International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 6, ISSN No. 2455-2143, Pages 74-95

ABSORPTION COOLING SYSTEM UTILIZING DIESEL ENGINE EXHAUST HEAT

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ABSTRACT— **The global industrial development, the increasing demand for energy, the limited availability of resources for the future generations of fossil fuels, and the prevention of environmental damage caused by their burning have led to public concern. Increasing energy consumption by buildings has led the wider global attention to its social, environmental, and economic implications. In this study, the emission gases from diesel engines have been utilized to drive a single effect absorption cooling system.**

In this study, water and lithium bromide mixture $\mathrm{H_2O} - LiBr$ is used as a working fluid in absorption cooling system to benefit from waste heat from diesel engine that it may reach 190°C. This system mostly require only waste heat as the energy source to function properly. It has several advantages such as lower required electricity compared with vapor compression system, and it uses safer refrigerant. Engineering Equation Solver EES was executed to analyze the performance of this system, and to study the effects of the temperature of the generator, the absorber, the condenser and the evaporator on the performance of the system and on the cooling capacity. The cycle simulation is based on the operating temperature ranges and fixed parameters which includes:

Evaporating temperature within a range of 5-20 °C, generator temperature within a range of 90-120°C, condenser temperature ranges from 25 to 38°C, absorber temperature range from 25 to 34°C, effectiveness of heat exchanger range from 0.64 to 0.8, strong solution flow rate 0.05 to 1.5 kg/s. The Coefficient of Performance COP of the system, based on these inputs, reaches about 0.76 and the cooling capacity reaches to 14 kW.

It is found that when the generator temperature is increased, the COP is decreased. This is because the increase in generator temperature lowers LiBr-water concentration. Also, the temperature increase of the generator increases the cooling capacity. The increase in the absorber temperature reduces the COP as well as the cooling capacity. This is due to a decrease in the concentration of the solution. The absorption rate could be raised by increasing the solution concentration. The higher the concentration, the greater the absorption rate. The COP and cooling capacity improves when the evaporator temperature increases. The increase in effectiveness of heat exchangers causes an increase of system COP.

Keywords— **EES, LiBr-H_2O Absorption Chiller, COP, Cooling Capacity, Diesel Engine**

I. INTRODUCTION

A. General Introduction

A very large percentage of the energy produced in the world is used for cooling and air conditioning purposes. Heating, Ventilation and Air Conditioning (HVAC) is generally responsible for a significant proportion of total building energy consumption. A typical system accounts for approximately 40% of total building consumption and 70% of base building consumption. The pie graph in Fig. 1 below shows the typical energy consumption breakdown of an office building [1]. Being 5% lighting, 22% equipment, 4% lifts, 1% domestic hot water and 9% other.

There are a number of key end uses in HVAC systems. The bar Graph in Fig. 2 shows the typical end use breakdown.

The market of refrigeration and air conditioning is rapidly expanding all around the world due to the increase of needs for comfort by a growing world population. This fast evolution has entrained a galloping consumption of energy in general and in electrical energy in particular. As this form of energy is mainly produced by combustion of fossil energy resources (i.e. oil, gas, coal), these cover approximately 80 % of the world energy demand today ,and their combustion contributes greatly to the emissions of greenhouse gases, essentiallyCO_2. Moreover CFC and HCFC refrigerants used in common refrigerators and chillers working according to the technique of vapor compression are destructive for the ozone layer which protects the life on earth and, consequently, highly harmful.

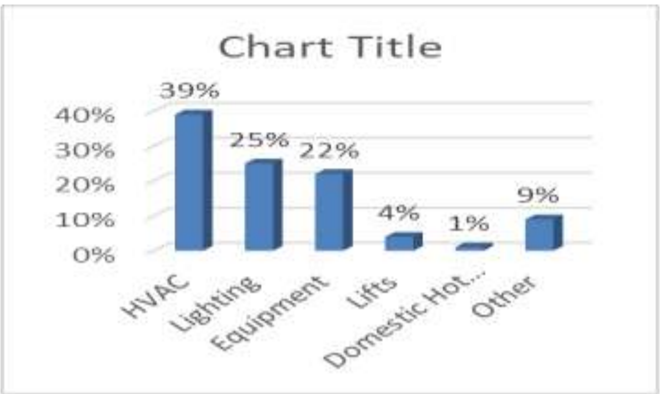


Fig.1Typical Energy Consumption Breakdown in an Office Building

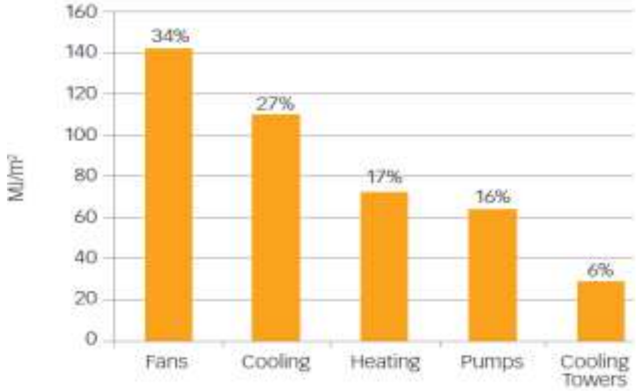


Fig. 2 Typical HVAC End Use Breakdown

To reduce the emissions of greenhouse gases and the gases responsible for the enlargement of the ozone hole that is observed in the atmosphere, several protocols and international agreements were signed: protocol of Montreal in 1987 to limit the use of the CFC and HCFC refrigerants, Kyoto protocol in 1998 for the CO_2 and the greenhouse gases, etc. These agreements have the objective to bring the signatory countries to reduce their greenhouse gas emissions by at least 5% compared with the level of 1990 during the period of commitment from 2008 to 2012. In 2015 the United Nations Climate Change Conference (COP21) was held in Paris, France. The objective of this conference was to achieve, for the first time in over 20 years of the United Nations negotiations, a binding and universal agreement on climate, from all the nations of the world, with the aim of keeping global warming below 2°C. On April 2016, 174 countries signed the agreement and began adopting it within their own legal systems (through ratification, acceptance, approval, or accession) [2].

The amounts of heat emitted from thermal power plants, turbines and engines in general are wasted energies and are also a source of thermal pollution that affects the surrounding environment, and there are many applications that can benefit from this wasted energy. One of these applications is used in the field of refrigeration, especially in desert and hot regions. Absorption cooling lithium bromide - water or ammonia - water is the system used to benefit from this waste heat energy.

The engines used in Sudanese Pipelines Petroleum Company (SPPC) works to pump fuel from the depots of Port Sudan to Khartoum via diesel engines. These engines emit high thermal emissions, so this wasted thermal energy has been utilized to generate a single-effect lithium bromide-water absorption cooling system to cool a server's room in the company.

The engines used in this system is the MTU diesel engine, and its specifications are as follows:

Version: MTU-p-2000; 4 Stroke – 12 Piston (V shape); Power = 480 Kw; Rated speed = 1560 rpm; Actual exhaust heat = 200℃.

B. Statement of the Problem

The global demand for air conditioners is increasing daily, this increases their need for more energy, and on the other hand the waste energies from internal combustion engines increase and affect the environment. This behavior accelerates global warming and impact the ozone layer. Up to 60% of the heat energy produced in internal combustion engines is waste energies, one third of this energy is wasted in engine cooling system and one third in of energy is wasted as exhaust gases. Fig. 3 below illustrates the amounts of heat dissipated from engines [3].

The increasing demand for air conditioning and refrigeration, and these amounts of wasted energies lead us to think about cooling systems that are powered by wasted thermal energies such as absorption cooling system. An Exhaust gases reaches to 200 ℃ of an internal combustion engine with power 480 Kw and speed reaches to 1560 rpm have been utilized to operate a single effect $H_2O - LiBr$ absorption cooling system.

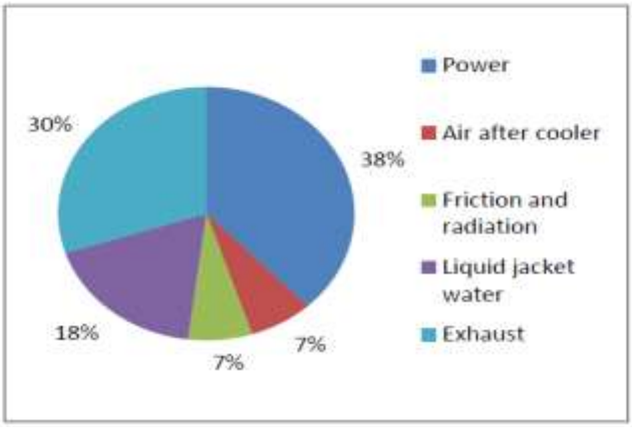


Fig. 3 Amounts of Heat Dissipated from Engines

C. Objectives

1- Know how to utilize waste energy gases in conditioning and refrigeration purposes.
2- Study the performance of absorption cooling system in the atmospheric conditions of Port Sudan city.
3- Analyzes the effect of the temperature change of vapor absorption component of the generator on the system.
4- Study the coefficient of performance of the system at different generator temperatures.
5- Arrived to optimal design values for $H_2O - LiBr$ absorption cooling system by simulating the values by EES software.

D. Methodology

The following activities provided are used to boost efforts for accomplishing the above mentioned objectives:

In the initial stages, focus is directed towards gaining an exhaustive understanding of the field of thermal driven air conditioning and refrigeration systems. Particular attention was paid to modeling and simulation of them. Relevant scientific articles from a number of bibliographic databases obtained and read which provided a foundation for literature review.

The second stages present the various mathematical and thermodynamics modeling approaches that existed in literature. These methods are carefully explored and one selected for preliminary modeling of a single-effect absorption cooling system. To get a full understanding and first-hand synthesis of the simulation results a quick comparison with results obtained by other authors has been done.

Using EES and mathematical models constructed and their output tested and validated against the outputs of the physical model selected from existing models presented in literature review.

- Analyzing program results (EES) and making comparisons of the effect of variables with each other and obtaining the system's efficiency through analysis.

II. BASIC PRINCIPLES AND LITERATURE REVIEW

A. Absorption Refrigeration System

An absorption refrigeration system is a heat activated thermal cycle; it exchanges the thermal energy with its surroundings. It operates often (always in a LiBr system) at lower pressure than the atmospheric pressure, where this pressure is regulated by the vapour pressure of the working fluid. The vapour pressure of the working fluid is obviously strongly related to the temperature of the working fluid. An absorption system could be, at its simplest, a single effect or more advanced multiple effect absorption cycle. A single effect can be considered to occupy two pressure levels where the pressure difference only occurs in the flow regulators and solution pump, neglecting the pressure drop along the circuit and changes in elevation [4].

A single effect refrigeration system basically consists of one solution pump, two flow regulators and five heat exchangers where four of them will transfer the heat from the external source while the rest will work internally within the system as a solution heat exchanger. It is optional to install the solution heat exchanger in a basic single effect absorption refrigeration system, but in order to increase the refrigeration performance such a unit should be attached.

A specific format of an absorption refrigeration system's components can be drawn on a Duhring plot which will describe the cycle based on the temperature and pressure level of each component and their position within the system, together with their energy transfer between the system and the environment (Fig. 2-1). As a basic representation of a specific heat transfer process, a Duhring chart can only schematically show the saturated states while the superheated and sub-cooled states cannot be accurately presented. The arrows that point out and into the cycle indicate the energy flow from the system out to the external environment and the energy flow that is supplied to the system, respectively. Heat rejection is employed by the absorber and condenser while the heat is injected into the system through the desorber and the evaporator. Fig. 2-1 below shows Duhring plot for single effect absorption system.

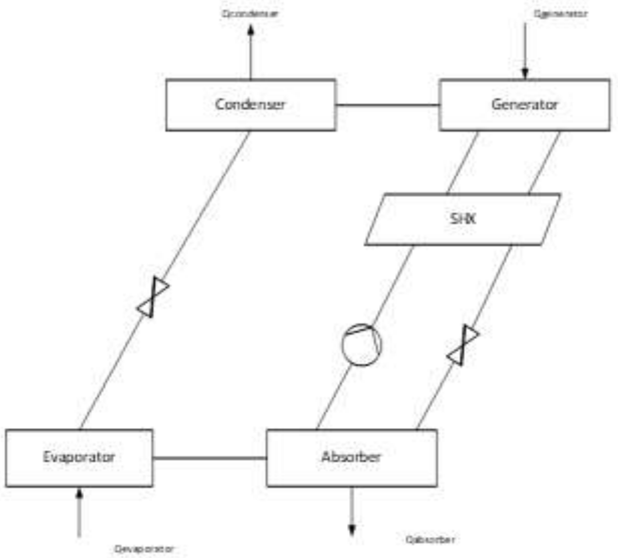


Fig. 4 Duhring Plot for Single Effect Absorption System

Working fluid from the outlet of the absorber is pumped by the solution pump to the higher pressure level. In the desorber the refrigerant is then extracted from the working fluid solution by the addition of extra heat from an external heat source into the desorber and the rest of the solution in liquid state is drained back to the absorber as absorbent, ready to absorb the refrigerant vapour from the evaporator. Heat rejection and the condensation process of the refrigerant vapour occur inside the condenser giving a liquid phase of the refrigerant. The liquid then passes through an expansion valve, which lowers the pressure environment and produces a low temperature refrigerant liquid that is ready to be used for refrigerating purposes. The mixing of the absorbent and the refrigerant will bring the solution back into the initial liquid state condition and makes it possible to be pumped by the solution pump to the next cycle.

