CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Energy is nature’s gift for mankind and is available in various forms like conventional and non-conventional energy. Conventional energy is obtained from non renewable fossil fuels. These are depleting day by day at a very rapid rate, consequences of same resulted in hike in fuel prices. Thus I.C engine manufacturer started to scout for more energy efficiency solutions. Usage of more energy efficient technologies can contribute a part to energy conservation. Efficiency of I.C engines can be improved by utilizing the waste thermal energy coming out of buses and heavy vehicles. A considerable amount of primary energy can be saved with the help of suitable technologies. Absorption refrigeration system can be driven by low-potential thermal energy like solar energy, geothermal energy and waste heat of thermal systems.

These days more emphasis is given on recovery of waste heat coming out from various thermodynamic systems. This heat can be utilized to run VAR systems for cooling and air- conditioning purposes. It is observed that 55-65% of primary energy consumed by the vehicle is discharged into environment in the form of waste. Effective utilization of waste heat from vehicle has become one of the key projects. VARS are heat operated, they can utilize the portion of this waste heat. Thus VARS can contribute towards energy efficient solutions by reducing primary energy discharged into environment. VAR systems don’t operate with ozone-depleting refrigerants such as CFCs & HCFCs. This technology is environment friendly and is harmless to ozone layer placed in stratosphere.

In VAR system mechanical compression is replaced by thermal compression. Solar energy can be used to drive the ARS which is renewable in nature but one drawback of using solar energy is its intermittent availability in nature. Many unavoidable obstacles alter COP of the system as a result actual COP is much less than ideal COP. To overcome this problem analysis of system using first and second law of thermodynamics has been done. First law of thermodynamics only deals with the magnitude of energy. It doesn’t give any information regarding irreversibility of the system which is actually responsible for the degradation of COP.

It brings need of second law of thermodynamics that made us familiar with the concept of exergy using property called entropy. Second law analysis is used to calculate irreversibility and with the help of irreversibility it is easy to identify actual component responsible for poor performance. Exergy analysis uses both first and second law of thermodynamics to calculate entropy generation in different components like evaporator, condenser, generator, absorber etc and other possible components of system involved in the VAR system. So components can be arranged priority wise for the further improvement of the performance of the system. It is only second law of thermodynamics that helps us to identify and minimize the entropy generation of system. Exergy analysis is a powerful tool in the design, optimization, and performance evaluation of energy systems. The principles and methodologies of exergy analysis are well-established. While a wide literature exists on exergy analysis of power plants, the application of the exergy approach to the built environment may be considered at an earlier stage. Exergy is defined as the maximum theoretical work obtainable from the interaction of a system with its environment until the equilibrium state is reached. It can also be seen as the departure state of one system from that of the reference environment. Therefore, exergy is a thermodynamic property dependent on the state of the system under consideration and its surrounding environment, called ‘‘reference environment’’.

1.2 MOTIVATION

As a regular DTC bus passenger one day it struck to my mind that lot of heat energy is being carried away with the exhaust gases, expelled by the engines into the atmosphere. According to my common knowledge of thermodynamics, I could guess the heat energy which is being wasted with the exhaust gases is not less than 60% of calorific value of the fuel burnt by the engine. In case even a part of this waste heat is utilized either by inter-cooling it with VAR system for air conditioning requirement or the system fully operated on this energy it would result in immense comfort to the passengers with no extra cost or reduction in cost of operating the air conditioning system which hitherto operated on use of conventional fuels. This would result in overall economy in operational cost of A/C passenger buses.

1.3 OUTLINE OF THE THESIS

- In the second chapter references are discussed.
- In the third chapter, theory of vapour absorption refrigeration system and thermodynamics is discussed briefly.
- In the fourth chapter proposed vapour absorption system is described and its working is discussed.
- In chapter 5, First and second law analysis of mathematical model is discussed along with the thermodynamic equations.
- In chapter 6 and 7 results and conclusions are discussed followed by references.

CHAPTER 2

LITERATURE REVIEW

***S.A Tassou et al* [1],** discussed about shifting from vapour compression refrigeration system to other alternative refrigeration system to provide desired cooling effect for food transport refrigeration. He analysed that the considerable amount of energy can be recovered from waste heat of the vehicle's exhaust. He proposed several methods like thermoelectric cooling, thermoelectric power generation, and air cycle refrigeration and reported on design, construction, and testing of an air cycle demonstrator plant for refrigeration in road transportation. It is observed that alternative technologies can produce power from the waste heat of automobile and the same power can be used to run refrigeration system. Vapour absorption refrigeration is also a promising technology for the food transport refrigeration and it will shifts our dependence from conventional fuels and can be a big step towards sustainable development.

***Yijian He et al* [2],** did experimental study on an absorption refrigeration system which is operating on low temperature source. He proposed and discussed the heat driven auto cascade absorption refrigeration cycle for low cooling and better performance. He successfully obtained -47^{0}C under generator temperature 163^{0}C using conventional refrigerant i.e; R-23 + R-134a/DMF as a working pair in the proposed system but unfortunately refrigerant so chosen is ozone depleting in nature.

***Ilhami Horuz et al* [3],** discussed idea of replacing vapour compression refrigeration system from vapour absorption refrigeration system for food transport refrigeration. It is observed that vapour compression refrigeration system consumes electric power to run compressor. It is possible to replace VCR from VAR for the same purpose. VAR system runs on waste VAR also runs quietly and is almost maintenances free. It was observed that VAR system can also fulfil air conditioning needs of vehicles running on the road. It is still challenge to extract waste heat from vehicle's exhaust without sufficient pressure drop.

