THE SHERPHA PROJECT
NATURAL REFRIGERANTS FOR HEAT PUMPS

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ABSTRACT

The global aim of the SHERHPA (Sustainable Heat and Energy Research for Heat Pump Application) project is to develop the next generation of heat pump systems using natural refrigerants such as ammonia, carbon dioxide and propane. The technical challenges are quite clear in that natural refrigerants have different thermodynamic and chemical properties to existing refrigerants. This requires redesigning the principal components like heat exchanges and compressors to optimise the heat transfer. At the same time, appropriate control strategies have to be developed considering both the application and the types of components used. Other challenges involve material compatibility and requirement imposed by EU regulations to minimise the amount of refrigerant in the system.
The initial performance of components have been checked, and the results have been used to determine parameters like mass flow rates, durability, leakage and control parameters and also build confidence in the ability of the various components to be successfully integrated. In a next phase it is likely that as many as 10 prototype systems will be designed, manufactured and evaluated with sizes ranging from 2 to 100 kW.

1. INTRODUCTION

Sustainable energy systems, such as heat pumping technologies, provide an efficient use of renewable energy from the ambient and of waste heat sources. Typical applications are space heating, domestic hot water and processes with combined heating and cooling. Doubling the number of heat pumps in Europe by 2010 would increase the annual energy and CO2 emission savings to 100 TWh and 40 million tons respectively. To achieve such an ambitious target on European level and to support the creation of a strong market impact, in addition to the European Heat Pump Association, EHPA (policy, strategy and marketing) and the European Heat Pump Network, EHPN (dissemination of information, Website) a dedicated project towards Small and Medium Enterprises (SMEs) is jointly proposed by GRETh (Heat Equipment Association) and EHPA.
This project deals with the development of heat pumps that are cost-energy efficient and in compliance with the future environmental regulations. The new environmental regulations, concerning greenhouse gases and the protection of the ozone layer, will lead to the phase out of conventional refrigerants. For example, in the EC the ‘Freon’ R22 phase out is scheduled in 2010. Therefore ‘natural fluids’ have to be adopted (hydrocarbons, carbon dioxide or ammonia), but this implies a change in the components technology and control system. Heat pumps are components that allow energy savings for heating and cooling buildings and for many industrial applications, and concern a very large spectrum of applications much wider than the existing heat pump market.
During the first half of the project, components and subsystems (heat exchangers, controllers, ground coupling system, heat recovery…) have been developed, tested and optimised. Afterward, during the second half of the project, prototypes will be developed and tested in laboratories prior to

field tests. In parallel with these research activities, a training programme will be set-up. This programme will include technical training and e-learning for engineers.
This project is coordinated by two independent associations (Greth and EHPA), that have complementary activities; the core group is composed of 19 SMEs from 12 countries, including participants from the newly associated states; and the research and technical development work will be performed by 10 centres of excellence, from 9 EC and associated countries, in the area of heat pumps, energy and control.

The SHERHPA project focuses on heat pumps for commercial, residential, district heating and industrial applications. The key points developed are:

- The use of 'natural' working fluids such as hydrocarbons, CO2 or ammonia (development and adaptation of components)
- Advanced control system
- New ground-coupled, liquid to liquid and air to air systems
- New advanced applications in industry
- Process integration (design and optimisation of heat pumps and refrigeration cycles)
- Simulation tools for technical and economic comparison of technologies
- Field tests and system integration
- Guidelines and best practice for heat pump design, manufacturing and installation

The RTD activity is divided in two major phases. The phase 1 concerns the development, testing and optimisation of the individual components and subsystems, and the phase 2 is dedicated to the development and testing of prototypes at lab-scale and includes field tests. The technical work is carried out in 6 technical work packages, plus one dissemination activity and exploitation of the results (figure 1).

