THERMODYNAMIC ANALYSIS OF VAPOUR ABSORPTION REFRIGERATION SYSTEM USING VARIOUS SOLUTION PAIRS

DISSERTATION

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By

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CERTIFICATE

I hereby certify that the work which is being presented in the Dissertation-II entitled **"THERMODYNAMIC ANALYSIS OF VAPOUR ABSORPTION REFRIGERATION SYSTEM USING VARIOUS SOLUTION PAIRS"** in partial fulfillment of the requirement for the award of degree of **Master of Technology** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjabis an authentic record of my own work carried out during period of Dissertation-II under the supervision of **Mr. Sudhanshu Dogra**, **Assistant Professor**, Department of Mechanical Engineering, Lovely Professional University, Punjab.

The matter presented in this dissertation has not been submitted by me any where for the award of any other degree or to any other institute.

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Date **(Shubham Srivastava)**

This is to certify that the above statement made by the candidate is correct to best of my knowledge.

Date: **(Mr. Sudhanshu Dogra)**

SUPERVISOR

ACKNOWLEDGEMENT

This Dissertation-II was a welcome and challenging experience for me as it took a great deal of hard work and dedication for its successful completion. It's my pleasure to take this opportunity to thank all those who help me directly or indirectly in preparation of this report.

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There times in such projects when clock beats you again and again and you run out of energy and you want to finish it once and forever. Last but not the least I would like to thank family and friends for their boost and support in every sphere. Their vital push infused a sense of insurgency in me.

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ABSTRACT

In the present days sources of producing energy and their depletion rate, there is a large shift of attention on using non-conventional sources of energy so that the conventional one's can be sustained. Similarly, the role of refrigeration also comes very handy at times when the amount hotness in the atmosphere is over an optimum level. At present times when the sources of generating electricity are on a decline; for example: coal hence it's not possible for to utilize the conventional vapour compression refrigerator as it requires electricity for its functioning.

Due to this problem now the researcher are shifting their minds toward methods that could be used to continue the phenomenon of refrigeration with the help of non-conventional energy resources. For example: Solar Energy, Geothermal Energy, Biogas etc.

Now in this thesis work one such source in taken into consideration and i.e. "Solar Energy" and the technology that combines both principles of solar as well as refrigeration is known as "Vapour Absorption Refrigeration System". This system utilizes the solar energy in order to perform the operation of refrigerator. The other working components of the system are generator, absorber, condenser, evaporator expansion valves & the most important of all "WORKING FLUID PAIR". The main stress of this project is laid on the "working fluids" itself and how is possible to enrich the performance of the system.

1. INTRODUCTION

It is quiet well known that energy is the basic degree of every type of work performed by the humans or by the nature. According to the physics, it is defined as the property of objects, transferable among them and is convertible in different forms but neither could be created nor be destroyed. In our nature whatever happens could be represented as the "flow of energy in one or the other form". Many people use the term "energy" as input to their bodies or to machines.

Different Classification of Energy Resources

1. **Primary Energy Source**: These could be defined as the source which provides us with the net supply of energy. For example: Coal, Natural Gas, and Oil. The energy obtained from these sources is much less than what they produce by the process of combustion. Hence it's very essential to utilize such fuels moderately.

2. **Secondary Fuels Source**: Despite of being an essential part of economy the net production of energy through them is negligible. Example: Solar energy, Wind energy, Hydro energy etc.

3. **Supplementary Energy Source**: These sources are those whose net energy yield are zero but still needs high investment in terms of energy. Example: Geothermal and Ocean thermal sources.

These are also classified as "Renewable and Non-Renewable" which is based upon their existence in nature

a) **Renewable Sources**: These are generally defined as sources which are naturally replenished on human timescale. Based upon REN[1]2014 report these sources involve 19% to our electric consumption and 22% to our electricity generation in last two years. Example: Solar, Wind, Bio-Gas, Thermal.

b) **Non-Renewable Sources**: There are those sources which would end after a particular interval of time and would not exist for longer duration as same as that of renewable sources. Example: Coal, Fossil Fuels.

[1] **REN21**, the **Renewable Energy Policy Network for the 21st Century,** is a global renewable energy policy network that provides international leadership for the rapid transition to renewable energy.

1.1 VARIOUS SOURCES OF ENERGY

1.1.1Bio-mass and Bio-energy

Biomass is defined as “organic substance made-up from plants and animals”. They consists stored energy from the sun by the process of “photosynthesis”. The chemical energy inside the plants keeps on moving forward onto the animals and then on to the humans who feed them. It is one the renewable energy source because crops and plants can be grown more, and thus waste will always exists. For example: wood, crop and some garbage. These are convertible to other forms of energy like methane and fuels like ethanol and others.

Methane is one of major components of natural gas. Crops such as sugarcane are fermented in order to produce fuels like ethanol. Biodiesel, are also produced by the left over products like vegetable oils and animals fats. The biomass fuel provides nearly about 3% of energy in United States. Using biomass as a source of energy the amount of waste could be reduced to some extent and have a lot environmental benefits.

1.1.2 Geothermal Energy

The inside heat of the earth leads to making of the “geothermal energy”. This heat crawls up toward the surface of the earth and warms water in between hundreds to thousands of meters. These volumes of hot water are known as “geothermal deposits” and they are utilized to provide heat and electricity in regard to their temperature. Very low deposit water which is in between 10-50^{o}C is used for the purpose of heat greenhouse effect.

Low energy-deposits between 50-90^{o}C and depth between 1500-2000 meters could be utilized as for district heating. Medium energy-deposits between 90-150^{o}C and depth of 2000-2500 meter are required in order to supply electricity. Turbines can be operated directly using high energy-deposits at a temperature above 150^{o}C but not far below surface.

1.1.3 Nuclear Energy

It is the form of the energy that is stored in the nucleus of an atom and which is released because of the process of fission or fusion. This energy form follows the relation, $\boldsymbol{E = mc^2}$ **where E is the energy, m is the mass and c is the speed of light.** The most difficult problems concerning this source of energy are the probability of accident at the site of nuclear reactors or fuel plants.

1.1.4 Ocean Energy

Ocean Thermal Energy Conversion are used to produce power by using variety of temperature difference of sea water at various depths. This includes pumping of cold water from the ocean depth on to the surface and so extracts the energy from the movement of heat in between the cold water and hot surface water. As we know very well, that the oceans are continuously heated by the sun and covers nearly 70% of the earth's surface, this temperature difference consists of a huge amount of solar energy that could be trapped in and taken in for human use.

This system performs action which nearly resembles to that of a heat engine which works between the two temperature sources, where heat flows from high to low temperature and at the very same time the engine extracts some of heat in terms of work. In spite of using heat energy by burning fuel, OTEC draws power on temperature difference caused by the sun's warming of the ocean surface.

1.1.5 Wind Energy

Wind turbines are generally used by wind energy in order to generate electrical energy systems by diminishing the power of the wind. Wind is one of the forms of solar energy, which is caused as a result of uneven heating of the earth's surface. The speed of the wind varies with altitude and it increases as we go on the higher altitudes. The wind plants are able to produce both Direct Current (DC) as well as Alternating Current (AC).

DC plants are used for the purpose of charging batteries or else to produce electricity without any sort of storage. AC wind plants are used to provide electricity either for direct use or else for supply of energy to the utility grid. Some wind plants have Vertical Axis Wind Turbines [VAWT] or some have Horizontal Axis Wind Turbine [HAWT].

1.1.6 Solar Energy

It is form of the energy that is produced in the sun because of the phenomenon of nuclear fusion reactions. It is then transmitted to the earth through the space in the form of some packets of energy that are called as "photons", which interacts with earth's atmosphere and surface. The strength of the solar radiation which is occurring at the outer edge of the earth's atmosphere when the earth is to be taken at average distance from the sun and is known as the "solar constant" which has a mean value of 1.37*106 ergs per sec per cm^3.

Among the total energy transmitted from the sun, the upper atmosphere of earth receives 1.5*1021 watt-hrs of solar radiation annually which is very huge amount of energy and is more than 23,000 times that is required by the humans needs. Some amount of solar radiation is reduced to an extent before reaching the earth's surface by the atmosphere which removes or alters part of the incident energy by processes of "reflection, scattering and absorption". The radiations that arrived directly to the surface are known as "direct radiations". The global radiations are the amount of radiations that are incident to the surface and it includes direct and diffused ones as well.

In the field of research and technology development in this category thus aims at finding the most efficient ways of capturing low-density solar energy and developing systems to convert the captured energy for different important purposes. Solar energy could be converted into useful work or heat with the help of application of solar collectors which are used to absorb solar radiations and allow maximum of the sun's radiant energy to be converted into the heat.

1.2 FIELD OF APPLICATIONS

- Solar Distillation
- Solar Pumping
- Solar Furnace
- Solar Cooking
- Solar Green Houses
- Solar Refrigeration and Air-Conditioning

1.3 REFRIGERATION

Well we can define the refrigeration as the phenomenon of obtaining and maintaining the temperature lower than that of the surroundings, where the main motive is to cool some products or needed space to the temperature needed. In other words; we can also express the term "refrigeration" as the phenomenon to be taken in regard to remove heat from a body that is kept for cooling.

The methods that could be used in order to accomplish them are:

- With the help of melting solid,
- From the sublimation process of a solid, and
- Also by the evaporation phenomenon of liquid

At present maximum of the refrigeration is made achievable due to the evaporation of the liquid which is often termed as "refrigerant". The factors on which "mechanical refrigeration" depends are the evaporation of the liquid refrigerant and the arrangement that involves the components named as "**Condenser**, **Compressor, Expansion Valve and Evaporator**". In order to provide to achieve thermal comfort for the human beings concept of refrigeration is also applicable but is known as "air-conditioning", where it is referred as the treatment of air so as to manage quantities like as temperature, moisture content, cleanliness and circulation.

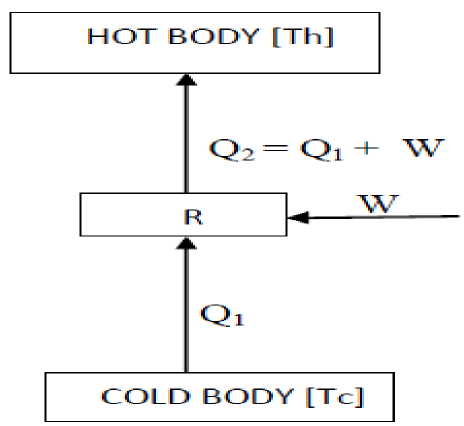


Figure 1 Simple Refrigerator

1.3.1 AREA OF INTREST:

- Making of Ice
- Industrial & Residential air-conditioning
- Chemical and related industries
- Treatment and production of metals
- Preservation of food products.

