



Modeling and Simulation of Solar Absorption Cooling System for Maiduguri, Borno State, Nigeria

¹Daniel Isuwa, ²Sulaimon Shodiya, ²Fasiu A. Oluwole

¹Alliance for international Medical Action.

²Department of Mechanical Engineering, University of Maiduguri

ABSTRACT

Aspen plus model was used to predict the performance of the solar absorption cooling system using weather data of Maiduguri. This work simulates, analyze and optimize absorption refrigeration system using a flat-plate solar collector and LiBr-H₂O mixture as the working fluid. The LiBr-H₂O solution used shows higher cooling performance compared to other mixtures under the same absorption cooling cycle conditions. The cooling capacity and the coefficient of performance of the system (COP) were analyzed by varying all the independent parameters, namely: generator temperature, evaporator temperature, refrigerant concentration, and solar collector area. The result shows that these parameter values increases with increase in generator temperature but with negligible effects of evaporator and condenser pressures on the cooling capacity and cooling performance of the solar absorption cooling system. The coefficient of performance of 0.79 was obtained.

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INTRODUCTION

The high consumption of electricity contributes to economic and social problems in hot places. Massive use of cooling machines and prolonged used of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants causes destruction of the ozone layer and possible global warming due to excessive burning of fossil fuel. Absorption cooling system is a physiochemical process that replaces the mechanical process of the vapor compression system by using energy in the form of heat rather than mechanical work. The implementation of thermal system computer modeling places series of advantages by eliminating the cost of building prototypes, optimization of the system components, estimation of thermal energy loads delivered or received from or into the system, and prediction of

variation of the system parameters (e.g. Temperature, pressure and mass flow rate). The aim of this work is to model and simulate solar absorption cooling system for Maiduguri, Nigeria using Aspen plus software and lithium bromide-water as the working fluid.

Generally, there are two types of refrigeration cycle; vapor compression refrigeration cycle and vapor absorption refrigeration cycle. Vapor compression cycle is the conventional one which consumes a lot of electrical energy and uses CFC's refrigerants which is not environmentally friendly.

The absorption refrigeration technology has attracted much attention all over the world, for the reason that it is environmentally friendly and could make use of the low-grade energy, which refers to the ignored energy embedded in the



exhaust steam of low pressure and low temperature.

The development of absorption technology started in the early 1700's through 1860. During this period both the $\text{H}_2\text{O-LiBr}$ and the $\text{H}_2\text{O-NH}_3$ machines were in existence with the former machine introduced for cooling of industrial processes and the latter for ice making and food storage. Since then, the two machines became commercialized and can be acquired in various cooling capacities. Windhausen et al (1878) used this principle of absorption refrigeration system on H_2SO_4 Water which is a strong absorbent of NH_3 . If NH_3 is kept in a vessel that is exposed to another vessel containing water, the strong absorption potential of water will cause evaporation of NH_3 and it requires no compressor to drive the vapors. A liquid pump is used to increase the pressure of the strong solution and is then heated in a generator and passed through a rectification column to separate the water from ammonia. The ammonia vapor is then condensed and recycled. The pump power is negligible hence; the system runs virtually on low grade energy used for heating the strong solution to separate the water from ammonia. These systems were initially run on steam. Later on oil and natural gas based systems.

Balzar von Platen and Carl Munters, (1992) were two students of the Royal Institute of Technology, Stockholm that invented a three fluid system that did not require a pump. A heating based bubble pump was used to circulate strong and weak solutions which hydrogen was used as a non-condensable gas to reduce the partial pressure of NH_3 in the evaporator. Mittal et al. (2005) performed numerical simulations of a solar-powered single-stage absorption cooling system

using a flat-plate solar collector and $\text{LiBr-H}_2\text{O}$ solution. A modular computer program was developed for the absorption system to simulate various cycle configurations with the help of weather data of Bahal village district of Bhiwani on the western fringe of Haryana, India. The effects of hot-water inlet temperatures on the coefficient of performance and the surface area of the absorption cooling component was studied and the results showed that increment of hot-water inlet temperature decreases the absorber and solution heat exchanger surface area, while the sizes of the other components remain the same. In addition, Assim et al (2016) modeled an absorption chiller operated by hot water using an evacuated tube collector in TRNSYS software. It was found that the use of a hot water storage tank and a 12 m^2 collector area were sufficient to maintain the room temperature at 26°C or below during the cooling season. Sokhansefat et al. (2017) carried out a parametric analysis to find the optimum configuration for a 5-ton capacity solar absorption system in transient conditions using TRNSYS software in Tehran. The results indicated that the performance of the setup is capable of 28% enhancement. The optimum values were a collector area of 55 m^2 , temperature set point of the auxiliary boiler of 77°C , solar collector mass flow rate at 1000 kg/h , and collector slope of 33° .

