

**DESIGN OF SOLAR ABSORPTION AIR
CONDITIONING SYSTEM FOR SMALL OFFICE
BUILDING**

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**A PROJECT REPORT SUBMITTED TO THE DEPARTMENT
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DECEMBER, 2019.

CERTIFICATION

This is to certify that the project work titled “DESIGN OF SOLAR ABSORPTION AIR CONDITIONING SYSTEM FOR SMALL OFFICE BUILDING” was carried out by:

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DEDICATION

This project work is dedicated to God Almighty for His abiding grace, love, wisdom and power that has brought us this far.

And a to our parents, guardians, friends, well-wishers and all our course mates who have been there for us in our good and trying times throughout the duration of our course of study.

ACKNOWLEDGEMENT

Fore mostly, we are really grateful to God Almighty for His grace that has seen us through this work and our stay in the university.

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We also appreciate Prof. A.I. Obanor and Engr. Dr. E. G. Sadjere for all the assistances they willingly rendered us in the course of this project.

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Of course, our parents, guardians and siblings, we are indeed grateful for your love, care, prayers, support and all God used you to do in our lives. We love you.

To our fellow course mates (Mech. Family), fellowship brethren (St. Albert and DLCF), the journey would have been boring without you, you made our stay in the university lively and meaningful, we love you all.

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ABSTRACT

The demand for indoor cooling is on the increase especially in a tropical weather country like Nigeria. Air conditioning has been the most common cooling mechanism for providing indoor cooling for office buildings. However, the conventional air conditioners consume a lot of electricity and also make use of chlorofluorocarbon (CFC) and hydrofluorocarbon (HCFC) refrigerants which contribute to global warming.

The solar absorption air conditioning system utilizes heat from solar radiation to drive an absorption system which produces the refrigerating effect. A lot of research work has been carried out to analyse and improve the system.

The aim of this project work is to design a solar absorption air conditioner by determining the size and type of the required solar collector and the maximum coefficient of performance (COP) that can be achieved by varying the generator temperature.

The solar collector area with an efficiency of 0.76 was calculated to be 2.375m^2 , for an optimum generator temperature of 95°C . The COP at this generator temperature was calculated to be 0.736

CHAPTER 1

INTRODCION

1.1 BACKGROUND TO STUDY

There is an increasing demand for indoor cooling especially in tropical weather countries like Nigeria due to increase in cooling load and demand for more comfort. The air conditioning system has been the most common cooling mechanism for providing indoor cooling. It consists of sequentially arranged components and equipments to heat or cool, humidify or dehumidify, clean and purify, alternate objectionable equipment noise, transport the conditioned outdoor air and recirculate air to the conditioned space, and control and maintain an indoor or enclosed environment at optimum energy use.

The common air conditioner (vapor compression) consists of compressor-driven machines that use electrical energy to generate a cooling effect. While In an absorption system, the refrigeration effect is produced by means of thermal energy input. After liquid refrigerant produces refrigeration during evaporation at very low pressure, the vapor is absorbed by an aqueous absorbent. The solution is then heated and the refrigerant is again vaporized and then condensed into liquid form. The liquid refrigerant is throttled to a very low pressure and is ready to produce the refrigeration effect again. The heat can be generated by a gas furnace or solar energy (which is uses in this case). Solar energy is trapped in the form of heat, with the help of solar collectors and is used to heat up water, which then drives the absorption chiller to produce a refrigeration effect

This solar based cooling system consists of two parts—the solar portion which includes the solar collector, storage tanks (incorporated to store excess solar heat) and auxiliary heater/boiler (to account for any inadequacies in heat generation). And the cooling portion which includes the absorption chiller, cooling tower (to dispose waste heat).

1.2 STATEMENT OF THE PROBLEM

The conventional air conditioners (vapor compression air conditioners) consume a lot of electricity (about 40% of total electricity consumption in comparison to other electrical appliances in small office buildings), leading to a decrease in fossil fuel (as more electricity needs to be generated), which then leads to green house emission, thereby worsening global warming. Also, with the poor power supply and high electricity tariff in a country like Nigeria, it doesn't seem to be so efficient and cost effective. Another problem with the vapor compression air conditioners is that it uses chlorofluorocarbon (CFC) and hydro chlorofluorocarbon (HCFC) refrigerants which have great devastating effect on the ozone layer.

This disadvantages/draw back necessitates the need for low level renewable source of energy for air conditioning systems

1.3 AIM AND OBJECTIVES

Aim:

Design of solar absorption air conditioning system for a small office , with 995W cooling load.

Objectives

The objectives are:

- (i) Determine the size of solar collectors to produce the needed heat energy
- (ii) Determine the optimum coefficient of performance of the system by varying the generator temperature

1.4 SCOPE OF WORK

This project work entails the determination of the size of solar collectors, and components of an absorption system, for air conditioning, using radiation data and cooling load data.

1.5 JUSTIFICATION OF THE WORK

This solar air conditioning system uses solar energy (which is abundant and clean) to drive an absorption chiller, requiring less electricity demand. Also, the working fluids such as lithium bromide/water do not contribute to global warming. Therefore, the system contributes little or nothing to global pollution as well as being cost effective on the long run.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF SOLAR ABSORPTION COOLING

The absorption refrigerator cycle has been in existence since 1858, invented by Ferdinand Carrié (Granryd and Palm, 2005) (with the use of water and sulphur in acid). But the refrigeration market has been since its origins dominated by the vapor compression cycles, and especially since 1930 with the introduction of halogenated Hydrocarbons as working fluid from the refrigeration machine. Commercial absorption chillers have been available since the 1940 (simple effect machines) and 1970 – 1990s (double effect machines), (Garcia-Casals, 2006) but due to their high cost and the low price of energy, coupled with the wide spread of vapor compression machine, limited their use. But in recent times, the absorption chillers are receiving a renewed attention for their use in the exploitation of residual thermal energy flows in combined heat and power installations besides their potentiality in solar cooling system

2.2 ANALYSIS AND COMPARISON OF DIFFERENT SOLAR AIR CONDITIONING SYSTEMS

Several research works have been done to compare different solar air conditioning systems in terms of cost and performance. (Fong et al, 2010) carried out a comparative study for five cooling systems: solar PV for vapor compression, solar mechanical compression, solar solid desiccant cooling, solar absorption refrigeration and solar adsorption refrigeration for a subtropical city. The results indicated that the energy saving is higher for solar PV for vapor compression and solar absorption refrigeration in Hong

Kong.(Kim and Ferreira, 2008) carried out a comparative analysis of solar PV-refrigeration system and solar thermal refrigeration system on the bases of energy efficiency and economic feasibility. The results showed that solar thermal systems are more economical than solar PV- refrigeration systems.

(Mokhtar et al, 2010) analyzed different solar cooling technologies. The methodology was based on assessing the performance of the various cooling system, considering cost, performance, weather and cooling load. It was applied to twenty five solar cooling systems in Abu Dhabi. The results indicated that large scale cooling plant are economical, also multi crystalline PV cells with vapor compression were the most efficient.

(Hartmen et al, 2011) carried out a comparison between solar thermal and solar electric cooling for a small office building for two different climates [Madrid and Freiburg]. The grid coupled PV system consumed less energy than the solar thermal system at both locations.

2.3 ANALYSIS OF SOLAR THERMAL AIR CONDITIONING SYSTEM

Several studies have been done on solar thermal air conditioning system. (Tsoutsos et al, 2003) carried out an economic analysis for solar absorption cooling system and solar adsorption system. The study revealed that in terms of capital cost solar absorption system cheaper (50% of solar adsorption system).

