Analysis of Pump less Vapour Absorption Refrigeration system (Einstein-Slizard Refrigerator)

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Abstract— Cooling in the contemporary world has become an essential need. About 10 to 20% of the Electric power produced worldwide is consumed in cooling applications. VAR systems have dominated the industry, however these systems are characterized by the use of the usage of electrical energy which is proving to be an expensive means in the recent times and is also playing an egregious role in contributing to global warming. This highlights the fact that an energy efficient cooling system is very important; primarily to reduce the rate of consumption of natural sources of energy and to reduce to the concern around global warming. In this study, the Einstein-Slizard refrigeration cycle is analysed with an input of solar energy and is a single pressure absorption cycle. The driving mechanism used in this study is a two-phase boiling phenomenon achieved by the use of a bubble pump.

Single pressure absorption system also called a diffusion absorption system, is characterized by employing not just absorbing and refrigerant mediums but also a pressure-equalizing medium. The principle of this system is analogous to a VAR system but the total pressure of this system in all the components in the cycle remains constant.

Keywords—Einstein refrigerator, pump less var.

I. INTRODUCTION

In this cycle Butane is used as the refrigerant, Ammonia as the pressure equalizing fluid and Water as absorbing liquid. Starting in the evaporator, liquid butane arrives from the condenser/absorber. In the evaporator, the partial pressure above the butane is greatly reduced by ammonia vapor flowing from the generator. With its partial pressure reduced, the butane evaporates near the saturation temperature of its partial pressure and cools itself, the ammonia, and the surroundings. Now ammonia-butane mixture flows out of the pre-cooler into the condenser/absorber which is being continuously cooled by the environment.

Meanwhile, liquid water from the generator is sprayed into the condenser/absorber. Because of its great affinity for ammonia vapor, this sprayed water absorbs the vapor ammonia from the ammonia-butane mixture. This absorption of the ammonia vapor increases the partial pressure on the butane vapor to nearly the total pressure, allowing it now to condense at butane's saturation temperature for the total pressure (higher than butane's saturation temperature at the partial pressure of the evaporator). The butane and the ammonia water separate due to their respective density differences and the fact that ammonia-water is immiscible with butane at the condenser/absorber's temperature and pressure. Since liquid butane is less dense than liquid ammonia-water, it is the top liquid and is siphoned back to the evaporator. Meanwhile, the ammonia-water mixture leaves from the bottom of the condenser/absorber.

Inside the generator, heat is applied to the strong ammonia-water solution driving off ammonia vapor. The remaining weak ammonia-water solution is pumped up to a reservoir via a bubble pump. The weak ammonia water solution falls to the solution heat exchanger where it gives up its heat to the strong ammonia-water solution leaving the condenser. Finally, the water is sprayed into the condenser/absorber.

While the overall pressure of the cycle is constant, there are slight pressure variations within the cycle necessary for fluid motion. These are due to height variations and are not large enough to significantly affect property evaluation.

The Einstein proposed System can be seen in the following diagram. Certain changes have been made in the proposed system which can be seen in the fig followed by Einstein-Slizard model.
Fig 1. Ammonia-Butane Cycle (Einstein proposed system) , A. Einstein & L. Szilard, Refrigerator, 1930, US Patent 1781541

II. METHODOLOGY ADOPTED

This study examines the single pressure direct driven heat pump cycle described by Albert Einstein and Leo Szilard (the Einstein cycle). The Patel-Teja cubic equation of state, fitted to experimental data, is used for all fluid modeling (pure substances and mixtures). For the ammonia-butane mixture, the Patel-Teja equation of state predicts vapor-liquid-liquid equilibrium and azeotropic behavior at the pressures and temperatures in the evaporator. Experimental measurements on the ammonia-butane system verify this and the equation of state was fit to the experimental data (Wilding, 1996).

This study also develops general criteria for working fluids of the cycle. The three fluids were generalized as the refrigerant fluid, the inert fluid, and the absorbing fluid. The original cycle used butane, ammonia, and water, respectively. First law and conservation of mass analysis is made on the system and the mass flow rates along with the specifications of the evaporator are modeled.

III. DESCRIPTION OF THE WORK

A. Assumptions made

- The Pressure of the system is fixed at 4 bar.
- The Temperature of the generator is assumed to be 375K.
- The system is considered to be under steady state while performing mass flow and first law analysis.
- The behavior of Ammonia-Butane mixture in the evaporator is assumed to be azeotropic in nature.

B. Derivations made from the assumptions

- Since the pressure of the system is 4 bar, the ammonia-butane mixture condenses at 315 K, hence the temperature of condenser is assumed to be 315 K.
- The Ammonia-Butane mixture for the same assumed system pressure boils as low as 266K, hence temperature of the evaporator=266K.

C. Analysis of Evaporator:

Pure saturated liquid butane flows in from the condenser/absorber at the condenser/absorber temperature. Simultaneously, saturated vapour ammonia is bubbled into the liquid butane. The presence of the ammonia vapour reduces the partial pressure of the butane causing it to evaporate. As it evaporates into the ammonia vapour, the butane cools itself, the ammonia vapour, and produces external cooling. A small amount of ammonia vapour is also absorbed into the liquid butane producing some heat of absorption which is also removed by the evaporating butane. For a given system pressure, the temperature in the evaporator depends upon the relative butane-ammonia flow rates.
To prevent a temperature glide, which increases the evaporator temperature, the design condition is taken to be at the azeotrope.

