

Experimental Investigation on Solar Absorption Refrigeration System in Malaysia

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Abstract:- The experimental investigation of the performance of a solar absorption refrigeration system is described. The influence of generator, evaporator and condenser temperatures on the system performance is studied using evacuated tube solar collectors and ammonia-water as working fluid. It was seen that if higher cooling capacity and also lower evaporator temperature are desired from the system, the generator temperature should be increased considerably. In general, a solar absorption system can work only if the collectors' outlet temperature is higher than the cut in/cut off temperature, and there exists an optimal value for this temperature. This paper is provided an actual compact unit and operated under real outside conditions for Malaysia and similar tropical regions. It is produced an air conditioning and refrigeration capacity of 1.5 ton and reached a COP of 0.6. This unit is considered a step forward toward commercial use.

Key-Words: Operating Parameters; Experimental performance; Refrigeration; Absorption

1 Introduction

In hot climates, the heating and cooling demand of domestic dwellings can be reduced substantially with various measures such as good insulation, double glazing, use of thermal mass and ventilation. However, due to the high summer temperatures, the cooling demand cannot be reduced to the level of thermal comfort with passive and low energy cooling techniques, and therefore, an active cooling system is required. It is preferable that such a system is not powered by electricity.

During the last few decades, an increasing interest, based on research and development, has been concentrated on utilization of non-conventional energy sources, namely solar energy, wind energy, tidal waves, biogas, geothermal energy, hydropower, hydrogen energy, etc. Among these sources, solar energy, which is available in such climates, and could be used to power an active cooling system based on the absorption cycle.

Ammonia-water and lithium bromide-water absorption units are the most suitable for solar

applications, since low cost solar collectors may be used to power the generator of the machine. Research has been performed for ammonia-water absorption systems theoretically [1-6] and experimentally [7-9].

The first purpose of the study is to design and construct an absorption refrigeration system powered by solar energy and ammonia-water as working fluid. The second purpose of the study is to investigate experimentally the effects of the operating temperatures on the coefficient of performance of the system. Also, it should be noted that to the best of our knowledge the separate influences of adding a rectifier or a heat exchanger experimentally has not been reported previously. Thus, the effect of adding both these components to the basic system is taken into consideration in the experimental investigation.

2 Description of Experimental Setup

A schematic diagram of the solar absorption refrigeration system that was constructed in the present study is shown in Fig. 1. The system was installed in Bangi ($\phi=3.1^\circ$), University Kebangsaan Malaysia on the roof of the physics department, labs of Science Faculty. The experimental setup was illustrative by photograph in Fig. 2.

The experimental system consisted of three sides: ammonia-water side, hot water side, and coolant water side. The main components of the ammonia-water side consist of generator, rectifier, condenser, evaporator, absorber, solution heat exchanger, storage tank, expansion device and solution pump. The solution heat exchanger and rectifier were designed as a single U-tube heat exchanger. The generator, evaporator, condenser and absorber were designed as a shell and tube heat exchanger.

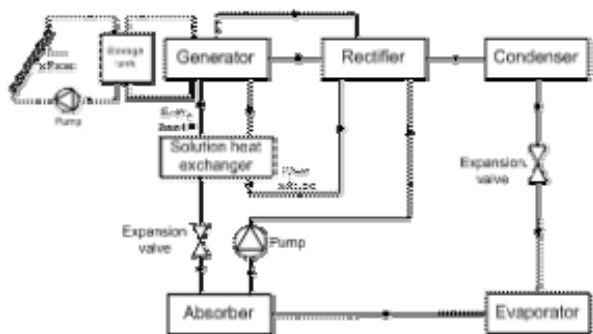


Fig. 1 Schematic of the experimental system concept



Fig. 2 Photograph of the experimental system

The hot water side is composed by the solar collector, the storage tank, and the water side of the vapor generator. The evacuated tube solar collector has a total surface area of 10 m^2 . The auxiliary electrical heater is used to elevate or maintain the fluid medium temperature at the inlet of the vapor

generator. A circulation pump is used to circulate the water between the storage tank and the generator. Hot water side can provide within ($60\text{--}100^\circ\text{C}$) heat input, for a finite period of operation. The generator, storage tank and associated tubing are well insulated. The coolant side used water as a coolant. The cooling tower maintains a constant coolant temperature within ($18\text{--}30^\circ\text{C}$), in the cooling water tank.

