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Performance optimization of solar driven small-cooled absorption–diffusion chiller working with light hydrocarbons

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ABSTRACT

We present in this paper a HYSYS (Aspen One) model and simulation results for 1 kW capacity water-cooled absorption/diffusion machine using different binary mixtures of light hydrocarbons as working fluids (C_3/n-C_6, C_3/c-C_6, C_3/c-C_5, propylene/c-C_5, propylene/i-C_4, propylene/i-C_5) in combination with helium as inert gas. The driving heat is supposed to be provided by an evacuated solar collector field. TRNSYS is used to address the solar aspects of the simulations. For the optimal chiller the driving heat temperature was found to be 121 °C for an evaporator exit temperature of 0 °C. The cooling water flow rate circulating between chiller and cooling tower is 140 l/h. Bubble pump and generator are heated by pressurized water from an insulated tank (70 l/m^2) maintained at a maximum temperature of 126 °C – with make-up heat when needed – and storing solar heat at an estimated 4.2 kW power. The solar energy cover only 40% for the energy supplied to drive the chiller. It's found that the necessary collector surface area is about 6 m^2 with annually total costs of 1.60 €/kW h with 20 years lifetime period for the installation. The avoided CO_2 emissions are estimated at 1396 kg. The equivalent saved energy is 521 l of diesel or 604 l of gasoline.

1. Introduction

Air-conditioning technology using conventional compression chillers is required to evolve due to many international legislations, such as the Montreal Protocol (phasing out CFCs and HCFs depleting the ozone layer), Kyoto Protocol (reducing CO_2 emissions). The use of the absorption technique for the production of cold for refrigeration and air-conditioning using heat energy particularly solar energy driving the machines could be an attractive alternative to the vapor-compression technique [1].

Active research on alternative working fluids for solar driven absorption machines has been boosted by the restriction or interdiction of the use of the environmentally harmful CFCs and HCFCs [2]. Yet, only two working fluid mixtures continue to be used: lithium bromide and aqueous ammonia solutions. However, some drawbacks limit the use of these standard mixtures. The ammonia/water mixture can provide cooling at low temperatures, −20 °C to −30 °C [3], but requires high driving heat temperatures, higher than 150 °C, incompatible with solar heat from plate collectors or common evacuated tubes [4]. Furthermore, ammonia is corrosive to copper, the material of choice for this kind of equipment. The lithium bromide/water system on the other hand can be auctioned with lower driving heat temperatures, largely accessible for thermal solar energy sources, but presents some drawbacks related to very low pressures and the crystallization of the salt under the prevailing operating conditions [4,5]. Because water is the refrigerant, lower temperatures than 0 °C are not possible.

Some binary mixtures of light hydrocarbons as working fluids for diffusion/absorption chiller (DAC) have already been considered [6]. These compounds are thermally stable for air-conditioning applications [7], available, non-toxic and non-corrosive which allows the use of copper as manufacturing material.

The possible use of solar energy as the main heat input for a cooling system has led to several studies of available cooling technologies; these studies could be carried out as simulation approach, experimental analysis or both together.

Li and Sumathy [8] presented the simulation of a solar-powered absorption lithium bromide air conditioning system. Kim and Infante Ferreira [9] have theoretically investigated a low temperature-driven absorption cycle for the development of an air-cooled LiBr–water absorption chiller to be combined with low-cost flat plate collectors for solar air conditioning in hot and dry climates. Desideri et al. [10] described different technical installations for solar cooling and analyzed their technical and economic feasibility.

In recent years, various types of solar powered air-conditioning systems are being investigated. More than 254 solar driven cooling

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Nomenclature

Symbol

DAC	diffusion/absorption chiller
GHX	gas heat exchanger
SHX	solution heat exchanger
COP	coefficient of performance
ETC	evacuated tube collector
€	euro

Parameters

Q	heat energy
T	temperature
P	pressure
y_1	bubble pump outlet fraction
X_W	weak solution composition
X_r	rich solution composition
$\dot{m}$	flow rate
K_1	longitudinal incident angle modifier at 50°
K_2	transversal incident angle modifier at 50°
h	hour
a_1	first-order coefficient equation in collector efficiency equation
a_2	second-order coefficient equation in collector efficiency equation
C	cost
I	increase in energy cost rate