MATERIAL AND METHOD

Aspen Plus V8.4 Software was used for the modeling and simulation of the Solar absorption cooling system. The inputs to the Model were mainly data collected from Borno state meteorological Agency for the year 2016. The theory of absorption refrigeration system working with Lithium Bromide (LiBr) and water, illustrated by Figure 1.1, consist of a condenser, an

expansion valve, an evaporator and a thermal compressor. In this cycle, water condenses (rejecting heat) and evaporates (extracting heat from the thermal load) similar to a refrigeration cycle by

mechanical compression. However, the thermal compressor located between the evaporator and condenser, performs vapor compression by using energy in the form of heat (solar energy in this case).

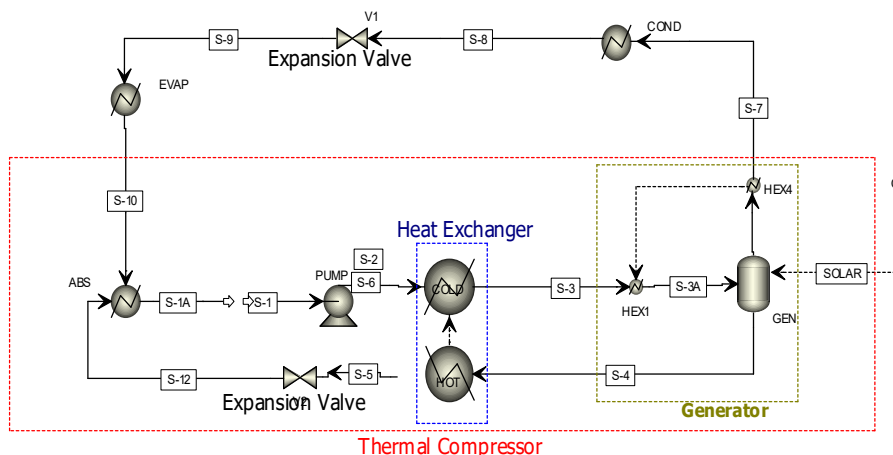


Figure 1.1: Process Diagram of the Water-LiBr absorption refrigerator

The thermal compressor consists of two major unit operations: Absorption and distillation. In the absorption, water vapor is absorbed by LiBr due to its affinity with water forming a weak LiBr/water solution in the absorber and in distillation (generator) the water vapor is separated from the strong LiBr/Water solution consuming heat. For a better cycle efficiency, separation must be almost complete, and water quality must be close to 1 (~0.999) in the generator output (Herold, et al., 1996). For improvement of the efficiency of the system, a regenerative heat exchanger is used between the absorber and generator.

Generally, the heat is removed from the system by cooling tower. The cooling water passes through the absorber first then the condenser. The temperature of the absorber has a higher influence on the system efficiency than the condensing temperature of the cooling tower where the heat is dissipated to the environment.

In the case that the sun is not shining, an auxiliary heat source is used by electricity or conventional boiler to heat the water to the required generator temperature. It is highly recommended to use a partitioned hot-water storage tank to serve as two separate tanks. In the morning, the collector system is connected to the upper part of the tank, whereas in the afternoon, the whole tank would be used to provide heat energy to the system.

Electrical energy consumption in an absorption cycle is minimal when compared to a compression cycle, since only the pump uses this energy to raise the pressure of the liquid solution formed in the absorber. In a vapor compression cycle, the compressor consumes much more electrical energy to raise the pressure of the refrigerant vapor that comes out of the evaporator. Table 3.1 describes the block used in ASPEN PLUS to represent each unit operation in the process.



Table 3.1: ASPEN PLUS Model Representation adopted from Balghouthi et al, 2008.

