Transport and Communications Science Journal, Vol.74, Issue 1 (01/2023), 72-80

Transport and Communications Science Journal

THERMODYNAMIC ANALYSIS OF A WASTE HEAT RECOVERY LIBR/H_2O SINGLE EFFECT ABSORPTION CHILLER SYSTEM IN TEXTILE IN VIETNAM

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ARTICLE INFO

TYPE: Research Article
Received: 14/08/2022
Revised: 27/09/2022
Accepted: 17/11/2022

https://doi.org/10.47869/tcsj.74.1.7
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Abstract. Model for energy and exergy analysis of absorption refrigeration using waste heat from textile factory has been built. The analysis that uses different models of heat exchangers are the overall heat conductance (UA) model, and the effectiveness model. The result show that the exergy loss in the generator and absorber are the larger than condenser and evaporator. Therefore, it is necessary to focus on improving these two important devices in absorption chiller. For the convenience of system operation, the research analyzed the effects of generator inlet temperature and solution pump mass flow rate on the energetic and exergetic performance of the absorption chiller. The study results indicated that the exergy efficiency of the absorption chiller decrease from 0.2776 to 0.2146 when increasing the solution pump mass flow rate from 1.5 kg/s to 2.5 kg/s and the generator inlet temperature from 80 ^{o}C to 98 ^{o}C. Meanwhile, energy efficiency will increase slightly initial from 0.769 to 0.779 and then decrease from 0.779 to 0.776 as the generator inlet temperature increases from 80 ^{o}C to 98 ^{o}C when solution mass flow rate is 1.5 kg/s. And energy efficiency decreases from 0.769 to 0.734 when the solution pump mass flow rate increase from 1.5 kg/s to 2.5 kg/s.

Keywords: Energy analysis, exergy analysis, waste heat recovery, absorption chiller, overall heat conductance model.

1. INTRODUCTION

Due to the impact of climate change, heat waves are taking place more and more seriously around the world. Many countries have recorded record temperatures in recent times. Our Vietnam as well as countries in Asia is no exception. In 2019, the heat in the North and Central Vietnam broke a series of historical record milestones maintained for many previous years, in August alone, it recorded a high temperature exceeding the historical value in the same period in August of many years ago. Because of the hot weather, the level of energy consumption also increases. Power consumption soared to an all-time high of 45,528 megawatts at noon Tuesday as people turned on air-conditioners and other devices to beat the searing heat. Therefore, the research on alternatives to traditional air conditioners such as absorption air conditioners is being strongly focused.

Vietnam's textile and garment industry, after more than 20 years of continuous development with an average growth rate of 15% per year, has now risen to become the leading economic sector in the country, with export turnover contributing from 10% -15% of GDP annually. So, research on energy saving and greenhouse gas emission reduction to contribute to the sustainable development of the textile industry is very necessary.

Textile industry often use boilers to generate steam and hot water for use in processing. However, the amount of fuel that is actually useful is usually only a small part of the total amount of fuel burned. This not only increases the cost of products of enterprises, but also wastes resources and seriously affects the environment and the atmosphere. Part of the waste heat in these plants is the exhaust fumes with high temperature, flash steam, and hot water. On the other hand, these factories also have a great demand for using air conditioners to cool the garment areas. Therefore, taking advantage of waste heat to use air conditioners like absorption chiller will help businesses save a lot of energy costs and reduce emissions significantly.

F. PanahiZadeh and N. Bozorgan [1] have been employed to evaluate energy and exegetic efficiency of the single effect absorption chiller which is used for air conditioning purpose. It can be concluded that the exergy analysis has been proven to be a more powerful tool in pinpointing real losses and can be used an effective tool in designing an absorption chiller and obtaining optimum operating conditions.

A. Khaliq et al. [2] is studyed the thermodynamic analysis through energy and exergy of an Industrial Waste Heat Recovery Based Cogeneration Cycle for Combined Production of Power and Refrigeration. This analysis contributes further information on the role of composition, exhaust gas temperature, and pinch-point influence on the performance of a waste heat recovery based cogeneration system from an exergy point of view.

