28	513.78	296.50	1.0612	2.1088
11	3.853	1.071	83.13	0.934	12.03	219.03	514.42	295.40	1.0673	2.1073
12	3.981	1.074	80.53	0.931	12.42	220.78	515.07	294.29	1.0733	2.1059
13	4.113	1.077	78.02	0.929	12.82	222.54	515.70	293.17	1.0793	2.1045
14	4.248	1.079	75.61	0.926	13.23	224.30	516.34	292.04	1.0854	2.1031
15	4.386	1.082	73.28	0.924	13.65	226.06	516.97	290.90	1.0914	2.1017
16	4.528	1.085	71.04	0.922	14.08	227.83	517.59	289.76	1.0974	2.1003
17	4.673	1.088	68.89	0.919	14.52	229.60	518.22	288.61	1.1034	2.0990
18	4.821	1.091	66.80	0.917	14.97	231.38	518.83	287.46	1.1094	2.0976
19	4.973	1.094	64.80	0.914	15.43	233.16	519.45	286.29	1.1154	2.0963
20	5.129	1.097	62.86	0.912	15.91	234.94	520.06	285.12	1.1214	2.0950
21	5.289	1.100	60.99	0.909	16.40	236.73	520.66	283.94	1.1273	2.0937
22	5.452	1.103	59.19	0.907	16.89	238.52	521.26	282.75	1.1333	2.0924
23	5.619	1.106	57.45	0.904	17.41	240.31	521.86	281.55	1.1392	2.0911
24	5.790	1.109	55.77	0.902	17.93	242.11	522.45	280.34	1.1452	2.0898
25	5.964	1.112	54.15	0.899	18.47	243.91	523.04	279.13	1.1511	2.0886
26	6.143	1.115	52.58	0.897	19.02	245.71	523.62	277.91	1.1571	2.0873
27	6.326	1.118	51.07	0.894	19.58	247.52	524.20	276.67	1.1630	2.0861
28	6.512	1.122	49.61	0.892	20.16	249.34	524.77	275.43	1.1689	2.0849
29	6.703	1.125	48.19	0.889	20.75	251.15	525.34	274.18	1.1749	2.0837
30	6.898	1.128	46.83	0.886	21.36	252.97	525.90	272.92	1.1808	2.0825
31	7.098	1.132	45.50	0.884	21.98	254.80	526.45	271.65	1.1867	2.0813
32	7.301	1.135	44.23	0.881	22.61	256.63	527.00	270.37	1.1926	2.0801
33	7.509	1.138	42.99	0.878	23.26	258.46	527.55	269.08	1.1985	2.0789
34	7.722	1.142	41.79	0.876	23.93	260.30	528.09	267.79	1.2044	2.0777
35	7.939	1.145	40.63	0.873	24.61	262.15	528.62	266.48	1.2103	2.0765
36	8.160	1.149	39.51	0.870	25.31	264.00	529.15	265.16	1.2162	2.0754
37	8.386	1.152	38.42	0.868	26.03	265.85	529.67	263.82	1.2221	2.0742
38	8.617	1.156	37.37	0.865	26.76	267.71	530.19	262.48	1.2281	2.0731
39	8.852	1.160	36.35	0.862	27.51	269.57	530.70	261.13	1.2340	2.0719