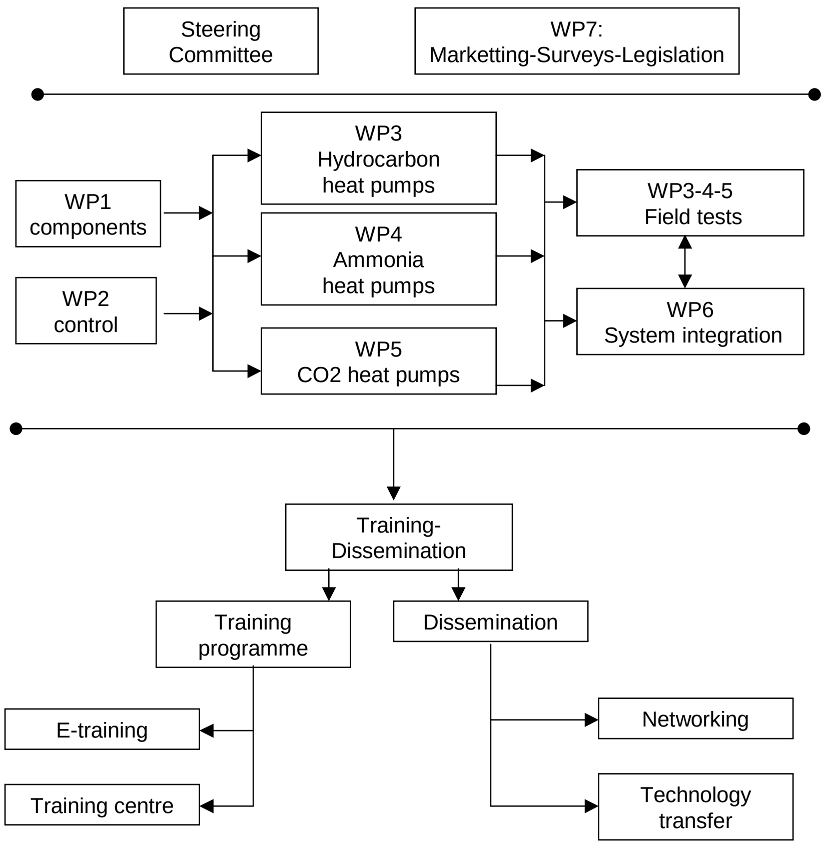

Figure 1. Organisation of the work programme

The major outputs of these WP's are new components for heat pumps and prototypes developed in collaboration with the SME core group members, but also guidelines and best practice, which will be used for disseminating information.
In the next sections the scientific and technical work performed within the project will be presented and discussed. It concerns more specially:

- Components (heat exchangers and compressors)
- Hydrocarbon heat pumps
- Ammonia heat pumps
- CO2 heat pumps

2. COMPONENTS

The objective is to develop new components which face the legislation, safety and environmental requirements, while being cost effective, or to select the best components available in the market with reference to the same requirements. The two critical components are the heat exchangers and the compressor.
For hydrocarbons the internal volume of the heat exchangers have to be minimised for safety and regulations aspects, and for CO_2, the level of pressure is much higher (up to 150 bars) compared to conventional refrigerants. Based on these considerations, several types of innovative heat exchangers have been evaluated and/or developed: micro-channel heat exchangers, compact brazed plate heat exchangers, semi-welded or totally welded plate heat exchangers, spiral heat exchangers, plate-fin heat exchangers, enhanced and low-finned tubes. A literature review has been started to check correlations for the thermal performance of heat exchangers for hydrocarbons (Thonon, 2005), ammonia and carbon dioxide.
The brazed plate heat exchangers are considered as the first choice and the benchmark for minimizing the charge. A 100 kW reversible propane heat pump has been selected for a case study and will be manufactured in a next stage (Bisco and Mantovan, 2005). The basic design principle is to confine the propane and to have secondary water loops connected to the heat and cold sources (figures 2 and 3). Such design minimises the refrigerant charge in the system and therefore being in accordance with the standards (Corberan et al., 2005)

