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First Law Analysis of Absorption Heat Transformer

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***Abstract*— In the present study, performance evaluation of an absorption heat transformer (AHT) is done on the basis of amount of hot fluid produced in the absorber using first law of thermodynamics. The heat input to evaporator and generator is waste heat or part of low grade heat. To analyze, a mathematical model was developed in Engineering Equation Solver. Working pair used is water-lithium bromide. Operating parameters like temperature, mass flow rate etc. were varied to predict the performance of the system. The amount of useful heat available in the absorber is 491.6 kW with mass flow rate of 0.224 kg/sec. COP of the system is about 0.4642. In the present work same amount of hot water is supplied, firstly to evaporator and thereafter from evaporator to generator.**

Keywords*— *Absorption heat transformer, first law, waste heat, COP.

I. INTRODUCTION

A large amount of thermal energy in the temperature range of 40-80°C is released in the atmosphere by many commercial installations such as agro-feed, paper mills, dairies, power generating stations etc. Irrespective of oil and gas, the need to further utilize this rejected energy is justified owing to the fact that the oil and gas reserves are ever decreasing. It can be reused by increasing its temperature and achieved by employing a heat pump. There are two principles on which heat pump can be operated. Conventional heat pump has a compressor which further required high grade energy i.e. electrical energy. But vapor absorption heat pump is an alternate of vapor compressor heat pump. In the vapor absorption heat pump compressor is replaced by an absorber, a generator and a water pump. Out of these three, only water pump required high grade energy, but it is negligible in comparison to compressor energy consumption. Fig 1 shows the schematic view of absorption heat transformer. The two commonly used pairs are those of refrigerant $NH_3 + H_2O$ and refrigerant LiBr + H_2O. Main problem with $NH_3 + H_2O$ pair is that both are volatile, so there is fear of water going with ammonia in evaporator which reduced the COP of transformer where NH_3 is working fluid and water is absorbent. Working fluid used in the transformer is pair of LiBr + H_2O. LiBr act as absorber and water serves the function of working fluid. Due to very high latent heat of LiBr, it is preferred over the $NH_3 + H_2O$ pair. But using LiBr + H_2O mixture limits its application and it is suitable where temperature do not go below 0°C in the cycle. Since LiBr is salt, it exerts no vapor pressure. So the vapor leaving the generator is pure refrigerant.

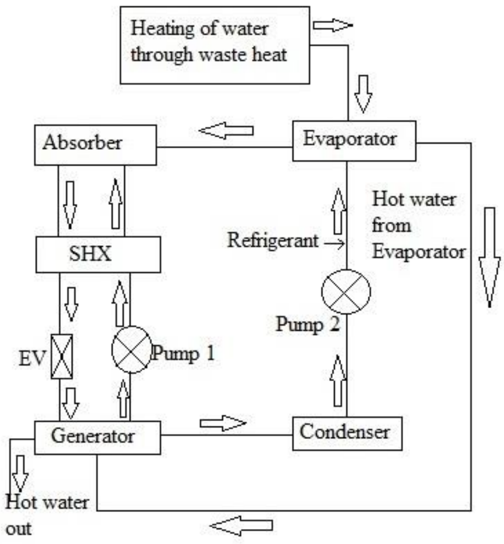

Fig1 Vapor absorption heat transformer

In recent years a lot of research is being done on vapor absorption heat transformer. Researchers used different types of working fluid and designs for numerical as well as experimental analysis to optimize the working of heat transformer.

Mehrdad Khamooshi et al. (2014) [1] used first law of thermodynamics to analyze and optimize the performance of a triple absorption heat transformer operating with LiBr/H_2O as the working pair and found that the systems condensation temperature should always be kept at minimum value and the gross temperature lift must be lower for higher COP. Armando Huicochea et al. (2013) [2] used first and second laws of thermodynamics to analyze the behavior of an experimental heat transformer integrated to a single effect water purification system. Djallel Zebbar et al. (2012) [3] discussed the thermodynamic optimization of an absorption heat transformer. It was found that the exergy analysis allows determining the local and overall structural analysis and determining (Coefficient of Structural bonding) CSB for each element of the AHT.

