EVALUATION OF A COMBINED SOLAR-ASSISTED EJECTOR ABSORPTION CHILLER

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Abstract: *The experimental investigation of the performance of a combined solar ejector absorption cooling system has been carried out. The system was installed in the solar energy park at University Kebangsaan Malaysia. The influence of various operating conditions on the COP is studied using evacuated tube solar collectors and NH3-H2O as working fluid. The results showed that, the absorption chiller provides high COP than that of the conventional absorption system. The maximum COP of the cycle in the order of 0.6 when the improvements of rectifier and solution heat exchanger are added while the maximum increase in COP in case of combined cycle is about 50% higher than the basic cycle. This study is provided an actual compact unit of 1.5 cooling capacity and operated under real outside conditions for Malaysia and similar tropical regions.*

Key Words: *Buckling Ejector, Absorption chiller, NH3-H2O, COP.*

INTRODUCTION

The continuous increase in the cost and demand for energy has prompted rising research and development interest in the utilization of non-conventional energy sources, namely, solar energy, wind energy, tidal waves, geothermal energy, biogas, hydrogen energy, and hydropower. Solar cooling technology for air-conditioning and refrigeration applications is seen as an environment-friendly and sustainable alternative. A majority of research and development studies on solar-assisted absorption cooling systems deal with the single-stage system type.

Bejan *et al.* designed a single-stage solar-driven ejector system with 3.5 kW of refrigeration capacity at an evaporating temperature of 4°C and a generating temperature of 90-105°C with R114 [1].

Huang *et al.* developed a solar ejector cooling system using R141b as the refrigerant; obtaining the overall COP of around 0.22 at a generating temperature of 95°C, an evaporating temperature of 8°C and solar radiation of 700 W/m^2 [2]

A solar assisted ejector-vapour compression cascade system was proposed by Göktun [3].The inter-cooler was installed serving as a condenser for the vapour compression system and an evaporator for the ejector system.

Experiments on a solar-powered passive ejector cooling system were also performed by Nguyen et al. [4]. Water was used as the working fluid with an evacuated tube solar collector. Cooling capacity was designed for 7 kW. This system is also capable of delivering heat up to 20 kW during the winter period.

Sözen and Özalp proposed a solar-driven ejector-absorption system. The main focus of this study is to investigate the possibility of using this system in Turkey [5]. As a result of the analysis, using the ejector, the COP improved by about 20%.

Performance variations of a solar-powered ejector cooling-system (SECS) using an evacuated-tube collector has been presented by Ersoy et al in different cities in Turkey [6]. A SECS, based on a constant-area ejector flow model and using R-123, was considered. For all the cities, the cooling capacities of the SECS were very similar.

Varga et al. carried out theoretical study to assess system and refrigeration efficiencies of a solar-assisted ejector cycle using water as the operating fluid [7]. The results indicated that in order to achieve an acceptable coefficient of performance, generator temperatures should not fall below 90°C. Evaporator temperatures below 10°C and condenser temperatures over 35°C.

The first purpose of the study is to design and fabricate a combined solar-assisted ejector absorption chiller which was the combination of both absorption refrigeration system and ejector refrigeration system. This combined system brings together the advantages of the two conventional cooling systems. The second purpose of the study is to investigate experimentally the effects of the operating temperatures on the COP of the system. The effect of adding heat exchanger, rectifier and ejector to the basic system is taken into consideration in the experimental investigation.

EXPERIMENTAL SETUP

From Figures 1-3, the experimental setup consisted of three sides: ammonia-water side, hot water side, and coolant water side. The main part of the system is representing by ammonia-water side, taking into account the ejector design and flow process, see Fig 1.The components of this part consists of generator, rectifier, ejector, condenser, evaporator, absorber, solution heat exchanger, liquid storage tank, expansion device, and solution pump.

The hot water side is composed by the solar collector, the storage tank, and the water side 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 (60-100 °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 (18-30 °C), in the cooling water tank. Material compatibility is a serious concern with ammonia solutions. All components are selected to have no reaction with the working fluid. The tubing and fittings are made of stainless steel and the tanks are of mild steel.