1.3.2 VARIOUS REFRIGERATION SYSTEMS

1.3.2.1 Air refrigeration system [ARS]

1.3.2.2 Vapour compression refrigeration system [VCRS]

1.3.2.3 Vapour absorption Refrigeration System [VARS]

1.3.2.1 AIR REFRIGERATION

Major elements of this system are:

- Compressor
- Air Cooler
- Expander
- Refrigerator

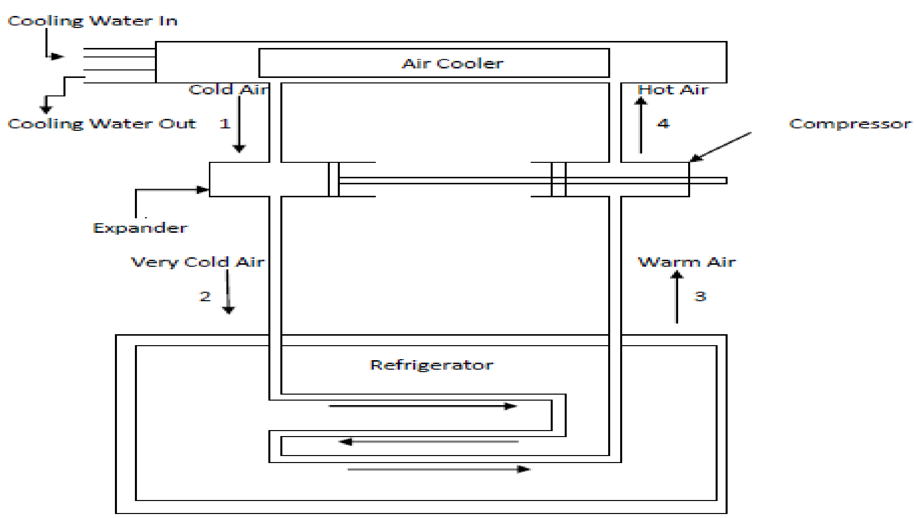


Figure 2 Schematic Diagram of Air Refrigeration System

In such systems, net work is obtained from expander and is utilized for compression of air, so as a result of this, less external work is required for proper working of the system. This can also be depicted as the "Modified Reversed Carnot Cycle", with the two isothermal processes of Carnot cycle are replaced by two isobaric heat transfer processes [12].

TABLE-1 Description of Air Refrigeration System

PROCESS	NATURE OF PROCESS	COMPONENT IN WHICH TAKES PLACE
1-2	Isentropic Compression	COMPRESSOR
2-3	Constant Pressure Cooling	AIR COOLER
3-4	Isentropic Expansion	EXPANDER CYLINDER
4-1	Constant Pressure Expansion	REFRIGERATOR

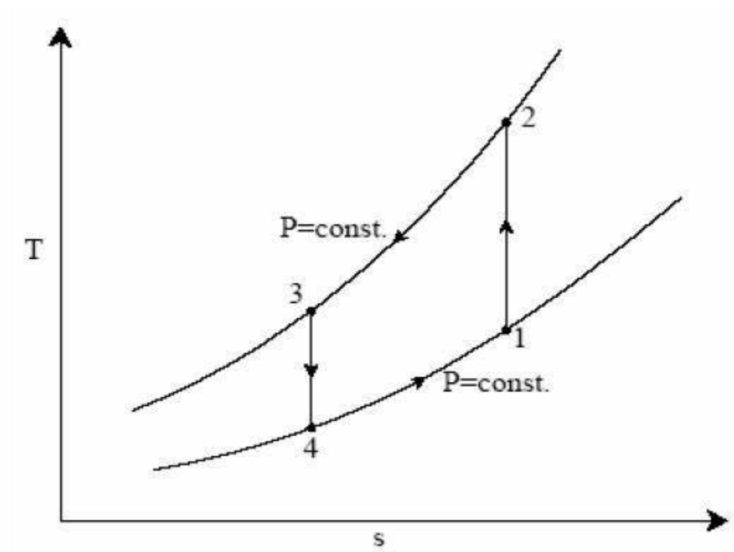


Figure 3 [T-s] diagram for Air Refrigeration System

Thus for such cycles assuming polytrophic compression and expansion;

$$\textbf{Coefficient of Performance; COP} = \frac{c_{p\ (T1-T4)}}{c_{p\ (T2-T3)} - c_{p\ (T1-T4)}} \quad (1)$$

Here; T_1 = Temperature of cold air before entering expander

T_2 = Temperature of very cold air after moving out of expander

T_3 = Temperature of air after moving out of refrigerator

T_4 = Temperature of air after exit from the compressor.

1.3.2.2 Vapour Compression Refrigeration System [VCRS]

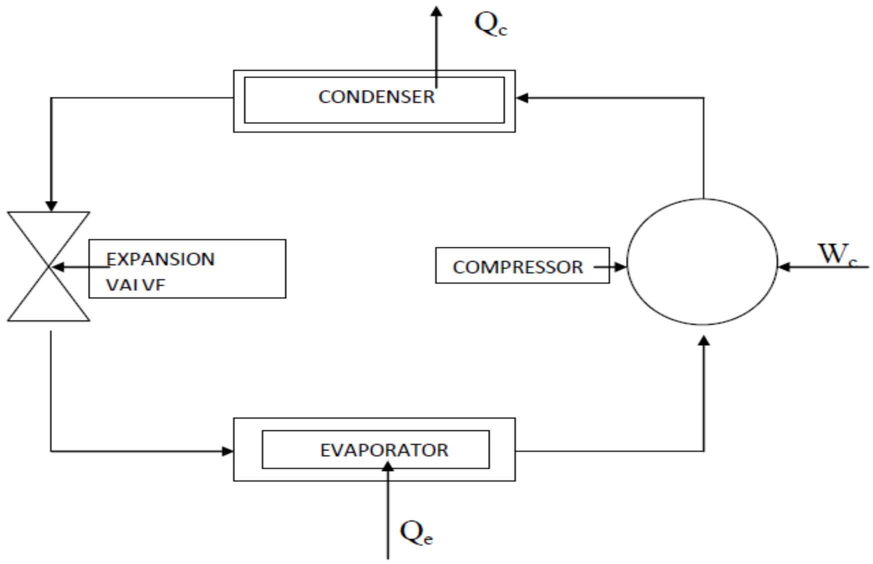


Figure 4 Standard Vapour Compression Refrigeration System

The working fluid for this type of system is vapour. It such system "vapour" is evaporated and condensed or is changed alternately between the vapour and the phases without leaving the refrigeration plant. In during the process of evaporation, vapour absorbs the heat from a colder body and utilizes it as the latent heat for converting from liquid to vapour. In during condensation process, it rejects heat to the external body, thus leading to the required cooling effect in the working fluid. This refrigeration system is so thus works as a heat pump since it pumps latent heat from the cold body and reject/delivers it to the external hot body. The elements in this system are:

- Compressor
- Condenser
- Expansion
- Evaporator

Compressor: It draws the low pressure and temperature vapour from the evaporator and raises its temperature and pressure to a level where it could be taken to condense.

Condenser: In during the passage of refrigerant through the condenser, gives the latent heat to the surrounding medium which is mostly in general is either water or air.

Expansion Valve: The prime functions of the expansion valve are as follows:

- To regulate the amount of refrigerant moving inside the evaporator.
- It is also used for pressure reduction of the liquid entering inside the evaporator such that liquid vaporizes in the evaporator at desired low temperature and taking out an appropriate quantity of heat.

Evaporator: It provides with the surface which is responsible for heat transfer and through which heat could pass from the refrigerated space into the vaporizing refrigerant.

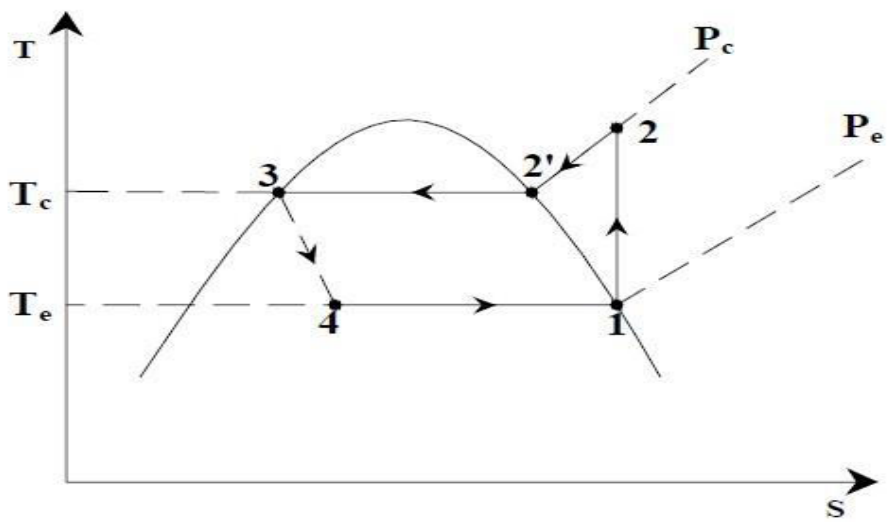


Figure 5 [T-s] plot for standard Vapour Compression Refrigeration System

$$\textbf{Coefficient of Performance; COP} = \frac{c_{p(T1-T4)}}{c_p(T2-T1)} \qquad (2)$$

1.3.2.3 Vapour Absorption Refrigeration System [VARS]

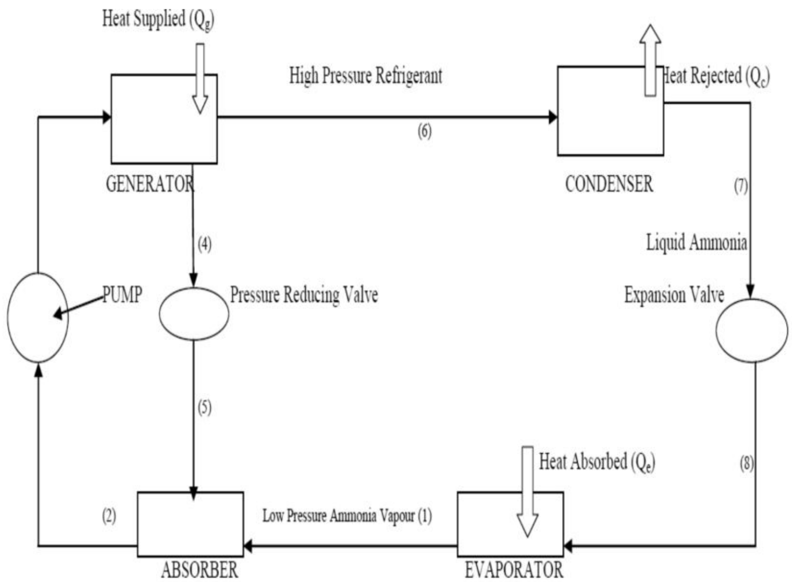


Figure 6 Vapour Absorption Refrigeration System

This system of refrigeration is different from the previous two in manner that in this there is no compressor presents rather its role is played by trio of expansion device, pump and the absorber. In this system the energy used is of low-grade i.e. for example (solar energy, biogas etc.) rather than high-grade energy.

The components are:

- **Generator**
- **Rectifier**
- **Condenser**
- **Expansion Valve**
- **Absorber**
- **Evaporator**
- **Pump**

Generator: Here the refrigerant vapour is produced at high pressure from the strong mixture of the "solution pair i.e. refrigerant and absorbent" using an external source which is "solar energy" in this case.

Rectifier: It is also known as "dehydrator" acts as the water cooled heat exchanger performing the function of condensing water vapour and helps in sending it back to the generator.

Absorber: Here the weak solution of "refrigerant and absorbent" transforms to the strong solution after absorbing the refrigerant vapour.

Pump: It is used for the purpose of pumping strong solution of absorbent and refrigerant to the generator from the absorber.

CYCLE DESCRIPTION

Figure 6 depicts the working diagram of the vapour absorption system. In such systems, low pressure refrigerant vapour exists from the evaporator and enters the absorber. Here the formation of "solution pair" takes place i.e. combination of refrigerant and absorbent and the formed solution is strong in nature. Now this strong solution then is pumped to the generator and here the pressure increases. In the generator this strong solution is heated by some external source which in this case study is "solar energy".

