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Pre-industrial development and experimental characterization of new air-cooled and water-cooled ammonia/lithium nitrate absorption chillers

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ABSTRACT

Two pre-industrial prototypes of a new ammonia/lithium nitrate absorption chiller, a water-cooled one and an air-cooled one, have been built and experimentally characterized. The single-effect configuration of the absorption refrigeration cycle was selected for both prototypes in which brazed plate heat exchangers were used in all thermal components. These prototypes, designed for air conditioning applications, were tested under various operating conditions to assess their performance. The water-cooled prototype yields 12.9 kW of cooling capacity and an electrical COP_{elec} of 19.3, when operating at a 15 °C chilled water temperature, 90 °C hot water temperature and a 35 °C cooling water temperature. In the case of the air-cooled prototype, at a 15 °C chilled water temperature, 90 °C hot water temperature and a 35 °C ambient air temperature, the cooling capacity is 9.3 kW and the electrical COP_{elec} is 6.5.

Développement pré-industriel et caractérisation expérimentale de nouveaux refroidisseurs à absorption d'ammoniac/nitrate de lithium refroidis à l'eau et à l'air

Mots clés : Refroidisseur à absorption ; Ammoniac ; Nitrate de lithium ; Echangeur de chaleur à plaques

1. Introduction

During the first decade of this century several low capacity absorption chillers have appeared on the European scene focused especially on solar thermal cooling applications for the residential sector. The majority were single-effect units using the water/lithium bromide working pair as the ROTARTICA, PHONIX or WEGRACAL products. Other consolidated manufacturers of large scale absorption chillers such as

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Nomenclature

BPHE	brazed plate heat exchanger
COP	coefficient of performance
EEV	electronic expansion valve
F	fan rotation speed (rpm)
LMTD	logarithmic mean temperature difference (°C)
P	pressure (bar)
Pw	electrical power input (kW)
Q	thermal power (kW)
RHX	refrigerant heat exchanger
SHX	solution heat exchanger
T	temperature (°C)

Subscripts

AC	absorber/condenser
AIR	ambient air
E	evaporator/evaporation
elec	electrical
G	generator/generation
Hyd	hydraulic power of the circulation water pump due to pressure drop in a heat exchanger
pump	solution pump
ther	thermal
w	water side
1	inlet to the chiller (*)
2	outlet from the chiller (**)
(*)	when not indicated, T_E denotes chilled water outlet temperature
(**)	when not indicated, T_G, T_{AC}, T_{AIR} denote temperatures at the chiller inlet

Greek letters

$\dot{v}$	volumetric flow ($m^3\ h^{-1}$)
ε	heat exchanger efficiency
ΔP	Pressure drop (bar)
η	pump efficiency

YAZAKI, THERMAX and BROAD have also extended their product range to cooling capacities lower than 30 kW. These single-effect absorption chillers can be activated with hot water at low temperatures (i.e. 80–95 °C), produced by flat solar collectors, and can achieve a thermal coefficient of performance (COP_{ther}) of 0.7.

Another innovative cooling machine that has additionally experimented good commercial diffusion is the CLIMATEWELL adsorption machine that operates with water/lithium chloride as a working pair.

Moreover, the traditional working pair ammonia/water has also been used in solar cooling applications with single-effect cycle configurations such as those in the chillers manufactured by PINK and AGO. On the other hand, gas-fired ammonia/water absorption chillers have always been present in cooling applications, with manufacturers like ROBUR keeping a steady presence in the sector over the years. Nowadays, the GAX (Generator–Absorber–Exchanger) thermodynamic cycle is employed in these gas-fired absorption chillers.

A review of all of these new machine concepts can be found in Marcos (2008), Jakob and Kohlenbach (2010) and Deng et al. (2011).

The most important drawback of water/lithium bromide technology is the risk of crystallization at high absorber temperatures. Because of this commercial chillers that use this working pair are commonly water-cooled, hence requiring cooling towers. Air-cooled machines with water/lithium bromide are still scarce; the ROTARTICA machine equipped with a dry cooler was an exception because of its particular rotary operation. The need for a cooling tower introduces a certain rejection in the residential HVAC market because of the higher maintenance costs which are necessary to avoid risk of Legionella. Different research efforts have been conducted in this field such as those reported by Kim and Machielsen (2002), Kim and Infante Ferreira (2009) and González-Gil et al. (2011).

Ammonia/water GAX chillers can be air-cooled but they require higher activation temperatures, which makes the use of the cheaper flat solar collectors impossible in solar cooling applications.

In this context, the HVAC manufacturer CIAT and the CREVER research group from the Rovira i Virgili University, launched a research and development project for a new absorption chiller of 10 kW of nominal cooling capacity using the ammonia/lithium nitrate mixture as a working pair. Between 2006 and 2011 a laboratory prototype and two pre-industrial prototypes, a water-cooled one and an air-cooled one, were manufactured and tested using BPHE in all the thermal components (Zamora et al., 2011).

In comparison with the water/lithium bromide absorption chillers that operate under vacuum, the assembly process of ammonia absorption chillers is more similar to the technique employed in the vapour compression chillers which operate under pressure. Furthermore, an ammonia/lithium nitrate absorption chiller does not require a rectifier while an ammonia/water chiller does. This reduces the machine weight and cost. However, in order to be competitive with vapour compression chillers, there are still some drawbacks of ammonia absorption chillers that must be overcome. Firstly, though the running cost of the absorption refrigeration system is much lower than that of the vapour compression system, its initial capital cost is still much higher. Secondly, the refrigerant charge must be reduced to its minimum, due to the ammonia toxicity.

Nowadays, Brazed Plate Heat Exchangers (BPHEs) are the most common heat transfer geometry used in compression chillers due to their compactness and lower system refrigerant charge and cost.

This paper presents the current work carried out, showing the most significant results achieved during the development of the aforementioned new absorption chiller.

2. Ammonia/lithium nitrate absorption refrigeration systems

Ammonia/lithium nitrate mixture has been reported as a working pair for absorption refrigeration systems since the first half of the twentieth century. The English patent 358.844 claimed the thermodynamic design of an absorption chiller using ammonia as refrigerant and a solution of ammonia with an anhydrous non-volatile salt, such as lithium nitrate as absorbent (Electrolux Ltd, 1930). Its interest for solar cooling