USE OF ENERGY METHOD TO SIMULATE THE PERFORMANCE OF LiBr/H_2O ABSORPTION SYSTEM

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ABSTRACT

Absorption refrigeration system provides large potential for reducing heat pollution of the environment. In this paper, a model has been developed for description of a simple LiBr / H_2O absorption system in a climatic setting that is amenable to change. The fundamental characteristics and performance index of the system which effects its selection were obtained by using the energy balance method. The simulation of the system was carried out using Engineering Equations Solver. Results of simulated performance of this system and the effects of the initial temperature of a given mass of load on the coefficient of performance, COP of the system are given. The performance of the system increased with increasing initial temperature of the cooling load.

Keyword: absorption, refrigeration, energy method, simulation

Nomenclature

$\dot{m}$ = mass flow rate
$\dot{Q}$ = heat transfer rate
P = pressure
h = enthalpy
w = warm fluid
T= temperature
LMTD = log mean temperature difference
X = concentration.
W =power
C= cold fluid (1 = inlet; 2 = outlet)
U = global heat transfer coefficient of heat exchanger
A = area of heat exchanger
ΔT = change in temperature
ref. = refrigerant
eva. = evaporator

1.0 INTRODUCTION

The location of Nigeria between latitude 4° and 14° north of the equator, in the Sunbelt of the tropics, creates attractive potentials for refrigeration applications. Refrigeration is important in a number of ways to the society. Some of the ways include making intemperate locations habitable, enabling food preservation both on transit and in-situ, enabling production and storage of medical and pharmaceutical materials, and preventing the spread of diseases. Refrigeration also makes many important production processes possible, increases worker productivity, and provides thermal comfort.

At present in Nigeria the above needs are met through mechanical vapour compression system. With the preponderant cases of grid electricity supply unreliability or prices inflations of petroleum products used to run private generating sets natural convectional processes are employed to satisfy the mentioned refrigeration needs. These worrisome situations lead to huge losses in terms of both economic and human productivity. The problem is even worse in the remote areas unconnected to national grid and who serve as food centers for the nation. There are many of such remote areas and suburbs in cities who seek relieve from perennial cooling problems through thermally operated alternatives.

There is literature on widely adopted refrigeration technologies. Typical refrigeration systems are mechanical vapour compression, absorption cycle in which vapour is absorbed into a liquid or solid prior to pumping, cryogenics and adsorption using activated carbon, zeolite, silica gel etc [1]. Enibe [2] conducted an experimental study on absorption cycle using solar powered solid absorption refrigerator. Anyanwu [1] based on local raw materials, also carried out experimental study on adsorption system using activated carbon, zeolite and silica gel. However, the performances of the two systems are similar in many respects, except that the latter is a bulk phenomenon, while adsorption is essentially a surface phenomenon. Comparing absorption system to mechanical vapour compression type, [3] stated that the former differs from the latter in that it achieves compression work, by a seamless process using a suitable working pair, consisting of a refrigerant and absorbent solution driven by electric motor. Among these refrigeration systems there is renewed interest in absorption system because of its ability to reduce demand for electricity unlike mechanical vapour compression and cryogenics that depend heavily on it.

In this study, the focus is on simulating real absorption refrigeration system. The absorption system technology plays predominant role in the refrigeration market in Asian-pacific countries like China, Japan, and Korea, even the demands for it are high in Europe, Canada and USA. The criteria for selection, in most of these places, are based on cost preference, local manufacturer representation and service options, operating preferences and perceptions of reliability. In Africa, there is limited preference for absorption system among the other systems because of problem of lack of robust information on its real behavior and characteristics with respect to tropical setting. Thus, simulation of the system with operating conditions is a necessity. System simulation refers to the process of obtaining quantitative information on the behavior and characteristics of the real system by analyzing, studying or examining a model of the system [4]

1.1 Objectives of the study

This study therefore, aims to capture the various interrelated thermodynamic processes of heating and cooling involved in absorption system. The specific objectives include developing a model of simple lithium bromide/water ($LiBr/H_2O$) absorption system, to simulate the model and to obtain critical performance characteristics of the system using engineering equation solver, EES software. With the software, the quantitative characteristics such as flow rate, vapour fraction at each state point in the system, and heat duty at each component are calculated from a database of thermodynamic properties using energy method. The energy method is a derivative of the first law of thermodynamics. The results of this study, particularly with ambient temperature, would be helpful in making logical deduction and analysis of the real system.