Solkane® 152a

Release 1.02

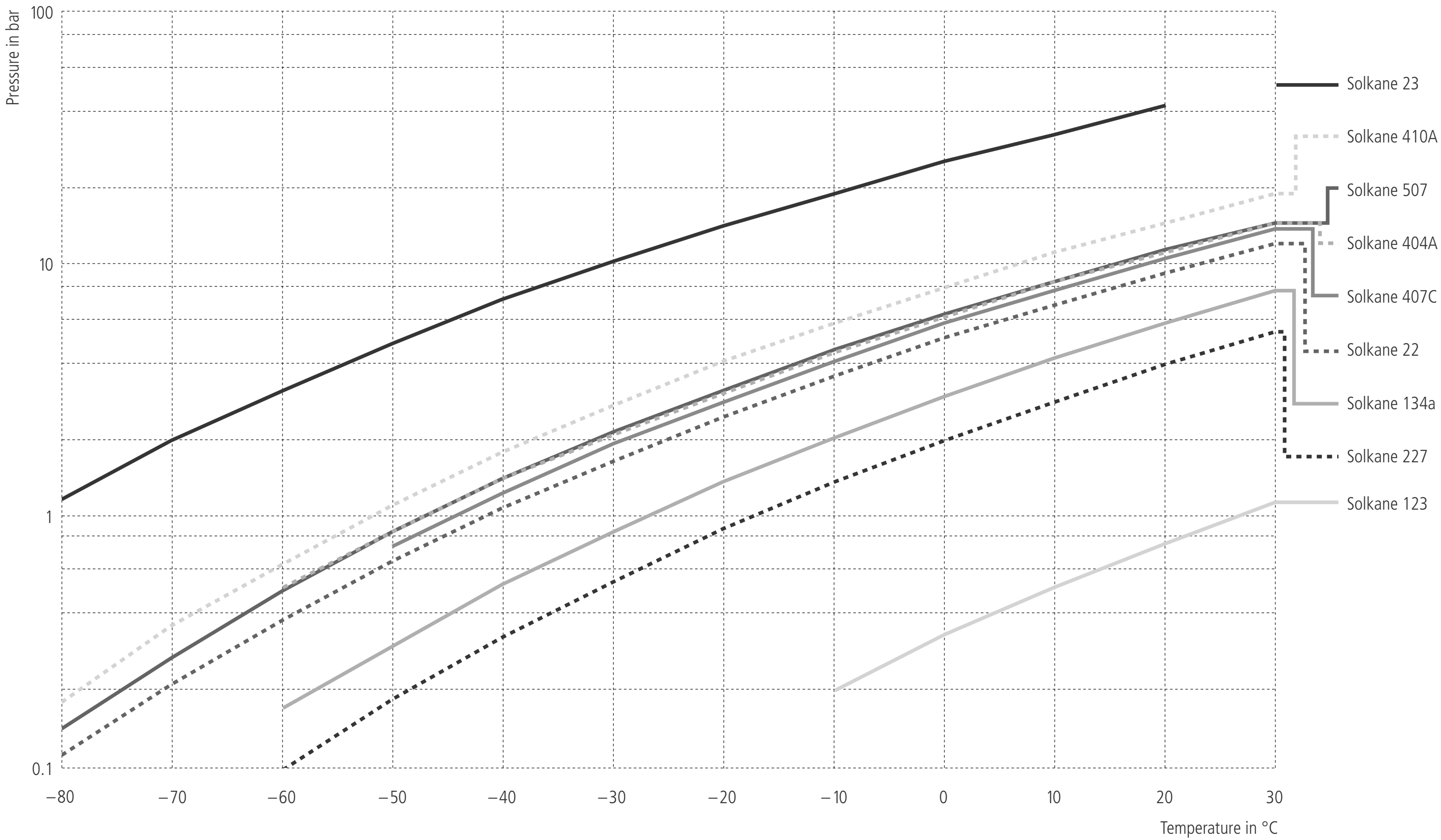
t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
40	9.093	1.164	35.36	0.859	28.28	271.44	531.20	259.76	1.2399	2.0708
41	9.338	1.167	34.41	0.857	29.06	273.31	531.70	258.39	1.2458	2.0696
42	9.588	1.171	33.48	0.854	29.87	275.19	532.19	257.00	1.2517	2.0685
43	9.843	1.175	32.58	0.851	30.70	277.07	532.67	255.60	1.2576	2.0673
44	10.103	1.179	31.71	0.848	31.54	278.96	533.14	254.18	1.2635	2.0662
45	10.368	1.183	30.86	0.845	32.41	280.86	533.61	252.75	1.2694	2.0651
46	10.639	1.187	30.04	0.842	33.29	282.76	534.07	251.31	1.2753	2.0639
47	10.914	1.191	29.24	0.839	34.20	284.67	534.53	249.85	1.2812	2.0628
48	11.195	1.195	28.47	0.837	35.13	286.59	534.97	248.38	1.2872	2.0616
49	11.482	1.200	27.72	0.834	36.08	288.51	535.41	246.90	1.2931	2.0605
50	11.774	1.204	26.99	0.831	37.06	290.44	535.84	245.40	1.2990	2.0594
51	12.071	1.208	26.28	0.828	38.05	292.37	536.26	243.88	1.3050	2.0582
52	12.374	1.213	25.59	0.825	39.08	294.32	536.67	242.35	1.3109	2.0571
53	12.683	1.217	24.92	0.821	40.13	296.27	537.07	240.80	1.3169	2.0559
54	12.997	1.222	24.27	0.818	41.20	298.23	537.46	239.24	1.3228	2.0547
55	13.317	1.227	23.64	0.815	42.30	300.20	537.85	237.65	1.3288	2.0536
56	13.643	1.231	23.03	0.812	43.43	302.17	538.22	236.05	1.3348	2.0524
57	13.975	1.236	22.43	0.809	44.58	304.16	538.59	234.43	1.3407	2.0512
58	14.313	1.241	21.85	0.806	45.77	306.15	538.94	232.79	1.3467	2.0500
59	14.657	1.246	21.29	0.803	46.98	308.15	539.29	231.13	1.3527	2.0488
60	15.007	1.251	20.74	0.799	48.22	310.17	539.62	229.45	1.3588	2.0476
61	15.363	1.256	20.20	0.796	49.50	312.19	539.94	227.75	1.3648	2.0464
62	15.726	1.262	19.68	0.793	50.81	314.22	540.25	226.03	1.3708	2.0452
63	16.095	1.267	19.18	0.789	52.15	316.27	540.55	224.28	1.3769	2.0439
64	16.471	1.272	18.68	0.786	53.53	318.32	540.83	222.51	1.3829	2.0426
65	16.853	1.278	18.20	0.782	54.94	320.39	541.11	220.72	1.3890	2.0414
66	17.242	1.284	17.73	0.779	56.39	322.47	541.37	218.90	1.3951	2.0401
67	17.637	1.290	17.28	0.775	57.87	324.56	541.62	217.06	1.4012	2.0388
68	18.039	1.295	16.83	0.772	59.40	326.66	541.85	215.19	1.4073	2.0374
69	18.448	1.302	16.40	0.768	60.97	328.78	542.07	213.29	1.4135	2.0361
70	18.864	1.308	15.98	0.765	62.58	330.91	542.27	211.36	1.4196	2.0347
71	19.287	1.314	15.57	0.761	64.23	333.06	542.46	209.40	1.4258	2.0333
72	19.717	1.321	15.17	0.757	65.93	335.21	542.63	207.42	1.4320	2.0319
73	20.154	1.327	14.78	0.753	67.68	337.39	542.79	205.40	1.4382	2.0305
74	20.599	1.334	14.39	0.750	69.48	339.58	542.92	203.35	1.4444	2.0290
75	21.051	1.341	14.02	0.746	71.33	341.78	543.04	201.26	1.4507	2.0275
76	21.510	1.348	13.66	0.742	73.23	344.01	543.15	199.14	1.4570	2.0260
77	21.977	1.355	13.30	0.738	75.19	346.25	543.23	196.98	1.4632	2.0244
78	22.452	1.363	12.95	0.734	77.20	348.50	543.29	194.79	1.4696	2.0228
79	22.934	1.371	12.61	0.730	79.28	350.78	543.33	192.55	1.4759	2.0211
80	23.424	1.379	12.28	0.725	81.42	353.07	543.35	190.27	1.4823	2.0195
81	23.922	1.387	11.96	0.721	83.63	355.39	543.34	187.95	1.4886	2.0177
82	24.429	1.395	11.64	0.717	85.91	357.72	543.31	185.59	1.4951	2.0160
83	24.943	1.404	11.33	0.712	88.26	360.08	543.26	183.18	1.5015	2.0142
84	25.465	1.413	11.03	0.708	90.69	362.45	543.17	180.72	1.5080	2.0123
85	25.996	1.422	10.73	0.703	93.20	364.85	543.06	178.22	1.5144	2.0104
86	26.536	1.431	10.44	0.699	95.80	367.27	542.92	175.65	1.5210	2.0084
87	27.083	1.441	10.15	0.694	98.49	369.71	542.75	173.04	1.5275	2.0063
88	27.640	1.452	9.87	0.689	101.28	372.18	542.55	170.37	1.5341	2.0042
89	28.206	1.462	9.60	0.684	104.18	374.67	542.30	167.63	1.5407	2.0020