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 System (ARS) industry. 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 the solid absorbents [5].

There are several common combinations of absorbent-refrigerants:

- Water and Ammonia $H_2O - NH_3$
- Lithium Nitrate and Ammonia $NH_3 - LiNO_3$
- Lithium Bromide and Water $H_2O - LiBr$
- Lithium Chloride and Water $LiCL - H_2O$

A recent developmental process of refrigerant-absorbent pairing improves the performance of the absorption system, for example:

- Lithium Bromide and (Water-Ammonia) $LiBr\ and\ H_2O - NH_3$
- Glycerol and Water $C_3H_8O_3 - H_2O$
- (Lithium Nitrate-Potassium Nitrate-Sodium Nitrate) and Water ($LiNO_3 - KNO_3 - NaNO_3$) and H_2O

Lithium Bromide-Water and Water-Ammonia as conventional fluids still have desirable properties compared to other working fluid variants, especially for the high number of latent heat so can minimize the need of refrigerant flow rate. The Lithium Bromide-Water combination is limited to temperatures above the freezing point of water while the Water-Ammonia combination is favourable for sub-zero refrigerant temperatures, so Lithium Bromide-Water is the system that will be used in this study.

A.1 Absorber

The absorber is a chamber where the absorbent and the refrigerant vapour are mixed together. It is equipped with a heat rejection system, i.e. bundles of tubes as in the condenser, and operates under a low pressure level which corresponds to the evaporator temperature. The absorption process can only occur if the absorber is at a sensible low temperature level, hence the heat rejection system needs to be attached. The mixing process of the absorbent and the refrigerant vapour generate latent heat of condensation and raise the solution temperature. Simultaneous with the developmental processing of latent heat, heat transfer with cooling water will then lower the absorber temperature and, together with the solution temperature, creates a well blended solution that will be ready for the next cycle. A lower absorber temperature means more refrigerating capacity due to a higher refrigerant's flow rate from the evaporator.

A.2 Generator

The generator operates under high pressure which is controlled either by the temperature of the incoming heat to the generator or the condensation temperature required by the cooling water entering the condenser. The desorption process generates vapour and extracts the refrigerant from the working fluid by the addition of the external heat from the heat source; it could be desorption of water out of a lithium bromide-water solution. The refrigerant vapour travels to the condenser while the liquid absorbent is gravitationally settled at the bottom of the desorber; the pressure difference between the desorber and the absorber then causes it to flow out to the absorber through an expansion valve.

A lithium bromide-water system has lower temperature requirements for a refrigerant desorption process (75-120°C) [6].Changes in fraction during the extraction process of a refrigerant is fully controlled by the amount of heat supplied to the desorption process and vice versa. A strong lithium bromide solution is produced during desorption process for lithium bromide system. These strong lithium bromide acts as the absorbent that will absorb the refrigerant in the absorber.

A.3 Condenser

The liquid state of the refrigerant is essential to the operation of the refrigeration process. Hence, the vapour phase of a refrigerant from the desorber is altered to a liquid by the condenser. The condensing process of a high pressure refrigerant vapour is done by rejecting the vapour's latent heat to the sink, following a regular heat balance formulation.

The sub-cooled liquid from the condenser is then passed through an expansion valve which lowers the pressure level; a consequence of this process is that some low quantity may flash into vapour. However, the refrigerant can still take latent heat from the environment.

A.4 Evaporator

The temperature of evaporation regulates the lower pressure level of the absorption system. A low pressure of two phase refrigerant from the flow regulator continues to evaporate due to the addition of latent heat from the refrigeration environment. A complete evaporation process will convert the two phase refrigerant into vapour.

A.5 Expansion Valve

An expansion valve is a component that reduces the pressure and splits the two different pressure levels. In a simple model of a single-effect absorption cooling system it is assumed that the pressure change occurs only at the expansion valve and the solution pump. There is no heat added or removed from the working fluid in the expansion valve. The enthalpy of the working fluid remains the same on both sides. The pressure change process between the two end points of the expansion valve, while there is no mass flow change and the process is assumed as an adiabatic process, can change the volume if the fluid generates a small amount of steam phase via flashing.

The presence of the Solution Heat Exchanger (SHX) and Refrigerant Heat Exchanger (RHX) will drive the expansion valve's input fluid close to a sub-cooled state, and at the end will affect the amount of the steam flash out of the expansion valve.

A.6 Solution Heat Exchanger

A solution heat exchanger is a heat exchange unit with the purpose of pre-heating the solution before it enters the desorber and removing unwanted heat from the absorbent. The heat exchange process within the solution heat exchanger reduces the amount of heat required from the heat source in the desorber and also reduces the quantity of heat to be rejected by the heat sink (cooling water) in the absorber as well. The heat exchange process occurs between the low temperature of the working fluid and the high temperature of the absorbent which will benefit both.

A.7 Solution Pump

Although the main distinction between compression and absorption refrigeration is the replacement of the mechanically driven system by a heat driven system, the presence of a mechanically driven component is still needed in an absorption system. A solution pump will mainly circulate and lift the solution from the lower pressure level side to the higher pressure level side of the system.

The pumping process is negligible; it only consumes a small amount of energy compared to the overall system heat transfer process. Although the existence of the solution pump can be ignored thermodynamically, practical experience shows that the pump is a critical component that must be carefully engineered [6].

B. Water/Lithium Bromide Absorption System

Lithium bromide aqueous solution is one of many other solutions widely used in the operation of the absorption heat pumps that are used for heating and cooling purposes. It has been used since the 1950s when the technology was pioneered by several manufacturers where water acts as the refrigerant which absorbs and removes heat from the specific environment while lithium bromide becomes the absorbent that absorbs the water vapour into a solution and makes it possible to be circulated by a solution pump [7]. As an absorbent, Lithium bromide is advantageous because it is essentially non-volatile, resulting in cycle designs that avoid the need of rectifiers. Water is advantageous as the refrigerant because it does not crystallize; its limitation is that it will make the system work only for refrigeration temperatures above 0°C or even 5°C, due to the freezing point of water. Lithium bromide is a lithium salt substance and indeed it is solid under normal conditions. However lithium bromide salt is highly soluble in fluids. It dissolves in water and forms a lower equilibrium vapour pressure of solution than pure water at the same operating temperature. As a comparison at the same 50°C reference temperature, a 60% Lithium Bromide has 6.47 kPa vapour pressure and pure water has 12.35 kPa. This condition could be found between the evaporator and absorber which would drive the refrigerant naturally from the evaporator side (pure water condition) to the inlet of the absorber (Lithium Bromide-water solution). A complete equilibrium chart for an aqueous lithium bromide solution for various solution concentrations is presented in Fig. 5.

There are five assumptions for the thermodynamic states occupied by the cycle as illustrated in Fig. 6: saturated liquid (points 1, 4 and 8); saturated vapour (point 10); superheated vapour (point 7); sub-cooled liquid (points 2, 3 and 5); and two-phase solution (points 6 and 9). Point 6 can often also be saturated or nearly saturated liquid. These assumptions are still valid in order to achieve a simple modelling process and do not introduce a large error [7] since in the real machine the saturated condition will not be exactly saturated and the liquid stream would be sub-cooled while the vapour stream would be superheated. For the temperature range and typical single effect application, carbon steel and copper are the preferred construction materials. Lithium bromide absorption machines have been proven to have a life expectancy of approximately 20 years; afterwards significant corrosion can be observed [7].

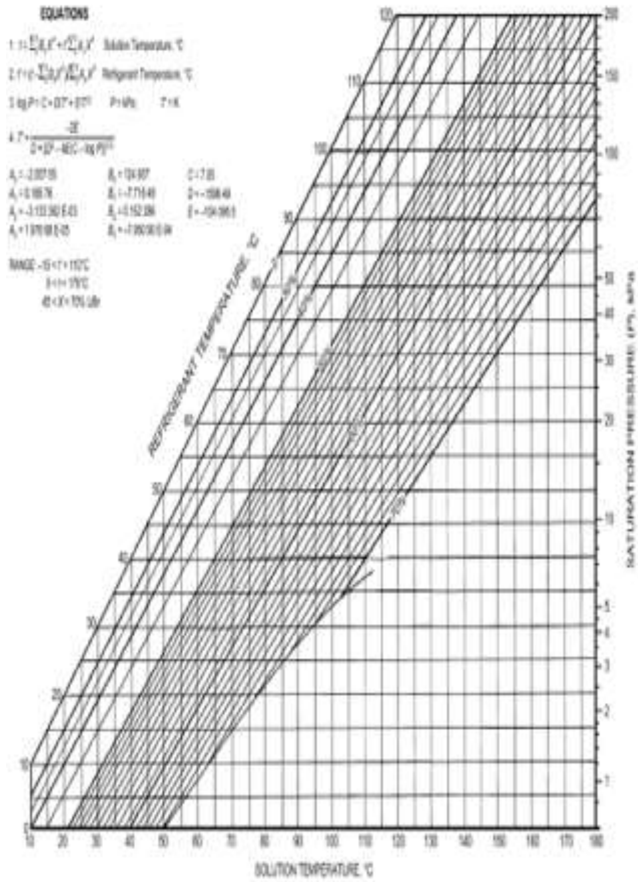


Fig. 5 Equilibrium Chart for Aqueous Lithium Bromide Solutions

(ASHRAE, 2005) [8]

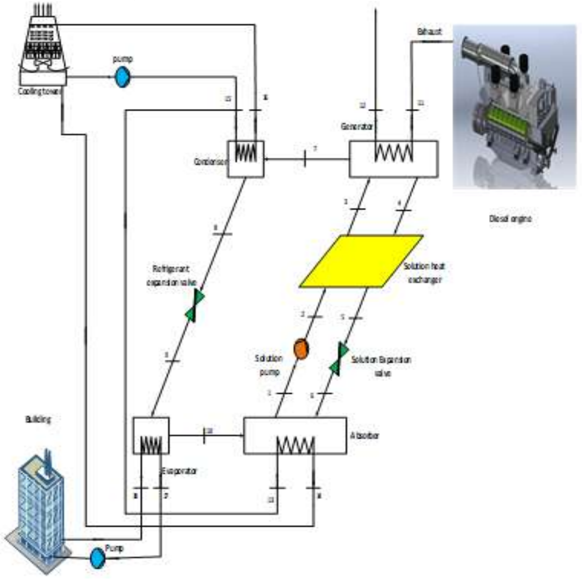


Fig. 6 Schematic Diagram of Single Effect Lithium Bromide-Water Absorption System

C. Literature Review

Salameh et al. [9] analyzed the performance of a single-effect (LiBr-water) absorption chiller driven by hot fluid rejected from either a geothermal power plant or the outlet of a thermal solar collector by using Engineering Equation Solver (EES) software, to highlight the effect of the heat exchanger size on the coefficient of performance of the chiller. The analysis proved that the proposed device can operate with excellent cooling capacity, reaching 16 kW, and a relatively high coefficient of performance (~ 0.7) while being driven by the low-grade energy. The heat source temperature, solution heat exchanger effectiveness and the size of the absorber were shown to be key parameters for the design and operation of absorption chillers. Moreover, increasing the heat source mass flow rate has a significant impact on both cooling capacity and coefficient of performance at low values and high value (< and > 10 kg/s).

Fischer et al. [10] studied the influence of the external flow rates on single effect LiBr - water absorption chiller. A thermodynamic modeling of a single effect absorption chiller was developed based on mass, energy and species balances in steady state condition to analyze the effects of the external flow rates in this chiller. The increase of the hot water flow rate or the cooling water flow rate produces better performance of the chiller. If the chilled water flow rate decreases, the performance improves consequently. In the flow rates range analyzed of the chiller, the best performance configuration is obtained with 120% of hot water flow rate and the cooling water flow rate, and 80 % of chilled water flow rate. Higher inlet hot water temperatures result in higher coefficient of performance (COP) and heat removed as well as lower inlet cooling water temperature.