(Cleveland et al, 2010) developed a model to analyze options for commercial solar thermal systems. It also presented the analysis of system costs and energy costs. The net present value (NPV) of conventional cooling and that of solar thermal were

approximately the same for thirteen to fourteen years. The results indicated that the net present value (NPV) for the solar systems was better in the remaining years.

(Moreno et al, 2010) studied factors that affect solar air conditioning system of building to resolve the external conditions of radiation and temperature in order to achieve the desired room temperature. The results revealed that solar supply curves decreases with increase in surface area of the collectors because of the average increase in temperature of water in the collectors, which causes a decrease in the performance. Also, as the volume of storage tank increases, the yearly cost of gas boiler also increased. This shows that increase in losses as a result of larger surface exposure is greater than the increase in capacity of the heat storage as a result of increase in volume.

2.4 MODELLING AND OPTIMISATION OF SOLAR ABSORPTION SYSTEM

There have been many attempts to predict and optimize the performance of solar absorption air conditioning system. (Ahamadu et al, 2016) carried out modeling, stimulating and optimization of solar absorption air conditioning system for an office block in Zaria using the TRNSYS software. Meteorological data of a typical year for Zaria was used for the stimulation and optimization. The optimization was done by investigating the effect of varying the component sizes on the coefficient of performance (COP), solar coefficient of performance (SCOP) and solar fraction (SF). The results showed that the system was able to attain an average annual solar fraction (SF) of 0.79 in the given location.

(Yin Hang et al, 2011) conducted an economical and environmental assessment of an optimized solar cooling system for medium sized benchmark office building in Los

Angeles, California. The solar cooling system consisted mainly of evacuated tube solar collectors, hot water storage tank, single effect LiBr-H₂O absorption chiller, and a gas fired auxiliary heater. The system performance optimization was done by varying two major parameters (storage tank volume and solar collector area). The results showed that there is a trade-off between the economic performance and energy environmental performance.

(Bvumbe et al, 2015) carried out analysis of performance data for an autonomous solar heating and cooling system installed at the Vodafone site system innovation centre, at the Vodacom campus in Midrand. The system performance data was collected from beginning of December 2011 to the end of January 2012 and used to estimate the system long term performance. The chiller had an average coefficient performance (COP) of 0.51 while the solar COP had an average value of 0.24.

(Alili et al, 2010) modeled a solar powered absorption cycle for Abu Dhabi. The modeled system uses evacuated tube collectors to drive a 10kW_c absorption chiller (ammonia – water). TRNSYS was used to simulate the complete system and based on the thermal analysis, the system collector area of 6m²/kW_c and a specific tank volume of 0.1m³/kW_c. The modeled system required 47% less of electrical energy than the vapor – compressor cycles of same cooling capacity. Also, economic analysis was performed and it proved that the solar collector area was the key parameter to determine the payback period. The system was also formed to reduce 12 metric year of CO₂ emissions due to energy saving.

2.5 EXPERIMENTAL WORK AND INSTALLATION OF SOLAR ABSORPTION AIR CONDITIONING SYSTEM.

Beyond research, modeling and predicting; there have been several attempts to utilize solar absorption system for cooling and air conditioning. (Kulpanich et al, 2008) designed and installed a solar driven 10 – ton LiBr-H₂O single effect absorption cooling system at the School of Renewable Energy Technology (SERT) in Thailand. The system consists of 72m² evacuated tube solar collector which provided an annual average solar fraction of 81%, the balance of 19% required thermal energy was supplied by an LPG-fired backup unit.

(Sumathy et al, 2002) designed a 100kw double stage solar powered LiBr-H₂O absorption cooling system in south china. The experimental results indicated that the system is capable of operating when the temperature of the generator varies from 60⁰C to 75⁰C.

(Izquierdo et al, 2008) carried out an experimental research to determine the performance of a 4.5kw air cooled single effect LiBr-H₂O absorption chiller. The experiments were carried out at the Eduardo laboratory at La Poveda, Madrid in 2005 and the parameters were gotten over a period of 20days. The hot water inlet temperature in the generator varied from 80⁰C to 107⁰C all day. The total energy supplied to the generator was 1,085.5kwh and the heat removed in the evaporator was 534.5kwh. The average COP over the period was 0.49 and the COP (when electric power for auxiliary equipment was factored) was 0.37.

(Agyemin et al, 2010) developed a domestic scale prototype solar powered 4.5kw LiBr-H₂O absorption cooling system. The system includes a 12m² vacuum tubular solar collector, 6kw fan coil and 1000 litre cold storage tank. The experimental results showed that the average COP of the system was 0.58; it also showed that solar powered, single effect absorption chillers were capable of working with the driving temperature range of 65⁰C to 100⁰C.

(Bermejo et al, 2010) designed a 174kw gas/solar powered double effect v absorption cooling system in Spain using 352m² linear concentrating Fresnel collectors. The experimental results showed that the solar energy contributed 75% of the total heat generated and it had a COP of 1.1-1.25 when the evaporator temperature was set at 8⁰C.

(Rosiek and Garrido, 2012) gave the performance of a solar assisted air conditioning system with two chilled water storage tanks installed in the Solar Energy Research Centre Building. The system includes solar collectors, hot water absorptions chiller, cooling tower, two hot storage tanks, auxiliary heater and two cold storage tanks. The 30% of the water consumed can be saved because of the chilled water tanks. However, it also shows that the incorporation of the chilled water storage tanks reduced the sudden on/off absorption chiller cycles, which therefore improves the efficiency of the system.

2.6 DETERMINATION OF COOLING LOAD

The cooling load is a very important factor to determine the size of air conditioning system. The air condition cooling load for room 133 in the department of mechanical engineering, University of Benin has been calculated to be 0.995kW (Emoghene and Morka, 2018).

2.7 COMPONENTS OF THE SOLAR ABSORPTION AIR CONDITIONING SYSTEM

The solar absorption air conditioning system consists of:

- 1) Solar Collectors
- 2) Storage Tank
- 3) Auxiliary Heater
- 4) Absorption Chiller
- 5) Cooling Tower