Solkane® 152a

Release 1.02

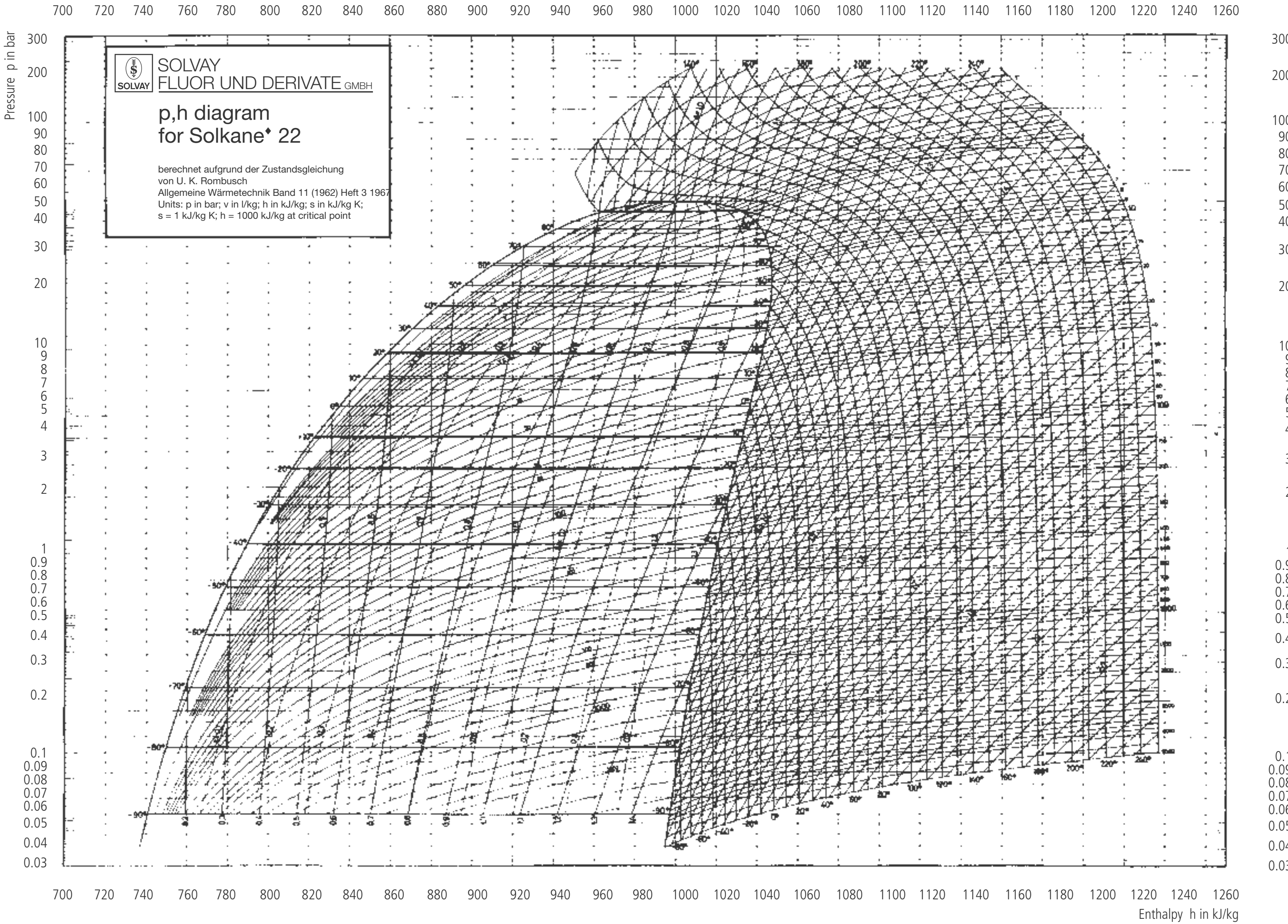
t [°C]	p [bar]	v´ [dm³/kg]	v´´ [dm³/kg]	ρ´ [kg/dm³]	ρ´´ [kg/m³]	h´ [kJ/kg]	h´´ [kJ/kg]	r [kJ/kg]	s´ [kJ/kg·K]	s´´ [kJ/kg·K]
90	28.780	1.473	9.33	0.679	107.18	377.19	542.03	164.83	1.5473	1.9998
91	29.363	1.485	9.07	0.674	110.30	379.74	541.71	161.97	1.5540	1.9974
92	29.956	1.497	8.81	0.668	113.55	382.31	541.34	159.04	1.5607	1.9950
93	30.558	1.509	8.55	0.663	116.93	384.91	540.94	156.03	1.5674	1.9924
94	31.170	1.522	8.30	0.657	120.47	387.54	540.48	152.94	1.5742	1.9898
95	31.791	1.536	8.05	0.651	124.16	390.19	539.96	149.77	1.5810	1.9870
96	32.422	1.550	7.81	0.645	128.03	392.88	539.39	146.51	1.5878	1.9841
97	33.064	1.565	7.57	0.639	132.08	395.60	538.75	143.15	1.5947	1.9810
98	33.715	1.582	7.33	0.632	136.35	398.36	538.05	139.69	1.6016	1.9778
99	34.377	1.599	7.10	0.626	140.86	401.14	537.26	136.12	1.6086	1.9744
100	35.050	1.617	6.87	0.619	145.62	403.96	536.38	132.43	1.6155	1.9708
101	35.733	1.636	6.64	0.611	150.68	406.81	535.41	128.60	1.6226	1.9670
102	36.428	1.657	6.41	0.603	156.08	409.70	534.33	124.62	1.6296	1.9628
103	37.134	1.680	6.18	0.595	161.87	412.63	533.11	120.48	1.6368	1.9584
104	37.852	1.704	5.95	0.587	168.11	415.60	531.75	116.15	1.6439	1.9536
105	38.583	1.732	5.72	0.578	174.89	418.60	530.20	111.60	1.6511	1.9484
106	39.326	1.762	5.48	0.568	182.35	421.64	528.43	106.79	1.6583	1.9427
107	40.082	1.796	5.25	0.557	190.64	424.73	526.39	101.66	1.6656	1.9362
108	40.852	1.835	5.00	0.545	200.04	427.86	523.99	96.13	1.6729	1.9289
109	41.637	1.881	4.74	0.532	210.99	431.03	521.09	90.06	1.6803	1.9203