The motivation for absorption refrigeration system is to take advantage of low cost heat sources available in Nigeria [5]. In Nigeria, owning to abundant primary energy sources, there is massive rejection into the atmosphere of low grade affluent heat from power plants, process industries and flow stations. This practice is capable of increasing atmospheric temperature. The choice of absorption refrigeration is fascinating as it increases efficiency and cost effectiveness of fuel use in the plants and because its operation is heat based, it provides large potential for reducing heat pollution of the environment. An inherent disadvantage of the absorption refrigeration cycle, however, is its low coefficient of performance, less than unity, and is low compared with vapour compression refrigeration cycle [6].

2.0 SYSTEM DESCRIPTION

A typical absorption system may be grouped as single effect (simple), double effect or triple effect depending on level of thermal efficiency desired and source of required heat energy. This characteristic grouping enables it to be installed in small to large scale ranges. The paper focuses on single effect cycle. The cycle comprises four main components, namely evaporator, absorber, generator and condenser. The auxiliary components include pump driven by electric motor, throttle valves, solution heat exchanger that is interfaced between generator and absorber, and external cooling water compartment to ensure system continues in a cycle.

The most common absorption refrigeration systems are lithium bromide/water (LiBr/H_2O) and water/ ammonia (H_2O/NH_3) [7-8]. The first substance of the systems is absorbent, being aquous solvent with high thermal stability, while the second is refrigerant which in nature is volatile substance.

3.0 SYSTEM MODELLING

The modeling of LiBr/H_2O is based on following assumptions:

- There is pressure drop due to heat transfer in the piping network is negligible;
- flow pattern is steady state and
- Solution pump is used to maintain constant mixture level at generator is adiabatic and its work input is negligible [9].

The LiBr/H_2O system is modeled such that the refrigerant flows in a closed configuration through an evaporator, at low pressure circuit, to a high pressure generator as shown in figure 1. At the evaporator, the low pressure refrigerant extracts heat from a refrigerating body and boils off vapour which is absorbed in lithium bromide solvent contained in absorber compartment. This forms an non-azeotropic weak mixture. As phase equilibrium occurs there is isentropic elevation of the mixture pressure by pump to high condenser pressure that prevails in the generator. The high pressure mixture is subjected to steam and the vapour becomes regenerated such that only hot LiBr is returned to the absorber compartment. During this process the cold liquid LiBr/H_20 passing through counter flow heat exchanger is preheated by hot LiBr solution and this result in net energy savings required for the generator. Then, the regenerated vapour is condensed to liquid at the condenser as heat is rejected to atmosphere. The liquid refrigerant experiences pressure drop as it is throttled down to the evaporator through expansion valve. At this stage the refrigerant's cycle is repeated.