***Shiming Xu et al* [4],** analysed the performance of absorption- compression hybrid refrigeration system. To run proposed system they utilized waste heat coming out of the coach engine. This system can meet the desired cooling load when coach is running above 100 km/hr and when coach slows down, cooling load shifts to the vapour compression refrigeration system. Thus absorption-compression hybrid refrigeration system provides cooling demand of the coach engine by recovering waste heat from engine and it consumes less fuel. In future compact and light weight design of structure will be most useful to integrate this designed system in narrow range of coach engine.

***Mathew Aneke et al* [5],** analysed several alternative refrigeration cycle for food processing industry by extracting waste heat from the industries. He carried out comparison of waste heat driven absorption refrigeration system and organic Rankine cycle powered vapour compression refrigeration system (VCRS). After simulation it was observed that for the same cooling requirement ORC using VCR system has better COP and second law efficiency compared to VAR system but when pressure ratio increased beyond breakeven point , the system performance seems to conflict the well known notation that system with high irreversibility should have lower efficiency and vice versa.

***Biplab Chaudhary et al* [6],** discussed developments in absorption refrigeration system for sustainable development. He observed that major portion of electricity's consumption is involved with refrigeration and air conditioning needs. It is a serious threat for sustainable development. In order to meet desired demand of electricity for refrigeration and A/C purposes more of fossil fuels are burning in thermal power plants. As a result low temperature or waste heat driven refrigeration and air conditioning technologies have gained people's interest in last few years. Efforts are made to increase the performance of system because VAR have very low COP. Recent advancements in nano-technology in the field of absorbent material can play a big role for making this technology more competitive in market. It is observed that activated technologies are good alternatives because it helps in energy conservation. Environment friendly refrigerants used in vapour absorption refrigeration is also motivating factor for alternative refrigeration technologies.

***Wei Han et al* [7],** proposed absorption-compression refrigeration system which utilizes mid-temperature waste heat. NH_3- H_2O working fluid is used to run vapour absorption system. Low temperature exhaust heat coming out of steam turbine is supplied to the generator to vaporize pure ammonia on the other side mid temperature heat source is used to drive compressor of VCR system. It was observed that proposed system is capable of utilizing sensible heat present inside flue gases. The COP of the system comes out to be 0.71 which is 41.9% higher than conventional NH_3-H_2O absorption refrigeration system.

***Le Garousi Farshi et al* [8],** used low grade heat sources in combined ejector-absorption refrigeration system. He observed that temperature obtained from waste heat is not sufficient to operate LiBr-H_2O double effect refrigeration system and this temperature is too hot to run single effect systems because high temperature causes crystallization. Thus to obtain best efficiency he combines ejector system with LiBr-H_2O absorption refrigeration system. First and second law analysis is done to show the advantages of using combined cycle over single absorption refrigeration system. It was observed that combined ejector-absorption cycle is more efficient and overall efficiency of system is also improved.

***Z. Seyfouri et al* [9],** analysed various configurations of coupled refrigeration system consist of compression absorption refrigeration system run by micro-turbine. He analysed four different configurations to generate cooling at low temperatures and their energy efficiencies are compared. He showed that the use absorption chillier improves the overall efficiency of the system by reducing energy consumption in compression chillers. Reduction in the usage of conventional power would be a big step towards sustainable development. And it is observed that the system with the intercooler and sub cooler is best configuration and is helpful in energy conservation. Thus idea of using absorption refrigeration system powered by micro turbine gives us way of utilizing waste heat coming out of various sources and integration of such systems will definitely increase the overall efficiency of the system.

***W.B Ma et al* [10],** used low temperature heat source to drive two stage LiBr-H_2O absorption refrigeration system and it is observed that COP of the system increases with increase in generator temperature but with further increase in temperature beyond 87^0C, increase in COP is small because of increased heat losses. So it is concluded that generator temperature above 87^0C is not suitable to drive this proposed system.

***Andre Aleixo Manzela et al* [11],** did experiments on the feasibility of using engine's exhaust to run absorption refrigeration system. The engine was tested for different valve opening i.e. 25%, 50%, 75%, and full wide open throttle valve. It is observed that refrigerator took 3 hours to reach a stable temperature condition in between 4^0C-

13^0C after start-up of engine and showed that it also depends upon % of throttle opening valve. It is observed that CO emissions were reduced as well as there is no such pressure drop in the exhaust flow. Still there is lot of scope for the improvement of coefficient of performance using first law and second law analysis of the system

***Yang Zhao et al* [12],** studied the effective utilization of waste heat coming out from gas driven engine to run heat pump. They used ammonia water pair as a working fluid and carried out the analyses using mathematical model for extreme cooling conditions using MATLAB with the objective to optimize PER(primary energy ratio i.e the ratio of design cooling capacity to the total energy input to the engine) and heat exchanger. It was observed that when we decrease heat exchanger area to reduce capital investment PER also decreases. After combining absorption refrigeration cycle with engine driven conventional vapour compression refrigeration cycle it is found that combined cycle is very efficient because it increases the overall efficiency of the system.

***I.Horuz et al* [13],** performed experimental investigations on vapour absorption refrigeration system by changing various operating parameters like flow rate, cooling water inlet temperature using first law of thermodynamics and it is observed that as inlet water temperature decreases cooling capacity also decreases. For given atmospheric conditions and fixed energy input if flow rate of chilled water decreases then performance also decreases. In food transport refrigeration, this concept and analysis can be used in carrying out further investigations.