After the heating process is accomplished strong solution at high pressure moves to the condenser leaving back the weak solution which is send back to the absorber using an expansion valve. Now the high pressure refrigerant moves from generator to the condenser and here the refrigerant vapour is condensed to high pressure liquid refrigerant. Now from here the liquid refrigerant is passed to the expansion valve and where it is forwarded to the evaporator, where the refrigeration effect is achieved and thus completes the complete vapour absorption cycle

Absorber-Refrigerant Working Fluid Pair:

The importance and the role played by working fluid acts as the "backbone of the system" and play a very important role in absorption cooling system. In this system the "Coefficient of Performance" [19] depends on both physical and chemical properties of the system. The foremost requirement of a working fluid pair is that they always must be in bound of miscibility between them in given range of certain operating temperature in a liquid phase. Some other important points to ponder while selecting the working pair are as follows:

- It should be non-corrosive, pollution free & very much cost effective.
- The boiling point in between refrigerant and the absorber should be with differentiated with huge margin, under constant pressure.
- For maintaining the low circulation rate of refrigerant, the pair should have a very high concentration and latent heat within absorber.
- The viscosity, diffusion coefficient and also thermal conductivity s1hould be favorable.

- The property of the refrigerant such as "volatility" should allow it to get it separated from the absorbent.
- The working pair should be non-toxic, chemically stable and non-explosive also.

Derivation Of Maximum COP in VARS

In Fig - 4 we can easily observe the transfer of energy taking in the entire system among the components. Now, let's start with understanding the working of the system;

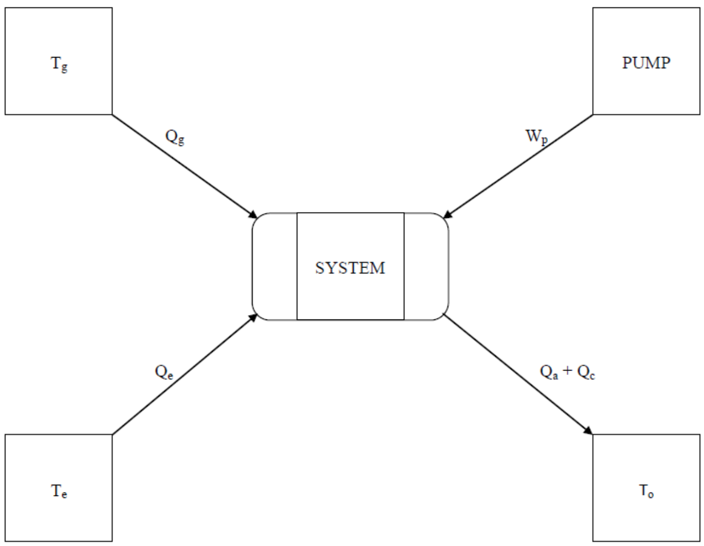


Figure 7 Various Energy Flows Taking Place across the Vapour Absorption Refrigeration System

As in accordance with the I[st] law, we can imply that;

$$Qg + Qe - Qa + c + Wp = 0 \quad (3)$$

Where;

(Q_e): It is the amount of heat being transferred into the absorption system at temperature of [T_e],

(Q_g): It is the net quantity of heat transferred to the generator of the absorption system at generator temperature [T_g]

(Q_{a+c}): It is the total heat transferred from the absorber and condenser of the absorption system at a certain temperature i.e. T_o and

(W_p): It is the net amount of work acting as the input to the solution pump.

Now as according to the IInd law of thermodynamics;

$$\Delta s\ (total) = \Delta s\ (system) + \Delta s\ (surrounding) \geq 0 \qquad (4)$$

Here;

Δs (total) is the net amount of entropy change and is equal to the combination of the entropy change of the system Δs (system) and also entropy change of the surroundings Δs (surrounding) Now since it is very well known, that the refrigeration system perform functions in a closed cycle, therefore the net amount of entropy change of the working fluid across the system undergoing the cycle is zero, i.e. Δs (system) = 0.

Hence; the entropy change occurring in the surrounding is given by:

$$\Delta s\ (surr.) = \frac{-\mathrm{Qe}}{Te} - \frac{\mathrm{Qg}}{Tg} + \frac{\mathrm{Q(a+c)}}{To} \qquad (5)$$

Substituting the expression of Ist law i.e. eqn. (3) in the above eqn. (5);

$$\mathrm{Q}g\ \left(\frac{Tg-To}{Tg}\right) \geq \mathrm{Qe}\ \left(\frac{\mathrm{To-Te}}{\mathrm{Te}}\right) - Wp \qquad (6)$$

After neglecting the pump work (W_p), hence the COP is given by:

$$COP\ (VARS) = \frac{\mathrm{Qe}}{\mathrm{Qg}} \leq \left(\frac{Te}{To-Te}\right)\left(\frac{Tg-To}{Tg}\right) \qquad (7)$$

From the above equation it can be observed that COP of ideal "Vapour Absorption Refrigeration System" equal to the product of:

- Carnot heat engine efficiency working between temperature T_g and T_o
- Carnot refrigeration system between T_o and T_e

and so has been represented in the Figure 8

$$COP\ ideal\ (VARS) = \frac{\mathrm{Qe}}{\mathrm{Qg}} \leq \left(\frac{Te}{To-Te}\right)\left(\frac{Tg-To}{Tg}\right)$$

$$= COP\ (carnot) * \eta\ (carnot) \qquad (8)$$

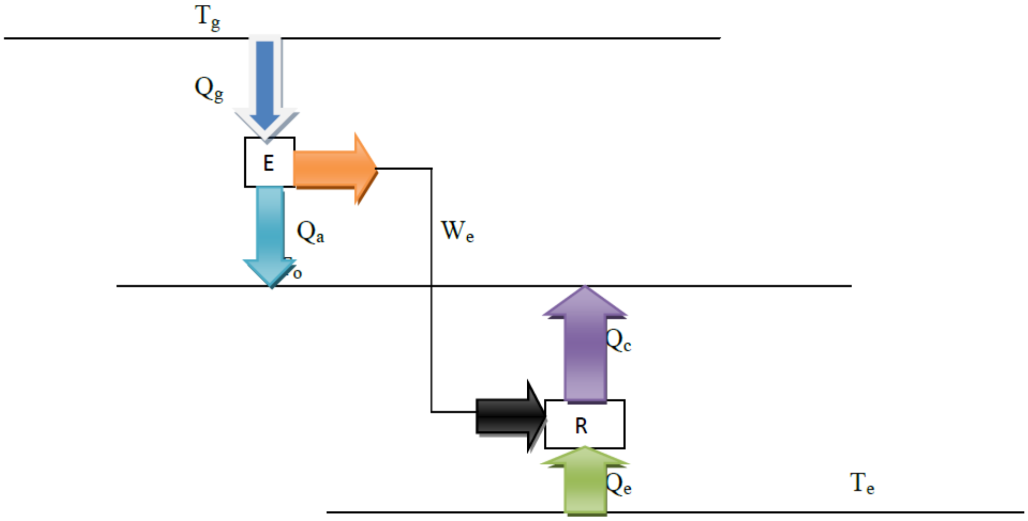


Figure 8 VARS as combination of engine and refrigerator

Here; T_e; Evaporator Temperature

T_c; Condenser Temperature

T_g; Generator Temperature respectively.

1.4 Solar Collectors

Solar Collectors are the devices used for the purpose of collecting solar radiations and transferring them to a fluid that passes in contact with it. In order to utilize the solar energy we are in requirement of the solar collectors.

These are basically classified into two categories:

1. Non-concentrating Solar Collector
2. Concentrating Solar Collector

The solar collectors are, associated with the absorber, forms as one of the most essential component of any system for the requirement of converting solar radiation energy into various other consumable forms (e.g. heat or electricity) [18]. In the non-concentrating collectors, the collector area is absolutely equal to that of the absorber area whereas on the other hand, in concentrating collectors the areas intercepting the solar radiations are much greater than that of the absorber area. With the help of concentrating collectors, higher temperature could be obtained in comparison to the non-concentrating type. Concentrating collectors may be used to generate medium pressured steam and also utilizes the proper set-up of the mirrors and lenses so as to concentrate the incoming sun rays.

1.4.1 Flat Plate Solar Collector

When the temperature below 90^{o}C are required, they are the most appropriate as these are utilized for the "space and service water heating". The flat plate collectors are of type of non-concentration that is quiet easy for usage with normal handling. They are made up of rectangular panels, with an overall dimension of 1.7 to 2.9 m^{2} in area and are relatively simpler to construct and erect. Flat plates can collect and absorb both direct as well as diffuse solar radiation also and so they are consequently partially effective on the cloudy days when there is net amount of available radiations almost negligible or is very much low of minimum value.
Flat plate solar collectors are divided into two major classes:

- Liquid heating collectors: They consist of a flat surface with very high absorptivity of the solar radiations known as the absorbing surface and is built-up of metal plate of steel or aluminum. These plates are soldered & clamped to bottom of absorber plate.
- Solar air collectors: In this fins are attached to the plate in order to obtaing much more contact surface. The back portion of the collector is heavily insulated by means of mineral wool. The most favorable condition of a collector for most appropriate heating only is facing due south at an inclination angle to the horizontal equal to 15^{o}

1.4.2 Concentrating Type Collectors

These are the devices that are used to for the purpose of collecting solar energy with high intensity of solar radiation on the energy absorbing surface. These types of collectors generally utilize the optical system in the form of reflectors. These are the special type of collectors that are modified by introducing a reflecting surface in between the incoming radiations and the absorber. In such type of collectors radiation falling on relatively large area is focused on to the receiver of considerably smaller area. As a result; the energy concentration fluids can be heated to temperature of about more than 250^{o}C.

An important difference between these collectors is the second one is that only the direct radiations coming from a specific direction. Thus the optical system is required to direct solar radiation onto the absorber of smaller area which is in general surrounded by the transparent cover. The combined effect of all losses is indicated through the term "optical efficiency". The density of more optical losses is compensated by the flux incident on the absorber surface is concentrated on a very small area.

Types of concentrating collectors are:

- Parabolic Trough Collector
- Fresnel Lens Collector
- Compound Parabolic Concentrator.

Figure 9 Fabricated 2-D Compound Parabolic Concentrator

2. OBJECTIVE OF THE STUDY

Through this thesis work we come to understand about the concepts behind usage of solar energy in the area of refrigeration. The technology that implies the combined use of concepts of “Solar Energy & Refrigeration” is known as “Vapour Absorption Refrigeration System”. In this concept we have to understand its principle, components, working, advantages and applications.

In such systems one very important component is the “SOLUTION PAIR” which acts as the backbone behind this technology. Now at present almost all the researchers have analyzed using the two common pairs i.e. of NH_3-H_2O & LiBr-H_2O. So in this work an attempt has been made to work upon some of the solution pairs that could act as alternatives to the pre-existing ones.

This will help in better evaluation and analysis about the system and also taken in regard with the order to increase the performance of the system.

3. LITERATURE REVIEW

V. R. Renjith et al [17] investigated the vapour absorption systems using different low grade energy. Basically the energy is classified on the basis of ease within which they can be converted from one form to another. Electrical energy is of "high grade" as it is very easily converted to other forms of energy but the thermal energy is "low grade". The working pair selected was "ammonia-water" combination and thus the system was analysed using different working conditions. The effectiveness of the absorber as well as generator is considered to be 100% It was finally concluded from the thermodynamic analysis of two pressure absorption system that as the temperature of the evaporaor increases, minimum generator temperature decreases whereas the condenser temperature increases and also with increase in generator temperature the overall COP of the system decreases.

