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PERFORMANCE OF SOLAR-ASSISTED ABSORPTION CYCLE AIR CONDITIONING SYSTEM

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Abstract

A study of the efficiency of the cycle of solar assisted absorption air conditioning system has been carried out. The absorption cycle system has been in operation in Malaysia, but only in large buildings such as the KL International Airport, government buildings in Putrajaya and KLCC buildings. This study focuses on a small-scale lithium-bromide (LiBr) absorption cycle air conditioning system for residential application. The important component of the system has been designed with the capacity of 3.517 kW cooling load suitable for small-capacity application. Generator, condenser, evaporator and absorber have been designed, fabricated, assembled and tested in the laboratory. A total of ninety-pieces of evacuated tube solar collectors have been installed to produce hot water to be used as a heat source to separate the absorbent and refrigerant. Lithium bromide-water pair was used in this experiment. With the concentration of lithium bromide of 33%, the average coefficient of performance (COP) obtained was 0.446, 0.438 and 0.431 for category A, category B and category C respectively. This study shows that the cycle of solar absorption air conditioning system in small scale can be used in Malaysia and tropical climate countries.

Keywords: Absorption cycle, solar-assisted air conditioning system, evacuated tube solar collector, cop

Abstrak

Satu kajian kecekapan kitaran serapan sistem penyamanan udara terbantu suria telah dijalankan. Sistem kitaran serapan telah digunakan dan beroperasi di Malaysia tetapi hanya di dalam bangunan-bangunan yang besar seperti di Lapangan Terbang Antarabangsa KL, bangunan kerajaan di Putrajaya, dan bangunan KLCC. Kajian ini memfokuskan sistem penyaman udara kitaran serapan LiBr yang berskala kecil untuk aplikasi rumah kediaman. Komponen-komponen penting telah direkabentuk bagi menyesuaikan sistem dengan kapasiti yang kecil iaitu 3.517 kW kapasiti beban penyejukan. Penjana, pemeluwap, penyejat dan penyerap telah direkabentuk, difabrikasi, dipasang dan diuji di makmal. Sebanyak sembilan puluh batang pengumpul suria berjenis tiub vakum telah dipasang untuk menghasilkan air panas untuk dijadikan sebagai sumber haba bagi memisahkan larutan dan air dalam penjana. Kombinasi litium bromida-air telah digunakan di dalam ujikaji ini. Dengan kepekatan litium bromida sebanyak 33%, purata nilai pekali kecekapan COP yang diperolehi ialah 0.446, 0.438 dan 0.431 untuk kategori A, kategori B dan kategori C masing-masing. Kajian ini menunjukkan bahawa kitaran serapan sistem penyamanan udara terbantu suria berskala kecil boleh digunakan di Malaysia dan di negara-negara beriklim tropika.

Kata kunci: Kitaran serapan, sistem penyamanan udara terbantu suria, pengumpul suria berjenis tiub evakuasi, pekali kecekapan

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1.0 INTRODUCTION

This paper reports the findings solar–assisted air conditioning absorption system for a small scale application. Electricity, one of the sources of energy, has become relatively more costly because of the increase price of fuel used to generate electrical energy. The cost to generate air conditioning in modern buildings is roughly estimated at 60% of overall electricity consumption. Despite its high cost to run the air conditioning system, it is necessary because the weather in tropical countries like Malaysia is quite hot and humid. The use of air conditioning systems is becoming increasingly popular in this country because of its emphasis on user comfort in working and living environment.

The living standard of the population in Malaysia has improved, which allows more people to afford air conditioning system in their homes. To reduce the electricity expenditure, an alternative must be found to run the air conditioning system. The research carried out is to use solar energy as an aid or in addition to the existing electrical-powered air conditioning system in an attempt to reduce the electricity cost. The use of solar energy in the system is highly relevant in Malaysia as solar radiation in the tropics can either reach up to 1000 W / m² or more.

Combined system of solar energy and absorption cycle air-conditioning systems is environmentally friendly in that it does not use refrigerant but instead uses water as a refrigerant. Today, when the world is facing the problem of global warming caused by emissions of gases like carbon dioxide, methane and ozone depleting CFCs, the reduction of the usage of chemical-based refrigerants would help to alleviate the global warming problem.

