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Experimental evaluation of a small-capacity, waste-heat driven ammonia-water absorption chiller

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A B S T R A C T

This paper presents the results from an experimental evaluation of a small-scale, waste-heat driven ammonia-water absorption chiller. The cycle is thermally driven, using the waste heat from diesel generator exhaust to desorb the refrigerant solution. The absorber and condenser are directly-coupled to the ambient air. The remaining heat exchangers are packaged in a compact microchannel monolithic structure for enhancing heat transfer. The system is designed to deliver 2.71-kW of cooling at extreme ambient temperature of 51.7 °C at a coefficient of performance of 0.55. Experiments on a heat pump breadboard system are conducted at ambient conditions of 29.7–44.2 °C, with delivered cooling duties of 2.54–1.91 kW. System and individual component performance is analyzed and compared with cycle model predictions, and deviations are explained. The absorber and desorber were identified to be the limiting components in the system. Effects of variation in ambient temperature are studied to characterize the performance at off-design conditions.

Évaluation expérimentale d'un refroidisseur à absorption à ammoniac-eau de faible puissance alimenté par de la chaleur perdue

Mots clés : Refroidisseur à diffusion-absorption ; Ammoniac-eau ; Récupération de chaleur perdue

1. Introduction

Vapor absorption based heating, ventilation and air-conditioning (HVAC) systems can utilize low-grade heat sources such as waste heat to provide heating and cooling. These systems also provide an alternative to conventional vapor compression systems in terms of reducing the peak demand for electricity (Ziegler, 1999). Specifically, waste-heat or solar energy driven systems can provide more economical cooling/heating solutions in

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Nomenclature

Cp	specific heat capacity [J kg^{-1} °C^{-1}]
h	specific enthalpy [J kg^{-1}]
HX	heat exchanger
ID	inside diameter [m]
$\dot{m}$	mass flow rate [kg s^{-1}]
OD	outside diameter [m]
P	pressure [kPa]
PWM	pulse-width modulation
q	vapor mass quality [–]
RPC	refrigerant pre-cooler
SHX	solution heat exchanger
T	temperature [°C]
x	ammonia concentration [–]

Subscripts

abs	absorber
cf	coupling fluid
conc	concentrated solution
cond	condenser
des	desorber
dil	dilute solution
evap	evaporator
in	inlet
liq	liquid
out	outlet
rec	rectifier
ref	refrigerant
vap	vapor

conjunction with power generation systems for combined heat and power (CHP) applications as shown by Ziegler and Riesch (1993) and Filipe Mendes et al. (1998). These systems also use environmentally benign working fluids, such as ammonia-water, with reduced global warming potential (GWP) (Lorentzen, 1995). Vapor absorption systems typically require more heat and mass exchange components compared to conventional vapor compression systems. The mechanical compressor is replaced by a set of heat and mass exchangers that enable heat source utilization (Herold et al., 1996; Srikhirin et al., 2001). This leads to larger system size and high capital cost, which has historically limited the use of such systems for residential and light commercial applications. To improve the efficiency of the single-effect absorption cycle, advanced cycles with internal heat recovery and multi-staged heat transfer mechanisms have been proposed by researchers in the past (Kang et al., 2000; Srikhirin et al., 2001; Ziegler, 1999; Ziegler and Riesch, 1993). However, in such systems, the increase in system complexity typically does not yield commensurate benefits in efficiency.

Some past research efforts experimentally evaluated absorption systems and advanced cycles for improved efficiency. Didion and Radermacher (1984) presented results on part-load performance and ambient temperature variation for a 10.5 kW cooling capacity gas-fired ammonia-water absorption chiller. It was observed that the COP and cooling duty decreased as the ambient temperature increased. Treffinger (1996) presented a direct gas-fired ammonia-water system for water heating applications. The COP of the system varied between 1.4 and 1.7, with the heating COP defined as the ratio of the total heat transfer rate from condenser and absorber to the heat input in the desorber. Erickson et al. (1996) demonstrated an ammonia-water generator-absorber heat exchange (GAX) cycle with cooling duty of 14.6 kW at a COP of 1.05. Mendes and Collares-Pereira (1999) presented results from the design and testing of a small-capacity solar absorption heat pump. The system demonstrated a cooling capacity of 5 kW (COP 0.56) and a heating capacity of 9 kW (COP 1.42). Sözen et al. (2002) presented results from testing of an ammonia-water absorption heat pump using solar energy. De Francisco et al. (2002) also presented experimental analysis of a solar powered ammonia-water system for small-scale refrigeration applications. The system was designed to provide a cooling duty of 2 kW, but the experiments showed limited performance and low COP due to using only natural convection for condenser and absorber heat rejection. This also led to very large component size. These studies report a need for more compact heat and mass exchangers to reduce the overall system footprint. Additionally, the vast majority of reported work did not consider extreme ambient conditions, which introduce further development challenges.

Reduction of the size of vapor absorption system components has been the focus of active research for some time. Garimella (1999) and Garimella (2004) presented a design for a microscale heat and mass exchange component for binary fluid mixtures. The falling-film type component utilized 1.58 mm OD tubes, and can be used as any component in the absorption cycle with minor modifications. Meacham and Garimella (2004) demonstrated the performance of the aforementioned device as an absorber and addressed issues with fluid distribution and techniques to improve the component performance. Later, Determan and Garimella (2011) and Garimella et al. (2011) demonstrated the use of the same device for desorption with minor modifications in fluid routing. However, all these designs were still less suitable for a compact heat pump packaged design with small fluid inventory.

Hu and Chao (2008) demonstrated the performance of a very small-scale water-lithium bromide absorption system with 40 W cooling capacity. The components were fabricated using silicon wafers with photo-chemically etched micro-channels of hydraulic diameter of 131 μm. Pence (2010) investigated micro-scale fractal flow networks for design of heat and mass exchangers to increase the vapor flow area and reduce the pressure drop in two-phase components. Determan and Garimella (2012) presented a micro-scale ammonia-water absorption heat pump with all the components in a single monolithic structure. The system delivered 300 W of cooling at a COP of 0.375. It demonstrated the potential of component integration and efficient packaging to achieve small system sizes, and the potential for scaling the systems to higher capacities. Keinath (2015) presented a compact absorption heat pump water heater for residential applications. The prototype system utilized a monolithic fabrication approach to integrate multiple heat and mass exchange components. It delivered 2.79 kW of heating at a COP of 1.74. Garimella et al. (2016) demonstrated the performance of a microchannel absorption chiller packaged unit. The natural gas fired system delivered a cooling duty of 3.3 kW at a COP of 0.47. Their work demonstrated the scalability of microscale designs.