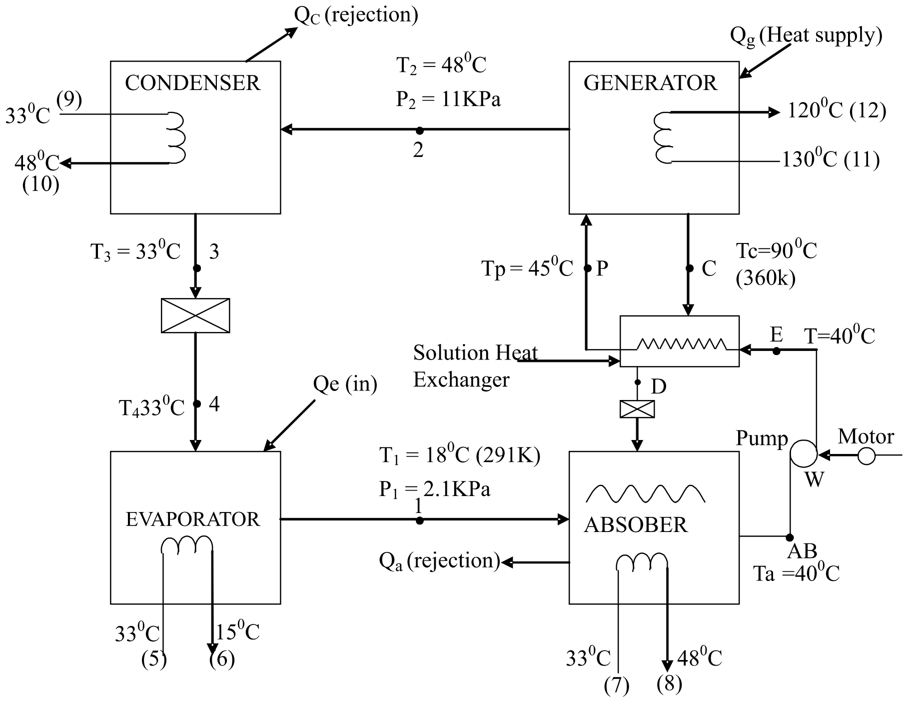

Fig. 1 Single Effect Absorption Cycle Model

The thermodynamic energy and mass balances for the cycle are stated below. Since the driving potential for heat transfer in the system components is the temperature difference, therefore method of log-mean-temperature difference, LMTD can be used to model the cycle, while assuming the components are heat exchangers with identical heat transfer coefficient. The thermodynamic energy and mass balances for the cycle are stated below. Since the driving potential for heat transfer in the system components is the temperature difference, therefore method of log-mean-temperature difference, LMTD can be used to model the cycle, while assuming the components are heat exchangers with identical heat transfer coefficient. Mathematically, the thermodynamic states point's summary is given for:

3.1 Evaporator

$\dot{m}_1 = \dot{m}_2 = \dot{m}_{ref}$ (Total mass balance)

$\dot{m}_i =$ flow rate at state point. (1a)

$Q_{eva} = \dot{m}_1(h_1 - h_4)$ (Energy balance) (1

$= (UA)_{eva}\,\Delta T_e$ (1c)

$$\Delta T_e = \frac{[T_5 - T_1) - (T_6 - T_4)]}{\ln\dfrac{T_5 - T_1}{T_6 - T_4}}$$

3.2 Absorber

$\dot{m}_1 + \dot{m}_d = \dot{m}_a$ (Total mass balance) (2a)

Taking account of solution concentrations (mass fractions): X_a and $X_g = X_d$. Applying the conservation of mass principle to the absorber water flow yields:

$$\dot{m}_1 + \dot{m}_d(1 - X) = \dot{m}_a(1 - X_a)$$

For steady state flow the rate of lithium bromide into absorber equals existing rate. Thus

$$\dot{m}_d X_d = \dot{m}_a X_a$$

$$Q_a + \dot{m}_a h_a + \dot{m}_1 h_1 + \dot{m}_d h_d \qquad \text{...(2d)}$$

We can rearrange equation (2d) to get absorber heat flux

$$Q_a = \dot{m}_1 h_1 + \dot{m}_d h_d - \dot{m}_a h_a \qquad (2e)$$

$$= (UA)_a \, \Delta T_a \qquad (2f)$$

$$\Delta T_a = \frac{[T_d - T_{81}) - (T_a - T_7)]}{\ln \dfrac{T_d - T_8}{T_a - T_7}}$$