***Ahmed Ouadha et al* [14],** developed the idea of using waste heat coming out of marine diesel engine and did the analyses to check the feasibility of the using exhaust heat to run systems operating on waste heat like vapour absorption refrigeration system. Then he took ammonia water vapour absorption refrigeration system and integrates it with the marine diesel engine. He Further developed mathematical model using thermodynamics equation like mass conservation, energy conservation and concentration balance. He analysed various operating parameters like generator temperature, evaporator temperature, heat exchanger effectiveness and absorber temperature's relation with coefficient of performance of system. It was found that increased coefficient of performance is achieved at higher generator and evaporator temperature and low condenser and absorber temperature. But it is also observed that he assumed ammonia vapour at the exit of generator is free from moisture that is practically not possible and analyses is restricted to first law of thermodynamics.

***Omer Kaynakli et al* [15],** carried out thermodynamic analyses of lithium bromide water absorption refrigeration system using first and second law of thermodynamics and used mathematical model to calculate the entropy generation at each component of LiBr-H_2O refrigeration system in order to find the component solely responsible for the poor performance of vapour absorption refrigeration system. With the help of second law, we can calculate the second law efficiency which is based on disorderness of the system. It is find that maximum entropy generation occurs at generator.

***L. Gaurousi Farshi et al* [16],** carried out analyses of absorption refrigeration system using different working pair i.e; ammonia /$LiNO_3$ and NH_3/NaSCN as an alternative to NH_3/ H_2O for the applications below 0^0C. As NH_3/ H_2O working pair is toxic in nature and not compatible with few material constructions. He developed computer programme using EES software for single effect absorption system it is observed that COP and second law efficiency of cycle increases and then decreases with the increase in generator temperature. At lower generator temperature ammonia /$LiNO_3$ system have more values of COP and second law efficiency compared to NH_3/NaSCN system but at higher temperature this result is reversed. Whereas circulation ratio for NH_3/NaSCN is more than ammonia /$LiNO_3$.

***E.Kurem et al* [17],** did comparison between NH_3-H_2O and LiBr-H_2O absorption refrigeration system on the basis of coefficient of performance and maximum pressure of the system. It is concluded that as far as mass transfer characteristics, inferior heat, price, thermodynamic properties and toxicity are concerned LiBr-H_2O refrigeration system is preferable but the disadvantage is to maintain pressure level below sub atmospheric. Another disadvantage of using LiBr is it crystallizes at higher temperature. For absorption heat pump LiBr-H_2O absorbent refrigerant pair shows better performance as compared to ammonia water refrigeration system. It is also observed that ammonia water working pair has wide range of miscibility over wide operating conditions but ammonia is toxic is nature. It is necessary to use rectifier to remove moisture so its use increases the cost of the system. Ammonia water refrigeration system is capable of achieving temperature below 0^0C which is impossible in case of LiBr-H_2O refrigeration system.

***Basant K Agarwal et al* [18],** proposed thermodynamics assessment of novel waste heat to run absorption refrigeration along with ejector and power generation. This combined cycle can produce refrigeration output of different magnitude at different inlet parameters. With the help of second law analysis of the tri-generation system it is observed that there is deviation of actual process from ideal process thus there is need to emphasis on minimizing entropy or irreversibility. After analysis it is found that thermal efficiency decreases but exergy efficiency increases. Effect of turbine inlet pressure on the refrigeration output is also observed.

***Francisco Taboas et al* [19],** carried out work on vapour absorption refrigeration systems using different working pair, One is ammonia/ water and another is ammonia / salt mixture to run VAR for refrigeration purposes. He utilizes heat extracted from jacket water carrying heat from ship's engine and this heat was sufficient enough to run absorption refrigeration cycles. It was observed that that with the help of ammonia/ $LiNO_3$(salt) working pair with heat source maintained at 85^0C. It is possible to achieve temperature of evaporator much lower than ammonia/ water absorption refrigeration system.

CHAPTER 3

VAPOUR ABSORPTION REFRIGERATION SYSTEM

3.1 REFRIGERATION

Refrigeration is the science of the producing and maintaining temperature of system below that of the surrounding. Refrigerating machine is a device which either cools or maintains a body at a temperature below that of surroundings. Heat always passes downhill from a warm body to a cooler one, until both bodies are at the same temperature. In refrigeration, heat is made to flow from a body at low temperature to the surrounding at high temperature. The equipments used to maintain system at a low temperature is termed as refrigeration system and system which is maintained at low temperature is called refrigerated system.

3.2 TYPES OF REFRIGERATION SYSTEM

The various refrigeration systems may be enumerated as below;

1. Ice refrigeration system
2. Air refrigeration system
3. Vapour compression refrigeration system
4. **Vapour absorption refrigeration system**
5. Special refrigeration systems
    a. Adsorption refrigeration system
    b. Cascade refrigeration system
    c. Mixed refrigeration system
    d. Vortex refrigeration system
    e. Thermoelectric refrigeration system
    f. Steam jet refrigeration system

The performance of a refrigeration system is expressed as the Co-efficient Of Performance (COP), which is defined as the ratio of heat absorbed by the refrigerant while passing through the evaporator to the work input required to compress the refrigerant in the compressor. The rating of the refrigeration machine is done with the unit of refrigeration known as standard commercial ton of refrigeration which is defined as the amount of heat extracted to convert one ton of water at 0^0C into one ton of ice at 0^0 C in 24 hours. Since the latent heat of fusion of ice is 336 kJ/kg, the refrigerating effect of 336×1000kJ/kg in 24 hours is rated as One Ton, in S.I unit it is rounded off to 3.5 kJ/s or 210 kJ/min.

