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Energy and exergy analysis of an absorption refrigeration system

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Abstract –

In the present study, energy and exergy analyses of a solar powered absorption refrigeration system are corried out by terms of the first and second laws of thermodynamics. NH_3-H_2O fluid couple is used in the system. The analyses are performed with the help of Engineering Equation Solver software program. Exergy destruction rate in each component, coefficient of performance and exergy efficiency of overall system are calculeted. In addition, effect of generator, evaporator and condenser temperatures are investigated on the system performance. Maximum COP and exergy efficiency are determined to be 0.50 and 36%, respectively. It is observed that generator, evaporator and condenser temperatures significantly affect the system performance.

Keywords – Energy, exergy, absorption refrigeration, NH_3-H_2O

I. INTRODUCTION

With the rapid development of renewable energy in recent years, researches have increasingly focused on the development of absorption refrigeration systems(ARS). The absorption refrigeration system is a promising technology for refrigeration applications. The increasing price of electricity is the main reasons which lead to the adoption of renewable and sustainable energy sources, as solar and geothermal energy [1–3]. Compared with the compression refrigeration system, the absorption refrigeration system effectively reduces electricity consumption by consuming low-grade thermal energy, such as solar energy [4]. The absorption refrigeration systems are quite similar to the mechanical vapor compression refrigeration systems. The main advantages of the absorption refrigeration system are to evaluate that the cycle is used physico-chemical processes instead of mechanical processing, a thermal compressor is used instead of a mechanical compressor and heat energy is used instead of mechanical and electrical energy. With the advantages of the cycle, the use of waste heat energy in various industrial plants and by the way of the using of solar energy as an inexhaustible source of energy make energy consumption more economical nowadays. There are many studies concentrated on the evaluation of the performance in these kinds of systems in terms of the first and second law of the thermodynamics.

Garousi et al. [5] made an thermodynamic analysis and comparison of combined ejector-absorption and single effect ARS. In this study the influence of the ejector on the performance of combined cycles is successfully investigated and compared to that of single effect cycles, utilizing the most recently published thermophysical property data of these solutions for enthalpy and entropy. Yiping et al. [6] carried out exergy analysis, parametric analysis and optimization for a novel combined power and ejector refrigeration cycle. Parameter optimization is achieved using exergy efficiency as the objective function by means of genetic algorithm. You-Rong et al. [7] proposed a novel combined-system driven by the low-grade waste heat using different refrigerants. The exergetic performance of a combined reheat regenerative vapor power cycle and LiBr based vapor absorption refrigeration (VARS) has been simulated in this study. Gogoi et al. [8] evaluated exergy based parametric analysis of a combined reheat regenerative thermal power plant and water-LiBr vapor ARS. Under partial refrigeration load, there is a linear relationship between the electricity output and the refrigeration capacity at a fixed work output from the turbine. The total irreversible loss decreases and the exergy efficiency increases with the decrease of the power ratio.

Numerous analyses have been examined for exergy investigation of ARS. The result of this study can be used either for sizing a new refrigeration cycle or rating an existing system. In the present work, a mathematical model of ARS has been analyzed at various operating parameters. The exergy losses for all components are obtained from a mathematical model as calculated in EES. The COP and exergy efficiency are evaluated for each component of ARS.

II. MATERIALS AND METHOD

A. System Description

Figure 1 shows the schematic view of a simple absorption refrigeration system. It consists of an absorber, a pump, a generator and two pressure reducing valves and an evaporator. NH_3-H_2O fluid pairs are selected as working fluids in the absorption refrigeration cycle. In the absorption refrigeration cycle ammonia and water are used as the refrigerant and absorbent, respectively. The refrigerant is circulated in points 1, 2, 3 and 4, solution is circulated in points 5, 6, 7, 8, 9 and 10. In this system, the low pressure ammonia vapour refrigerant leaving the evaporator enters the absorber, where it is absorbed by the cold water in the absorber. The water has an ability to absorb a very large quantity of ammonia vapour. It is usually employed water cooling as some form of cooling arrangement in the absorber to remove the heat of solution, this is necessary in order to increase the absorption capacity of water and the strong solution formed in absorber is pumped to the generator by the pump. The pump increases the pressure of solution. The strong solution of ammonia in the generator is heated by some external source such as solar energy. During the heating process ammonia vapour is emitted from the solution at higher pressure and leaving behind the hot weak solution in the generator. The weak solution leaving the generator from point 10 to the absorber where they don't dissolve and react with each other to form strong solution before, it releases some of its heat in the heat exchanger and enters to the pressure reducing valve where its heat and pressure decreases to the absorber level. Apart from that, the high pressure ammonia vapour leaving the generator from point 1 is condensed in the condenser to high pressure liquid ammonia thus liquid ammonia is passed to the expansion valve and to the evaporator and then vaporized working fluid in evaporator enters to the absorber. Thus, the cycle is completed.

