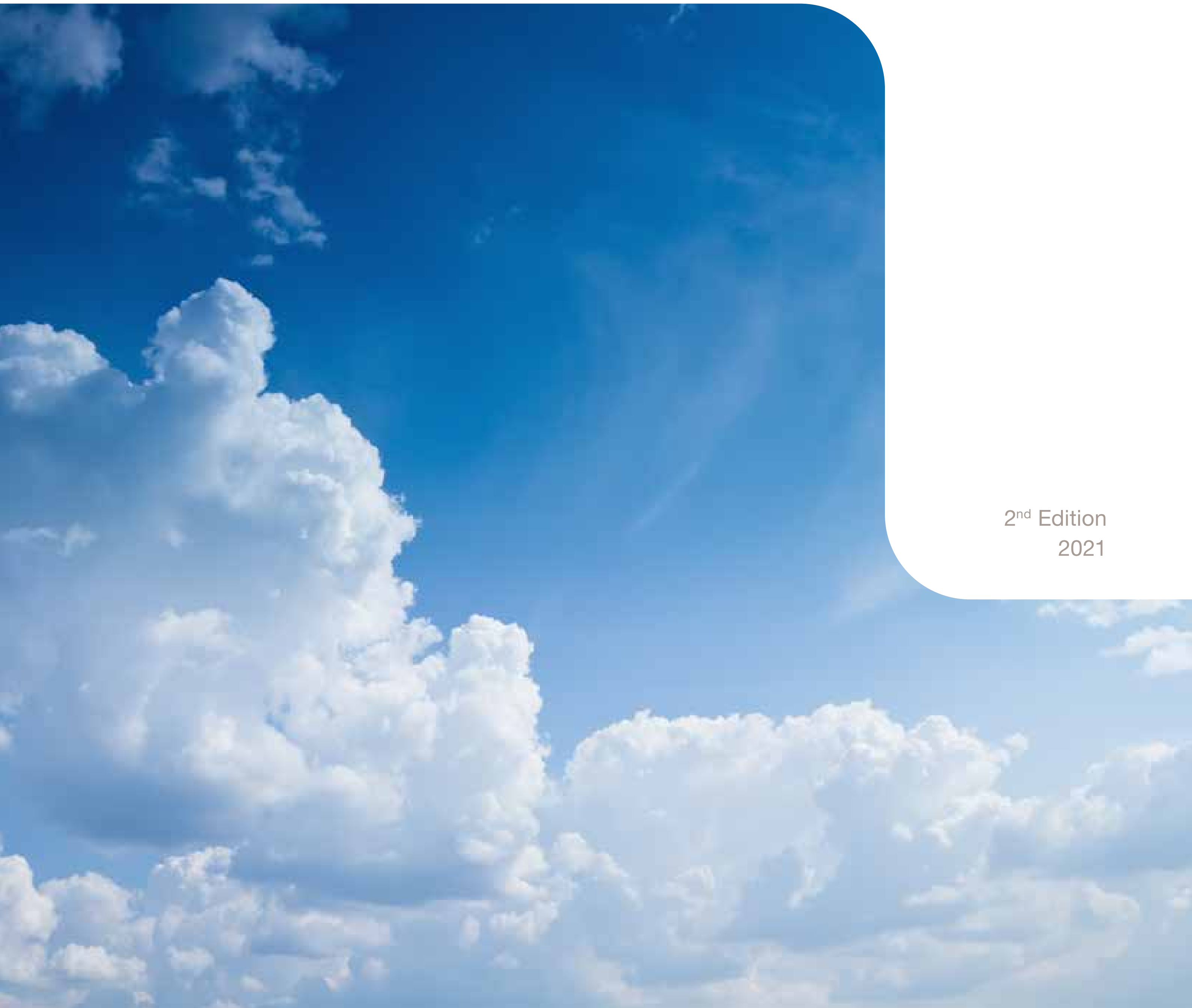
WHITE PAPER

Navigating a changing refrigerants market

A guide for selecting and accommodating refrigerants for diverse heating and cooling applications



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1. Introduction

A massive change is currently underway in the refrigerants market. Driven by environmental concerns, legislation is pushing a phase out of traditional F-gas refrigerants (hydrofluorocarbons - HFCs) in favour of alternatives with lower global warming potential (GWP).