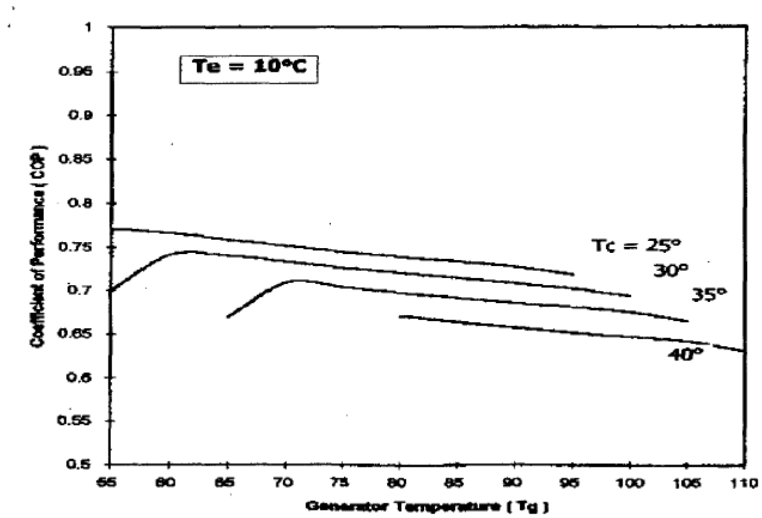


Figure 10 Variation of COP with Generator Temperature

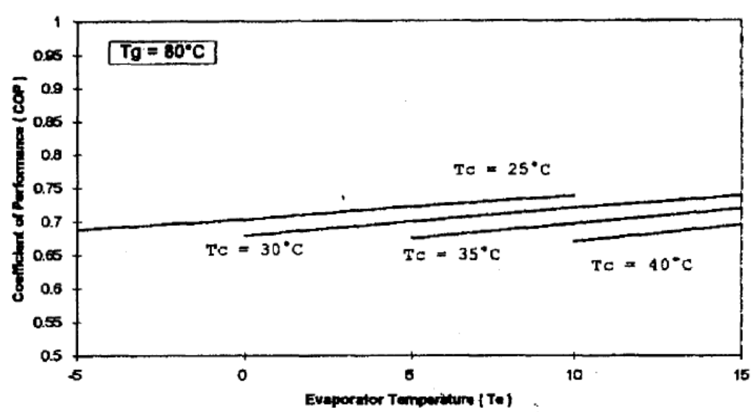


Figure 11 Variation of COP with Evaporator Temperature

Z Crepinsek et al [4] compared the performance of the absorption refrigeration cycles under possible alternative of working fluids such as R22-DMEU, R124-DMEU, R125-DMEU and their performances were compared with that of existing solution pair i.e. “ammonia-water”.

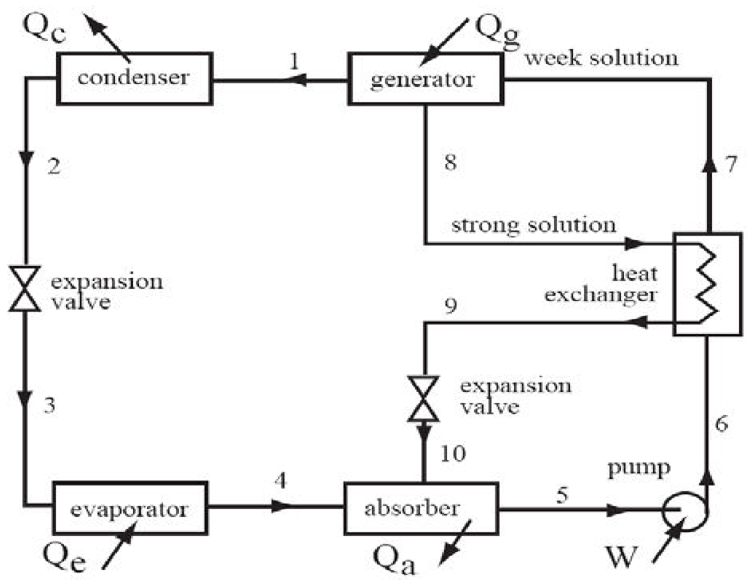


Figure 12 Schematic Diagram of Single Effect Absorption system

He described the COP of the single-effect absorption system as the ratio of net amount of heat removed from the evaporator to the amount of heat supplied at the generator and was given by:

$$\mathbf{COP} = \frac{\mathbf{\emptyset e}}{\mathbf{\emptyset g}} \quad (9)$$

They also defined another term known as “circulation ratio” which can be depicted as the ratio of mass flow rate of strong solution to that of refrigerant. They progressed in their analysis using a computer simulation program with following assumptions: $T_{e} = -5^{o}C$ $T_{g} = 70^{o}C$ and different absorber & condenser temperature of [$20^{o}C$, $25^{o}C$, $30^{o}C$] and obtained results as this:

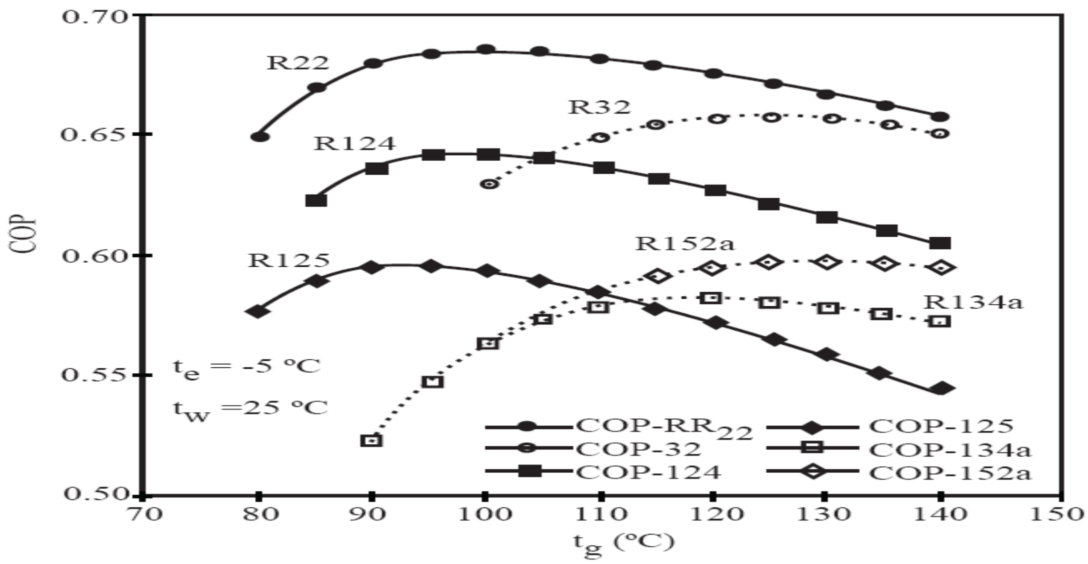


Figure 13 Variation of COP with Varying Generator Temperature for Different Working Fluids

Thus; among various working fluids used in during this analysis R124-DMEU & R125 DMEU are the possible alternatives in regard with the single effect absorption system and so they could be use in future aspect to enhance the performance of such systems.

R. Fathi et al [6] studied the performance of the solar water absorption refrigeration system. They tracked down the COP of the solar-single stage absorption refrigerator as the function of temperature in various components that are being utilized in the cycle; he then decided to change the dimension of the cycle by introducing a double line heat exchanger (in between generator-condenser and between evaporator-generator). It also presented the variation of COP and the heat transfer rate versus the different temperatures of the cycle and was compared with the obtained with the improved configuration. At the end after complete simulation was found that with the usage of double-line heat exchanger the COP increases by 4%.

Soteris A. Kalogirou [10] surveyed various solar thermal collectors along with their application. Initially he studied about the environmental harms and benefits that are caused by the usage of conventional sources of energy. The collectors whose thermal analysis he did were flat-plate, compound parabolic. He defined solar collector as the devices that absorbs the incoming solar radiations, and then converts it to heat with finally supplying this to heat a fluid. He presented the optical and thermodynamic analysis and evaluated their performance with applications in field of water heating, refrigeration, desalination, and some thermal systems.

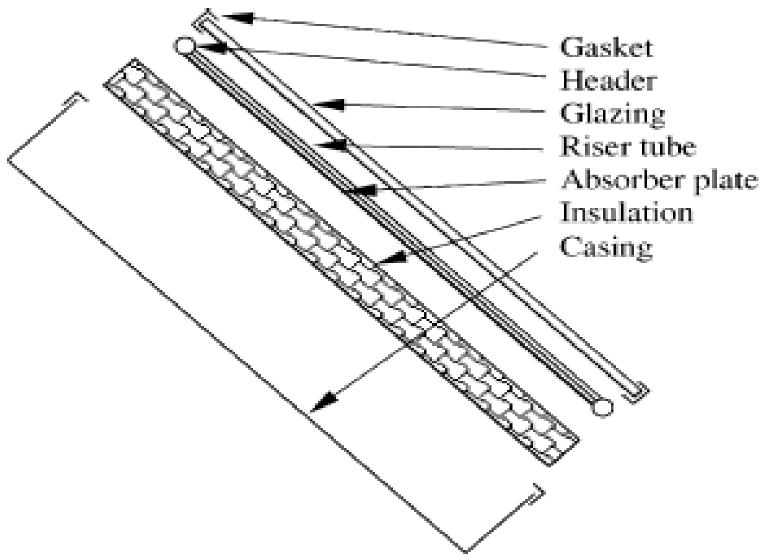


Figure 14 Flat Plate Collector

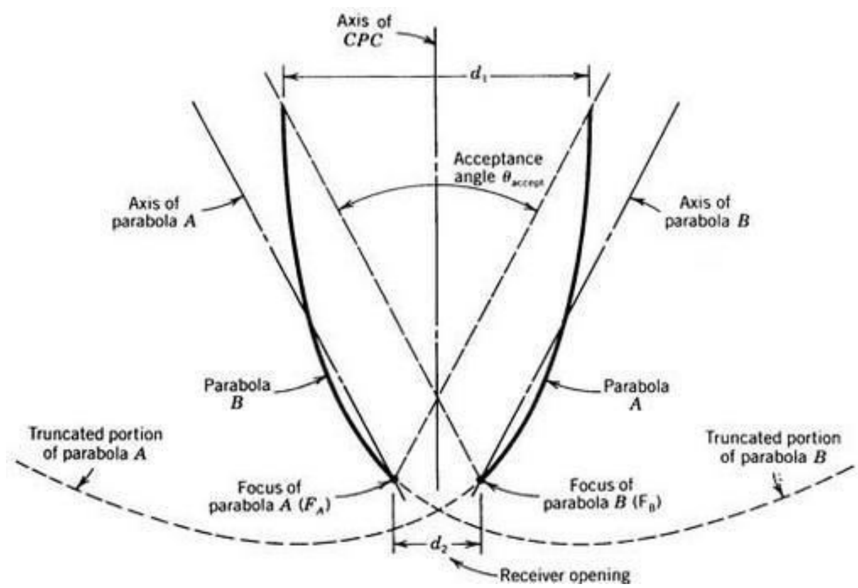


Figure 15 Geometry of a compound parabolic concentrating collector

Y. Fan et al [5] reviewed different solar absorption technologies along with their development and their applications. Among the technology he inducted with basic principles of both absorption as well as that of adsorption phenomenon. In absorption there exists the combination of a gas and a liquid and those on combining show strong affinity, to form a solution. The most common working pair working includes combination of NH_3-H_2O & LiBr-H_2O in which in first “NH_3 is the “refrigerant” whereas “H_2O is the absorbent” and in second “LiBr is absorbent” and “H_2O if the refrigerant”. The adsorption principles results from through the interaction in between a solid (absorbent) and a gas (refrigerant), the refrigerant is fixed at surface of absorbent by Van der Waal forces. These technologies proved to be attractive alternatives which serve in the applications of air-conditioning as well as refrigeration.

