Design and Performance Study of a Hot Water Driven 5 TR Capacity Absorption Cooling System

Anil Sharma¹, Bimal Kumar Mishra², Abhinav Dinesh³ and Ashok Misra⁴

¹*Department of Production Engineering, Birla Institute of Technology, Deoghar, India*

²*Department of Mathematics, Birla Institute of Technology, Ranchi, India*

³*Department of Electronics & Communication Engineering, Birla Institute of Technology, Jaipur, India*

⁴*Department of Mechanical Engineering, RTC Institute of Technology, Ranchi, India*

Abstract

Use of high grade electrical energy, generated from fossil fuels, for cooling has increased environmental concerns like global warming and ozone layer depletion. Hence, there is a need to reduce dependence on them and explore potential environmental friendly options. In this aspect, vapor absorption system has scope of utilizing low grade energy source i.e. hot water from solar panel, to generate cooling effect and are environment friendly as no chloro-floro-carbons are used. The most usual combination of absorber refrigerant pair in such system is lithium bromide water (LiBr–H₂O), where water vapor is the refrigerant. In present work, a hot water driven, single stage, absorption cooling system, using a lithium bromide water solution, is analyzed for determining the effect of various parameters on coefficient of performance (COP). Four basic stages in the absorption cycle are generation, condensation, evaporation and absorption with ideally no moving part. A configuration of these four stages, having 5 TR cooling capacity is determined and examined for the variation in COP corresponds to the change in pressure and concentration. The pressure parameter is varied in condenser and evaporator, resulting graph shows that the increment in pressure of evaporator increases the COP whereas increment of pressure in condenser decreases the COP. At lower inlet concentration of LiBr solution to the absorber gives increment in COP.

Keywords: Absorption cycle, low grade energy, system configuration, coefficient of performance

1. Introduction

Absorption and vapor compression technologies for space cooling are based on the principle of condensation and evaporation of a refrigerant. In compression systems the most common source of energy for the work required to compress the vapor is electricity, whereas in absorption systems it is heat, fed directly to the generator. Such thermally driven absorption refrigeration systems provides cooling effect by using heat as source energy, which can be obtained from solar energy, waste-heat sources and other forms of low grade heat.

Among various absorbent and refrigerant pair, LiBr- Water is most promising in chiller application due to high safety, high volatility ratio, high affinity, high stability and high latent heat. In the cycle, shown in Figure 1, water vapor evaporates and separates from aqueous LiBr solution in generator, and increases the concentration of LiBr in solution. For this process heat is supplied from external source. At the same pressure, the water vapors from generator are condensed in condenser and this condensed water is throttled to the

evaporator, which is at lower pressure. Due to reduced pressure, the water change phase and evaporate by taking latent heat of vaporization in the evaporator at low temperature and generates the cooling effect.

Nomenclature

h	specific enthalpy (KJ/kg)
m	mass flow rate (kg/sec)
P	pressure (kPa)
Q	Heat transfer rate (kW)
s	Specific Entropy (kJ/kg ⁰ K)
T	Temperature (⁰ K)
X	LiBr mass fraction (%)
COP	Coefficient of Performance

Subscript:

i	inlet
e	exit
a	absorber
g	generator
e	evaporator
c	condensor

1, 2, 3... represent state point in Figure 1

Figure 1. Schematic of a Single effect LiBr-Water Absorption System

At same pressure, the vapors from evaporator are absorbed by LiBr-aqueous solution supplied from generator having higher concentration of LiBr. The absorption of water vapor reduces the concentration of LiBr in aqueous solution; this solution is then passed to generator through pump at higher pressure. A solution heat exchanger is used between absorber and generator to increase the efficiency of system.

In this paper, a 5 TR (17.585 kW) capacity absorption system is simulated; to which heat is sourced for generator from hot i.e. 92⁰C at atmospheric pressure. This low grade energy can be obtained from solar panel, cooling of automobile engine, and other source of waste heat. Various components of the cycle are configured using empirical correlations and their

specifications had been determined. To release the heat, cooling water is circulated in absorber and condenser at ambient temperature.