Shang et al. [11] developed a transient dynamic model for a single-effect absorption refrigeration chiller using LiBr/H_2O. The model contains a series of sub-models presenting the components composing the chiller. The development of the sub-models of the four main components (i.e. generator, condenser, evaporator, and absorber), where the solution or refrigerant goes through phase change with complex heat and mass transfer progress, and is based on the conservation of mass and energy, by means of dynamic modeling approaches. The throttling devices, solution pump, and solution heat exchanger (SHE) adopt quasi-steady models because their thermal inertia is much smaller compared with the main components. The system model proposed in this study is finally simplified and expressed in the form of state space matrix, which enhances the model portability and computational efficiency. Ghodeshwar and Sharma [12] provided an analytical approach by the application of first and second Law of thermodynamics with mass and energy balance equation to study the vapor absorption refrigeration system by using solar energy refrigeration system. The main aim of this work is to study Lithium Bromide- Water (LiBr-H2O) absorption system with the capacity of 1.5 ton. The COP of the system is calculated on the basis of hot water as a heat source. Girisha et al. [13] studied effect of cooling water and COP (Coefficient of performance) on single effect Lithium Bromide–Water (LiBr–H2O) absorption based heat pump. They presented a detailed thermodynamic analysis of the single-stage LiBr–H2O vapor absorption heat pump.

Rasheed et al. [14] executed numerically thermodynamic analysis of a 4TR single stage absorption chiller by using Engineering Equation Solver (EES) software. In this chiller, water and lithium bromide mixture is used as a working fluid and they are supplied with hot water from electrical boiler at any temperature. The investigation is done to assess the effect of varying exit temperatures of the absorber, evaporator, generator, and condenser on the absorption chiller cycle performance. The cycle simulation is based on the operating temperature ranges and fixed parameters which include the following: evaporating exit temperature within a range of 2-11 °C, generator exit temperature within a range of 80-89°C, condenser exit temperature which ranges from 30 to 48°C, absorber exit temperature which ranges from 20 to 38°C, three magnitudes of effectiveness of heat exchanger (0.6, 0.65 and 0.7), strong solution flow rate 0.05 kg/s. The results depicted that the performance parameters are affected by the operation temperatures of main components and heat exchanger effectiveness.

Pandya et al. [15] developed a thermodynamic optimization analysis of single effect LiBr-H_2O vapour absorption cooling system of 1 TR capacity. The optimization analysis employed an engineering equation solver EES to calculate mathematical models. Minimum generator temperature required to operate the system that is cut off temperature has been evaluated. Experimental comparison of thermodynamic first and second law approaches have also been evaluated. It is found that cut off temperature from the system decreases with evaporator temperature and increases with condenser and absorber temperature. It is observed that optimum generator temperature decreases with evaporator temperature and increases with condenser temperature.

Shakti and Smrutirekha [16] analyzed the potential of an engine exhaust driven LiBr-water based absorption system for air-conditioning. The effects of generator, condenser, evaporator, and absorber temperatures on the energy and exergy performance of the absorption system are observed. The results of the analyses and observations indicate that the coefficient of performance increases with the increase of evaporator temperature, but decreases with the increase of condenser and absorber temperature. Salem et al. [17] developed a mathematical model for thermodynamic analysis of an absorption refrigeration system equipped with an adiabatic absorber using a lithium-bromide/water (LiBr /water) pair as the working fluid. The working temperature of the generator, adiabatic absorber, condenser, evaporator, the cooling capacity of the system, and the ratio of the solution mass flow rate at the circulation pump to that at the solution pump are used as input data. The model evaluates the thermodynamic properties of all state points, the heat transfer in each component, the various mass flow rates, and the coefficient of performance (COP) of the cycle. The results are used to investigate the effect of key parameters on the overall performance of the system. For instance, increasing the generator temperatures and decreasing the adiabatic absorber temperatures can increase the COP of the cycle.

Salhi et al. [18] studied an absorption chillers single effect powered by thermal energy of geothermal sources in Algeria, the influences of the components temperature and the heat exchanger effectiveness on the performance coefficients was studied to test optimum operating conditions for the proposed system, and also analyzed the machine in the following conditions: the coolant temperature is between 30 and 40 °C and the evaporation temperature between 2 and 20 °C, also this study calculated each influence of temperature component on the COP. The results show that the coefficient of performance of this system is quite high, however, very high temperature of the geothermal source. Merzouk et al. [19] studied the performance of a single effect solar absorption cooling system (LiBr-H_2O) by modeling and simulation of a 70 kW Yazaki absorption cooling machine working with water-lithium bromide mixture. The authors [19] presented the influence of the performance of different parameters (Heat exchanger efficiency, Generator, absorber and condenser temperatures) on the system.

Kumar et al. [20] performed through a thermodynamic analysis the feasibility of using waste heat from diesel engines to drive a Lithium Bromide-water absorption refrigeration system. An energy balance of a diesel engine shows that sufficient waste heat is provided. The results illustrate that higher performance of the system is obtained at generator temperature of approximately 361K for single effect and then it starts decreasing till 371 K. Guerrier et al. [21] studied the performance of single stage absorption chiller LiBr- H_2O driven by hot water and solved the model equations by EES program. A mathematical model was developed based on the principles of energy conservation, entropy, mass and species, by various functions for determining the thermo physical properties, and transfer coefficients of heat exchangers. The program data generated by the variation of the inlet temperature of hot water were used for the determination of a range of values of energy and exergy COP system whose maximum were 0.7406 and 0.2409 respectively. The model was also able to assess the influence of temperature and solution concentration of the absorption machine. Gupta et al. [22] generated an absorption refrigeration system to air conditioning an ordinary passenger vehicle by using energy from an exhaust of an internal combustion engine. Cooling load for the automobile has been estimated. The authors used EES software to study the effects of COP of system with change in different parameters.

Sharma et al. [23] studied the relationship between COP of a Li-Br Vapor Absorption System and the working pressure of its components, especially giving effect of pressure difference between evaporator and condenser on the COP of the system.

By using detailed thermodynamic model of a single stage Li-Br Vapor Absorption system and EES software. Various thermodynamic properties of each point (inlet and outlet of each component) are calculated and the equations used for these calculations are included in this study. System properties and performance parameters like COP, circulation ratio, heat supplied in Generator, heat rejected by evaporator (system capacity) is compared in EES software. It was observed that, the COP increases with the decrease in the pressure difference. Gaur et al. [24] designed and analyzed the solar vapour absorption system of 10.5 kW. A mathematical model of this study has been developed and parametric study of lithium bromide-water vapor absorption air conditioning system is carried out. The effect of generator temperature on ratio of the rate of solution circulation and on the coefficient of performance for different condenser temperature, evaporator temperature, absorber temperature has been evaluated and discussed. Papillion et al. [25] presented and validated a general mathematical model for the dynamic simulation of a single-effect LiBr/water absorption chiller. The model is based on mass and energy balances applied to the internal components of the machine, and it accounts for the non-steady behavior due to thermal and mass storage in the components. The validation of the mathematical model is performed through experimental data collected on a commercial small-capacity water-cooled unit. Due to the peculiar technology adopted in the real chiller, a special effort was made to identify the appropriate values of the main physical parameters. The validation of the model is based on the values of the water temperature at the outlet of the machine, as no measurement inside the machine was possible; anyway, a consistency analysis applied to the internal parameters is also presented. The agreement between experimental and simulated results is very good, both on a daily and on a seasonal basis.

Iranmanesh and Mehrabian [26] simulated a single-effect LiBr–H_2O absorption chiller considering the effects of thermal masses of main components by link between EES and MATLAB software. Six various cases are considered to evaluate the effect of thermal masses of all and some components on the key parameters of an absorption chiller. The results show that the heat transfer rate of high-pressure components (generator and condenser) are highly dependent on thermal mass of the condenser whereas the heat transfer rate of low-pressure components (evaporator and absorber) are hardly affected by thermal masses. Balaji and Kumar [27] built a hypothetical design of lithium bromide water absorption refrigeration system using waste heat from sugar industry steam turbine exhaust, and study the thermal and fiscal advantages of using single effect lithium bromide water absorption by means of waste heat from sugar industry. The hypothetical design based on the cooling effect required for DC thrust motor in a sugar industry. Energy consumption, energy savings, overall heat transfer coefficient, effectiveness and COP of the heat exchanger are also measured and calculated.

Iranmanesh and Mehrabian [28] studied the thermodynamic properties to a single-effect LiBr-H_2O absorption chiller from the EES software. By making a link between EES and MATLAB software, the simultaneous differential equations were solved in MATLAB environment and this process was continued until the convergence criterion was satisfied. Also the authors considers the effect of quality on the concentration of solution at the exits of generator and absorber. This effect was ignored in the previous works. In other words, the concentrations of solution at the generator and absorber were not assumed to be equal to the corresponding concentration at the exit of those components in this model. Marc et al. [29] performed an experimental study of a solar cooling absorption system implemented in Reunion Island, located in the southern hemisphere near the Capricorn Tropic. The particularity of this project is to achieve an effective cooling of classrooms, by a solar cooling system without any backup systems (hot or cold). The aim of this experimental study is to define the limits of the use of such system under tropical climate conditions without setting a set point temperature. Indoor thermal comfort is achieved by a self-stabilizing operating system that maintains the indoor temperature at 6 °C below the outdoor temperature during certain critical periods of the year, when the outdoor temperature is very high and when the solar cooling system cannot provide enough refrigerating production, thermal comfort inside the building is achieved by using ceiling fans. Firstly we will present the installation and the choices we made in the control and design process. In the second part, an analysis of the experimental results will be presented.

Arora and Kaushik [30] examined and analyzed the effects of generator, absorber, condenser, evaporator and dead state temperatures opposite the performance of system. The parameters computed are coefficient of performance (COP), exergy destruction rates, thermal exergy loss rates, irreversibility and exergetic efficiency. The results indicate that COP and exergetic efficiency of both the systems increase with the increase in the generator temperature. There exists different optimum values of generator temperature for maximum COP and maximum exergetic efficiency. The optimum generator temperature is lower corresponding to maximum exergetic efficiency as compared to optimum generator temperature corresponding to maximum COP. The effect of increase in absorber, condenser and evaporator temperatures is to decrease the exergetic efficiency of both the systems. The irreversibility is highest in absorber in both systems. Ziegler et al. [31] employed simulation and experimental analysis of a solar driven 30 kW of a single stage H_2O/LiBr absorption chiller with a field of 350 m² with partially wetted evaporator. The efficient operation of a solar cooling system strongly depends on the chiller behavior under part-load conditions since driving energy and cooling load are not constant. A simulation model has been developed for the whole absorption chiller (Type Yazaki WFC-10), where all internal mass and energy balances are solved. The connection to the external heat reservoirs of hot, chilled and cooling water is done by lumped and distributed UA-values for the main heat exchangers. The influence of these effects on cooling capacity and COP is calculated for three different combinations of hot and cooling water temperature. The comparison to experimental data shows a good agreement in the various operational modes of the evaporator. The model is able to predict the transition from partially dry to an overflowing evaporator quite well. The present deviations in the domain with high refrigerant overflow can be attributed to the simple absorber model and the linear wetted area model. Nevertheless, the results of this investigation can be used to improve control strategies for new and existing solar cooling systems.

Mazloumi et al. [32] simulated a solar single effect lithium bromide water absorption cooling system in Ahwaz (one of the sweltering cities in Iran). The solar energy is absorbed by a horizontal N–S parabolic trough collector and stored in an insulated thermal storage tank. The system has been designed to supply the cooling load of a typical house where the cooling load peak is about 17.5 kW (5 tons) of refrigeration which occurs in July. A thermodynamic model has been used to simulate the absorption cycle the working fluid is water, which is pumped directly to the collector. The results showed that the collector mass flow rate has a negligible effect on the minimum required collector area, but it has a significant effect on the optimum capacity of the storage tank. The minimum required collector area was about 57.6 m^2, which could supply the cooling loads for the sunshine hours of the design day for July. The operation of the system has also been considered after sunset by saving solar energy. Castro et al. [33] developed a prototype of an air-cooled absorption chiller of about 2 kW for air conditioning using H_2O-LiBr. Several tests have been carried out under different conditions. The experimental results have been compared with the theoretical ones based on global mass and energy balances over the different components of the system. Detailed simulation models for each heat exchanger have been developed and implemented in the numerical codes to calculate the overall heat transfer coefficients and sub cooling values for the whole system simulation. The conclusions reported will lead to future design revisions and improvements to achieve better performance and reliability.