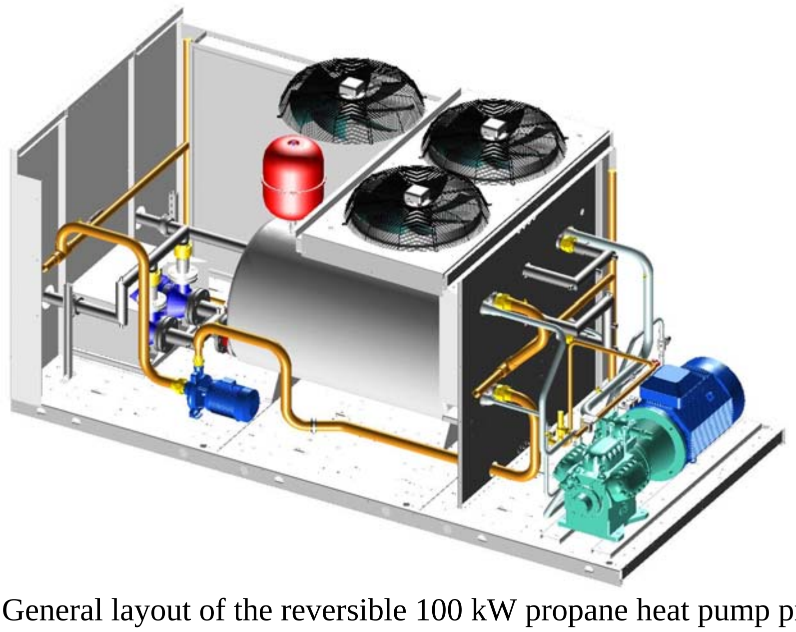

Figure 2: General layout of the reversible 100 kW propane heat pump prototype

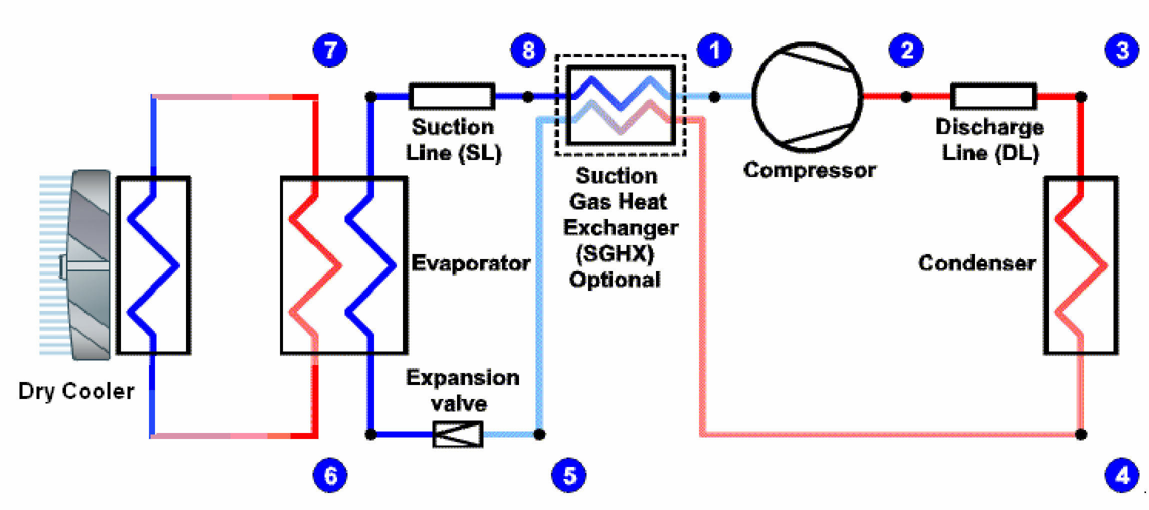

Figure 3: Principle of the 100kW reversible heat pump

A charge inventory model has been applied to the above heat pump prototype, yielding an evaluation of the total charge in the heat exchangers; the results are available in figure 4. As it can be seen, the total charge of refrigerant can be kept below 3 kg, but depending on the correlation and void fraction model adopted for the evaporator and condenser, the total estimated charge is between 1.5 and 2.95 kg. It is therefore recommended to be conservative while estimating the refrigerant charge.

Micro-fin tubes and mini-channel heat exchangers have also been evaluated for the same operating conditions. It appears that the use of 9 mm or 7mm external diameter finned tubes does not lead to significant improvement. The internal volume for this solution is slightly lower as compared to the brazed plate heat exchangers but the length of the shell and tube heat exchanger exceeds the acceptable value for this equipment. Using smooth minichannels of 2 mm internal diameter: both the tube length and the internal volume are significantly reduced as compared to the reference case. Volume reduction can be up to 60%.

