Technology Collaboration Programme
by IEA

Heat Pumping Technologies
MAGAZINE
Natural Refrigerants in Heat Pumps: Pushing the Boundaries of Sustainability
Vol.43 No.1/2025
A HEAT PUMP CENTER PRODUCT

Topical Article

Review of Heating and Cooling Applications where HCs have been Introduced as Refrigerants and Future Perspectives of their Use

DOI: 10.23697/6eng-8469

By Francisco Barceló, Jose Gonzálvez (Spain), Emilio Navarro-Peris, Spain

This paper aims to review some applications where the use of hydrocarbons, either due to the operating environment or the refrigerant quantity required, is currently considered the most viable solution. Examples include household refrigerators, dryers, and small commercial refrigeration units. The paper will also explore other applications such as heat pumps, commercial refrigeration systems, refrigerated transport, and high-temperature heat pumps, where their use may eventually be adopted in part of the sector. Additionally, the review will address some existing barriers and potential development paths to expand their usage.

Introduction

In recent years, hydrocarbons such as propane (R290) and isobutane (R600a) have emerged as key players in the refrigeration industry, offering a natural and eco-friendly alternative to traditional synthetic refrigerants. With their low global warming potential (GWP) and excellent thermodynamic properties, hydrocarbons are becoming increasingly popular across a variety of sectors. From domestic refrigeration and air conditioning systems to commercial and industrial applications, hydrocarbons are being integrated into real-world systems as the most sustainable option under certain conditions. This article explores the diverse fields in which hydrocarbons are being successfully utilized as refrigerants today, highlighting their growing role in transforming the refrigeration landscape and contributing to a greener, more energy-efficient future. It concludes with considerations of possible technological evolutions that could extend the application range of HCs in HPs.

HCs as Refrigerants in Small Systems

Even though their good properties as refrigerants, because of their flammability, their use were abandoned when other non-flammable alternatives appeared in the market in the beginning of the 20th century, and it was not until the late of it, when the potential for serious environmental effects caused by the use of certain synthetic refrigerants was assessed, that the use of these types of refrigerants was reconsidered despite their flammability.

In this regard, and as described in [1], it is worth highlighting the significant role played by Greenpeace and the company DKK/Foron in overcoming the reluctance to adopt a flammable refrigerant like isobutane as the standard in domestic refrigerators in Europe. It was crucial for the standards to establish a charge limit to market these types of devices with safety guarantees. This charge limit of 150 g, although low, was sufficient to give manufacturers explicit safety guarantees, allowing the predominance of isobutane as the standard refrigerant in domestic refrigerators in Europe since the early 21st century. In this regard, more than 70% of the total produced domestic refrigerators are using R600a as refrigerant nowadays.

The experience gained over these years demonstrated the low risk of working with these systems, promoted the use of propane in other low-power applications while keeping the refrigerant charge below 150 g, and nowadays, there are more than 1 billion units installed all over the world.

Another example of the adoption of hydrocarbons as refrigerants is the transition to propane as the standard refrigerant that has been developed in domestic heat pump-assisted clothes dryers since 2015, when the first appliance was put into the market in Germany by Siemens. These systems commonly used other traditional refrigerants such as R134a or R407C, but environmental regulations combined with the good thermodynamic properties of R290 for this application aimed the manufacturers to adopt this natural refrigerant. The adaptation of the design of the cooling cycle to the use of R290, with a charge limitation of 150g, for systems with condenser capacities of around 3 kW included the re-design of the heat exchangers, adopting 5mm tubes, or the reduction of the oil charge in the compressor. Nowadays, most of the clothes dryers produced in Europe and Asia use R290.

Compact-portable air conditioning units are another application where the standard solution in Europe and Asia is to use R290 as refrigerant. These units present a sealed circuit, commonly using rotary compressors and a low-charge, less than 150 g, refrigerant circuit with typical capacities of up to 3.5 kW.

Hydrocarbons are also used in other small household appliances such as water coolers or wine refrigerators, although in this concrete application, the low power and slight temperature difference make other technologies, such as thermoelectric cooling, the standard solution.

HC in Commercial and Industrial Applications

Regarding the applications of R290 in commercial refrigeration, following the previous experience with domestic appliances, since the beginning of the 2000s, the use of HCs in self-contained refrigeration systems of relatively small sizes has been quite extended in Europe, going from display cabinets to freezers or vending machine coolers. Most of these units have been autonomous units, but also some manufacturers have developed semi-plug-in display cases featuring water systems for heat removal. Today, self-contained propane waterloop systems are gaining traction in commercial refrigeration worldwide, particularly in Europe, where manufacturers like Freor have implemented numerous installations.