13 Vapor Pressure Diagram

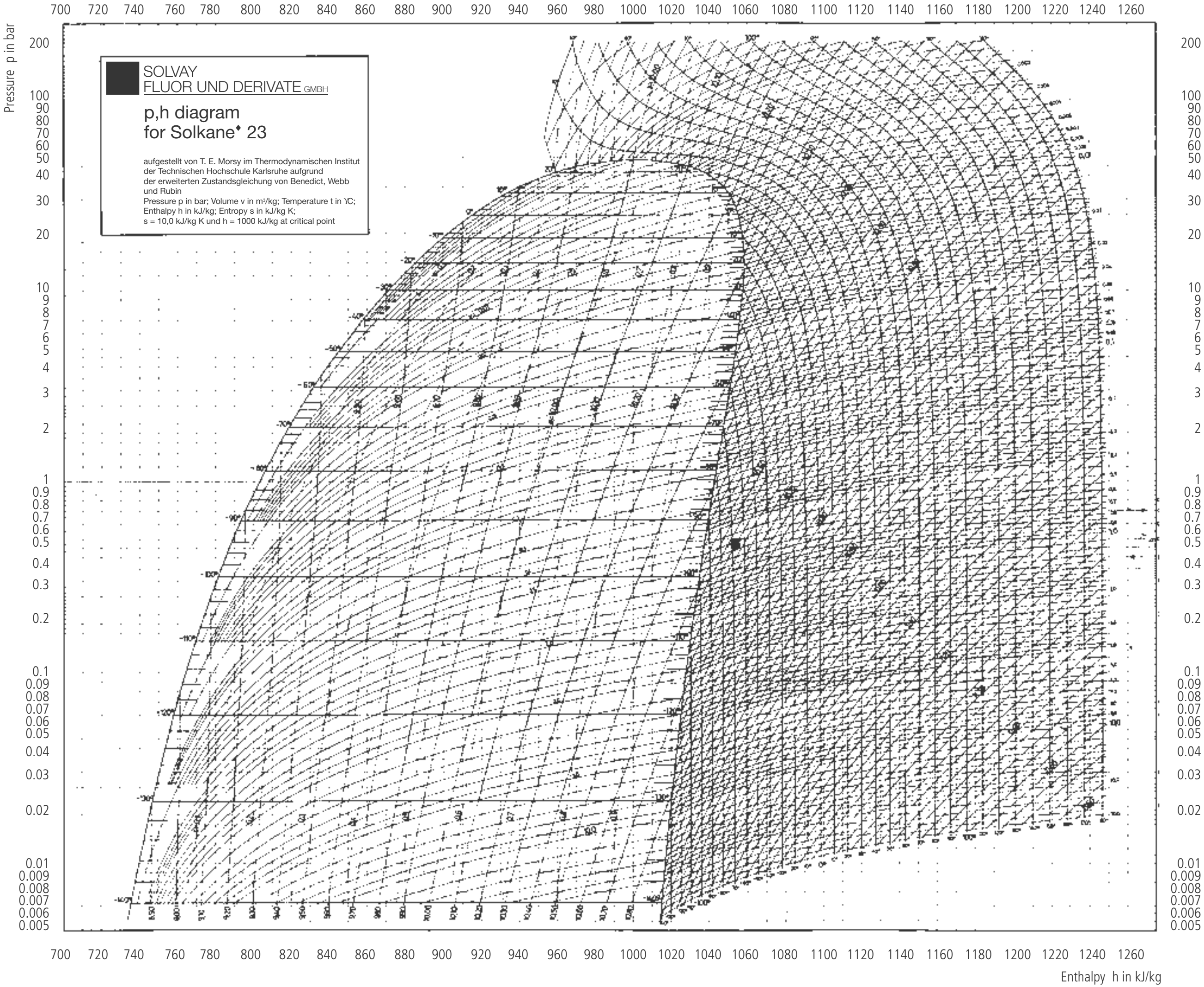


14 Mollier(-lg p, h-)diagrams

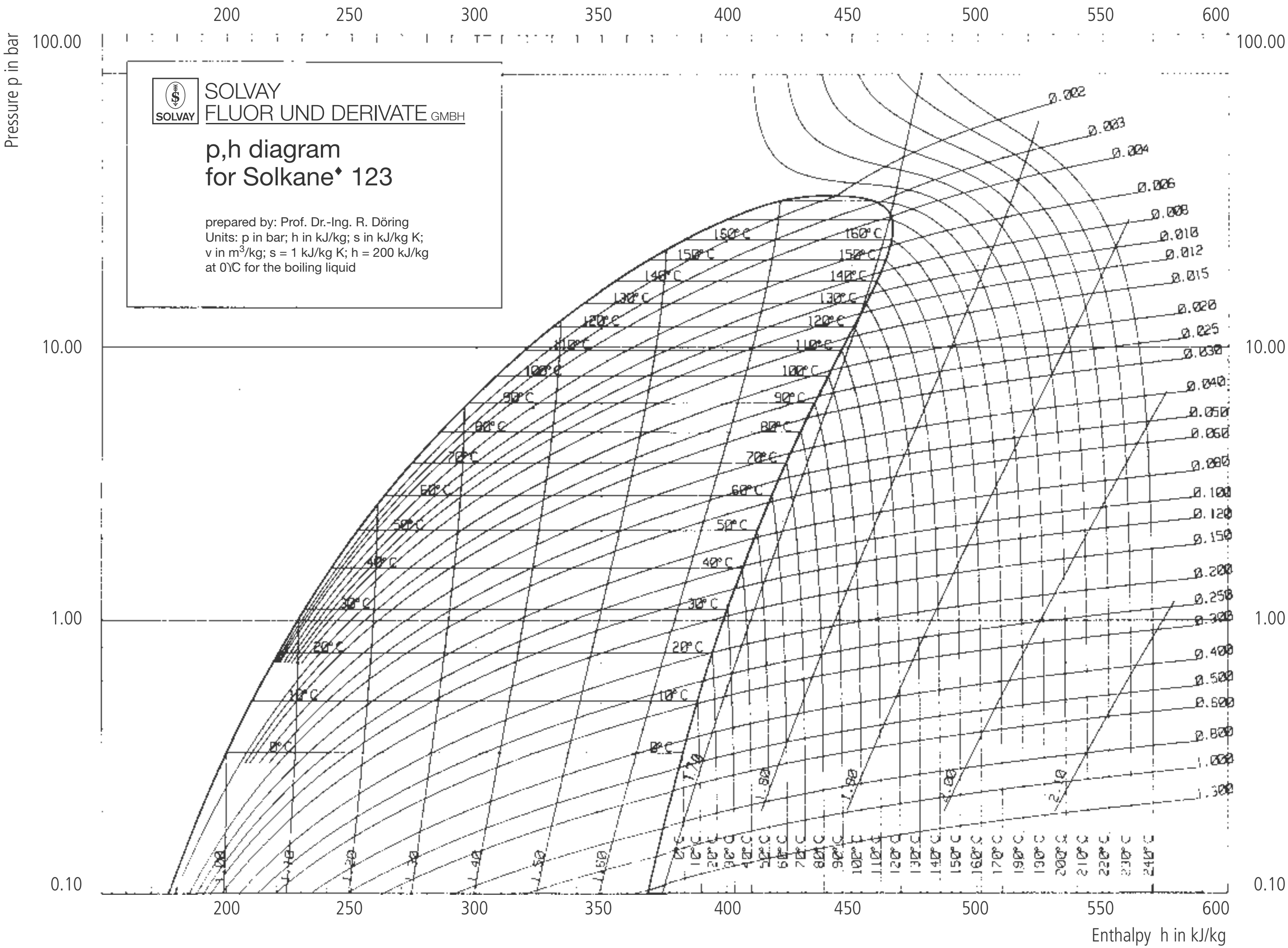