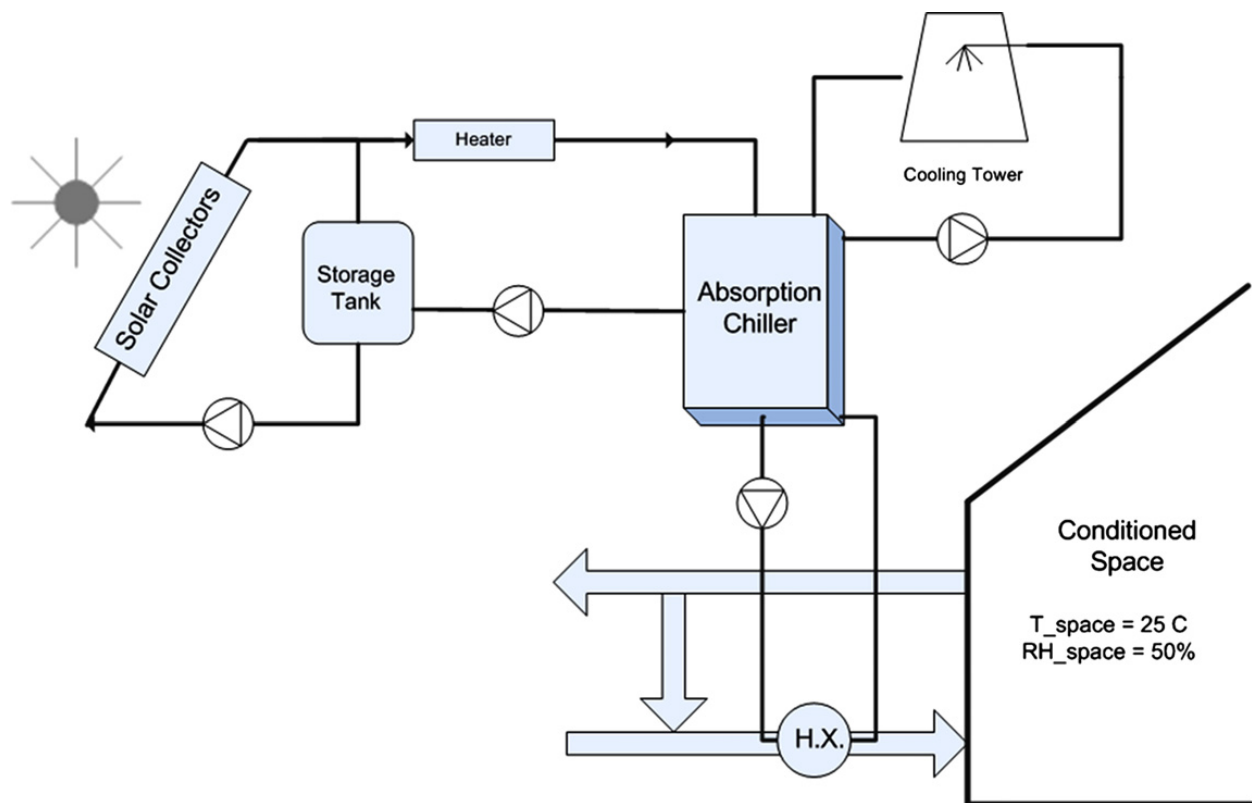


Fig 2.1: Solar absorption air conditioning system (source: Al-Alili et al 2012)

2.7.1 SOLAR COLLECTORS

The Solar Collector is one of the major components of the solar absorption air conditioning system. It is a device which traps solar radiation, converts it to heat energy and transfer the heat energy to the heating medium generator. Solar collector choice depends on the number of absorption effect solar radiation level and percentage of Direct Normal Radiance (DNI).

It is the device that converts solar energy to heat energy which drives the absorption chiller (Henning et al 2007). It can be classified according to its motion. They include stationary collectors and axis tracking collectors (Haw et al 2009). The axis tracking collector only utilizes the direct normal irradiance (DNI) (Batineh et Tanneh 2016). The stationary collectors can also harvest solar diffuse radiation and are easily available and relatively cheap. The commercial available types of the stationary solar collector are flat plate collector and evacuated tube collector.

2.7.1.1 FLAT PLATE COLLECTOR [FPC]

Flat plate collector is a collector which absorbs incident solar radiation on a flat surface with high absorption and transmits the absorbed energy to a running fluid.

Advantages of Flat plate Collector

- 1) It is economical for low temperature application
- 2) It has a longer life span
- 3) Its efficiency has been enhanced by Titanium Coating.

Disadvantages of Flat Plate Collector

- 1) There is a lot of heat loss by convection due to the exposed surfaces so it is not efficient for high temperature application
- 2) They deteriorate at intensive weather condition.

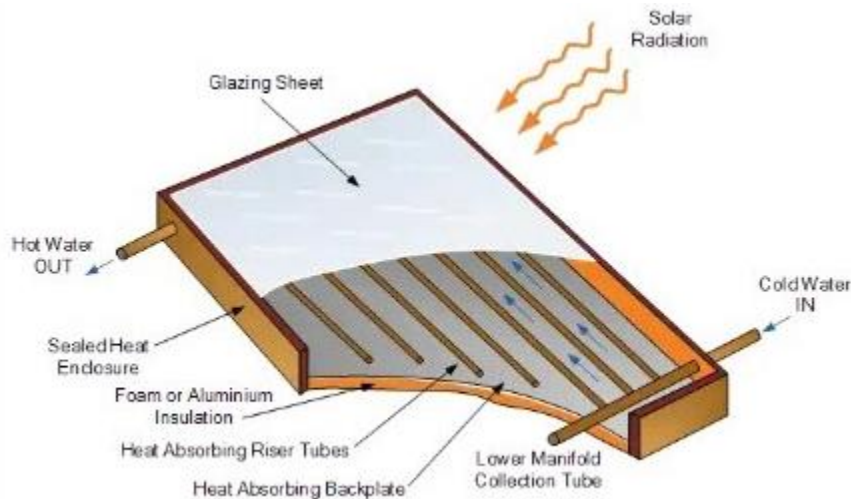


Fig 2.2: Flat plate collector (source: Alternative energy tutorial.com)

2.7.1.2. EVACUATED TUBE COLLECTOR (ETC)

It consists of a number of evacuated tubes in series that absorb solar radiation and convert it to heat energy. The outer tube has small reflectivity and absorptivity with high transmissivity. The space between the outer and inner tubes prevent heat loss. The inner plate has high absorptivity and transfers the energy to the fluid.

Advantages of Evacuated Tube Collectors

- 1) Its efficiency can be maintained over a wide range of temperature, hence it is efficient for high temperature application.

- 2) It is easy to maintain, since any faulty tube can be easily replaced without affecting the performance of the others.
- 3) The tubes can be easily installed.

Disadvantages of Evacuated Tube Collectors

- 1) The efficiency is badly affected by weather conditions, especially in cloudy and rainy weather.
- 2) It is more expensive than the flat plate collector.

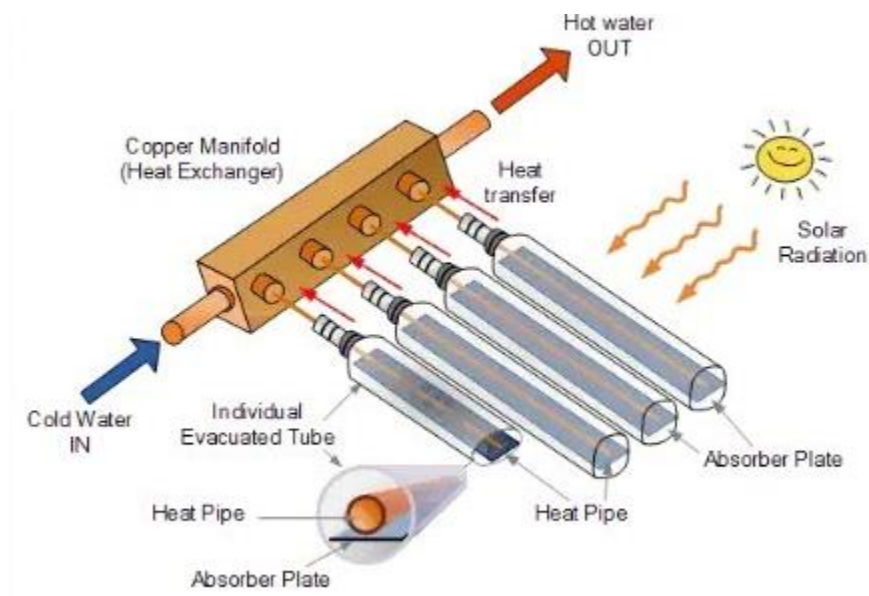


Fig 2.3: Evacuated tube collector (source: Alternative energy tutorial.com)

2.7.1.3 DETERMINATION OF EVACUATED TUBE SOLAR COLLECTOR AREA

(Omo-Oghogho, 2019) calculated the average daily solar irradiation data for Benin City as 1017.695W/m^2 , using data from the National Centre for Energy and Environment university of Benin.

