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Analysis of a solar powered absorption system

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ABSTRACT

Today, fossil fuel is the primary extensively used source of energy. However, its negative impact on the environment have forced the energy research continuity to seriously consider renewable sources of energy. Solar energy, in particular, has been the main focus in this regard because it is a source of clean energy and naturally available. This study presents the design and analysis of a solar powered absorption refrigeration system modified to increase its coefficient of performance (COP). The modifications include recovering of waste heat from a dephlegmator and utilization of a refrigerant storage unit. The simulation results indicate an increase of 10% in the COP of the conventional design using dephlegmator heat recovery and an increase of 8% in the COP of the conventional design due to the use of a refrigerant storage. The analysis for the combined effect of modifications indicates an increase of 18% in the COP compared to conventional design. Calculated values of coefficient of performance indicate a very good agreement with the ones obtained based on measurement.

1. Introduction

The technological advancement and economic growth of any country rest on the availability of utilizable form of energy in that country. The quantity of available energy also reflects its quality of life. So far, fossil fuel is considered and utilized as the prominent source of generating utilizable form of energy [1]. However, concerns are growing on daily basis over the negative effects on the environment that are caused by burning of fossil fuels that includes global warming and green-house gas effect on the ozone. Thus serious efforts are being made to explore alternatives that could reduce the fossil fuels burning. So far renewable energy represents the best alternative to reduce the burning of fossil fuels. Renewable energy refers to the form of energy that either do not get depleted or has the natural ability to renew itself. Renewable energy sources include biomass, geothermal, hydropower, wave, wind, solar and tidal energy sources. Among all of these naturally available and environmentally friendly sources, solar energy stands top on the list of renewable energy sources. The main reason behind the enormous potential of solar energy is its cleanliness and natural availability. It has also been calculated that the total solar radiation transmitted to the earth is about 1.74×10^{17} W [2] while the overall energy consumption of the world is about 1.84×10^{13} W [3]. Thus solar energy presents an enormous potential renewable energy source.

It is not possible to completely replace the conventional source of energy by renewable energy. However, a major portion of the consumption sector energy requirements can be met with the utilization of renewable energy. Gulf countries realizing the fact that they might end up (in few years) consuming more than 80% of the fossil fuel they produce to meet domestic energy demand; starting looking seriously into meeting some of this demand by utilizing solar energy. Solar energy is considered as the most appropriate option among other renewable energy sources since its peak coincides with the peak demand of air-conditioning [4], hence this will contribute to the reduction of fossil fuel consumption. So the recent focus is on utilizing renewable energy sources to meet the energy requirements for the consumption sector. Within the consumption sector in the gulf region, air-conditioning and refrigeration presents one of the highly energy consuming sector. This can be acknowledged by the statistic of 2010 [5], about 52% of the electrical energy produced in the KSA is consumed by the residential sector. 70% of this residential energy consumption goes to the comfort conditioning. Thus, more than 36% of electrical energy produced in the KSA is consumed by the air-conditioning sector which is also increasing as the years go by [6].

Solar electrical and thermal powered refrigeration systems can be used to produce cooling [7]. The first is a photo-voltaic based solar energy system, in which solar energy is initially converted

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Nomenclature

Symbols

η	efficiency
G	solar radiation
h	specific enthalpy
$\dot{m}$	mass flow rate
$\dot{Q}$	heat input/rejected/recovered
T	temperature
x	ammonia mass concentration

Abbreviations

ABS	absorber
APC	absorber pre-cooler
COND	condenser
COP	coefficient of performance
DEPH	dephlegmator
EVAP	evaporator
GEN	generator
GHX	heat recovery coils
HRHX	heat rejection heat exchanger
PUMP	solvent pump
RPC	refrigerant pre-cooler
SHE	solution heat exchanger

Subscripts

a	ambient
high	high concentration
i	input
low	low concentration
sc	solar collector
ss	strong solution
ws	weak solution

into electrical energy and then utilized for producing the refrigeration much like conventional methods. The second one utilizes solar thermal energy to power the generator of an absorption refrigeration system. Kim and Ferreira [8] made a comparison between the two systems both from the point of view of energy efficiency and economic feasibility. The comparison indicated that solar electric refrigeration systems using Photovoltaic appear to be more expensive than solar thermal systems. Otanicar et al. [9] showed that a very small portion (less than 35%) of the incident solar radiation is converted into electrical energy using photovoltaic cells while solar thermal systems can utilize more than 95% of the incident solar radiation. Due to these advantages of solar thermal systems over solar photovoltaic systems, recently more research has been carried out in the field of solar thermal cooling systems [10].