14.1.1 Solkane® 22



14.1.2 Solkane® 23

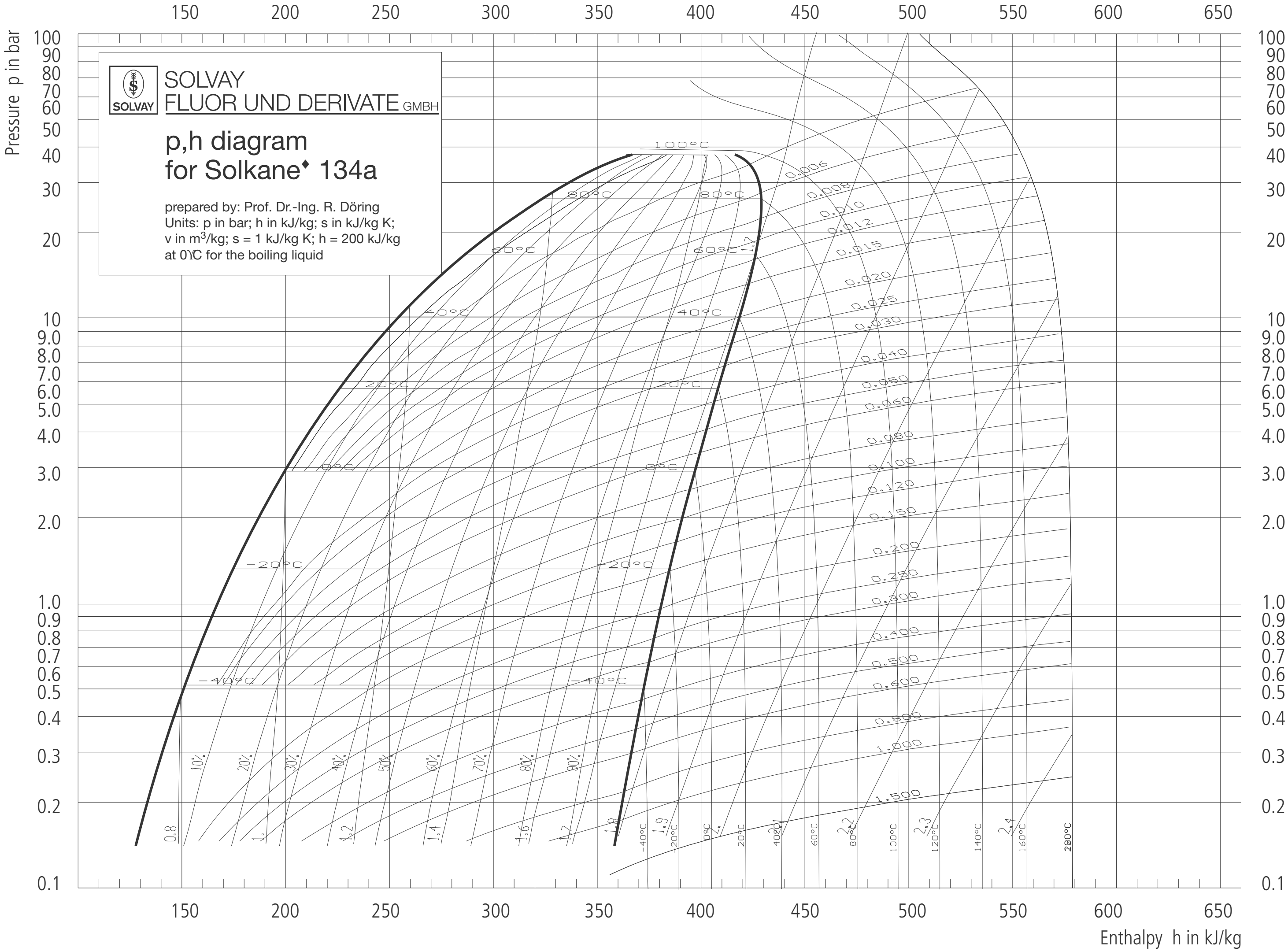


14.1.3 Solkane® 123



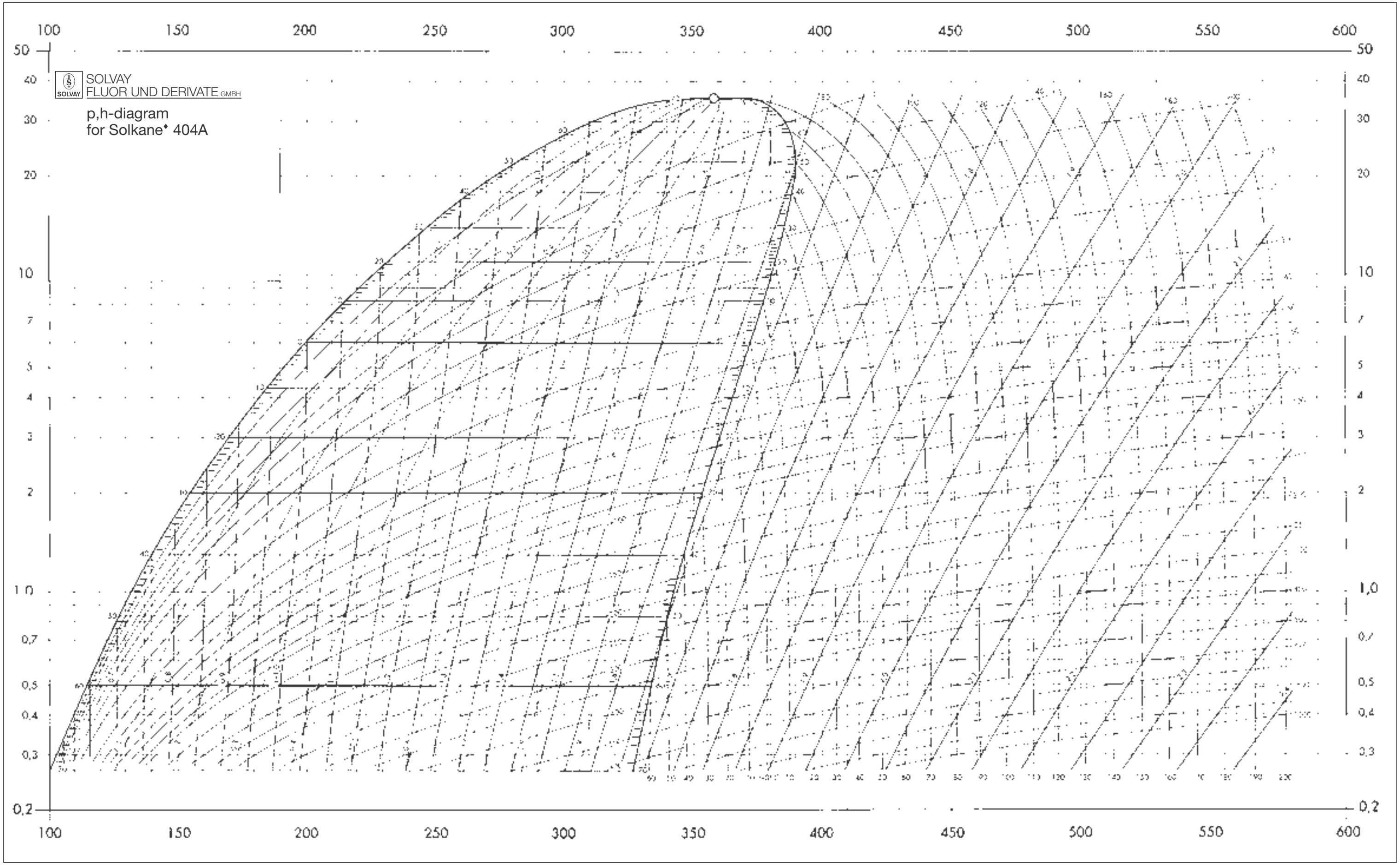
