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MODELLED PERFORMANCES OF A HEAT AND COLD PUMP WITH A HFC OR CO_2 AS A WORKING FLUID

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ABSTRACT

Since the ozone depleting substances were banned, HFCs[1] have become the leaders in refrigeration devices. The Kyoto Protocol classifies these fluids in the category of greenhouse gases responsible for global warming. In the future, HFCs are also likely to be banned. Carbon dioxide (R-744) seems to be the best candidate for replacement (GWP[2] = 1 for CO_2 and GWP = 1200 for HFC-134a). Performances of CO_2 are interesting in transcritical cycles. However, the CO_2 transcritical cycle sets a challenge concerning high pressures (over a 100 bar). The Heat and Cold Pump is intended to produce DHW[3], heat and cool residential and commercial buildings. It can satisfy simultaneous needs in heat and cold, a typical situation during in-between seasons in buildings with significant areas of glazings. The HCP[4] presents an innovative design of the refrigeration circuit, intelligent operating modes and defrosting system. Two HCPs (CO_2 and R-134a) were modelled and compared. Performances of the HCP CO_2 are lower by 16% in cooling and by 23% in heating but the recoverable energy for defrosting is 2.34 times higher.

Index terms: *Heating, Cooling, Domestic Hot Water, CO_2*

INTRODUCTION

Many buildings have simultaneous needs in heat and cold. Typically, during summer, they face needs in cooling and for domestic water heating. During in-between seasons, rooms facing north have to be heated and rooms facing south have to be cooled, especially in buildings with significant areas of glazing. In winter, only heating is required. The Heat and Cold Pump (HCP) was thought to satisfy the needs for domestic hot water production, space heating and cooling all year long and uses a special defrosting technique.

This article describes the Heat and Cold Pump and supports the choice of a working fluid, a criterion that will condition the performance and the sustainability of the system.

HEAT AND COLD PUMP

The HCP (figure 1) has three heat exchangers: a condenser and an evaporator that work on water to prepare hot and cold sources for heating and cooling and an exchanger that works either as a condenser or as an evaporator on ambient air to adapt the productions to the needs. This system evacuates the excess of cold in a heating mode and the excess of heat produced in a cooling mode.

The HCP works principally in three distinct modes: a heating mode using the water condenser and the air exchanger as an evaporator; a dual mode preparing hot and cold waters using the water heat exchangers; and a cooling mode using the water evaporator and the air heat exchanger as a secondary condenser. The cooling mode also integrates the production of domestic hot water by using the top part of the water condenser as a primary condenser.

The water condenser is divided into three parts. The top part is used for domestic water preparation, the middle part for the production of hot water for space heating and the bottom part is connected to the cold water tank. During winter, this feature allows to store heat in the cold tank. The HCP works alternatively in heating mode and in dual mode. In heating mode, the heat exchangers involved are the air evaporator and the three parts of the water condenser. The temperature of the cold tank increases up to a maximum of 15°C. The fins of the air evaporator get frosted. The HCP then changes mode to enter the dual mode. The fan of the air heat exchanger is stopped. The water evaporator and the top and middle parts of the water condenser are now involved. This enables to have a better COP by working on water as a source on both sides. In this mode, the defrosting system is automatic thanks to the circuit design of the HCP. After passing through the water condenser to produce hot water for domestic use and space heating, the working fluid enters the air heat exchanger at a temperature around 30°C and finishes condensation by heat exchange with the frosted fins. The dual mode is the default mode until the cold tank temperature is 5°C. Then the HCP switches back to heating mode and so on.