The impact of these new rules will dramatically alter the way heating and cooling applications are performed in a wide range of industries over the course of the coming years. Businesses where these applications are central are thus facing a major question:

Which refrigerant makes the best sense for my needs?

While this is hardly the first time the refrigerants market has seen big changes, the current shift differs from past experiences in the sheer number of refrigerant options that are available. Historically, the market has largely seen one-to-one transitions. Today, the reality is much more complicated. Regulatory guidelines mean that businesses face different requirements depending on where and how they operate.

For some, new, low-GWP, synthetic refrigerants offer a solution. Others, however, consider these as a new long-term toxic risk if emitted into the environment. This is why natural refrigerants, which have no negative long-term environmental effects and close to zero GWP, are becoming increasingly popular alternatives. However, the potential toxicity, flammability, or high-pressure demands of these refrigerants mean there are significant safety considerations to take into account.

In other words, we know that we need to move to low-GWP refrigerants, but we also know that there is no one-size-fits-all alternative. However, there has been intense innovation in new technologies to safely and efficiently adapt both synthetic and natural low-GWP refrigerants to today's heating and cooling applications. Every year brings new developments of compressors, heat exchangers, controls and various system designs.

This whitepaper seeks to demystify the confusing process of choosing the right low-GWP refrigerant for a specific application. The following chapters will provide a useful overview of existing legislative requirements and current market trends before offering a breakdown of different low-GWP refrigerants available today. Lastly, this text will look at new technologies for using alternative refrigerants in various air conditioning, heating, and refrigeration applications.

2. Regulatory overview

The complexity of the changing refrigerants market is driven in part by the ongoing development of legal frameworks, including the 2016 Paris Agreement. To prevent global temperature increase from exceeding 2°C above pre-industrial levels, signatories to the agreement are responsible for setting national targets to limit greenhouse gas emissions. This has contributed to the increased international focus on HFC (hydrofluorocarbon) refrigerants that contribute to global warming.

However, there is currently no global standard for which refrigerants must be phased out and by when. Instead, the situation is vastly different from country to country. The regulations that apply to a given business – as well as the options available to them – depend entirely on where they operate and the application in which the refrigerant is used.

Kigali amendment to the Montreal Protocol

One major effort to curb high-GWP refrigerants has been a 2016 amendment to the Montreal Protocol. In force since 1989, the Montreal Protocol on Substances that Deplete the Ozone Layer was originally developed to phase out ozone-damaging refrigerants like CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons). While the protocol has been almost universally successful worldwide, HFCs became the primary replacement for these earlier refrigerants.

At the 28th Meeting of the Parties to the Montreal Protocol in the Rwandan capital of Kigali, the protocol was amended to target planet-warming HFC gases. The new agreement involves phasing out HFCs by 2047, with different timetables for different countries. Highly developed regions were required to reduce production and consumption of HFCs beginning in 2019. Much of the rest of the world, including China and Brazil, will freeze HFC use by 2024. A smaller group of countries that includes India has until 2028 to institute a freeze. Although the updated Montreal Protocol provides a timetable, the Kigali amendment was not as ambitious as initially anticipated.

For businesses, this has meant a lack of clarity regarding expectations as well as the alternatives available to them. In particular, the protocol does not define what constitutes a suitable low-GWP refrigerant for replacing HFCs. For the time being, these issues have been left to the determination of regional and national legislatures.