Although the single effect LiBr – water absorption cooling system has been studied from several aspects such as thermodynamic analysis system, experimental studies, LiBr-Water generated by (solar energy, geothermal and exhaust heat), implementation the system on different sites and simulation the system by EES software. However, I would like to study the absorption cooling system on the Red Sea Coast region - Sudan by benefiting from the waste of exhaust gases emitting from diesel engines and studying its effectiveness and COP by applying operating conditions in EES software.

III. PARAMETRIC STUDY

A. Thermodynamic Analysis

Thermodynamic design of the Lithium Bromide - water absorption cooling system by the first law only is usually based on given or assumed steady-state operating conditions. The fundamental simplifications assumed for the system shown in Fig. 7 are as follows [34]:

- System is working under steady state condition.
- No radiation heat transfer.
- Refrigerant at the condenser outlet is saturated liquid.
- Refrigerant at evaporator outlet is saturated vapor.
- The generator and condenser are assumed to have the same pressure at equilibrium.
- The absorber and evaporator are assumed to have the same pressure at equilibrium.
- Pressure losses in the pipes and all heat exchangers are negligible.

The mass flow rate, species and energy balances for the components in this cycle are recognized as follows [14]:

Mass balance:

$$\sum \dot{m}_{in} = \sum \dot{m}_{ex} \tag{3.1}$$

Species balance:

$$\sum X_{in}\dot{m}_{in} = \sum X_{out}\dot{m}_{ex} \tag{3.2}$$

Energy balance:

$$\sum \dot{Q} + \sum \dot{W} + \sum \dot{m}_{in}h_{in} - \sum \dot{m}_{out}h_{out} = 0 \tag{3.3}$$

From the first law of thermodynamics:

$$Q_e + Q_g - Q_c - Q_a + W_p = 0 \tag{3.4}$$

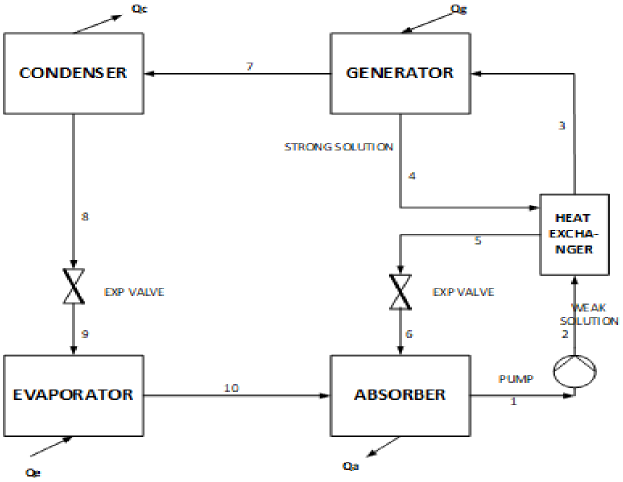


Fig. 7 Vapour Absorption Cooling System

The circulation ratio (f) is defined as the ratio of weak solution flow rate to refrigerant flow rate. Mathematically can be written as:

$$f = \frac{\dot{m}_w}{\dot{m}_r} \qquad (3.5)$$

Or, in concentrations term

$$f = \frac{X_{gen}}{X_{gen} - X_{abs}} \qquad (3.6)$$

The coefficient of performance COP for absorption chiller cycle is given by:

$$COP = \frac{\text{Chilled load}}{\text{Energy input}} = \frac{Q_e}{Q_{gen} + W_p} \qquad (3.7)$$

B. Components Analysis

Fig. 8 below shows sketch of individual components for absorption chiller.

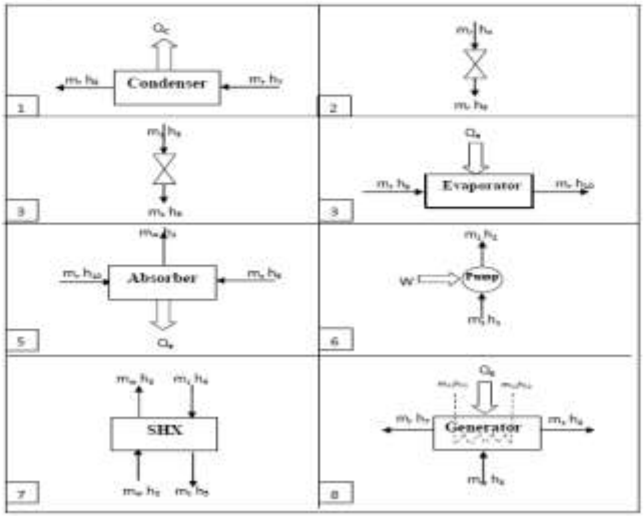


Fig. 8 Sketch of Individual Components for Absorption Chiller

The thermodynamic analysis is carried out across each component by applying the mass, species and energy balances. The cycle was treated as an independent element for each component with a certain number of input values. An eight standard components of absorption chiller is illustrated in Fig. 3-2. The components with their state points are: (1) Condenser, (2) Refrigerant expansion valve, (3) Solution expansion valve, (4) Evaporator, (5) Absorber, (6) Solution pump, (7) Solution heat exchanger and (8) Generator.

B.1 Condenser

The hot refrigerant vapor leaves the generator from point (7) and passes to condenser where it is condensed to liquid and exits from point (8). The liquid refrigerant is go back to the evaporator through expansion valve. The mass and energy balance in the condenser is given by equations:

$$\dot{m}_r = \dot{m}_8 = \dot{m}_7 \qquad (3.8)$$

$$Q_c + \dot{m}_8 h_8 = \dot{m}_7 h_7 \qquad (3.9)$$

$$Q_c = \dot{m}_r.(h_7 - h_8) \qquad (3.10)$$

B.2 Refrigerant Expansion Valve

$$\dot{m}_8 = \dot{m}_9 = \dot{m}_r \qquad (3.11)$$

$$h_8 = h_9 \qquad (3.12)$$

B.3 Solution Expansion Valve

$$\dot{m}_5 = \dot{m}_6 = \dot{m}_s \qquad (3.13)$$

$$h_5 = h_6 \qquad (3.14)$$

B.4 Evaporator

By passing through solution expansion valve refrigerant from condenser enters from point (9) and liquid refrigerant starts to evaporate at low temperature and pressure. Refrigerant vapor leaves evaporator at state point (10). Vaporization heat of refrigerant produces cooling effect of the whole system. Mass and energy balances for evaporator can be given by:

$$\dot{m}_r = \dot{m}_9 = \dot{m}_{10} \qquad (3.15)$$

$$Q_e + \dot{m}_9 h_9 = \dot{m}_{10} h_{10} \qquad (3.16)$$

$$Q_e = \dot{m}_r.(h_{10} - h_9) \qquad (3.17)$$

The value Q_e is chilled water

B.5 Absorber

The refrigerant vapor leaves the evaporator and enters the absorber from point (10) where refrigerant vapor is absorbed by the strong solution in absorber point (6) to form a weak solution point (1). The mass and energy balances for absorber are given by equations:

$$\dot{m}_1 = \dot{m}_w = \dot{m}_{10} + \dot{m}_6 \qquad (3.18)$$

$$Q_a + \dot{m}_1 h_1 = \dot{m}_{10} h_{10} + \dot{m}_6 h_6 \qquad (3.19)$$

$$q_a = h_{10} + (f-1)h_6 - f.h_1 \qquad (3.20)$$

While $f = \left(\dot{m}_1 / \dot{m}_{10}\right)$

$$q_a = (h_{10} - h_6) + f(h_6 - h_1) \qquad (3.21)$$

B.6 Solution Pump

The combined solution (refrigerant and absorbent) liquid enter the pump from point (1) and leaves at point (2) where the pressure of solution raises in the pump. The mass and energy balances for the pump are given by:

$$\dot{m}_w = \dot{m}_1 = \dot{m}_2 \qquad (3.22)$$

$$W + \dot{m}_1 h_1 = \dot{m}_2 h_2 \qquad (3.23)$$

$$W = \dot{m}_w (h_2 - h_1) \qquad (3.24)$$

B.7 Solution Heat Exchanger

Solution heat exchanger is an enhancement in absorption cooling cycle to avoid risks of irreversibility's due to high temperature at the generator. The SHX operates to preheat the cold diluted solution coming from the absorber and to cool the hot concentrated solution coming from the generator. The mass flow rate and heat transfer rate from the hot fluid to the cold fluid in the heat exchanger, is determined from energy balance:

$$\dot{m}_2 = \dot{m}_3,\ \dot{m}_4 = \dot{m}_5 \qquad (3.25)$$

$$C_{hot}.(T_4 - T_5) = \dot{m}_s(h_4 - h_5) \qquad (3.26)$$

$$C_{cold}.(T_3 - T_2) = \dot{m}_w.(h_3 - h_2) \qquad (3.27)$$

$$Q_{hx} = \dot{m}_w(h_3 - h_2) = \dot{m}_s(h_4 - h_5) \qquad (3.28)$$

Effectiveness of heat exchanger is given by:

$$\varepsilon_{shx} = \frac{\dot{Q}_{act}}{\dot{Q}_{max}} = \frac{(h_4 - h_5)}{(h_4 - h_2)} \qquad (3.29)$$

Or

$$\varepsilon_{shx} = \frac{(T_4 - T_5)}{(T_4 - T_2)} \qquad (3.30)$$

B.8 Generator

In the generator, regenerated weak solution entering from point (3). Then the weak solution starts to boil and generates vapor bubbles. These bubbles leaves the generator as water vapor from points (7) and (4) as strong solution. The mass and energy balances for the generator are given by:

$$\dot{m}_3 = \dot{m}_7 + \dot{m}_4 \qquad (3.31)$$

$$Q_{gen} + \dot{m}_3 h_3 = \dot{m}_7 h_7 + \dot{m}_4 h_4 \qquad (3.32)$$

$$Q_{gen} = h_7 + \left[\frac{\dot{m}_3 - \dot{m}_7}{\dot{m}_7}\right] h_4 - \frac{\dot{m}_3}{\dot{m}_7} h_3 \qquad (3.33)$$

$$q_{gen} = h_7 + (f - 1).h_4 - f.h_3 \qquad (3.34)$$

$$q_{gen} = (h_7 - h_4) + f(h_4 - h_3) \qquad (3.35)$$

Also, energy balance between generator and heat source (waste heat from diesel engine) gives:

$$Q_{gen} = \dot{m}_{11}(h_{11} - h_{12}) \qquad (3.36)$$

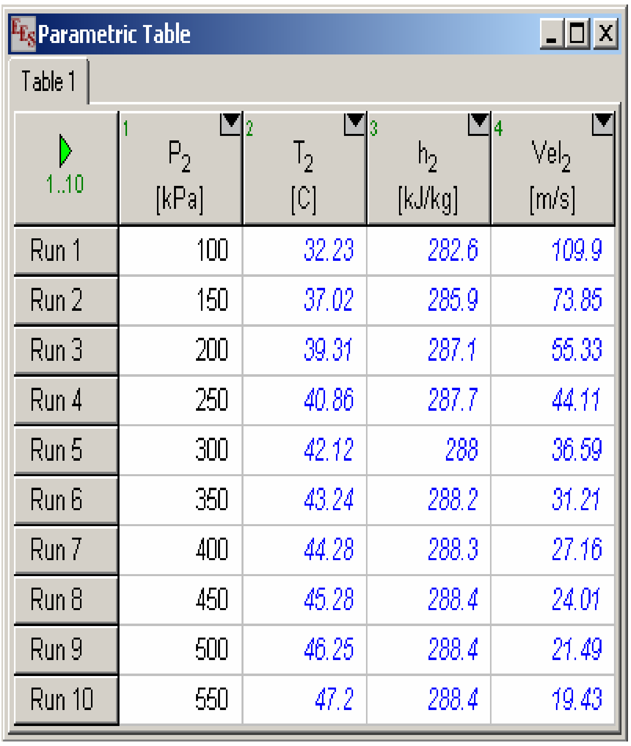
$$\varepsilon_{gen} = (T_{11} - T_{12})/(T_{11} - T_7) \qquad \mathbf{(3.37)}$$

C. Engineering Equation Solver (EES) Software

Engineering equation solver is a general equation-solving program that can numerically solve thousands of coupled non-linear algebraic and differential equations. EES program can also be used to solve the following:

- differential and integral equations
- can do optimization
- provide uncertainty analyses
- perform linear and non-linear regression
- convert units, and check unit consistency
- generate publication-quality plots

EES have a high accuracy thermodynamic and transport property database that is provided for hundreds of substances in a manner that allows it to be used with the equation solving capability [35]. Fig. 9 below shows parametric table in EES software.