L. Garousi Farshi et al. (2011) [4] developed a computational model to study and compare the effect of the working parameters on crystallization phenomenon in three classes (series, parallel and reverse parallel) of double effect LiBr – water absorption refrigeration system. In their study they found that the double effect parallel and reverse parallel flow arrangements are better in performance to series flow in term of crystallization risk.

W. Rivera et al. (2011) [5] studied the exergy analysis of an experimental single stage heat transformer with single water/lithium bromide and using additives like 1 - octanol and 2 – ethyl – 1 – hexanol. R. Sarvanan and S. Sekar (2011) [6] did experiment on an absorption heat transformer working with water – lithium bromide solution, coupled with a seawater distillation system of 5kg/h distilled water capacity. Rabah Gomri (2010) [8] studied the single stage absorption heat transformer system used for sea water desalination. It was found that the energy efficiency and exergy efficiency of the double effect absorption heat transformer are higher than single stage absorption heat transformer.

Rabah Gomri (2009) [9] studied the combination of flat plate solar collectors (FPC), a single effect heat transformer (AHT) and desalination system (WP) used to provide water to a beach house located in Skikda (East of Algeria). Glacomo Bislo et al. (2002) [12] studied the different methods used to upgrade the low level energy. W. Rivera and R. J. Romero (1998) [13] has studied an AHT operating on an aqueous ternary hydroxide working fluid consist of sodium, potassium and cesium hydroxides in the proportions of 40:36:24(NaOH:KOH:CsOH).

K. Abrahmsson et al. (1995) [14] studied a 10 kW absorption heat transformer unit operating with self circulation. Thermosyphon principle is the principle of self circulation. K P Tyagi (1989) [15] analyzed the performance of two stage absorption heat transformer using various binary mixtures. It was found that a large amount of heat in the form of hot water between temperature range 40°C to 80°C such as diaries, paper mills etc.

R. Best et al. (1987) [16] studied an absorption heat transformer working on ammonia – water, in which it has been seen that Gibbs Phase Rule and the thermodynamic properties of the working pair limit the choice of operating temperatures. K. P. Tyagi (1984) [17] studied the six binary mixture of ammonia salt binary for the vapor absorption refrigeration cycle. Then compare their COP and BHP/ton of refrigeration.

From available literature, it is concluded that a considerable amount of work is done to improve the COP of the AHT using different type of working pairs. But a little work is available on its overall size and its relation with the COP of AHT. So, present work aims to develop the thermodynamic model of AHT with its size to help the design engineer in manufacturing the system using the first law of thermodynamics. Optimization the AHT size along with better COP is the need of the hour to reduce the initial investment.

II. DESCRIPTION OF MODEL

Industrial waste heat is navigated to heat the water which is further used as an external fluid to provide heat in the evaporator and then in the generator. Firstly, the hot water is supplied to the evaporator at a temperature of 80°C and after supplying heat in the evaporator, it is circulated in the generator at the temperature of 73°C. The various input parameters are shown in table 1. Refrigerant vapors were produced by the heat supplied in the evaporator, which is absorbed in the absorber by the water- lithium bromide solution that enters the absorber in a strong form and mixing of refrigerant vapors makes the solution weak at the time of exit. The temperature of the external fluid has been increased due to heat absorption i.e. water supplied in the absorber which is referred as the hot water produced in AHT. Here it increases from 90ºC to 130°C. The weak solution after passing through the expansion valve travel to the generator where the refrigerant vapor has been removed from it and thus returned as a strong state to the absorber.

Table 1: Input Parameters

Temperature of absorber (T_{ab})	130ºC
Temperature of condenser(T_{co})	25ºC
Temperature of generator(T_g)	73ºC
Temperature of evaporator(T_e)	80ºC
Mass of refrigerant(kg/s)	0.2241666
Solution heat exchanger outlet temperature	120ºC

In the condenser, refrigerant vapor is condensed and it is pumped to evaporator, the heat of the external fluid help to evaporates it and the cycle continues. Thus, the AHT because of this property i.e. raising the temperature of the hot water produced above the external fluid temperature can be used for the heating purposes. To increase the performance of AHT, a counter flow heat exchanger between the weak and strong solutions is used and in the absorber we get a useful heat.