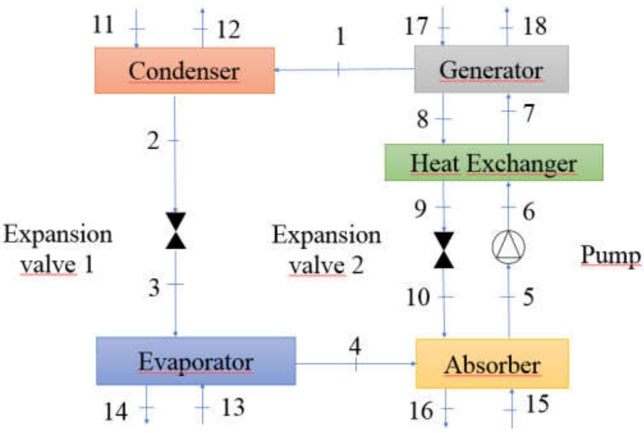

Figure 1- the schematic view of an absorption refrigeration system.

B. *Thermodynamic evaluation*

For carrying out thermodynamic analysis of the pro-posed Vapour Absorption Refrigeration system, following assumption are made: [9]

No pressure changes except through the flow pump.
1. At point1, 4 and 8, there is only Saturated Liquid.
2. At point10, there is only Saturated Vapour.
3. Pumping is isentropic.

The absorption refrigeration system is considered as steady flow open-system and modeled based on the first and second laws of thermodynamics, and these laws are applied to each component in the system.

C. *Analysis Method*

Ammonia balance with the circulation rate and the continuity equation in the generator can be expressed as follows;

Circulation ratio,

$$f = \frac{rich\ solution\ flow}{refrigerant\ flow} = \frac{m_7}{m_1} = \frac{1-X_8}{X_7-X_8} \tag{1}$$

$$m_7 = m_8 + m_1 \tag{2}$$

Ammonia balance in generator

$$m_7 \times X_7 = m_8 X_8 + m_1 \tag{3}$$

m_7 : *poor solution flow*
X_7 : *poor solution concentration*
X_8 : *rich solution concentration*

The general energy balance equation for an open system can be expressed as follows

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}(h + V^2/2 + gz)_{in} = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}(h + V^2/2 + gz)_{out} \tag{4}$$

The first and second term, $\dot{Q}$ and $\dot{W}$ show energy transfer as heat and work, respectively. The third term indicates the energy transfer by mass where h shows enthalpy as the other show kinetic and potential energy, respectively. $\dot{m}$ is the mass flow rate.

$$\dot{E}x_{heat,in} + \dot{E}x_{work,in} + \dot{E}x_{mass,in} = \dot{E}x_{heat,out} + \dot{E}x_{work,out} + \dot{E}x_{mass,out} + \dot{E}x_{dest} \tag{5}$$

The absorption refrigeration system can be evaluated by taking into account of the energy input only by mass and work and those be calculated as follows, respectively.

$$\dot{E}x_{work} = \dot{W} \tag{6}$$

$$\dot{E}x_{mass} = \dot{m}\left[(h - h_0) - T_0(s - s_0)\right] \tag{7}$$

where, T and s represent temperature and entropy, respectively. 0 index indicates ambient conditions. Energy and exergy balance equations have been applied to each component in the system are illustrated in Table 2.

Total exergy destruction for overall system can be calculated by sum of exergy destruction rates of all components (Eq.4)

$$\dot{E}x_{dest,tot} = \sum \dot{E}x_{dest,k} \tag{8}$$

The coefficient of the performance (COP) is an expression of the efficiency of a refrigeration system and can be described as a ratio of the refrigerating capacity generated by evaporator to the heat supplied to generator and electricity consumption of the pump

$$COP = \dot{Q}_{EV} / (\dot{Q}_{GE} + \dot{W}_{PU}) = \dot{m}_{EV}(h_6 - h_5) / \left(\dot{m}_{GE}(h_3 - h_1)\right) = \mu(h_6 - h_5)/(h_3 - h_1) \tag{9}$$

where EV, GE and PU show capacities of the evaporator, generator and pump, respectively.