Units	Block	Descriptions
Cond	Heater (Exchanger)	Condenser
V1 and V2	Valve	Expansion Valve 1 and 2
Evap	Heater (Exchanger)	Evaporator
ABS	Heater (Exchanger)	Absorber
PUMP	Pump	Pump
Heat Exchanger	Heater (Exchanger)	Regenerative Heat Exchanger
GEN	Flash2	Distillation
Hex1	Heater (Exchanger)	vapor heat control
Hex4	Heater (Exchanger)	vapor heat control

Preliminary material balance is taken across each unit i.e. the generator, absorber, evaporator, condenser and heat exchanger to analyze the working conditions of all components of the system. Energy balances are performed and a computer simulation is developed for the cycle analysis. A control volume analysis around each component, which covered the rate of heat addition in the generator, and the energy input of the cycle, is given by equation Klein, et al.(1994). (1.1):

$$Q_{Generator} = Q_{Solar} = m_4 h_4 + m_7 h_7 - m_3 h_3 \quad (1.1)$$

The rate of heat rejection out of the condenser is given equation (3.2):

$$Q_{Cond} = m_7 (h_7 - h_8) \quad (1.2)$$

The rate of heat absorption of the evaporator is given by equation (1.3):

$$Q_{Evap} = m_9 (h_{10} - h_9) \quad (1.3)$$

The rate of heat rejection of the absorber is given by equation (3.4):

$$Q_{ABS} = m_{10} h_{10} + m_{12} h_{12} - m_1 h_1 \quad (1.4)$$

An energy balance on the hot side of the heat exchanger is given by equation

$$Q_{shx-hot} = m_4 (h_4 - h_5) \quad (1.5)$$

Similarly, an energy balance on the cold side of the heat exchanger is given by equation:

$$Q_{shx-cold} = m_2 (h_3 - h_2) \quad (1.6)$$

Coefficient of performance (COP) according to Figure 1.1.is defined as follows:

$$COP = \frac{Q_{Evap}}{Q_{Generator} + Q_{Pump}} \quad (1.7)$$

The solar collector was modeled in this manner proposed by Klein, et al.(1994). The basic equation for the rate of useful energy gain by a flat-plate solar collector is given by:

$$Q_S = F_r A_c (IR - U_L (T_{ci} - T_a)) \quad (1.8)$$

Where:

F_r = collector heat removal factor (0.8)

I = radiation intensity, W/m²K

R = ratio of total radiation on tilted surface to that on plane of measurement (1.08)

U_L = overall loss heat transfer coefficient, W/m²oK, (7.811)

T_c = temperature of the Collector surface (48°C)

T_a = ambient temperature (25°C)

For simplicity, the above values in bracket will be use based on the results obtained by Ezechi et al (2010). Radiation Intensity (I) was obtained from monthly daily average solar energy parameters measured in Maiduguri by (Luqman, et al., 2016).

MODEL SIMULATION

Aspen plus was used to simulate the solar-powered lithium bromide absorption system. The generator and absorber were modeled by using a multipurpose flash column. ASPEN PLUS uses the flash column to visualize generator and absorber operations. Simultaneously, a modular mode was used to solve the algebraic equations of the flow sheet. The Non-random two-liquid (NRTL) model and latent-heat enthalpy model were used in the simulation to obtain the

thermodynamic properties and phase equilibrium of the Lithium bromide solution. The NRTL model software keeps all flashes as three-phase flashes (LLV) or two-phase flashes (LV). Liquid phase activity coefficients were calculated by the NRTL equation by the known values of the liquid phase mass fraction. The NRTL equation is a good method to solve the binary mixture where equilibrium prevails between liquid and vapor.

The input data required for simulating the system consists of the following: generator temperature, absorber temperature, generator and condenser pressure, and evaporator and absorber pressure, pump output pressure, mass flow rate entering generator, lithium bromide solution concentration entering the generator and fixed saturated liquid state from heat exchanger to generator. Figure 1.2 shows flow-diagram for how simulation works using input data. The output includes the generator heat gain, cooling capacity and COP.