Ali [1] states that ozone is a molecule consisting of three (3) oxygen atoms, O_3 reaction that occurs from the ultra violet rays of the sun on the oxygen atom. She added that ozone is important to humans as it absorbs ultraviolet rays of the sun. Ozone exists in the upper layers of the atmosphere 16-32 km from the earth to the protective layer of ultraviolet sun rays. The ozone layer is destroyed by man-made chemicals. Excessive exposure to ultraviolet light can cause skin cancer, eye pain and weaken the immune system. The increase in ultra violet also reduces crop yields and the marine food chain. Chlorofluorocarbon (CFC) is the main destroyers of the ozone layer in the stratosphere. Hydroclorofluorocarbon (HCFCs) is like CFC but has a low potential for ozone destruction. It is used as a temporary replacement for CFCs, and their use will be eliminated in 2030. Hydrofluorocarbons (HFCs) does not have the ozone destruction potential (ODP) and more ozone-friendly but HFCs have a global warming potential (GWP). These materials are used in air-conditioning equipment. It also causes the green house gases and the effects of global warming will cause the melting of snow and sea level rise. CFC, in accordance with the rules of the Montreal Protocol [2] for developing countries have experienced a freeze in 1999 and the depreciation rate of 50%, 85% and 100% in 2005, 2007 and 2010 respectively. CFC, CTC (Carbon Tetrachloride) and Halon are not allowed to be imported from 1 January 2010. Lithium bromide is the alternative for air conditioning to be used where no CFC or CTC involved. So it is a good move for healthy environment. The use of solar-assisted absorption cycle is hoped to reduce this problem for the comfort of life of future generations. In principle, this study is a combination of solar energy technology and air-conditioning systems.

Research on LiBr – water or ammonia – water system have been carried out by other researchers. However not many used solar-assisted absorption system.

A. Gonzalez-Gil [3] *et al.* was conducted experiment on air cooled single-effect LiBr-H_2O absorption prototype using 48m² flat-plate collectors. COP value obtained was 0.6 with cooling capacity varies from 2 kW to 3.8 kW.

M. Mazloumi [4] *et al.* was conducted a simulation of solar LiBr-H_2O absorption cooling system with parabolic trough collector in Iran. The results of COP for this system was between 0.6 and 0.8 with generator temperature in the range of 70-95 ºC. The designed cooling load peak was about 17.5 kW.

The COP 0.37 was obtained in 4.5 kW air-cooled single effect LiBr-H_2O absorption chiller in Madrid where the hot water inlet in the generator varies from 80 to 107 ºC. The experiment was carried out by M. Izquierdo *et al.* [5] in August 2005.

Lu and Wang [6] carried out various types of solar collectors integrated with various sorption chillers using traditional evacuated tube U pipe solar collectors to produce 60º C - 80º C, Compound Parabolic Concentrating (CPC) produced 85º C - 125º C while Parabolic Through Collector (PTC) solar collectors could produce up to 125º C - 150º C hot water. They can run a silica-gel-water adsorption chiller, single-effect and double-effect absorption chiller. Experimental results show that the coefficient of performance (COP) by using adsorption chiller and U pipe solar collectors is approximately 0.15 and silica-gel-water adsorption chiller can be carried out with hot water temperature up to 55ºC. The COP using solar collectors CPC and single-effect absorption chiller is 0.24 in hot weather conditions. PTC COP for solar collectors is about 0.5, while the coefficient of performance of the double-effect absorption chiller would be higher and economical.

Saleh and Mosa [7] conducted research on single-effect LiBr-water absorption system with flat-plate collectors to present a comprehensive analysis in order to optimize the solar-assisted absorption system operating in hot areas. To optimize system performance, the temperature of the heat source must be controlled as a function of incident solar radiation, temperature of chilled water and cooling water. With appropriate controls, external conditions can be monitored to detect and perform optimizations in real terms. Applying typical values encountered in these hot spots, the overall performance of the system takes an optimum value at a temperature between 75° C and 80° C. It was found that in designing or selecting a solar collector, a type of selective coating is necessary to produce hot water around 80° C - 90° C to optimize the operation of the absorption unit. To ensure the appropriate selection of component temperature, COP absorption unit can exceed the value of 0.8. Cold water temperature exceeding 40° C will significantly reduce the performance of the units required. In an extremely high external temperatures, dimensioning and selection of the condenser and absorber ensures that the value is less than this limit.

Ketjoy *et al.* [8] conducted a performance evaluation of 35 kW solar-assisted LiBr-water absorption system in Thailand driven by 72 m^2 heat pipe evacuated tube solar collectors to a gas backup system, by analyzing the COP based on the specifications of the manufacturer. Results from this study indicate that the actual average system COP is 0.33 while the maximum and minimum values are respectively 0.50 and 0.17. These results were obtained based on the average collector efficiency and solar fraction of 0.55 and at an ambient temperature of 32° C.

