Experimental Study On Combined Solar-Assisted Ejector Absorption Refrigeration System

J. M. Abdulateef, Nurul Muiz Murad, M. A. Alghoul, A. Zaharim and K. Sopian

Abstract— In this study, a combined ejector absorption refrigeration system driven by solar energy has been designed and constructed. The effects of the main operating conditions on system performance were experimentally investigated using evacuated tube solar collectors and ammonia-water as working fluid. The major components of combined system consist of generator, rectifier, ejector, condenser, evaporator, absorber, solution heat exchanger. Experimental study was performed over a range of generator temperatures from 60 to 98 ^{o}C, evaporator temperatures from 3 to 16 ^{o}C, and condenser temperatures from 23 to 39 ^{o}C. 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.

Keywords— Refrigeration; Ejector; Ammonia-Water; Experimental study.

I. Introduction

SOLAR cooling technology for air-conditioning and refrigeration applications has received increasing interests as an environmental-friendly and sustainable alternative. A majority of research and development studies regarding solar-driven ejector refrigeration systems deal with the single stage system type.

Murthy et al. (1991) tested different ejector dimensions at the cooling capacity about 0.5 kW. R12 was used as the refrigerant. A *COP* in the range of 0.08-0.33 was obtained.

Bejan et al. (1995) 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.

Al-Khalidy (1997) analysed the theoretical and experimental performance of a solar-driven ejector refrigeration system. Five refrigerants (R717, R12, R11, R113 and R114) were compared. From the analysis, it was found that R113 was more suitable than any other refrigerant. The *COP* of the refrigeration system and performance of the solar ejector refrigeration system as a whole, increased when the generating and the evaporating temperature increased and decreased when the condensing temperature increases.

Huang et al. (1998) 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 $W.m^{-2}$.

A solar assisted ejector-vapour compression cascade system was proposed by Göktun (2000). 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 in 2001 by Nguyen et al. (2001). 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 (2005) proposed a solar-driven ejector-absorption system. The main focus of this study is to investigate the possibility of using this system in Turkey. 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. (2007) in different cities in Turkey. 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. (2009) carried out theoretical study to assess system and refrigeration efficiencies of a solar-assisted ejector cycle using water as the operating fluid. 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 main objective of this paper is to design, fabricate and evaluate a new solar-assisted ejector absorption refrigeration system (EARS) which was the combination of both absorption refrigeration system (ARS) and ejector refrigeration system (ERS). This combined system brings together the advantages of the two conventional cooling systems.

A schematic diagram of combined solar-assisted ejector

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absorption refrigerating system (SEARS) that was constructed in the present study is shown in Fig. 1. The system was installed in Bangi (ϕ=3.1°), University Kebangsaan Malaysia on the roof of the physics department, labs of Science Faculty.

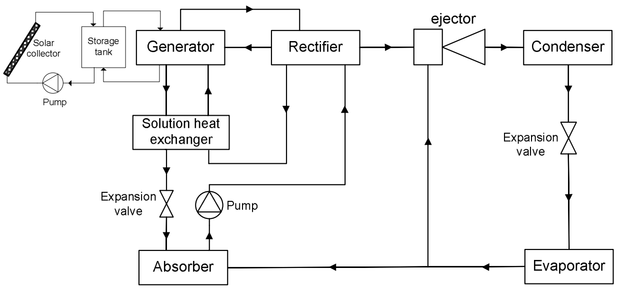

Fig. 1 Schematic of the experimental setup concept

II. Experimental Setup

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 2.The components of this part consists of generator, rectifier, ejector, condenser, evaporator, absorber, solution heat exchanger, liquid storage tank, expansion device, and solution pump.

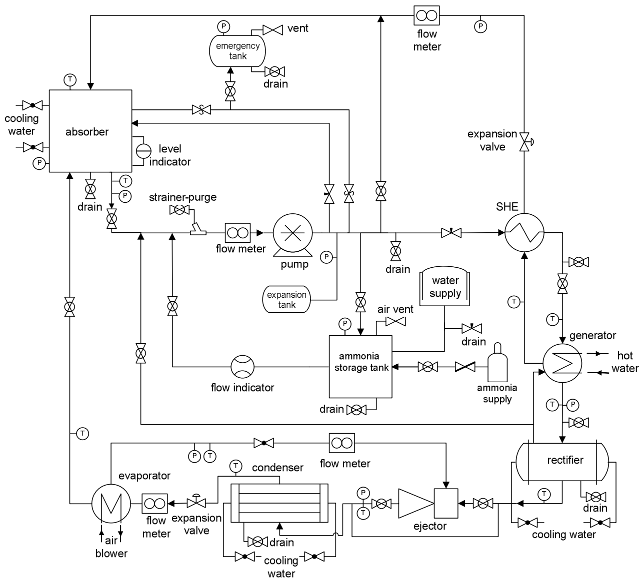

Fig.2 Schematic diagram of the experimental setup

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. 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.