1..10	1 P_2 [kPa]	2 T_2 [C]	3 h_2 [kJ/kg]	4 Vel_2 [m/s]
Run 1	100	32.23	282.6	109.9
Run 2	150	37.02	285.9	73.85
Run 3	200	39.31	287.1	55.33
Run 4	250	40.86	287.7	44.11
Run 5	300	42.12	288	36.59
Run 6	350	43.24	288.2	31.21
Run 7	400	44.28	288.3	27.16
Run 8	450	45.28	288.4	24.01
Run 9	500	46.25	288.4	21.49
Run 10	550	47.2	288.4	19.43

Fig. 9 Parametric Table in EES Software

EES also includes parametric tables that allow the user doing compare a number of variables at a time as seen in the Fig. 9. EES can also provide optimization tools that minimize or maximize of a chosen variable by varying a number of other variables. Lookup tables can be created to store information that can be accessed by a call in the code. Code allows the user to input equations in any order and obtain a solution.

The EES software contains thousands of equations, variables and element properties, including absorptive cooling equations from single stage to multi-stages, as well as the properties of lithium, ammonia and water used in these systems, which makes this program able to analyze these systems and study the Variables in system. EES program will be used to study a single effect lithium bromide water absorption cooling system, the program outputs are shown in the following Figures. Fig. 10 below shows equation and diagram windows.

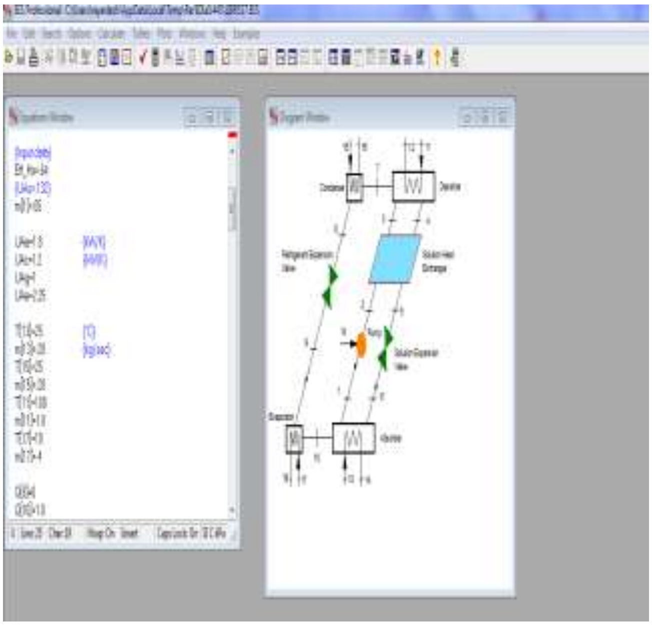


Fig. 10 Equation and Diagram Windows

Fig. 10 shows the equations and the diagram window of a single-effect absorption cooling system, where the equations window allows the user to enter the equations and variables required to solve the system.

Fig. 11 below shows solution and arrays table. After entering the required data and equations, the software solves the equations and shows them in the solutions window as illustrated in Fig. 3-5. The user can control the output data that it must be shown by entering in the equations diagram.

In Fig. 12, the variables information window enables the user to control the limits of the variables values and also enables to set units.

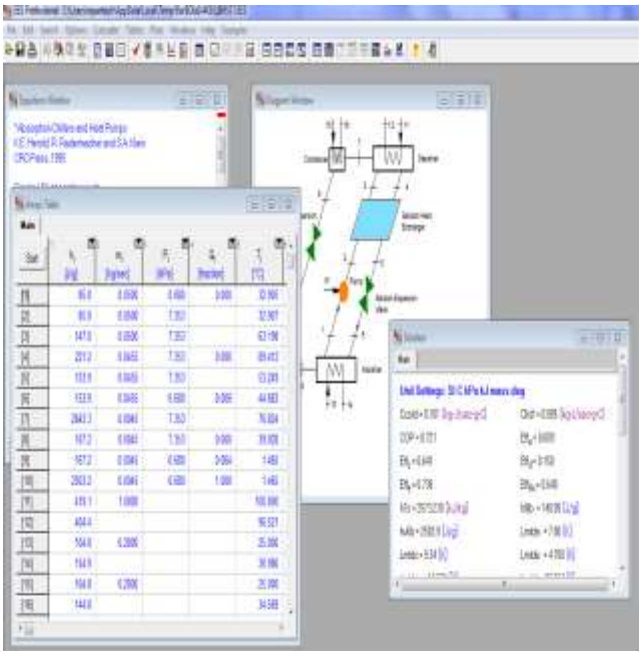


Fig. 11 Solution and Arrays Table

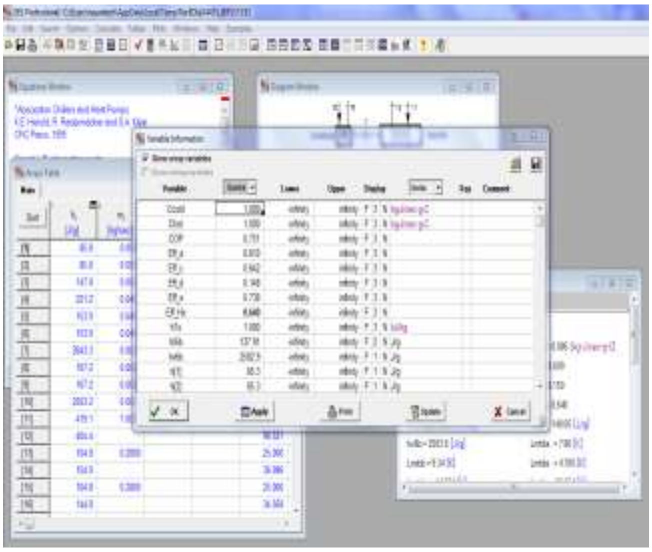


Fig. 12 Variable Information Window

D. Model Validation

To validate the present model, the simulation results have to be compared with the available data in the literature. The system modeling of $H_2O - LiBr$ absorption single-effect air-cooled system using waste heat from flue diesel engine is validated against the results of experiments data [6]. Fig. 13 below illustrates the absorption cooling system that is used in validation and Table 1 presents the system performance for the same operating conditions. According to the verified comparisons, the agreement between the two simulation results is good.

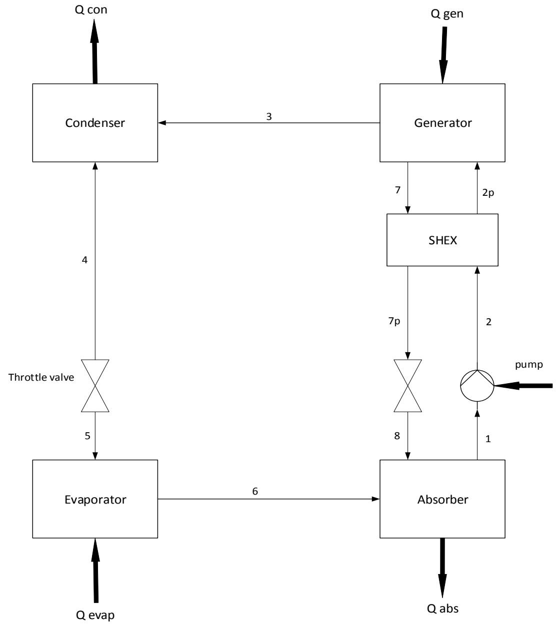
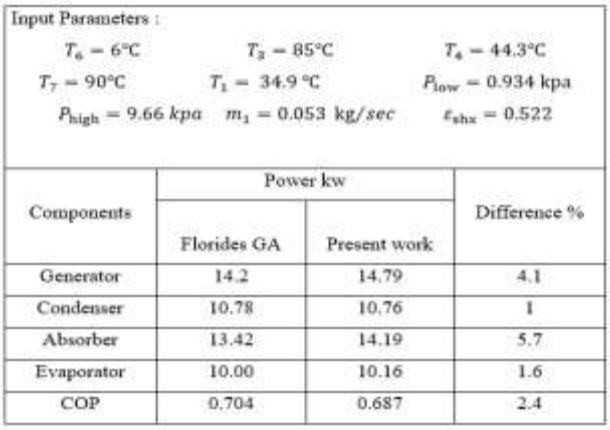


Fig. 13 Schematic Representation of H_2 O-LiBr Absorption Refrigeration Cycle

For the sake of comparison with the experimental work, the following are the main input parameters used in the present work simulation and which were used in the experimental work [6]: cooling power = 10 kW, generator solution exit temperature = 90°C, Generator vapour exit temperature = 70℃, Solution heat exchanger exit temperature = 65°C, evaporator temperature = 6°C and heat exchanger effectiveness = 0.522. The comparison shows the results of the maximum heat rates of the generator.

Table -1 Validation of the Model with the Results of the Florides GA



Input Parameters :

$T_6 = 6°C$ $T_3 = 85°C$ $T_4 = 44.3°C$

$T_7 = 90°C$ $T_1 = 34.9\ °C$ $P_{low} = 0.934$ kpa

$P_{high} = 9.66\ kpa$ $m_1 = 0.053\ kg/sec$ $\varepsilon_{shx} = 0.522$

Components	Power kw		Difference %
	Florides GA	Present work	
Generator	14.2	14.79	4.1
Condenser	10.78	10.76	1
Absorber	13.42	14.19	5.7
Evaporator	10.00	10.16	1.6
COP	0.704	0.687	2.4

E. Parametric Study

E.1 Introduction

By solving the mass and energy balance equations via using the set of the input parameters shown in Table 2, important results are obtained. These results could be used in the analysis and study of the effects on the absorption cooling system powered by waste heat from diesel engine. The parameters are: fluid flow rates $(\dot{m})$, inlet temperatures (T), and effectiveness of solution heat exchangers (ε), overall heat transfer coefficients (UA) and heat exchangers sizes. The full thermodynamic analysis is carried out via EES where all physical and thermal properties were extracted from the software library. In parallel, several manual calculations were done to verify the EES analysis using the same mass and energy balance equations. Fig. 14 below Illustrates single-effect water/lithium bromide absorption chiller with external heat transfer models used in this simulation.

Table -2 Input Parameters for Mass and Energy Balance Equations

Input Parameters	Value
UA_g	1.4 kW/K
UA_c	1.8 kW/K
UA_e	2 kW/K
UA_a	2.1 kW/K
UA_s	0.0111 kW/K
T_{11}	94 ℃
$\dot{m}_{11}$	1 kg/s
T_{13}	25 ℃
$\dot{m}_{13}$	0.3 kg/s
T_{15}	25 ℃
$\dot{m}_{15}$	0.3 kg/s
T_{17}	14 ℃
$\dot{m}_{17}$	0.7 kg/s
ε_{shx}	0.64
$\dot{m}_1$	0.057 kg/s

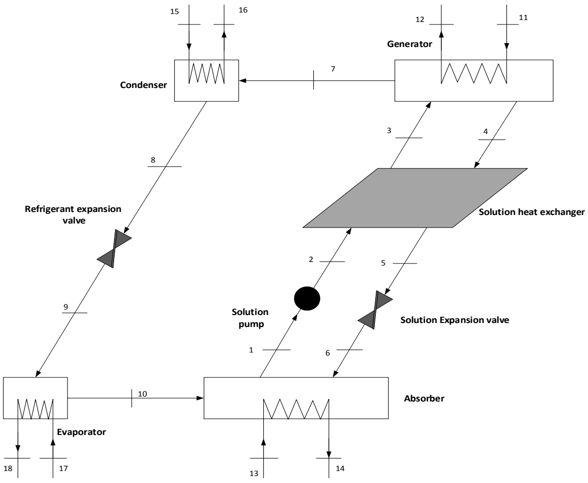


Fig. 14 Single-Effect Water/Lithium Bromide Absorption Chiller with External Heat Transfer Models

E.2 Results of Parametric Study

In the following sections, the effect of several process variables on the cooling capacity and COP are discussed. These variables include: the effect of the generator inlet temperature, effect of the heat source inlet mass flow rate and the effect of the absorber inlet temperature, effect of condenser temperature, and effect of solution heat exchanger effectiveness.

E.2.1 Effect of Generator Inlet Temperature

The temperature of heat source is an important parameter having a significant influence on the performance and operation of the refrigeration cycle. An increase or decrease in the source temperature or the flow rate has a clear effect on the performance of the system and on the cooling capacity of the system. To operate and sought single effect LiBr-water absorption cooling system, the temperature of the stream should be at least at 95 °C. This condition is easily achieved by flow the rejected hot flue gas from diesel engine. This effect is evident in Fig. 15. That shows the effect of generator inlet temperature designated by T_{11} at solution heat exchanger effectiveness (ε) of 0.80 and by fixing all variables that shown in Table 2, against the performance of the refrigeration cycle represented by the cooling capacity (COP).

