IEA Heat Pump CENTRE

Informative Fact Sheet

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Hydrocarbons as Refrigerant in Residential Heat Pumps and Air Conditioners

What are hydrocarbons?

Hydrocarbons (HCs) are a family of organic compounds composed entirely of carbon and hydrogen. The most common hydrocarbons (HC) refrigerants are propane (R-290), propylene (R-1270), isobutane (R-600a), and cyclopentane (R-600c). For the application of residential air-conditioners and heat pumps propane, with its similar pressure and temperature conditions can be considered as an alternative R-22 replacement. R-22 will be phased out by 2020 in developed countries, and earlier in some cases, e.g. in the European Union (EU) phaseout is scheduled for 2010 (2004 in new equipment applications).

Hydrocarbon properties

Refrigerant	ODP	GWP*
Propane (R-290)	0.0	3
Propylene (R-1270)	0.0	3
R-22	0.055	1500
R-134a	0.0	1300
R-407C	0.0	1530
R-410A	0.0	1730

*Based on a 100-year Integrated Time Horizon, with CO_2 =1

Thermodynamic and thermophysical properties of HCs are well established and available in handbooks and in computer software format. In Table 1 a typical selection of important properties required in system design is included for propane, propylene, and reference case HCFC and HFC refrigerants.

Advantages of hydrocarbon refrigerants

HC refrigerants have negligible global warming potential (GWP), as well as zero ozone depletion potential (ODP). The table above compares environmental characteristics of typical HCs with R-22 and some commonly used HFCs.

When used as refrigerant in typical air-conditioning and heat pump systems, propane:

- consumes about the same energy as R-22 and R-407C in new equipment, but is less efficient than R-410A
- has a refrigerant charge less than half that of R-22, R-407C and R-410A, e.g. only 1.3 kg required for a 10.5 kW heat pump
- operates at much lower discharge temperatures than R-22, thereby reducing risk of compressor damage
- is generally compatible with existing components and materials
- uses mineral oil as the lubricant in equipment

Disadvantages/Risks of hydrocarbon refrigerants

The major disadvantage of using HCs as refrigerants is their flammability and explosion/damage potential, with the risk that there is always the possibility for the HC to leak into the surroundings and reach the lower flammability limits of that particular HC. The limits vary with pressure and temperature but propane is flammable in concentrations in air typically between 2% and 10% by volume. A flammable refrigerant can become a safety risk if a combustible mixture of fluid and air is present within those limits and simultaneously an ignition source of sufficient intensity is present. However, the risk can be reduced by taking various approaches to limit or prevent leakage and to isolate any potential leakage from ignition sources.

Regulations and standards

In Europe the CEN standard EN 378 covering safety and environmental requirements for refrigerating systems and heat pumps is now in force and includes the use of flammable refrigerants. HCs are classified as L3 (low toxicity/high flammability) working fluids. According to the informative annex of this standard L3 refrigerants shall not be used in direct systems for human comfort cooling or heating. This implies that the use of HCs for residential heat pump applications should be restricted to external secondary loop systems, with only a brine heat transfer fluid circulating in the living space. However, since this informative annex is described as

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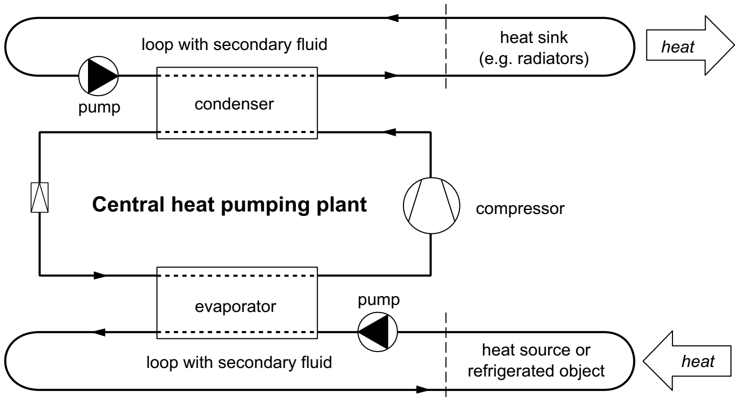
Fig. 1: Typical schematic of an indirect heat pump system.



a recommendation rather than a prescription, this leads to some ambiguities, and national standards may therefore take precedence, e.g. the DIN 7003 standard in Germany, and NPR 7600 Code of Practice in the Netherlands. In these circumstances limited amounts of HC charge may be permitted within the living space (dependant on room size, occupancy levels, etc.). A working group of the technical committee responsible for EN 378 is currently working to harmonize requirements of the standard with the EU Pressure Equipment Directive (PED), as necessary for all future CE labelling of such equipment for the European market.

Elsewhere other standards such as ANSI/ASHRAE Standard 15 in the USA prohibits the use of flammable refrigerants (classification A3) in high probability systems (e.g. direct systems), except in industrial and experimental applications.