III. RESULTS AND DISCUSSION

The calculation program was written in Engineering Equation Solver (EES) software. Table 1 shows the input parameters in order to carry out the energetic and exergetic analysis of the cycle. The calculated thermodynamic data at each point in the system are shown in Table 2.

Table 1: Input parameters to the system

Parameters	Values
Evaporator temperature	5℃
Condenser temperature	40℃
Generator temperature	100℃
Absorber temperature	40℃
Inlet temperature to generator of therminol vp1	220℃
Inlet temperature to condenser of cooling water	25℃
Outlet temperature from condenser of cooling water	30℃
Inlet temperature to evaporator of water	20℃
Outlet temperature from evaporator of water	15℃
Inlet temperature to absorber of water	25℃
Outlet temperature from absorber of water	30℃
Subcooling and superheating temperature	5℃
Effectiveness of solution heat exchanger	50%
Cooling capacity	20kW
Ambient pressure	101.325 kPa
Ambient temperature	25℃

Table 2: Data of ARS

Loc.	Subs.	$\dot{m}$ (kg/s)	P (kPa)	T(℃)	h (kJ/kg)	s (kJ/kg.K)	e (kJ/kg)
1	NH_3	0.01794	1555	100 ℃	1665	5.67	396.6
2	NH_3	0.01794	1555	35 ℃	366.1	1.566	321
3	NH_3	0.01794	516	5 ℃	366.1	1.598	311.5
4	NH_3	0.01794	516	10 ℃	1481	5.605	231.5
0	NH_3	-	101.3	25 ℃	1547	6.602	0
5	Water	0.1073	516	40 ℃	-60.39	0.4374	-186.3
6	Water	0.1073	1555	40.1℃	-59.11	0.4374	-185
7	Water	0.1073	1555	65.3℃	55.23	0.7885	-175.3
8	Water	0.08934	1555	100℃	219.8	1.247	-147.4
9	Water	0.08934	1555	70.05℃	82.52	0.8634	-170.3
10	Water	0.08934	516	60.18℃	82.52	0.8688	-171.9
11	Water	1.114	101.3	25℃	104.8	0.3669	0
12	Water	1.114	101.3	30℃	125.8	0.4365	0.1734
13	Water	0.9562	101.3	20℃	83.93	0.2962	0.1774
14	Water	0.9562	101.3	15℃	63.01	0.2242	0.7176
15	Water	1.933	101.3	25℃	104.8	0.3669	0
16	Water	1.933	101.3	30℃	125.8	0.4365	0.1734
0	Water	-	101.3	25℃	104.8	0.3669	0
17	Therminol VP1	0.1454	600	220℃	377.8	0.98	95.69
18	Therminol VP1	0.1454	600	60.85℃	77.95	0.252	12.89
0	Therminol VP1	-	101.3	25℃	20.1	0.1012	0

Fig 2 shows the effect of TG on COP, after 110°C the COP stays consistent with increase in generator temperature. The exergy efficiency of system increases up to 90°C but a further increase in the generator temperature makes that the exergy efficiency inclines a decreasing.

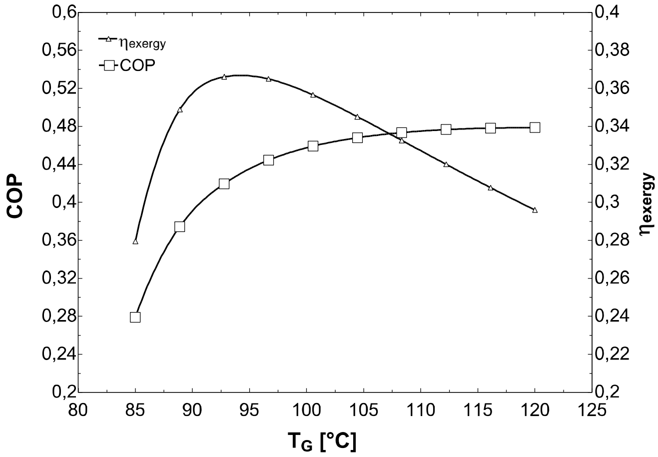

Figure 2: Variation of COP and exergy efficiency with Generator Temperature

Fig 3 shows the effect of TG on *total exergy destruction rate,* that presents the temperature of generator increases slightly when the total exergy destruction of the system decreases and then the total exergy destruction of the system stays consistent after 11kW.