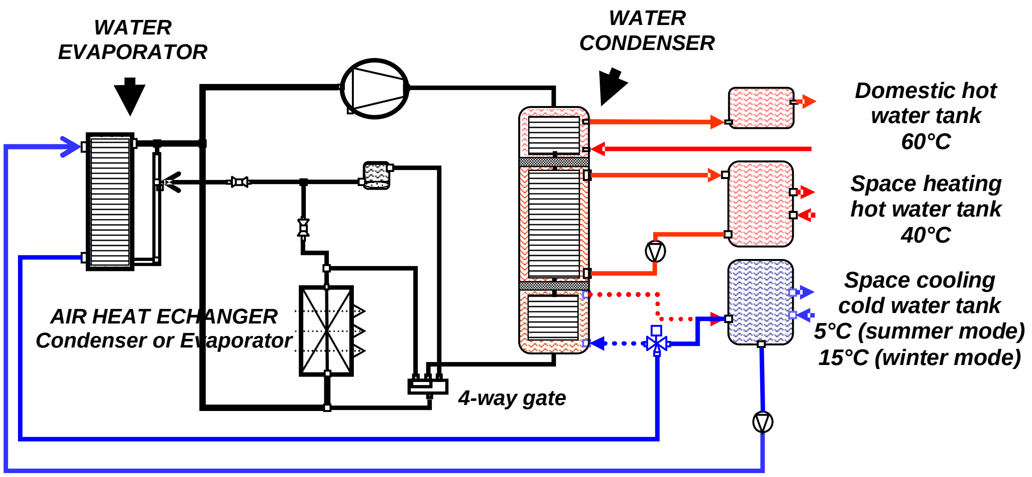

Figure 1: The Heat and Cold Pump

THE CHOICE OF THE REFRIGERANT

The choice of the refrigerant is linked to three criterions: performance, cost and security and environmental regulations. Hydrofluorocarbons (HFCs) are presently the most convenient and performant refrigerants on the market. However these substances are greenhouse gases that contribute to global warming. They are therefore likely to be banned by governments in the future. In parallel, since more and more concern is shown about ozone depletion (Montreal Protocol) and global warming (Kyoto Protocol), interest is growing for natural fluids like ammonia, propane and carbon dioxide.

Table 1 shows the most common fluids ever used in refrigeration. R-12 is a chlorofluorocarbon (CFC) and R-22 is a hydrochlorofluorocarbon (HCFC). Because of their impact on the ozone layer (Ozone Depletion Potential ODP ≠ 0), the sale of devices using these substances was banned in Europe in 2000 for CFCs and in 2004 for HCFCs. Widely used in mobile air-conditionning systems, R-134a is one of the most performant HFC but has a high Global Warming Potential (GWP = 1200). Some research, led by industrials, is aimed at developping new HFCs with GWP under 150. Ammonia is suited to bigger refrigerating systems. Because of its high toxicity and of the fact that it corrodes copper, it needs industrial structures. Propane is quite dangerous as well because it is easily flammable. According to Gustav Lorentzen, author of "Revival of carbon dioxide as a refrigerant" in 1994, CO_2 is today's best natural refrigerant as a substitute for HFCs. Table 1 shows that CO_2 is environmentally friendly, non toxic, non flammable and has a high refrigerating capacity.

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Table 1: Characteristics and properties of some refrigerants

Fluid	CFC-12	HCFC-22	HFC-134a	NH_3 R-717	C_3H_8 R-290	CO_2 R-744
Natural substance	No	No	No	Yes	Yes	Yes
Molar mass (g/mol)	120,92	86,48	102,03	17,03	44,10	44,01
Volumic refrigerating capacity at 0°C (kJ/m^3)	2740	4344	2860	4360	3870	22600
ODP	1	0.05	0	0	0	0
GWP (100 years)	7100	1500	1200	0	0	1
Flammable?	No	No	No	Feebly	Yes	No
Toxic?	Feebly	Feebly	Feebly	Yes	No	No

Indeed CO_2 is quite performant when used in transcritical cycles (fig. 2). In such cycles, low pressures are around 40 bar, high pressures can reach 120 bar. During the heat rejection, the pressure of the refrigerant is above its critical value (73.8 bar for CO_2). This implies that there is no changement of phase at heat rejection. When temperature decreases, supercritical gas turns progressively to supercritical liquid. The temperature of the fluid at the compressor outlet is between 70 and 100°C. The gliding temperature obtained at the heat rejection side enables to produce hot waters at different temperatures like wanted for the HCP (Dosmestic hot water at 60°C and space heating water at 40°C). Producing DHW with a HCP R-134a would have required an auxiliary heater. The CO2 transcritical cycle is for this other reason well suited to the applications selected for the HCP.