Some studies focus on energy and exergy analyses of several integrated absorption refrigeration systems with solar energy sources for production of colling and heating. [3-7]

In this study, the energy and exergy analysis are used to investigate the performance of waste heat recovery absorption chiller (WHRAC). A simulation model use UA-type heat exchanger models to directly the effects of the heat exchange process between the cycle and the external streams that provide heat exchange. These models need to be included in an absorption cycle model because they represent the most important irreversibility in a practical machine. After that, the simulation model is applied to evaluate the influence of generator inlet temperature and solution pump mass flow rate on the energy efficiency and exergy efficiency of WHRAC for the convenience of system operation.

2. SYSTEM DESCRIPTION

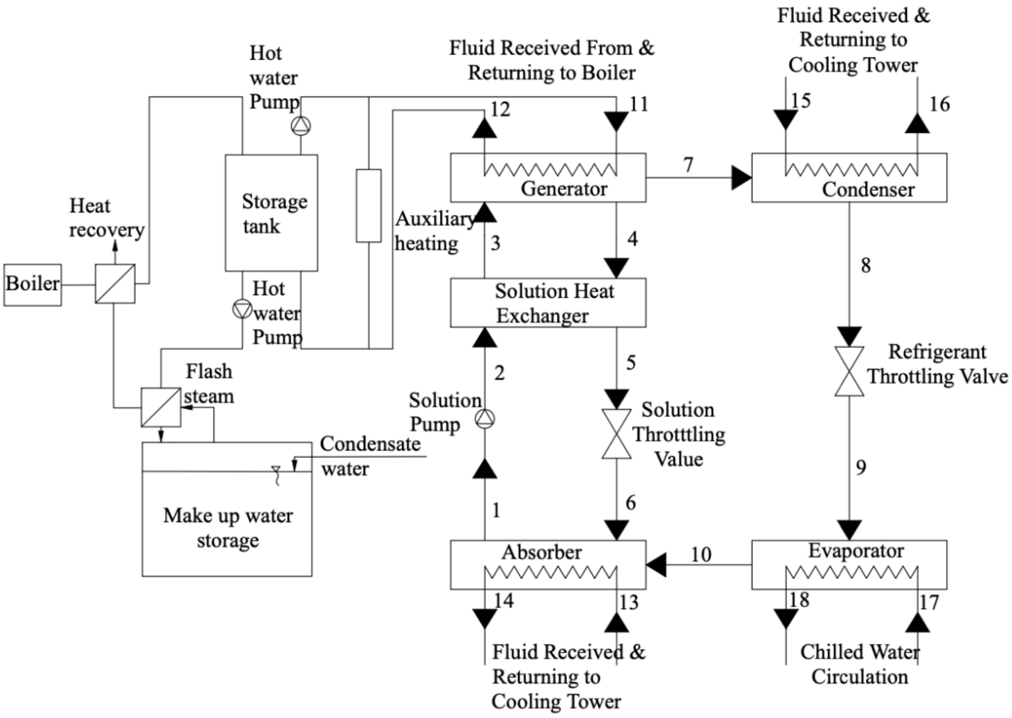

Figure 1. The schematic illustration of the waste heat recovery absorption chiller.

Waste heat recovery absorption chiller systems usually consist of absorption chiller linked to heat recovery system. The main components of system are the heat recovery; a heat storage tank; the Libr/H_2O single effect absorption chiller and an auxiliary (backup) subsystem (Figure 1). Where LiBr is the absorbent and H_2O is the refrigerant. The main four parts in a basic absorption cycle are: the generator, the condenser, the evaporator, and the absorber. There are other ‘auxiliary’ components: expansion valves, heat exchanger and solution pump. Points 1 to 18 in Figure 1 represent the thermodynamic states of the absorption refrigeration system.

The operating principle of the heat utilization system is described as follows: The water after heating for the absorption chiller will return through the heat exchanger No. 1 to receive heat from the dissociated steam at the feed water tank. After that, it continues to pass through the exhaust heat utilization to heat before returning to the tank to supply the absorption chiller. In case the waste heat utilization system does not meet the requirements, an auxiliary heater will be used. The operating principle of the absortion chiller can be find at [8].

3. ENERGY ANALYSIS AND EXERGY ANALYSIS

In analyzing this system, the principles of mass and energy conservation, and the second law of thermodynamics have been applied to each component. To simplify the theoretical analysis, some assumptions were made as follow:

This study is limited to the steady state condition;

The effect of the chemical exergy of the solution has been neglected;

The subcooling and superheating in discharge and suction lines are neglected;

Negligible potential, kinetic changes;

Negligible pressure and frictional losses in the sysem;

View the UA product as a constant for modeling purposes;

Reference environmemtal temperature and pressure are 25 °C and 100 kPa respectively.

