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Experimental investigation and exergy analysis of a triple fluid vapor absorption refrigerator

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ABSTRACT

This paper presents an energy and exergy analyses of a triple fluid vapor absorption refrigerator working with ammonia as refrigerant, water as absorbent and hydrogen as auxiliary gas. The experimental setup is constituted of a commercial unit equipped with the appropriate metrology. The temperature at the inlet and outlet of every component of the machine, as well as the cabinet and ambient temperature are continuously measured and monitored. A simulation model of the machine is developed using the process simulator Aspen-Hysys. The thermodynamic analysis includes energy and exergy efficiency calculations, destroyed exergy evaluation and degradation of the coefficient of performance (*COP*) in each component of the refrigerator. The results indicate that the absorber exhibits the largest source of irreversibility followed by the solution heat exchanger. These two components alone are at the origin of 63% of the total degradation of *COP*.

1. Introduction

The triple fluid vapor absorption system or diffusion absorption refrigeration system (DAR) is a single pressure cycle using ammonia as refrigerant, water as absorbent and hydrogen as auxiliary gas. It was first invented by the two Swedich engineers Von Platen and Munters [1]. This unit can be powered by different energy sources such as natural gas, liquid petroleum gas, waste, electric or solar heat. These refrigerators are used in domestic applications like hotel rooms. This kind of systems has very low *COP*. Many studies have been carried out to improve the unit performance. Researches have been focused on the working fluids, component configuration and thermodynamic modeling: Rodriguez and Belman-Flores [2] presented a review of the state of the art of the DAR technologies. They analyzed over 70 publications. Several researches have been done to identify other working mixtures. Pfaff et al. [3] have used the LiBr/H_2O mixture by a generator temperature between 66 °C and 78 °C. The mixtures NH_3/NaSCN, NH_3/$LiNO_3$ have been studied by Acina et al. [4]. The obtained results confirm that the NH_3/$LiNO_3$ system was 50% more efficient then the NH_3/H_2O/H_2 mixture and 27% more efficient than NH_3/NaSCN system. Koyfman et al. [5] have studied experimentally the mixture *R*22/DMF, the generator temperature was varied between 50 °C and 90 °C. Zohar et al. [6] analyzed the use of *R*32, *R*124, *R*125 and *R*134a as refrigerant and DMF as absorbent. These mixtures can be activated by a 150 °C thermal energy source. The activation temperature of the mixture R124/DMAC examined by Ben Ezzine et al. [7] was found between 80 °C and 180 °C. Sayadi et al. [8] performed different binary mixtures of light hydrocarbons as working fluids. The mixture (C3/n-C6) with a driving heat temperature of 121 °C was found the optimal one. Mazouz et al. [9] carried out an experimental study of a commercial DAR machine using hydrogen as inert gas, in order to determine its performance parameters under various operating conditions. Steady state and dynamic methods were applied to evaluate the characteristics of the machine. The best performance of the machine was obtained with a heat supply of 42 W. A value of 0.12 was found for the *COP*. Helium was also proposed as substitute for hydrogen [6,10,11], as well as neon and argon [11].

Many researches have studied the optimal component configurations: Chen et al. [12] have changed the configuration of the generator to increase by 50% the efficiency of the unit. A bubble pump with multiple tubes was used by Vicatos and Bannett [13]. A lower generator temperature and an increase in the cooling capacity of up to 13% can be obtained. Jacob et al. [14] have designed a unit for solar refrigeration applications. An increasing cooling capacity by 30% was found. Several studies were presented to develop a thermodynamic modeling of the DAR cycles. These models are based on the equation of mass and energy conservation [4,15,16]. The software Engineering Equation Solver (*EES*) was the most used.

To determine the thermodynamic sources of low efficiency, an exergy analysis is necessary: The first analysis of a DAR in terms of exergy was done by Ben Jemaa et al. [17]. A computer model

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Nomenclature

COP	coefficient of performance
ex	flow exergy (W)
$\dot{E}$	rate of energy (W)
$\dot{E}x$	rate of exergy (W)
h	specific enthalpy
$\dot{I}$	irreversibility (W)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
$\dot{Q}$	rate of heat transfer (W)
RI	relative irreversibility
s	entropy (J/kg)
T	temperature (°C)
(UA)	global heat transfer coefficient ($W\,K^{-1}$)
$\dot{W}$	heating power (W)
η	exergy efficiency

Subscripts

0	reference state
abs	absorber
cab	refrigerator cabinet
cond	condenser
D	destroyed
elec	electric
evap	evaporator
ext	exterior
gen	generator
ghx	gas heat exchanger
int	refrigerator interior
rect	rectifier
rev	reversible
shx	solution heat exchanger