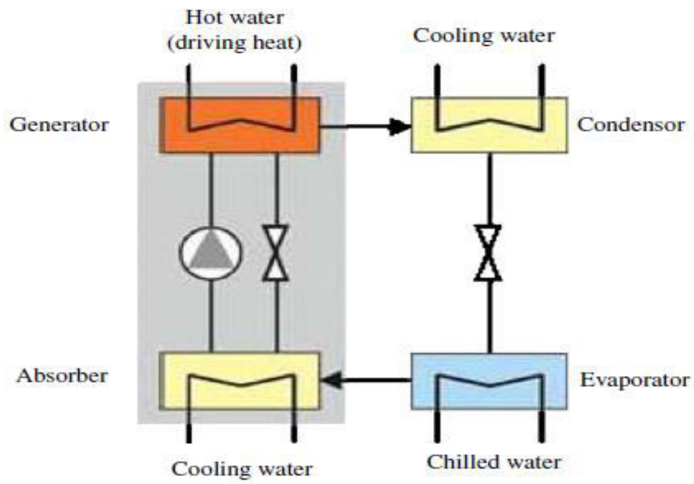


Figure 16 Schematic Diagram of Solar Absorption Refrigeration

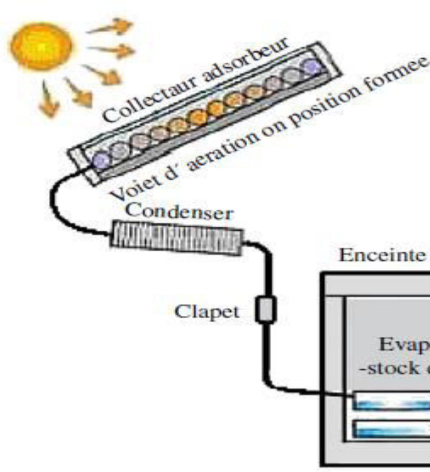


Figure 17 Schematic of Solar Adsorption Refrigerator

Jasim M. Abdulateef et al [1] investigated the solar absorption refrigeration system using new working fluid pairs. He described the complete cycle and then defined the Coefficient of Performance of the following system as:

$$COP = \frac{Qe}{Qg+Wp} \tag{10}$$

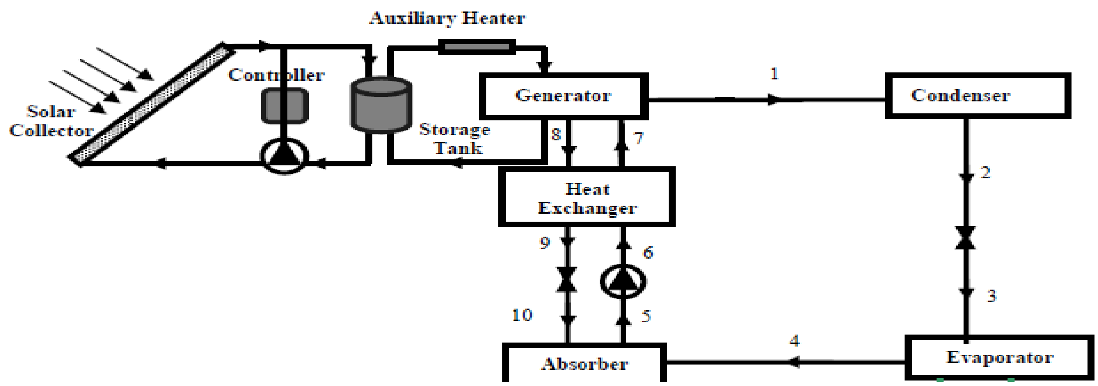


Figure 18 Schematic Illustration of Solar Absorption Refrigeration System

Then he analyzed each and every component of the system using energy and mass balance conservation principles followed by defining the solution properties i.e. temperature, pressure, density, enthalpy, concentration etc. of the alternative working pairs using various sources. Now they went for a computer program to achieve the best working conditions with the following pre-assumptions: T_g = 100C, T_c = 25C, T_a = 30C, T_e = -5C and the effectiveness of the generator to be taken as 80%. Thus, he proved that there are some other working fluids that could be used as alternatives for the existing solution pair's i.e. "NH_3-H_2O & LiBr-H_2O".

D.S. KIM et al [9] reviewed about different technologies that are at present available for the production of refrigeration effect from the solar energy. This includes solar thermal, solar electric and few emerging also. The solar thermal system involved thermo-mechanical & absorption phenomenon, thus the comparison were made among on basis of working and economic feasibility. He ranked the solar absorption as the best option among all followed thermo mechanical and at last by solar electric.

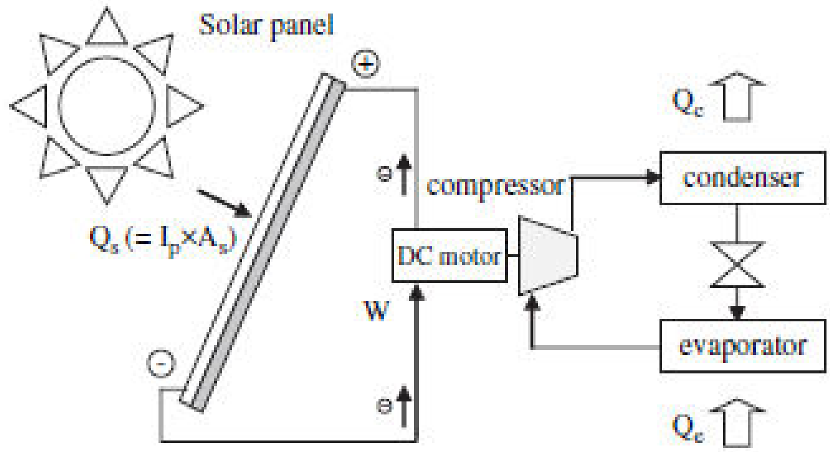


Figure 19 Schematic diagram of a Solar Electric Technology

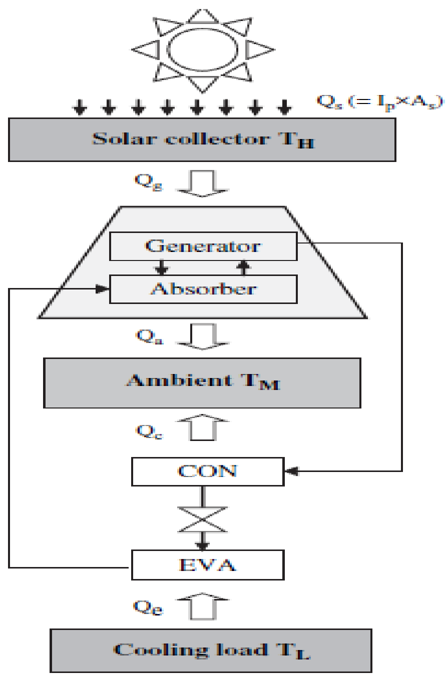


Figure 20 Solar Absorption Refrigeration Systems

M. Mazloumi et al. [14] performed simulation of solar "lithium bromide-water" absorption cooling system with the help of parabolic trough collector. "Lithium bromide" is chosen as because of their performance which is quiet is good and cost is low. In this case water was pumped to the solar collector and there is heated by incoming solar energy and then stored in tank from where it moves to the generator to vaporize the refrigerant. The superheated refrigerant is then condensed in the condenser by delivering heat to the cooling water. Now the refrigerant moves to evaporator via expansion valve and here refrigeration effect is produced.

After this refrigerant flows to the absorber and here it gets mixed with high concentration solution moving out from the generator and thus rejects heat to the cooling water. The temperature of condenser was in range of 30-36ºC, for evaporator was 6ºC and for generator was in between 75-100ºC with heat exchanger efficiency of about 50%

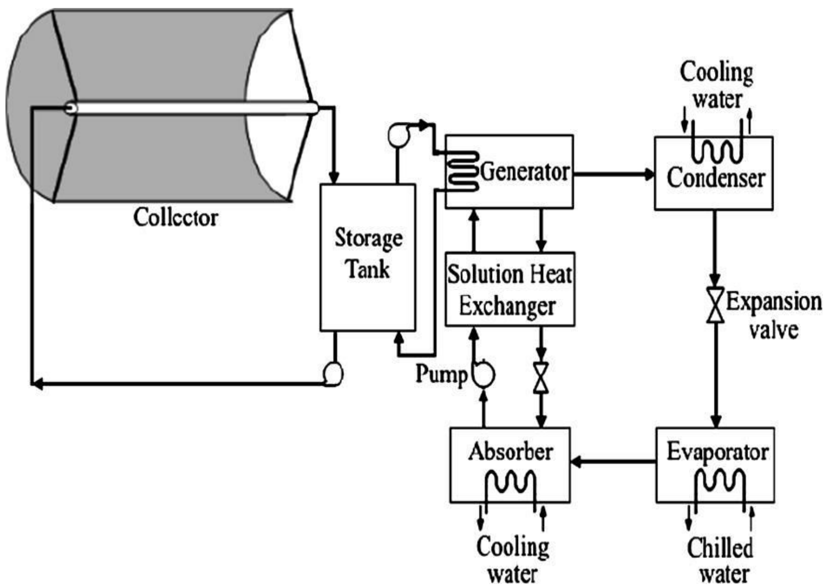


Figure 21 Schematic diagram of solar absorption cooling system

D Micallef et al [15] mathematically modeled a vapour absorption refrigeration unit. They started with the loss happening to the environment due to the usage of conventional refrigerants such as CFC. Later they discussed with the working principles and the basic components that were utilized in the system. He assumed several assumptions and that were:

- A the exit of the evaporator the refrigerant is in saturated state
- The specific enthalpy was same at two junctures that were first of super heated refrigerant at the inlet of the condenser and second of saturated refrigerant at the generator.
- The pressure of condenser and evaporator was same and also that absorber and generator was also same.
- Solution leaving the generator and absorber are saturated in state.

So the computations were done on the basis of the mathematical modeling and were taken for validation with the help of Sol absorb software and the conditions were: refrigeration capacity = 100KW, evaporator temperature = 3^{o}C, condenser temperature = 34^{o}C, absorber temperature = 25°C and the generator temperature = 80°C. Thus a thorough investigation was made and this was valid for either working fluids "ammonia-water" or "lithium bromide-water" to ensure the effective operation of the system. The system response was recorded by varying different components temperature and was analyzed.