3.3 VAPOUR ABSORPTION REFRIGERATION SYSTEM

Conventional refrigeration system i.e. vapour compression refrigeration system uses mechanical compression with the help of compressor which continuously withdraws vapour refrigerant from evaporator and raise its pressure and temperature so that heat extracted from the system is rejected to the surrounding by condensing it in the condenser. VCR system use electricity obtained from the conventional power plants to run compressor and the work required is relatively large because compression of vapours require large changes in specific volumes. Heat operated refrigeration system in which mechanical compression is replaced by physio-chemical process for purely mechanical process of compression cycle is known as vapour absorption refrigeration system.

In vapour absorption system, the role of compressor is accomplished in a three step process by the use of absorber, pump and generator as follows:

- **Absorber:** The purpose of absorber is to absorb refrigerant vapour coming from the evaporators which results in formation of rich or strong solution of refrigerant in the absorbent. This process is exothermic in nature so heat produced should be continuously removed by cooling water. In construction absorber resembles a shell and tube type heat exchanger.
- **Pump:** Pump is used for pumping the rich solution from the absorber pressure to generator pressure. Amount of work required to pump vapour is very small so pump work input is negligible in absorption system.
- **Generator:** Function of generator is distillation of vapour from rich solution leaving the poor solution for recycling after absorbing heat.

A simple vapour-absorption system, therefore consist of a condenser, an expansion device, and an evaporator as in vapour compression system. In addition, an absorber, a pump, a generator or desorber and a pressure- reducing valve to replace the compressor. Thus vapour absorption is heat operated unit which uses refrigerant that is alternatively absorbed by and liberated from the absorbent. The schematic representation of the system is shown in figure 3.1[20]

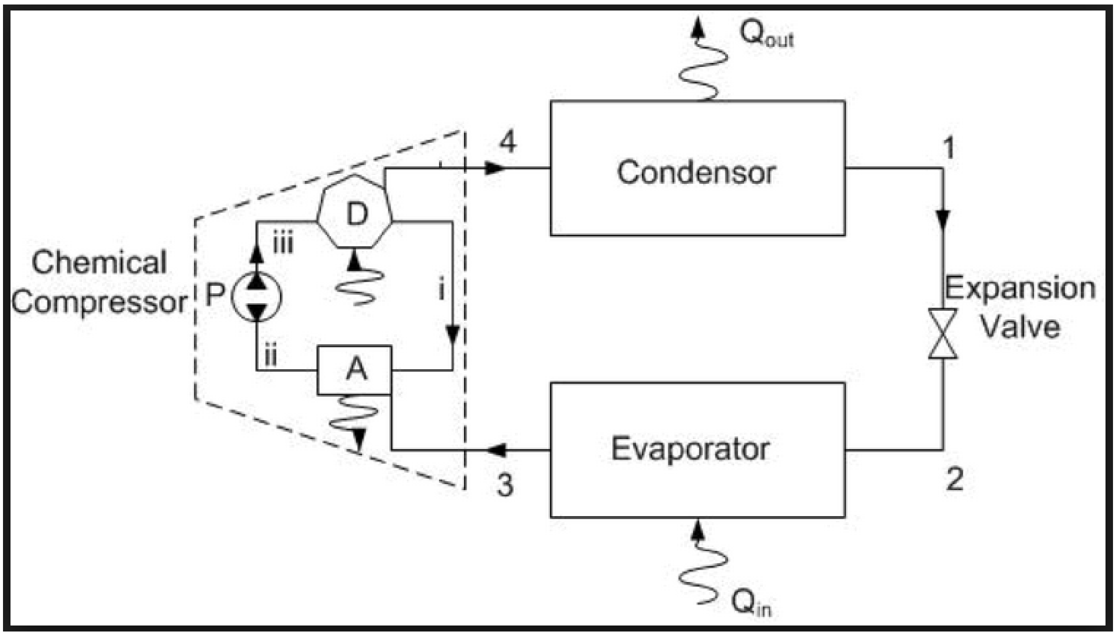


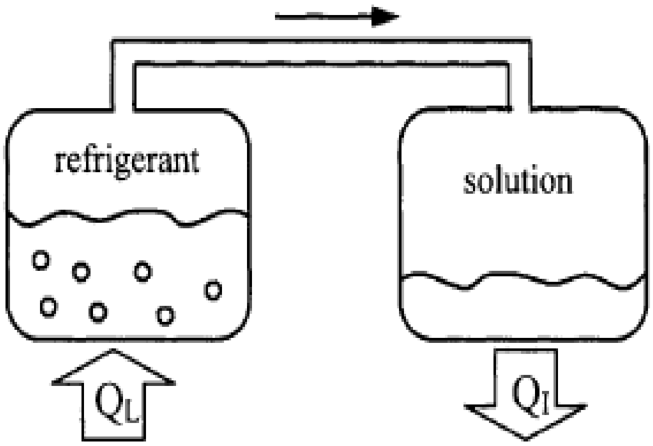
Fig 3.1 Vapor Absorption Refrigeration System[20]

As shown in figure 3.1[20], compressor work is replaced from physio-chemical compression in which Mechanical compression is replaced by using absorber, pump and generator/desorber.

