Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 11 (11): 2018-2023, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.2018.2023

Steady State Simulation of a Double-Effect Steam Absorption Chiller

Mojahid Sid Ahmed Mohammed Salih Ahmed and Syed Ihtsham Ul-Haq Gilani
Department of Mechanical Engineering, Universiti Teknologi PETRONAS
Bandar Seri Iskandar, 31750, Tronoh, Perak, Malaysia

Abstract: Owing to the serious environmental problems and the price of the traditional energy resources the use of industrial waste heat or renewable energy, as the driving force for vapour absorption cooling systems is continuously increasing. A steady-state model is developed to predict the performance of an absorption refrigeration system using LiBr-water as working pair. Each component of the cycle is modelled based on mass and energy balances. The design point parameters are determined. The refrigeration effect, coefficient of performance (cop) and load factor are analysed for different heat input. Simulation is carried out and the results are compared with actual data and showed good agreement.

Key words: Absorption chiller, heat input, cop, load factor

INTRODUCTION

Absorption cooling systems have become increasingly popular in recent years from the viewpoint of energy and environment. Despite a lower coefficient of performance (COP) as compared to the vapor compression, absorption refrigeration systems are attractive for using inexpensive waste heat, solar, geothermal or biomass energy sources for which the cost of supply is negligible in many cases. In addition absorption refrigeration use natural substances, which do not contribute towards ozone depletion and global warming (Manohar *et al*., 2006).

Many different thermodynamic cycles, machine types (refrigerating, heat pumps, heat transformers) and numerous authors all around the world have proposed new fluids in these last decades. Among these potential technical solutions one of the most interesting still remains the absorption cycle with water and lithium bromide, suitable for air conditioning. The refrigerant-absorbent pair H_2O LiBr, in fact, has numerous advantages such as high enthalpy of vaporization, no need of rectification; it is neither toxic nor dangerous (Asdrubali and Grignaffini, 2005).

In the last few years, the demand for energy conservation has increased significantly and there are increasing needs for research and development on absorption chillers includes their elemental design, reliability improvement, energy saving control and diagnosis of degradation of performance.

Manohar *et al*. (2006) developed steady state model of a double effect absorption chiller using steam as heat input. The model is based on the artificial neural network (ANN). The model predict the chiller performance based on chilled water inlet and outlet temperatures, cooling water inlet and outlet temperatures and steam pressure.

Park *et al*. (2004) analyzed the performance characteristics during part load operation and calculated the energy consumption amount of H_2O/LiBr absorption chiller with a capacity of 210 RT and they found that the performance of absorption system is more sensitive to the change of inlet cooling water temperature rather than the cooling water flow rate.

Kim and Ferreira (2008) presented a model capable of describing the behaviour of absorption cycles with a convenient number of characteristic constants for quick simulation of absorption systems. Though this model has been applied to several examples of single-effect absorption chillers using various aqueous working fluids, it may not adapt well enough to reproduce the performance of commercial or experimental chillers.

The design point information and geometrical configuration are the proprietary of the manufacturer, therefore, these information are not available. The operational data and well known heat transfer and thermodynamics equations are used to calculate the design point information.

DESCRIPTION OF DOUBLE-EFFECT ABSORPTION CHILLER CYCLE

The main components of a double effect steam absorption chiller are two generators, a condenser, an evaporator, an absorber, two solutions heat exchangers,

Corresponding Author: Mojahid Sid Ahmad Mohammed Salih Ahmad, Department of Mechanical Engineering, Universiti Teknologi PETRONAS Bandar Seri Iskandar, 31750, Tronoh, Perak, Malaysia

