Optimization of Irreversibilities in Water-Lithium Bromide Absorption Refrigeration System

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Abstract—The main objective of Vapour Absorption Refrigeration System (VAR) is to produce refrigeration effect by consuming low grade energy (Heat). The basic components of VAR system are Evaporator, Absorber, Generator, Solution heat exchanger, Expansion valve, Condenser. Since VAR system is heat operated cycle, the temperatures of generator, condenser, evaporator and absorber play a crucial role on performance of the VAR system. To analyze variation of temperatures on each component of VAR system a 2TR water lithium bromide system is designed based on first law analysis and Second law analysis is going to be carried out on each component of VAR to identify irreversibilities. After identification of the irreversibilities attempts to increase COP and decrease irreversibilities of VAR system is going to be done by optimization of temperatures on generator, condenser, absorber by keeping refrigerating load and evaporator temperature constant and writing entire procedure of thermodynamic analysis in MAT LAB script. The MAT LAB script runs on user provided inputs of generator, evaporator, absorber and condenser temperatures. After various iteration of temperatures on VAR system, the optimum temperatures are going to be found out on each component by keeping other component temperatures constant and varying the specified component temperature in VAR cycle. The temperature which produces minimum irreversibilities in the cycle (i.e. irreversibilities should be greater than zero if irreversibilities are less than zero process is impossible) is taken as optimum temperature. After finding out all optimum temperatures the program runs over optimized temperatures (or nearer to optimum temperatures care should be taken to avoid system entering into crystallization zone). The performance parameters (COP, irreversibilities, second law efficiency) are obtained. The performance parameters before optimization of VAR system are compared with obtained results.

Index Terms—MAT LAB, second law, irreversibilities, crystallization zone

I.INTRODUCTION

The continuous increase in the cost and demand for energy has led to move research and development to utilize available energy resources efficiently by minimizing waste energy. A better understanding of second law revealed that entropy generation minimization is an important technique in achieving optimal system configurations and/or better operating conditions. The vapour Absorption refrigeration system becoming more important because it can produce higher cooling capacity than vapour compression systems. And it can be powered by low grade heat sources like flue gases from boiler, geothermal, biomass other than electricity. The absorption cycle uses a heat driven concentration difference to move refrigerant vapour from evaporator to condenser. So with use of second law analysis optimum temperatures going to be found out. It is crucial to promote absorption based cooling system to meet the cooling demand in place of VCRS. A number of researchers have investigated the performance a VAR with aqua-ammonia and lithium bromide (LiBr) – water as absorbent refrigerant pair, with cooling capacity ranges from 5 to 50 kW. Small scale cooling system gives very low COP with slow cooling rate, which require a focus for improvement of its COP with compact designing. Additionally the small scale system must be operating on low temperature driving source. Most of the researchers inclined their work towards aqua-ammonia pair because of the low boiling temperature of ammonia (-33°C), which allows to go for cooling effect below 0°C. Ammonia is corrosive to copper tubings, toxic and flammable in nature. In addition to these limitations, water as absorbent is reasonably volatile which leads to presence of appreciable amount of water vapour in ammonia vapour leaving the generator. This may result in clogging of evaporator tubing due to which an analyzer and a
rectifier is used in aqua-ammonia system, which increases the system complexity. Based on these restrictions of aqua ammonia system, LiBr-water absorption system is more suitable to study. Most of research and development studies regarding solar absorption refrigeration systems (VARs) deals with the single stage system type. It is important to note that system performance can be enhanced by reducing the irreversible losses in the system by using the principles of the second law of thermodynamics. A better understanding of the second law of thermodynamics [1] has revealed that entropy generation minimization is an important technique in achieving optimal system configurations and/or better operating conditions. Some researchers [2,3,4] have used the principles of entropy generation minimization to analyze different systems and to improve the systems performance. Theoretical and experimental studies on the performance and thermodynamic analysis of VARs are available in the literature. Chen and Schouten [5] conducted an optimal performance study of an irreversible VAR. They considered irreversibility via an irreversibility factor and optimized the expression for COP with respect to a number of system parameters. Chua et al. [6] modeled an irreversible ammonia–water absorption chiller by considering the internal entropy production and thermal conductance of the heat exchangers. The model was applied to a single-stage chiller, and the results showed that the highest heat dissipation occurred in the rectifier. Kececiler et al. [7] performed an experimental study on the thermodynamic analysis of a reversible lithium bromide–water VAR. However, recent analyses of VARs have included the second law thermodynamics to provide better understanding of the thermal performance characteristics of each system components. This facilitated the detection of a component with high energy dissipation or irreversible losses. Attention can then be focused on such a component to minimize its irreversible losses. Lee and Sherif [8] applied both the first and the second law of thermodynamics to analyze multi-stage lithium bromide–water VARs. The second law efficiency of the chillers was calculated from the thermal properties, as well as the entropy generation and exergy of the working fluids. Furthermore, Lee and Sherif [8] used the second law efficiency to quantify the irreversible losses compared to the total entropy generation, which represents the energy dissipation of the system. Adewusi and Zubair [4] used the second law of thermodynamics to study the performance of single-stage and two-stage ammonia-water VARs. The entropy generation of each component and the total entropy generation of all the system components as well as the coefficient of performance (COP) of the VARs were calculated. The results show that the two stage system has a higher total entropy generation and COP, while the single-stage system has a lower total entropy generation and COP. Apart from other studies this paper deals with optimization of system performance by doing second law analysis on the system and finding out optimum temperatures and running simulation of VAR system nearer to optimum temperatures in mat lab script. The properties for calculations various state points for solutions at different concentration are taken from R. Gonzales3 and S. A. Nebra2[9].