The solar collector area can be determined by a simple method (Haw et al, 2009)

$$A = \frac{1}{G \cdot \eta \cdot \text{COP}} \left(\frac{\text{m}^2}{\text{kw}} \right)$$

Where:

G= incident solar radiation

η =solar collector efficiency

C.O.P. =COP of chiller

The efficiency of an evacuated solar tube collector has been estimated to be 0.79 (Maraj et al 2019)

2.7.2 STORAGE TANK

The storage tank is used to store either excess solar heat or excess cooling power in order to accommodate mismatches between solar gains and cooling loads. There are two possible places for incorporating storage tank (Haw et al, 2009). Excess solar heat can be stored in a cold storage tank and when used when the

solar heat is not adequate or excess cooling power of the chiller can be stored in a cold storage tank and utilized when the chiller can no longer meet cooling load.

It is more economical and efficient to store excess heat compared to cold production due to temperature difference between the environment and storage tank.

The advantages of not integrating a storage tank include:

1. Earlier cooling effect.
2. Leads to shorter time for the absorption chiller to reach its generator temperature.
3. Higher cooling power peaks can be attained
4. It gives lesser cost
5. Simpler designs.

However, without a storage tank, the absorption chiller cannot meet thermal load demand in the late afternoon because of lower generator temperatures (Batineh et Tanneh, 2016). the storage tank is needed to overcome any mismatch between cooling load and heat energy supply.

The hot water storage tank performs the following functions:

1. It stores excess heat for times when solar heat is not generated.
2. It reduces the needed capacity of auxiliary boiler/heaters
3. It ensures sufficient energy is available for the absorption chiller.

The size of thermal storage tank is a key factor for the energy performance of the system. The volume of the storage tank must be designed so that the temperature of the storage tank is close to that of the chiller operating temperature (Hang et al 2011) discovered that the solar fraction varied from 51% to 57% when the hot storage tank volume increased from 0.01m^3 to 0.11m^3 per unit area of solar collector. The optimal storage tank volume is between 0.05m^3 to 0.11m^3 per unit area of solar collector for cooling of office building (Mateus et Olivera, 2009)

2.7.3 ABSORPTION CHILLER

Absorption chiller is a machine that consists of interconnect chambers which produces a refrigeration effect through the use of a heat source (Haw et al, 2009). It works on the absorption cycle. The absorption cycle can be divided into 3 stages.

1. Evaporation: Here, the liquid refrigerant evaporates removing heat from its surroundings.
2. Absorption: gaseous refrigerant is absorbed by a liquid, hence decreasing its partial pressure (which would cause it to evaporate)
3. Regeneration: The liquid (with dissolved refrigerant) is heated which causes the refrigerant to evaporate.

The various configurations of absorption chiller available are:

1. The single effect absorption system
2. The double effect absorption system
3. Triple effect absorption system
4. Generator – absorber heat exchanger GAX Absorption Chiller.

2.7.4.1 SINGLE EFFECT ABSORPTION SYSTEM

The single effect absorption system has two circuits, the refrigerant circuit and the refrigerant/absorbent solution circuit as shown in the figure, It has the simplest configuration and few components. It can be applied for both air conditioning and refrigeration.

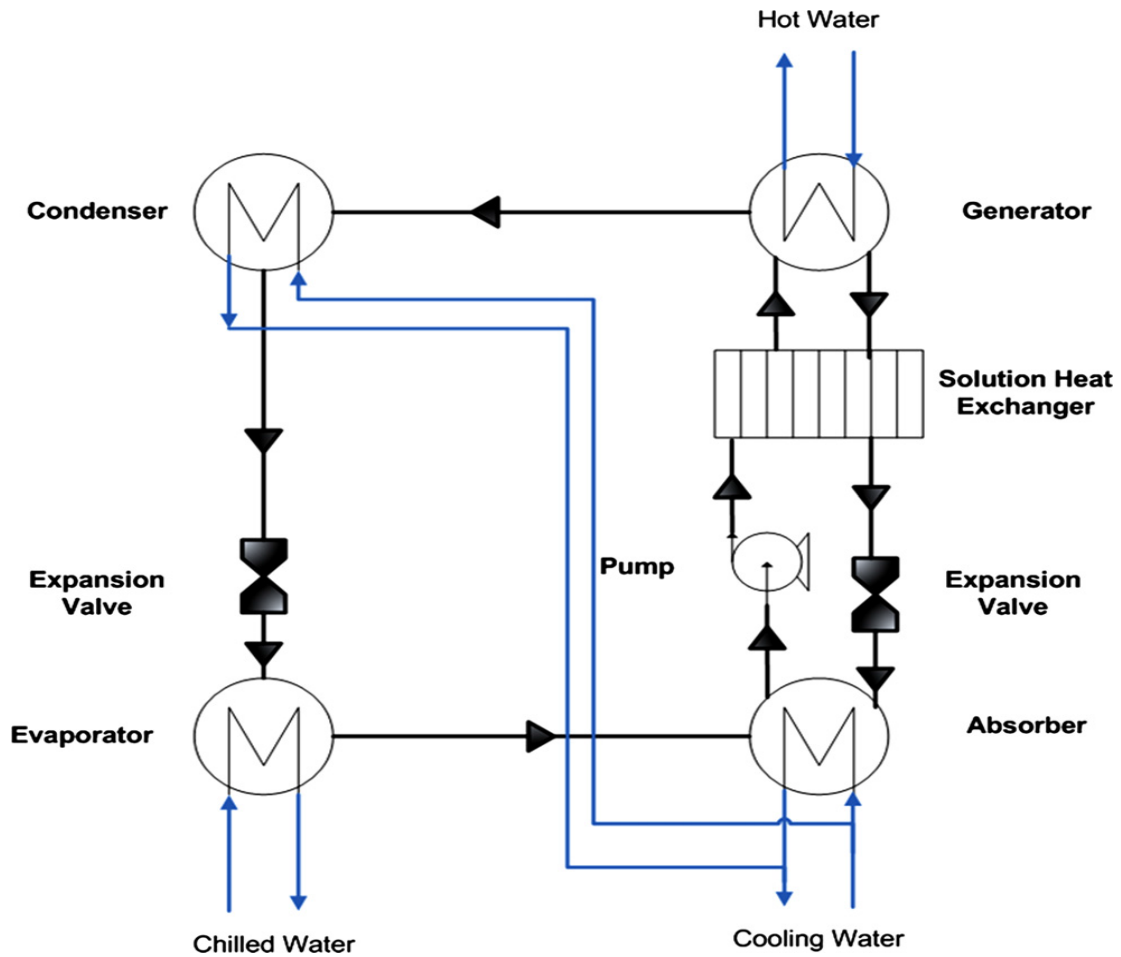


Fig 2.4: Single –effect absorption system (source:)

2.7.4.2 DOUBLE EFFECT ABSORPTION SYSTEM

It consists of a high pressure and low pressure stage. The vapour is compressed (high pressure) and passed to the evaporator (which us at low pressure). The system can operate with a lower generator temperature compared to single effect machines. Thus, the system can function even when solar radiation is low. It has a higher COP and able to operate at high condensation temperature T_c up to 53°C and low generation temperature T_g of 80°C (Batineh et Tanneh, 2016).

