DESIGN OF H_2O-LIBR SOLAR-DRIVEN ABSORPTION REFRIGERATING SYSTEM FOR NIGERIAN APPLICATION: A CASE STUDY

Madu, K. E. and Uyaelumuo, E. A,
Mechanical Engineering Department, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria.
Email: rexomanuel@yahoo.com, and tonychristus@gmail.com.

ABSTRACT

This paper presents the design of Water-Lithium Bromide (H_2O - LiBr) absorption refrigeration system powered by solar energy for application in the rural communities of South-Eastern part of Nigeria. Design consideration is given to the geographical and climatic conditions of Nigeria, since the country receives abundant solar radiated energy. With its teeming population of rural and sub-urban dwellers living with inadequate supply of energy from power companies, it becomes expedient to design a system that depends on energy from the sun for its operation. This system was designed with a generator/desorber temperature of 95^0C, evaporator temperature of 35^0C, and absorber temperature of 45^0C. Through the application of thermodynamic models, the analysis of the designed system parameters yielded the pressure limits of 0.87kPa at the evaporator of the system, and 5.29kPa at the condenser point of the system. The analysis of the designed system gives a very reasonable coefficient of performance (COP) of 0.807 and 1.259 at maximum. The available results show that the designed system with its thermodynamic parameters is very efficient and effective. The people of Nigeria and some sub-Saharan African nations can find the contrivance very invaluable.

Keywords: Solar Energy, Water-Lithium Bromide, Absorption System.

1.0 INTRODUCTION

The history of absorption cooling system development is dated back to 1858 when a French scientist named Ferdinand Carre invented an absorption cooling system using water and sulphuric acid. Solar energy is the most widely available renewable energy. The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. Utilizing and managing all available energy resources in a smart and wise manner is unarguable regardless of its renewability, sustainability or lack thereof. Many efforts have been made to advantageously use any wasted and un-utilized energy. Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW which is much larger than the present consumption rate on the earth, of all commercial energy sources known to man. In principle, solar energy could supply all the present and future energy needs of the world on continuous basis (Bajpai, 2012). In addition to solar energy size, it has two other advantages over fossil fuels and nuclear power; (a) it is an environmentally clean energy source; (b) it is free and available in adequate quantities in almost all parts of the world.

Moreno-Quintanar, Rivera, and Best (2011) developed a solar intermittent refrigeration system for ice production in Mexico using an ammonia /lithium nitrate/water ($NH_3/LiNO_3/H_20$) mixture with a COP of 0.98, which was 24% higher than those of the same system with $NH_3/LiNo_3$ mixture reported in literature. (Gunther, 1957). The refrigerant should be more volatile than the absorbent so that the two can be separated easily. Water is usually used as the refrigerant for solid absorbents. The need for two or more substances that should work together as a single solution of working fluid produced several variants of refrigerant–absorbent pairs in the absorption refrigeration industry. Chien, et al. (2013) investigated on an absorption refrigerator driven by solar cells; his efforts produced a low COP of 0.25. It was able to maintain a refrigeration temperature of 5.8^0C.

Oti (1995) reported that Nigeria has an estimated number of rural communities of over 97,000 whose population is characterized with deprivation from conventional energy, arising from poor supply of infrastructure. For instance, about 18% only of the rural population have access to electricity as at 1991/1992. However, where this convectional energy is available, its supply is unreliable. The readily available and widely utilized energy in the rural areas is the renewable energy type such as wood, agricultural and animal wastes, wind energy and solar energy which are mainly used for cooking, cottage industrial applications, winnowing and open-to sun-drying process (Augustine and Nnabuchi, 2010). Therefore, with abundant availability of solar energy in this West African nation Nigeria, it becomes imperative to utilize this energy for cooling processes such as refrigeration and air-conditioning and other areas of applicability. Electrolux absorption refrigerator uses ammonia, hydrogen and water as its working substances. At atmospheric conditions, ammonia is a gas with a boiling point of 33^0C. The cooling starts with high pressure liquefied ammonia entering the evaporator at ambient temperature. The partial pressure of the hydrogen gas affects the boiling point of the ammonia. As ammonia boils in the evaporator, it requires energy to overcome the enthalpy of vaporization. This energy is drawn from the refrigerator cabin providing the desired cooling effect (Karthk, 2014).