2. Heat and Mass Transfer Calculations

2.1. Mass Flow Rate Calculations

Mass flow rate in evaporator (m_9) = Load / (Change in enthalpy)

Mass flow rate for weak and strong solution

$$m_4 \times X_{ia} = m_3 \times X_{ig}$$

$$\text{Also, } m_3 = m_4 + m_7$$

$$\text{And } m_1 = m_2 = m_3 ; \quad m_4 = m_5 = m_6 ; \quad \text{and } m_7 = m_8 = m_9 = m_{10}$$

2.2. Heat Transfer Rate

Heat transfer rate in evaporator is taken as 5 TR (Load), base on this selected parameter heat transfer rate at other components are calculated as follows.

2.2.1. At Condenser

$$Q_c = m_7 (h_7 - h_8)$$

h_7 = Enthalpy of super heated steam at saturation temperature of solution in generator and Condenser pressure

h_8 = Enthalpy of water (saturated liquid) at condenser pressure and saturated temperature.

2.2.2. At Generator

$$Q_g = m_4 h_4 + m_7 h_7 - m_3 h_3$$

h_4 = Enthalpy of solution at exit of generator temperature and X_{ia} Concentration

h_3 = Enthalpy of solution at inlet of generator temperature and X_{ig} concentration.

2.2.3. At Absorber

$$Q_a = m_6 h_6 + m_{10} h_{10} - m_1 h_1$$

h_6 = Enthalpy of solution at inlet of absorber temperature and X_{ia} concentration

h_{10} = Enthalpy of saturated water vapor at evaporator pressure and its saturation temperature.

h_1 = Enthalpy of solution at exit of absorber temperature and X_{ea} concentration.

2.3. Coefficient of Performance (COP)

COP (ideal) = Heat taken out in Evaporator / Heat supplied in generator

$$= Q_e / Q_g$$

In the above ideal COP, work by the pump, pressure drops and other losses are not included.

Lower value of COP for absorption system compare to compression technology is because of using low grade energy rather than highly concentrated electric energy.

3. Configuration of a 5 TR System

3.1. Selection of Operating Parameters

After considering the optimum values in respect to ambient temperature, water properties and chilling requirements, following operating parameters are selected for various components of the cycle as shown in Table 1.

Table 1. Operating Parameters for Cycle

Pressure in generator and condenser	7 kPa
Pressure in absorber and evaporator	1 kPa
Saturation temperature in generator	82.863 °C
Saturation temperature in condenser	38.199 °C
Saturation temperature in evaporator	6.315 °C
Solution Temperature in absorber	36 °C
Solution Concentration at 3	55 %
Solution Concentration at 5	60 %
Evaporator capacity	5TR

3.2. Configuration of Heat Exchangers

Configuration for heat exchangers based on various empirical correlations is shown in Table 2. Standard dimensions of copper tubes had been selected from manufacturer's guide. Table: 2 reveal that the absorber is having maximum dimensions among other and the compactness of complete system depends on the size of absorber.

4. Coefficient of Performance Analysis

4.1. Effect of Solution Concentration

To check the solution concentration effectiveness, a constant difference of 5 % between the absorber inlet LiBr percentage ratio (X_{ia}) and absorber exit ratio (X_{ea}) are considered.

Table 2. Specifications of Components

	Absorber	Evaporator	Generator	Condenser
Inner diameter of tube	0.545 inch	0.43 inch	0.545 inch	0.43 inch
Outer diameter of tube	0.625 inch	0.5 inch	0.625 inch	0.5 inch
Number of tubes	38	18	16	8
Tube orientation	Vertical	Vertical	Horizontal	Horizontal
Length of tubes	1.2m	1.2 m	2.7 m (with one shell pass)	2.2m (with one shell pass)
Overall heat transfer coefficient ($W/m^2°C$)	487.43	1507.07	719.35	1782.19
Water inlet temperature	28°C Cooling	12°C Chilled	92°C Hot	28°C Cooling