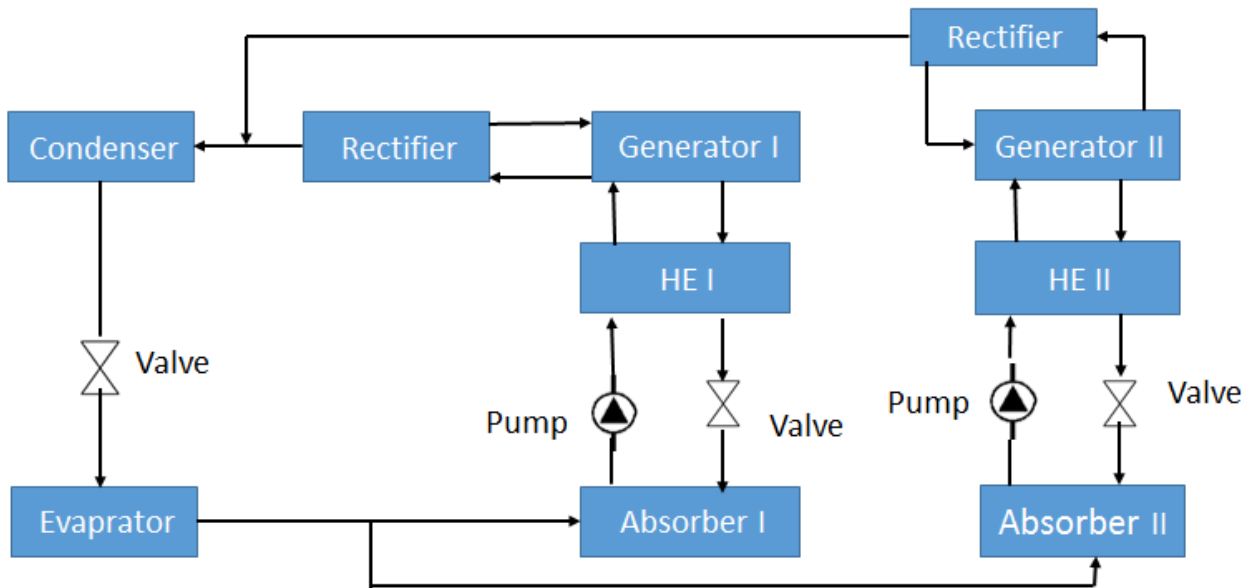


Fig 2.5: Double-effect absorption system (source; Batineh et Tanneh, 2016)

2.7.4.5 TRIPLE EFFECT ABSORPTION SYSTEM

The triple effect absorption system has the higher COP when used with high temperature solar collectors with generator temperature above 150°C but this

leads to high initial cost (Batineh et Tanneh, 2016). It consists of heliostat and central receiver used to power triple effect absorption chiller which is suitable for refrigeration application.

2.7.4.6 GAS-ABSORBER HEAT EXCHANGER GAX ABSORPTION

This cycle has a better performance than the single effect system.

2.7.5 COEFFICIENT OF PERFORMANCE

The coefficient of performance of a refrigeration system is the ratio of its ability to remove heat from a cold source to the supplied energy for its operation. This ratio is a measure of the efficiency of the cooling system. The solar COP

is defined as:

$$COP = \frac{Q_{cold}}{Q_{heat}}$$

Where:

Q_{cold} is the cooling effect produced at the evaporator, and

Q_{heat} is all the solar energy received by the solar collector surface.

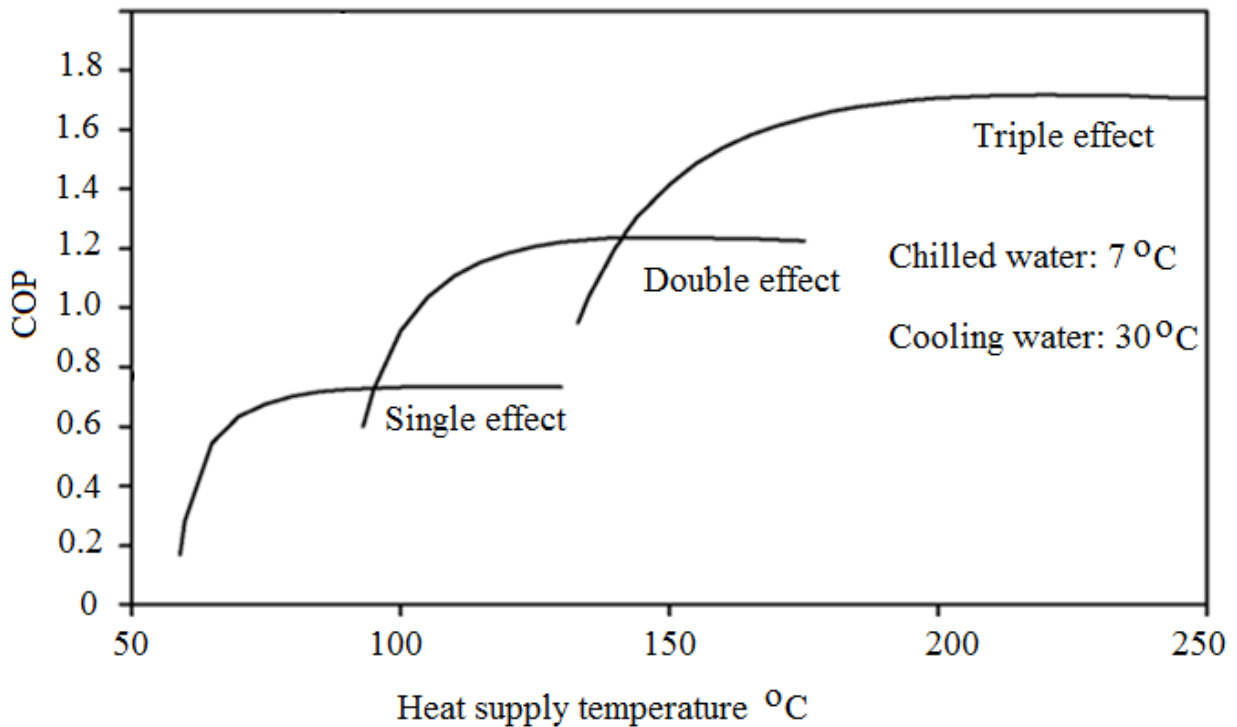


Fig 2.6: Performance of different absorption systems with solar collectors (source: Eicker, 2009)

2.7.6 COOLING TOWER

Cooling tower is a device where cooling water is brought into contact with ambient air in order to transfer heat to the ambient air. There are two basic types of cooling tower, the open-circuit systems and closed circuit systems (where there is no direct contact between the two fluids across heat exchanger walls).

From the literature review, it can be concluded that:

1. Solar air conditioning system is more feasible where cost of electricity is high/increased

2. Solar thermal air conditioning system is a better option than solar PV-vapor compression system.
3. Economically, solar absorption system is more feasible than solar adsorption system
4. LiBr-H₂O is so far the best pair for air-conditioning application.
5. Several analyses, experimental works, researches and stimulating have been carried out on solar absorption system.

However, all the works done were based on the central cooling of buildings and not a single office.