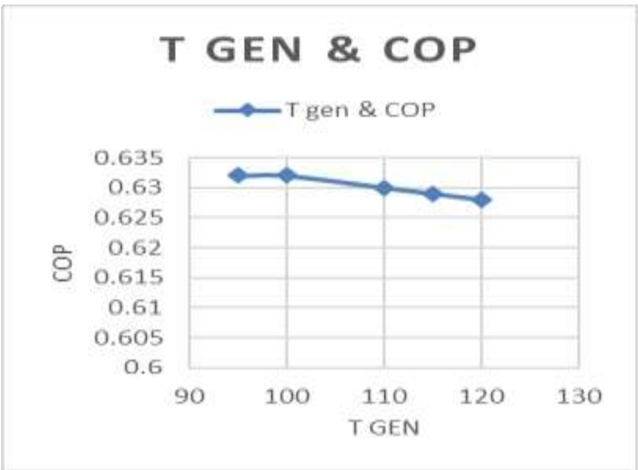


Fig. 15 Effect of Heat Source Temperature T_{11} on COP and Solution Heat Exchanger Effectiveness (ε) 0.8

The Coefficient of Performance COP values in Fig. 15 is observed to decrease with increasing heat source temperature in the range between 95 to 120 °C. In reality, the COP would increase first then reaches an inflection point where maximum value is achieved and then decreases again, this is observed when the inputs are converging to the source temperatures. Therefore, the COP always decreases by increasing the temperature of the generator. Also, the effectiveness of solution heat exchanger have effect on the performance of the system, where the COP increases if it is studied at a constant temperature of the generator. It is also observed that the increase in the solution mass flow rate $\dot{m}_1$has an effect on changing the performance of the system as in the curve shown below in Fig. 16. It was noticed that, at the same temperature of the generator which was 95 °C the COP was 0.672, and this happens when $\dot{m}_1$ equals 0.18 and the effectiveness of the exchanger equals 0.75. When the flow rate is increased to 0.3 and the effectiveness heat exchanger approaches 0.80, the performance factor was 0.632.

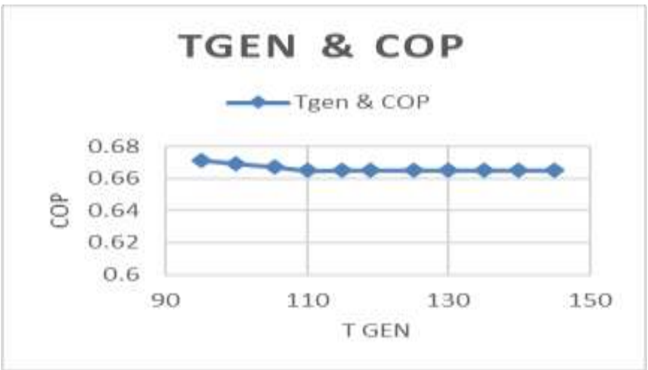


Fig. 16 Effect of Heat Source Temperature T_{11}on COP at ε_{shx}= 0.75 and $\dot{m}_1$=0.18

On the other hand, It is found that the thermal load ($\dot{Q}_e, \dot{Q}_g, \dot{Q}_c, \dot{Q}_a$) increases gradually by increasing the temperature of the generator T_{11} in a consistent fashion as in the following Fig. (Fig. 17). At $\varepsilon_{shx} = 0.8$ and $\dot{m}_1 = 0.3$, the increase can be explained by the increase of the log mean temperature difference (LMTD) of each heat exchanger. However, this increase of log mean temperature difference results in an increase in the irreversibility in the real heat exchanger. Also, this may explain the behavior of the COP with the increase of the temperature of the generator.

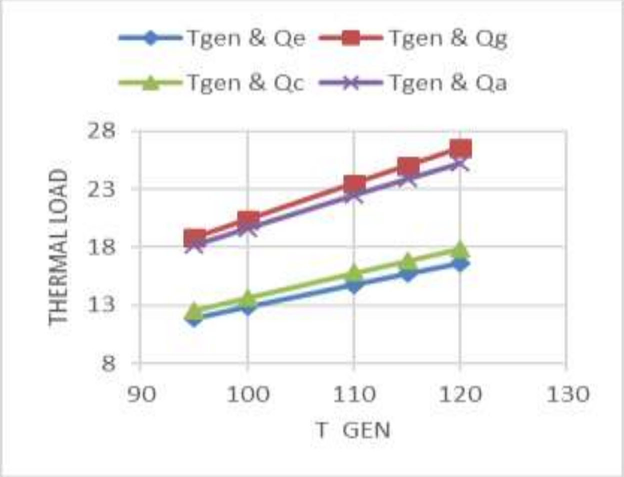


Fig. 17 Effect of Heat Source Temperature T_{11}on the Thermal Load for Evaporator, Generator, Condenser, and Absorber at ε_{shx}= 0.8

E.2.2 Effect of Condenser Inlet Temperature

When the solution mass flow rate is 1.5 kg/s and all other parameters are constant at their base value and the only exception is the changes in condensate temperature T_{15}, and as shown in Fig. 18 the coefficient of performance (COP) is having a higher value at lower condenser temperature and generator temperature. As the condenser and generator temperature increases COP starts to decrease gradually, but at very high condenser temperature an exponentially fall in the value of COP is observed. This is due to reduction of strong solution concentration. These results are consistent with those reported by other authors [36].

With the same data in Fig. 18, and by taking the effect of the condenser temperature on the thermal loads of evaporator, generator, condenser, and absorber $(\dot{Q}_e, \dot{Q}_g, \dot{Q}_c, \dot{Q}_a)$ in Fig. 19, it is found that the highest amount of heat is reached at the lowest temperature of the condenser and then gradually decreases.

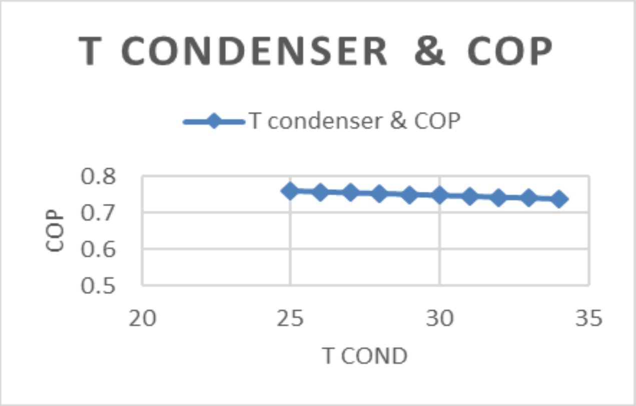


Fig. 18 Effect of Condenser Temperature T_{15}on COP at ε_{shx}= 0.64 and $\dot{m}_1$=1.5kg/s

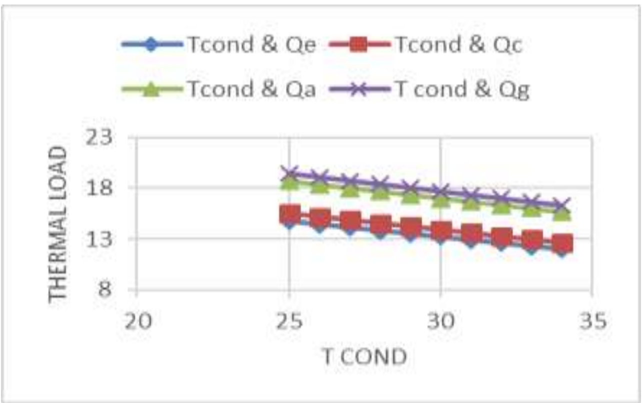


Fig. 19 Effect of Condenser Temperature T_{15} on Thermal Load for Evaporator, Generator, Condenser, and Absorber

E.2.3 Effect of Absorber Inlet Temperature:

From the two Fig.s 20 and 21 it is observed that there is a gradual decrease in the performance of the coefficient COP and the cooling capacity $\dot{Q}_e$. At the lowest degree of absorption, the performance of the system and cooling rates are higher and they decrease with the increase in the absorption temperature. This is attributed to the decrease in the concentration of the solution. The absorption rate could be raised by increasing the solution concentration. The higher the concentration, the greater the absorption rate. Also it has been observed through experiments that the size of the heat exchanger in the absorber has an effect on its decrease in its performance, so it could be concluded that the overall heat transfer coefficient UA is often greater than its counterparts in absorption cooling systems. These results are consistent with experimental results reported by other authors [37].

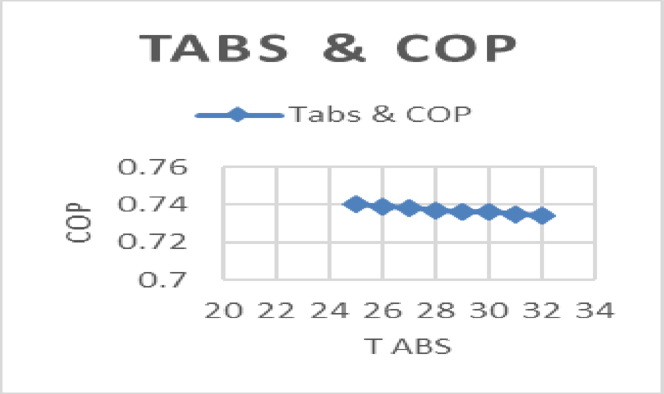


Fig. 20 Effect of Absorber Temperature T_{13}on COP

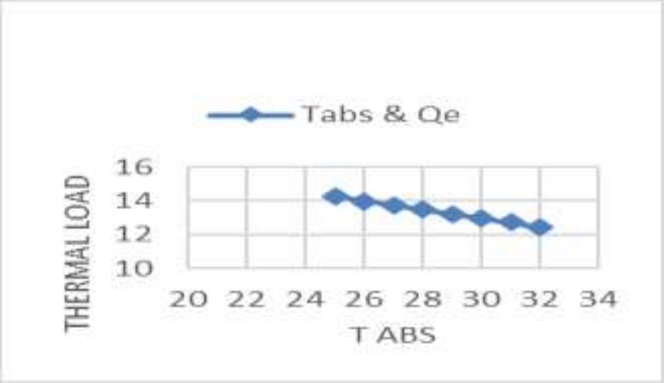


Fig. 21 Effect of Absorber Temperature T_{13}on Cooling Capacity

E.2.4 Effect of Evaporator Inlet Temperature:

The coefficient of performance increases with the increasing in evaporator temperature as shown in Fig. 22. As the temperature of the refrigerant increases, this helps to increase the performance of the refrigerant that will pass to the absorber. Often the evaporator is operated under vacuum pressure, so refrigerant gains heat, and more thermal load helps refrigerant to transfer into the gaseous state that it is supposed to pass through to the absorber.

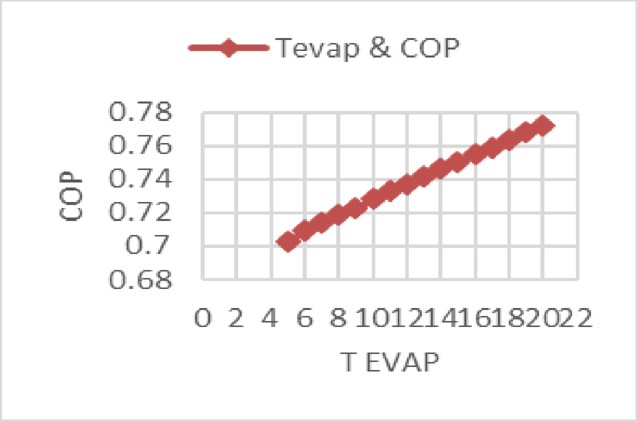


Fig. 22 Effect of evaporator temperature T_{17}on COP

It is also observed that, the increase in the evaporator temperature is affected by the increase of the thermal load of the generator, evaporator, condenser and absorber as shown in the Fig. 23.

