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Experimental analysis of a novel concept of a "thermally driven" solution pump operating a small-capacity ammonia/water absorption heat pumping system

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ABSTRACT

Only a few electrical solution-pumps are available on the market suitable for ammonia/water absorption heat pumping systems with an evaporator capacity lower than 20 kW. In order to improve this, a "thermally-driven" solution-pump is proposed, offering several advantages, as e.g. an oil-free, simple and leak-proof design. "Thermally-driven" means this pump is driven by a power process within the absorption heat pumping-cycle instead of electricity. The experimental analysis of this novel pump operating in a commercially available ammonia/water-absorption chiller shows that it can be easily integrated and works without any relevant operating limits. However, the measured COP of the considered chiller is decreased by at least 0.1 (15%) by this thermal-pump compared to the existing electrical-pump. Nevertheless, thermal energy (e.g. cost and CO_2-free waste heat) can be used to drive this pump and due to lower production cost it can be an interesting alternative from an economical and ecological point of view.

Analyse expérimentale d'un nouveau concept de solution de pompe "entrainée thermiquement" entrainant un système de pompe à chaleur à absorption à ammoniac/eau de petite capacité

Mots clés : Absorption ; Pompeà chaleur ; Refroidisseur ; Chaleur exploitée ; Expériences ; Pompe à diaphragme

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Nomenclature

Parameters

A	area in m^2
f	circulation ratio in kg kg^{-1}
COP	coefficient of performance in –
h	specific enthalpy in kJ kg^{-1}
m	mass flow rate in kg s^{-1}
p	pressure in Pa, bar
P	(electrical) power in kW
Q	heat capacity or thermal power in kW
s	specific entropy in kJ kg^{-1} K^{-1}
T, t	temperature in K, °C
V	volume in m^3
V	volume flow rate in m^3 s^{-1}

Greek symbol

Δ	difference
ζ	NH_3-concentration in kg kg^{-1}
η	efficiency in –
Λ	delivery rate, volumetric efficiency in m^3 m^{-3}
ρ	density in kg m^{-3}
τ	time in s

Abbreviations, sub- and superscripts

*	with ThermoPump
0	cold, evaporator, refrigeration
1	large diaphragm
2	small diaphragm
ABS	absorber
AHP	NH_3/H_2O-absorption heat pump
C	cooling, evaporator, refrigeration
COLD	cold water cycle
CON	condenser
COOL	cooling water cycle
EVA	evaporator
GEN	generator
high	high-side
HOT	hot water cycle
in	inflow
losses	losses
low	low-side
max	maximal
min	minimal
out	outflow
PC	pumping chamber
PS	poor solution
Pump	required for ThermoPump or solution pump
Ref	refrigerant
RS	rich solution
RTH	refrigerant throttle
SHX	solution heat exchanger
STH	solution throttle
theo	theoretical
vapor	vapor
WC	working chamber

1. Introduction

Ammonia/water-absorption heat pumping systems (AHPs) offer a large ecological potential for a sustainable energy supply by the integration of renewable energy, as e.g. solar heat, geothermal heat, ambient heat, etc., for both cooling and heating applications, as discussed by e.g. Ziegler (2002, 2009) or Li et al. (2012).

According to Fumo et al. (2009), Denga et al. (2011), Radermacher et al. (2013) and Ramming (2013), the combination of co-generation plants with AHPs to the so called tri-generation systems are recently of growing interest. These combined cooling, heating and power units allow a significant contribution to the reduction of anthropogenic greenhouse-gas emissions due to a high overall efficiency. Additionally to the ecological benefit from an economic point of view this combination offers the possibility to increase the fuel utilization, because heat from the prime mover can be used to drive an AHP for cooling purposes at times of no heat demand. Several prime movers for the AHP can be considered, as e.g. an internal combustion engine (Ramming, 2013) or a fuel cell (Radermacher et al., 2013).

Particularly, small-capacity tri-generation systems offer various application possibilities for a decentralized use in households, commercial buildings or industry. For these applications, in many cases AHP plants with an evaporator capacity below 20 kW are required. Furthermore, the use of ammonia/water as working fluid of the AHP allows cold water temperatures below 0 °C, which increases the possibilities for cooling and heating applications. However, the market success of an ammonia/water AHP plant depends generally on its investment costs, the energy price and its efficiency and operating hours. Therefore the reduction of the investment costs of ammonia/water AHPs is of major interest.

To reduce the investment cost of AHPs a reduction of the cost of each single component has to be realized. The solution pump of an AHP is a core element of such plants, because it is required to overcome the difference between low and high side pressures. Nevertheless, the solution pump, which is most commonly an electrically driven pump, is one of the cost drivers of small-capacity ammonia/water AHP plants, accounting to 10–25% of the system cost. According to Safarik (2003) a solution pump of an ammonia/water AHP has to meet several technical requirements. Particularly, for small-capacity plants the delivery rate is very low but the necessary pressure lift is high. For example, depending on the operating conditions of the AHP only about 400–600 l/h of rich solution has to be delivered by the solution pump for about 20 kW of evaporator capacity and the pressure lift amounts to about 10–20 bar. Therefore, only a few electrically driven solution pumps are available on the market, which are suitable for small capacity ammonia/water AHPs and most of them are relatively complex, expensive and have substantial potential for improvements (De Francisco et al., 2002; Sakr et al., 1987; Safarik, 2003).

In order to improve this situation a so called "thermally driven" or "heat operated" pump can be considered (Zotter et al., 2011). Thermally driven solution pump means that this pump