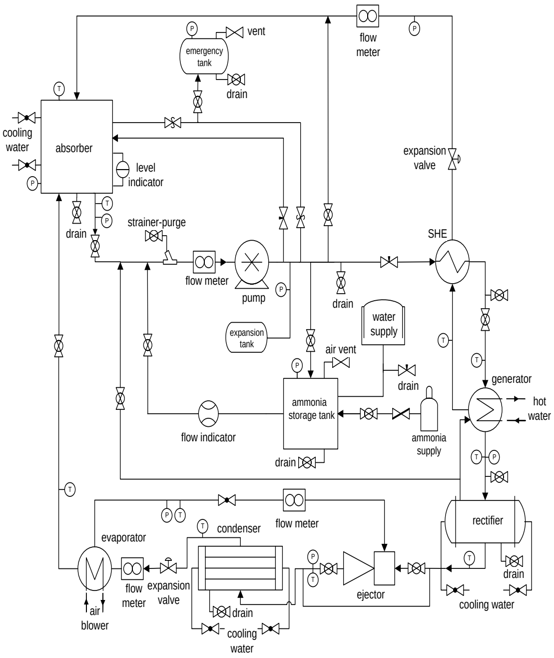

Figure 1. Schematic of the experimental setup.

The ejector was designed based on mathematical model provided by Abdulateef [8]. The ejector mainly consisted of a primary nozzle, a mixing chamber, a constant-area throat, and a subsonic diffuser. Stainless steel is used as material for the ejector. The main parts of the ejector are connected by fine screws. Design details and important dimensions for ejector are given in Table 1.

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. 1.

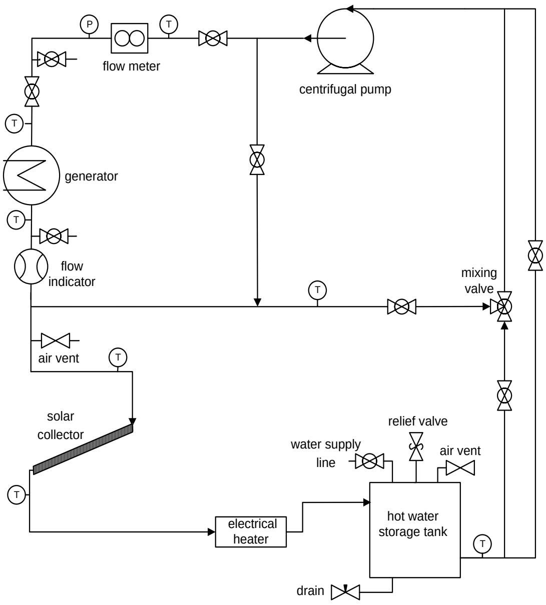

Figure 2. Components of the hot water side.

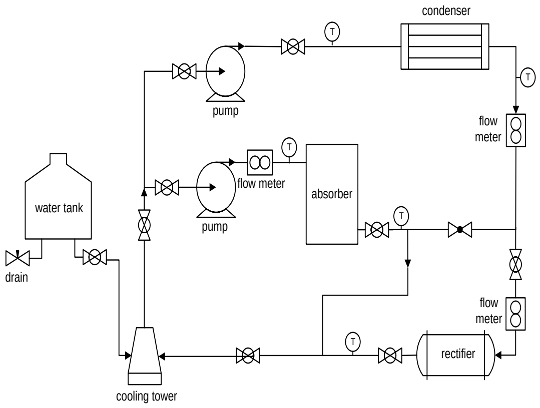

Figure 3. Components for the coolant side.

Table 1: Specification of Ejector

Parameter	Value
Nozzle throat diameter, mm	2.6
Mixing chamber diameter, mm	8.1
Mixing chamber length, mm	64
Nozzle Divergent length	16.8
Diffuser Divergent length	60
Nozzle Divergent angle	10
Diffuser Divergent angle	10
Ejector body rod, mm	50
Material: Stainless steel	

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 ±5% W/m^2 accuracy pyranometer.