This trend is also expected to be promoted by the update of the IEC 60335-2-89, which has increased the charge limit of this kind of system from 4xLFL to up to 13xLFL for self-contained systems in such a way that the cost of these units could be even more competitive as the number of refrigeration circuits used nowadays could be reduced. In fact, in a survey of OEMs, ATMOsphere [2] estimated that 3.2 million hydrocarbon-based retail cabinets have been installed in Europe as of December 2023. An increase of 10% from 2022, when there were an estimated 2.9 million.

In recent years, there has also been an increase in the number of products available for industrial chiller applications. Several manufacturers are offering chillers of 100 kW of capacity, and more than 5000 chillers have been reported installed in the EU, and some R744 (carbon dioxide) refrigeration systems in supermarkets in hot climates uses HCs for the mechanical subcooling part of the circuit.

Finally, the descarbonization of the industry is opening a new application field related to the high-temperature heat pumps to produce vapor at temperatures up to 200ºC, where HCs like butane, pentane, or isopentane can supply an efficient solution.

HC in Domestic Heat Pumps for Heating and Cooling

The normative for these applications was also updated some years ago by IEC 60335-2-40 and was approved in the EU last year. This normative introduces some concepts to make the safe use of HCs in the domestic sector more flexible, combined with the F-gas regulation approved last year has made some manufacturers [3] claim that HCs could be used in the heat pump market up to capacities of 70 kW and there are some projections that assume that Hcs will be the main refrigerant for heat pumps with a capacity lower than 12 kW in EU in future.

From that perspective, nowadays, it is easy to find liquid-to-water heat pumps of small capacities (6 kW) with 150 g of charge for indoors commercially available, and most important manufacturers in the EU have air-to-water heat pump models commercially available using R290 as a refrigerant. A wide review of the state of this sector is done in [4]. Nevertheless, in that sense, it should be pointed out that air-to-air split systems, which represent the most extended systems nowadays, still work mainly with F-gases, and even

though their use with HCs has been demonstrated safe for some small capacity applications, their presence in the market is not so significant, probably being its most important consideration to work the fact that in most cases their final installation must be done in situ. In that context, the experience on the introduction of these systems in India or China by some manufacturers like Midea, Haier or Clivet could be relevant for a wider diffusion of them.

Mobile and Transport Applications

Mobile HVAC (MAC) and refrigerated transport applications are key sectors regarding energy consumption and a number of installed cooling systems, where nearly every new vehicle for passenger transport (automobile, bus, or train) comes with one or several refrigeration units for passenger comfort or technical requirements. In fact, this sector was the first one in the EU to receive a directive to reduce the use of HFCs in 2006, and since then, HFOs and in some vehicles, R744 have been the dominant refrigerants.

Regarding the automotive industry, a transition is undergoing, where hybridization and electrification demand more efficient and reversible cooling systems, with the additional thermal management needs produced by the battery packs. In this regard, and as a consequence of the possible restrictions to the use of HFOs in the EU byEuropean Chemicals Agency (ECHA), some car manufacturers are exploring the use of R290 as a refrigerant. The most direct solution to ensure safety in the passenger compartment is using indirect cooling systems with an air-to-water heat pump, which feeds the climate control system and the battery thermal management system. This is the approach followed by some manufacturers like Ford and Denso for electric vehicles, considering the requirements of a global solution, including thermodynamic performance and regulatory limitations. Tata is developing in collaboration with Mahle, in the framework of a United Nations Industrial Development Organization (UNIDO) project, secondary loop MAC (mobile air conditioning) and battery cooling systems with R290 for EVs in India.

The transport of people industry is also considering the switch to HCs, and the most recent developments arriving on the market are using propane as refrigerant. In this sector, cooling systems also need to cover several services, but the typical solution is to have different systems for each requirement. For instance, in electric buses, in addition to the cooling system for passengers, an additional thermal management system consisting of an air-to-water heat pump is needed to control battery temperature. Or in trains, additionally to climate control, galleys require cooling for food and beverages.