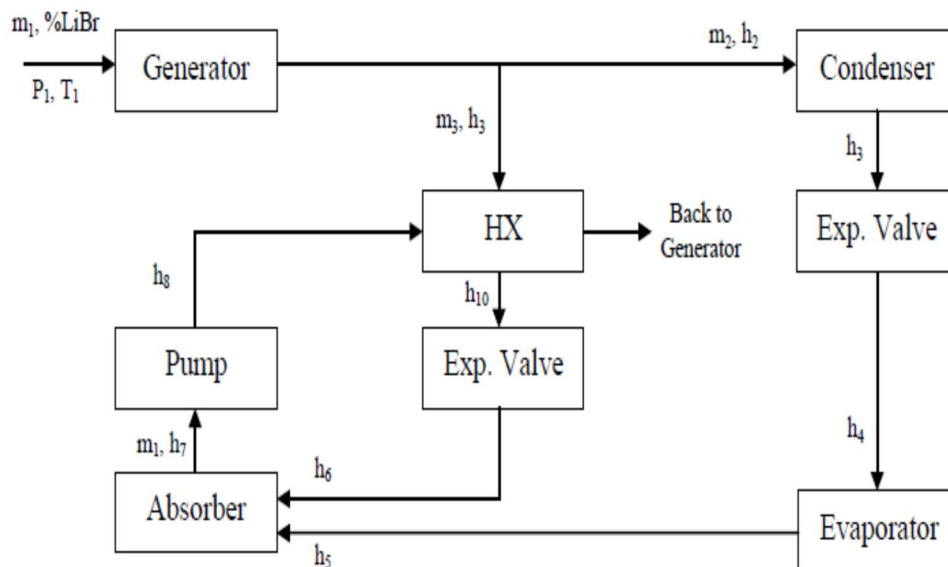


Figure 1.2: Modified Information-flow diagram for solar-powered absorption cooling system.

RESULT AND DISCUSSION

Two distinct studies were conducted. Firstly, sensitivity analysis study was conducted on the model in order to know the effect of different operating parameter on its Coefficient of Performance (COP). Parameters selected were based on the four major part of the system i.e. Generator temperature and duty, Evaporator Temperature and duty, condenser duty, absorber duty, LiBr-concentration, Solar insolation, and Solar collector area. Finally, an optimization study was conducted to determine the

optimum performance of the solar-powered absorption cooling system.

The effect of the variation of the generator temperature with Coefficient of performance (COP) and cooling capacity against generator temperature is shown in figure 1.3. The cooling capacity increases rapidly from a low value of 13 kW (at 79°C) up to 669 kW (at 150°C). The COP rises from a low value of 0.24 (at 79°C) to reach a constant value of 0.781 (at 111°C). The cooling capacity increases as the generator temperature increases.

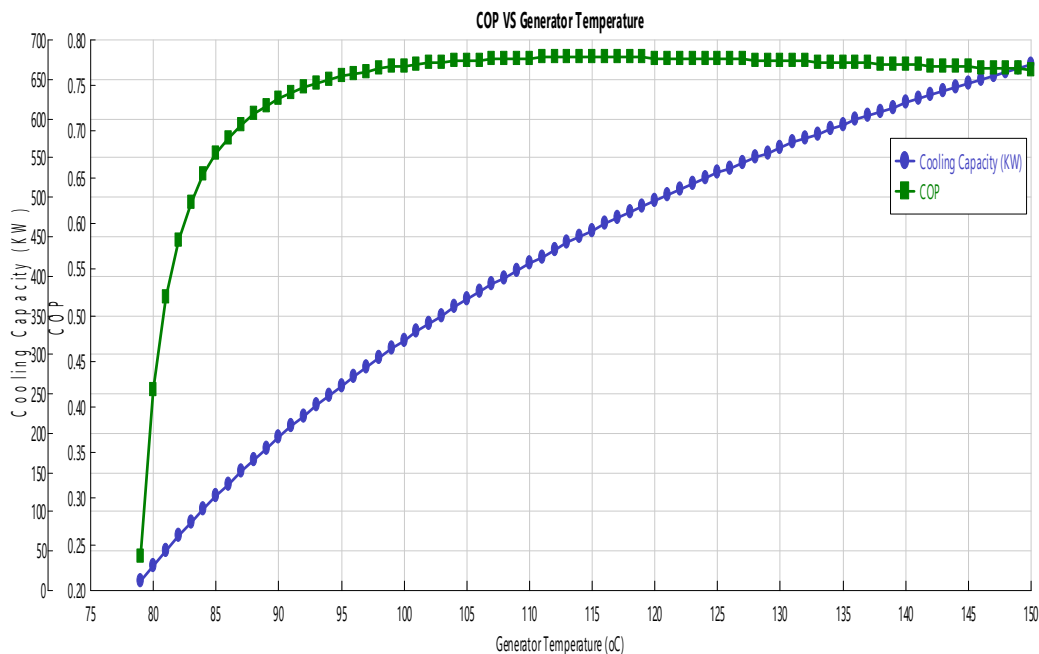


Figure 1.3: Effect of generator temperature on cooling capacity and COP as Predicted by ASPEN model.

The COP increase significantly with increasing generator/collector temperature, but as the generator/ collector temperature increases, the heat transfer in all the heat exchangers of the system also increases as shown in Figure 1.3. The figure shows similar increase in the heat transfer in all of evaporator, condenser and absorber when

varying the generator (or collector) temperature.

The concentration of Lithium Bromide (LiBr) solution increases rapidly with increase in generator temperature (See Figure 1.4). This is expected, since more water evaporates with temperature which results in more LiBr with less water in the generator (hence higher concentration).