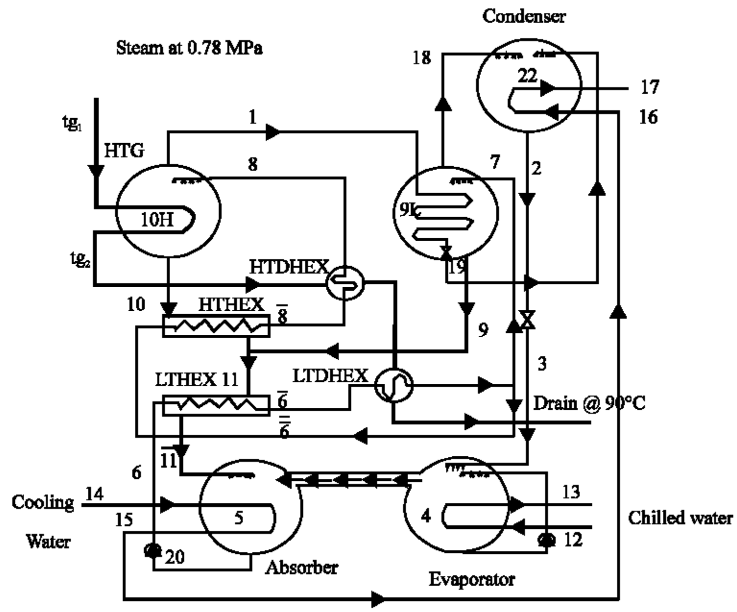

Fig. 1: Schematic diagram for a double-effect steam absorption chiller

solution pump, refrigerant pump and two refrigerant expansion valves (Fig. 1).

The solution pump assures the circulation of the solution inside the system. The dilute solution (in LiBr) leaving the absorber is pumped through the heat exchangers to the first and second generators. In the first generator heat is added to the solution from steam circulating in the tube side and water vapor is given off by the solution. This vapor is in superheated state, due to the elevation of the boiling point of water caused by the presence of LiBr solute.

The vapor from first generator is used to heat the solution in the second generator. Thus, the heating coil (tube side) of the second generator (LTG) is also condenser for the first generator (HTG). The vapor generated by LTG is condensed in the condenser, which usually is enclosed in the same vessel or section of shell as in the second generator. The vapor generated in the first generator, after condensing is throttled to the pressure of the condenser.

The concentrated solutions from the first and second generators are reunited at the solution heat exchanger, transferring heat to the dilute solution coming from the absorber and then the united stream inters the absorber where it is sprayed onto the absorber tubes, thus facilitating the absorption of the refrigerant vapor from the evaporator. A throttling process occurs in the absorber spraying nozzles that reduce the pressure of the concentrated solution to the absorber pressure. The absorber and evaporator are normally operated at the same pressure. The absorber by absorbing the refrigerant vapor produces low pressure that is required for the operation of the evaporator (Gordon and Ng, 2001).

ABSORPTION CHILLER MODELING

Applying mass balance, energy balance and equation of state for the LiBr-H_2O solution each component of the double effect steam absorption chiller model is formulated. Some simplifying assumption have been made for the analysis, these are:

- The analysis is made under steady conditions
- The refrigerant (water) at the outlet of the condenser is saturated liquid
- The refrigerant (water) at the outlet of the evaporator is saturated vapour
- The lithium bromide solution at the absorber outlet is a weak solution and it is at the absorber temperature
- The outlet temperatures from the absorber and from generators correspond to equilibrium conditions of the mixing and separation respectively
- Pressure losses in the pipelines and all heat exchangers are negligible
- The system rejects heat to cooling water at the condenser and absorber
- The temperature of water vapor and of the solution leaving the generators is assumed to be the same
- There is no heat loss or gain from the ambient
- Constant pumping rate, the mass flow rate of weak solution from absorber to generators is constant

The governing equations of each component:

- **The first generator:**

The mass balance equation:

$$\dot{m}_{10} = \dot{m}_8 - \dot{m}_1 \tag{1}$$

Concentration balance equation:

$$\dot{m}_{10} x_{10} = \dot{m}_8 x_8 \tag{2}$$

The conservation of energy equation is:

$$\dot{Q}_1 = \dot{m}_{steam} C_P (t_{g1} - t_{g2}) \tag{3}$$

The heat transfer equation is:

$$\dot{Q}_1 = (UA)_1 \frac{(t_{g1} - t_{10}) - (t_{g2} - t_8)}{\ln\left(\frac{(t_{g1} - t_{10})}{(t_{g2} - t_8)}\right)} \tag{4}$$

$(UA)_1$ is the overall conductance of the heating coil in the first generator.

- **The second generator:**

The mass balance equation:

$$\dot{m}_9 = \dot{m}_7 - \dot{m}_{18} \tag{5}$$

Concentration balance equation:

$$\dot{m}_9 x_9 = \dot{m}_7 x_7 \tag{6}$$

The conservation of energy equation is:

$$\dot{Q}_2 = \dot{m}_1 (h_1 - h_{19}) \tag{7}$$

The heat transfer equation is:

$$\dot{Q}_2 = (UA)_2 \frac{(t_{19} - t_7) - (t_{19} - t_9)}{\ln\left(\frac{t_{19} - t_7}{t_{19} - t_9}\right)} \tag{8}$$