3.3 Solution Heat Exchanger

$$\dot{m}_e + \dot{m}_c = \dot{m}_p + \dot{m}_d \qquad \text{(Total mass}$$

$$\dot{m}_e h_e + \dot{m}_c h_c = \dot{m}_p h_p + \dot{m}_d h_d \qquad (3b)$$

$$q_{shx} = (UA)_{shx} \, \Delta T$$

$$\Delta T = \frac{(T_{w,i} - t_{c,2}) - (T_{w,2} - t_{c,1})}{\ln[(T_{w,i} - t_{c,2}) / (T_{w,2} - t_{c,1})]}$$

3.4 Pump

$$W_{pump} = \dot{m}_a \left(\frac{P_2 - P_1}{\rho} \right) \qquad (4)$$

where r = density of solution

3.5 Generator

$$\dot{m}_p = \dot{m}_2 + \dot{m}_c \qquad \text{Mass balance} \quad (5a)$$

$$Q_g = \dot{m}_p h_p - \dot{m}_2 h_2 - \dot{m}_c h_c \qquad \text{Energy balance)} \quad \text{... (5b)}$$

$$= (UA)_g \, \Delta T_g \qquad (5c)$$

$$\Delta T_g = \frac{[T_{11} - T_C) - (T_{12} - T_2)]}{\ln \dfrac{T_{11} - T_C}{T_{12} - T_2}}$$

3.6 Condenser

$$\dot{m}_2 = \dot{m}_3 = \dot{m}_1 (2b) \qquad (6a)$$

$$Q_{con} = \dot{m}_2 (h_3 - h_2) \qquad \text{energy balance} \quad (6$$

$$= (UA)_{con} \, \Delta T_c \qquad (6c)$$

$$\Delta T_c = \frac{[T_9 - T_3) - (T_{10} - T_3)]}{\ln \dfrac{T_9 - T_3}{T_{10} - T_3}}$$

Solution circulation ratio, *f* is another useful mass flow parameter that sometimes its advantage is taken in establishing dependent mass flow rate. It is expressed as:

$$f = \frac{\dot{m}_a}{\dot{m}_1} = \left(\frac{X_d}{X_d - X_a} \right)$$

Thermal coefficient of performance,

$$COP = \frac{(Q_{eva})}{(Q_g)} \qquad (7)$$

4.0 SIMULATION, RESULTS AND DISCUSSIONS

With increasing complicity in design and applications of absorption system the need for computational simulation tool is indispensable. Such tools include Absorption Simulation, ABSIM [10] and EES [11]. There are two major differences between EES and other equation-solving programs or software [9]. Essentially, EES allows equations to be entered in any order with unknown variables placed anywhere in the equations; EES automatically reorders the equations for efficient solutions [12].

In simulating the system performance, critical variables such as pressure, temperature, flow rate, energy input/output, density, concentrations and mass transfer rates of refrigerant and absorbent solutions are considered. Figure 1 shows the initial defined states at which energy and mass balance principles were applied.

By means of EES program basic characteristics of the system were evaluated at different operating conditions. For example, varying inlet temperatures of refrigeration load were investigated in a parametric analysis and some of the remarkable performances were as shown in figures 2 through figure 4. Figure 2 indicates that an increase in the refrigeration load inlet temperature causes an increase in COP. COP is the criteria of performance of the system and was obtained to be 0.93. This is acceptable for a simulated system. This result is significant since by nature the tropical climate is subject to varying refrigeration load consequent upon relatively varying ambient temperature. Figure 3 shows that the increased inlet temperature of the refrigeration load caused the finite temperature difference between the hot and cold solutions to decrease. This development is significant since low finite temperature difference is good requirement for conduction of heat at low irreversibility in the solution heat exchanger. However, the increase in inlet temperature could cause both weak and strong solutions of the system to become more concentrated as illustrated in figure 4. A continued increase of solution concentration will result in crystallization of the refrigerant. This characteristic behaviour can be employed as control strategy in prevention of crystallization if the inlet temperature that corresponds to the crystallization point for LiBr/H_2O system is known.