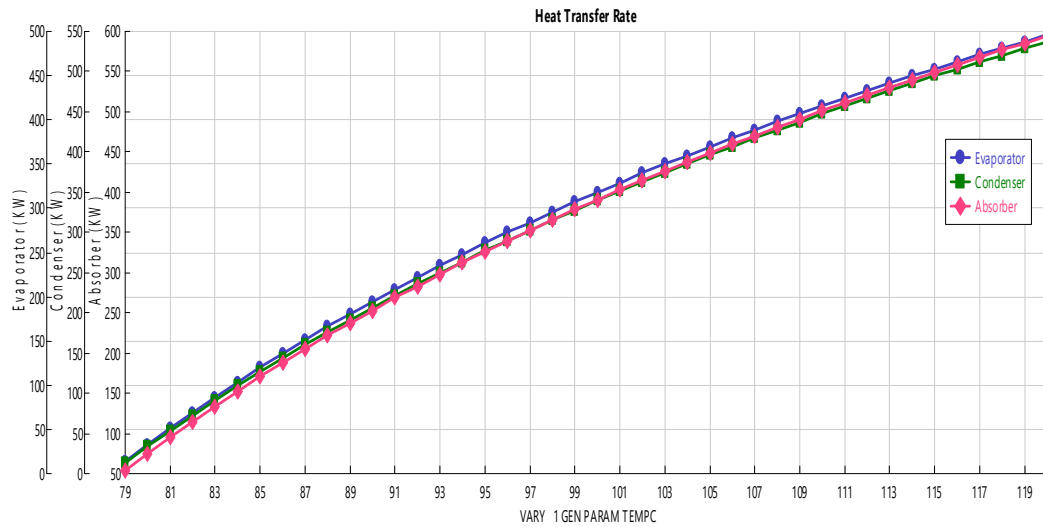


Figure 1.4: Effect of generator inlet temperature on evaporator, absorber, and condenser against generator heat transfer rates.

The concentration of Lithium Bromide (LiBr) solution increases rapidly with increase in generator temperature (See Figure 1.5). This is expected since more

water evaporates with temperatures which result in more LiBr with less water in the generator (hence higher concentration).

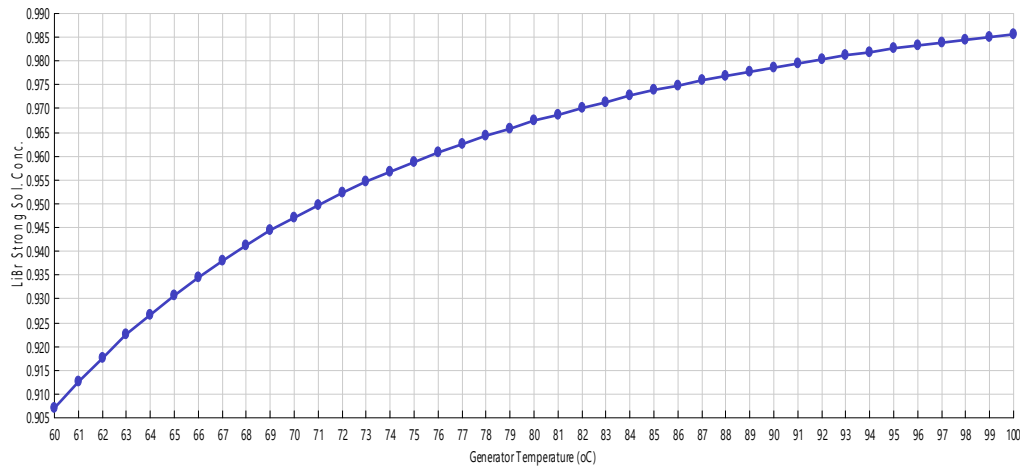


Figure 1.5: Effect of generator temperature (°C) on LiBr-H₂O concentration (kg)

The generator inlet temperature could not be increased or decreased too much because of the crystallization of the lithium bromide as seen in figure 1.6. Because lithium bromide is a salt, in its solid state it has a crystalline structure. There is a specific minimum solution temperature for

any given salt concentration when lithium bromide is dissolved in water. The salt begins to leave the solution and crystallize below this minimum temperature. In an absorption system, if the LiBr-solution concentration is too high or if the LiBr-solution temperature is reduced too low,

Corresponding author: Daniel, I. ✉ mr.daisuwa@yahoo.co.uk ✉ Alliance for international Medical Action. © 2020, Faculty of Technology Education, ATBU Bauchi. All rights reserved

crystallization may occur. The crystallization influences the cycle performance and the temperatures at different streams.