Subscripts

rebo	reboiler
heat	heater
r	rectifier
ab	absorber
c	condenser
e	evaporator
tow	cooling tower
h	driving heat
c	cold
ref	refrigerant
g	generator
A	annual
Ad	discounted annual cost
VAT	value added tax
Id	discounted investment cost
ATD	annual total discounted cost
E	energy
M	maintenance
U	wall transmittance
α_{front}	front solar absorbance
α_{back}	back solar absorbance
e	thickness
A	surface
E_{saved}	energy saved
N	installation working hours
C_I	investment cost

installations are installed in Europe under different climate zones [11]. Rosiek and Garrido [12] experimentally investigated a solar -assisted air conditioning system with two chilled water storage tanks installed in the Solar Energy Research Center Building at Almerea (Spain). The potential utilizing of solar cooling has been studied by Fasfous et al. at the University of Jordan for a 41 m^2 laboratory [13]. The results show that the proposed solar collectors of 40 m^2 area can provide solar heat for an 8 kW$_{\text{cooling}}$ solar air-conditioning system. Ajib and Günther provided some investigation results on solar thermally driven system in small capacity range [14].

Moreover, there have been several papers published aiming at evaluating solar assisted cooling systems by considering energetic, economic and environmental performance simultaneously. System simulations for an 11 kW$_{\text{cooling}}$ absorption chiller using TRNSYS gave an optimum collector area of only 15 m^2 and a storage volume of 0.6 m^3 for a building with 196 m^2 surface [15]. In another system simulation study [16], the heat needs of a 10.5 kW$_{\text{cooling}}$ chiller are supplied by 50 m^2 collector area and 75 l/m^2 storage tank volume. According to the solar air-conditioning in Europe (SACE) evaluation report [17], the average specific collector area for ammonia/water chiller is found to be 7.2 m^2/kW$_{\text{cooling}}$ and 3.4 m^2/kW$_{\text{cooling}}$ for LiBr/water machines, for capacities ranging from 5 to 12 kW$_{\text{cooling}}$. Alili et al. [18] assessed the feasibility of a solar ammonia/water absorption cycle under Abu Dhabi's weather conditions. The selected system size for 10 kW capacity single effect machine requires a specific collector area of 6 m^2/kW$_{\text{cooling}}$ and a specific tank volume of 0.1 m^3/kW$_{\text{cooling}}$. TRNSYS simulations were carried out for a Tunisian typical house of 170 m^2 with 7 kW$_{\text{cooling}}$ cooling demand. It is shown that the water-cooled chiller can be thermally driven by 2 m^2/kW$_{\text{cooling}}$ evacuated tube collector field and 0.14 m^3/kW$_{\text{cooling}}$ of water storage tank, with specific annual total costs of about 3.52 €/kW h [4].

The different studies described above have generally focused on the common working fluids (ammonia/water or water/LiBr). In the literature very few results have been obtained with organic working fluids. Chekir and Bellagi [19,20] investigated the performance of a butane/octane absorption chiller. Ben Ezzine et al. [3] experimentally investigated an electric powered DAC using the C_4H_{10}/C_9H_{20} as working fluids and helium as the auxiliary gas. Koyfman et al. [21] designed and performed an experimental bubble pump system for a DAC with organic working fluids. Computer simulations were conducted by Zohar et al. [22] in order to study the performance of a diffusion/absorption cycle system with dimethyacetamide as organic absorbent.

In conclusion, diffusion/absorption chillers working with light hydrocarbons to produce cooling is not yet considered in the field of the solar air-conditioning. The present study is based on this innovative idea.

As the economic aspect is one of the decisive factors in the field of solar cooling, the environmental impact, interesting analysis in this study, is also considered in a significant position.

2. Methodology

In the following, we first theoretically investigate by simulation the feasibility of a solar assisted water-cooled air-conditioning DAC working with various light hydrocarbons mixtures (C_3/n-C_6(**C_3H_8/C_6H_{14}**), C_3/c-C_6(**C_3H_8/C_5H_{12}**), C_3/c-C_5(**C_3H_8/C_5H_{10}**), propylene/c-C_5(**C_3H_6/C_5H_{10}**), propylene/i-C_4(**C_3H_6/C_4H_{10}**), propylene/i-C_5(**C_3H_6/C_5H_{12}**) in combination with helium as inert gas. The chiller modeling and simulations are being performed with the flow sheeting software HYSYS of ASPEN-One and the solar aspects of the solar air-conditioning system under the Tunisian climate conditions are simulated by TRNSYS. The optimal machine is then chosen to ensure the cooling needs of a room in a house. A detailed economical analysis is then performed in order to evaluate the costs and