3.4 PRINCIPLE OF OPERATION

As shown in figure 3.2 [20]**,** two evacuated vessels are connected to each other through a pipe, vessel on left side is having refrigerant and on the right hand side is having binary solution containing refrigerant and absorbent. Refrigerant from left vessel is absorbed by the binary solution placed in right vessel, as a result pressure drops due to which temperature of the remaining refrigerant reduces. This is called refrigerating effect that took place in left vessel. At the same time the concentration of refrigerant absorb in the binary solution increases called as absorption. Since the process is exothermic in nature heat get released from the right vessel and refrigerant absorb in the solution dilutes the solution i.e. concentration of refrigerant increases this is called absorption and this process is exothermic in nature as a result heat get released from the right vessel to the surrounding in order to maintain its absorptive behaviour.

Whenever the solution cannot continue with the absorption process because of saturation of the refrigerant, the refrigerant must be separated out from the diluted solution. Heat is normally the key for this separation process. It is applied to the right vessel in order to dry the refrigerant from the solution as shown in Fig. 3.2 (b) [20]. The refrigerant vapour will be condensed by transferring heat to the surroundings. With these processes, the refrigeration effect can be produced by using heat energy. However, the cooling effect cannot be produced continuously as the process cannot be done simultaneously. Therefore, an absorption refrigeration cycle is a combination of these two processes as shown in Fig. 3.3[20]. As the separation process occurs at a higher pressure than the absorption process, a circulation pump is required to circulate the solution.



(a)

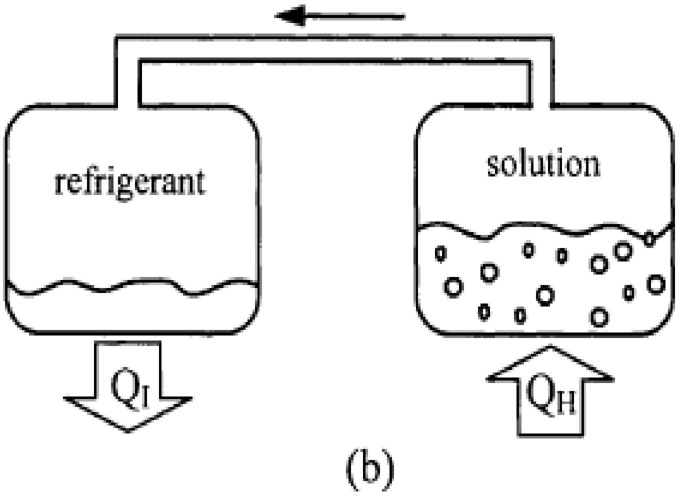


Figure 3.2 (a) Absorption process occurs in right vessel causing cooling effect in the other; (b) Refrigerant separation process occurs in the right vessel as a result of additional heat from outside heat source. [20]

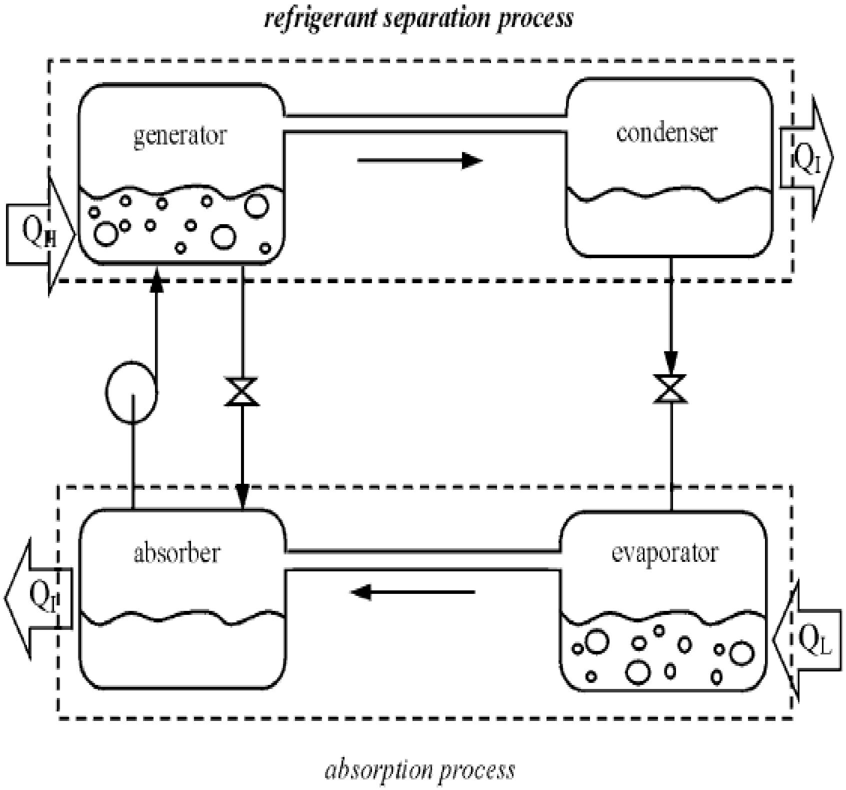


Figure 3.3 A continuous absorption refrigeration cycle composes of two processes mentioned in the earlier figure [20]

Coefficient of Performance of an absorption refrigeration system is obtained from;

$$\text{COP} = \frac{\text{refrigerating effect at evaporator}}{\text{Heat supplied to generator + work supplied to pump}}$$

The work input for the pump is negligible relative to the heat input at the generator; therefore, the pump work is often neglected for the purposes of analysis.