There are several causes for crystallization. Air leakage into the system is one of most common reason for crystallization. Air leakage results in increased pressure in the evaporator. This, in turn, results in higher evaporator temperatures and, consequently, lower cooling capacities. In the other case, at high load conditions, the control system increases the heat input to the generator, resulting in increased solution concentrations to the level where crystallization may occur. Non-absorbable gases, like hydrogen, produced during

corrosion, can also be present; this can reduce the performance of both the condenser and the absorber. Electric power failure is found to be another reason for crystallization. Crystallization is most likely to occur when the machine is stopped while operating at full load, when highly concentrated solutions are present in the solution heat exchanger. To solve this problem, during normal shutdown, the system should go into a dilution cycle, which lowers the concentration of the LiBr-solution throughout the system, so that the machine may cool to ambient temperature without crystallization occurring in the solutions.

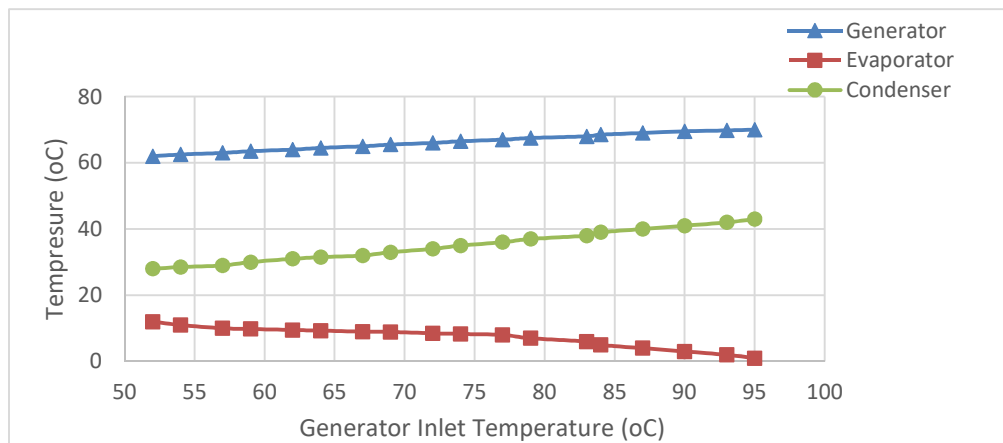


Figure 1.6: Effect of generator temperature ($^{\circ}\text{C}$)

Variation of Evaporator Temperature against COP

The greater the collector area the greater the heat gained. This can be good for the auxiliary boiler as seen in figure 1.6 above. Once the heat gained is increased, less heat is required from the auxiliary boiler to maintain the required generator temperature.

The next parameter of interest is evaporator temperature. This is an

important parameter to consider because it has a significant effect on chiller performance, as a higher evaporator temperature means a higher COP. The evaporator temperature is a set value that is dictated by the desired cooling temperature, but since a variety of cooling temperatures are needed in an LNG plant, it is important to consider a variety of evaporator temperatures.

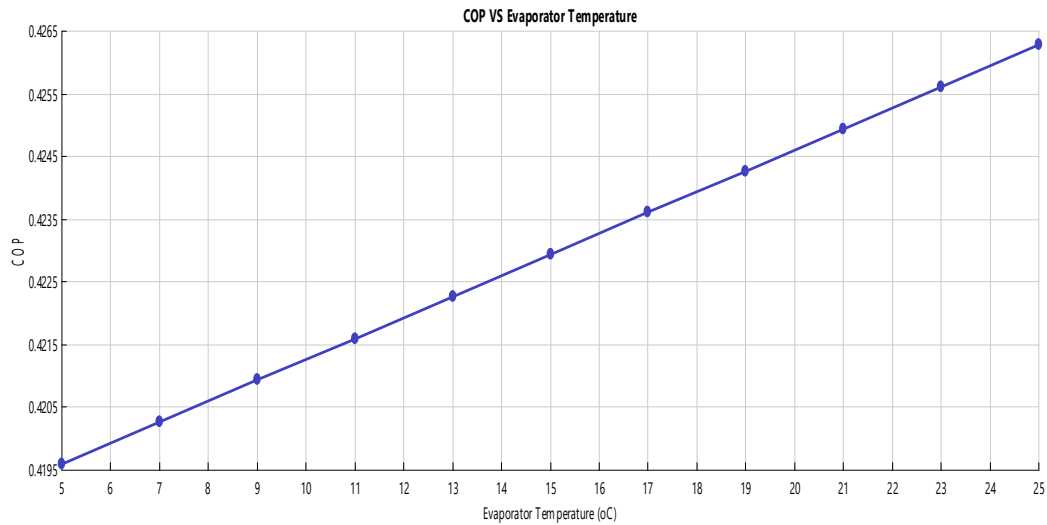


Figure 1.7: Effect of evaporator temperature on absorption cooling system COP as predicted by ASPEN model

From this Figure, it can be seen that; within the range of temperature investigated, the absorption cooling system COP increases from 0.4195 to 0.4262.