The ejector was designed based on mathematical model provided by Abdulateef (2010). The drawing of the ejector used in the present study is shown in Figure 3. 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.

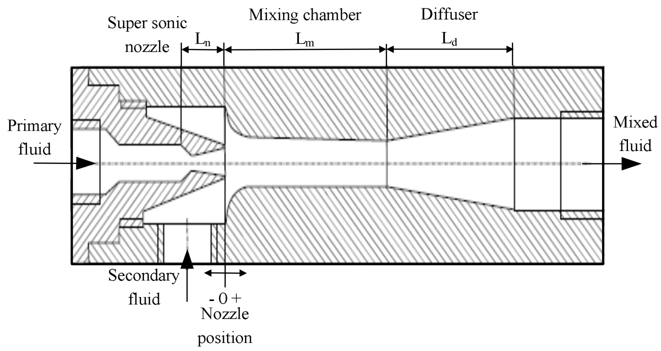

Fig. 3 The ejector used in the experimental setup

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	

III. Experimental Procedure

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.

IV. 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 ^oC and 98 ^oC, evaporator temperature between 3 ^oC and 16 ^oC, and condenser temperature between 23 ^oC and 39 ^oC at the mass flow rate of refrigerant of 1 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. The *COP* was calculated as the ratio of refrigeration capacity to generator heat input, neglecting the pump work. The solar radiation measurements which were used for solar performance estimation are based on Abdulateef (2009).

V. Results and Discussion

Figures 4-6 show the influence of the operating temperatures on the *COP* of conventional system. First, the influence of the generator temperature was investigated as shown in 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.

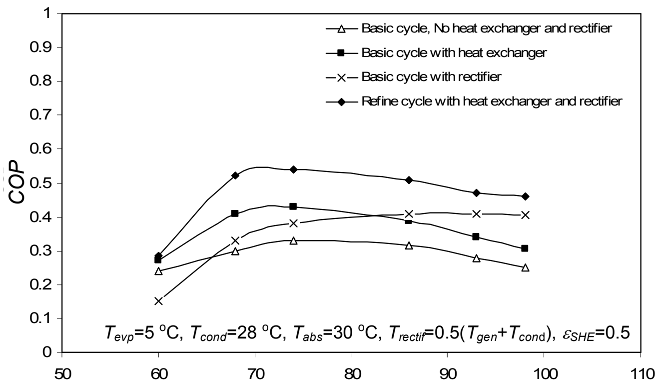

Fig. 4 Variation of *COP* with generator temperature (conventional system)

The effect of next variable, the evaporating temperature, is shown in Figure 5. In general, the *COP* values changed from 0.33 to 0.58 when the evaporator temperature was varied between 3 and 16^oC. 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.

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.

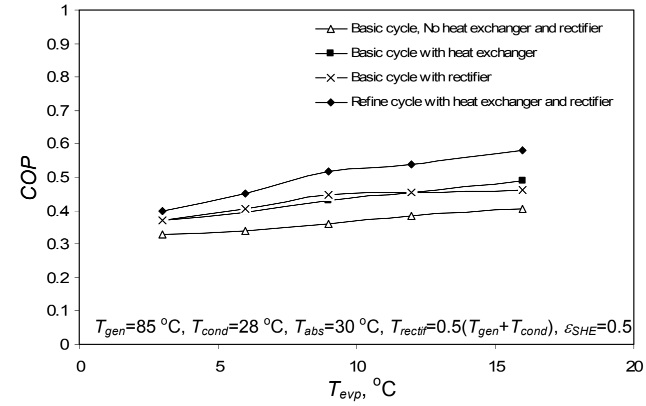

Fig. 5 Variation of *COP* with evaporator temperature (conventional system)

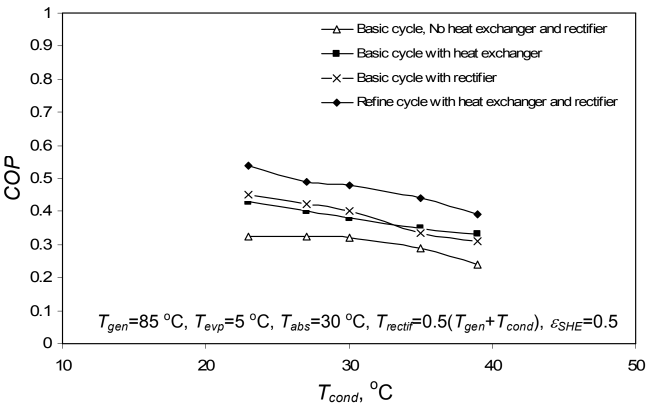

Fig. 6 Variation of *COP* with condenser temperature (conventional system)

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.