3.5 SELECTION OF REFRIGERANT

In order to run vapour absorption refrigeration system with higher COP, selection of proper refrigerant-absorbent pair is very important. Vapour absorption refrigeration system depends upon chemical, physical, and thermodynamic properties of working fluid like ammonia, lithium bromide etc [21, 22].

Various requirements of working fluid are:

- Both the refrigerant and the absorbent must be in liquid phase.
- They should have large margin of miscibility within the operating range of temperature.
- Mixture should be non-explosive, non-toxic, environmental friendly , chemically stable and have low viscosity
- Absorbent and refrigerant should have a difference in boiling point at least by 200^0 C, so that the absorbent exerts negligible vapour pressure at generator temperature. Thus only refrigerant is boiled off from the generator and absorbent alone returns to the absorber.
- Refrigerant should have more than Raoult’s law solubility in the absorbent and the refrigerant, so that a strong solution highly rich in the refrigerant is formed by the absorption of refrigerant vapour.
- Refrigerant should have low viscosity and freezing point, so as to minimize pump work.
- The absorbent should have a strong affinity for the refrigerant.
- Refrigerant should have high latent heat to reduce mass flow rate.

- The refrigeration must be more volatile than the absorbent for easy separation in the generator.

Vapour absorption refrigeration system with NH_3 as a refrigerant, widely used for cooling purposes because ammonia and water both have:

1. Both are highly stable over a wide range of operating range
2. Ammonia has high latent heat of vaporisation
3. Low temperature up to -77^0C can be achieved.

Along with advantages there are few disadvantages of using ammonia - water as working pair are:

1 Ammonia and water both are volatile in nature. Thus system requires rectifier/dephlegmator at the exit of generator. Otherwise water would accumulate in the evaporator and affect the performance of the system.

2 Ammonia is toxic and with Cu and Cu alloy it is corrosive in nature.

However NH_3 - H_2O working pair is cheap and environment friendly. Thermodynamic property of ammonia water for absorption system is discussed [21]. Around 1930 LiBr / H_2O working pair came to existence where LiBr as absorbent and water as refrigerant. Attention drawing property of this pair was the non volatile nature of LiBr which eliminates the need of rectifier or dephlegmator. On the other hand water has very high latent heat of vaporization. Still it didn’t gain so much of popularity because using water as a refrigerant limits the cooling up to 0^0 C, here we cannot go below 0^0 C. Another drawback with water as refrigerant is that the system must be operated under vacuum conditions & at higher concentration, solution is more prone to crystallization. Like Ammonia-Water refrigeration system, it is also corrosive to some metal and expensive as well. Thermodynamic properties of LiBr/ H_2O can be obtained from [23-26]. Some inhibitor is used to prevent corrosion while using LiBr/H_2O as working pair.

3.6 SINGLE EFFECT VAPOUR ABSORPTION REFRIGERATION SYSTEM

Single effect vapour absorption refrigeration system is most commonly used refrigeration system. In single effect VAR system two pressure levels are used high pressure level and low pressure level. Since the system make use of only two pressure levels it is called as single effect refrigeration system and is very common design. In single effect vapour absorption system Generator and condenser are placed at higher pressure level whereas evaporator and absorber are placed at low pressure level. Single effect refrigeration system is classified on the basis of absorbent as:

3.6.1 Single-Effect System Using Non-Volatility Absorbent

LiBr/ H_2O refrigeration system is an example of this category of refrigeration system. In this system LiBr salt act as an absorbent and water as a refrigerant. Since water is used as a refrigerant, this system is very useful for the air conditioning purposes and have got very much attention for commercial purposes. The components of the LiBr/ H_2O refrigeration system are evaporator, generator, condenser, absorber, pump, evaporator, cooling and heating coils and heat exchanger and the arrangement of complete system is shown in figure 3.4 [20].

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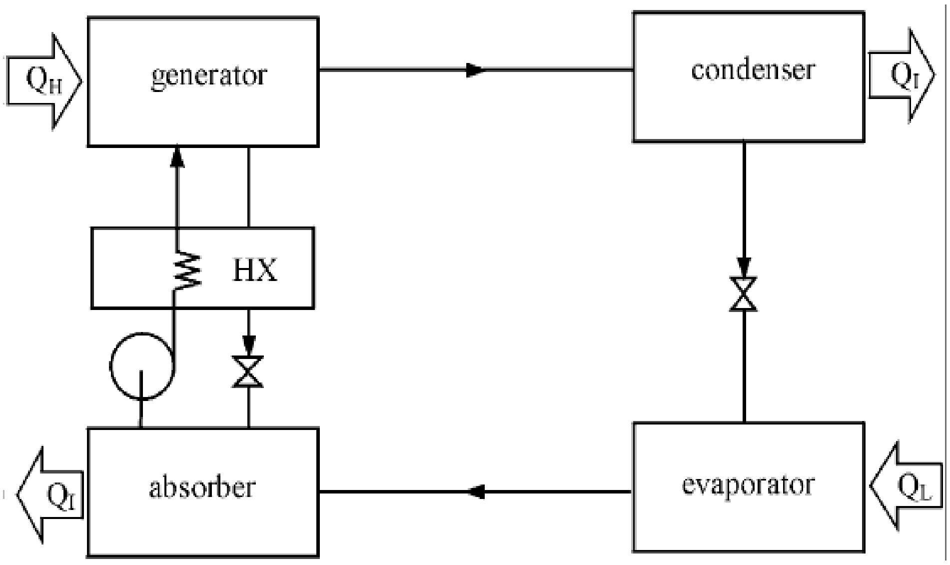

Figure 3.4 A Single-Effect LiBr / H_2O Absorption Refrigeration System With A Solution Heat Exchanger [20].