In the international standards area a joint ISO/IEC working group is currently developing amendments to ISO 5149 and IEC-60335-2-40, aimed at addressing safety aspects in mechanical and electrical equipment related to the use of flammable refrigerants in residential heating/cooling appliances.

Risk analysis

Risk assessment is a systematic methodology used to address safety aspects of an operation, identify the possibility of accidents, analyze the consequences, and assess related risk probability. The results are highly dependent on assumptions relating to servicing procedures, frequency of leaks, etc.

Quantitative Risk Assessments (QRAs) have been conducted by experts in Norway, the Netherlands, and in the USA on various heat pumping and refrigeration systems using HCs. For example one QRA carried out for a 10.6 kW (heating) typical residential heat pump using propane concluded that the calculated lethal risk can be accepted for all groups of exposed people, when compared to the established intolerable levels of individual risk criteria used in several developed countries. These results presupposed the adoption of various risk-reducing measures and safety precautions, including placement of the unit within a gas-tight casing, and location in a room space greater than 80 m^3.

Safety aspects

Further acceptance of HC refrigerants for residential heat pump applications will require a comprehensive risk and hazard assessment to develop appropriate safety standards and risk mitigation methods. Such safety precautions will also need to extend to corresponding manufacturing processes, equipment servicing, packaging, storage, shipping, and other steps in the HC utilization chain.

Given the risks of flammability and explosion/damage potential of HC refrigerants it is essential to adopt adequate safety measures when installing systems or conducting servicing procedures with these refrigerants. Such measures may include:

- ***Leakage and ignition control***
  e.g. minimizing the number of joints in refrigerant piping, keeping electrical components away from refrigerant circuit, protecting refrigerant-containing components from accidental punctures
- ***Flame suppressants***
  Flammability of HCs can be reduced by addition of suitable flame suppressants, but the performance of the ensuing mixture may be severely downgraded
- ***Secondary heat transfer loops***
  The use of secondary loops ensures that only secondary brine fluids circulate within the living space, and the HC circuit is completely outdoors (Fig.1). However, the additional loop leads to reduced performance and increased cost
- ***Special equipment rooms***
  If indoor room volumes are not large enough to meet the space requirements of the applicable standard, a separate mechanical ventilation room can be used to house the HC unit components

State-of-the-art of the technology

In recent years there has been considerable development of new equipment and components suitable for use in hydrocarbon system applications. This includes hermetic and semi-hermetic compressors operating in hermetically sealed systems in order to minimize leaks. The use of brazed plate heat exchangers is especially important in systems where the charge should be minimized to ensure that in the event of any refrigerant leak the HC concentration in the surroundings will not reach the explosive threshold.

Other design requirements for new equipment using HC refrigerants should include:

a using brazed joints instead of flared joints in refrigerant tubing (in addition to minimizing the number of connections);

b avoiding the use of suction accumulators to reduce the hydrocarbon charge;

Table 1: Important physical and thermophysical properties of propane, propylene and selected HFC working fluids and R-22

PROPERTIES	R- 290	R-1270	R-134a	R-407C	R-410A	R-22
Normal boiling point, NBP [°C]	-42.1	-47.7	-26.2	-43.8	-51.6	-40.8
Critical temperature [°C]	96.8	91.8	101.1	87.3	72.5	96.1
Critical pressure [bar]	42.5	46.2	40.7	46.3	49.5	50
Saturation pressure at -30°C [bar]	1.7	2.1	0.84	1.88	2.71	1.64
Saturation pressure at +50°C [bar]	17.1	20.6	13.18	22.10	30.61	19.4
Specific enthalpy of evaporation at -30°C [kJ/kg]	412.2	418.7	219.5	233.8	252.6	226.8
Volumetric refrigerating capacity at -30°C [kJ/m^3]	1,594	1,967	972	1,450	2,678	1,674
Pressure ratio, -30°C/+30°C [-]	6.4	6.2	9.1	7.2	7.0	7.3
Pressure ratio, 0°C/+50°C [-]	3.6	3.5	4.5	3.9	3.8	3.9
Density, *liquid* at -30°C [kg/m^3]	567	587	1,388	1,339	1,281	1.377
Density, *liquid* at +50°C [kg/m^3]	448	456	1,102	1,014	912	1.082
Density, vapour at -30°C [kg/m^3]	3.9	4.7	4.4	6.2	10.6	7.4
Density, vapour at +50°C [kg/m^3]	38.7	45.8	66.3	91.1	140.0	86.0
Specific heat capacity, *liquid* at -30°C [kJ/kg·K]	2.310	2.259	1.273	1.324	1.397	1.105
Specific heat capacity, *liquid* at +50°C [kJ/kg·K]	3.123	3.078	1.566	1.779	2.227	1.419
Specific heat capacity, *vapour* at -30°C [kJ/kg·K]	1.537	1.421	0.781	0.808	0.906	0.635
Specific heat capacity, *vapour* at +50°C [kJ/kg·K]	2.498	2.469	1.246	1.457	2.296	1.113
Thermal conductivity, *liquid* at -30°C [mW/m·K]	122.1	144.6	105.8	116.7	132.3	108.5
Thermal conductivity, *liquid* at +50°C [mW/m·K]	85.8	92.4	70.4	74.3	80.3	72.3
Thermal conductivity, *vapour* at -30°C [mW/m·K]	12.5	11.9	9.0	9.0	9.3	7.6
Thermal conductivity, *vapour* at +50°C [mW/m·K]	21.5	22.8	16.7	17.7	26.7	14.5
Dynamic viscosity, *liquid* at -30°C [µPa·s]	172.7	193.6	406.4	306.6	238.3	304.6
Dynamic viscosity, *liquid* at +50°C [µPa·s]	73.4	71.9	143.1	108.3	82.8	123.1
Dynamic viscosity, *vapour* at -30°C [µPa·s]	6.8	6.3	9.5	10.1	10.7	10.2
Dynamic viscosity, *vapour* at +50°C [µPa·s]	9.9	8.8	13.1	14.4	16.4	14.2