European Union F-gas Regulation

Currently, the European Union's regulation on fluorinated greenhouse gases represents the most substantial requirements for curbing HFC usage. Originally adopted in 2006, it was updated in 2014 and is up for revision again in 2021 to set concrete GWP limits for acceptable replacement refrigerants. While the regulation applies to all companies operating within EU member states, specific GWP levels, as well as the deadlines for meeting them, differ regarding the application in question, as shown in the following table. European businesses weighing alternative refrigerant options must therefore consider that requirements will depend on the way the refrigerant is used. See the below limits as of the 2014 regulatory update.

Table 2.1: GWP limits for refrigerants in the EU

Application	GWP Limit	Deadline
Domestic refrigeration	150	2015
Stationary refrigeration[1]	2500	2020
Hermetically sealed commercial refrigeration	150	2022
Centralized commercial refrigeration[2]	150	2022
Moveable room AC	150	2020
Single split AC[3]	750	2025

[1] ≥ -50°C

[2] ≥ 40 kW Exception in place for the primary circuit of cascade systems, where refrigerants with a GWP < 1500 may be used.

[3] < 3 kg of fluorinated greenhouse gases.

3. Refrigerant categories

There are two main groups of low-GWP refrigerants:

- Synthetic refrigerants, which are invented
- Natural refrigerants, which are substances that already exist in our environment

3.1 Synthetic refrigerants

While there are many individual options for synthetic refrigerants, we can broadly organize these into two main categories:

- High-density HFCs refrigerants with lower GWP, such as R32
- Low-density refrigerants, including both hydrofluoroolefins (HFOs) and HFC-HFO blends

Understanding the different options according to these categories greatly simplifies the process of selection.

3.1.1 High-density refrigerants (HFCs with lower GWP)

High-density refrigerants represent the first main category of alternatives on the market today. The most prominent of these is R32 or difluoromethane. There are also a few similar, so-called R32-like refrigerants that fall into this category.

As an organic compound with zero-ozone-depletion potential, R32 offers clear environmental benefits compared to earlier CFCs or HCFCs. R32 also transfers heat more efficiently than refrigerants such as R410A, meaning it can help dramatically reduce energy consumption in, for example, air conditioning applications.

However, R32 also presents new challenges. Like many alternative refrigerants, it is mildly flammable. The right equipment and proper safety measures are therefore essential. Additionally, businesses should consider that R32 has a GWP of 675. This is significantly lower than R22 or R410A, but it means that R32 is not be appropriate for applications where, for example, European Union or Japanese targets have set thresholds of 150 or lower. Businesses looking for an environmental argument to differentiate their production from the competition may likewise want to consider alternatives with a lower GWP.

3.1.2 Low-density refrigerants (HFOs and HFC-HFO blends)

The second category of today's synthetic refrigerants are the low-density variety. This term largely refers to HFOs and HFO blends. Like HFCs, HFOs are composed from hydrogen, fluorine, and carbon. However, as an unsaturated compound, HFOs are more reactive due to the presence of a carbon-carbon bond. This also means that HFOs are a more environmentally friendly alternative to both HFCs and CFCs. Like higher density refrigerants, they offer an ozone-depletion potential of zero. In addition, the GWP of HFOs can be as low as 0.1% of comparable HFCs.

It is nevertheless important to keep in mind that the exact GWP will vary depending on the HFO blend in question. For businesses operating in the European Union or Japan, it may therefore not provide a suitable long-term solution in some applications. Furthermore, there are once again safety issues to consider.

Like R32, the flammability of some HFOs can be a risk if not properly accounted for. A secondary concern is that HFOs can decompose under high temperatures, resulting in the formation of hydrogen fluoride and, subsequently, dangerous acids.

3.2 Natural refrigerants

Business seeking to minimize the global warming potential of their heating and cooling applications have largely turned to natural refrigerants, the third main category of alternatives.

The term natural refrigerant is mainly used today to refer to three options:

- Hydrocarbons like R290 (propane), R600a (isobutane), R1270 (propene)
- R717 (ammonia)
- R744 (carbon dioxide/CO_2)

However, we can also include air and water as "natural refrigerants".