There are two pressure levels high pressure level and low pressure level. At high pressure level Generator and condenser are placed and at low pressure level absorber and evaporator are placed as shown in figure 3.4 [20]. After condenser water refrigerant throttled and goes to the evaporator where it will evaporate by absorbing heat (latent heat transfer take place) and thus produces cooling effect. It lowers the temperature up to 2-4^0 C inside the evaporator chamber by maintaining pressure at 5.5 cm of Hg. The cooled water in the evaporator is used to give desirable cooling effect. Then this water vapour goes to absorber where it is absorbed by the strong lithium bromide salt solution sprayed in the absorber as shown in figure 3.4[20], maintaining very low pressure (high vacuum) in the evaporator. After absorbing water vapour, strong lithium bromide salt solution becomes diluted in the absorber. This weak solution is pumped to the generator pressure level as shown in figure 3.4 [20]. In the generator it is heated from waste heat, thus a part of water is removed in the form of vapour and makes the lithium bromide salt solution strong. This strong solution is again passed into the absorber via heat exchanger as shown in figure. The water vapour generated in the generator is passed through condenser where it is condensed by the cold water supplied externally. This condensed water is again send back to evaporator through expansion valve to compensate the water evaporated in the evaporator and it completes the cycle.

As the water vapour enters the absorber heat is produced inside the absorber. This heat must be removed from the absorber to enhance the absorptive capacity of the lithium bromide solution and is done by circulating cold water through tubes as shown in figure 3.4 [20].

Heat exchanger used here is placed in between generator and absorber which plays significant role in increasing the performance of the system. In the heat exchanger Lithium Bromide coming down from the generator exchange heat with the strong liquid before going into generator and increases the efficiency of the system. This type of system has two pressure levels as discussed above upper shell at high temperature and lower shell at low pressure level i.e. why this system is also said to be two shell systems.

Lithium Bromide is non volatile in nature therefore rectifier and dephlegmator is not required in this refrigeration system. In this system operating pressure is very low thus due to low pressure difference between two pressure shells, valve is not required and pressure losses between pipes are often advantageous. Due to small pressure difference there is no need of pump to lift solution from low pressure region to high pressure region. This is the specific advantage of using Lithium-Bromide water system over ammonia water refrigeration system.

3.6.2 Single-Effect System Using Volatility Absorbent

Ammonia water refrigeration system is the example of this type of absorption refrigeration system. In this system ammonia is used as a refrigerant and water is used inside the absorber. As ammonia is used as refrigerant hence low temperature below 0^0C can be achieved.

The basic components of practical ammonia water refrigeration system are evaporator, water jacketed absorber, heat exchanger, generator, condenser, pump, expansion valve 1 and expansion valve 2, Dephlegmator, rectifier as shown in figure 4.3. Initially ammonia water absorption system was not economical then few extra auxiliaries added like analyser, rectifier and heat exchanger that exceptionally helped in the improvement in coefficient of performance of the system.

In the ammonia water absorption refrigeration system as shown in figure 4.3 vapour coming out of the generator is mixed with few traces of water vapour, if it reaches the evaporator it may freeze in the evaporator and this will offset the system and result in poor performance of the system. Thus to avoid this situation analyser or dephlegmator is used after the generator. The dephlegmator thus performs the function of dehydration by bringing the vapour in contact with the aqua richest in the ammonia and by cooling the vapour with this aqua. If the dehydration is not completed then there is need of added rectifier. After dephlegmator pure ammonia vapour sent to the condenser where it condenses with rejecting its latent heat to atmosphere and then through expansion valve it comes to evaporator pressure. Ammonia refrigerant evaporates and leaves cooling effect and lowers the temperature below 0^0C in the evaporator chamber. Then ammonia vapour goes to absorber where it is absorbed by the absorbent (water solution sprayed inside evaporator).Water jacketing in the absorber is used to absorb the heat produced inside absorber to increase the absorptive capacity of weak solution. After it strong solution pumped to generator pressure with the help of pump through the heat exchanger where it exchanges heat and becomes heated. In the heat exchanger strong solution exchange heat before going to generator from the hot weak solution coming from the generator. The solution heat exchanger saves amount of cooling needed in the absorber and amount of heat required in the generator. Inclusion of this heat exchanger improves the coefficient of performance of the system thus effective economy can be achieved.

Ammonia water combination is used because it possesses various desirable properties listed as:

a) Boiling point at atmospheric pressure is -33.3^{0}C.
b) Specific heat of ammonia is 4.68 kJ/kg-K
c) Critical temperature of ammonia is 132.6^{0}C
d) Ammonia is environment friendly.
e) It doesn’t pose any problem to ozone layer.