The absorption refrigeration system operates on the principles of absorption cycle rather than the compression cycle. This absorption cycle eliminates the need of a compressor by replacing it with an absorber and a generator [11]. In case of a compression cycle, the refrigerant pressurization is required which is performed by the compressor in the vapor phase. However, in case of an absorption cycle, the refrigerant pressurization is not performed in the vapor phase. Instead, the refrigerant is first absorbed in an absorbing material and is then pressurized in the absorbed liquid phase. The pressurized absorption mixture is then reheated in the generator to regenerate the pressurized refrigerant vapor. The advantage of the absorption system over the compression system is that very little or no electrical power is required to pressurize the refrigerant compared to conventional compression system which requires considerably large amount of electrical power [12]. However, such absorption systems require heat input to regenerate the refrigerant vapor. Such heat is provided by solar thermal collectors in case of solar powered absorption refrigeration systems [13].

One of the earliest solar absorption chillers was developed by Trombe and Foex [14]. They reported preliminary experimental results with a pilot plant using aqua-ammonia. Followed their work, Chinnappa [15] made a systematic experimental study of an absorption refrigeration cycle employing two binary systems (NH_3–H_20 and NH_3–$LiNO_3$) with maximum solution temperatures up to about 405 K. In addition to those a simple refrigerator operated with flat plate collectors was built at Colombo, Ceylon by Chinnappa [16] as well. They reported that an evaporator temperature of 10°F can be reached on a clear day for every three to four square feet of collector area using flat plate collectors. Most of the earlier solar absorption chillers were manufactured for intermittent operation however researchers later focused over continuous operation chillers because of low coefficient of performance of the intermittent chillers. The aqua-ammonia represents the most commonly used refrigerant–absorbent working pair in the continuous operation based solar powered absorption refrigeration systems. Several simulation and experimental researches have been conducted over aqua-ammonia absorption chillers based on continuous operation. Most of such researches focused over estimating the performance of chiller under varying operating conditions and increasing the coefficient of performance of absorption chillers. One of the recent simulation studies was conducted by Raghuvanshi and Maheshwari [17] using MATLAB software. They showed that a coefficient of performance of 0.227 can be reached by operating the absorption system at a generator temperature as low as 50 °C. Said et al. [18] conducted a simulation study using Engineering Equation Solver (EES) software and concluded that an aqua-ammonia absorption system equipped with a refrigerant storage provides better coefficient of performance when operated continuously on a day and night basis. The comparison was made between refrigerant storage, heat storage and cold storage systems for continuous operation of the aqua-ammonia absorption chiller. Notably, the chiller design used for simulation purposes [17,18] does not utilize heat recovery from dephlegmator.

The thermodynamic design of the absorption system leads to the heat exchanger design for its components in terms of its UA value. The UA value of a heat exchanger is its heat capacity per unit temperature rise/drop. In this regard, Bangotra and Mahajan [19] performed UA analysis of different components of aqua-ammonia absorption system. A similar form of detailed UA analysis for the heat exchanger design of different components of absorption system have also been presented by Lavanya and Murthy [20]. Both of the above mentioned researches [19,20] were focused over UA analysis utilizing conventional chiller that neither recover heat from dephlegmator nor utilizes a refrigerant storage unit. First law thermodynamic analysis on a conventional aqua-ammonia absorption chiller has been recently carried out by Abdulateef et al. [21]. They focused on showing the influence of the effectiveness of solution heat exchanger over the performance of the system. Their simulation results indicated 50% increase in the coefficient of performance of the system when increasing the effectiveness of solution heat exchanger from 0 to 1. Similarly, a simulation study of conventional aqua-ammonia absorption system based on the first and second law of thermodynamic have been