International Conference on Environment and Energy at Jawaharlal Nehru Technological University Hyderabad on December 15 - 17

Dynamic Simulation and Thermodynamic Analysis of Single Effect Vapour Absorption Refrigeration System Using Lithium Bromide - Water as Working Fluid

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Abstract: Absorption refrigerators produce cooling by using heat energy and have no moving parts. The simulation is done to determine the thermodynamic properties, and heat loads of various components such as evaporator, absorber, generator, and condenser. These are estimated by mass and energy balance. The simulation is done in C++ language. The object oriented format of C++ enables easy simulation analysis and verification. The performance of both the generator and the solution heat exchanger is limited by the problem of crystallization and the generator temperature cannot be increased too high. The result obtained specifies the maximum COP attained is 0.82 at an evaporator temperature of 10^{o} C. The solution circulation ratio can be reduced by increasing the concentration of solution in the generator or decreasing the concentration of solution in the absorber. The concentration of solution increases when the temperature increases or the pressure decreases, and vice versa. It is clear that the increasing evaporator temperature results a higher COP. At higher generator temperature, this effect is less significant. This is due to the increase in the absorber and condenser temperatures. At lower evaporator temperature the COP increases at higher rate at the generator temperature 70^{o} C to 85^{o} C. Increasing the generator temperature also resulted in increased COP. This is more significant at higher evaporator temperatures. This effect becomes less dominant at lower evaporator temperatures.
Keywords:Dynamic simulation; Lithium bromide – water; absorption refrigeration system

1. Introduction

Absorption refrigeration systems are heat operated and for this reason, large amount of electric power is not required. In this way, where power is expensive or unavailable, or where there is waste, gas, geothermal or solar heat available, absorption systems provide reliable and quiet running. A number of refrigerant-absorbent pairs are used, for which the most common are water-lithium bromide and ammonia-water. These two pairs offer good thermodynamic performance but the water-lithium bromide systems are environmentally benign.

Lithium bromide-water refrigeration systems are single and the double effect. The single effect absorption system is mainly used for building cooling loads. The coefficient of performance (COP) varies between 0.6 and 0.9. Single effect systems can operate with hot water temperature ranging from about 80°C to 120°C when water is pressurized. Vapour absorption systems are generally lesser COP compared to vapour compression systems but it is run by the use of low grade energy ie. Waste heat, automobile exhaust, geothermal waste etc. Water-lithium bromide systems possesses several advantages compared to other refrigeration systems

- It is composed of simpler components since it can work efficiently without the need of rectification columns.
- Less pump work is needed compared to other units due to operation at vacuum pressures.
- Since harmful working fluid, such as CFC and HCFC are eliminated in this system, it is environment friendly.
- Lesser ozone depletion and global warming effects

As energy conservation is becoming increasingly important, there is a need to optimize thermodynamic processes for minimum consumption of energy. Many parameters affect the performance of absorption refrigeration system. In order to optimize their thermal design, a thorough thermodynamic analysis is required.

The first and second law thermodynamic analysis of a single-stage absorption refrigeration cycle with water/lithium bromide as working fluid pair is formed (Omer Kaynakli et al 2007). Heat transfer rate of each component in the cycle and some performance parameters are calculated from the first law analysis. Using the second law, the entropy generation of each component and the total entropy generation of all the system components are obtained. Variation of the performance and entropy generation of the system are examined at various operating conditions. With increasing generator temperature, total entropy generation of the system decreases whereas maximum entropy generation occurs in the generator at various operating conditions, entropy generation in the refrigerant heat exchanger, expansion valve and solution pump is negligibly small.

An improved cycle was adopted to raise the pressure inside the absorber of the machine in order to intensify the absorption effect of thick Lithium bromide solution and enhance the COP of the absorption refrigeration system (GuozhenXie, et al 2006). By means of the tool of simulation, a set of software used for computing the thermal physical properties and predicting the performance of a single effect or double effect LBAC have been got. Based on the software, some performance, such as refrigerating or COP, of the single effect LBAC were predicted, and got useful results: the efficiency of LBAC cycle could be improve by increasing the absorption pressure. These results have laid a foundation for investigating further and promoting the performance of LBAC.

The paper provides an easy to follow description of the second law of thermodynamics method as applied to a single-effect absorption refrigerator cycle (Aphornratana et al 1995). Results are presented in a novel graphical format, which aids insight and understanding of those factors that most affect the performance of absorption refrigerators, and which in turn provides strong indicators for the direction of future research.