Natural refrigerants offer the lowest GWP levels available on the market today. Propane has a GWP of just 3, CO_2 has a GWP of 1 and ammonia's is 0. The selection of these refrigerants could thus be an easy choice. However, their usage entails several other trade-offs that require further consideration. The good news is that there is constant progress within both technological development and regulation, making natural refrigerants a viable choice for a growing number of applications.

3.2.1 Hydrocarbons

Refrigeration plants using hydrocarbons have been in operation all over the world for many years. This not only because it is a natural refrigerant, but also due its ideal refrigerant characteristics and widespread availability at low cost.

- R600a (isobutane) is already widely used in domestic refrigerators.
- R290 (propane) has good thermal properties for efficient use in all areas of refrigeration, as well as air conditioning and heat pump applications.

However, hydrocarbons are flammable, which necessitates increased safety measures and careful following of relevant regulations. The current International Electrotechnical Commission (IEC) standard for self-contained commercial refrigeration cabinets (60335-2-89) recently changed the maximum allowed refrigerant charge. For hydrocarbons, it will be increased from 150g to approximately 500g. This will create more possibilities for the use of hydrocarbons if and when local regulations move to the new IEC standard.

3.2.2 Ammonia (R717)

Ammonia is one of the most efficient refrigerants available, with wide usage possibilities within a wide range of temperatures and capacities. Apart being a natural substance, the use of ammonia opens for possibilities to reduce energy consumption and secure long-term cost efficiency and sustainability.

The downside of ammonia is that it is a toxic refrigerant and can also be flammable at certain concentrations. That is why all ammonia systems must be designed with safety in mind.

Fortunately, with ignition energy 50 times higher than that of natural gas, ammonia will not burn without a supporting flame. Due to the high affinity of ammonia for atmospheric humidity it is rated as “hardly flammable”. Ammonia also has a characteristic, sharp smell, which provides a clear warning sign of a toxic leak, even when concentrations below of 3 mg/m^3 are present in the air. This means that ammonia can be detected by humans at levels far below those which endanger health (>1,750 mg/m^3). Furthermore, ammonia is lighter than air, and will rise quickly into the atmosphere if well ventilated. Clear safety rules for installing equipment with ammonia exist in most parts of the world.

To further increase safety, there is a trend to design systems that reduce the ammonia charge by applying a secondary cooling system. This means connecting the system via liquid evaporators to a secondary fluid circuit on the cold side. In some cases, it can involve containing the ammonia charge completely in the machine room via liquid cooled condensers on the hot side. This substantially reduces ammonia charge while using efficient heat exchangers that maintain high energy efficiency. Using CO_2 as secondary fluid (as in a cascade system or as a brine) could also be a good, efficient option in applications with very low temperatures.

3.2.3 CO_2 (Carbon dioxide/R744)

Although CO_2 is not the most efficient natural refrigerant, it is gaining popularity due to the fact that it is neither flammable nor toxic. However, there is a remaining danger to human health, since carbon dioxide is an odourless gas that is heavier than air and can have a narcotic and asphyxiating effect at high concentrations in enclosed environments. Leak detectors should therefore be present where there is a potential risk.

A further consideration is that use of CO_2 as a refrigerant requires high operating pressures. Another potential risk is that standstill pressure in systems where CO_2 is used with other refrigerants (for example, cascade systems) can be higher than the maximum rated suction pressure. In these cases, a pressure-relief valve is required to protect the system from a sudden rise in pressure after, for example, a power failure.

In the last 10-15 years, system components, pipe work, tools and equipment have been developed to safely handle the pressure challenges associate with CO_2. New technologies are constantly emerging to increase efficiency in a transcritical systems using CO_2.