Variation of Lithium Bromide Concentration against COP

In this section, Lithium Bromide concentration was varied in the refrigerate solution in other to determine it significant on the COP. From Figure 1.8, it is shown

that the COP decreases rapidly with increase in LiBr-concentration. From this Figure, an increase in the concentration of LiBr from 0.03 to 0.88 LiBr kg/kg solution resulted in a decrease in the COP from 37 to 2 %. This is due to the little or lack of the absorbent (water) present for circulation in higher concentration of LiBr. Since higher LiBr concentration means lower water present.

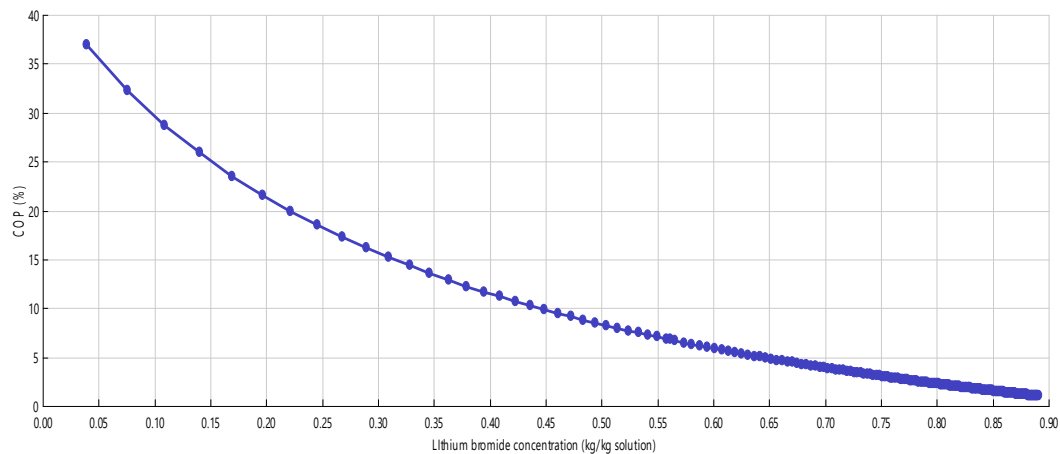


Figure 1.8: Effect of lithium-bromide concentration on the COP as predicted by Aspen model.

Variation of Solar Collector Area against COP

Increase in solar collector area on the same setting will supply more energy to the system, which in turn increase the

temperature of the generator thereby making more water to evaporate, this decrease the performance of the system. This behavior is depicted in Figure 1.9.

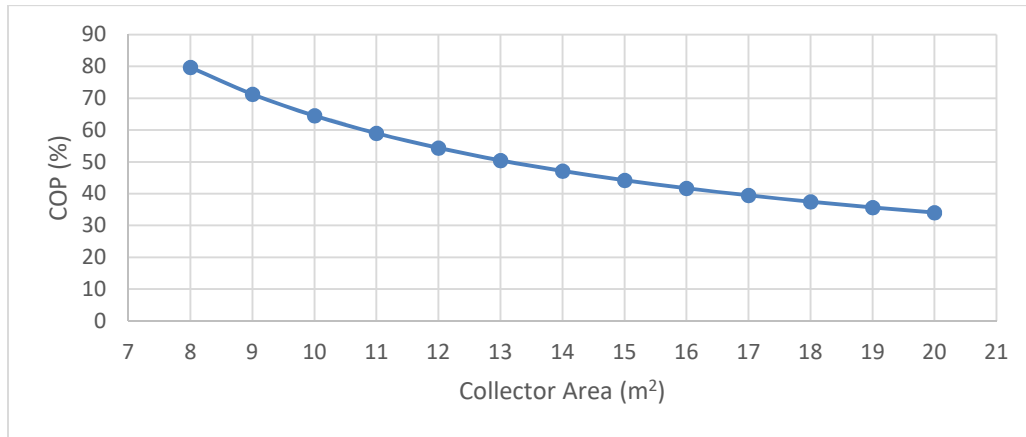


Figure 1.9: Effect of Solar Collector area on the COP as predicted by Aspen model.