Nowadays, there has been developing interest for analyzing and evaluating the thermodynamic properties of thermal systems based on thermodynamic laws. Embracing this approach in this study dynamic simulation and thermodynamic analysis of single effect water-lithium bromide vapour refrigeration system is performed. Thermodynamic properties of each state points are obtained and the heat loads of various components are also evaluated in order to improve performance of the system.The purpose of this work is to develop an absorption system that would pollution free, consume less power. It should be environment friendly not only in terms of emission of harmful gases but also in terms of noise pollution. Normal refrigeration systems generally use CFC's for vapour compression which as we know depletes ozone layers, there by causing climate change. But this work deals with a refrigeration system that does not use harmful products for vapour absorption instead it uses lithium bromide as absorbent and water as refrigerant.

3. Principle of operation

The working fluid in an absorption refrigeration system is a binary solution consisting of refrigerant and absorbent. In fig, two evacuated vessels are connected to each other. The left vessel contains liquid refrigerant (water at temperature 30^0 C and pressure 4.24KPa) while the right vessel containing a binary solution of absorbent /refrigerant (Lithium bromide water solution at temperature 30^0 C and pressure 1.22KPa). The solution in the right vessel will absorb refrigerant vapour from the left vessel causing pressure to reduce. While the refrigerant vapour is being absorbed,the temperature of the remaining refrigerant will reduce (water at 10^0 C) as a result of vaporization. This causes refrigerating effect to occur inside the left vessel.

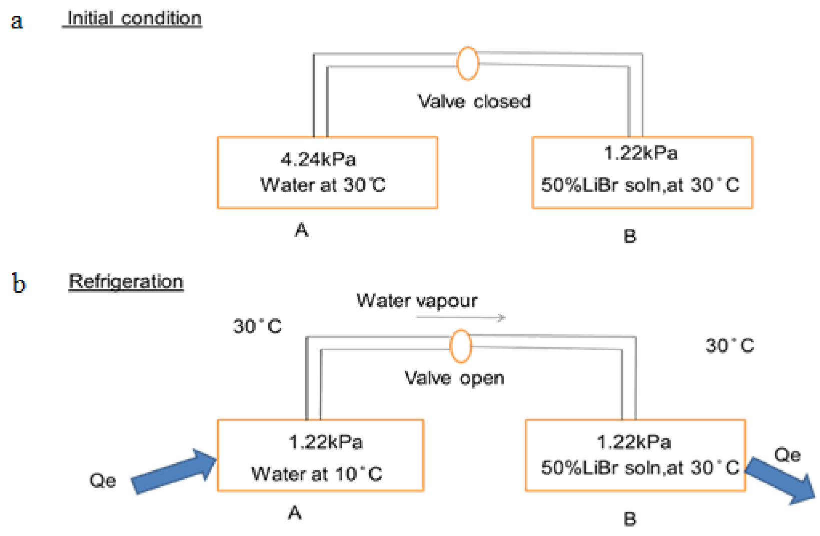

Figure 1. Principle of operation (a) initial condition; (b) refrigeration

4. System description

The cycle has five main components as shown in figure: the generator (sometimes called desorber), the condenser, the evaporator, the absorber, and the solution heat exchanger. Starting with state point 4 at the generator exit, the stream consists of absorbent- refrigerant solution, which flows to the absorber via the heat exchanger. From points 6 to 1, the solution absorbs refrigerant vapour 10 from the evaporator and rejects heat to the environment. The solution rich in refrigerant 1 flow via the heat exchanger to the generator 3.In the generator thermal energy is added and refrigerant 7 boils off the solution. The refrigerant vapour 7 flows to the condenser, where heat is rejected as the refrigerant condenses. The condensed liquid 8 flows through a flow restrictor to the evaporator. In the evaporator, the heat from the load evaporates the refrigerant, which then flows 10 to the absorber.