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

EXPERIMENTAL PROCEDURES

To begin with, solar energy is absorbed by the collector and accumulated in the storage tank. The vapor generator is a device in which high pressure and temperature vapor is generated by utilizing energy sources such as solar energy. 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 is also contain some water vapor. 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. In case of ejector, the primary vapor at the high pressure leaving the generator enters the supersonic nozzle of the ejector. The very high velocity vapor at the exit of the nozzle produces a high vacuum at the inlet of the mixing chamber and entrains secondary vapor into the chamber from the evaporator where it causes the pressure to decrease.

The two streams first mix in the mixing chamber, and then, the pressure of the mixed stream rises to the condenser pressure in the diffuser. The mixed stream discharges from the ejector to the condenser where it condenses from a vapor to a liquid by rejecting heat to the surroundings. The liquid refrigerant leaving the condenser enters the evaporator after passing 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.

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. 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.

The condenser temperature was 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 air or water to be cooled.

PERFORMANCE EVALUATION

The first purpose of this experiment is to study the influence of operating conditions on the *COP* of the conventional system without ejector by 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. The second purposes is to investigate experimentally the *COP* of the proposed combined system taking into account the ejector design and flow process.

Experiments were conducted for a range of operating conditions as follows: generator temperature between 60 ^{o}C and 98 ^{o}C, evaporator temperature between 3 ^{o}C and 16 ^{o}C, and condenser temperature between 23 ^{o}C and 39 ^{o}C at the mass flow rate of refrigerant of 1 kg/min and the effectiveness of solution heat exchanger ($\varepsilon_{\mathrm{SHE}}$) 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.

RESULTS AND OBSERVATIONS

Figures 4-6 show the influence of the operating temperatures on the *COP* of conventional system. From Figure 4, it can be 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. Another interest observation is the maximum of an optimal temperature at which a maximum value of the *COP* is obtained. The *COP* for the refine cycle is higher than that of the basic cycle. It is clearly seen that the addition of a heat exchanger and rectifier are a logical improvement. Figure 5 shows that the *COP* values changed from 0.33 to 0.58 when the evaporator temperature was varied between 3 and 16°C. The evaporator temperature affects the low pressure of the system. 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.

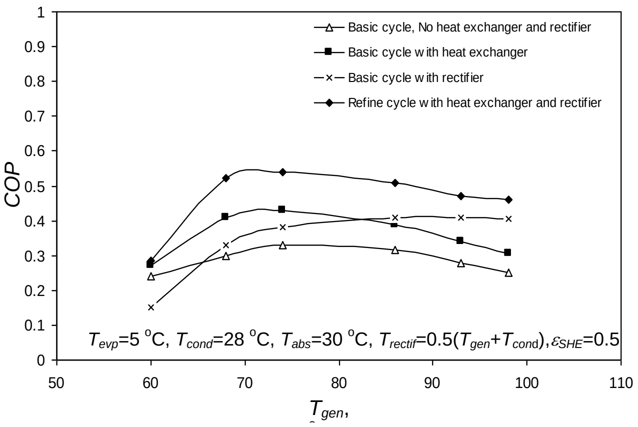

Figure 4. Variation of *COP* with generator temperature (conventional system).

The effect of condenser temperature on the *COP* is shown in Figure 6. The *COP* values decrease with increasing condenser temperature. It can be seen that the maximum *COP* of the cycle in the order of 0.6 when the improvements of rectifier and solution heat exchanger are added.