Ali Al-Alili *et al.* [9] have reviewed that the solar cooling system is a good example for tackling climate change. In the paper, he provideed an overall summary of the principles of solar thermal cooling technologies and reviewed the work undertaken for the advancement of the technology of the most recent publications.

Francis *et al.* [10] conducted an experimental prototype system based on a domestic scale solar cooling using H_2O-LiBr absorption system and tested during summer 2007 and autumn months at Cardiff University, UK. The system consists of 12 m^2 of vacuum tube solar collectors, with a 4.5 kW LiBr / H_2O absorption chiller, 1000 liter storage tanks cool and 6 kW fan coil. System performance, and the performance of each component in the system, has been assessed based on physical measurements of daily solar radiation, ambient temperature, fluid inlet and outlet temperature, mass flow rate and electricity consumption by component. The average COP system is 0.58, based on the cooling of thermal power output of each unit is solar heat energy of 12 m^2 DF100 Thermomax vacuum tube collectors on a hot sunny day with an average insolation peak of 800 W / m^2 (between 11 and 13:30 hours) and an ambient temperature of 24°C. The system generates electrical COP of 3.6. The experimental results demonstrate the possibility of a new concept showing its potential to be used in cooling domestic scale buildings.

Assilzadeh *et al.* [11] carried out simulation of LiBr solar absorption cooling system with 35 m^2 evacuated tube collectors sloped at 20 ° on a 0.8 m^3 hot water storage tank for 3.5 kW refrigeration load. COP obtained was between 0.645 and 0.665.

Ahmed Hamza *et al.* [16] did performance assessment of an integrated cooling plant having both free cooling system and solar powered single-effect lithium bromide-water absorption chiller in August 2002 in Germany. Absorption chiller capacity was 35.17 kW using vacuum tube collectors. Chiller COP obtained varies from 0.37 to 0.81.

A.A.V. Ochoa *et al.* [17] made a dynamic analysis of a single-effect, lithium bromide-water absorption chiller. They found that the COP being approximately 0.7 for operating condition. The largest absolute differences found when validating the model by means of the experimental numerical values in the water circuits were approximately 1.0 °C, 0.7 °C and 0.2 °C for hot, chilled and cold water, respectively.

Yin Hang *et al*. [18] were conducted experiment in California using external compound parabolic concentrator (XCPC) solar collectors to drive a 23 kW double-effect absorption chiller. The average coefficient of performance (COP) of the LiBr absorption chiller is between 0.91 and 1.02 with an average of 1.0, and the daily solar COP is approximately at 0.374.

Most researchers in absorption chiller were using LiBr-H_2O pair because LiBr causes no harm to our environment and easily to get. LiBr-H_2O absorption chiller has no compressor and this is good for maintenance because less rotating equipment used.

2.0 METHODOLOGY

The main components in the LiBr-H_2O absorption cycle air-conditioning system are generator, condenser, absorber, evaporator, heat exchanger, vacuum tube collectors, pumps, hot water storage tank and thermocouples. Data logger, computer and software were used to record the collected data. Refer to Figure 1 and Figure 2 for detailed description of these components.

Before running the experiment, the components such as the generator, condenser, heat exchanger and absorber were prepared under a vacuum condition by using a vacuum pump. Once the work is completely vacuumed, LiBr-H_2O solution was incorporated into the generator through the channels provided. LiBr-H_2O solution flowed from the generator to the absorber via the heat exchanger.

Water pipe was inserted into the hot water storage tank with the pump to supply hot water supply from the tank to the vacuum tube collectors. The pump operated at around 8:00 in the morning when the sun just started to rise. If the weather on the day was cloudy or rainy, the heater will be used to heat the water in the hot water storage tank. By simply using vacuum tube collectors only from 8:00 am until 5:00 pm, the vacuum tube collector efficiency can be measured by taking a temperature reading in and out of vacuum tube collectors. LiBr-H_2O absorption cycle with the help of solar energy is to save electricity consumption of heating therefore both sources of thermal energy from the heater and vacuum tube collectors were measured.