14.1.4 Solkane® 125

14.1.5 Solkane® 134a



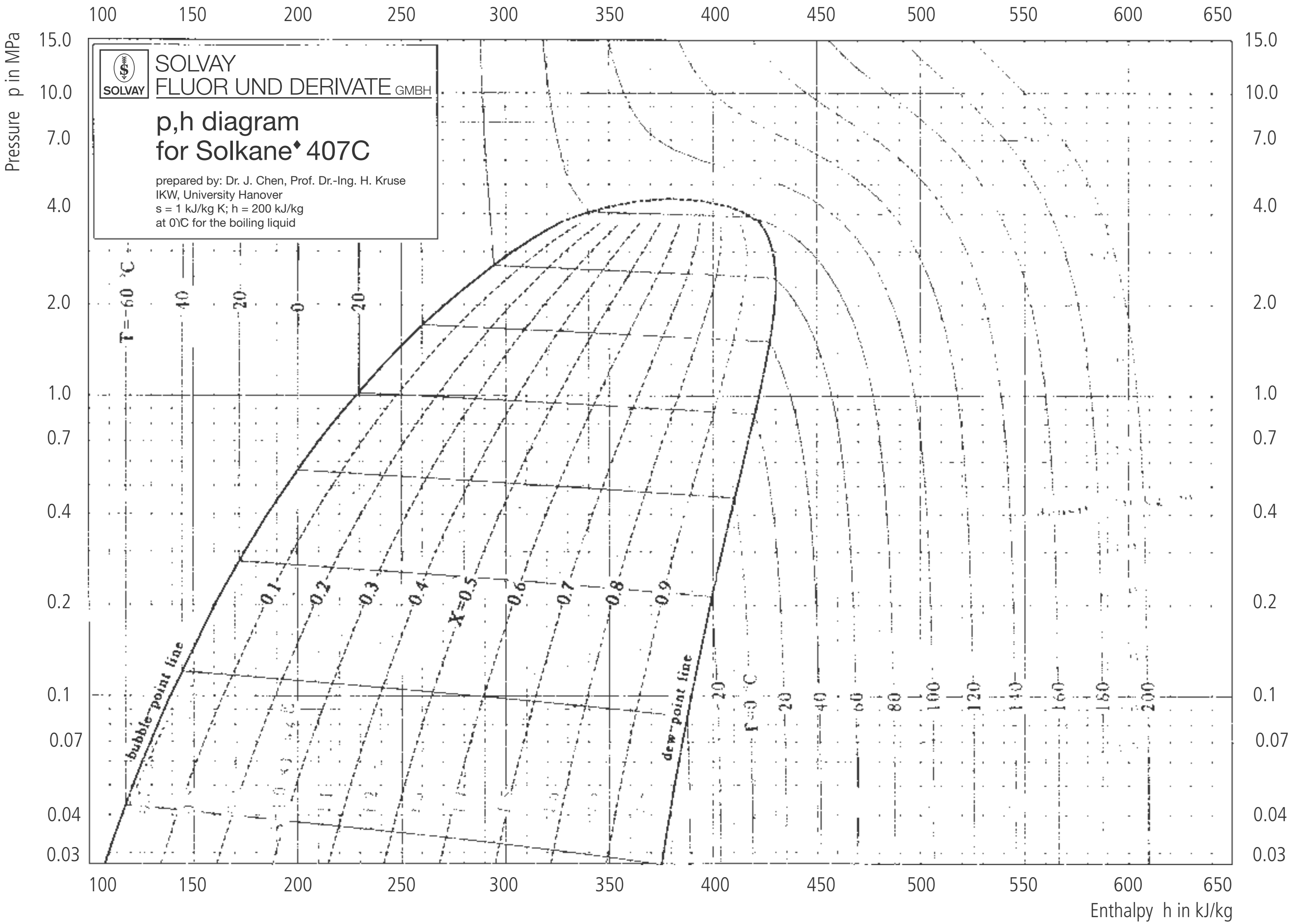
14.1.6 Solkane® 404A

Pressure p in bar

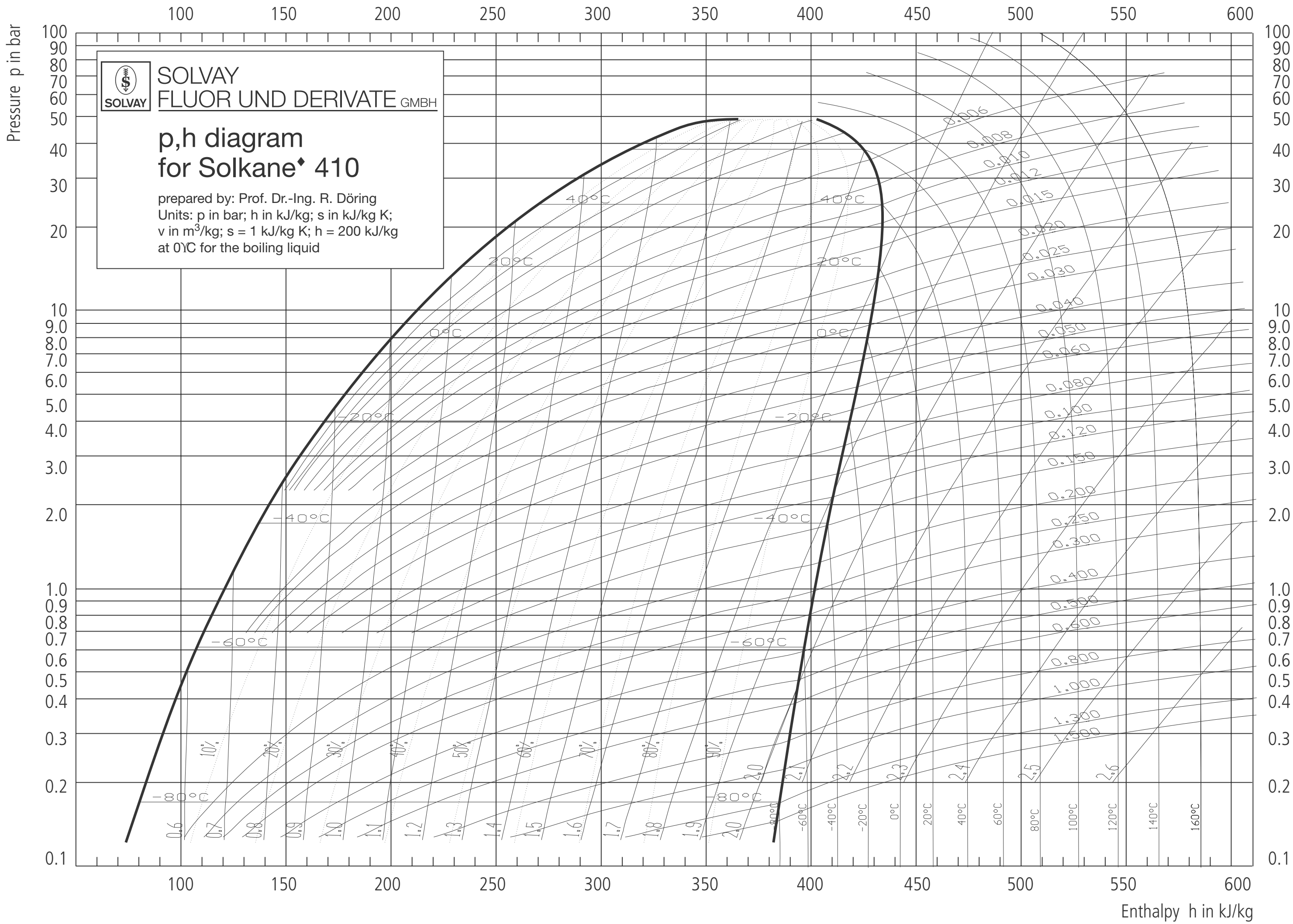