A. Assumptions:

The following assumptions have been made to develop the mathematical model of the systems as under:

- The condition of the system is steady state only.
- In expansion device, Isenthalpic process will occurs.
- The pressure drop due to friction is eliminated.
- Heat loss to the environment from the system is neglected.
- The condition of the refrigerant leaving the evaporator and condenser is saturated state.
- The pump work is neglected.

The mass and energy equations are analyzed for all the components of AHT. In its general form mass and energy equations are written as under:

Equation of Mass balance, $\Sigma m = 0; \Sigma xm = 0$

Equation of Energy balance, $\Sigma Q + \Sigma W + \Sigma mh = 0$

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IV. VALIDATION OF THE MODEL

By using Engineering Equation Solver (EES), a computer program has been developed, for carrying out the energy analysis of the absorption Heat Transformer Systems.The results of energy analysis of the systems are compared with the work of Ilhami Horuz and Bener Kurt(2010) [7] and the details are presented in Table 2. In the present analysis, the effectiveness of the solution heat exchanger for the configuration is kept constant at a value of 0.8 while the reference work has fixed different value of the temperature of weak solution coming out form the solution heat exchanger, therefore has considered different effectiveness for the system.

V. RESULTS AND DISCUSSION

The energy analysis by the first law is carried out for the thermodynamic model of the system. With the help of engineer equation solver, various properties at the inlet and outlet of each component are found. Keeping all the input same as reference work. The heat available for use in absorber is 491.6KW. COP is about 0.4642, which is more than the reference work. As heat supplied to evaporator and generator is low grade heat and so increase in this heat is economical also. Table 1 shows the key result of analysis.

Table 2: Validation

S N	Parameters	Present work	Reference work
1	Available heat in absorber	491.6KW	487.3KW
2	Heat rejection in condenser	567.6KW	589.8KW
3	Heat supplied to evaporator	559.6KW	558.14KW
4	Heat supplied to generator	496.1KW	495.6KW
5	COP AHT	0.4642	0.46
6	Flow ratio	18.72	18.63
7	Strong solution concentration	0.6243	0.6244
8	Weak solution concentration	0.5962	0.59260

VI. PERFORMANCE STUDY OF THE AHT SYSTEMS

The various components of the AHT are broadly effects its performance when the operating parameters are changed. In the present work, the operating temperature for the evaporator is the inlet temperature of external fluid and for the absorber and generator, the operating variable is the temperature at which both are maintained.

A. Effect of inlet temperature of external fluid to evaporator:

Graph 1 shows that as the temperature of inlet water to evaporator is decreased, its COP is also decreased due to decrease in desired effect . But there is no effect on the Carnot COP of the heat pump.

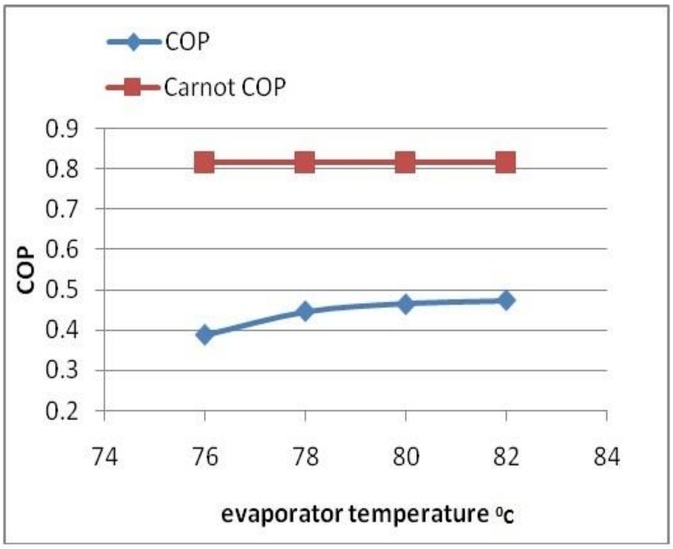

Fig 2 Evaporator Temperature vs COP

B. Effect of temperature of absorber on COP of system:

As the graph 2 indicates when the absorber temperature is reduced, the COP is increased and there is also slight increment in Carnot COP.