Refrigeration is a thermodynamic process in which external work is provided in order to move heat from one location of lower temperature to another location maintained at a higher temperature. (Mohanty and Padhiary, 2015). The primary purpose of refrigeration is lowering the temperature of an enclosed space or substance and then maintaining that lower temperature. The term cooling refers generally to any natural or artificial process by which heat is dissipated. Cold is the absence of heat, hence in order to decrease a temperature, one removes heat rather than adding cold. Presently, most of the cooling produced is by vapour compression or vapour absorption refrigeration system. The compressor of these vapour-compression systems uses a huge amount of electrical energy generated by burning fossil fuel. However, the scarcity of energy and depletion of fossil fuel sources around the world creates the need for the development of a refrigeration system that may run on an alternative source of energy. Therefore, this is where a solar powered vapour absorption refrigerating system (VARS) comes into play with great advantage. Moreno-Quintanar, Rivera, and Best (2011) developed a solar intermittent refrigeration system for ice production in Mexico using an ammonia /lithium nitrate/water ($NH_3/LiNO_3/H_20$) mixture with a COP of 0.98, which was 24% higher than those of the same system with $NH_3/LiNo_3$ mixture reported in thermodynamics literatures.

Refrigeration and air conditioning system as we know consume very high voltage and amperage for their effective operations. Even where there is reasonable supply, the cost of running this conventional refrigerating system, in homes, is exorbitantly high. Conventional refrigerating system which is dependent on electric power also has a draw-back of being environmentally hazardous due to the use of refrigerants like CarbonFluoroCarbon gases (CFC). These gases have very high global warming potential (GWP) and high Ozone Layer Depletion Potential (ODP).

There is a renewed interest in alternative energy, as scientists all over the world, are working hard to replace the conventional energy sources. Solar driven absorption refrigerating system, therefore, provides this alternative opportunity and environmental friendly operation.

2.0 METHODOLOGY

The design approach in this system is based on the consideration that the system will be put into use in the South–East geo-political zone of Nigeria. This solar powered absorption refrigeration system was designed on actual data obtained through metrological reports on solar radiation over Nigeria (Enugu and Owerri). Other parameters employed in the thermodynamic analysis of the system cycle were based on the actual and ideal conditions of operation. The material selections were designed based on standard specifications. Therefore, this study is to design and analyze an absorption refrigeration system driven by solar energy making use of H_20 (refrigerant) and LiBr (absorbent).

2.1. Evaporator: In the evaporator the temperature of evaporation regulates the lower pressure level of the absorption system. Due to the addition of latent heat from the refrigeration environment, the two phase refrigerant continues to evaporate. A complete evaporation process will convert the two phase refrigerant into vapour.
Energy balance for the evaporator is given as:

$$m_{10}(h_{11} - h_{10}) = m_{26}(h_{26} - h_{25}) \tag{2.1}$$

This is for H_20 –LiBr system and for $NH_3 – H_20$ system we have:

$$m_{12}(h_{13} - h_{12}) = m_{26}(h_{26} - h_{27}) \tag{2.2}$$

Thermodynamic diagram of H_20- LiBr AR-System

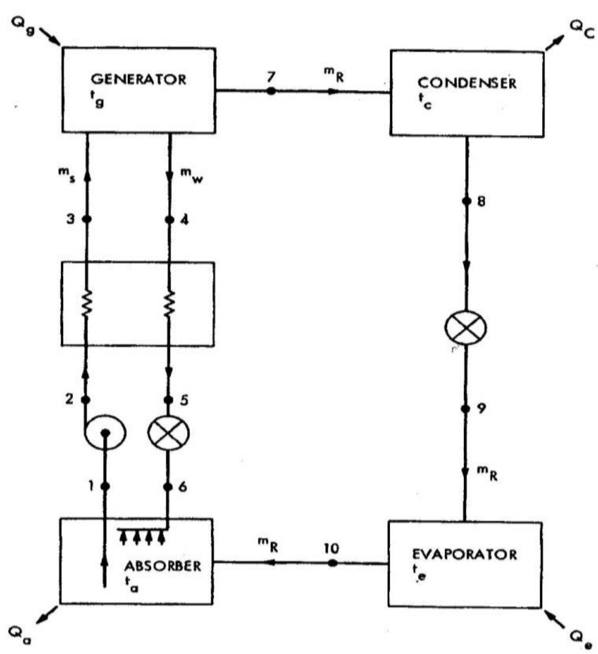

Figure 1: Flow Diagram for a Lithium Bromide/Water Absorption System (Lansing, 2000)