The total cooling capacity can be measured by the amount of Q_e, resulting in fan coil unit (FCU) using the formula

$$Q_e = m\ Cp\ \Delta T \qquad \textit{Equation 1}$$

Where, Q_e = cooling load obtained, kW
m = the flow rate of cold water, kg / s
Cp = specific heat of air, J / kg °C
ΔT = gradient of air temperature, °C

Othman *et al.* [12] states that the collector efficiency is defined as the rate of heat received by the air passing through the collector to the amount of solar radiation that hit the collector. Mathematically this can be written as

$$\eta_c = \frac{V\rho\Delta T C_p}{A_c I_c} 100\% \qquad \textit{Equation 2}$$

Where, V = volume of air through the collector, m^3 / s
ρ = density of air, kg / m^3
ΔT = gradient of air temperature, °C
C_p = specific heat of air, J / kg °C
A_c = area of the collector which is exposed to solar radiation, m^2
I_c = intensity of solar collector surface overwrite W / m^2

The coefficient of performance is

$$COP = Q_e / Q_g \qquad \textit{Equation 3}$$

Where, Q_e = cooling load obtained, kW
Q_g = heat added at generator, kW

Hariadi [13] estimated the COP by obtaining the equation as a function of evaporator temperature.

$$COP = -0.0175\ T_{\text{evaporator temperature}} + 1.0097$$
(Equation 4)

Data were taken in the experiments as per Table 1. Mass flow rate of chilled water was 2.6 L/min (0.0433 kg/s) and mass flow rate of LiBr solution was 2.2 L/min (0.0367 kg/s) for all categories.

Table 1 Experimental Testing Condition

Category	Chilled water valve (near point 7)	Cooling water valve (near point 9)
A	Fully opened	Half opened
B	Fully opened	Fully opened
C	Half opened	Fully opened

The study is to calculate the coefficient of performance (COP), the cooling load (Q_e) and the heat exchanger efficiency (ε). The concentration of Lithium Bromide (LiBr) X is equal to 33%. LiBr solution concentration obtained through the following formula:

X = Mass of LiBr (kg) / [mass of LiBr (kg) + mass of water (kg)]

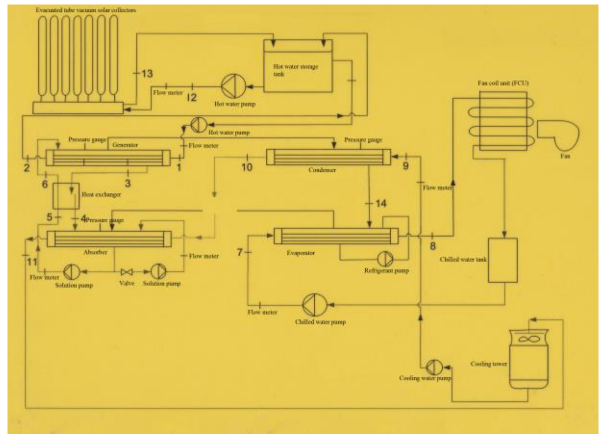

Figure 1 Schematic diagram of solar-assisted absorption cycle

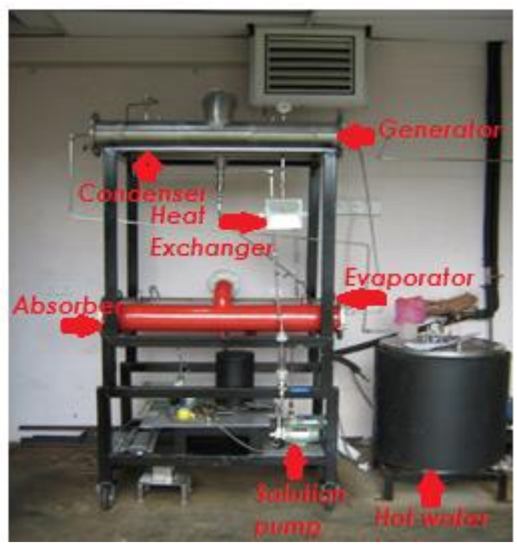

Figure 2 Experimental device used in absorption chiller

3.0 RESULTS AND DISCUSSION

The analysis shows that for all the categories in Table 1, the efficiency of the heat exchanger is between 0.4 and 0.5, as shown in Figure 3 This shows that there is no significant change to the efficiency of the heat exchanger when the valve configuration of chilled water valve and cooling water valve were changed.

In Figure 4, the analysis shows that there are very significant changes to the cooling load where category B recorded the highest reading at 6:00 pm which is 1.941 kW, while category A highest reading was recorded at 5:00 pm which is 1.542 kW and category C, its highest reading was at 6:00 pm with a record of 0.818 kW.

Figure 5, shows results of COP. It is clear that all three categories are more or less the same in any of the categories. For category A, COP is between 0.416 - 0.492, for category B, COP is between 0.401 – 0.485 and lastly for category C, COP is between 0.409 – 0.467. The COP value is approximately equal to the value generated by the COP obtained by Mulyanef [14], who used heating systems with integrated solar and obtained COP of 0.422.