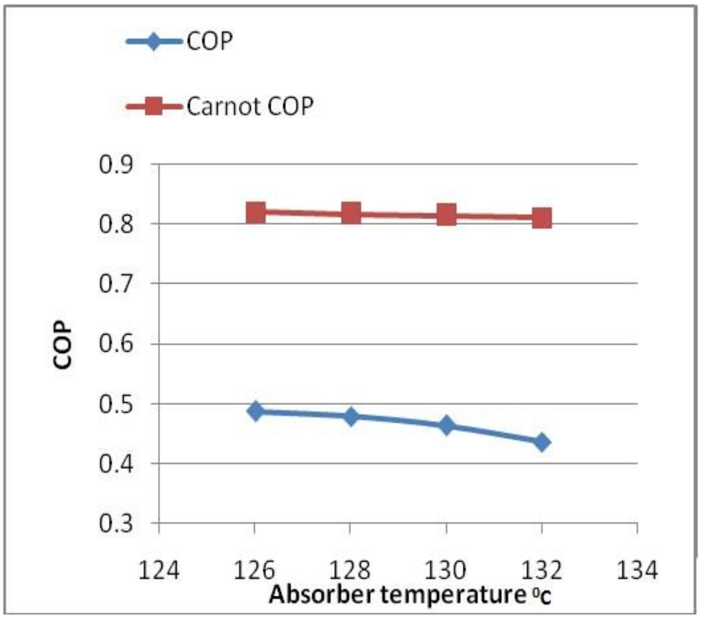

Fig. 3 Absorber Temperature vs COP

C. Effect of generator temperature on cop:

As generator is one of the part of AHT, in which refrigerant vapor is produced. Keeping all other variables as constant, with the increasing of generator temperature COP and Carnot COP both increased. As shown in the graph3.

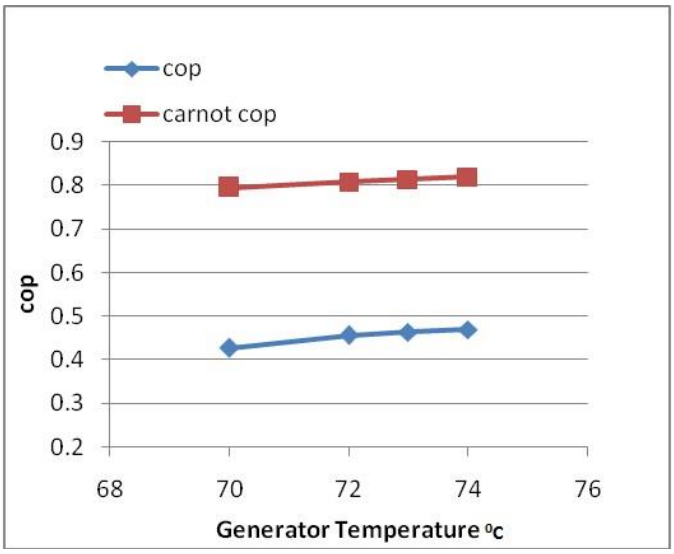

Fig. 4 Generator Temperature vs COP

VII. CONCLUSIONS

In the present work, the amount of useful heat available is found 491.6 kW and actual COP is about 0.4642 and Carnot COP of system is 0.8141 obtained. As evaporator and generator are the part of AHT in which refrigerant change its phase from liquid to vapor. So for complete phase transformation of vapor it is necessary to supply sufficient heat in these parts of AHT. But heat required for absorber and generator is low grade so it is available in large amount. As a result system COP increased with the increase in temperature of generator and evaporator. If the temperature of absorber is kept lower higher COP is obtained.

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