3.1. Energy analysis

To properly apply the exergy analysis, it is necessary to evaluate the mass conservation and energy balance of each component of the cycle. The state of each stream was calculated with data collected from parameter;

The mass balance equation across each component of the cycle can be written as [8, 9]:

$$\sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out} = 0 \tag{1}$$

and

$$\sum_{in} x_{in}.\dot{m}_{in} - \sum_{out} x_{out}.\dot{m}_{out} = 0 \tag{2}$$

Where $\dot{m}$, *kg/s* represents mass flow rate; *x* represents concentration of the solution.

The energy balance equation of the generator is given as [8, 10]:

$$\sum_{in} \dot{m}_{in}.h_{in} - \sum_{out} \dot{m}_{out}.h_{out} + \sum_{in} \dot{Q}_{in} - \sum_{out} \dot{Q}_{out} + \sum_{in} \dot{W}_{in} = 0 \tag{3}$$

Where the enthalpy, heat transfer rate, and power are represented by h, *kJ/kg*, $\dot{Q}$, *kW*, $\dot{W}$, *kW* respectively.

Heat transfer rate of the Generator, Condenser, Evaporator, Absorber respectively can be written as [1]:

$$\dot{Q}_G = \dot{m}_{11}.(h_{11} - h_{12}) \tag{4}$$

$$\dot{Q}_C = \dot{m}_{15}.(h_{16} - h_{15}) \tag{5}$$

$$\dot{Q}_E = \dot{m}_{17}.(h_{17} - h_{18}) \tag{6}$$

$$\dot{Q}_A = \dot{m}_{13}.(h_{14} - h_{13}) \tag{7}$$

Other hand, the UA-type heat exchanger models are useful when modeling generator, condenser, evaporator, absorber as equation follows [11]:

$$\dot{Q} = UA.\Delta T_{lm} \tag{8}$$

Where: UA value is the product of the overall heat transfer coefficient U, *kW/m^2.K*, and the heat exchanger area, A, *m^2* ; ΔT_{lm}, *K* is log-mean temperature difference can be written as:

$$\Delta T_{lm} = \frac{\Delta T_{max} - \Delta T_{min}}{ln\frac{\Delta T_{max}}{\Delta T_{min}}} \tag{9}$$

Heat transfer rate of heat exchanger use effectiveness models follows as:

$$\dot{Q}_{HX} = \varepsilon.\ (\dot{m}.C_p)_{min}.(T_4 - T_2) \tag{10}$$

Where ε is defined as the ratio of the actual heat transfer to the maximum possible heat transfer for the given inlet conditions.

$$\varepsilon = \frac{\dot{Q}_{act}}{\dot{Q}_{max}} \tag{11}$$

$(\dot{m}.C_p)_{min}$ is minimum heat capacity can occur on either the hot or cold sides of the heat exchanger.

$$(\dot{m}.C_p)_{hot}.(T_4 - T_5) = \dot{m}_4(h_4 - h_5) \tag{12}$$

$$(\dot{m}.C_p)_{cold}.(T_3 - T_2) = \dot{m}_2(h_3 - h_2) \tag{13}$$

Where C_p, kJ/kg.K is the specific heat; T, K is the temperature.

The performance of an absorption refrigenation system is measured using the coefficient of performance. The energetic coefficient of performances of absorption refrigeration system are defined as [1]:

$$COP = \frac{\dot{Q}_e}{\dot{Q}_g + \dot{W}_P} \tag{14}$$

3.2. Exergy analysis

The exergy transfer to steady flow system is equal to the exergy transfer form it plus the exergy destruction within the system. The general exergy balance for the steady flow system could be expressed as follow [1]:

$$\sum_{in} \dot{m}_{in}.ex_{in} - \sum_{out} \dot{m}_{out}.ex_{out} + \sum_{in} \dot{Q}_{in}(1 - \frac{T_0}{T}) - \sum_{out} \dot{Q}_{out}\left(1 - \frac{T_0}{T}\right) + \sum_{in} \dot{W}_{in} - \sum_{in} \dot{Ex}_{dest} = 0 \tag{15}$$