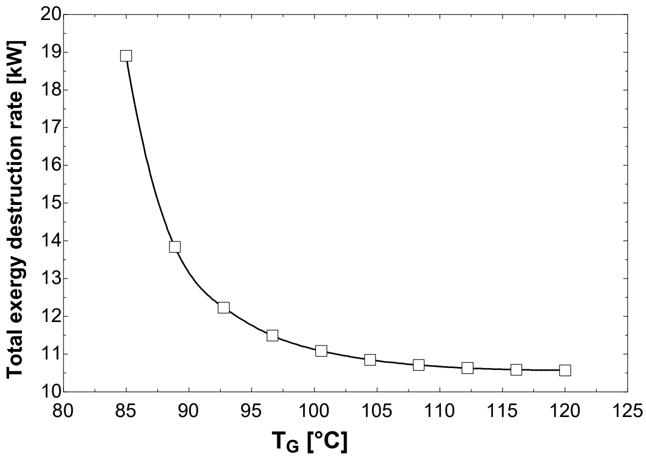

Figure 3: *Variation of Total exergy destruction rate with Generator Temperature*

Fig 4 shows the effect of TC on COP, the tendency of the graph indicates that the increase in condenser temperature up to 50°C and as the condenser temperature increases, the exergy efficiency of present system increases up to 42°C but a further increases in the condenser temperature makes that the exergy efficiency inclines an decreasing. Also, as the condenser temperature increases, COP of the system decreases.

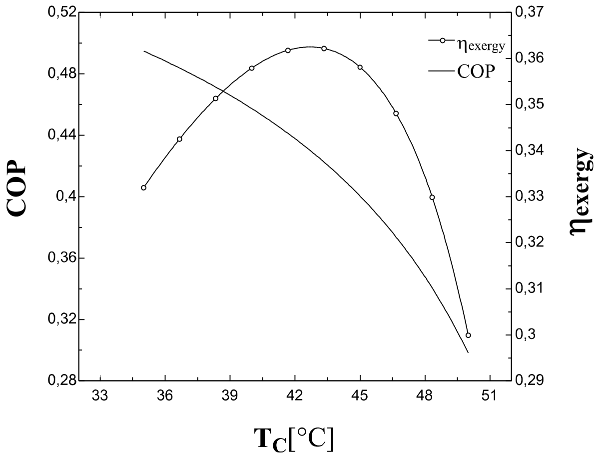

Figure 4: Variation of COP and exergy efficiency with Condenser Temperature

Fig 5 shows the effect of TE on COP that represents the change in evaporator temperature with respect to various COP and exergy efficiency. The COP of ARS varies between 0.2 to 0.5 and the maximum value is obtained at higher evaporator temperature and both COP and exergetic efficiency increase with an increase of the heat.

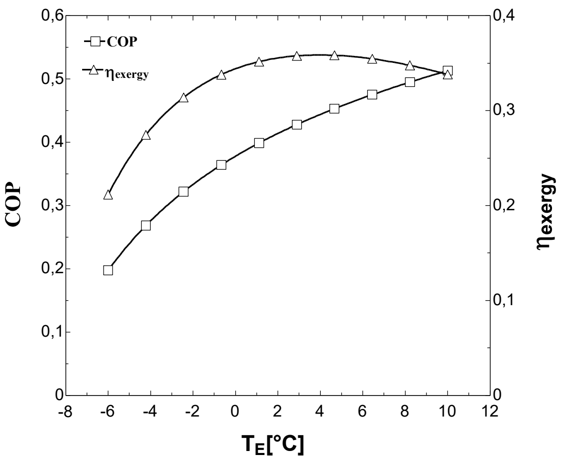

Figure 5: Variation of COP and exergy efficiency with Evaporator Temperature

IV. CONCLUSION

In this study, the first and second laws of thermodynamics are applied to an ammonia-water absorption refrigeration system. The thermodynamic analysis of the system is carried out by using EES. A program has been written for energy and exergy calculations of ARS. Exergy losses in each component and exergetic efficiency are also calculated. These results are very important in the improvement of absorption systems. It is observed that COP and exergy efficiency increase with an increment in generator and evaporator temperature and decrease together with the condenser temperature. Total exergy destruction rate remains almost consistent with a further generator and evaporator temperature, but it increases together with condenser temperature.

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