- **The absorber:**

The mass balance equation:

$$\dot{m}_{20} = \dot{m}_{\overline{11}} + \dot{m}_4 \tag{9}$$

Concentration balance equation:

$$\dot{m}_{20} x_{20} = \dot{m}_{\overline{11}} x_{\overline{11}} \tag{10}$$

The conservation of energy equations are:

$$\dot{Q}_a = \dot{m}_{cw} C_{Pw} (t_{15} - t_{14}) \tag{11}$$

$$\dot{Q}_a = \dot{m}_4 h_4 + \dot{m}_{\overline{11}} h_{\overline{11}} - \dot{m}_{20} h_{20} \tag{12}$$

The heat transfer equation is:

$$\dot{Q}_a = (UA)_a \frac{(t_{20} - t_{14}) - (t_{\overline{11}} - t_{15})}{\ln\left(\frac{t_{20} - t_{14}}{t_{\overline{11}} - t_{15}}\right)} \tag{13}$$

- **Condenser:**

The mass balance equation:

$$\dot{m}_{22} = \dot{m}_1 + \dot{m}_{18} \tag{14}$$

The conservation of energy equations are:

$$\dot{Q}_c = \dot{m}_1 h_{19} + \dot{m}_{18} h_{18} - (\dot{m}_1 + \dot{m}_{18}) h_{22} \tag{15}$$

$$\dot{Q}_c = \dot{m}_{cw} C_{Pw} (t_{16} - t_{17}) \tag{16}$$

The heat transfer equation is:

$$\dot{Q}_c = (UA)_c \frac{(t_{22} - t_{16}) - (t_{22} - t_{14})}{\ln\left(\frac{t_{22} - t_{14}}{t_{12} - t_{15}}\right)} \tag{17}$$

where, $(UA)_c$ is the overall conductance for heat transfer surface of the condenser

- **The evaporator:**

The conservation of energy equations are:

$$\dot{Q}_e = \dot{m}_4 (h_4 - h_2) \tag{18}$$

$$\dot{Q}_e = \dot{m}_{chw} C_{Pw} (h_4 - h_2) \tag{19}$$

The heat transfer equation is:

$$\dot{Q}_e = (UA)_e \frac{(t_{12} - t_4) - (t_{13} - t_4)}{\ln\left(\frac{t_{12} - t_4}{t_{13} - t_4}\right)} \tag{20}$$

$(UA)_e$: The overall conductance for the heat transfer surface of the evaporator

- **Solution heat exchangers:**

High temperature solution heat exchanger:

$$\dot{Q}_{HTHEX} = (UA)_{HTHEX} \frac{(t_{10} - t_{\bar{8}}) - (t_{11} - t_{\bar{\bar{8}}})}{\ln\left(\frac{(t_{10} - t_{\bar{8}})}{(t_{11} - t_{\bar{\bar{8}}})}\right)} \tag{21}$$

$$\eta_{HTHEX} = \frac{h_{10} - h_{11}}{h_{10} - h_{\bar{\bar{6}}}} \tag{22}$$

$$\dot{Q}_{HTHEX} = \dot{m}_{\bar{\bar{6}}}(h_{\bar{8}} - h_{\bar{\bar{6}}}) \tag{23}$$

$$\dot{Q}_{HTHEX} = \dot{m}_{10}(h_{10} - h_{11}) \tag{24}$$

Low temperature solution heat exchanger:

$$\dot{Q}_{LTHEX} = (UA)_{LTHEX} \frac{(t_{11} - t_{\bar{6}}) - (t_{\overline{11}} - t_6)}{\ln\left(\frac{(t_{11} - t_{\bar{6}})}{(t_{\overline{11}} - t_6)}\right)} \tag{25}$$

$$\eta_{LTHEX} = \frac{h_{11} - h_{\overline{11}}}{h_{11} - h_6} \tag{26}$$

$$\dot{Q}_{LTHEX} = \dot{m}_6(h_{\bar{6}} - h_{\bar{6}}) \tag{27}$$

$$\dot{Q}_{LTHEX} = \dot{m}_{11}(h_{11} - h_{\overline{11}}) \tag{28}$$

- **Drain heat exchangers:**

High temperature drain heat exchanger:

$$\dot{Q}_{HTDHEX} = \dot{m}_{\bar{\bar{8}}}(h_8 - h_{\bar{8}}) \tag{29}$$

Low temperature drain heat exchanger:

$$\dot{Q}_{LTDHEX} = \dot{m}_{\bar{\bar{6}}}(h_{\bar{\bar{6}}} - h_{\bar{6}}) \tag{30}$$

The thermal properties of LiBr solutions and steam used in the calculations are obtained from Abdullagatov