V. K. Bajpai [2] discussed about the designing phenomenon of Solar Powered Vapour Absorption Refrigeration System. He firstly did the mathematical modeling and then after set-up was made with full calculation of COP. He assumed the refrigeration capacity to be 1TR, with fixed condenser pressure, he then found out mass flow rate of refrigerant and heat removed/added from among the various components and thus finally evaluated Coefficient of Performance (COP) by given formulae:

$$COP = \frac{Refrigeration\ Effect}{Heat\ input\ in\ the\ Generator} \quad (11)$$

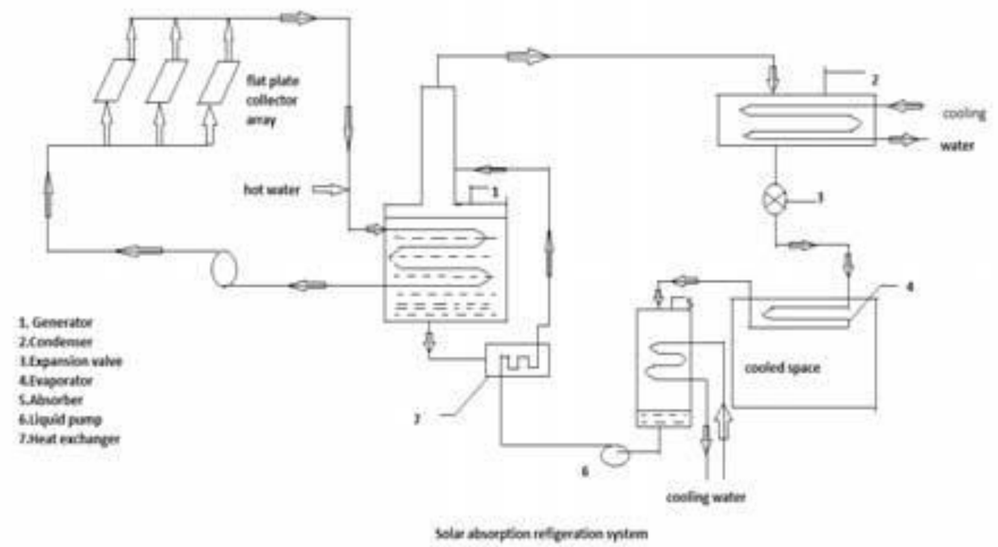


Figure 22 Design layout of a solar absorption refrigeration system

Y. Tian et al [24] in their review paper presented some of the thermal energy storage systems that are used in for solar applications. In this they discussed with the designing parameters, required designing materials and also about the present as well as the upcoming technologies. The main aspects that were considered behind designing were the "technical properties, cost effectiveness and environmental impact".

At first the "technical properties" dealt with the technical feasibility of the system with initially with high thermal storage capacity, good heat transfer rate in between heat storage material and the moving fluid and finally avoided degradation after number of thermal cycles. Second "cost effectiveness" helps in determining the pay-off period of the investment, and it mainly consists of storage material, heat exchanger and land cost. The materials used for solar storage are basically: sensible, chemical and latent heat storage. For example: cast steel, firebricks for sensible storage, potassium carbonate, sodium carbonate for latent storage, metal oxides (Zn & Fe), alumina as for chemical form of heat storage. Finally, it concluded that the molten salts with excellent properties had been identified after comparison is the ideal material for thermal storage applications.

K.R. Ullah et al [25] presented the study of the solar refrigeration with specific focus on the solar absorption as well as solar adsorption under different working fluids. They predicted various criteria that should be considered carefully during the selection of working fluid as they play very important role in during the performances of such systems. The boiling point of the mixture and the pure refrigerant must have a large difference, properties like thermal conductivity, viscosity etc. should be favorable. He studied the LiBr-H_2O cycle with single, double and half-effect. In case of adsorption some of the working fluids are "silica gel/water, activated carbon/methanol, zeolite/water" etc.

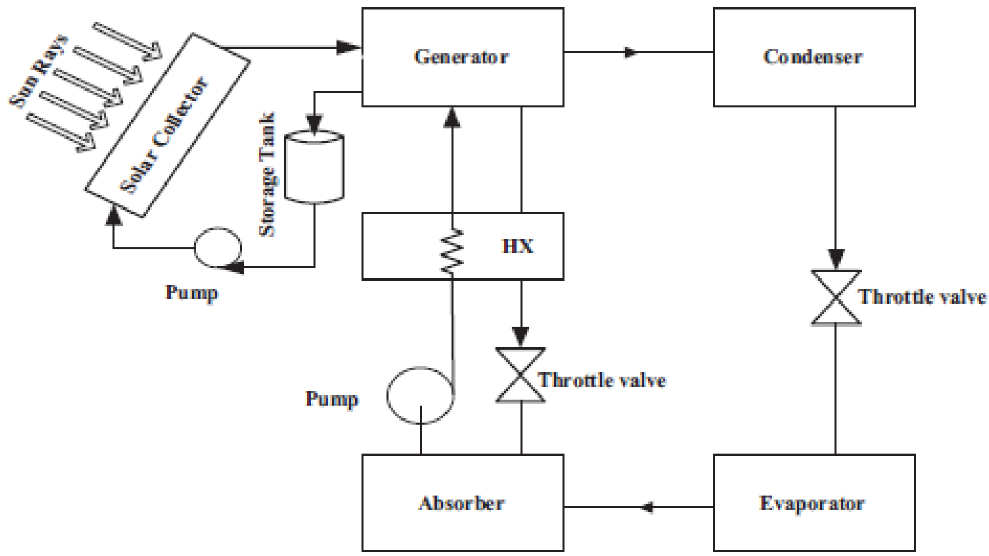
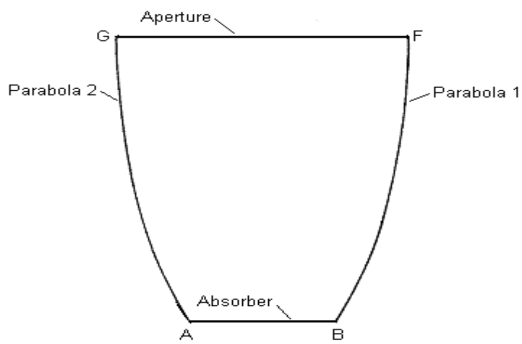


Figure 23 Solar Assisted LiBr-H2O absorption cycle

Ioan Sarbu et al [21] presented the comparison among the various solar refrigeration technologies on the basis of thermal Coefficient of Performance [COP]. Absorption system operated in between temperature range of 60ºC-165°C and obtained COP in the range of 0.50-0.73, adsorption system worked in between range of 53-82ºC with COP of 0.51 and steam refrigeration system operated on temperature 118ºC with an overall COP of 0.85. One more factor was taken into the account and i.e. "annual EER" which is defined as annual cold production to the annual heat input and for this case the most appropriate system found was of LiBr-H_2O as the working fluid and also studied the single, half, double and triple effect absorption system. They concluded on a note that there must be search carried on for the working fluids which are environment friendly and needs low operating temperature.

Mansi G. Seth [22] depicted the idea behind the design and development of compound parabolic concentrating solar collector and after fabricating thermal analysis of the collector was also performed. For a temperature range of about 100ºC flat plate collectors are used and where as for application utilizing above 100ºC are far better suitable. The CPC's basically consists of three elements that are "receiver, cover and reflector". For receiver the material should be of high absorptivity as well as high reflective nature in order to absorb maximum solar radiation and efficient heat transfer into the flowing fluid. The cover should be made-up of a transparent insulation that leads to the passage of radiation in between the reflector and receiver, with a high transmittance property of solar radiation and very less that of thermal radiation from the receiver. The reflector performs the job of focusing solar-beam radiations upon the receiver, which is at the focus of system. For absorber mild steel is the most appropriate material as can transfer maximum amount of heat through it.



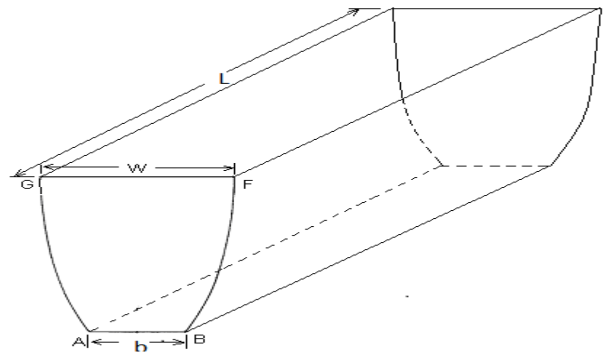


Figure 24 Cross Section of Compound Parabolic Collector Figure 25 2-D CPC

Tarik Shaikh et al [23] reviewed the solar absorption refrigeration system using lithium bromide-water as the working fluid pair. He depicted that dependency on fossil fuels could be reduced and thus eco-friendly options can also be utilized. The LiBr-H_2O cycle consists of four steps: generation, condensation, evaporation and absorption with no moving parts coming into the act. He also enlisted various advantages of solar thermal systems which are as follows:

- It reduces our dependence on fossil fuels
- Improves diversity of the energy supply
- It helps in saving the natural sources
- Also helps in reducing air pollution
- Heating load is reduced and helps in stimulating local economy.

The effect of changing refrigeration load inlet temperature has with respect to COP and also with the variation of heat exchanger been observed. The influence of changing inlet temperature was also recorded in regard with the nature of solution concentration.

Joydeep Chakraborty et al [3] presented review paper on solar energy operated vapour absorption system using LiBr-H_2O as the working fluid combination. The electricity consumption in vapour absorption refrigeration system is very less and this is very much eco-friendly. He also dictated the phenomenon through which the chlorofluorocarbon carbon affected the ozone layer, the reaction is as follows:

- CCl_2F_2 (R-12) = $CClF_2$
- $Cl + O_3 = ClO + O_2$.

Thus through these reactions the depletion of ozone layer takes place and which allows the ultraviolet radiations of sun to reach to us. He also depicted the advantages of using solar energy:

- Availability of Solar Energy is in enormous amount
- Damage to the environment by the solar energy is minimal.

They then pointed out some of the gap that they have identified from the literature review:

- Observing COP under varying evaporator temperature
- Observing COP under varying condenser temperature.

R Sai Lavanya [13] he studied with the measures that are to be taken into account in during phenomenon of designing "aqua-ammonia refrigeration system". He initially started with basic working of all the components that are involved in followed by describing the full-working of the aqua-ammonia system.

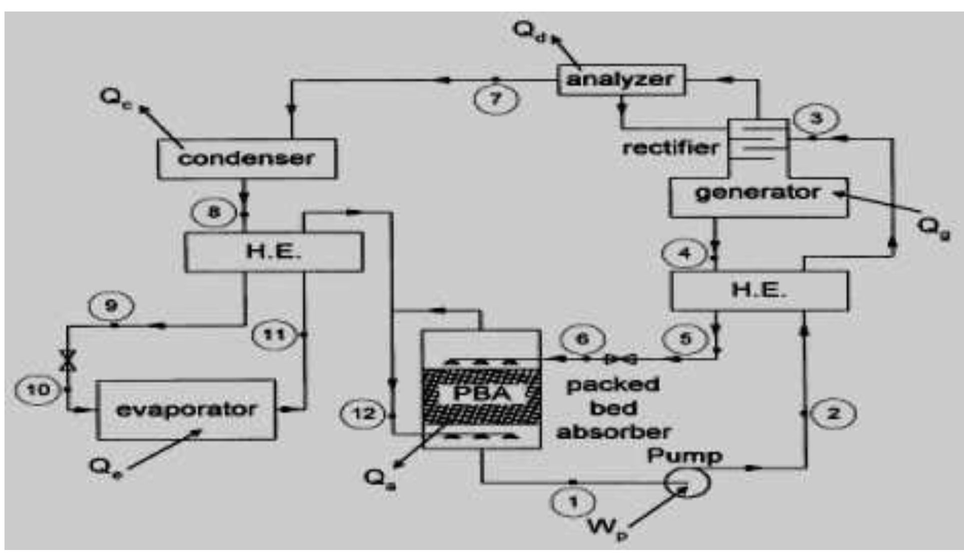


Figure 26 Aqua-Ammonia Absorption System Cycle

Then he started with the designing of the components i.e. generator, absorber, condenser, pump, evaporators, heat exchangers and also of the solar collector using various laws of thermodynamics, heat & mass transfer as well. In this way he established the full designing of vapour absorption refrigeration system for domestic purposes and depicted the applications in as for water-coolers in hospitals, laboratories, educational institutes etc.

C. A. Infante Ferreira [7] described the use of property data for enthalpy as well as entropy calculations for the ammonia solutions. Since the ammonia solutions have high coefficients of performance hence there is no need of purifying the refrigerant vapour. They proposed ammonia lithium nitrate as the new working fluid pairs for the system and so there property was needed to be calculated.