Variation of Solar Insolation against Months of the Year.

Figure 1.10. Illustrate a typical climatic condition of Maiduguri in a particular month, as depicted by the insolation variation in the month. This

values used in the model to provide the heat required in the generator based on Equation 1.8. From this Figure, it can be seen that more heat (energy) is expected between Augusts to December of the year.

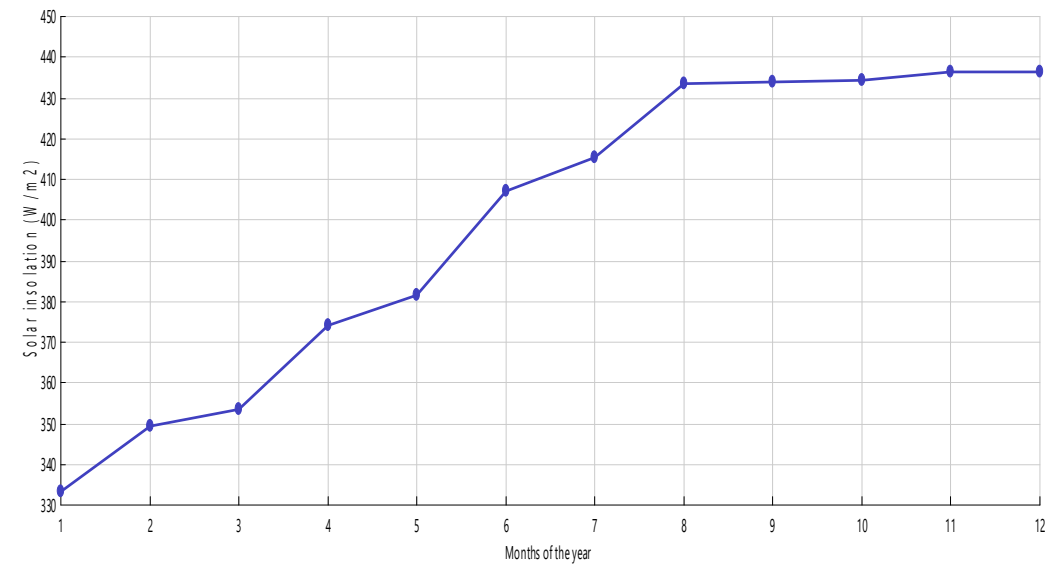


Figure 1.10: Effect of Solar Collector area on the COP as predicted by Aspen model.



CONCLUSION

Model for solar absorption cooling system was developed, the simulation of the solar absorption cooling system was carried out and a COP of the optimal absorption cooling system was obtained to be 0.684. The COP after optimization increases from 0.684 to 0.79

REFERENCES

- Asim, M., Dewsbury, J., Kanana, S. (2016). TRNSYS simulation of a solar cooling system for the hot climate of Pakistan. *Energy Procedia*, 91, 702–706. [CrossRef]
- Dara, J. E., (2010). Modeling and evaluation of Paasive Flat- plate solar collector, AKWA: Nnamdi Azikiwe University.
- Herold, K. E., Radermacher, R., and Klein, S, (1996). "Absorption chillers and heat pumps, CRC Press, Boca Raton. *International Journal of Refrigeration*, 24(6), pp. 531-543.
- Klein, S. A. (2018). EES Engineering Equation Solver, User Manual, F-Chart Software. Available online: <http://www.unh.edu/p2/ihf/ees.pdf> (accessed on 1 November 2018).
- Mittal, V., Kasana, K.S., and Thakur, N.S., (2005). Performance evaluation of solar absorption cooling system of Bahal (Hatyana)," *Journal of Indian institute of Science*, vol. 85, pp. 295-305.
- Sokhansefat, T.; Mohammadi, D.; Kasaeian, A.; Mahmoudi, A.R. (2017). Simulation and parametric study of a 5-ton solar absorption cooling system in Tehran. *Energy Convers. Manag.* 148, 339–351. [CrossRef]
- Sparber, A. Napolitano, P. Melograno, (2007). Overview on worldwide installed solar cooling systems, *Proceedings of 2nd international conference on solar air conditioning*, Spain.
- Wilbur, P.J, and Mitchell, C.E, (1975). "Solar absorption air conditioning alternatives," *Solar Energy*, vol.17, no. 3, pp. 193-199.
- Yeung M.R., Yueu P.K., Dunn A., Cornish L. S., (1992). Performance of a solar powered air conditioning system in Hong Kong. *Solar energy*, Vol. 48, N°5, pp. 309-319.