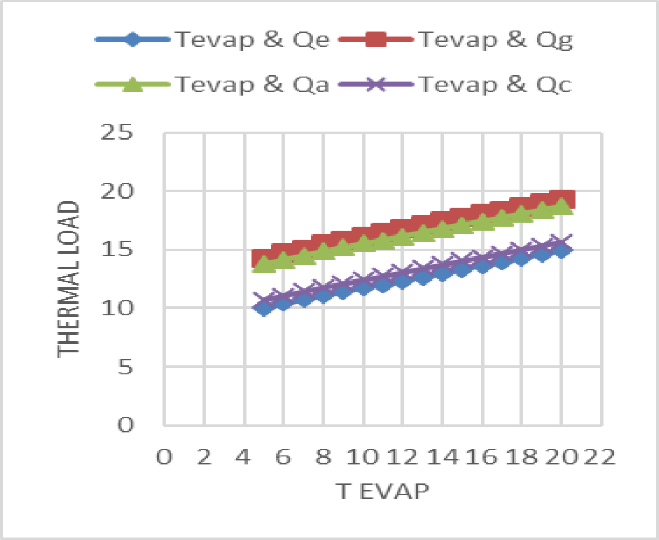


Fig. 23 Effect of Evaporator Temperature T_{17}on Cooling Capacity

E.2.5 Effect of Effectiveness of Solution Heat Exchanger

Fig. 24 illustrates the effect of solution heat exchanger effectiveness (ε_{shx}) on the coefficient of performance (COP). Baseline conditions were shown in Table 2. The purpose of internal heat exchanger device is to reduce external heat input requirements by utilizing energy available within ARS which would otherwise be wasted. Hence, as the effectiveness of heat exchanger is varied, outlet states of both sides of heat exchanger will be changed, and will affect heat transfer requirements in both generator and absorber. As effectiveness increases, COP and cooling capacity will be increased. This increase indicates that the sensitivity of COP to heat exchanger effectiveness is quite high. Additionally, as seen in Fig. 24, with value of solution heat exchanger near to be neglected (i.e. 0.15), absorption cooling system powered by waste heat produces a COP of only 0.652. This is due to the fact that generator heat requirements are significantly higher in absence of heat exchanger between legs of solution circuit.

So, since the heat exchanger in absorption cooling system is improved in design it is found that, it contributes significantly to increasing performance of system and cooling capacity.

In Fig. 25 it is observed that as the effectiveness of heat exchanger increases, thermal load in the generator $\dot{Q}_g$ and absorber $\dot{Q}_a$ decreases, this phenomenon explains the effect of heat exchanger on system. On the other hand, thermal load on other side of system (condenser $\dot{Q}_c$ and evaporator $\dot{Q}_e$) increases by increasing effectiveness of heat exchanger.

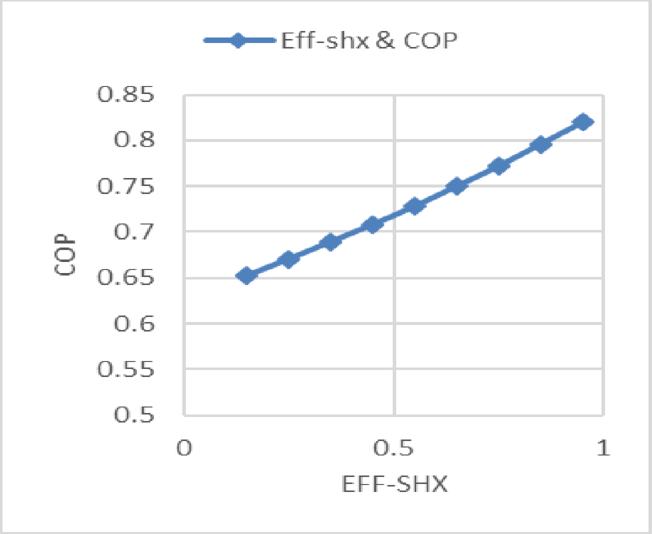


Fig. 24 Effect of Solution Heat Exchanger Effectiveness (ε_{shx}) on COP

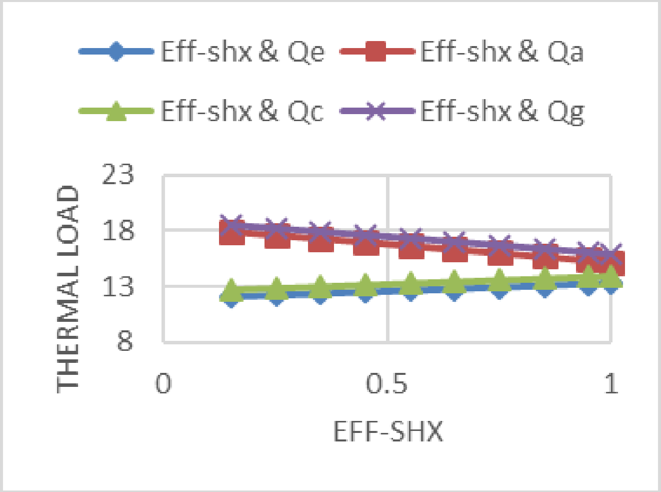


Fig. 25 Effect of Solution Heat Exchanger Effectiveness (ε_{shx}) on ($\dot{Q}_g$, $\dot{Q}_e$, $\dot{Q}_a$, $\dot{Q}_c$)

E.2.6 Effect of Solution Pump Mass Flow Rate

Fig. 26 shows the effect of strong solution mass flow rate $\dot{m}_1$ on COP for absorption cooling system at values of parameters which are mentioned in Table 2. COP reduces when mass flow rate increases. To understand this effect thermal load $\dot{Q}_{shx}$ on solution heat exchanger that is present in Fig. 27 is examined. As seen in these Figures, the increase of solution mass flow rate increases thermal load on the solution heat exchanger significantly as there is more energy available in solution stream leaving to generator and more energy needed in stream leaving to absorber. This indicates that more heat transfer occurs across generator and absorber as the mass flow rate is increased. This explains increase in heat load of the generator and absorber in Fig. as shown in Fig. 28. Also, it is observed that a decrease in thermal load of condenser and evaporator, will negatively affects cooling efficiency.

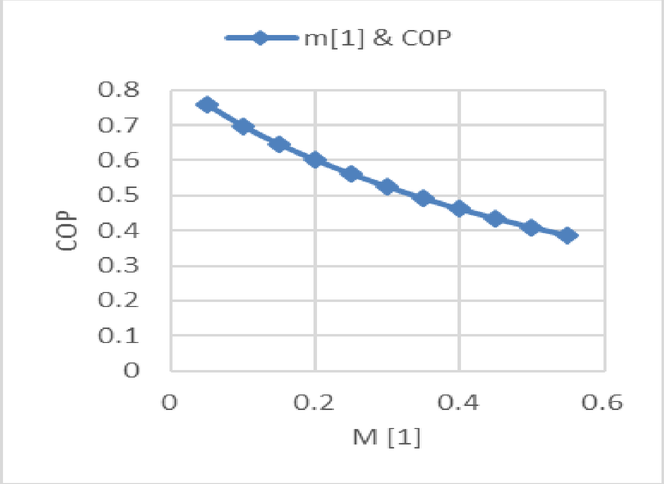


Fig. 26 Effect of Solution Pump Mass Flow Rate $\dot{m}_1$on COP

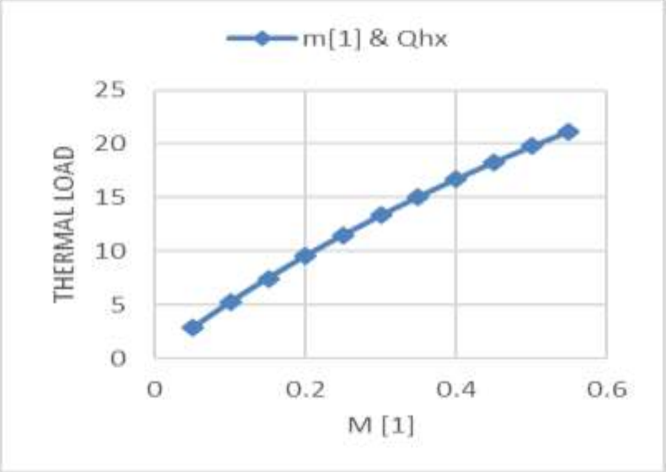


Fig. 27 Effect of Solution Pump Mass Flow Rate $\dot{m}_1$on $\dot{Q}_{shx}$

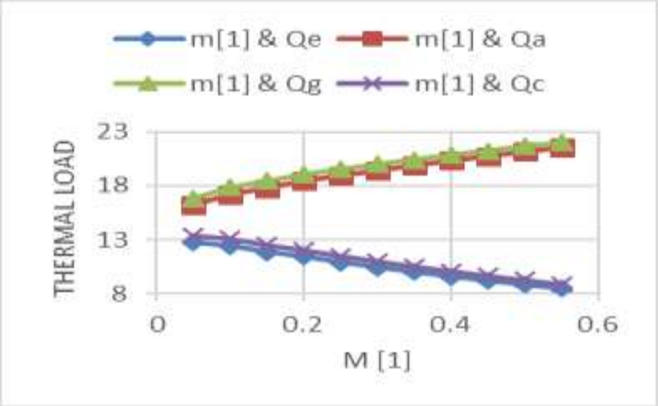


Fig. 28 Effect of Solution Pump Mass Flow Rate $\dot{m}_1$ on ($\dot{Q}_g$, $\dot{Q}_e$, $\dot{Q}_a$, $\dot{Q}_c$)

F. System Design

In the previous parametric study, the performance of the absorption cooling system was analyzed at different values for each of the generator, condenser, absorber, evaporator temperatures and effectiveness of heat exchanger. In this section, the design values of the lithium bromide-water absorption cooling system will be presented.

When studying the effect of generator temperature on the coefficient of performance and on cooling capacity by using the EES software, it was found that at a temperature of 95 ° C, COP was at its highest value of 0.632 and cooling capacity at this temperature was 12KW.

A cooling tower is used to absorb heat in absorption and condensation stages. When studying the effect of changing the condensing temperature and absorption, it is found that COP have a highest value at $T_{cond} = T_{abs}$ = 25 ° C which is 0.76 and cooling capacity $\dot{Q}_e$ at the same temperature is

15KW. So, with temperatures ranging between 25 and 35 ° C for the condenser and absorber, it is found that COP values range from 0.73 to 0.76 and $\dot{Q}_e$ values ranging from 12 to 15KW.

Also, when studying the effect of evaporator temperature on coefficient of performance and cooling capacity, it is observed that COP values range from 0.70 to 0.77 at evaporator temperatures ranging from 5 to 20° C and the cooling capacity ranges from 10 to 15KW. Average temperature can be taken whose value corresponds to the rest of system input to achieve the required performance, for example evaporator temperature of 14 ° C.

Finally, when studying the effect of effectiveness of heat exchanger on system performance, it is found that the optimum values of system coefficient of performance and cooling efficiency are achieved at value of ε_{shx} ranges from 0.64 to 0.80.

From the previous review of parametric study, which are obtained at optimal values that can be used in the water/lithium bromide absorption cooling system generated by waste gases from diesel engine, and by using EES software to analyze this system it is found suitable cooling capacity to cool the required space is obtained. These values are shown in the Table 3 below:

Table -3 Baseline Inputs Defining Single-Effect Operating Conditions

Parameter	Value	Parameter	Value
ε_{SHX}	0.64	T_{13} (°C)	25
$\dot{m}_1$ (kg/sec)	0.057	$\dot{m}_{13}$ (kg/sec)	0.3
$UA_a(kW/K)$	2.1	T_{15} (°C)	25
$UA_c(kW/K)$	1.8	$\dot{m}_{15}$ (kg/sec)	0.3
$UA_g(kW/K)$	1.4	T_{11} (°C)	94
$UA_e(kW/K)$	2	$\dot{m}_{11}$ (kg/sec)	1
		T_{17} (°C)	14
		$\dot{m}_{17}$ (kg/sec)	0.7

IV. SYSTEM PERFORMANCE

In the previous section, the operating values of the water absorption and lithium bromide absorption cooling system were optimized in the EES program, enabling the appropriate performance of the system to be implemented.

In this section, these values were used to study and find out the extent to which their performance corresponds to the area to be cooled by the lithium bromide-water absorption cooling system.

The cooling system in this study is operated by the waste gases of the SPPC diesel engines in Port Sudan. Fig.s 29 and 30 show an engine whose thermal waste is utilized. Two engines alternate to pump diesel fuel through 24 hours. The speed of a single engine is about 1560 rpm with 12 cylinders, and this machine emits high heat from the exhaust into the environment.

Fig. 29 Diesel Engine

Fig. 30 Exhaust System of the Diesel Engine

A reading of the temperature of the exhaust gases during the operating hours was taken, and it was found that the average temperature of the exhaust gases that would be used to operate the absorption cooling cycle was about 190 ° C. The absorption cooling system used to benefits from wasted heat is single-effect and operates at temperatures ranging from 90 to 120 ° C. This means that, it is not possible to utilize all the heat emitted from the exhaust so it will be utilized in its passing through generator, until the required performance of the system to cool the required space is reached. After entering the optimal values on the EES model used to operate the single effect lithium bromide absorption cooling cycle shown in Fig. 6, the values mentioned in Tables 4 below are obtained.