II. SYSTEM DESCRIPTION AND WORKING

Fig.1 shows main components of Vapour Absorption Refrigeration system. Qg is the heat input rate from source rejecting by fluid entering at point 15 and leaving at 16. The Weak solution from the solution heat Exchanger enters into generator by gaining heat water vapour at state1 enters into condenser and rejects heat to external circuit. Which flows at cooler temperature (T17) by gaining heat it gets heated taking Qc from the water vapour at Point 1 and converting it into high pressure liquid at Point 2. After the Expansion valve the pressure of refrigerant is decreased to point 3 (saturated liquid). After getting Qe heat load from Evaporator circuit refrigerant gains latent heat and becomes saturated vapour at point 4. Circulating Water is cooled from Point 11(T11) to Point(12) (T12). In the absorber strong solution absorbs water vapour from the evaporator and becomes weak solution at point 5. Pump pressurizes weak solution up to generator pressure at point 6. After entering into solution heat exchanger Weak solution at point 6 is heated to point 7 by taking heat from strong solution coming from generator at point 8 (which is equals to generator temperature). The strong solution is cooled to point 9 after heat
exchanger and expanded to point 10 after strong solution expansion valve.

Figure 1: Vapour Absorption Refrigeration system

III. THERMODYNAMIC ANALYSIS OF 2TR WATER-LITHIUM BROMIDE REFRIGERATION SYSTEM

Generator Temperature = 90ºc
Absorber Temperature = 35 ºc
Condenser Temperature = 35 ºc
Evaporator Temperature = 10 ºc
Generator source Temperature = 150 ºc (Isothermal heat addition)
Absorber cooling water entering Temperature = 20 ºc
Absorber cooling water leaving Temperature = 25 ºc
Condenser cooling water entering Temperature = 30 ºc
Condenser cooling water leaving Temperature = 35 ºc
Refrigerating load = 6.18 kW

III.1. FIRST LAW & SECOND LAW STEADY STATE ANALYSIS ON VAPOUR ABSORPTION REFRIGERATION SYSTEM

Mass conservation:

\[(\Sigma m)_{in} = (\Sigma m)_{out}\]

\[3 = \frac{m_{libr}}{(m_{libr}+m_w)}\]