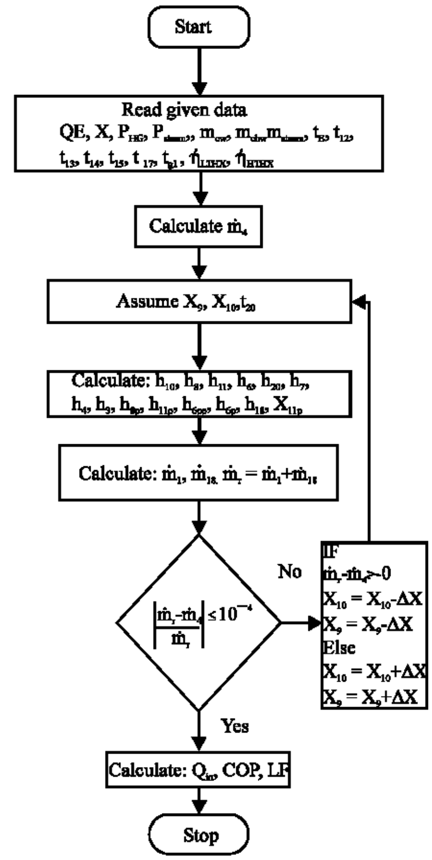

Fig. 2: Flow chart of the simulation of a double-effect steam absorption chiller

and Magomedov (1997), ASHRAE (1997), Herold *et al*. (1996), Lee *et al*. (1990), Ozisik (1985) and Rogers and Mayhew (1992). Figure 2 shows simulation flow chart of a double-effect steam absorption chiller.

RESULTS AND DISCUSSION

Using the formulated mathematical equations that govern the operation of the steam absorption chiller and from partly available design data the rest of the design parameters are calculated and presented in Table 1.

The simulation program is validated with real data for Ebara Carrier parallel-flow double effect steam absorption chiller model RAW 150LE with capacity of 1250 RT. The chiller is erected in university technology PETRONAS (Gas District Cooling Plant).

As shown in Fig. 3 the refrigeration effect is increasing as the heat input increase. The simulation results are compared with the actual data and the trend replicated with 1.12% deviation.

Table 1: Design point values of double-effect steam absorption chiller

Component and state point	Temperature (°C)	Pressure (kPa)	Concentration (%)	Flow rate (kg s^{-1})	Heat load (kW)
Evaporator					
4	4	0.8		1.881	
12	13.5			140	4395
13	6			140	
Absorber					
20	36		57	20.533	
11	45		62.6	18.65	
5	36	0.8			5341.1
14	32			255.55	
15	37			255.55	
High temperature generator					
8	135		57	12.739	
10	150		63	11.709	
10H	150	80			3138.8
1	150	80		1.03	
1S	169.3	780	80	1.528	
2S	169.3			1.528	
Low temperature generator					
7	80		57	7.794	
9	90		61	6.941	
9L	90				2458.6
18	90			0.853	
19	93.5			1.03	
Condenser					
22	41	7.7773			
2	41			1.883	
16	37			255.55	2674.3
17	39.5			255.55	
High temperature heat exchanger					
8	130		57	12.739	1381.1
Low temp. heat exchanger					
6	68		57	20.533	1283.2

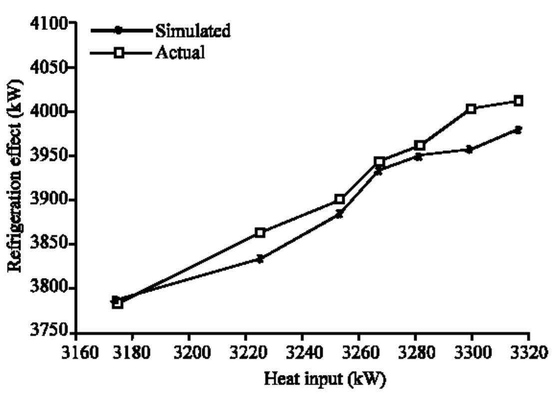

Fig. 3: Variation refrigeration effect for different heat input

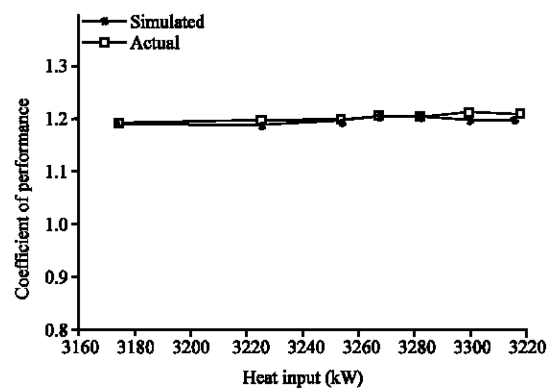

Fig. 4: Variation coefficient of performance with heat input

Figure 4 shows the variation of the coefficient of performance for different heat inputs. The coefficient of performance is slightly increasing this is because the increase in heat input is small. The actual is included for comparison and the deviation is about 1.1%.