CHAPTER 3

METHODOLOGY

In order to achieve the previously listed objectives, the following approach was adopted:

1. A comprehensive literature review of solar air-conditioning systems. This includes a thorough study of absorption systems and the feasibility of solar absorption system in Nigeria..
2. Collection of the required metrological data for Benin City (average daily solar irradiation data, weather, and so on).
3. Cooling load determination/estimation.
4. Design and sizing of the air conditioning system using weather data and selected design conditions.
5. Optimization of the system with the aim of least cost energy.
6. Performance evaluation and economic analysis; the economic effectiveness of the system will be evaluated,
7. Techno-economic investigation to evaluate the technical feasibility of several.

3.1 ASSUMPTIONS

The following basic assumptions have been made.

1. There are no kinetic and potential energy effects and there is no chemical or nuclear reaction.
2. All processes are steady state and steady flow.
3. The system surrounding is considered as large thermal reservoir and no influence of local activity of source or sink.

4. The refrigerant-absorbent are considered to be ideal.
5. No pressure changes except through the flow restrictors and the pump.
6. Pump is isentropic.

3.2 DESIGN SPECIFICATIONS

The design specification gives the specific quantitative and qualitative information and operating performance of the air-conditioner and the components.

The major specifications which will be considered include the following:

Air conditioner data

Cooling Load of building.....0.995kW

Condenser temperature.....40⁰C

Absorber temperature.....30⁰C

Evaporator temperature.....10⁰C

Ambient temperature.....35⁰C

Room temperature24⁰C

Room relative humidity.....50%

Refrigerant..... water

Absorbent..... Lithium-Bromide

Condenser cooling.....free/natural convection

Evaporator type..... aluminum plate placed in the enclosed space

Inlet temperature of water to solar collector27⁰C

Outlet temperature of water from solar collector 95⁰C

Solar Data

Average daily solar radiation of Benin City1017.695W/ m²

Collector Type.....Evacuated tube collector

Evacuated Tube Collector efficiency.....0.76

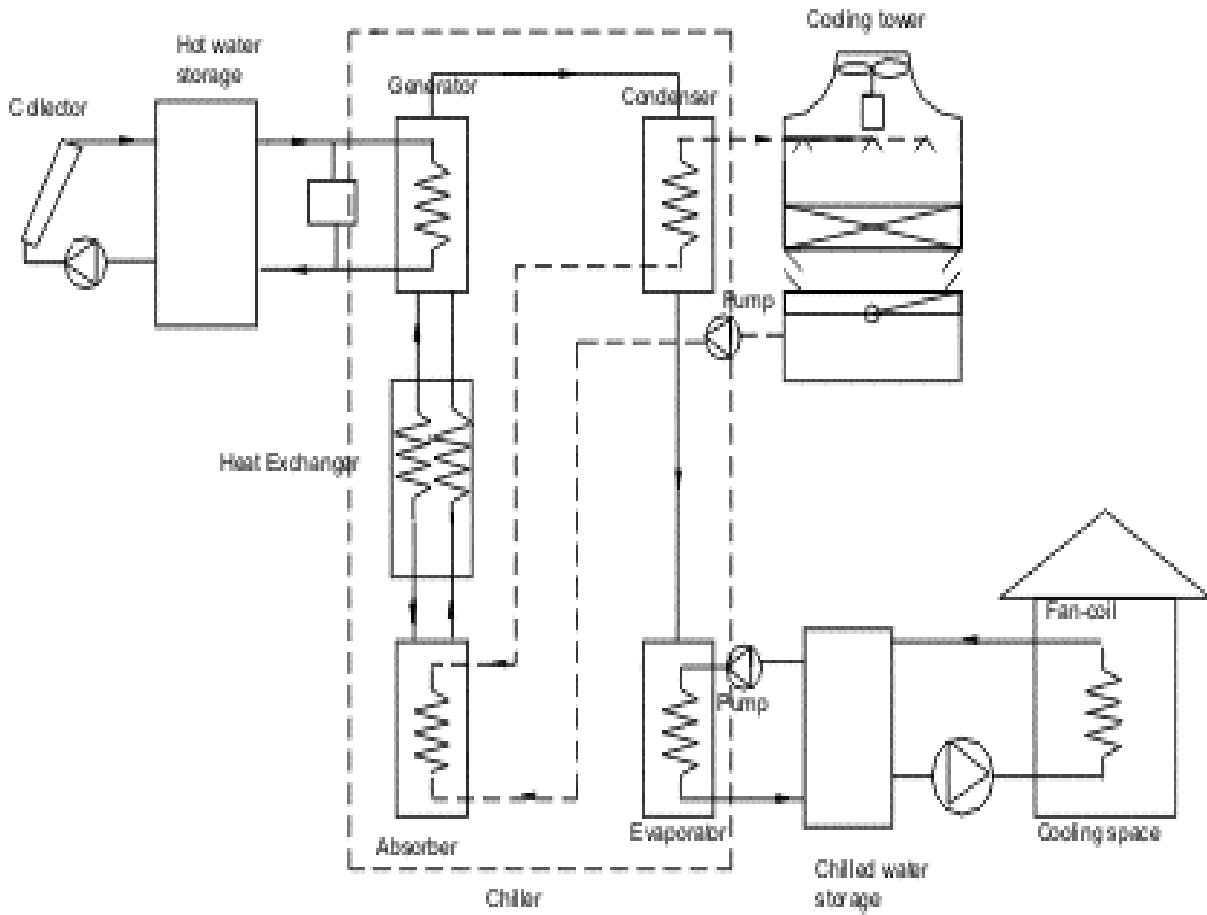


Fig 3.1: Working diagram of the solar absorption system

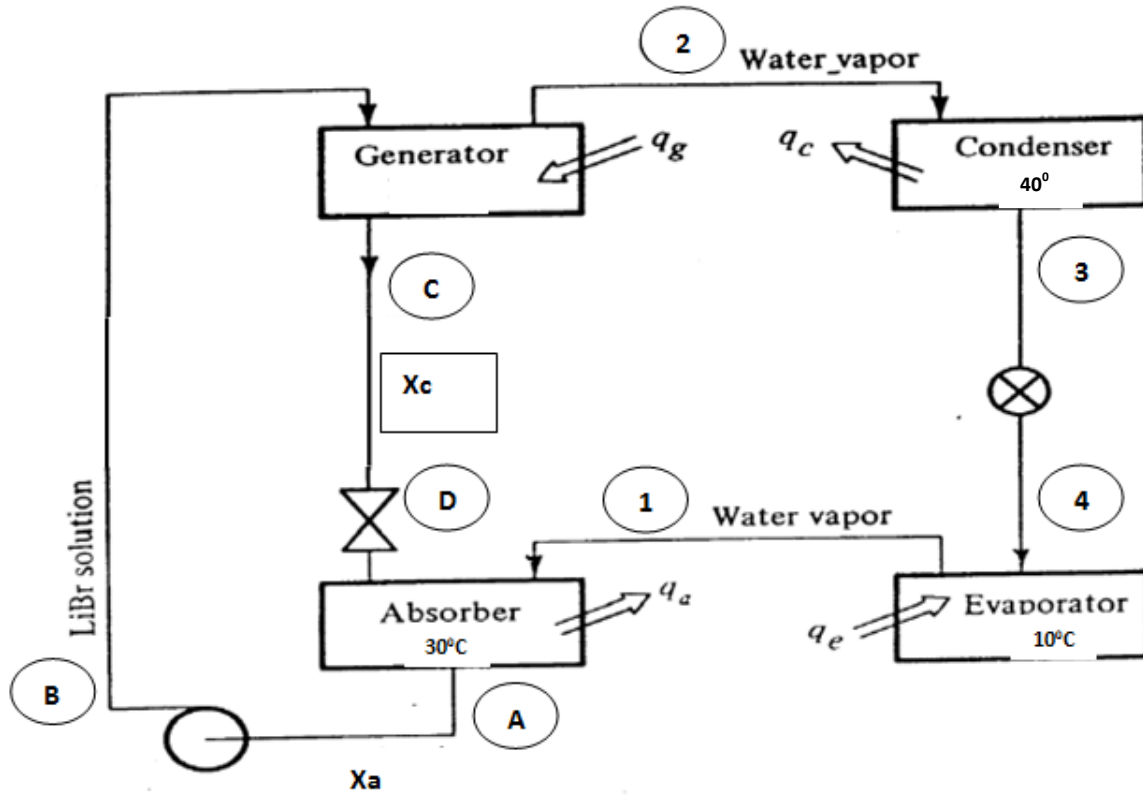


Fig 3.2: Absorption cycle schematics

3.3 SOLAR COLLECTOR CALCULATION

Evacuated solar tube efficiency=0.79

$$A = \frac{1}{G \cdot \eta \cdot \text{COP}} \left(\frac{\text{m}^2}{\text{kw}} \right)$$

Where:

G= incident solar radiation

η =solar collector efficiency

C.O.P. =COP of chiller

CHAPTER 4

RESULTS AND ANALYSIS

4.1 DESIGN CALCULATIONS

4.1.1 ABSORPTION SYSTEM CALCULATION

For generator temperature of 75°C

At Condenser

$$\begin{aligned}H_2 &= H_g \text{ at generator temperature } (75^{\circ}) \\ &= 2634.7\text{kJ/kg}\end{aligned}$$

$$\begin{aligned}H_3 &= H_f \text{ at condenser temperature } (40^{\circ}) \\ &= 167.5\text{kJ/kg}\end{aligned}$$

At evaporator

$$\begin{aligned}H_4 &= H_3 \text{ (Isenthalpic Throttling)} \\ &= 167.5\text{kJ/kg}\end{aligned}$$

$$\begin{aligned}H_1 &= h_g \text{ at evaporator temperature } (10^{\circ}\text{C}) \\ &= 2519.2\text{kJ/kg}\end{aligned}$$

Mass flow of refrigerator through evaporator

$$m_e = m_1 = m_2 = m_3 = m_4$$

