Hydrocarbons as refrigerants

Hydrocarbons convince with their environment-friendliness and economic feasibility.

A developed society cannot function without refrigeration. At home, in food production and storage (e.g. frozen foods, yogurt, and or coffee), in the production processes of the automotive or chemical-pharmaceutical industry, or for air conditioning – wherever you look, "cooling" is essential. Industrially generated "coldness" is a central pillar of modern life. In Germany, 14 % of the primary energy consumed is used for cooling purposes. Negative influences on the environment can be reduced by using natural refrigerants.

Hydrocarbons are called natural refrigerants because they occur in the earth's material cycle, e.g. as a byproduct of natural gas production, or in oil refineries. They were first used as refrigerants in the early 1920s, but replaced by fully and partially halogenated fluorinated hydrocarbons in the early 1950s (CFC/ HFC). Being non-toxic and non-flammable, these substances were often referred to as "safety refrigerants". Meanwhile, it has become generally known that CFC and HCFC have a fatal effect on the environment and the global climate, resulting in them being banned.

Refrigerating systems using natural refrigerants can make an important contribution to counter global warming – a valid reason for promoting the increase of the market shares of such systems. In a number of fields, hydrocarbons are feasible in many areas as a sensible alternative to synthetic refrigerants because they feature similar pressure levels and similar specific refrigerating capacities. They have application-specific advantages when selected correctly.

The most important hydrocarbons

	Formula	Refrigerant	Boiling point	Critical temperature
n-butane	C_4H_{10}	R600	- 0.5 °C	152.0 °C
iso-butane	C_4H_{10}	R600a	- 12.0 °C	135.0 °C
propane	C_3H_8	R290	- 42.0 °C	96.6 °C
propylene	C_3H_6	R1270	- 47.7 °C	91.0 °C
ethane	C_2H_6	R170	- 88.7 °C	91.0 °C
Ethylene	C_2H_4	R1150	-103.8 °C	9.5 °C

In order to generate properties for specific applications, mixtures of hydrocarbons are commercially available as well. Some of these are already listed in the ASHRAE nomenclature and specified in EN 378.

Convincing properties

Hydrocarbons are just as beneficial as ammonia or carbon dioxide when considering aspects of climate. They have no harmful effect on the ozone layer, and compared with many other synthetic refrigerant substances, their global warming potential is negligible or non-existent.

Distinctive properties of hydrocarbons

Hydrocarbons are highly flammable, combustible, and their smell is barely noticeable. Ethylene is lighter than air, and ethane has about the same density as air, while the densities of butane, propane, and propylene are higher than that of air. In the case of a leak they can collect on the ground, displacing the breathable air. These properties necessitate special provisions when planning and constructing hydrocarbon-based systems. For sufficient safety, all national and international safety provisions (e. g. EN 378, pressure equipment directive, ATEX directives) must be absolutely complied with for the construction, operation, and maintenance of refrigerating systems. For more detailed information, please refer to VDMA Einheitsblatt 24020-3.

Safety groups

The relevant standards and directives must be observed for the construction and operation of refrigerating systems using hydrocarbons. The selected refrigerant is classified based on its toxicity and flammability according to EN 378-1 and the pressure equipment directive (DGRL):

Safety groups according to EN 378-1, and fluid groups according to DGRL:

	Toxicity Flammability	Toxicity Flammability	
	Group A	Group B	Fluid group
	Low toxicity	Increased toxicity	
No flame propaga-tion	A1	B1	2
Low flammability	A2	B2	1
Higher flammability	A3	B3	1

The flammability, toxicity and DGRL fluid group defined in EN 378-1 provide the basis for sound project planning of a hydrocarbon-based system in any location. Hydrocarbons belong to safety group A3 and fluid group 1, meaning low toxicity and higher flammability.