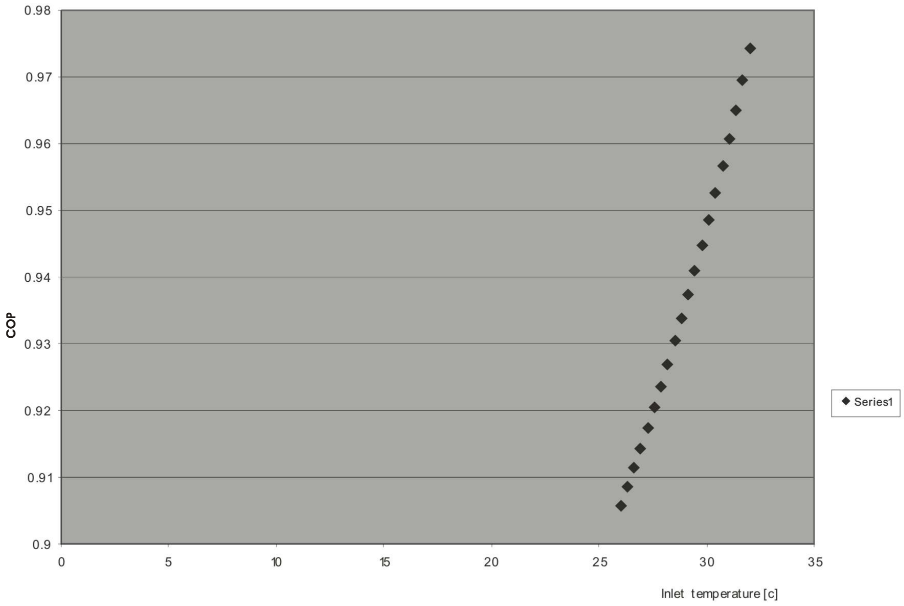

Fig. 2. COP Increases with refrigeration load inlet temperature

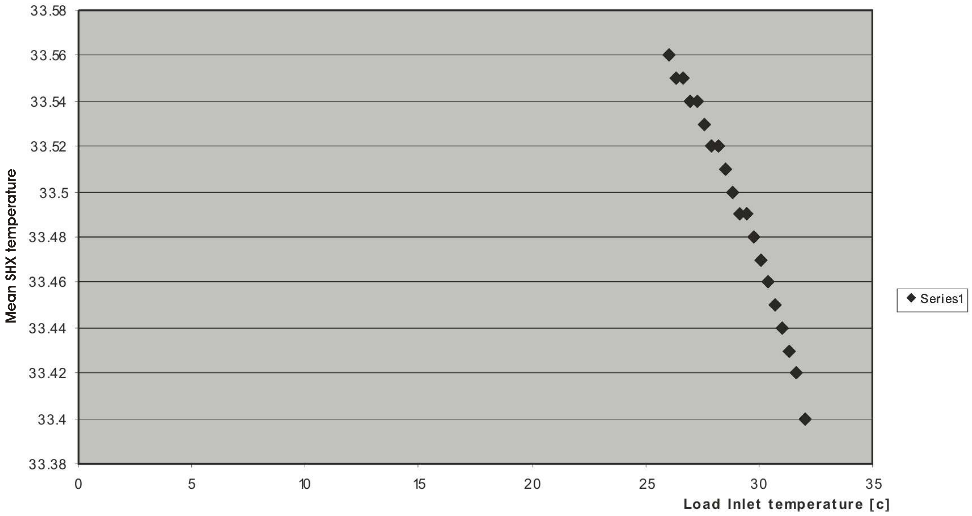

Fig. 3: Variation of SHX temperature with changes in load inlet temperature

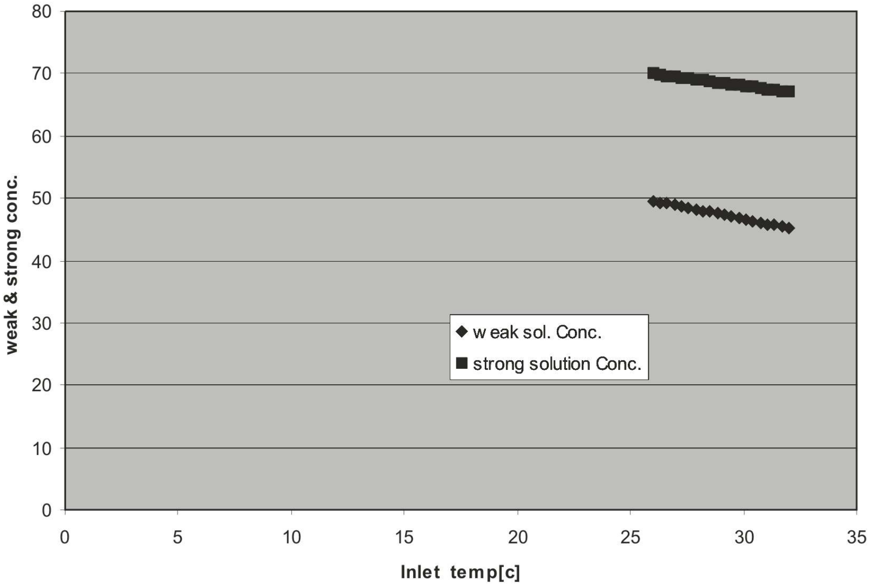

Fig. 4: Influence of changing inlet temperature on solutions concentration.

In a parametric analysis of ambient temperature, COP and effectiveness it was observed that COP and effectiveness increased linearly as the ambient temperature was varied. Figure 5 shows this relationship. The relationship between effectiveness of heat exchanger and COP of the system on variation of ambient temperature is noteworthy since both are measures of performance. The overall system performance is measured by COP while effectiveness is a measure of heat exchanger performance. The implication of this result is that choice of ambient temperature is critical to operation of absorption cycle in a tropical region than it is for temperate region where its value remains nearly constant.

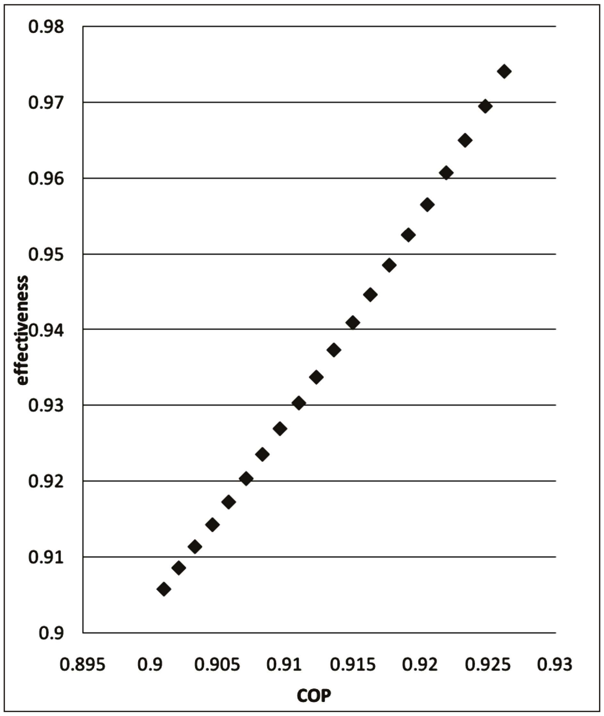

Figure 5: Effectiveness vs COP

5.0 CONCLUSION

A configuration of a simple LiBr/H_20 absorption system is developed in this paper. The effects of changing refrigeration load inlet temperature have been investigated and shown. The variation of inlet temperature at constant solutions flow rates and constant external heat supply rate impacts on the performance index of the system and the effectiveness of solution heat exchanger. However, unlimited upward variation of inlet temperature of refrigeration load brings the system near its crystallization point. The implications of this behaviour for real absorption refrigeration system design are clear.

With the current results tropical ambient conditions, particularly temperature will boost adoption of absorption refrigeration system. The application of the system in Nigeria would not only ensure comfort for improved productivity at workplaces and homes but could complement strategy to achieve healthy society, job creation and poverty reduction, which are indices for sustainable development.

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