3 Instrumentation

Experimental performance evaluation of the solar absorption refrigeration system is carried out on the basis of data derived from tests. Temperature, pressure and flow rate were the main parameters measured during experimentation at locations shown in Fig. 3

Chromel-alumel thermocouples (K-type) connected to a data acquisition system were used to record temperatures. Pressure transducers are used to record pressure data directly through the data acquisition system. Gage pressures are used in same place of transducers while they were being repaired or for double checking. Flow meters are in place to measure the flow rates of the interested positions. The liquid level gauges are provided in major system components. A flow indicator connects the storage tank with the system in order to monitor whether liquid or vapor is flowing. The solar radiation on the collector surface was measured by a $\pm 5\% \text{ W/m}^2$ accuracy pyranometer.

A personal computer was used as a data logger. Measurement devices were connected to a data acquisition board to obtain simultaneous readings. Connecting the board to the computer, all readings were recorded automatically and monitored by the computer.

All instruments and devices used for data acquisition were calibrated. Thermocouples are calibrated within $\pm 0.5^\circ\text{C}$ using constant temperature bath. Pressure gages are calibrated within $\pm 0.3 \text{ bar}$ using dead weight pressure tester. The flow rates of the interested positions are measured with an accuracy of $\pm 3\%$ and liquid level gages are calibrated within $\pm 2\%$ accuracy.

4 Experimental Procedures

The main parts of the system are shown in details by the schematic in Fig. 3. To begin with, solar energy is absorbed by the collector and accumulated in the storage tank. The solar heat collection system and the ammonia-water side are linked through the vapor generator heat exchanger which receives the

solar supplied heat. A circulation pump is used to circulate the water between the storage tank and the generator.

In the high pressure generator, the ammonia-water solution in it is boiled off to separate water from ammonia. The relatively low concentration solution exits the bottom of generator while high concentration ammonia vapor leaves through the top of the generator and then pass to condenser. When ammonia is evaporated off the generator, it also contain some water vapor. Any water carried on through to the evaporator penalizes the performance there by lowering the enthalpy of refrigerant at the evaporator outlet, it may also freeze along the pipelines. To remove as much water vapor as possible, the vapor driven off at the generator first flows countercurrent to the incoming solution in the rectifier. By this process, only a small amount of water vapor escapes and passes from evaporator to the absorber.

High pressure ammonia vapor from generator is cooled down in the condenser and then passed to the evaporator, through an expansion valve that reduce the pressure of the refrigerant to low pressure exist in evaporator. The liquid refrigerant vaporizes in the evaporator by absorbing heat from the material being cooled and the resulting low pressure vapor passes to the absorber. The condenser and absorber temperatures were adjusted manually by varying the cooling water flow rate by a regulating valve. The liquid refrigerant level in the evaporator was kept constant by adjusting the refrigerant flow rate by the expansion valve for each cooling capacity. The evaporator temperature was changed by controlling the temperature and/or flow rate of the water to be cooled.

In the absorber, the strong solution of ammonia and water coming from generator through an expansion valve absorbs the low pressure ammonia vapor leaving the evaporator and forms the weak solution and then pumped from the absorber with a solution pump capable of producing the high generator pressures of interest. An expansion tank is positioned after the pump to dampen the pulses in the flow rate.

Leaving the pump, the weak solution flows countercurrent to the incoming flow in the rectifier and solution heat exchanger, and then entering the generator. The remaining solution in the generator flows back to the absorber and, thus completes the cycle. By weak solution (strong solution) is meant that the ability of the solution to absorb the refrigerant vapor is weak (strong), according to the ASHRAE definition [10].