Comparison of the global warming potentials (GWP) of different refrigerants

Refrigerants	**GWP***
R717 (ammonia, NH_3)	0
R744 (carbon dioxide, CO_2)	1
R290 (Propane) (HC)	3
R22	1810
R134a	1430
R404A	3922
R410A	2088

*Source: EN 378, AR 4

Properties of hydrocarbons

Ecological	no ozone depletion potential, global warming potential GWP ≤ 3
Thermodynamic	good COP (EER), even at high condensation temperatures
Physical	good heat transfer properties
Chemical	flammable/explosive in combination with air, good material compatibility, compatible with copper, steel, and oils conventionally used in cooling units
Physiological	non-toxic

Hydrocarbons have excellent thermodynamic properties, which reduce the primary energy required for generating a certain refrigerating capacity, and thus the indirect global warming effect.

Hydrocarbon-based systems have a better TEWI balance (Total Equivalent Warming Impact) than synthetic refrigerants. The TEWI balance states the sum of a refrigeration system's direct and indirect global warming effects. The direct global warming effect takes into account the CO_2 equivalent from refrigerant emissions to the environment, and also refrigerant losses due to leakage and recovery processes. The indirect global warming effect takes into account the CO_2 percentage required to generate the amount of energy needed for operating the refrigerating system during its entire service life. To reduce global pollutuion to the environment, the goal should be to keep the TEWI value as low as possible – for example by using hydrocarbons.

Unlike synthetic refrigerants, hydrocarbons are also very cost-efficient. The price differences are not only noticeable when initially charging the system, but also especially when refilling after leakage loss. Another advantage to be considered is the cost-efficient waste disposal after the system's operational life has expired.

Saving energy with hydrocarbons

Hydrocarbon-based systems are also one step ahead in terms of operating costs. One of the reasons for this, beside the reduction of costs caused by leakage as mentioned above, is the lower energy consumption. Propane for example, is considered to be one of the most efficient refrigerants. This is true even for systems that use a refrigerant medium circuit for safety reasons.

Due to their beneficial properties, hydrocarbons also have the potential to develop new areas of applications. For this reason, hydrocarbon-based refrigeration is the way to go - they are not only ecologically, but also economically sustainable.

Hydrocarbons are already in use in various fields of industry. In terms of design, refrigerating systems with a refrigerant medium circuit (e.g. brine, glycol or CO_2) and cascades in combination with carbon dioxide as a low-temperature refrigerant have become the established standard. In both cases, the required amount of hydrocarbon is considerably reduced.

Applications

Having been in use in household refrigerators and freezers for more than 20 years, hydrocarbons are now more and more often used in single-stage refrigerating systems for the air conditioning, medium and low temperature, and also in heat pumps. As early as 1995, hydrocarbons were cited as alternative refrigerants for refrigeration and heat pump technologie [1].

Among the products available today are also split air-conditioning units using propane, cooling cabinets using propane and isobutane, wall-mounted multideck cabinets using propylene, air- and water-cooled water chillers, and cascaded refrigeration systems using carbon dioxide/propane[2].

Typical applications for hydrocarbons include:

- Household refrigerators and freezers
- Bottle coolers
- Commercial deep-freeze cabinets and freezers
- Commercial cooling cabinets and refrigerators
- Beer coolers
- Drink vending machines
- Dehumidifiers
- Heat pumps
- Refrigeration in grocery stores
- Air-conditioners
- Low-temperature cascades (all stages)
- Water and brine chillers for indirect cooling, especially for outdoor installation

Which synthetic refrigerants can be replaced?

The following refrigerants (HFC) can be replaced by hydrocarbons (HC):

HFC	HC alternative	Note
R134a	R600a	Household appliances – larger deviations regarding refrigerating capacity and pressure levels
R134a	R290/600a mixtures	Commercial applications
R404A, R507A	R290, R1270, R290/1270 mixtures	Commercial applications, industrial plants (e.g. petrochemistry)
R407C	R290, R1270	Air-conditioning and heat pump systems
R410A	R1270/170 mixtures	Deviations regarding refrigerating capacity and pressure levels
R23, R14	R170, R1150	Low-temperature cascades
R227ea	R600a	High temperature applications
R236ea, R236fa, R245fa	R601, R601a	High temperature applications, ORC applications

Annex – Practical examples

R290 deep-freeze storage room, refrigerating capacity 2 x 2.2 kW, charge 250 g each

A deep-freeze storage room for the storage of sensitive goods at -20 °C, volume of 37 m^3, was installed north of Munich. Two microchannel condensers were used to keep the charge as low as possible. Not only does the propane in the refrigeration circuits feature a very good energy efficiency, the energy consumption is further reduced by EC fan.