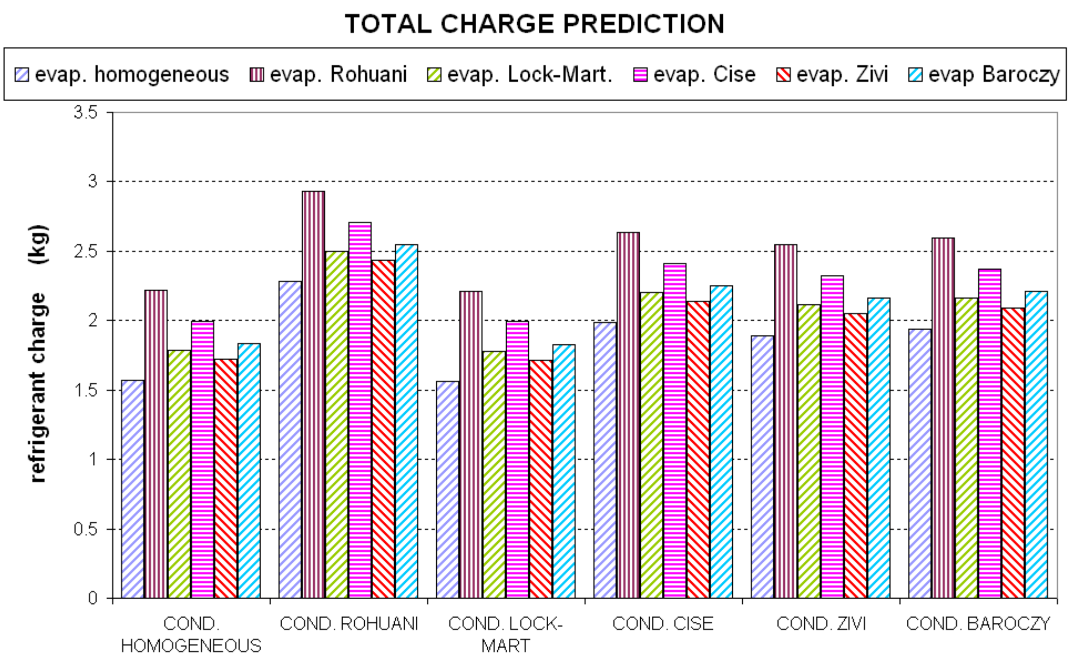

Figure 4: Total charge in heat exchangers for different void fraction models

Spiral heat exchangers have also been experimentally evaluated (figure 5). The tests have been performed with several hydrocarbons: propane, isobutane-butane mixture and propane-isobutane mixtures. The tests were carried out by varying the outlet temperature of the cold and hot water. The preliminary results exhibit fairly good heat transfer coefficients in evaporation and condensation, as compared to classical brazed plate heat exchangers. Only the internal volume is still important and induces a high liquid holdup. A new design of the heat exchangers is under evaluation, the reduction of the inlet and outlet manifolds, could lead to a reduction rate up to 50% of the internal volume.

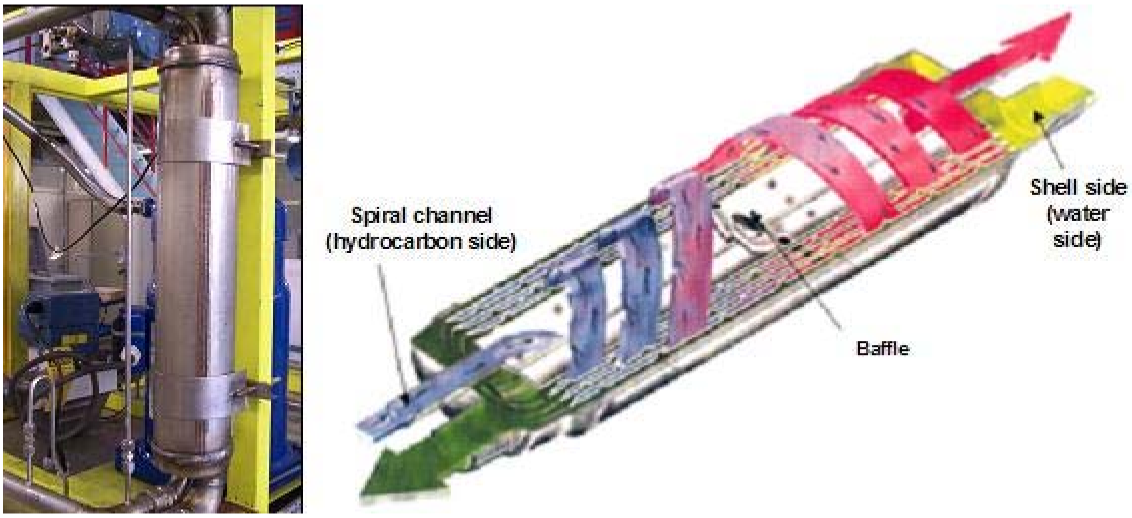

Figure 5: View and principle of the spiral heat exchanger.