c isolating electrical components in air-tight compartments, e.g. fan and blower motors;
d using either sealed or solid state control devices and spark proof switches;
e providing appropriate leak detection facilities;
f labeling new equipment to clearly indicate that the refrigerant is flammable;
g required procedures for service and repair.

Status of application of hydrocarbons

The acceptance of flammable refrigerants in the market differs from one country to another. Until now the application of HCs in residential heat pumps is primarily confined to countries of western and northern Europe, where the interest is mostly in heating-only heat pumps.

In Germany most manufacturers of heat pumps now use propane as the working fluid. It is estimated in recent years that about 20% of residential installations are using HCs. In 1998 this penetration rate was closer to 50% (2000 units). Most new HC based systems are designed with the HC circuit located outdoors. They use ambient air, ground, and groundwater sources, and are connected to hydronic floor heating systems with typical distribution temperatures in the 35 to 45°C range.

In Austria propane is being used in direct-expansion ground-coupled heat pumps where the entire unit is located outside, enclosed in a waterproof containment. In combination with low temperature floor heating systems, propane heat pump units installed in Austrian low energy houses have achieved a minimum Seasonal Performance Factor (SPF) of four.

In Sweden exhaust air heat pumps are popular for residential applications, where heat is recovered from warm outgoing ventilation air to provide a source for the delivery of space heating and warm water. In 1999 it was estimated that about 20,000 such units have been built and installed using propane as refrigerant, and no flammability problems have been reported.

In the Netherlands a newly-designed ground-coupled brine-to-water heat pump using propane as the working fluid has been installed in about 100 homes during 1997 and 1998. This unit has a heating capacity of 4.8 kW at design conditions, with a working fluid charge of approximately 1 kg. Operating with a secondary loop the heat pump delivers space heating through a hydronic heat distribution system at 55°C supply temperature and also provides hot water at 60°C. These installations are considered to be successful.

Cost impact

A detailed computer simulation conducted by a US equipment manufacturer evaluated the performance, cost and environmental impact for a 10.5 kW typical residential ducted air-to-air split system air conditioner operating with propane, as compared to equivalent R-22 and R-410A systems. Flammability mitigation measures were analyzed for the propane system, and corresponding additional costs of design modifications estimated.

Computer model results indicated that the propane system costs were 35% greater than the R-22 baseline. Other output showed the propane system having 2% improvement in energy efficiency compared to R-22, and a 10% reduction in TEWI over a 15-year equipment lifetime (equivalent to approximately 3,400 kg of CO_2). Corresponding results for R-410A showed a system cost 18% lower than propane, 5% higher efficiency, and a 6% increase in TEWI (1,700 kg CO_2).

Conclusion

On an international level the acceptability of HCs as refrigerants remains a controversial issue, and continues to generate discussion and differing opinions related especially to attitudes towards safety and risks.

References

- ANSI/ASHRAE Standard 34-1992, Number Designation and Safety Classification of Refrigerants (US).
- ANSI/ASHRAE Standard 15-1994, Safety Code for Mechanical Refrigeration (US).
- EN 378-2000, Specification for refrigerating systems and heat pumps. Safety and environmental requirements (EU).
- IEC 60335-2-40, Safety of Household and Similar Electrical Appliances. Part 2: Particular Requirements for Electrical Heat Pumps, Air Conditioners and Dehumidifiers, 1995-05.
- ISO 5149:1993, Mechanical Refrigerating Systems Used for Cooling and Heating Requirements.
- IIR 13th Informatory Note on Refrigerants: Standards for Flammable Refrigerants, December 1997.
- TNO-MEP-R96/477, Risk Assessment of Typical Cooling and Heating Systems Using Natural Working Fluids - Propane Residential Heat Pump, (TNO Report).

Glossary

- ANSI - American National Standards Institute
- ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers
- CE - Comité Européen
- CEN - Comité Européen de Normalisation
- DIN - Deutsches Institut für Normung
- ISO - International Organization for Standardization
- IEC - International Electrotechnical Commission
- NPR - Nederlandse Praktijk Richtlijn
- TEWI - Total Equivalent Warming Impact

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