$$\text{At absorber} \quad m_e = \frac{R.C}{R.E}$$

$$R.C = 0.995\text{kW}$$

$$P_{\text{aeva}} = P_{\text{cond}} = 0.01227\text{bar}$$

$$= 1.227.7\text{Kpa}$$

X_a = Concentration of Lithium bromide leaving absorber to generator at $t = 30^{\circ}\text{C}$, $P = 1.23 \text{ k}$

$$= 50 \%$$

$$= 0.5$$

$$H_a = - 168\text{kJ/kg}$$

At the generator

X_c = concentration of lithium bromide leaving generator to absorber at $t = 75^{\circ}\text{C}$

$$P_{\text{gen}} = P_{\text{cond}} \text{ at } 40^{\circ}\text{C}$$

$$= 0.07375\text{bar}$$

$$= 7.375\text{kpa}$$

$$X_c = 56.5\%$$

$$= 0.565$$

$$H_c = - 95\text{kJ/kg}$$

$H_c = h_d$ (Isenthalpic Throttling)

Mass balance at absorber

Mass of solution only

$$X_d m_d = m_a x_a$$

$$0.565 m_d = 0.5 m_a$$

$$0.5 m_a - 0.565 m_d = 0 \dots\dots\dots(1)$$

Mass balance at generator

$$m_2 + m_c = m_a$$

$$0.000423 + m_c = m_a$$

$$M_a - m_d = 0.0002623 \dots\dots\dots(4)$$

Solving equation (1) and (4) simultaneously

$$M_a = 0.00368 \text{ kg/s}$$

$$M_d = 0.003254 \text{ kg/s}$$

Heat received at the generator (Q_{gen})

$$\begin{aligned} Q_{\text{gen}} &= m_2 H_2 + m_c H_c - m_a H_a \\ &= 0.000423 \times 2634.7 + 6.003254 \times (-95) - 0.00366 \times (-168) \\ &= 1.4245881 \text{ Kw} \end{aligned}$$

$$\text{C.O.P} = Q_{\text{cva}} = 0.995$$

$$\begin{aligned} & \frac{Q_{\text{gen}}}{1.4235881} \\ &= \mathbf{0.699} \end{aligned}$$

For generator temperature of 80°C

$$x_a = 0.5$$

$$x_c = \text{Concentration of Lithium bromide leaving generator at } t = 80^\circ\text{C} \quad P = 7.375 \text{ k.p}$$

$$= 59\%$$

$$= 0.59$$

$$H_c = H \text{ at } x_c \text{ and } t = 80^\circ$$

$$= -82 \text{ kg/kg}$$

$$H_2 = H_g \text{ at } t = 80^\circ$$

$$= 2643.2 \text{ kJ/kg}$$

Mass balance at absorber

Mass of solution only

$$X_d m_d = x_a m_a$$

$$0.59 m_j = 0.5 m_a$$

$$0.5 m_a - 0.59 m_j = 0 \dots \dots \dots (1)$$

Mass balance at generator

$$M_2 + m_c = m_b$$

$$M_a - m_d = 0.000423$$

Solving equation (I) and (II) simultaneously

$$M_a = 0.002773 \text{ kg/s}$$

$$M_1 = 0.00235 \text{ kg/s}$$

heat received at generator (Q_{gen})

$$\begin{aligned} Q_{\text{gen}} &= M_2 H_2 d + M_c H_c - M_b H_b \\ &= 0.000423 \times 26432 + 0.00235 \times (-87) - 0.002373 \times (-168) \\ &= 1.3912 \text{ KW} \end{aligned}$$

$$\text{COP} = Q_{\text{eva}} = 0.995$$

$$\begin{aligned} \frac{Q_{\text{gen}}}{Q_{\text{eva}}} &= \frac{1.3912}{0.995} \\ &= \mathbf{0.715} \end{aligned}$$

For generator temperature of 90°C

$$x_a = 0.5$$

x_c = Concentration of lithium bromide leaving generation at $t = 90$, $p = 7.35 \text{ kp}$

$$= 65\%$$

$$= \mathbf{0.63}$$

$$H_c = -64\text{kJ/kg}$$

$H_c = h_d$ (Isenthalpic Throttling)

Mass Balance at absorber

Mass of solution only

$$X_d m_d = x_a m_a$$

$$0.63 m_d = 0.5 m_a$$

$$0.5 m_a - 0.63 m_d = 0 \dots \dots \dots (1)$$

Mass balance at generator

$$M_2 + m_c = m_b$$

$$0.000423 + m_d = m_a$$

$$M_a - m_d = 0.000423 \dots \dots \dots (2)$$

Solving equation (1) and (2) simultaneously

$$M_a = 0.00205\text{kg/s}$$

$$M_d = 0.00163\text{kg/s}$$

$$H_2 = H_g \text{ at } 90$$

$$= 2659.7\text{kJ/kg}$$

Heat received by generation (Q_{gen})

$$Q_{gen} = m_2 H_2 + m_c H_c - m_b H_b$$

$$= 0/000423 \times 2659.7 + 0.00163 \times (-64) - 0.02/205 (-168)$$

$$= 1.3651331 \text{KW}$$

$$\text{C.O.P} = Q_{\text{cva}} = 0.995$$

$$\begin{aligned} Q_{\text{gen}} &= 1.365144 \\ &= \mathbf{0.729} \end{aligned}$$