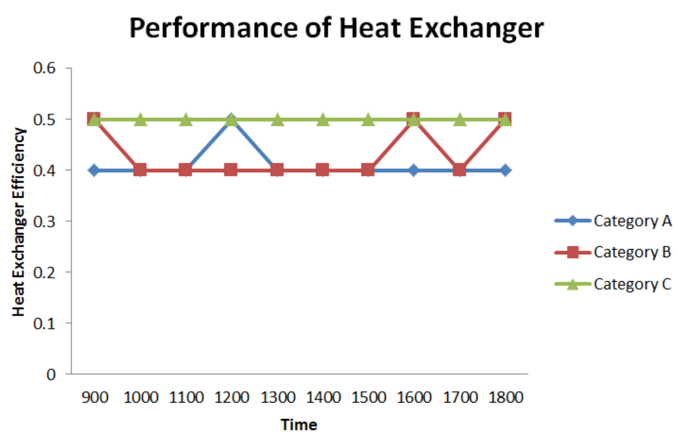

Figure 3 Efficiency of heat exchanger versus time

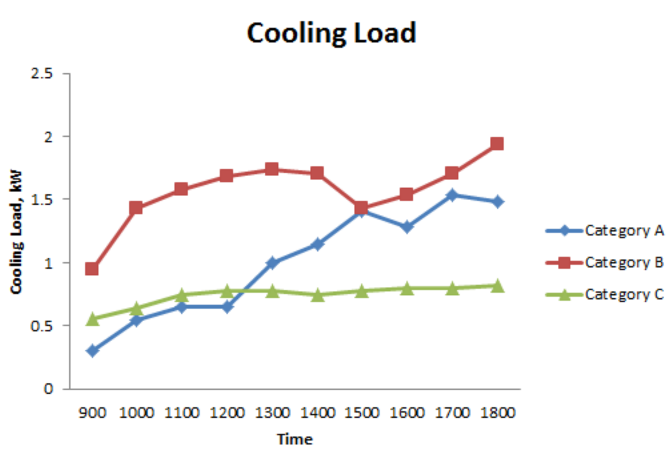

Figure 4 Cooling load versus time

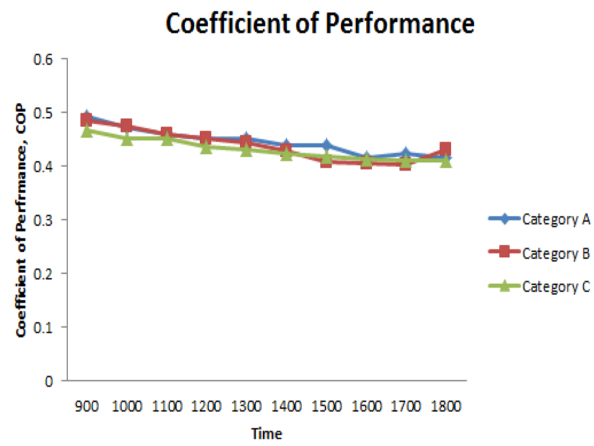

Figure 5 Coefficient of performance, COP versus time

The results have shown that the cooling system can be generated based on the calculation of COP and cooling load.

In this study, the tests were conducted at three operation settings, which is known as Category A, Category B and Category C. Comparison between the three categories were as follows:

Table 2 Comparison of COP generated for categories A, B and C

Category	Concentration (% LiBr)	Average COP
A	33	0.446
B	33	0.438
C	33	0.431

Table 3 Comparison of COP generated researchers for the absorption system

Researchers	COP
Hammad and Audi, 1992 [15]	0.30 – 0.69
Mulyanef, 2005 [14]	0.422
Hariadi, 2005 [13]	0.67
Z.S. Lu and R.Z. Wang [6]	0.24 (CPC), 0.5 (PTC)
A. Saleh and M. Mosa [7]	0.8
Nipon Ketjoy *et al.* [8]	0.17 – 0.5

4.0 CONCLUSION

The study was conducted on the absorption cycle air-conditioning system using solar energy in the laboratory. The objective of the study was to determine whether solar energy as an alternative energy can help to run the air conditioning system in Malaysia in particular and in tropical countries nearby.

From research and analysis and discussions have been held, the solar energy system has to be treated as a system suitable for use in air-conditioning systems. The conclusions that can be made are as follows: -

The COP obtained was between 0.431 – 0.446. The results of these experiments show that solar energy can produce similar results with integrated solar energy with heating system. It shows that Malaysia and tropical climate countries have the potential to develop solar air-conditioning systems. This study can be continued with a greater load capacity.

The study obtained the highest cooling load is 1,941 kW. The preliminary estimate cooling load for this study was 3.517 kW (1 ton).

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