Energy conservation:

\[(\Sigma m*e)_{in} = ((\Sigma m*e)_{out}\]

Irreversibility generation rate:

\[I = T_0*[m_R*(S_{system out} - S_{system in}) + m_{surroundings}*(S_{surr out} - S_{surr in})]\]

Coefficient Of Performance:

\[Q_e/(Q_g + W_p)\]

III.2. ASSUMPTIONS:

1. The system is operated under steady state conditions.
2. Pressure drops and heat transfer losses in the pipelines are neglected.
3. Expansion of the LiBr- water mixture through throttle valves is isenthalpic in nature.
4. The solution pump is isentropic in nature.
5. The refrigerant states at outlet of condenser and evaporator are saturated liquid and saturated vapour respectively.

III.3. EVAPORATOR:

\[\dot{m}_3 = \dot{m}_4\]

\[m_{11} = m_{12}\]

\[Q_e = \dot{m}_3(h_4 - h_3)\]

\[\dot{Q}_{evaporator} = T_0 [\dot{m}_3 (S_4 - S_3) + \dot{m}_{11} (S_{12} - S_{11})]\]

III.4. ABSORBER:

\[\dot{m}_3 + \dot{m}_{10} = \dot{m}_5\]

Refrigerant mass balance:

\[\dot{m}_3 + \dot{m}_{10} (S_\omega) = \dot{m}_5 (S_\omega)\]

\[\dot{m}_{13} = \dot{m}_{14}\]

\[Q_a = \dot{m}_3 h_3 + \dot{m}_{10} h_{10} - m_3 h_3\]

\[\dot{Q}_{absorber} = T_0 [(\dot{m}_5 S_5 - (m_3 S_3 + \dot{m}_{10} S_{10})) + \dot{m}_{13} (S_{14} - S_{13})]\]
III.5. PUMP:

\[ W_p = \dot{m}_t(h_2-h_3) \]

III.6. HEAT EXCHANGER:

\[ \dot{I}_{shx} = T_0[\dot{m}_{10}(S_9-S_8)+ \dot{m}_5(S_7-S_6)] \]

III.7. GENERATOR:

\[ \dot{m}_7 = \dot{m}_8+ \dot{m}_1 \]

\[ \dot{m}_{15} = \dot{m}_{16} \]

\[ Q_g = \dot{m}_h+\dot{m}_8h_8-\dot{m}_7h_7 \]

\[ \dot{I}_{generator} = T_0[\dot{m}_1(S_1+S_8)-( \dot{m}_7S_7)+ ( \dot{m}_{15}(S_{16}-S_{15})] \]

III.8. CONDENSER:

\[ Q_c = \dot{m}_1(h_2-h_1) \]

\[ \dot{m}_{17} = \dot{m}_{18} \]

\[ \dot{I}_{condenser} = T_0[\dot{m}_1(S_2-S_1)+ \dot{m}_{16}(S_{18}-S_{17})] \]

\[ \dot{I}_{total} = \dot{I}_{generator}+ \dot{I}_{shx}+ \dot{I}_{absorber}+ \dot{I}_{condenser}+\dot{I}_{evaporator} \]