For generator temperature of 95°C

X_c = Concentration of Lithium bromide at $t = 95^\circ$ $P = 7.375 \text{kpa}$

$$X_c = 68\% = 0.68$$

$$H_c = -60 \text{kJ/kg}$$

$$H_c = H_d \text{ (Isenthalpic Throttling)}$$

$$\begin{aligned} H_2 = H_g \text{ at } 95^\circ \text{ from thermodynamic label} \\ = 22667.8 \text{kJ/kg} \end{aligned}$$

Mass balance at the absorber generation

$$0. m_2 + m_c = m_b$$

$$0.000423 + m_c = m_b$$

$$M_a - m_d = 0.000423 \dots \dots \dots (2)$$

Solving equation (1) and (2) simultaneously,

$$m_a = 0.001833 \text{kg/s}$$

$$m_d = 0.00141 \text{kg/s}$$

Heat received by the generator (Q_{gen})

$$Q_{\text{gen}} = M_2 H_2 + M_c H_c - H_b M_b$$

$$= 0.000423 \times 2667.8 + 0.00141 \times (-60) - 0.001333 \times (-160)$$

$$= 1.3518234 \text{KW}$$

$$\text{CO.P} = Q_{\text{cva}} = 0.995$$

$$Q_{\text{gen}} = 1.3518234$$

$$= \mathbf{0.736}$$

For generator temperature of 75%

At condenser

$H_2 = H_g$ at generator temperature (75°)

$$= 2634.7 \text{kJ/kg}$$

$H_3 = H_f$ at condenser temperature (4c)

$$= 167.5 \text{kJ/kg}$$

at evaporation

$H_4 = H_3$ (Isenthalpic Throttling)

$$= 167.5 \text{kJ/kg}$$

$H_1 = H_g$ at evaporator temperature (10°C)

$$= 2519.2 \text{kJ/kg}$$

Mass flow of refrigerant through evaporation

$$m_c = m_1 = m_2 = m_3 = m_4$$

$$m_c = \text{R.C}$$

$$\text{R.E}$$

From the calculations done above, the following system parameters have been calculated/estimated.

- 1) Mass flow rate of refrigerant (M_1) = 0.000423kg/s
- 2) Generator temperature with respective COP
- 3) Optimum generator temperature=95⁰C with generator heat energy=1.3518kW
- 4) COP at optimum generator temperature= 0.736

Size of Collector needed

$$\text{Collector area (A)} = \frac{1}{G \cdot 7 \cdot \text{C.O.P}}$$

$$G = 1.017695 \text{KW/m}^2$$

$$7 = 0.76$$

$$\text{C.O.P} = 0.736$$

$$A = \frac{1}{1.017695 \times 0.76 \times 0.736} = 1.756673106 \text{m}^2/\text{KW}$$

Since we are designing of regeneration with C.O.P = 0.736

$$Q_{\text{gem}} = 1.35182344 \times 1.756673106$$

$$A = 1.3518234 \times 1.756673106$$

$$= 2.37471811 \text{m}^2$$

$$= 2.385 \text{m}^2$$

Each evacuator tube has 0.1m² area

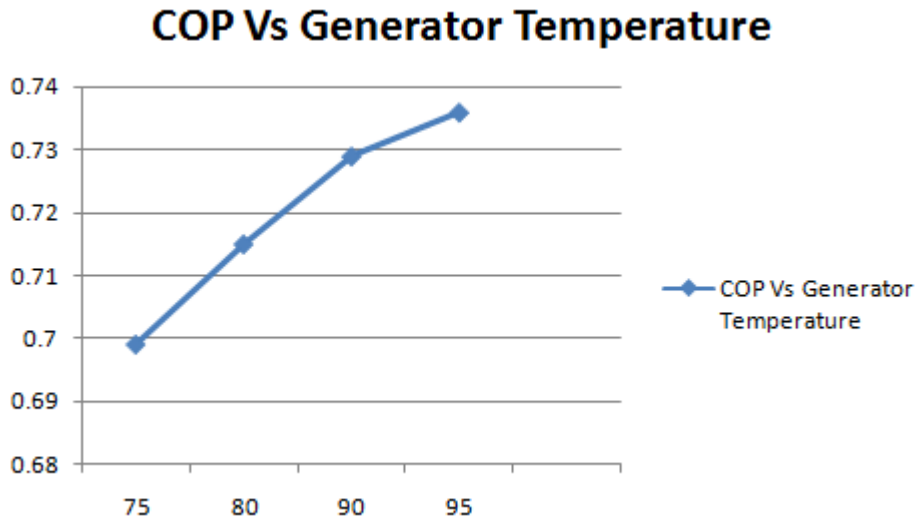
$$= \frac{2.375}{0.1}$$

= 24 evacuated tubes required.

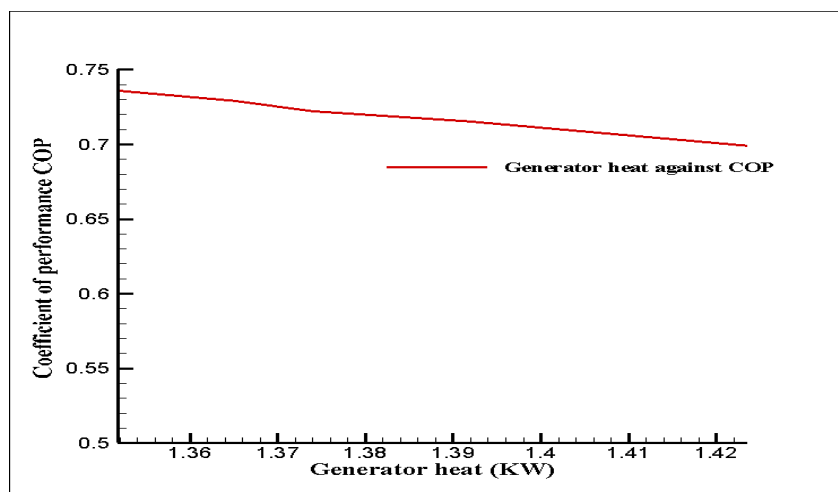
ANALYSIS

The following graphs were plotted:

(1) Graph of Generator temperature against COP (using Excel)



(2) Graph of Generator heat gain against COP (using Techplot)



CHAPTER 5

5.1 RECOMMENDATIONS FOR FUTURE RESEARCH WORK

The solar powered absorption air-conditioning system is a complex, dynamic system. This difficulty and ambiguity of the system evaluation is a further hindrance to the wider application of solar cooling.

For there to be a better system improvement in the design of solar powered absorption air-conditioning system, a parametric study have to be carried out to evaluate the influence of the key parameters on the general system performance. If experiments were to be used to carry out the parametric study, effects of one key parameter on the overall system performance would normally require different cooling seasons therefore years to establish a concrete conclusion. It is also extremely difficult to keep the performance of all the components of the system to be optimal all through the experimental period as the system deteriorate with time.

Therefore, to avoid this uncertainty, difficult and expensive experimentation, researchers can develop and validate a robust dynamic model of the solar powered air- conditioning system and simulation can be done to study the system. This will help to perform the parametric study on the model rather than the physical system itself.

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