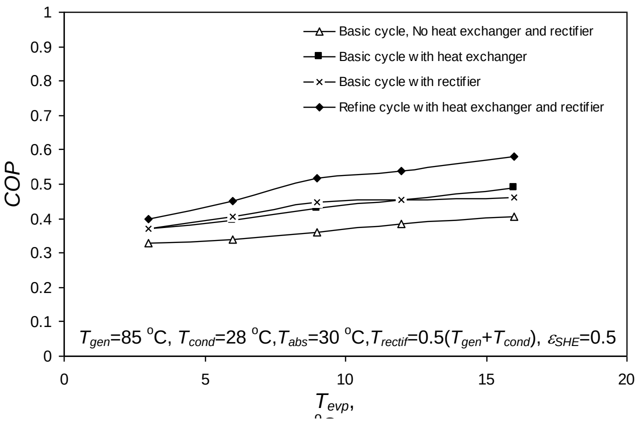

Figure 5. Variation of *COP* with evaporator temperature (conventional system).

Figure 7 shows the performance comparison between the conventional system and the combined system under the same operating conditions. There is a minimum generating temperature above which the operation of the cycle is possible. Any increase in driving pressure ratio (*Dr*) leads to increase in entrainment ratio (*w*) from the evaporator. As the generator temperature increases with given condenser temperature and evaporator temperature, the entrainment ratio varies from 0.04 to 0.15. The results show that, the combined cycle provides potentially high *COP* than that of the conventional absorption machine. The maximum increase in *COP* is about 50% higher than the basic cycle.

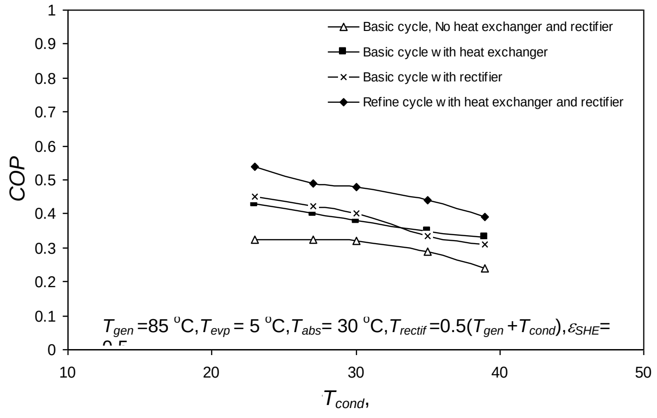

Figure 6. Variation of *COP* with condenser temperature (conventional system).

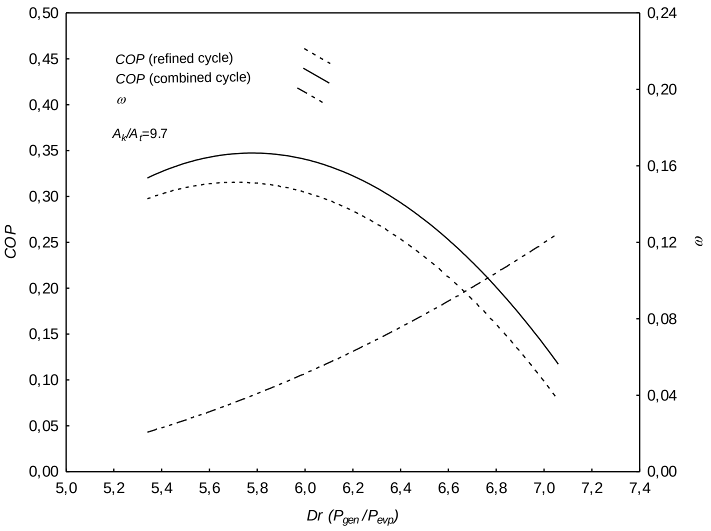

Figure 7. Comparison of *COP* and *w* for both conventional and combined system.

CONCLUSION

In this study, an experimental absorption chiller powered by solar energy was designed and constructed and the system was tested successfully.

The effects of the main operating parameters on the *COP* were experimentally investigated. The results showed that, the absorption chiller provides high *COP* than that of the conventional absorption system. The maximum *COP* of the cycle in the order of 0.6 when the improvements of rectifier and solution heat exchanger are added while the maximum increase in *COP* in case of combined cycle is about 50% higher than the basic cycle. This study is provided an actual compact unit of 1.5 cooling capacity and operated under real outside conditions for Malaysia and similar tropical regions.

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