Figure 5 shows the load factor variation with heat input. As indicated in the figure at a given heat input range the load factor is more than 85%. The maximum is around 91%. As the heat input increase the load factor increases that is expected. The maximum load factor may be achieved by increasing the heat input.

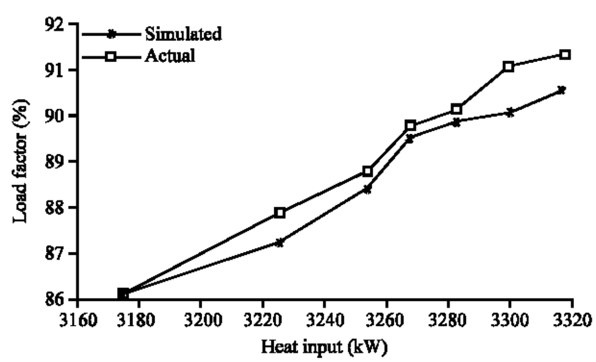

Fig. 5: Variation load factor with heat input

CONCLUSION

The steady state model of double effect steam absorption chiller is developed to study the performance of the system. Using partly available data the design parameters are calculated. The model gives a good predicting means for absorption chiller over a wide range heat input. For thermo physical and thermodynamic properties for lithium bromide-water solution, set of computationally efficient formulations are used.

ACKNOWLEDGMENT

The authors wish to thank University Technology PETRONAS for the opportunity to use the company's own data to perform the investigations and for the research grant.

NOMENCLATURE

$\dot{m}$ = Mass flow rate (kg sec^{-1})
x = Concentration of the solution (x/100)
$\dot{Q}$ = Heat transferred rate (kw)
h = Enthalpy (KJ kg^{-1})
C_p = Specific heat(KJ/kg.°C)
A = Heat transfer area (m2)
U = Overall heat transfer coefficient (KW/m2 °C)
COP = Coefficient of performance
t = Temperature(°C)
ή = Heat exchanger effectiveness

Subscripts

g_1, g_2 = First and second generators
a = Absorber
c = Condenser
e = Evaporator
HTHEX = High temperature heat exchanger
LTHEX = Low temperature heat exchanger
1,2,3,... = State points
r = Refrigerant

REFERENCES

ASHRAE, 1997. Handbook of Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta, GA., ISBN-13: 9781883413446.

Abdullagatov, I.M. and U.B. Magomedov, 1997. Measurements of thermal conductivity of aqueous LiCl and LiBr solutions. Phys. Chem., 101: 708-711.

Asdrubali, F. and S. Grignaffini, 2005. Experimental evaluation of the performances of a H2O-LiBr absorption refrigerator under different service conditions. Int. J. Refrigerat., 28: 489-497.

Gordon, J. and K.C. Ng, 2001. Cool Thermodynamics. Cambridge International Science Publishing, USA.

Herold, K.E., R. Radermacher and S.A. Klein, 1996. Absorption Chillers and Heat Pumps. CRC Press, Boca Raton, FL.

Kim, D.S. and I.C.A. Ferreira, 2008. Analytic modeling of steady state single-effect absorption cycles. Int. J. Refrigerat., 31: 1012-1020.

Lee, R.J., R.M. DiGuilio, S.M. Jeter and A.S. Teja, 1990. Properties of lithium bromide-water solutions at high temperatures and concentration. II. Density and viscocity. ASHRAE Trans., 96: 709-728.

Manohar, H.J., R. Saravanan and S. Renganarayanan, 2006. Modeling of steam fire double effect vapour absorption chiller using neural network. Energy Conversion Manage., 47: 2202-2210.

Ozisik, M., 1985. Heat Transfer: A Basic Approach. McGraw-Hill Book Company, New York.

Park, C.W., J.H. Jeong and Y.T. Kang, 2004. Energy consumption characteristics of an absorption chiller during the partial load operation. Int. J. Refrigerat., 27: 948-954.

Rogers, G.F.C. and Y.R. Mayhew, 1992. Thermodynamic and Transport Properties of Fluids: SI Units. 4th Edn., Blackwell Publishers, UK.