A high pressure spiral heat exchanger for CO2 has also been developed, with the aim to be efficient and compact, pressure and corrosion resistant. Pressure tests up to 300 bar were carried out with no leakage, as well as mechanical resistance studies, which avoid internal deformation that could have an impact on the hydraulic and thermal performances of the heat exchanger. The CO2 heat exchanger prototype is designed according to the specifications for the CO2 heat pump prototype.

3.CONTROL

Regulation and control aspects have been investigated and a report is available on the project web site. Employing an effective control strategy can increase the efficiency of a heat pump system. Several approaches can be taken to implement an enhanced control scheme; examples of which include capacity control techniques, improved expansion valve control and optimised secondary side control. A product survey of commercially available heat pumps revealed little diversity amongst packaged heat pump models. Some of the more sophisticated models employ hot-gas bypass capacity control, manual stepped control of the indoor fan speed and automatic stepless control of the outdoor fan speed. Advanced control devices, like inverter driven variable speed compressors and electronic expansion valves (EEVs) were only evident in higher-value units, like multi-split air conditioning systems. However, there is evidence to suggest that some of these technologies are being employed in packaged heat pump units. Table 1 summarises the range of control techniques that were considered.

Table 1 Heat Pump Control Techniques.

Category	Capacity Control	Expansion Device	Condenser Pressure Control
Control Techniques	Compressor Cycling Hot Gas Bypass Cylinder Unloading Suction Gas Throttling Variable Speed Compressor	Thermostatic Expansion Valve Electronic Expansion Valve	Fixed Head Pressure Control Floating Head Pressure Control Optimised Floating Head Pressure Control

A direct comparison between electronic expansion valves (EEVs) and thermostatic expansion valves (TXVs) revealed that EEVs perform better. The main drawback of EEVs has been their high cost relative to TXVs. However, as the technology develops, this is likely to be less of an issue. Further studies indicated that significant energy savings could be achieved over alternative forms of capacity control by employing a variable speed compressor. However, incorporating a variable speed drive into an existing fixed speed compressor can have a negative impact on performance because of inverter and motor losses. Furthermore, employing a variable speed compressor is often subject to the inclusion of an electronic expansion valve, because thermostatic expansion valves are incapable of operating over the required range of refrigerant flow rates. Variable speed compressors are not commonly used in heat pumps at present because of the high capital cost associated with inverters and other ancillary equipment, however they are used extensively in air-conditioners and are likely to be increasingly utilised in heat pumps in the coming years. Of the three forms of condenser head control that were examined, optimised floating head pressure control proved to be the most efficient. This type of control fixes the condenser pressure at a value that minimises the total power consumption of the condenser fan and the compressor motor.

4. HEAT PUMP PROTOTYPES

4.1 Hydrocarbon heat pump

5 hydrocarbon heat pump prototypes will be designed, manufactured and tested. The heating capacity will range from 2 kW for an exhaust air heat pump to 100 kW for a reversible heat pump for commercial application. The heat exchangers will be either brazed plate or spiral. For the low capacity heat pumps, the refrigerant charge will be kept below 150 g, this will be achieved by a careful design of the piping and heat exchangers. For the compressor, the initial problem with undertaking research and development on a heat pump using a scroll compressor with a hydrocarbon refrigerant is not a technical one. The problem is that it is very difficult to find a scroll compressor manufacturer who is currently interested in supplying products for use with hydrocarbon refrigerants, as hydrocarbon refrigerants are flammable. The reason for this is simple – the compressor manufacturers are very concerned about potential litigation, which could cause them a financial penalty, if any person was injured in any way by a fire or explosion of such a compressor if a flammable refrigerant was used. Several compressor manufacturers have been approached and agreements for the use of scroll compressors for hydrocarbon applications have been obtained with some of them. The other option is to use semi-hermetic reciprocating compressors, as they are available for hydrocarbon applications. Hermetic compressors used for domestic refrigerators or AC systems have unfortunately too low capacities.