For enthalpy calculation formula used was;

$$h\ (T, X) = h\ (T{=}0°C, X) + \int_0^T c_p\, dT + X*200 \quad (12)$$

For entropy calculation formula to be used was

$$s_l = (s_l)_{0°C} + \int_{273.16}^{T} c_p\, \frac{dT}{T} \quad (13)$$

Thus, the value of enthalpy as well as entropy was calculated at different states for ammonia solutions using software named "Engineering Equation Solver" and the obtained results were validated from the work of Gupta et al [8] thus were found to be varying within deviation of 10% from the previous results.

Sachin Kaushik [11] provided us with an analytical performance of absorption refrigeration technology. He derived the function of COP using the help of first & second law of thermodynamics. He made a few assumptions during the analysis and that were:

- The analysis should be done in regard with steady flow and steady state.
- There would be negligible pressure drop as a result of friction.
- There should be only pure refrigerant let to go inside to the generator.

With mathematical analysis he calculated the rate of heat coming in or moving out of different components of the system and finally concluded that COP of the overall system is greatly influenced by the temperature of the components that are taken into the application in the system.

Onchie et al [16] performed an experimental study of solar thermal refrigerator with "methanol as refrigerant". He firstly estimated the average solar energy available needed for driving the absorption system. Then he selected the material for designing the solar collector modules and also for the storage tank with its dimensions. It was all followed by the accumulation of data property of the methanol refrigerant []. Finally the testing was done with methanol as refrigerant and lithium bromide as absorbent. At the end he found the COP of the complete system was around 0.6 and also gave the ways for further innovations and improvements that could be utilized in order to achieve better performance of the system.

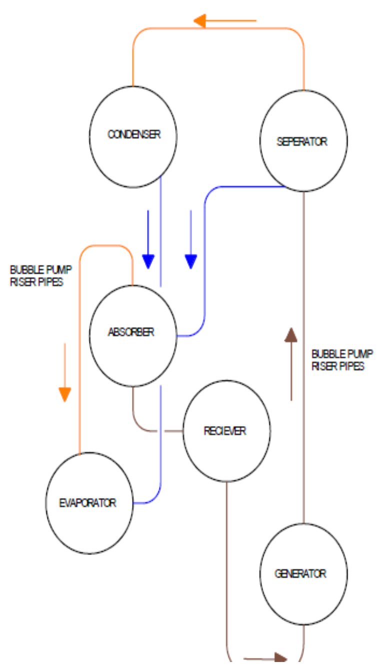


Figure 27 Flow Description among Various Components Of System

4. PRESENT WORK

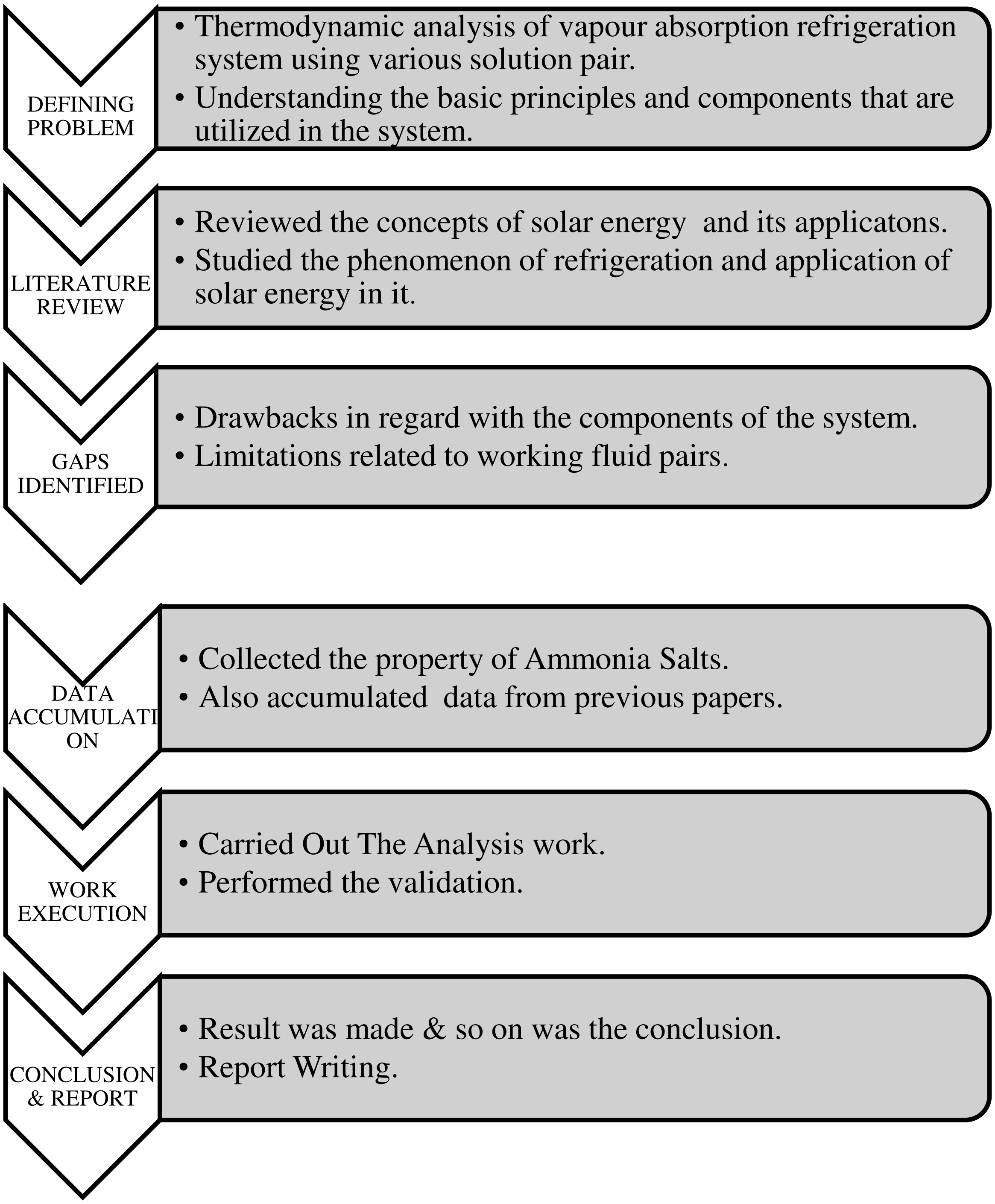
4.1 PROBLEM FORMULATION

The area of “Vapour Absorption System” is very vast and it constitutes the principles of two fields, one is “Solar Energy” and the other is “Refrigeration”. With the application of principles of solar energy to the area of refrigeration leads to the growth of the concept which is known as “Vapour Absorption Refrigeration System”. Now the important constituents that are held responsible for the performance of such system are:

- Generator
- Absorber
- Evaporator
- Condenser
- Expansion Valves
- Working Fluid

Among these all components of the system the backbone of complete system is the “working fluid often known as “solution pair”. Now taking in regard to this till date at present the scientists and researchers all across the world are working so as to achieve the better coefficient of performance [COP] for the system. The working fluids mostly used till today are “Ammonia/Aqua [NH_3-H_2O] and Lithium Bromide/Aqua [$LiBr/H_2O$]”. Now there is need to look for some extra solution pair that not only act as alternatives to the existing one but also helps in order to have more improved performance for the system and so to achieve this thesis works deals with two new combinations of working fluids and those are “Ammonia Lithium Nitrate [NH_3-$LiNO_3$] and Ammonia Sodium Thiocyanate [NH_3-NaSCN]” and thus a comparison of the performance has been made up with that of the existing solutions.

4.2 RESEARCH METHODOLOGY



4.2.1 SYSTEM DESCRIPTION

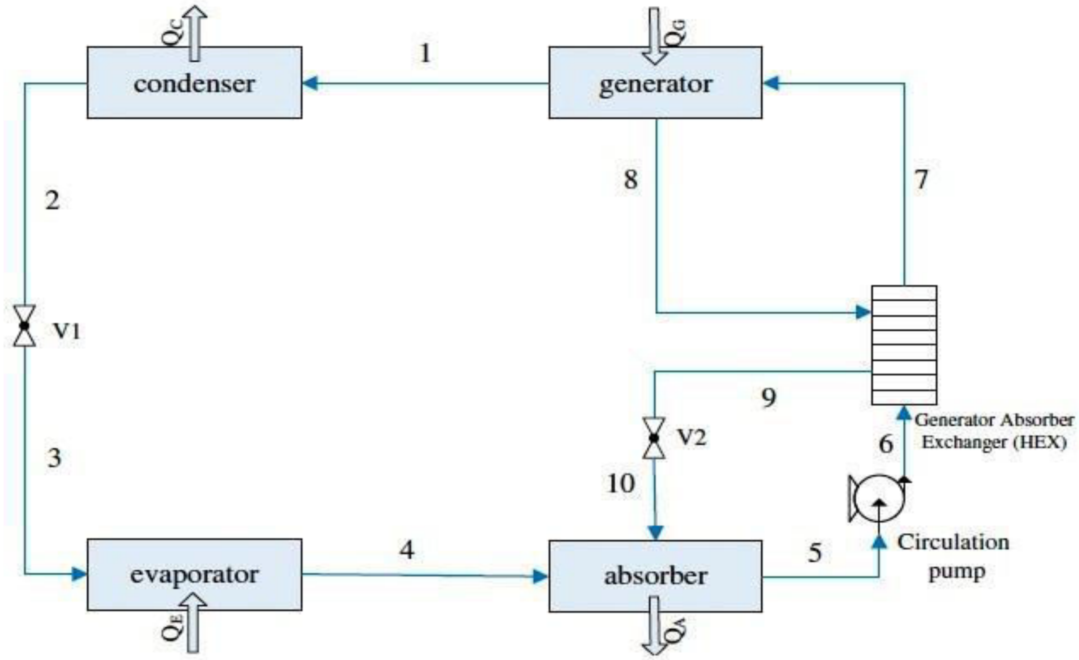


Figure 28 Schematic Diagram of Vapour Absorption System

COP in such a system is given by:

$$COP = \frac{Q_e}{Q_g + W_{me}} \tag{14}$$

Taking in regard with Figure 27; let's now get started with the mass and energy conservation for all components one by one;

Let's begin with the generator $\quad m_7 = m_1 + m_8$ (full mass balance) (15)

$$m_7 X_7 = m_1 + m_8 X_8 \quad (NH_3 \text{ mass balance}) \tag{16}$$

$$Q_g = m_1 h_1 + m_8 h_8 - m_7 h_7 \tag{17}$$

On solving (14) & (15) we can obtain flow rate of strong as well as weak solution;

$$m_8 = \left(\frac{1 - X_7}{X_7 - X_8}\right) m_1$$

$$m_7 = \left(\frac{1 - X_8}{X_7 - X_8}\right) m_1$$

Then next component that is taken in regard is the generator and so applying energy balance;

$$T_9 = E_{ex} T_6 + (1 - E_{es}) T_8 \quad (18)$$

$$h_7 = h_6 + {m_8}/{m_6} (h_8 - h_9) \quad (19)$$

For the case of PUMPING;

$$h_6 = h_5 + (P_6 - P_5)\, v_6 \quad (20)$$

$$W_{me} = (P_6 - P_5) v_6 \quad (21)$$

Now let us apply the energy balance to the evaporator, absorber and condenser and so are as follows;

$$Q_e = m_1 (h_4 - h_3) \quad (22)$$

$$Q_a = m_4 h_4 + m_{10} h_{10} - m_5 h_5 \quad (23)$$

$$Q_c = m_1 (h_1 - h_2) \quad (24)$$

4.2.2 PROPERTY DESCRIPTION

In either case when ammonia lithium nitrate or ammonia sodium thiocyanate is used role of refrigerant is played by "NH_3" whereas in first case "$LiNO_3$" and in second case "NaSCN" acts as the absorbent. Now the property of the absorbents was studied by Ferreira [7] & that of ammonia in different state was provided by Sun et al. [20]. From figure 28 it was observed that has to be determined by NH_3 [1-4] and at the same time from the state was found on the basis of mixture of the solution pairs [5-10].