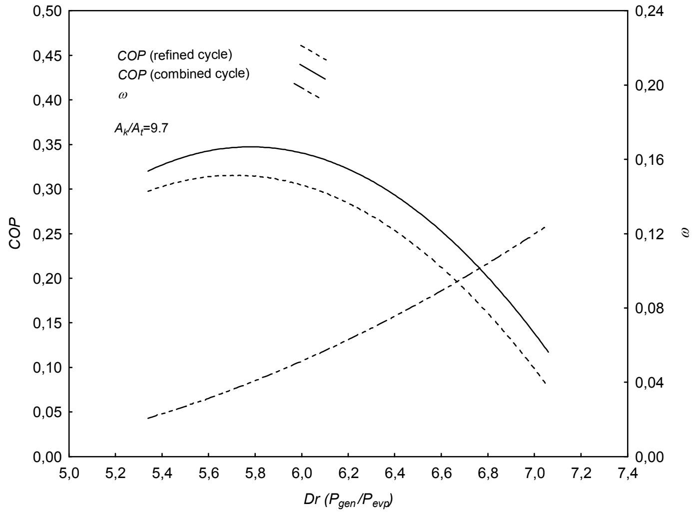

Fig. 7 Comparison of *COP* and *w* for both conventional and combined system

VI. Conclusions

In this paper, results related to both conventional and combined systems driven by solar energy using ammonia-water are presented and the effects of operating temperatures are investigated. 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. 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.

Nomenclature

A	area (m^2)
CAP	coefficient of performance
Dr	driving ratio(pressure ratio between the generator and the evaporator)
L	length (mm)
P	pressure (kPa)
T	temperature (°C)

Greek symbols

β	tilt angle of solar collector
ϕ	latitude angle
w	entrainment ratio (mass flow rate ratio between evaporator and generator)
ε	effectiveness

Subscripts

abs	absorber
cond	condenser
d	diffuser
evp	evaporator
gen	generator
n	nozzle
m	mixing chamber
k	cross section of exit of constant area
rectif	rectifier
SHE	solution heat exchanger
t	throat

VII. References

[1] Murthy, S. S., Balasubramanian, R. and Murthy, M. V. K. 1991. Experiments on vapour jet refrigeration system suitable for solar energy applications. *Renewable Energy*, **1**(5/6): 757-768.

[2] Bejan, A., Vargas, J. V. C. and Sokolov, M. 1995. Optimal allocation of a heat-exchanger inventory in heat driven refrigerators. *International Journal of Heat and Mass Transfer*, **38**(16): 2997-3004.

[3] Al-Khalidy, N. 1997. Performance of solar refrigerant ejector refrigerating machine. *ASHRAE Transactions*, **103**(1): 56-64.

[4] Huang, B. J., Chang, J. M., Petrenko, V. A. and Zhuk, K. B. 1998. A solar ejector cooling system using refrigerant R141b. *Solar Energy*, **64**(4-6): 223-226.

[5] Göktun, S. 2000. Performance analysis of a heat engine driven combined vapor compression-absorption-ejector refrigerator. *Energy Conversion and Management*, **41**: 1885-1895.

[6] Nguyen, V. M., Riffat, S. B. and Doherty, P. S. 2001. Development of a solar-powered passive ejector cooling system. *Applied Thermal Engineering*, **21**: 157-168.

[7] Sözen, A. and Özalp, M. 2005. Solar-driven ejector-absorption cooling system. *Applied Energy*, **80**: 97-113.

[8] Ersoy H.K., Yalcin, S., Yapici, R. and Ozgoren, M .2007. Performance of a solar ejector cooling-system in the southern region of Turkey. *AppliedEnergy*,84(9): 971-983.

[9] Varga, S., Oliveira, A.C. and Diaconu, B. 2009. Analysis of a solar-assisted ejector cooling system for air conditioning. *Int. J. Low-Carbon Tech.* 4 (1): 2-8.

[10] Abdulateef, J.M., Sulaiman, M.Y., Lim Chin Haw, Baharudin Ali, Sohif Mat, Muhammad Yahya, Alghoul, M.A., Zaharim, A. and Sopian, K. 2009 An economic viability analysis and optimization of solar cooling system, Proceeding of the 4th IASME/WSEAS International Conference on Energy& Environment, Cambridge.

[11] Abdulateef, J.M. 2010. Combined solar-assisted ejector absorption refrigeration system. Ph. D. thesis. Solar Energy Research Institute (SERI). Universiti Kebangsaan Malaysia.