Fig 3. Control Volume of Evaporator

Conservation of mass and 1st law analysis

\[ y_{a,2} \cdot m_2 = x_{a,2} \cdot m_2 + m_4 \]
\[ y_{b,3} \cdot m_3 = x_{a,2} \cdot m_2 \]

Considering the equilibrium concentration diagram at 4 bar for ammonia butane mixture, concentrations of ammonia and butane are known and hence the above equations can be written as

\[ 0.552 m_4 = m_2 \]
\[ 0.447 m_3 = m_2 \]
\[ Q_{\text{evaporator}} = m_3 \cdot h_3 - m_1 \cdot h_1 - m_4 \cdot h_4 \]

D. Analysis of Condenser:

Fig 4, Control Volume of the condenser/absorber

In the Einstein refrigeration cycle, the condenser and absorber are combined into a single component where both processes occur simultaneously.

When the vapor mixture enters the condenser/absorber, it encounters a large surface area created by a falling film of sub-cooled liquid water weak in ammonia. The water film, which enters the condenser/absorber at state point 9, readily absorbs the ammonia from the vapor mixture. This increases the concentration of butane in the vapor and hence the partial pressure on the butane in the vapor. Now the butane can condense at its saturation temperature for this system pressure which is well above the temperature at which it evaporated earlier in the evaporator.

The liquid water, now rich in ammonia, and butane descend the walls of the condenser/absorber. Since the ammonia-water solution is immiscible with the butane, and is denser, it sinks to the bottom of the condenser and flows out at point 7. The light, immiscible butane floats atop the solution and exits at point 1. The condenser operates at steady state and the liquids leaving the condenser are assumed to be in thermal and vapor-liquid equilibrium at the temperature of the condenser.

\[ m_1 + m_7 = m_2 + m_3 + m_{bg} \]
\[ x_{i,1} \cdot m_1 + x_{i,2} \cdot m_7 = x_{i,5} \cdot m_5 + x_{i,3} \cdot m_3 + x_{i,2g} \cdot m_{bg} \]

At 4 bar considering the concentrations of ammonia and butane,

\[ m_1 = 0.447 m_3 \]
\[ 0.45 m_7 = 0.2 m_9 + m_4 \]

\[ Q_{\text{condenser}} = m_3 \cdot h_3 - m_1 \cdot h_1 - m_7 \cdot h_7 - m_3 \cdot h_3 - m_{bg} \cdot h_{bg} \] (Energy conservation equation)

E. Analysis of Generator:

Fig 5 Control volume of Generator

In the generator, ammonia rich water arriving from the condenser is heated. This generates vapor ammonia which then flows to the evaporator.
The remaining water, containing less ammonia, drops to the bottom of the generator where it flows into the bubble pump and is returned to the condenser.

\[ m_7 = m_4 + m_8g + m_9 \]

\[ x_{a,7} \cdot m_7 = x_{a,9} \cdot m_9 + m_{14} + x_{a,8g} \cdot m_8g \]

At 4 bar considering the concentrations of ammonia and butane,

\[ m_7 - m_4 = m_9 \cdot 0.45m_7 - m_4 = 0.2m_9 \]

(energy conservation equation)

IV. RESULTS

A. Results of mass conservation equations

Mass flow through the bubble pump is \( m_9 \). Designing the bubble pump for the mass flow rate of 10 gm/sec and solving the above equations:

\[ m_8 = m_9 = 10 \text{ gm/s}, m_1 = m_2 = 3.8 \text{ gm/s}, m_3 = m_6 = 8.5 \text{ gm/s}, m_5 = m_7 = 4.5 \text{ gm/s} \]

B. Results of Analysis of first law of Thermodynamics:

The enthalpy values at various states have been calculated using the Patel-Teja equations and Peace software as

\[ h_1 = h_2 = 0.64 \text{ KW}, h_3 = h_6 = 1.35 \text{ KW}, h_5 = h_4 = 1.706 \text{ KW}, h_7 = 0.315 \text{ KW}, h_9 = 0.427 \text{ KW} \]

Substituting the various enthalpy values and mass flow rates we get:

Refrigeration capacity of evaporator \( Q_e = 1.19 \text{ KW} \)

Heat emitted from condenser \( Q_c = 8.7 \text{ KW} \)

Heat supplied to the Generator \( Q_g = 7.48 \text{ KW} \)

Actual COP of the system = \( Q_e / Q_g = 0.16 \)

V. CONCLUSIONS

- Refrigeration capacity of the system is 1.19 KW.
- COP of the system is 1.16.

REFERENCES

[5] Mohammad Naghash zadegan, Koroush Javaherdeh, Design and construction of a low capacity pump-less absorption system, Mechanical Engineering Department, University Of Guilan, Iran.
[6] T-x-x-y diagram of ammonia butane mixture
[7] H-C chart of aqua ammonia