In this research we use exergy of the inlet and outlet streams instead exergy associated with heat transferred from the source maintained at temperature T. So, the exergy balance for the steady flow system could be expressed as follow:

$$\sum_{in} \dot{m}_{in}.ex_{in} - \sum_{out} \dot{m}_{out}.ex_{out} + \sum_{in} \dot{W}_{in} - \sum_{in} \dot{Ex}_{dest} = 0 \quad (16)$$

Where: ex_i *kJ/kg*, is the exergy of a fluid stream can be defined [1]:

$$ex_i = (h_i - h_0) - T_0.(s_i - s_0) \quad (17)$$

The second law efficiency of the absorption chiller can be defined as the ratio of the chilled water exergy at the evaporator to the exergy of the heat source at the generator, and can be written as [1]:

$$ECOP = \frac{\dot{m}_{17}\ (ex_{18} - ex_{17})}{\dot{m}_{11}\ (ex_{11} - ex_{12})} \quad (18)$$

4. RESULT AND DISCUSSION

This section presents the simulation results of system using models developed in the section 3. Textile factory in Hung yen is selected for the case study. The factory uses a boiler with a capacity of 13,000 kg/h with FO fuel, output steam pressure of 7-7.5 Bar, exhaust temperature of 220-250 ^oC. The factory has a cooling capacity requirement of about 600 kW. Other input parameters of simulation are presented in table 2.

Table 1. System Parameter.

ε	0.64	η_i	0.85
m_1, *kg/s*	1.5	t_{13}, ^oC	32
UA_A, *kW/K*	180	t_{14}, ^oC	37
UA_C, *kW/K*	120	t_{15}, ^oC	32
UA_G, *kW/K*	100	t_{16}, ^oC	37
UA_E, *kW/K*	225	t_{17}, ^oC	12
t_a, ^oC	25	t_{18}, ^oC	7
p_a, *kPa*	100		

The results obtained when simulation of system are presented in table 3 and table 4. It can be seen that the heat transfer rate in generator is highest. The Cooling capacity is 625.3 kW. The work of the solution pump is 0.00734 kW. The COP value of the absorption chiller is 0.776. The exergy destruction of individual components are shown in table 4. The higher destruction occurs in the generator and absorber.

Table 2. The result of state point for absorption Chiller.

Point	***t*** **(°C)**	***p*** **(kPa)**	***m*** **(kg/s)**	***x***	***h*** **(kJ/kg)**	***s*** **(kJ/kgK)**
1	32.3	0.936	1.5	0.5325	75.9371	0.2162
2	32.3	7.526	1.5	0.5325	75.942	0.2162
3	61.5	7.526	1.5	0.5325	137.1411	0.4076
4	96.2	7.526	1.233	0.6477	250.5451	0.5141
5	55.3	7.526	1.233	0.6477	176.1002	0.3005
6	55.3	0.936	1.233	0.6477	176.1002	0.3005
7	70.9	7.526	0.2669	0	2632.474	8.426
8	40.4	7.526	0.2669	0	169.0142	0.5771
9	6	0.936	0.2669	0	169.0142	0.6064
10	6	0.936	0.2669	0	2511.919	8.999
11	98		38.25		410.7334	1.285
12	93		38.25		389.668	1.227
13	32		37.02		134.0952	0.4642
14	37		37.02		154.9946	0.5322
15	32		31.46		134.0952	0.4642
16	37		31.46		154.9946	0.5322
17	12		29.8		50.4096	0.1806
18	7		29.8		29.4266	0.1064

Table 3. Exergy destruction and relative irreversibility of components.

Component	Generator	Absorber	Condenser	Evaporator	Heat exchanger	Refrigerant valve
Heat transfer rate (kW)	805.8	773.7	657.5	625.3	91.8	-
Exergy destruction rate (kW)	26.03	19.83	12.54	8.24	7.044	2.33