The 5 heat pump prototypes are presently at the design or manufacturing stage, and they will be first tested in laboratories in 2006, prior to field tests during the 2006-2007 heating period.

4.2 Ammonia heat pump

A small ammonia heat pump has been designed with a heating capacity of less than 10 kW. The work during this first year has concentrated on identifying suitable components and to build a first laboratory pre-prototype for testing (Palm, 2005). The main problem areas are the compressor and the expansion device, for which the choices are very limited. It has only been found one type of semi-hermetic compressor suitable for ammonia. However, this compressor has just been released from a Japanese manufacturer and the details and the delivery dates are not known. One manufacturer of "canned motor" compressors for ammonia has also been identified. This type may be used, but the electric efficiency of this type of compressor motor is slightly lower than for other types. Open compressors of the necessary size range are sold by a few different manufacturers. For the pre-prototype an open compressor from Bock was used. For the expansion valve, a thermostatic valve from Danfoss was identified which, according to specifications, could be used for the low capacities of the single family heat pump. The valve in itself is normally used for substantially higher capacities, but by using the smallest orifice available the necessary capacity may be reached, according to the manufacturer. The heat exchangers selected for the pre-prototype were fully welded plate heat exchangers. The objectives and experimental results obtained on this first prototype are summarised in table 2. Even if the goals are not fully reached, these first results are very promising. Further development should allow reducing the refrigerant charge and increasing the capacity.

Table 2: Ammonia heat pump performance

	Goals	Achieved
Charge	100 g	220 g
COP	4.3	Almost 3
Heating capacity	5-10 kW	4.9 kW

4.3 CO2 heat pump

In the first phase the concept design for the CO2 heat pump prototype was carried out. The challenge of this task is not only to overcome the technical difficulties but also to ensure the economic competitiveness of the system compared to the present state of the art. Simultaneously, a search for patents and components was started to ensure the availability of the required components within the scheduled time. The difficulty to find the required components for the prototype not provided by any partner of the consortium could already be solved in most cases. Based on the system definition, a first functional prototype with a 3 kW capacity for space heating and hot water production was built using the available components. A second prototype having a higher capacity will also be developed.

5. CONCLUSIONS

During the first year of the project, significant progress towards the objectives has been achieved. Concerning the development of components, specific heat exchangers with low charge inventory have been developed and tested using hydrocarbons and ammonia. The compressors available on the market have been evaluated regarding their capacity to work with natural refrigerants such has propane, ammonia or carbon dioxide. Regulation and control aspects have been investigated and a report is publicly available in January 2006. Reports on design methods and review of standards and regulations have been issued for hydrocarbon refrigerant. Similar documents will be prepared for ammonia (available publicly in November 2006) and for carbon dioxide. All the reports are available on the project website www.sherhpa.com.

More than 10 heat pump prototypes using various natural refrigerants will be developed and tested during the project. Domestic and industrial applications are covered for both hot water production and heating purposes. The heating capacity ranges from a few kW for domestic applications, to several hundreds of kW for industrial usage. These prototypes are presently at the design phase and some have already been manufactured and are presently tested in laboratory conditions. All these prototypes will be installed for test under real conditions by the end of the project.

ACKNOWLEDGEMENT

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REFERENCES

Bisco F. and Mantovan M., 2005, Heat Pumps with Natural Fluids, Proceedings of the IIR/IIF conference, Thermophysical Properties and Transfer Processes of Refrigerants, Vicenza, August 30- Sept. 2, pp.375-382.

Corberan J.M., Gomez B., Colbourne D., Gonzalvez J. Urchueguia J.F. and Segurado J., 2005, Current situation and evolution of standards upon the use of Hydrocarbon refrigerants on A/C, heat pump and refrigeration equipment, Proceedings of the IIR/IIF conference, Commercial Refrigeration, Vicenza, August 30- Sept. 2, pp. 249-256

Palm B., 2005, Ammonia in small heat pump and refrigeration systems, Proc. IIR Conference on Ammonia refrigeration and heat pump systems, Ohrid, Macedonia, May 6 -8

Thonon B.,2005, A review of hydrocarbon two-phase heat transfer in compact heat exchangers and enhanced geometries, Proceedings of the IIR/IIF conference, Thermophysical Properties and Transfer Processes of Refrigerants, Vicenza, August 30- Sept. 2, pp. 367-373