Table 1. Thermodynamic Properties at various points of system

<table>
<thead>
<tr>
<th>State points</th>
<th>P (kPa)</th>
<th>T (°C)</th>
<th>h (kJ/kg)</th>
<th>s (kJ/kg °k)</th>
<th>( \dot{m} ) (kg/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.62</td>
<td>90</td>
<td>2660.1</td>
<td>7.480</td>
<td>0.0126</td>
</tr>
<tr>
<td>2</td>
<td>5.62</td>
<td>35</td>
<td>146.6</td>
<td>0.505</td>
<td>0.0126</td>
</tr>
<tr>
<td>3</td>
<td>1.23</td>
<td>10</td>
<td>42</td>
<td>0.151</td>
<td>0.0126</td>
</tr>
<tr>
<td>4</td>
<td>1.23</td>
<td>10</td>
<td>2520</td>
<td>8.902</td>
<td>0.0126</td>
</tr>
<tr>
<td>5</td>
<td>1.23</td>
<td>35</td>
<td>52.5</td>
<td>75.85</td>
<td>0.26</td>
</tr>
<tr>
<td>6</td>
<td>5.62</td>
<td>35</td>
<td>52.5</td>
<td>75.85</td>
<td>0.26</td>
</tr>
<tr>
<td>7</td>
<td>5.62</td>
<td>62</td>
<td>151.6</td>
<td>0.445</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5.62</td>
<td>90</td>
<td>235.3</td>
<td>0.478</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5.62</td>
<td>57</td>
<td>156.5</td>
<td>0.282</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.23</td>
<td>57</td>
<td>156.5</td>
<td>0.282</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Heat transfer rates into and out system and irreversibility generation rate in VAR along with COP and second law efficiency obtained from MAT LAB script

<table>
<thead>
<tr>
<th>S.No</th>
<th>Out puts(kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qe</td>
<td>6.18</td>
</tr>
<tr>
<td>Qa</td>
<td>7.0433</td>
</tr>
<tr>
<td>Qg</td>
<td>7.2547</td>
</tr>
<tr>
<td>Qc</td>
<td>6.269</td>
</tr>
<tr>
<td>Total</td>
<td>2.369</td>
</tr>
<tr>
<td>(COP)designed system</td>
<td>0.85185</td>
</tr>
<tr>
<td>Second law efficiency</td>
<td>0.45631</td>
</tr>
</tbody>
</table>

IV. RESULTS AND DISCUSSIONS

Optimization of Temperatures by Second law analysis:- Since the analysis mainly focuses on minimization of irreversibilities. The system must be operated at various temperatures to decrease irreversibilities. Temperature differences among the system must be minimized so that system runs nearer to thermal equilibrium. While varying temperatures the irreversibilities produced at expansion valve are constant. So while plotting graphs irreversibilities associated with expansion valve are omitted. During variation of temperatures on a particular component remaining temperatures are held fixed.

IV.1. Variation of Generator Temperature:- From Fig.2&Fig.3,it is observed that Actual cop decreases with increase in generator temperature. This is may due to increase in finite temperature difference between heat exchanger. which is also effects Irreversibility’s associated with the system. Although
the higher temperature difference produce more vapour at the same time this will result in increase in absorber load will effect absorption process and Cop of system decreases beyond 85ºC. But Irreversibilities associated with system in other hand increases continuously due to increase in temperature difference among the components.

IV.2. Variation of Evaporator temperature:- From Fig.4 & Fig.5 by increasing evaporator temperature increases the vapour pressure in absorber leads in significant increase in absorption process of the strong solution at constant cooling load with increase in evaporator temperature causes generator load, absorber load decreases. Irreversibilities among the cycle decreases due to decrease in temperature difference among the components. So heat addition at low temperature difference causes lower entropy generation and low irreversibilities.

IV.3. Variation of condenser Temperature:- From Fig.6 & Fig.7 it is observed that if cooling load is kept constant then with increase in condenser temperature increases corresponding increase in condenser pressure. This leads to increase in load in generator as a result cop decreases with increase in condenser temperature. But increase in condenser temperature causes drop in temperature difference across circuit so irreversibilities decreases with increase in temperature.

IV.4. Variation in absorber Temperature:- From Fig.8 & Fig.9 the absorption efficiency decreases with increase in absorber temperature this results in increase in generator load and absorber load with increase in mixing losses at absorber. As the temperature difference between strong solution and weak solution increases with increase in absorber temperature negatively impacting with absorption process. The process is similar for external reservoir temperatures (i.e. source, sink temperatures) to find out optimal temperatures to produce minimum irreversibilities. Temperatures obtained from the mat lab simulation which produces least irreversibilities and higher cop are noted. And the system again runs nearer to these optimum temperatures. By considering both internal and external irreversibilities. Since condenser operating temperature change can cause opposite effects for Cop and irreversibilities. Organic rankine cycle is placed near the condenser to decrease Irreversibilities at Condenser.