The redundancy requested by the operator was realized by using two separate circuits.

While the maximum admissible charge, calculated on the basis of 37 m^3 x 8 g/m^3 (admissible limit for propane according to EN378), would be 300 g per circuit; in this case it is only 200 g. This means that, according to the pressure equipment directive, no separate approval by a notified body is required.

The fact that the condensing units are installed outdoors provides additional safety, along with a gas detector inside the cold store which cuts off the entire system in the case of a gas leak.

R600a high-temperature heat pump, heating capacity 50 kW

A small brewery in St. Gallen (Switzerland) is using a local long-distance heat line providing a temperature of 85 °C. For the production process, however, up to 120 °C is required. Until now, a 50 kW resistance heater was used to raise the temperature level. Looking for a sustainable solution while at the same time reducing the operating costs, the owner opted for a high-temperature isobutane heat pump that needs only 15 kW, with a refrigerant charge of 6 kg.

A frequency-controlled compressor adapts the heat quantity perfectly to the process.

R290 water chiller for data center and air conditioning, refrigerating capacity 20 kW

The municipal energy suppliers of Lübbecke need a 20 kW cooling system for cooling their server room, and for their air-conditioning. Points of particular importance for this customer were operational safety and reliability.

An outdoor water chiller with propane as refrigerant was installed that uses only 2.5 kg of refrigerant. As the unit was installed in a residential area, there were particular requirements to be met regarding sound attenuation. An important part of the solution was to use speed-controlled axial fans for the condensers. The water chiller has been in permanent use since the fall of 2011 [3].

R290 heat pump for heating/cooling, 700 kW

The constructors of a new home improvement store in Vorarlberg (Austria) were looking for an energy-saving solution for the heating/cooling system. They opted for a propane heat pump. Since its start-up in March 2008, it has saved about 30 % of energy compared to comparable stores of the same chain.

Using propane, the heat pump has two circuits with four semi-hermetic compressors each. To cover the heating capacity of 700 kW, the building's ductile foundation piles were used as a heat source. The heat pump is installed in a machine room inside a building (as per EN 378). The charge is 25 kg of propane per circuit[4].

R290 energy station for heating and cooling, 2x 250kW

For a shopping center of Mythencenter AG in Ibach (Switzerland), a project was conceived to provide heating, cooling and industrial water in an energy efficient manner using natural refrigerant.

Here, two ES Basis 250 energy stations with hydraulic modules and refrigerant R290 were used to heat and air-condition the building. Both systems have a nominal heat output of

250kW. It is possible to switch between heating and cooling by means of the hydraulic modules. Heat and cold air are dissipated by a heat exchanger.

The units have been designed for continuous load-dependent permanent operation with the highest COP and EER values possible by means of the high-performance and frequency controlled compressors.

The dual-circuit design has a refrigerant charge of 15 kg of R290 per cooling circuit. A BAC net interface enables integration into a GLT system.

The system is located in a machine room and exhaust air is blown out of the housing into the open air by means of an explosion-proof fan.

Literature

[1] Manfred Petz: Kohlenwasserstoffe als Kältemittel, Expert-Verlag, 1995.

[2] GTZ Proklima: Guidelines for the safe use of hydrocarbon refrigerants, Eschborn, 2010.

[3] Magazine Die Kälte, Issue 12/2011, Article p.40: Mit Propan wirtschaftlich und umweltfreundlich kühlen.

[4] Lecture by Karl Huber, March 2010 at DKV BV Rhein-Main and VDI-Wissensforum in Stuttgart, June 2010.

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