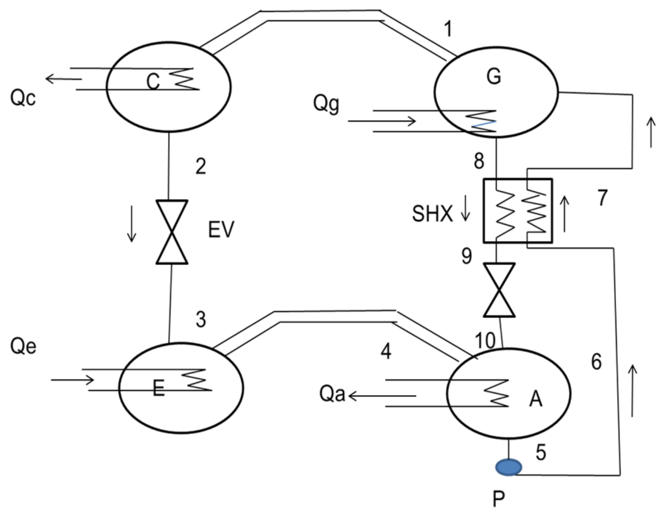

Figure 2. Schematic diagram of Lithium bromide water absorption refrigeration system

5. Modeling of each component

The computer program was based on heat and mass balances, heat transfer equations, and thermodynamic property relations written in terms of static point properties for each of the subunits and matched at the connecting points. The initial conditions read into the program included the ambient conditions, component temperature, cooling capacity, and effectiveness. With the given parameters, the program calculated the thermodynamic properties of the system. The COP was also calculated, which is defined as the ratio of the evaporator load to the generator load. The computer program was written in C++. The output list of the computer program is presented in Appendix.

6. Thermodynamic properties

Thermodynamic properties and heat loads of each state points and components are evaluated by applying mass and energy balance to the individual components of Lithium bromide – water absorption refrigeration system. Thermodynamic properties are mass flow rate, pressure, temperature, and enthalpy at various state points are evaluated. Condenser load, generator load, absorber load and solution heat exchanger load are estimated by mass and energy balance.

6.1. Evaporator

Mass balance

$$m_9 = m_{10} = m \quad (1)$$

Energy balance

$$Qe = m\,(h_{10} - h_9) \quad (2)$$

6.2. Condenser

Mass balance

$$m_7 = m_8 = m \quad (3)$$

Energy balance

$$Qe = m\,(h_7 - h_8) \quad (4)$$

6.3. Absorber

Total mass balance

$$m = m_{ss} + m_{ws} \quad (5)$$

$$m_{ss} = f\, m \quad (6)$$

$$m_{ws} = (1 + f)\, m \quad (7)$$

Refrigerant mass balance

$$m + (1 - \xi_{ss})\, m_{ss} = (1 - \xi_{ws})\, m_{ws} \quad (8)$$

Circulation ratio

$$f = \xi_{ss} \,/\, (\xi_{ss} - \xi_{ws}) = m_{ss} / m \quad (9)$$

$$Qa = m_{10}h_{10} + m_6h_6 - m_1h_1 \quad (10)$$

6.4. Generator

Mass balance

$$m_3 = m_4 + m_7 \tag{11}$$

Energy balance

$$Qg + m_{ws} = mh_7 + m_{ss} h_4 \tag{12}$$

$$Qg = m\left[(h_7 - h_3) + f (h_4 - h_3) \right] \tag{13}$$

Solution heat exchanger

$$Q_{HX} = f\, m\, (h_4 - h_5) \tag{14}$$

Table 1.Heat Loads at the constant capacity of 3.5 kW

Description	Symbol	kW
Capacity (evaporator output power)	Qe	3.50
Absorber heat, rejected to the environment	Qa	4.476
Heat input to the generator	Qg	4.648
Condenser heat, rejected to the environment	Qc	3.672
Coefficient of performance	COP	0.753

7. Results and discussion

The effect of generator temperature on COP of the system is analyzed. From Figure4 it can be seen that the COP of the system increases with increasing generator temperature, but the rate of increase of the COP becomes smaller at higher generator temperature. At lower evaporator temperature (Te = 5℃) the COP variation is higher at lower generator temperatures. The maximum COP is obtained at high evaporator temperature (Te = 10℃). The COP variation is less significant in high evaporator temperature.