The log mean temperature difference is given as:

$$LMTD_e = \frac{(T_{26} - T_{11}) - (T_{27} - T_{10})}{In\left(\frac{T_{26} - T_{11}}{T_{27} - T_{10}}\right)} \tag{2.3}$$

2.2. Concentration of Absorber Solution: This is determined by applying equation (2.3) as follows

$$X_1 = X_2 = X_3 = X_{stong\ solution} = \frac{49.04 + 1.125\, t_a - t_e}{134.65 + 0.47 t_a} \tag{2.4}$$

2.3 Concentration of Generator Solution: This can be determined by applying the following equation:

$$X_4 = X_5 = X_6 = X_{weak\ solution} = \frac{49.04 + 1.125\, t_g - t_c}{134.65 + 0.47 t_g} \tag{2.5}$$

It may be noted that X_4 is always larger than X_1 and

$$X_7 = X_8 = X_g = X_{10} = 0 \tag{2.6}$$

2.4 Liquid – Liquid Heat Exchanger Temperatures:

Once the heat exchanger effectiveness E_L, the mass flow rates (M_w, M_s), and the concentrations (X_4, X_1) are obtained, it is possible to determine the solution temperatures t_3 and t_5 from Fig. 3.3. Going by the weak solution side, which has the minimum heat capacity, the effectiveness E_L is defined by (Kays and London, 1958):

$$E_L = \frac{t_g - t_5}{t_g - t_a} \tag{2.7}$$

Or by the strong solution side we have:

$$E_L = \frac{(m_s.\ C_{x_1}).(t_3 - t_a)}{(m_w\ .C_{x_1})\ .(t_g - t_a)} \tag{2.8}$$

And

$$\left.\begin{aligned} C_{x_1}\ 1.01 - 1.23X_1 + 0.48X_1^2 \\ C_{x_4}\ 1.01 - 1.23X_4 + 0.48X_4^2 \end{aligned}\right\} \tag{2.9}$$

Equations (2.8) and (2.9) can be rewritten using equations as temperatures t_3 and t_5 as:

$$t_5 = t_g - E_L(t_g - t_a) \tag{2.10}$$

And

$$t_3 = t_a + \left[E_L\left(\frac{X_1}{X_4}\right)\left(\frac{CX_4}{CX_1}\right)(t_g - t_a)\right] \quad 2.11)$$

Enthalpies H_1 and H_5will be calculated by applying equation;
$H_{x,25} + C_x(t - 25)$
Or

$$42.81 - 425.92\,X + 404.67X^2 + (1.01 - 1.23X + 0.48X^2)(t) \quad (2.12)$$

Therefore;

$$H_1 = (42.81 - 425.92\,X_1 + 404.67X_1^2) + (1.01 - 1.23X_1 + 0.48X_1^2).t_a \quad (2.13)$$

$$H_5 = (42.81 - 425.92\,X_4 + 404.67X_4^2) + (1.01 - 1.23X_4 + 0.48X_4^2).t_5 \quad (2.14)$$

2.5. Coefficient of Performance (COP): This is usually defined as follows:

$$COP = \frac{refrigeration\ effect}{external\ heat\ input} = \frac{Q_E}{Q_G} \quad (2.15)$$

It can simply be derived from equation (3.28) as:

$$COP = \frac{(H_{10} - H_8)(X_4 - X_1)}{[X_1H_5 + (X_4 - X_1)H_7 - X_4H_1]} \quad (2.16)$$

2.6. Ideal Coefficient of Performance: The maximum coefficient of performance of this designed absorption cycle is obtained as:

$$(COP)_{max} = \frac{T_e(T_g - T_a)}{T_g(T_c - T_e)} \quad (2.17)$$

Where T_e, T_a, T_c and T_g are the absolute temperature of evaporator, absorber, condenser and generator respectively. The relative performance ratio, which shows deviation from reversible cycle operation is given as:

$$Ratio = \frac{(COP)_{actual}}{(COP)_{max}} \quad (2.18)$$

3.0 RESULTS

The procedure followed in the analysis of design parameters of this VARS shows that the performance characteristics of a water/Lithium Bromide absorption system depends on many factors, like the temperature of fluid entering the generator/desorber, the cooling load at the evaporator, and the temperature of inflowing cooling fluid at the condenser or absorber. This system was designed based on the evaporator temperature of 5^0C. Therefore, from the analysis of results, it was obtained that the lower pressure in the evaporator and the higher pressure in the condenser are 0.87Kpa and 5.29KPa. The generator temperature of up to 95^0C, the condensation temperature of 35^0C, the absorber temperature at 45^0C and the evaporator temperature of 5^0C which were employed in the design, gave a very good coefficient of performance of 0.807 and a maximum COP of 1.259. The result of our design can be compared with that obtained by Lansing (2013), where 90^0C generator temperature, 40^0C condenser temperature, 40^0C absorber temperature and 7^0C evaporator temperature were used in running the system. The actual COP was 0.776 while the maximum COP was 1.1689. Therefore, the design parameters adopted by this study is quite recommendable for designing of Water-Lithium Bromide (H_2O - LiBr) absorption refrigeration powered by solar energy for application in Nigeria and most sub-Saharan African nations.

CONCLUSION

From many research analyses, it was seen that the level of global solar radiation recorded over this region especially in Nigeria were high. These values are adequate in citing solar driven systems as there is enough energy to power them all year round. Therefore, designing Water-Lithium Bromide (H_2O - LiBr) absorption refrigeration powered by solar energy that would be affordable but efficient for those living in the rural areas within Nigeria becomes imperative as majority of the rural dwellers are below poverty level. This will in no small measure enhance the living conditions of these people which are one of the objectives of the Millennium Development Goals (MDG) of Nigerian government.

Moreover, the present design uses environment friendly refrigerant, which presents a sustainability advantage when compared to other refrigerant selections. To minimize environmental hazards associated with refrigeration system operation, it is reasonable to evaluate the preferred refrigerant by the designer and the prospects of a clean source of energy. Hence, the design of a H_2O-LiBr absorption refrigerating system powered by solar energy is very invaluable. In this study the temperatures, pressures and concentration ration at different points were designed and evaluated. Thus the results indicate that a suitable and functional solar vapour absorption refrigerating system can be designed keeping in view the climatic conditions of the South-East geographical area of Nigeria.

REFERENCES

Alsagoor, S. and Alqdah, K. S. (2014), “Performance of a Refrigeration Absorption Cycle Driven by Different Power Sources”, Smart Grid and Renewable Energy, Vol. 5, pp. 161-169.

Augustine C., and Nnabuchi, M. N. (2010), “Analysis of some Meteorological Data for some selected Cities in the Eastern and Southern Zones of Nigeria”, African Journal of Environmental Science and Technology, Vol. 4, No. 2, pp. 22-99.

Bajpai, V. K. (2012). “Design of Solar Powered Vapour Absorption System". Proceedings of the World Congress on Engineering, Vol. III, London, U.K.

Chakraborty, J., and Bajpai, V. K. (2013), “A Review Paper on Solar Energy Operated Vapour Absorption System Using LiBr-H_2O”, International Journal of Engineering Research and Technology, Vol. 2, Issue 8, pp. 1-3.

Chien, Z. J., Cho, H. P., Jwo, C. S., Chien, C. C., Chen, S. L., and Chen, Y. L. (2013), “Experimental Investigation on an Absorption Refrigerator Driven by Solar Cells”, International Journal of Photoenergy, Hindawi Publishing, pp. 1-6.

Gunther, R. C. (1957). “Refrigeration, Air Conditioning and Cold Storage”, 2nd Edition, Chilton Company, Philadelphia, pp. 1232.

Karthik, K. (2014). “Design Fabrication and Analysis of Solar Vapour Absorption Refrigeration System”, International Journal of Emerging Technology and Advance Engineering, Vol. 4, Issue 9, pp. 435-441.

Oti, M. I. (1995). “Design, Manufacture and Installation of Multi-bladed Windmill”, NJSE, Vol. 13, pp. 110-117.

Moreno W. Q., Rivera, W. and Best, R. (2011), “Comparison Of The Experimental Evaluation of a Solar Intermittent Refrigeration System for Ice Production Operating with the Mixtures $NH_3/LiNO_3$ and $NH_3/LiNO_3/H_2O$.

Mohanty, D. K., and Padhiary, A. (2015) “Thermodynamic Performance Analysis of a Solar Vapour Absorption Refrigeration System”. International Journal of Enhanced Research in Science Technology and Engineering, Vol. 4, Issue 4, pp. 45 -54.