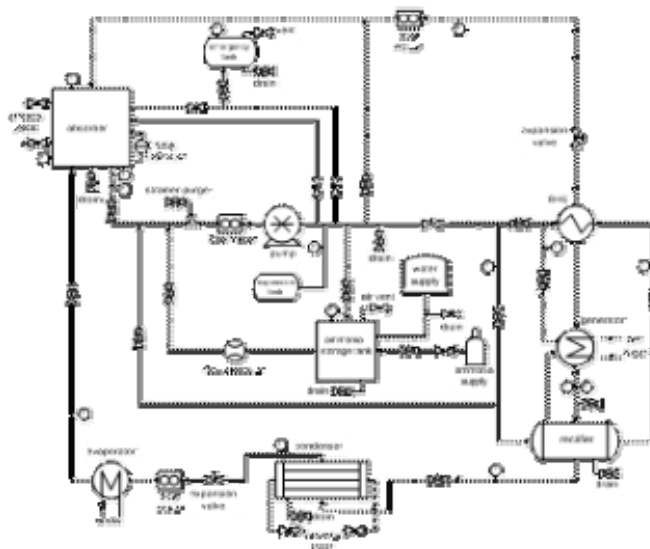


Fig.3 Schematic diagram of experimental apparatus

To investigate the effect of adding a solution heat exchanger and a rectifier to basic system, these components could be connected either direct or by pass while the COP test was carried out. Each experiment lasted from 8:00 am until 4:00 pm, on 5 days of each week of the month of January, February, March, and April 2009. The measurements included solar irradiation, mass flow rate, various pressures, and various temperatures.

5 Performance Evaluation

The main objective of this experiment was to study the influence of generator, evaporator and condenser temperatures on the system performance with four cycles alternatives: (1) basic cycle (without heat exchanger and rectifier), (2) cycle with heat exchanger added, (3) cycle with only rectifier added, and (4) the refine cycle with both these components. Experiments were conducted for a range of operating conditions as follows: generator temperature between 60 °C and 98 °C, evaporator temperature between 3 °C and 16 °C, and condenser temperature between 23 °C and 39 °C at the mass flow rate of refrigerant of 0.6 kg/min and the effectiveness of solution heat exchanger (ϵ_{SHE}) equal to 0.5. The refrigeration capacity and heat rejected were obtained as products of mass flow of water, specific heat and temperature difference across respective component. Heat input to the generator was estimated by measuring heat supplied from solar heating system. Calculations were also done based on measurements made on the refrigerant-side by evaluating enthalpies of refrigerant at inlet and outlet to each component. The coefficient of performance (COP) was calculated as the ratio of

refrigeration capacity to generator heat input, neglecting the pump work. The thermodynamic properties for aqua-ammonia mixture and the sample of calculation which were employed for experimental performance evaluation are based on [11,12] and are not given here. While the solar radiation measurements which were used for solar performance estimation are based on [13].

6 Results and Discussion

The influence of the operating temperatures on the coefficient of performance (COP) was calculated with the aid of the experimental tests. First, the influence of the generator temperature was investigated as shown in Fig. 4. It can be seen that, as expected, the COP value increases with increasing generator temperature. It's clearly seen that there is a minimum generating temperature above which the operation of the cycle is possible. This temperature is called cut in/cut off temperature [12]. This temperature indicates the condition of equalization of ammonia concentrations in the solution which is pumped into and out of the generator.