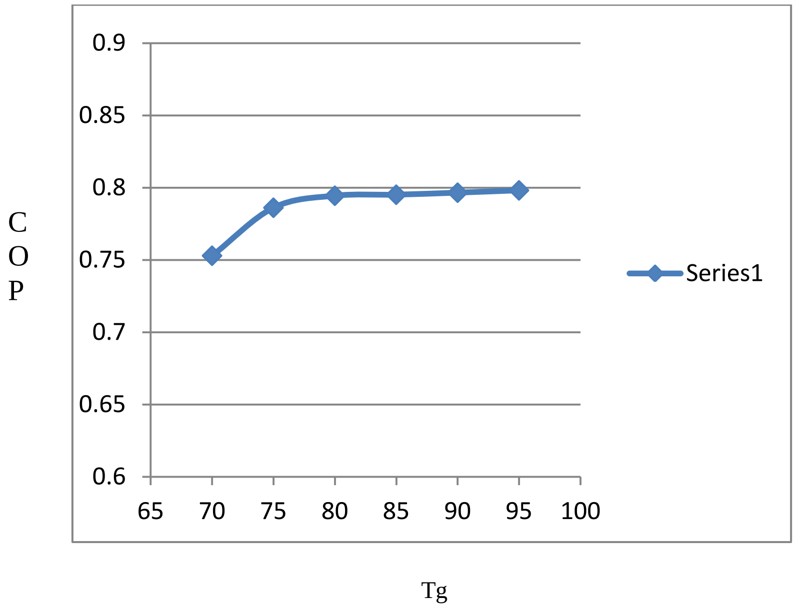

Figure 3. COP of the absorption refrigeration system with the generator temperature

Table 2. Variation of COP with generator temperature at evaporator temperature Te = 5℃

Tg ˚C	COP
70	0.68
75	0.76
80	0.78
85	0.783
90	0.782

Table 3. Variation of COP with generator temperature at evaporator temperature, Te = 8˚C

Tg ˚C	COP
70	0.774
75	0.796
80	0.801
85	0.8007
90	0.797

Table 4.Variation of COP with generator temperature at evaporator temperature,Te = 10˚C

Tg ˚C	COP
70	0.804
75	0.813
80	0.814
85	0.811
90	0.806

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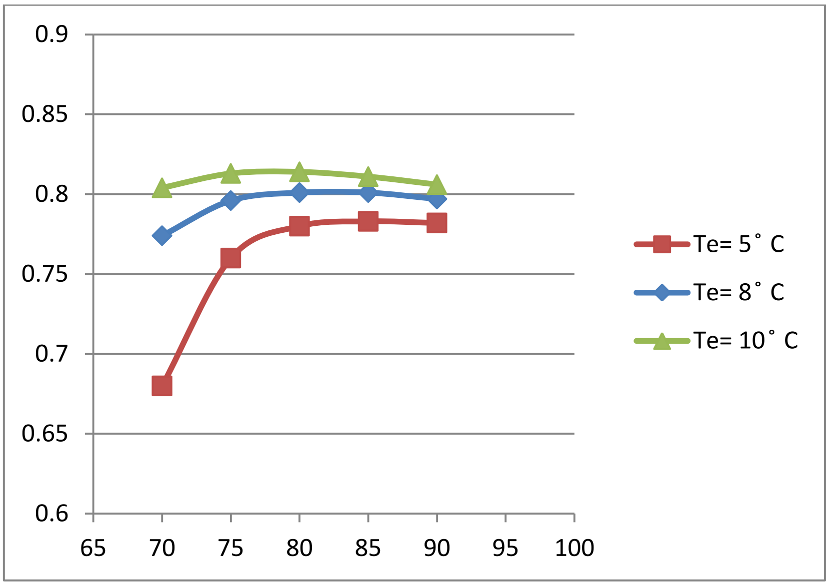

Tg

Figure 4. COP of the absorption refrigeration system with the generator temperature for different evaporator temperatures

8. Conclusion

The ratio of the heat load at the evaporator to the heat input at the generator is called the coefficient of performance for the refrigeration cycle. The Coefficient of performance of the system obtained can be varied by varying the generator temperature. The sum of the heat input at the generator and at the evaporator is equal to the heat rejected at the condenser and at the absorber. First law analysis determines and analyzes thermodynamic properties.The solution circulation ratio can be reduced by increasing the concentration of solution in the generator or decreasing the concentration of solution in the absorber. The concentration of solution increases when the temperature increases or the pressure decreases, and vice versa. The solution circulation ratio is low when the system is operated at high generator and evaporator temperatures, or at low absorber and condenser temperatures. The performance of both the generator and the solution heat exchanger is limited by the problem of crystallization, and therefore generator temperature cannot be increased too high.

Second law analysis presented here, it is more thermodynamically efficient if absorption systems are operated using low-grade waste heat rather than high temperature heat sources. Second law analysis provides an alternative view of cycle performance and provides an insight that the first law method cannot. It is proved to be a simple and effective tool, by providing information about how losses at different devices are interdependent and where a given design should be modified for best performance.

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