- NH_3 [Refrigerant]

Pressure: $P\,(T)\, 10^3 \sum_{i=0}^{6} a_i\, (T - 273.15)^i$

Specific Enthalpy: $h_l(T) = \sum_{i=0}^{6} b_i\, (T - 273.15)^i$

$h_v(T) = \sum_{i=0}^{6} c_i\, (T - 273.15)^i$

- AMMONIA WATER [NH_3-H_2O]

The standard relation between temperature and pressure followed for "ammonia-water";

$$\log P = A - \frac{B}{T}$$

Where; $A = 7.44 - 1.767X + 0.9823X^2 + 0.3627X^3$

$$B = 2013.8 - 2155.7X + 1540.9X^2 + 194.7X^3$$

Now the inter relation between pressure, concentration and enthalpy is as follows:

$$h\,(T, \bar{X}) = 100 \sum_{i=0}^{16} a_i \left(\frac{T}{273.15} - 1\right) m_i \bar{X}_{ni}$$

Here: $\bar{X}$ is mole fraction and is given by the relation as $\bar{X} = \frac{18.015X}{18.015X + 17.03\,(1-X)}$.

- AMMONIA LITHIUM NITRATE [NH_3-$LiNO_3$]

The standard P-T relation is given by: $\ln P = A + \frac{B}{T}$

Such that: $A = 16.29 + 3.859\,(1 - X)^3$ and,

$$B = -2802 + 4192(1 - X)^3$$

Now again comes the relation between enthalpy, pressure and concentration:

$$h(T, X) = A + B(T - 273.15) + C(T - 273.15)^2 + D(T - 273.15)^3$$

in this values of A,B, C & D are as follows:

$$A = -215 + 1570(0.54 - X)^2$$

$$B = 1.15125 + 3.382678X$$

$$C = 10^{-3}(1.099 + 2.3965X)$$

$$D = 10^{-5}(3.9333X)$$

- AMMONIA SODIUM THIOCYANATE [NH_3-NaSCN]

There exists a relation between saturation pressure and temperature and which is:

$$\ln P = A + \frac{B}{T}$$

And here;

$$A = 15.7266 - 0.298628X \quad \text{and} \quad B = -2548.65 - 2621 - 92(1 - X)^3$$

For this working pair the relationship among pressure, concentration and enthalpy is as follows:

$$h(T, X) = A + B(T - 273.15) + C(T - 273.15)^2 + D(T - 273.15)^3$$

so the values of the coefficients are as follows:

$$A = 79.72 - 1072X + 1287.9X^2 - 295.67X^3$$

$$B = 2.4081 - 2.2812X + 7.2921X^2 3.5137X^3$$

$$C = 10^{-2}(1.255 - 4X^2 + 3.06X^3)$$

$$D = 10^{-5}(-3.33X + 10X^2 - 3.33X^3)$$

5. RESULT AND CONCLUSION

Now in order to examine and compare the performance of the alternatives working fluid pairs i.e. [NH_3-$LiNO_3$ & NH_3NaSCN] with the existing one's i.e. [NH_3-H_2O], the data has been accumulated and taken into the regard for the theoretical analysis with the operating conditions as effectiveness of heat exchanger = 75%, T_g = 100℃, T_c = 30℃, T_e = -5℃. Since the properties of every combination of working fluid are different from each other, hence would result in various energy flows. The amount of pump work is very small and hence it is neglected, COP level is determined by energy usage at the generator as in case of evaporator is same for all.

Figure 29 depicts the variation of value of COP with respect to the evaporator temperature and can easily be seen that for temperature less than 0℃, NH_3NaSCN is giving the best performance in comparison to all and that for above 0℃ , NH_3-$LiNO_3$ is the best of all.

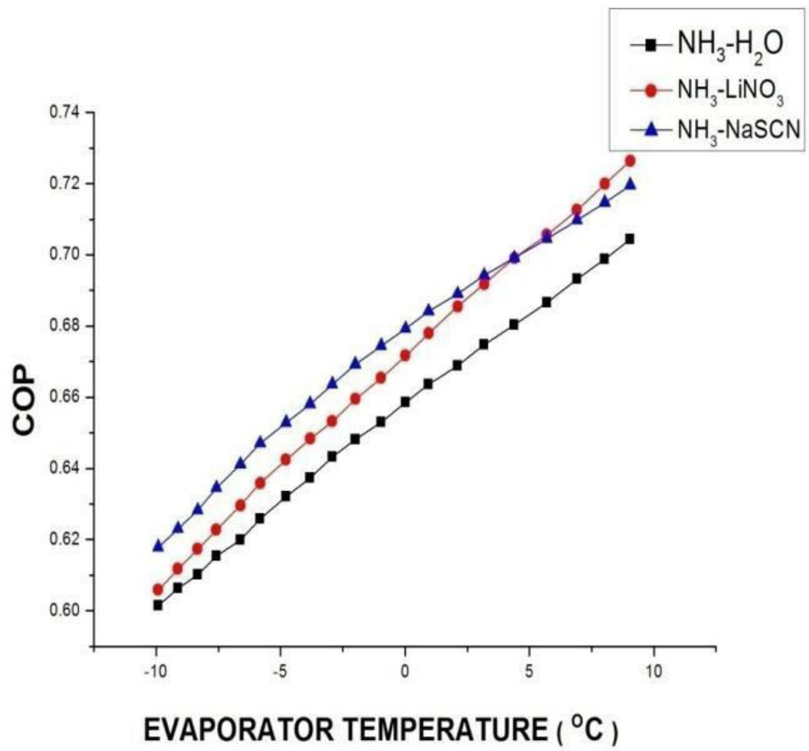


Figure 29 Variation of COP with Evaporator Temperature

From figure 30 it can be observed about the plot of the values of COP with respect to the condenser temperature. So for lower value of condenser temperature, NH_3NaSCN proves to be the best working fluid pair whereas in case of high condenser temperature NH_3-$LiNO_3$ acts as the best.

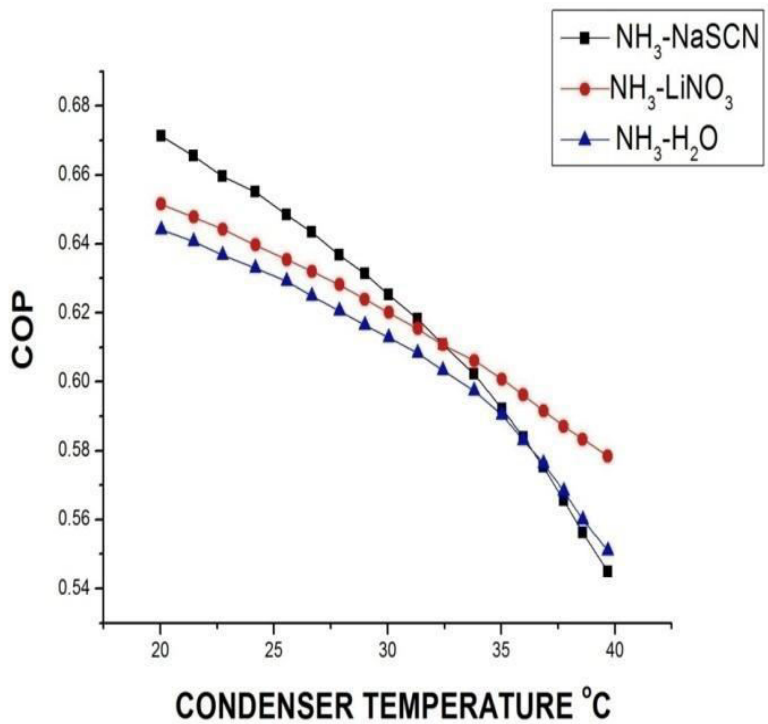


Figure 30 Variation of COP with Respect to Condenser Temperature

From figure 31, we conclude that for the lower value of absorber temperature the best working pair among them is NH_3-NaSCN is the most appropriate as it shows the maximum value of COP whereas for high absorber temperature NH_3-$LiNO_3$ acts as the best.

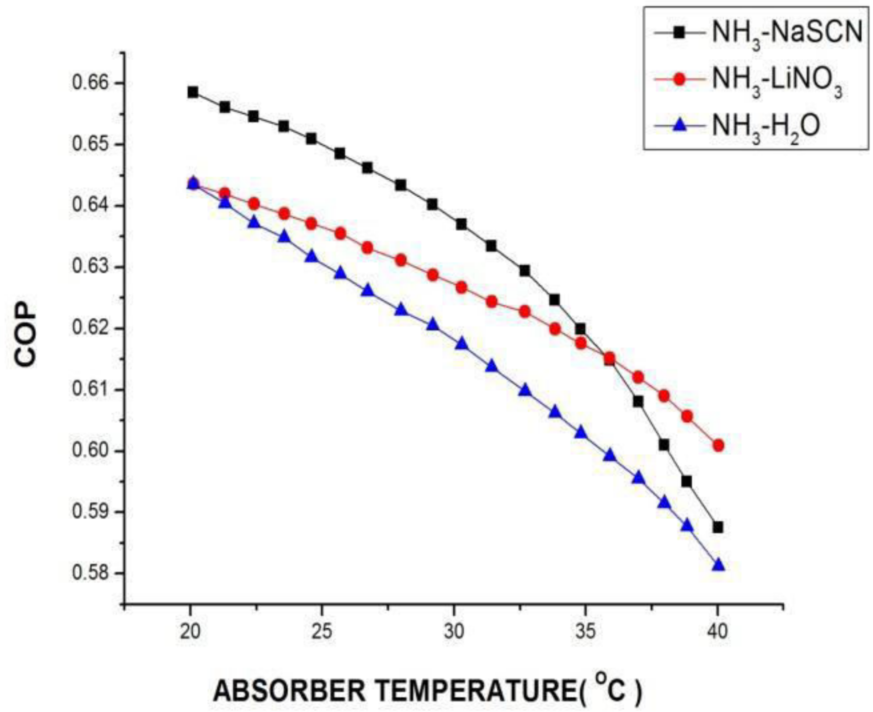


Figure 31 Variation of COP in Regard with Absorber Temperature

6. SUMMARY AND FUTURE SCOPE

SUMMARY

In this work initially we came to know about the various sources of energy and its classification. Then we come up with the principles and sub-categories of refrigeration and solar collectors and also with their application area. Then on combining the principles solar energy in aspect of refrigeration and thus obtained the "VAPOUR ABSORPTION REFRIGERATION SYSTEM". In this we came to study the COP of it along with its derivation and thus in regard to it viewed the relevant literature. Then with further assumptions the thermodynamic analysis of the system was done and the relevant comparison was made and thus the results were predicted and so the conclusions were made.

FUTURE SCOPE

From the complete thesis work we come to know that although VARS system is quiet complicated but still it's provides us with an upper hand in area of refrigeration. Now the innovation & further improvements have to be done in to accomplish the increase in performance of the refrigeration system. This could be achieved by few ways such as:

- Improvements in the components designing
- Trying for some new "solution pairs" that could lead us to better
- Working with some other renewable resources of energy instead of solar energy. For example: biogas & geothermal energy.

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