Water exit temperature	31 ⁰ C Cooling	8 ⁰ C Chilled	84 ⁰ C Hot	34 ⁰ C Cooling
Log mean temperature difference (LMTD)	18	13.5	17	19.61

The x-axis in graph 1 represents the exit concentration of solution in absorber. The concentration of LiBr solution decrease while passing through the absorber due to absorption of water vapor. Enthalpy, which is a function of LiBr solution concentration and temperature at various state points as referred in figure 1 are determined using properties of solution from reference [2]. Following conditions are assumed:

1. Evaporator capacity 5 TR.
2. Solution heat exchanger exit temperature, 69.36⁰C.
3. Generator solution exit temperature, 82.86⁰C.
4. Absorber solution exit temperature, 55.86⁰C.
5. Saturation temperature in condenser, 38.19⁰C.
6. Saturation temperature in evaporator, 6.315⁰C.
7. Pressure in generator and condenser 7 kPa.
8. Pressure in absorber and evaporator 1 kPa.

4.2. Effect of Evaporator Pressure on COP.

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4. Absorber solution exit temperature, 55.86⁰C.
5. Saturation temperature in condenser 38.19⁰C.
6. Pressure in condenser 7 kPa.
7. Absorber inlet LiBr concentration (%) 60.
8. Absorber exit LiBr concentration (%) 55.

The graph: 2 show the variation in COP corresponds to different pressure in evaporator.

4.3. Effect of Condenser Pressure on COP

To check this effect, the following conditions were assumed:

1. Evaporator capacity 5 TR.
2. Solution heat exchanger exit temperature, 69.36⁰C.
3. Generator solution exit temperature, 82.86⁰C.
4. Absorber solution exit temperature, 55.86⁰C.
5. Saturation temperature in evaporator, 6.315⁰C.
6. Pressure in absorber and evaporator 1 kPa.
7. Absorber inlet LiBr concentration (%) 60.
8. Absorber exit LiBr concentration (%) 55.

The graph: 3 show the variation in COP corresponds to different pressure in condenser.

5. Results and Discussion

By using empirical correlations related with heat and mass transfer, specifications for various heat exchangers in the absorption cycle were determined in Table 2. Among all components, size of the absorber is maximum and affects the compactness of the overall system. The assumed temperature of cooling water availability depends on the ambient

temperature, which can affect the overall dimensions of the system. Use of solution heat exchanger reduces the overall size of the system, and increases the efficiency. Generated graph 1 gives the COP variation with exit concentration of LiBr solution in absorber. The COP is more at the low exit concentration and reduces as the exit concentration increase. The graph is plot with constant difference of 5% in concentration. The concentration reduces due to affinity of solution to absorb water vapors. Graph 2 shows that, increasing pressure in evaporator gives more COP, but this need to be considered with the required chilling water temperature, as at higher pressure the saturation temperature of water increases which again make the chilling unfeasible compare to ambient temperature. Therefore the atmospheric temperature is an important criterion for the selection of optimum pressures in the condenser as well as in the absorber. Graph 3 shows that, at low pressure in condenser the COP is more, but the saturation temperature of water also reduces, which make the low pressure in condenser unfeasible due to cooling water availability from the ambient temperature.

Hot water as a driving source for the system can be obtained from various renewable or waste heat sources, specifically from flat solar panel in desert area where ambient temperature reaches up to 50°C in summer and cooling requirement is at peak.

6. Conclusion

Such modeling of thermal systems presents many advantages; the most important are the elimination of the expense of building prototypes, the optimization of the system components, estimation of the amount of energy delivered from the system, and prediction of temperature variations of the system. In current paper, specification of 5 TR capacity absorption systems provides fundamental information about the product design and economic feasibility of the system being driven by hot water. The performance of the system is discussed in corresponds to parameters such as concentration, pressure and temperature, which helps in optimum selection of parameters.

The current calculations have used some assumptions which need further study i.e. no jacket heat loss. In the analysis of absorber, empirical correlation for outside heat transfer coefficient ignores the fact of simultaneous mass transfer. Other fields of investigation are creating and sustaining vacuum, throttling process and optimum size of pump.

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