Enthalpy h in kJ/kg

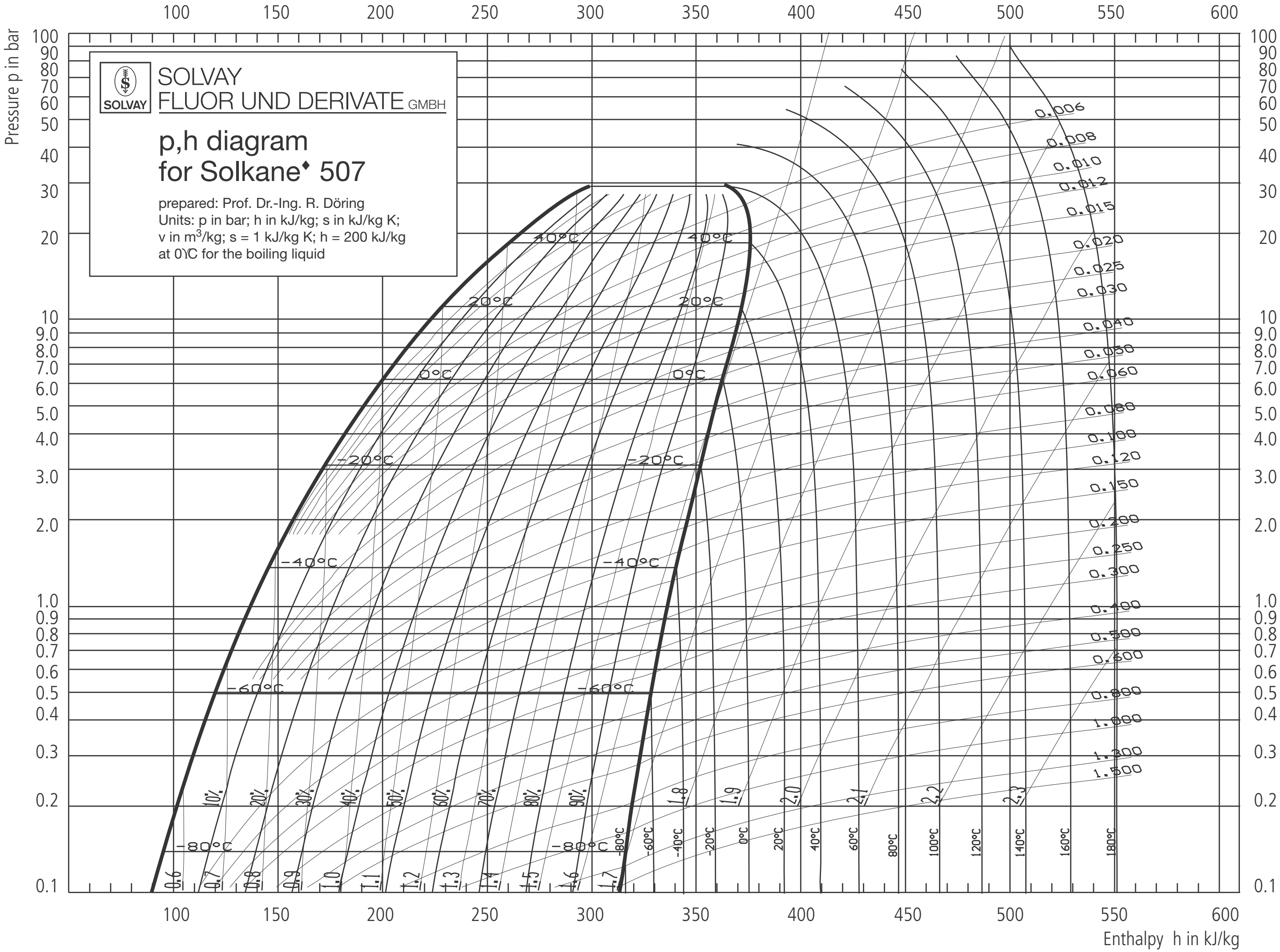
14.1.7 Solkane® 407C



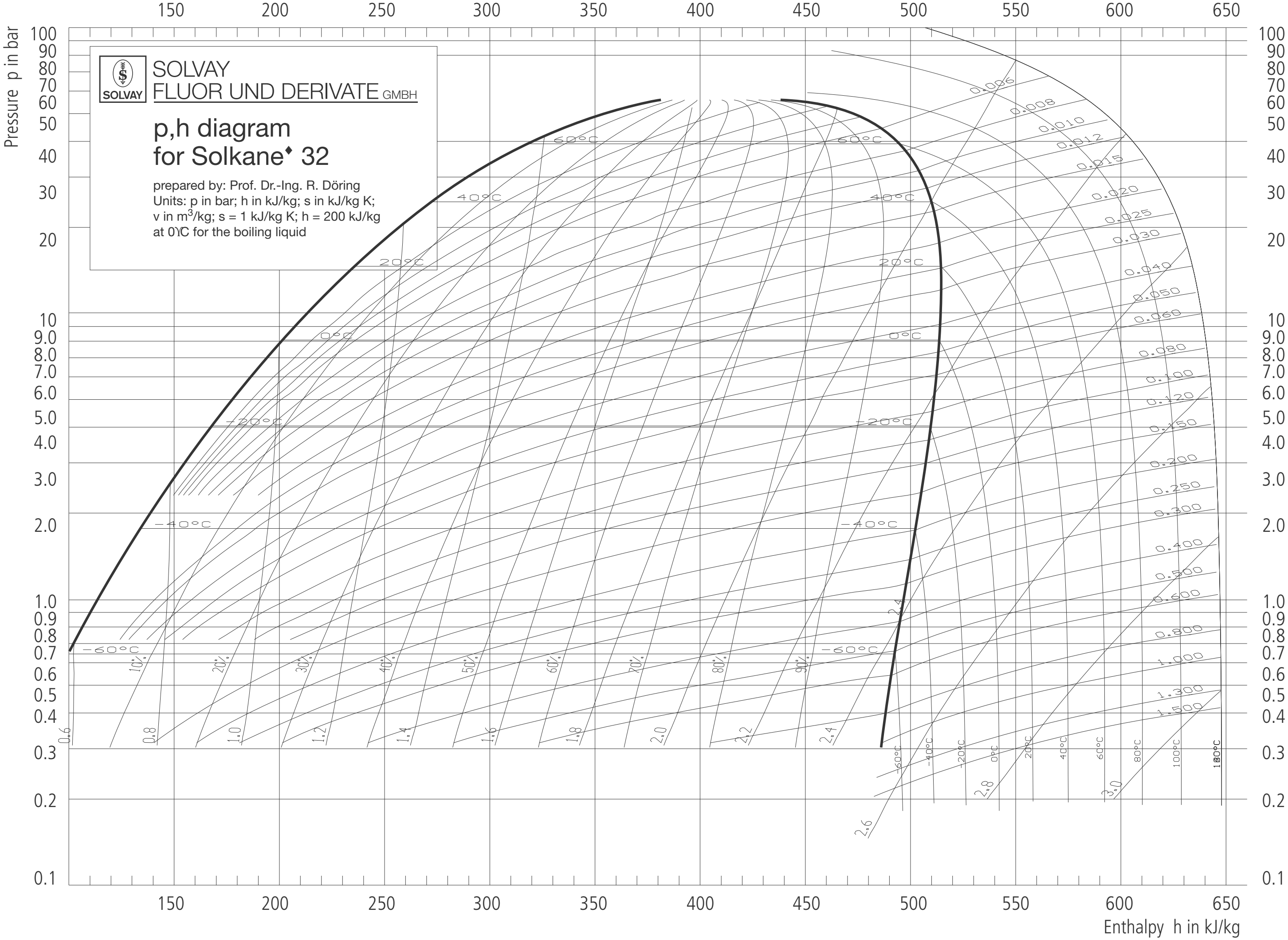