A transcritical CO_2 system only uses CO_2 and can work above the critical point. The term critical point does not refer to a danger point, but rather to the point above which it exists as a supercritical fluid. For CO_2, the critical point is at 31°C (88°F), which is lower than that of other commonly used refrigerants. A system using CO_2 operates in transcritical mode when the condensing temperature exceeds 31° C. At this point, no distinction can be made between the refrigerant as a fluid or a vapor. Due to this, the condenser acts as a kind of gas cooler.

A transcritical system's efficiency will decrease in a warm climate area when it needs to operate above the critical point for longer periods. However, recently developed technologies can allow the system to operate efficiency also in warm climates. Examples include adiabatic condensers, parallel compressors, ejectors or subcooling systems. Recovering high temperature gas energy for heating is an additional way of increasing total efficiency of a transcritical CO_2 installation.

4. Market trends

As the previous chapter indicates, the first step for selecting a new refrigerant is to consider which alternative makes the most sense for the intended application according to local requirements. However, even within application areas, there are often several options to choose from that will comply with national or regional regulations.

It is therefore important to consider how a decision may impact competitive advantage: How do I want to position my product in the market? How do I want to differentiate the product or even the company from my competitors?

The answers to these questions can play a big role. Within heating and cooling application areas today, there are several clear trends that provide a starting point for finding these answers. It is important to consider how a decision may impact competitive advantage.

4.1 Heat pumps

In the domestic heat pump markets of highly developed regions, synthetic R32 (difluoromethane) has emerged as the leading alternative to the previous R410A standard for heat pump applications. However, R32 is not the only option available. An increasing number of producers are selecting the natural refrigerant R290 (propane) with a substantially lower GWP than R32. CO_2 is used as well, especially when higher temperatures are required.

Larger commercial and industrial heat pumps which are increasingly used to supply sustainable heating energy to local or district heating networks. These installations are mostly reliant on R717 (ammonia) as the leading natural refrigerant, but the use of synthetic HFO blends is also evolving.

Heat pumps, Alternative refrigerants	Substance	GWP	Composition	Replacement for
Natural refrigerants	R290 (propane)	3	–	R134a R407A R410A
	R717 (ammonia)	0	–	R134a R407A R410A
	R744 (CO_2)	1	–	R134a R407A R410A
Synthetic HFC-HFO blends	R452B	698	R32/125/1234yf	R410A
	R454B	466	R32/1234yf	R410A
	R455B	148	R32/1234yf/C02	R410A
	R513B	631	R1234yf/134a	R134a
Synthetic HFOs	R1234ze	7	–	R134a R407A R407A
Synthetic HFCs	R32	675	–	R134a R407A R410A

4.2 Air conditioning

Development for air conditioning in advanced markets has been similar, with previous users of R410A choosing R32 or similar refrigerant options. In applications involving R134a (1,1,1,2-Tetrafluoroethane), however, the trend has been toward HFO blends, such as R1234ze (1,3,3,3-Tetrafluoropropene). The most used natural refrigerant is ammonia for bigger central air conditioning and hydrocarbons for small residential applications. CO_2 is increasingly used in supermarkets, combining the refrigeration and air conditioning systems.

Air Conditioning Alternative refrigerants	Substance	GWP	Composition	Replacement for
Natural refrigerants	R290 (propane)	3	–	R134a R407A R410A
	R717 (ammonia)	0	–	R134a R407A R410A
	R744 (CO_2)	1	–	R134a R407A R410A
Synthetic HFC-HFO blends	R452B	698	R32/125/1234yf	R410A
	R454B	466	R32/1234yf	R410A
	R455B	148	R321234yf/CO2	R404A
	R513B	631	R1234yf/134a	R134a
Synthetic HFOs	R1234zd	4,5	–	R134a R410A
	R1234ze	7	–	R134a
Synthetic HFCs	R32	675	–	R134a R407A R410A

4.3 Refrigeration

Instead of the high-GWP R404A, some businesses have begun employing synthetical lower HFC-HFO blends, such as R448A and R449A. In contrast to the air conditioning and heat pump markets, however, the growing trend in refrigeration has been in favour of natural refrigerants. The development of technologies to further increase energy efficiency while using natural refrigerants will spur this trend going forward.