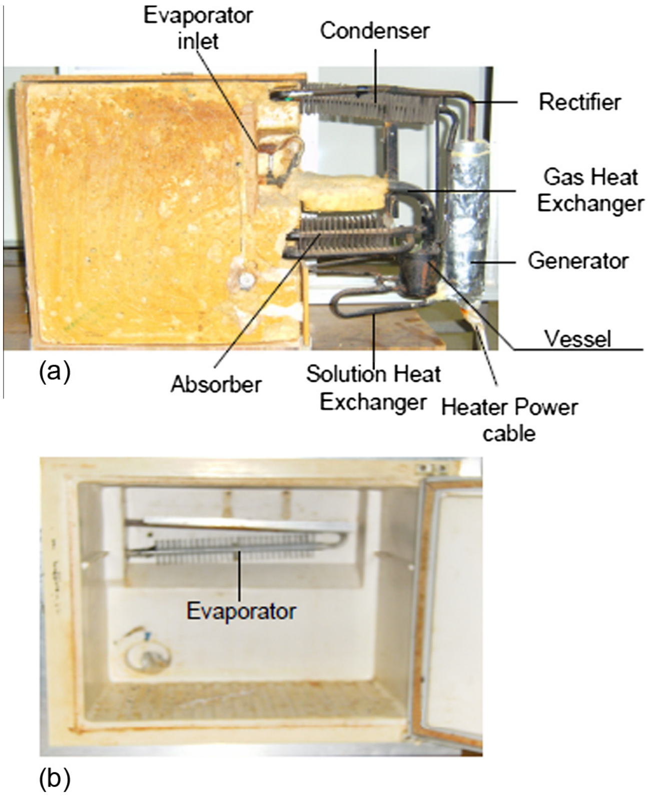

Fig. 1. Tested diffusion absorption refrigerator.

has been developed using the EES software to calculate the thermodynamic properties of all state points, heat flow rates, exergy losses and *COP* degradation in each component of the system. A parametric study was performed to investigate the effect of evaporating, generator and ambient temperature on the coefficient of performance and the exergy efficiency of the unit. Ziapour and Tavakoli [18] presented an exergetic study of a diffusion absorption refrigeration heat pipe (DARHP) cycle. They have developed a computer model using EES software for an NH_3/H_2O device cycle with helium as inert gas. The model was validated by comparing it with previously published experimental data for DARHP system. A. Yildiz and Ersoz [19] designed, constructed and tested a DAR system. It uses three component working fluids: ammonia, water and helium. The energy and the exergy losses for each component of the system are investigated numerically and experimentally. The values obtained from theoretical analysis are compared with experimental values.

In this paper an experimental study on a commercial diffusion absorption refrigerator was performed. A simulation model of the unit was developed using the software ASPEN-HYSYS to study the exergy performance.

2. System description

The tested diffusion absorption refrigerator is shown in Fig. 1 [20,21], and a schematic diagram of the unit is presented in Fig. 2. The main elements of the unit are a generator, rectifier, condenser, evaporator, absorber, solution heat exchanger (SHX) and gas heat exchanger (GHX). The heat supplied to the generator is given by an electric heater.

The bubble pump contains initially a rich ammonia solution (8). When the heat flow $\dot{Q}_{Gen}$ is applied to the bubble pump, ammonia vapor separates from the water and rises inside the small tube carrying with it the ammonia solution (18). Vapor (10) exits to the rectifier and the condensate (17) to the ammonia-weak solution (19) which enters the solution heat exchanger. Refrigerant vapor (1), leaving the rectifier, is condensed (2) by exchanging heat $\dot{Q}_{cond}$ with ambient air. Liquid refrigerant (2) flows in the inner tube of the gas heat exchanger. In the outer annular space circulates the gas (hydrogen and refrigerant vapor) from the absorber (5) and towards the evaporator (3). The fluid flowing in the second tube (inner annulus) is the ternary mixture of ammonia-water-hydrogen (7) leaving the evaporator. It will cool the other two fluids, being heated and continues its downward stroke to the tank (9). The two streams (3 and 16) from the gas heat exchanger are mixed at the inlet of the evaporator. During its progression in the evaporator, the mixture exchange heat $\dot{Q}_{evap}$ with the medium to be cooled. In the absorber, the mixture of ammonia and hydrogen (9), from the gas heat exchanger, flows upwardly counter-currently to the weak solution (12) introduced into the upper part. The ammonia vapor is absorbed in the poor solution. The liquid solution is enriched in ammonia, descends in the tank, and continues to solution heat exchanger (13) and the generator. Hydrogen, with unabsorbed residual ammonia (5), head to the gas heat exchanger. The absorption phenomenon is accompanied by exchange of heat $\dot{Q}_{abs}$ to the ambient environment. The rich solution (13), leaving the tank is heated in the solution heat