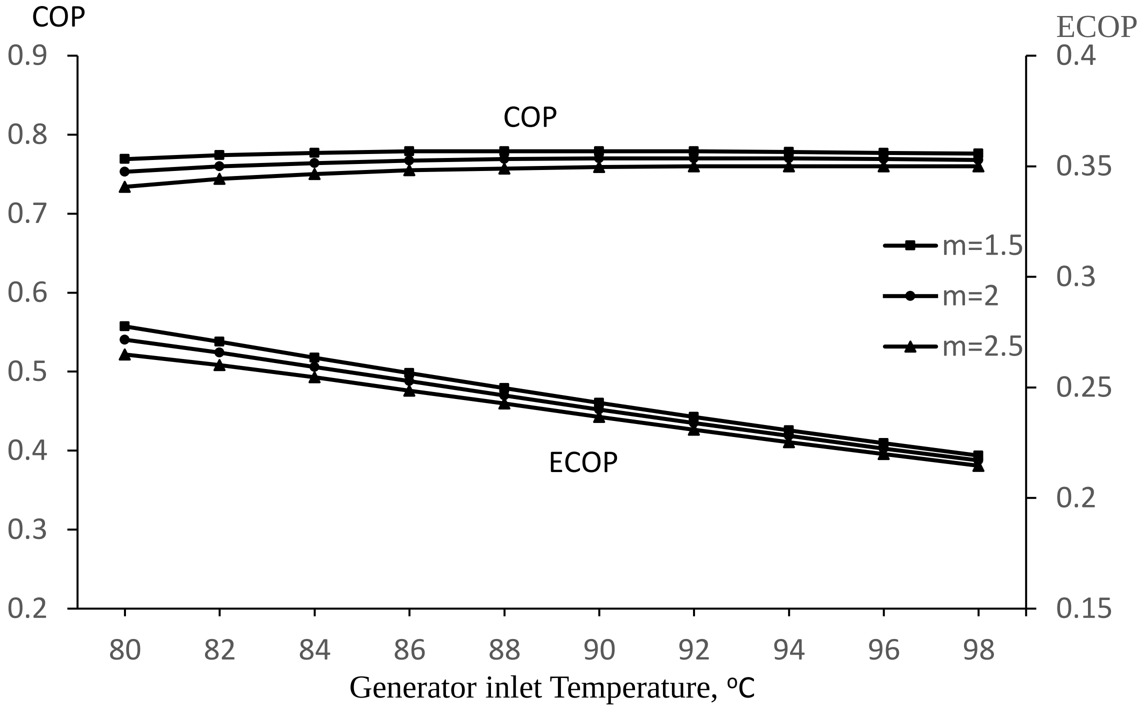

Figure 2: The variation of COP and ECOP with generator inlet temperature and solution pump mass flow rate.

Fig. 2 shows the effect of generator inlet temperature and solution pump mass flow rate on the COP, ECOP under the parameter of Table 2. It can be observed that the COP, ECOP reduced with solution mass flow rate raised from 1.5 to 2.5. At the generator inlet temperature of 90 °C when the solution mass flow rate is 1.5 kg/s the COP is 0.779 while the solution mass flow rate increases to 2.5 kg/s the COP decreases to 0.759. Similarly, the ECOP of 0.243 when the solution mass flow rate is 1.5 kg/s has decreased to 0.2367 when the solution mass flow rate is increased to 0.25 kg/s. Increased the solution mass flow rate will cause devices such as generators, absorbers and heat exchangers to perform more heat transfer, which will lead to irreversible losses of these devices. Thus, both COP and ECOP decrease as the solution mass flow rate increases.

It can be seen that when the generator inlet temperature increased the ECOP decreased. As seen in Fig 2, at the solution mass flow rate 1.5 kg/s and the generator inlet temperature from 80 °C to 98 °C the ECOP decreased from 0.2776 to 0.2192. However, the COP is different. The COP increased initially from 0.769 to 0.779 because the temperature raised from 80 °C to 86 °C are strong enough to cause an overall increase in COP, then decreased becasue as the heat transfer in components increase and the heat transfer irreversibility cause the COP to decrease.

5. CONCLUSION

In this study, thermodynamic analysis of the absorption chiller integrated with heat recovery has been conducted. The following can be concluded from this study:

Exergy losses were higher in the generator and absorber than in the condenser and evaporator. Irreversible losses during heating and mixing of Libr and H_20 cause more losses than in condensers and evaporators with only irreversible losses due to heat exchange.

When the solution mass flow rate increase, COP and ECOP of absorption chiller integrated with heat recovery decrease by increasing the exergy destruction across system components.

Increasing the generator inlet temperature resulted the exergetic of system reduced while the COP slight increase, and then decreased.

ACKNOWLEDGMENT

This research is funded by University of Transport and Communications (UTC) under grant number T2022-CK-010

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