Commercial refrigeration Alternative refrigerants	Description	GWP	Composition	Replacement for
Natural refrigerants	R290 (propane)	3	–	R134a R404A R407A
	R717 (ammonia)	0	–	R134a R404A R407A
	R744 (CO_2)	1	–	R134a R404A R407A
Synthetic HFC-HFO blends	R448A	1387	R32/125/1234yf/1234ze(E)/134a	R404A
	R449A	1397	R32/125/1234yf/134a	R404A

5. Technological solutions – plate heat exchangers

Today's modern plate heat exchanger technology can offers a wide range of possibilities to optimize performance in your application according to the demands of your choice of low-GWP refrigerant. Compared to alternative thermal technologies, plate heat exchangers provide greater heat transfer within a compact design and smaller footprint. As a result, it is possible to perform the same duties with a lower refrigerant charge.

Plate technology further makes it possible to achieve a closer temperature approach at reasonable pressure drop cost. This means the plate heat exchanger technology will increase the overall system performance.

When considering how to best meet the needs of synthetic and natural low-GWP refrigerants, there are three main types of plate heat exchanger technologies to focus on:

- Copper-brazed plate heat exchangers
- Semi-welded plate heat exchangers
- Fusion-bonded plate heat exchangers

5.1 Copper-brazed technologies

Today, there are a number of plate heat exchangers constructed with copper brazing that have been optimized to operate with:

- Carbon dioxide (CO_2), especially in transcritical refrigeration systems
- Hydrocarbons (mainly propane) for heating, cooling and refrigeration
- Synthetic low-GWP refrigerants for heating cooling and refrigeration

Copper-brazed plate heat exchangers are heat exchangers developed to support the largest possible number of alternative refrigerants, though they do not support ammonia. Today, it is possible to find brazed plate innovations that make it possible to support the highest design pressures for CO_2 gas coolers (130 bar). There are also new features that enable a very low refrigerant charge asymmetric channel design for high-density and propane refrigerants.

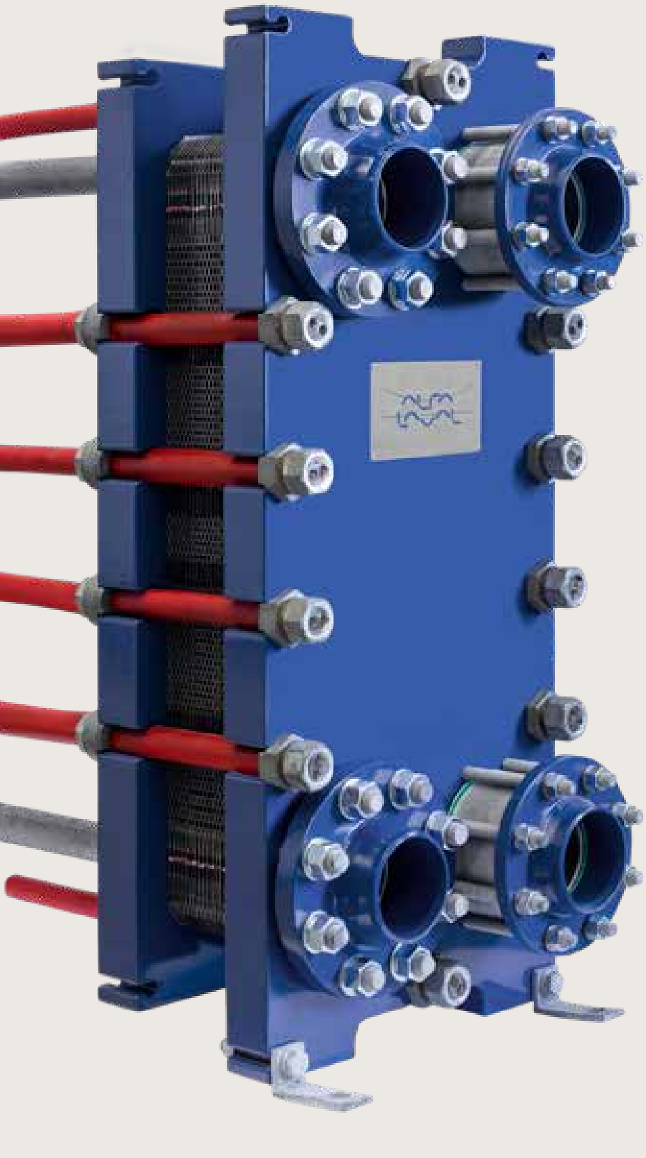
You may also be able to fully tailor the distribution system of the heat exchanger to fit your specific purposes. While this may initially seem like a small detail, it helps ensure the optimal level of efficiency for any alternative refrigerant.