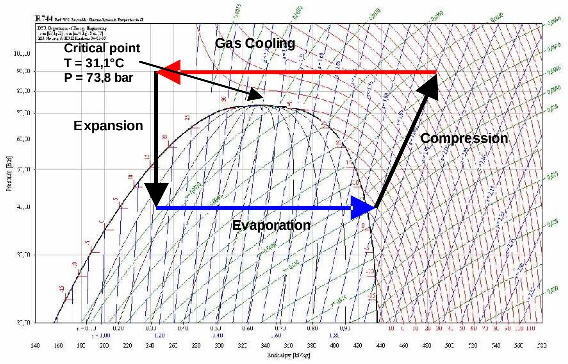

Figure 2: Transcritical cycle on the Mollier diagram

COMPARISON OF THE PERFORMANCES IN SPACE HEATING AND COOLING CAPACITY OF THE HCP WITH R-134a AND CO_2 AS WORKING FLUID

In the refrigeration cycle itself, HFCs are a priori more performant than carbon dioxide. The following simulation will help to evaluate the loss in performances for CO_2 compared to the gain on environmental aspects.

The Heat and Cold Pump has been simulated for the refrigerant HFC-134a and for carbon dioxide on a basis of a steady state system in dual mode with empirical models of compressors and LMTD models for the heat exchangers. This modelling technique gives a good estimate of the HCP performances shown on figure 3.

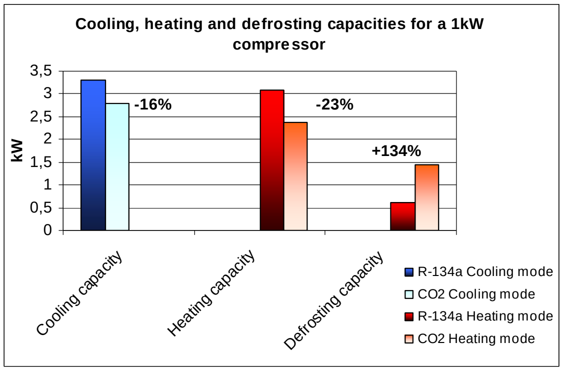

Figure 3: Performances of the HCP with R-134a or CO_2 as working fluid

The capacities of the Heat and Cold Pump working with CO_2 are lower by 16% in cooling and by 23% in heating but the recoverable energy for defrosting is 2.34 times higher.

CONCLUSION

The choice of the refrigerant appears quite clearly. As DHW can be directly produced, as the efficiency of defrosting is an important factor for a heat pump and as the loss in heating and cooling capacity is reasonable, CO_2 is chosen for the Heat and Cold Pump.

The Heat and Cold Pump appears to be a performant and environmentally friendly machine. With carbone dioxide as a working fluid, the impact on global warming will be devided by 1200.

However, the CO_2 transcritical cycle sets a challenge concerning high pressures particularly in the different heat exchangers but the industrial sector also seems to work on the subject to design improved CO_2 components for refrigeration.

RÉFÉRENCES

[1] **KUMMERT**, M., Le protocole de Kyoto : Situation en Europe et en Amérique du Nord, Colloque CIFQ 2005, Saint-Malo, France, pp. 13-18.

[2] Protocole de Kyoto à la convention-cadre des nations unies sur les changements climatiques, 1997.

[3] **FRANCOIS**, S., Critères de choix des fluides frigorigènes en réfrigération et climatisation, Chaud froid Plomberie n°656 Avril 2003 pp. 57-61.

[4] IKK 2004 à Nuremberg : quels fluides frigorigènes pour demain, Chaud Froid Plomberie n°674 Décembre 2004 pp. 39-47.

[5] **LORENTZEN**, G., The use of natural refrigerants: a complete solution to the CFC/HCFC predicament, International Journal of Refrigeration Vol. 18 n°3 pp. 190-197, 1995.

[6] **PEARSON**, A., Carbon dioxide - new uses for an old refrigerant, International Journal of Refrigeration 28 pp. 1140–1148, 2005.

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[7] **FLEMING**, J., Carbon Dioxide as the Working Fluid in Heating and/or Cooling Systems, Bulletin of the IIR – n° 2003-4 – Review Article;
[8] **LENAT**, Y., Cours de Froid Industriel, 2004.
[9] Solar Energy Laboratory, University of Wisconsin-Madison « TRNSYS, A Transient Simulation Program, Volume I, Reference Manual », march 2000.
[10] CoolPack - A Collection of Simulation Tools for Refrigeration, Department of Mechanical Engineering, Technical University of Denmark, 1998 – 2001.

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