IV.5. Optimized values taken from MAT LAB are:-

- Evaporator operating temperature = 10ºC
- Condenser operating temperature = 35 ºC
- Generator operating temperature = 85 ºC
- Absorber operating temperature = 30 ºC
- Chilled water entering temperature = 30 ºC
- Chilled water cooling temperature = 10 ºC
- Absorber Cooling water entering temperature = 25 ºC
- Absorber Cooling water leaving temperature = 30 ºC
- Generator hot water temperature at entering = 130 ºC (vapour)
- Generator hot water leaving temperature = 130 ºC (liquid)

From the above optimized values given to the mat lab script the values obtained are as follows

Table 3. Thermodynamic properties required for MAT LAB Script

<table>
<thead>
<tr>
<th>State point</th>
<th>T (ºC)</th>
<th>Concentration</th>
<th>s(kJ/kg-k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>30</td>
<td>49.449</td>
<td>0.2173913</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>49.449</td>
<td>0.2173913</td>
</tr>
<tr>
<td>7</td>
<td>60.2</td>
<td>49.449</td>
<td>0.43478</td>
</tr>
<tr>
<td>8</td>
<td>85</td>
<td>62.90</td>
<td>0.4673912</td>
</tr>
<tr>
<td>9</td>
<td>46.5</td>
<td>62.90</td>
<td>0.2434</td>
</tr>
</tbody>
</table>

COP = 0.867

İtotal = 1.94170 kW

second law efficiency of system = 0.50435

VI. Figures
Fig. 2. Variation of COP with $T_g$

Fig. 3. Variation of irreversibilities with $T_g$

Fig. 4. Variation of COP with $T_e$

Fig. 5. Variation of irreversibilities with $T_e$

Fig. 6. Variation of COP with $T_c$
V. CONCLUSION

- Second law analysis provides minimum temperatures to operate cycle to avoid exergy destruction.
- COP of system is optimized without affecting the feasibility of process.
- COP of system after optimization is increased by 1.9%
- Irreversibilities after optimization of temperatures is decreased by 17%
- Heat added in generator, Heat rejected in absorber is decreased slightly compared to original system.
- Circulation ratio of the system is decreased by 12.4%. As circulation ratio decreased COP increases.
- Irreversibilities at condenser are negligibly decreased so in order to decrease destruction of availability any heat recovery system is used to decrease destruction of exergy.
- Since in practical systems irreveribilities at generator are so high but by making system design by thermodynamic analysis generator irreversibilities can be decreased considerably.
- Second law efficiency of the system is improved by 10%.
- MAT LAB gives reasonable accurate results and avoids number of iterations and find outs optimum temperatures with minimum data input.

NOMENCLATURE

Te,Tg,Tc,Ta=
Evaporator, generator, condenser, absorber temperatures(°C)

ṁ= mass flow rate(kg/sec)
in = entering into system

ʒ = concentration of lithium bromide in solution

m_w = mass of water in solution

S_system in = specific entropy of working fluid entering into system in (kJ/kg-k)
\[ S_{\text{system out}} = \text{specific entropy of system leaving from system (kJ/kg-k)} \]

\[ m_{\text{surroundings}} = \text{mass flow rate entering from external sources and sinks (kg/sec)} \]

\[ S_{\text{surr in}} = \text{specific entropy of surroundings at entry of system (kJ/kg-k)} \]

\[ S_{\text{surr out}} = \text{specific entropy of surroundings at exit of system (kJ/kg-k)} \]

\[ Q_e = \text{evaporator load in kW} \]

\[ Q_g = \text{heat supply at generator in kW} \]

\[ Q_c = \text{condenser heat rejection rate in kW} \]

\[ Q_a = \text{absorber heat rejection rate in kW} \]

\[ W_p = \text{Work supplied to pump in kW} \]

\[ h = \text{specific enthalpy (kJ/kg)} \]

**REFERENCES**