Table -4 Operating Conditions for a Single-Effect Water/Lithium Bromide System

State points	h (j/g)	$\dot{m}$ (kg/sec)	P (kPa)	Vapor Quality	T (°C)	x (kg/kg)
1	80.4	0.0570	0.873	0.000	33.650	55.0
2	80.4	0.0570	7.134		33.652	55.0
3	137.2	0.0570	7.134		61.107	55.0
4	206.9	0.0514	7.134	0.000	85.318	60.9
5	144	0.0514	7.134		52.252	60.9
6	144	0.0514	0.873	0.004	45.722	60.9
7	2635.3	0.0056	7.134		72.602	0.0
8	164.8	0.0056	7.134	0.000	39.362	0.0
9	164.8	0.0056	0.873	0.058	5.009	0.0
10	2509.7	0.0056	0.873	1.000	5.009	0.0
11	393.8	1.0000			94.000	
12	376.3				89.849	
13	104.8	0.3000			25.000	
14	160.7				38.364	
15	104.8	0.3000			25.000	
16	150.5				35.940	
17	58.7	0.7000			14.000	
18	40.1				9.553	

	Summary of energy Quantities	
$\dot{W}$	Pump power	0.225 W
COP	Coefficient of performance	0.746

Component	Heat transfer Rate(Kw)
Generator	17.470
Absorber	16.772
Condenser	13.730
Evaporator	13.032
Solution HX	3.24

	Summary of energy Quantities	
$\dot{W}$	Pump power	0.225 W
COP	Coefficient of performance	0.746

Component	Heat transfer Rate(Kw)
Generator	17.470
Absorber	16.772
Condenser	13.730
Evaporator	13.032
Solution HX	3.24

The target area for cooling in this system in a SPPC station is a room with servers and communication devices belonging to the control room. The size of the room is (10 × 5 ×3) m^3 and is exposed to sunlight from the eastern side, and it is about 10 meters away from the diesel engine. Fig. 31 below shows a picture of server's room.

Fig. 31 Server's Room

It was found that it needs approximately 14 KW, which is equivalent to 4 T.R. The single effect $H_2O - LiBr$ absorption cooling system used in this study saves this amount of energy to cool the room when using the optimal values.

V. CONCLUSIONS

Current concerns about global warming resulting from emissions of harmful gases and hydrocarbon compounds require appropriate techniques to conserve energy wasted in the form of thermal energy that harms the environment and to ensure that it is used in appropriate technologies to accomplish useful tasks. H_2O-LiBr single-effect absorption chillers can utilize waste heat emitted to the environment from suitable sources to provide refrigeration and air conditioning effects but, the usability of these systems must be carefully studied. Emission gases from diesel engines used in factories, ships and thermal power plants provide a suitable platform for carrying out energy technology performance assessments that can be expanded to include single-effect H_2O-LiBr absorption coolers.

There are several programs used to analyze absorption cooling systems to study effects of sources used to run the generator in this cycle. The program used in this thesis is the EES program, this program contains the properties of the solutions used in this system, the program allows the designer to write and enter codes and equations that enable him/her to study his/her system according to his/her conditions. The EES program is not specialized to study absorption cooling systems only. For this reason the system designer or researcher is forced to restrict it to equations and codes that limits it in a specific range to obtain results, and here the analyst may face some obstacles if he/she wants to study a case in the system outside the range of inputs. For example, the temperatures emitted from the engines used to operate the generator could reach 190 ° C, the benefit of which is 120 ° C. This is due to limited capacity of the selected generator.

By looking at the performance analysis of absorption cooling systems, there are more specialized programs in absorption cooling cycles, and certainly the results will be more accurate, such as ABSYS and TRNSYS, which can be used in the same system and compare their results with the current program.

The EES program model was used to analyze the lithium-bromide-water absorption cooling cycle that depends on the waste thermal energy of diesel engine for the purpose of cooling a building area in the engine workplace. The model contains the thermodynamic properties of various working fluids, and it is used to find the performance of the absorption cooling cycle. The results show that the cycle performance is dependent on a number of variables including: the temperatures of absorber, condenser, generator, and evaporator, the mass flow rate of the LiBr and the effectiveness of the solution heat exchanger. According to the simulation results, it is concluded that:

1. When the generator temperature is increased, the COP is decreased. This is because the increase in generator temperature lowers LiBr-water concentration. Also, the temperature increase of the generator increases the cooling capacity.
2. The increase in the absorber temperature reduces the COP as well as the cooling capacity. This is due to a decrease in the concentration of the solution. The absorption rate could be raised by increasing the solution concentration. The higher the concentration, the greater the absorption rate.
3. The COP and cooling capacity improves when the evaporator temperature increases.
4. The increase in effectiveness of heat exchangers causes an increase of system COP.

To further improve this research, some suggestions may make progress in the field of study, which will be addressed later, perhaps by other researchers, and they are:

1. If all the heat emitted from the diesel engine is utilized to generate the absorption cooling cycle it will give a higher cooling capacity which can cool a larger space, so I suggest using a double effect absorption cooling cycle.
2. It is suggested for the institution that has made use of the waste of its thermal engines to put the system under close supervision and control so as to reduce harmful emissions to the environment and reduce the consumption of electrical energy used in conditioning the space, which can be used in other applications throughout the period of operating hours of the engine. Note that fuel pumping engines do not stop working except during no derivatives for pumping or for maintenance purpose.
3. The operating sources of the absorption cooling system are available, such as the exhaust gases of engines and solar energy. Therefore, I recommend to design a model for a laboratory absorption cooling system to study and analyze these systems so as to utilize these energies in our country.

VI. REFERENCES

[1] Lecamwasam L, Wilson J, Chokolich D. Guide to best practice maintenance & operation of HVAC systems for energy efficiency: Department of Climate Change and Energy Efficiency; 2012.

[2] Mansouri R. Theoretical and experimental study of absorption and absorption/diffusion refrigerating machines using ammonia as a refrigerant: Simulation under steady-state and dynamic regimes and experimental characterization of a pilot: Universitat Rovira i Virgili; 2016.

[3] Sarmah K, Gupta P. Refrigeration by waste heat recovery. International Journal of Interdisciplinary Research. 2017;3(1).

[4] Tesha. Absorption Refrigeration System as an Integrated Condenser Cooling Unit in a Geothermal Power Plant: United Nations University, Geothermal Training Programme; 2009.

[5] Gunther RC. Refrigeration, air conditioning, and cold storage. 1969.

[6] Florides GA, Kalogirou SA, Tassou SA, Wrobel L. Design and construction of a LiBr–water absorption machine. Energy conversion and management. 2003;44(15):2483-508.

[7] Herold KE, Radermacher R, Klein SA. Absorption chillers and heat pumps: CRC press; 2016.

[8] Ashrae. 2005 ASHRAE Handbook: Fundamentals: ASHRAE; 2005.

[9] Tawalbeh M, Salameh T, Albawab M, Al-Othman A, El Haj Assad M, Alami AH. Parametric study of a single effect lithium bromide-water absorption chiller powered by a renewable heat source. Journal of

Sustainable Development of Energy, Water and Environment Systems. 2020;8(3):464-75.

[10] The influence of the external flow rates on an absorption chiller. Australian Journal of Basic and Applied Sciences. 2019.

[11] Zhang X-d. Comparison and analysis of lithium bromide-water absorption chillers using plastic heat transfer tubes and traditional lithium bromide-water absorption chillers. International Journal of Mechanical and Mechatronics Engineering. 2010;4(5):424-7.

[12] Ghodeshwar A, Sharma P. Thermodynamic Analysis of Lithium Bromide-Water (LiBr-H2O) Vapor Absorption Refrigeration System Based on Solar Energy. International Research Journal of Engineering and Technology (IRJET). 2018;5(01).

[13] Manu S, Chandrashekar T, Girisha C, editors. Effect of Cooling Water on the Performance of Lithium Bromide–Water (LiBr–H2O) Absorption Based Heat Pump. IOP Conference Series: Materials Science and Engineering; 2018: IOP Publishing.

[14] Rasheed Al-Amir Q, Kadhem Hamzah H, S Al-turaihi R. Performance Assessment of LiBr-H2O Absorption Chiller for Air Conditioning Purposes. journal of kerbala university. 2017;13(3):160-73.

[15] Pandya B, Patel J, Mudgal A. Thermodynamic evaluation of generator temperature in LiBr-water absorption system for optimal performance. Energy Procedia. 2017;109:270-8.

[16] Jena SP, Mishra S. Thermodynamic analysis of LiBr and water based vapour absorption air-conditioning system utilizing waste exhaust heat energy of Diesel Engine. Energy.10:5.

[17] Osta-Omar SM, Micallef C. Mathematical model of a lithium-bromide/water absorption refrigeration system equipped with an adiabatic absorber. Computation. 2016;4(4):44.

[18] Salhi K, Hadjiat M, Ouali S, editors. Thermodynamic Analysis of a Single-Stage Absorption Refrigeration System Using (HFC-Organic Absorbents) as a Working Fluids Assisted by Geothermal Energy. 2018 6th International Renewable and Sustainable Energy Conference (IRSEC); 2018: IEEE.

[19] Ketfi O, Merzouk M, Merzouk NK, El Metenani S. Performance of a single effect solar absorption cooling system (Libr-H2O). Energy procedia. 2015;74:130-8.

[20] Singh R, Vats S, Baghel N, Kumar R, editors. Integration of Water-Lithium Bromide Absorption Refrigeration System with Diesel engine: A Thermodynamic Study. International Conference of Advance Research and Innovation (ICARI); 2014.

[21] Villa A, Dutra JCC, Guerrero JRH. Energy and exergy analysis of the performance of 10 TR lithium bromide/water absorption chiller. Rev Tech Ing. 37: University Zulia; 2014. p. 38-47.

[22] Mathapati S, Gupta M, Dalimkar S. A study on automobile air-conditioning based on absorption refrigeration system using exhaust heat of a vehicle. International Journal of Engineering Research and General Science. 2014;2(4):80-6.

[23] JATIN PATEL AM, ANUP SHARMA, , CHOUDHARY S. EFFECT OF PRESSURE DIFFERENCE IN VAPOUR ABSORPTIONSYSTEM. International Conference-Proceedings of ICRIEST-AICEEMCS.

[24] Sharma NK, Singh MP, Gaur D, Bulandshahr M, Dadri V. Design & analysis of solar vapour absorption system using water and lithium bromide. International Journal of Engineering Research and Technology. 2013;2(6).

[25] Evola G, Le Pierrès N, Boudehenn F, Papillon P. Proposal and validation of a model for the dynamic simulation of a solar-assisted single-stage LiBr/water absorption chiller. International journal of refrigeration. 2013;36(3):1015-28.

[26] Iranmanesh A, Mehrabian M. Dynamic simulation of a single-effect LiBr–H2O absorption refrigeration cycle considering the effects of thermal masses. Energy and buildings. 2013;60:47-59.

[27] Balaji K, Kumar RS. Study of vapour absorption system using waste heat in sugar industry. IOSR Journal of Engineering. 2012;2(8):34-9.

[28] Iranmanesh A. Transient characteristics of a single-effect absorption refrigeration cycle. Energy Engineering & Management. 2013;2(4):40-7.

[29] Marc O, Lucas F, Sinama F, Monceyron E. Experimental investigation of a solar cooling absorption system operating without any backup system under tropical climate. Energy and buildings. 2010;42(6):774-82.

[30] Arora A, Kaushik S. Theoretical analysis of LiBr/H2O absorption refrigeration systems. International Journal of Energy Research. 2009;33(15):1321-40.

[31] Albers J, Nurzia G, Ziegler F, editors. Simulation and experimental analysis of a solar driven absorption chiller with partially wetted evaporator. Energy Sustainability; 2008.

[32] Mazloumi M, Naghashzadegan M, Javaherdeh K. Simulation of solar lithium bromide–water absorption cooling system with parabolic trough collector. Energy Conversion and Management. 2008;49(10):2820-32.

[33] Castro J, Oliva A, Pérez-Segarra CD, Cadafalch J. Evaluation of a small capacity, hot water driven, air-cooled H2O-LiBr absorption machine. Hvac&R Research. 2007;13(1):59-75.

[34] Ezgi C. Design and thermodynamic analysis of an H2O–LiBr AHP system for naval surface ship application. International journal of refrigeration. 2014;48:153-65.

[35] Klein S. Engineering Equation Solver (EES) for Microsoft Windows Operating Systems, Commercial and Professional Version. F: Chart Software. 2006.

[36] Patel HA, Patel L, Jani D, Christian A. Energetic analysis of single stage lithium bromide water absorption refrigeration system. Procedia Technology. 2016;23:488-95.

[37] Aphornratana S, Sriveerakul T. Experimental studies of a single-effect absorption refrigerator using aqueous lithium–bromide: effect of operating condition to system performance. Experimental thermal and fluid science. 2007;32(2):658-69.