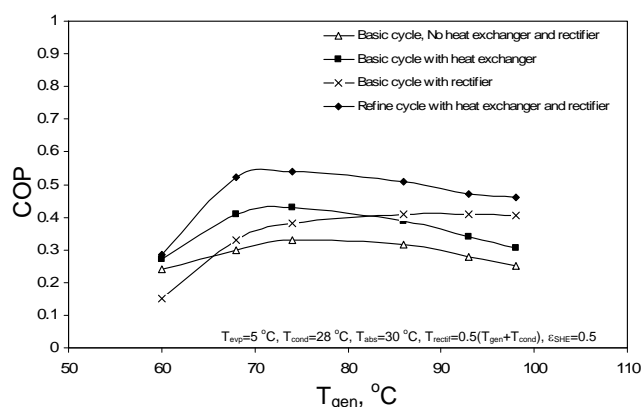


Fig. 4 Variation of COP with generator temperature

Another interest observation is the maximum of an optimal temperature at which a maximum value of the COP is obtained. This optimal temperature depends on the type of the cycle but the highest maximum value of COP is obtained for the system containing both a rectifier and a heat exchanger. The COP for this cycle is about 50 per cent higher than that of the basic cycle. The system has a rated refrigeration capacity up to 6 kW. The general trend of the curve shown in Fig. 4 is in accordance with that of other works [6,12].

The insertion of a heat exchanger between the generator and absorber is a logical improvement, it is an energy saving component. The immediate effect of the heat exchanger is to reduce the heating

requirement in the generator which improves the COP. Also, there is an appreciable improvement with the addition of the rectifier, the primary function of which is to purify the refrigerant vapor that goes onto the condenser and evaporator.

The effect of next variable, the evaporating temperature, is shown in Fig. 5. In general, the COP values changed from 0.33 to 0.58 when the evaporator temperature was varied between 3 and 16 °C. If the evaporator temperature rises, the concentration of the weak solution increase while the circulation ratio between the mass flow rate of weak solution and refrigerant decrease. They cause a decrease in both generator and absorber thermal load. Thus, the COP increases almost linearly with evaporator temperature. It was seen that if higher cooling capacity and also lower evaporator temperature are desired from the system, the generator temperature should be increased considerably.

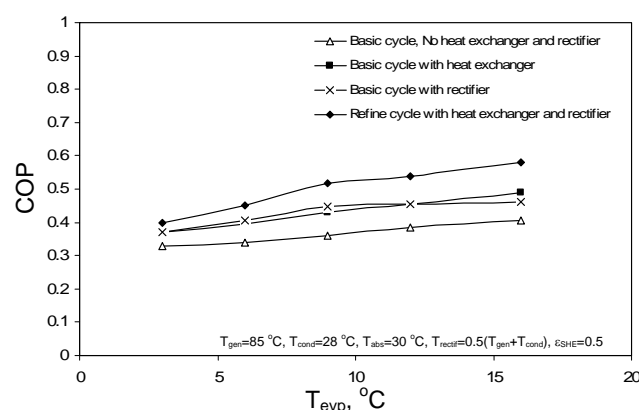


Fig. 5 Variation of COP with evaporator temperature

The effect of condenser temperature on the COP is shown in Fig. 6. The COP values decrease with increasing condenser temperature. When the temperature of the condenser increase, the thermal load of the generator rises, and the performance of the system gets worse. The high pressure of the system increases and the concentration of the strong solution increases when the condenser temperature increases. With increasing strong solution concentration, the circulation ratio increases, and in this case, the thermal loads of both generator and absorber increase.

