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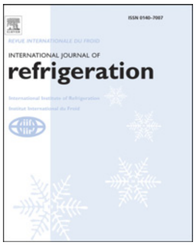

Ammonia in low capacity refrigeration and heat pump systems

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ABSTRACT

Ammonia has been used as refrigerant in large vapour compression systems continuously since the beginning of the era of refrigeration. In small systems, it has hardly been used at all since the introduction of the halogenated hydrocarbons around 1930. Lately, with the search for alternatives with less influence on global warming, the use of ammonia in small systems has come into focus again.

In the present paper, the work done at the Royal Institute of Technology (KTH) with the aim of developing a prototype of a domestic water to water heat pump with a heating capacity of 9 kW is presented. It has been shown that such a system can be designed to operate with about 100 g of ammonia.

Crucial problems in the development of the direct expansion system were to arrange for oil return, and to achieve good heat transfer in the evaporator. These problems were solved by use of an oil which is soluble in ammonia.

The main obstacle for introducing this technology commercially is the limited supply of components. Particularly, there are no hermetic or semi-hermetic compressors for ammonia available in this size range.

L'ammoniac utilisé dans les systèmes frigorifiques et à pompe à chaleur de faible puissance

Mots clés : Système frigorifique ; Pompe à chaleur ; Sol-eau ; Enquête ; Ammoniac ; Technologie ; Échangeur ; Performance

1. Introduction

The interest from the European Union in developing the technology of alternative refrigerants has resulted in a number of research projects supported by EU on this subject. Two of these have wholly or in part, been devoted to development of small ammonia systems. In the project with the acronym OSCAR (Innovation in small capacity ammonia refrigeration plants) several systems in sizes between 3 and 20 kW cooling were built and tested briefly. All used the mixture of 60% ammonia and 40% dimethyl ether denominated R723. Most, if not all, of the systems were designed using copper tubing and

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brass fittings, and some were even built with standard hermetic compressors designed for HFC refrigerants. In short it was concluded that, during the time of the tests, no corrosion on the copper was found using refrigerant with less than 400 ppm of water. All systems built with hermetic compressors failed after a very short time, sometimes within hours. This was found to be caused by the ammonia obliterating the electric insulation on the windings of the compressor motors. More information about this project is found in the OSCAR Final Report (2005) and in a contribution to the Gustav Lorentzen conference (Hansen, 2006).

The second EU project focusing in part on development of small ammonia systems is called SHERHPA (sustainable heat and energy research for heat pump applications). This project is focused on the development of heat pump systems using different types of natural refrigerants, including hydrocarbons, carbon dioxide and ammonia. Being a collective research project, one of the prime objectives is to support small and medium size enterprises developing technology for components and systems of heat pumps with natural refrigerants. As a part of the project, the Royal Institute of Technology (KTH) has been working on a pre-prototype of a liquid to liquid domestic heat pump. The aim is to use the experience gained from this system for building a prototype as close as possible to the design of a commercial unit. This prototype will be built in cooperation with the Swedish heat pump manufacturer Thermia, and will be based on one of their standard units.

2. Basis for choice of system design

The pre-prototype is designed to mimic a typical ground source heat pump of the type sold on the Swedish market. Such heat pumps are for heating only and typically have heating capacities of 5–10 kW. Heat is extracted from a borehole in the ground, 100–200 m deep, or from the surface soil by a secondary brine circuit containing a glycol or ethanol solution. Typically, the temperature of the brine coming from the borehole is around zero or a few degrees below zero, and the temperature is reduced by around 3 K while passing through the evaporator. Some systems, however, have been designed to run at temperatures above zero at all conditions. This requires longer boreholes, and is a challenge as the undisturbed ground temperature is about +8 °C in the Stockholm area.

The heat from the heat pump is used both for heating water for distribution to radiators, convectors or floor heating system around the house and for heating the sanitary hot water. The necessary distribution temperatures at design conditions vary depending on the heating system. With floor heating it could be as low as 35 °C, but with convectors or radiators the outgoing temperature could be up to 55 °C or even higher in some cases. Usually, the systems are designed to cover about 60% of the capacity required on the coldest day. This sizing results in the heat pump covering about 90% of the annual heating demand. The rest is covered by auxiliary heating, usually in the form of electric heating. The sanitary hot water should be heated to 60 °C, at least periodically, to prevent growth of legionella bacteria.

3. System design

Based on the typical conditions and design of heat pumps on the Swedish market stated above, the ammonia heat pump design is targeted for a heating capacity of 9 kW at heat source temperatures around zero and heat sink temperatures of 40 °C. Hot water production will be covered mainly by desuperheating of the refrigerant coming from the compressor in a dedicated desuperheater. The fact that ammonia gives high discharge temperatures, which is sometimes considered as a drawback of this refrigerant, can in this way be turned into an advantage: hot water can be produced at relatively high temperatures without need for increasing the condensing temperature.

A detailed schematic view of the test setup is shown in Fig. 1. As shown, the water returning from the (simulated) distribution system (here denoted Tap Water Input) first passes through the condenser. The flow is then divided so that a minor part is passed through the desuperheater, while the main part returns to the distribution system. In actual practice, we could imagine the heat pump heating a tank of water: cool water from the bottom of the tank is heated in the condenser, after which the main part of the water is returned to the middle of the tank, while a minor part is heated further in the desuperheater and returned to the top of the tank. Hot water at medium temperatures is taken from the middle of the tank to the hydronic (heating) system and returned to the bottom of the tank. Sanitary hot water is heated by passing it through a coil inside the tank, starting at the bottom and coming out at the top.

On the water side, the pre-prototype was supplied with two automatic valves: a three-way valve to mix hot water heated by the condenser with cold water to get the return temperature (condenser inlet temperature) from the simulated heating system to a pre-set value (usually 40 °C), and a two-way valve to regulate the flow rate through the desuperheater to get a constant water outlet temperature out of the desuperheater of 60 °C. The water flow rate through the condenser was kept constant and chosen so that the temperature change of the water passing through the condenser was 3–5 °C depending on the capacity.

On the cold side, the secondary circuit contained an ethyl alcohol solution, and the brine was heated by electric heaters which could be regulated in several steps, thereby determining the evaporation temperature. The brine flow rate was chosen so as to get a temperature increase of the brine of about 3 °C at nominal conditions.

As already mentioned, there are no hermetic or semi-hermetic compressors for ammonia available in the size range required for the present application. Therefore, an open ammonia compressor, model F2 from Bock (Fig. 2b), was used. This is a two-cylinder piston compressor with a displacement of 10.5 m^3/h at 1450 rpm. At an evaporation temperature of −5 °C the highest recommended condensing temperature is +40 °C, at which condition the heating capacity should be close to 9 kW (at 0 °C evaporation temperature the corresponding numbers are +50 °C and 10.5 kW). The compressor was directly connected to a standard 4.5 kW electric engine. Another alternative which was also