5.2 Semi-welded technologies

Semi-welded plate heat exchangers with gaskets are often an ideal solution for supporting the needs of:

- Ammonia (R717) refrigeration systems and heat pumps, at medium-to-large capacities
- Carbon dioxide (R744) evaporators
- Ammonia/CO_2 (R717/R744) cascade systems

Semi-welded plate heat exchangers consist of a series of thin corrugated twin plates (cassettes) which are laser welded on one side and gasketed on the other side. Optimal performance will be determined by the design of your heat transfer plates, and today you can take advantage of new plate developments to ensure the lowest pressure drop, such as non-circular ports and distribution areas that optimize media flow.



Semi-welded technologies combine the flexibility and serviceability of standard gasketed plate heat exchangers, while enabling reliable operation at higher design pressures. Modern designs with optimized sealing further reinforce the heat exchanger’s dependability. Semi-welded plate heat exchangers can also offer high resistance against ice formation and fatigue stresses from pressure and/or temperature variations.

Depending on size, the units can handle temperature ranges from -45°C (-49°F) to 150°C (302°F) and pressure ranges from below vacuum up to what is required in an ammonia heat pump (63 bar or 900 psi). They can be specified in stainless steel (AISI304, AISI316, SMO254) or titanium, enabling the handling of a wide variety of fluids including sea water or various brines.

5.3 Fusion-bonded technologies

Fusion-bonded heat exchangers are a unique technology that can work with all refrigerants, but they are especially suitable for:

- R717 (ammonia) in small capacity heating, cooling and refrigeration systems
- Hydrocarbons and synthetic low-GWP refrigerants with clean water or hygienic media

AlfaFusion is a breakthrough fusion bonding manufacturing technique developed by Alfa Laval that offers a 100% stainless steel heat exchanger. It combines improved hygiene and corrosion resistance with the high efficiency and compact footprint of a brazed plate heat exchanger. Thanks to the fully stainless steel construction, these heat exchangers can be used in installations normally reserved for semi-welded and welded technologies.

6. Conclusion

At first glance, natural refrigerants and the number of new low-GWP refrigerant options seem like a heavy challenge for businesses with crucial heating and cooling demands. Indeed, with so many available options, each with their own corresponding demands, the potential risks of choosing wrong can be quite intimidating.

On closer inspection, however, it is possible to see the current changes in the market as a tremendous opportunity – a chance to differentiate your alternative offer and get ahead of competitors. While each alternative refrigerant presents several potential drawbacks, they also provide distinct advantages. With the help of a well-designed, modern, multi-refrigerant heat exchanger platform, the right features, and a capable supplier, it is possible to minimize those drawbacks while simultaneously maximizing the advantages.

7. Contact Alfa Laval

If you have any questions or would like to discuss heat exchangers for you plant, please contact us. You can find contact information for your nearest Alfa Laval representative on our web site: **www.alfalaval.com**. We look forward to hearing from you.

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