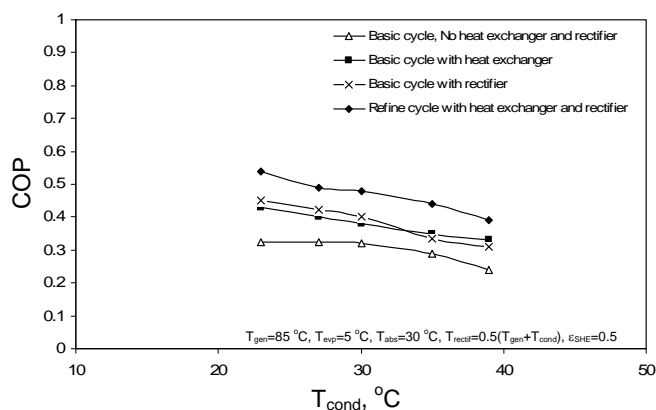


Fig. 6 Variation of COP with condenser temperature

7 Conclusions

In this study, an experimental absorption refrigeration system powered by solar energy was designed and constructed and the system was tested successfully. The effects of the main operating parameters on the system performance were experimentally investigated. It was seen that if higher cooling capacity and also lower evaporator temperature are desired from the system, the generator temperature should be increased considerably. In general, a solar absorption system can work only if the collectors' outlet temperature is higher than the cut in/cut off temperature, and there exists an optimal value for this temperature at which a maximum value of the COP is obtained. The maximum COP of the cycle in the order of 0.6 when the improvements of rectifier and solution heat exchanger are added. In this case, the maximum increase in COP is about 50% higher than the basic cycle. This paper is provided an actual compact unit and operated under real outside conditions for Malaysia and similar tropical regions. It is produced an air conditioning and refrigeration capacity of 1.5 ton, used selected market components. This unit is considered a step forward towered commercial use.

References

- [1] I. Horuz, A comparison between ammonia-water and water-lithium bromide solutions in vapor absorption refrigeration systems, *Int. Comm. Heat Mass Transfer* 25(5)(1998)711-721.
- [2] M. Hammad, S. Habali, Design and performance study of a solar energy powered vaccine cabinet, *Appl Therm Eng* 20(2000) 1785-98.
- [3] A. De Francisco, R. Illanes, J.L. Torres, M. Castillo, M. De Blas, E. Prieto., Development and testing of a prototype of low-power water-

ammonia absorption equipment for solar energy applications, *Renewable Energy* 25(2002) 537-544.

- [4] N. Ben Ezzine, M. Barhoumi, Kh. Mejbri, S. Chemkhi, A. Bellagi, Solar cooling with the absorption principle: First and second law analysis of an ammonia-water double-generator absorption chiller, *Desalination* 168(2004)137-144.
- [5] A. Sencan, Performance of ammonia -water refrigeration systems using artificial neural networks, *Renewable Energy* 32(2007)314-328.
- [6] J.M. Abdulateef, K. Sopian, M.A. Alghoul, Optimum design for solar absorption refrigeration systems and comparison of the performances using ammonia-water, ammonia-lithium nitrate and ammonia-sodium thiocyanate solutions. *International Journal of Mechanical and Materials Engineering (IJMME)* 3(1)(2008) 17-24.
- [7] M. Bogart, *Ammonia Absorption Refrigeration in Industrial Processes*, Gulf, Houston, Texas (1981).
- [8] D. Butz, K. Stephan, Dynamic behavior of an absorption heat pump, *Int. J. Refrig.* 12(1989) 204-212.
- [9] F.Z. Sierra, R. Best, F.A. Holland, Experiments on an absorption refrigeration system powered by a solar pond, *Heat Recovery Systems & CHP* 13(1993)401-408.
- [10] ASHRAE, *ASHRAE Handbook*, 1994. Refrigeration Systems and Applications. Chapter 40, p. 40.1. ASHRAE, 1791 Tullie Circle, N. E., Atlanta, GA 30329.
- [11] C.P. Jain, G.K. Gable, Equilibrium property data equations for aqua-ammonia mixtures, *ASHRAE Trans*, 77(1)(1971)149-151.
- [12] W.F. Stoecker, L.D. Reed, Effect of operating temperatures on the coefficient of performance of aqua-ammonia refrigerating system, *ASHRAE Trans* 77(1)(1971)163-170.
- [13] J.M. Abdulateef, M.Y. Sulaiman, Lim Chin Haw, Baharudin Ali, Sohif Mat, Muhammad Yahya, M.A. Alghoul, A. Zaharim, K. Sopian, An economic viability analysis and optimization of solar cooling system, *Proceeding of the 4th IASME/WSEAS International Conference on Energy& Environment*, Cambridge, 2009.