Several railway services are starting to use HVAC systems with R290. In September 2024, Mitsubishi Electric Klimat Transportation Systems S.p.A received an order from Siemens Mobility GmbH for 1350 HVAC systems to be installed in in next-generation trains of the S-Bahn rail system in Munich, Germany. Stadler Polska Sp. z o.o. placed an order of 80 R290-HVAC units to Liebherr Transportation Systems in June 2024 for equipping 20 Flirt trains, which will serve regional routes in Helsinki, Tampere, and Lahti. Deutsche Bahn is testing 16 R290 units in two ICE3 neo trains, reporting no issues with the refrigerant and expecting to operate more than 2000 units using propane by 2027. Other railway HVAC systems

manufacturers, such as Hispacold or Konvekta, are also selling or developing R290 units. It is relevant to point out that some of these systems are using direct refrigerant circuits and have shown that with under the right design consideration, it could be a feasible alternative. Regarding other uses of cooling in railway, new generation ICE4 German high-speed trains will be equipped with R290 cooling systems at their galleys, manufactured by Wölfle GmbH. Manufacturers are also developing indirect cooling systems for buses and electrical buses, where propane is an excellent option due to its high performance and availability to work at a wide range of temperatures. Copeland presented its YRH(V)*KTG range of horizontal scroll compressors for R290 and transport applications, focused on bus and railway applications in the same way as Bitzer did with its SPEEDLITE ELV52 PRO compressor.

Even in the sector of marine transport that could be more resistant to the introduction of flammable refrigerants, there are some initiatives like [5] which are promoting the use of R290 in this sector, which nowadays is still dominated by R134a, but it is facing a transition to low-GWP refrigerants.

Conclusions

The growing concern for the environment and the catastrophic effects that the emission of greenhouse gases can have on our society has led to reconsider the use of flammable refrigerants in the heating and cooling sector.

In that context, this paper has shown that the use of HCs is going to be the dominant refrigerant for some applications, and although their use in the past was restricted to low-capacity applications, nowadays some higher capacity applications like chillers of capacities of 100 kW are considering it as a reliable alternative.

Even in the transportation sector, which was reluctant in the past to the use of flammable refrigerants, is beginning to use it, and from the accumulated experience, it has seen that it is possible to design safe HCs systems without a significant increase in the cost. It is convenient to point out that up to now, the design of refrigeration systems has not considered in deep the operation with flammable refrigerants. But there are aspects like refrigeration circuit design with the perspective of charge minimization, charge release, techniques to avoid flammable atmosphere, or even the increase of prepared technicians that could extend their use to other applications.

Finally, trying to make a perspective on the future, the adoption of HCs and other natural refrigerants have the advantadge that once the transition to those refrigerants is made for an application/sector in which their introduction is feasible, there will be no more future change of refrigerant for those systems and the successful case of the adoption of HCs in domestic refrigerators support that.

References

[1] Colbourne D, 2021. "History of Flammable Refrigerants," in Proc. Institute of Refrigeration, London.
[2] Christina Hayes, Jae Haroldsen, Saroj Thapa, 2023. Natural Refrigerants: State of the Industry. Atmo Report.
[3] Hydrocarbons21 (January 12th, 2023) ATMO Europe: F-Gases No Longer Needed for Residential Heat Pumps, Says Viessmann. Available: https://hydrocarbons21.com/atmo-europe-f-gases-no-longer-needed-for-residential-heat-pumps-says-viessmann/
[4] Navarro-Peris E., Colbourne D., Oltersdorf T., Palm B., Coronas A. (coord). 2024. Domestic heat pumps using hydrocarbons: current status and market overview in Europe. 58th Technical Brief on Refrigeration Technologies. International Institute of Refrigeration (IIR), Paris. http://dx.doi.org/10.18462/iir.TechBrief.11.2024
[5] Kirsten Orschulok, Lydia Ondraczek, Adrian Fillmann, Philipp Denzinger, Mark Major, Manuel Enrique Salas Salazar. 2025. Accelerating the transition to climate and environmentally friendly refrigerants.
https://www.green-cooling-initiative.org/fileadmin/user_upload/Greener_Reefers.pdf

Author contact information

Name	Francisco Barcelo Ruescas
Title	Assistant Professor
Affiliation	Universitat Politecnica de Valencia
Postal address	Camino de Vera s/n
E-mail address	Fbarcelo@iie.upv.es

Name	Jose Gonzalvez-Macia
Title	Professor
Affiliation	Universitat Politecnica de Valencia
Postal address	Camino de Vera s/n
E-mail address	jgonzalv@ter.upv.es

Name	Emilio Navarro-Peris
Title	Professor
Affiliation	Universitat Politecnica de Valencia
Postal address	Camino de Vera s/n
E-mail address	Emilio.navarro@iie.upv.es
Phone number	+34677822930