14.1.8 Solkane® 410



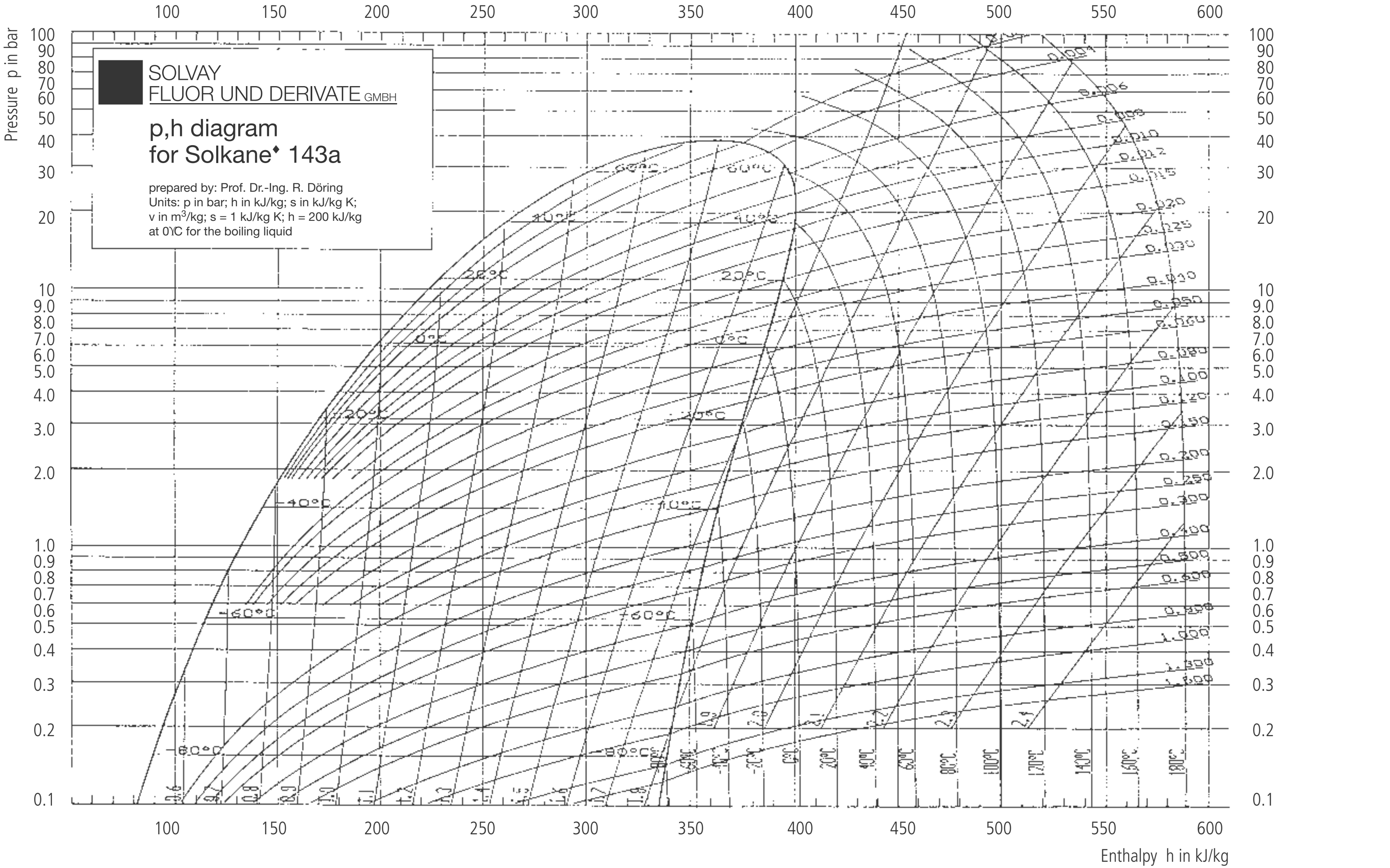
14.1.9 Solkane® 507



14.2.1 Solkane® 32



14.2.2 Solkane® 143a



14.2.3 Solkane® 152a