Advantages of absorption refrigeration over conventional vapour compression refrigeration system listed in table 3.1

Table 3.1 Difference between VAR system and VCR system

S.NO	**Vapour Absorption Refrigeration System**	**Vapour Compression Refrigeration System**
1.	In VAR system mechanical compression is replaced by thermo-chemical compression.	In vapour compression system mechanical compression is obtained by using electricity
2	Can be used in remote areas where electricity is not available	For this system electricity is required to run compressor
3	There is no moving parts in entire system and operation is quite and silent	Moving parts are involved and compressor causes noise and vibration
4	Waste heat can be used to run system	Electricity is necessary to run compressor
5	Coefficient of performance of this system is very low compared to VCR system	Coefficient of performance of this system is very high compared to VAR system
6	Absorption refrigeration technique is environment friendly.	VCR system is not environment friendly it is responsible for ozone layer depletion

CHAPTER 4

DESCRIPTION OF PROPOSED SYSTEM

4.1 ENERGY ANALYSIS OF DIESEL ENGINE

Despite of several latest developments in the field of I.C engine/Automobiles. The maximum efficiency achieved in I.C. engines is less than 40-45% in the other way we can say that system is rejecting approximate 55-60% of its heat as waste into the atmosphere in form of exhaust gases, radiation losses, looses through coolants etc. It clearly indicates more than half of the percentage of as a waste coming out of engine as a waste has sufficient calorific value. After injection of fuel inside combustion chamber a large amount of heat is released at the end of compression that will result in power stroke. Indeed only small fraction of energy is utilized to produce mechanical work and rest of the residual energy discharges at many places during his stay in the cylinder. Depending upon the load of engine these losses are recoverable. For a diesel engine according to first law of thermodynamics we can write:

Net heat input = Net heat output

$$\dot{Q}_{\text{input}} = \dot{Q}_{\text{radiation}} + \dot{Q}_{\text{coolant}} + \dot{Q}_{\text{exhaust}} + \dot{W} \qquad (4.1)$$

Where, $\dot{Q}_{\text{input}}$ = heat supplied to the engine.

$\dot{Q}_{\text{radiation}}$ = heat transferred to the atmosphere by means of radiation mode of heat transfer.

$\dot{Q}_{\text{exhaust}}$ = heat rejected by exhaust gases.

$\dot{W}$ = mechanical work output produce by engine.

$\dot{Q}_{\text{coolant}}$ = Heat rejected to coolants.

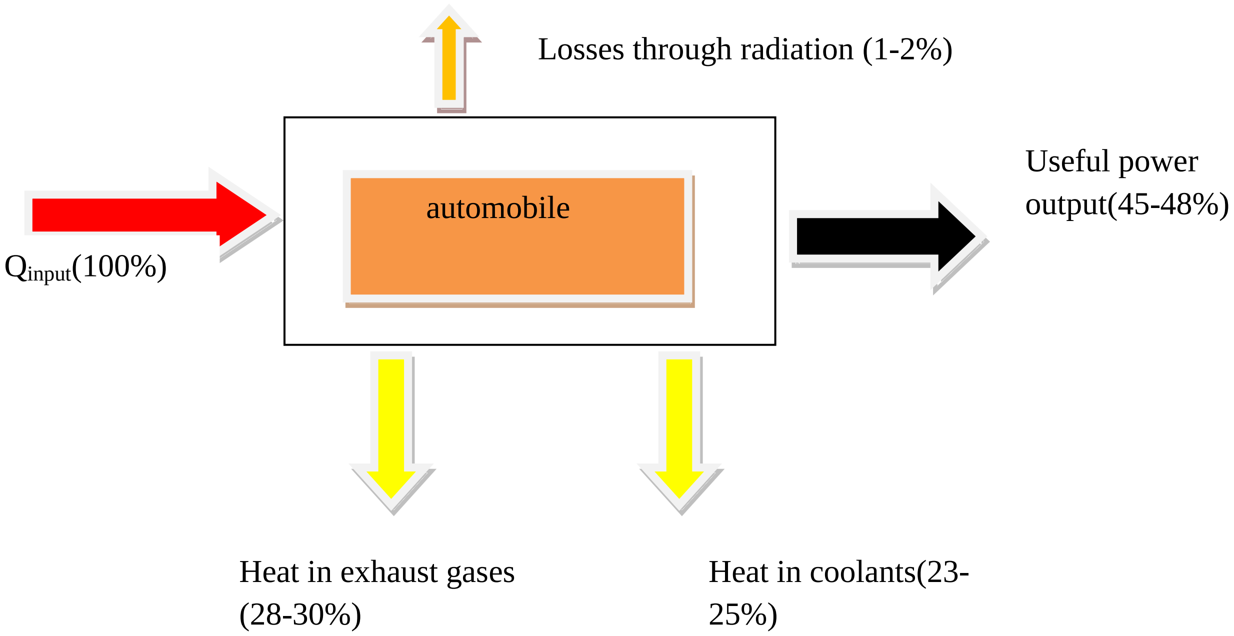

Fig 4.1 Energy Balance of Diesel Engine

Energy balance of diesel engine is shown in figure 4.1. It shows that out of 100% energy input to I.C. engine only 45-48% is utilized to produce power rest 52-55% goes in the atmosphere as a waste in different forms i.e. 1-2 % through radiation losses; 23-25% heat goes to coolants while 28-30% goes to atmosphere along with exhaust gases. Analysis shows that waste heat has potential to be recovered heat at various temperature levels like through radiation (60-110^{0}C); jacket water temperature (70-90^{0}C); exhaust temperature (200-500^{0}C) can be maintained. This waste heat is utilized to run absorption refrigeration system. In the figure 4.2 it is shown that exhaust gases coming out from the IC engine is supplied to the generator.

Energy balance for the generator of absorption system is shown in figure 4.2, can be represented by equation 4.2

$$\dot{Q}_{exhaust} + \dot{w}_p = \dot{Q}_{ARS} + \dot{Q}_{condenser} \qquad (4.2)$$

Where,

$\dot{Q}_{exhaust}$ = Exhaust heat

$\dot{w}_p$ = Pump work

$\dot{Q}_{ARS}$ = Heat rejected by absorber

$\dot{Q}_{condenser}$ = heat rejected by condenser

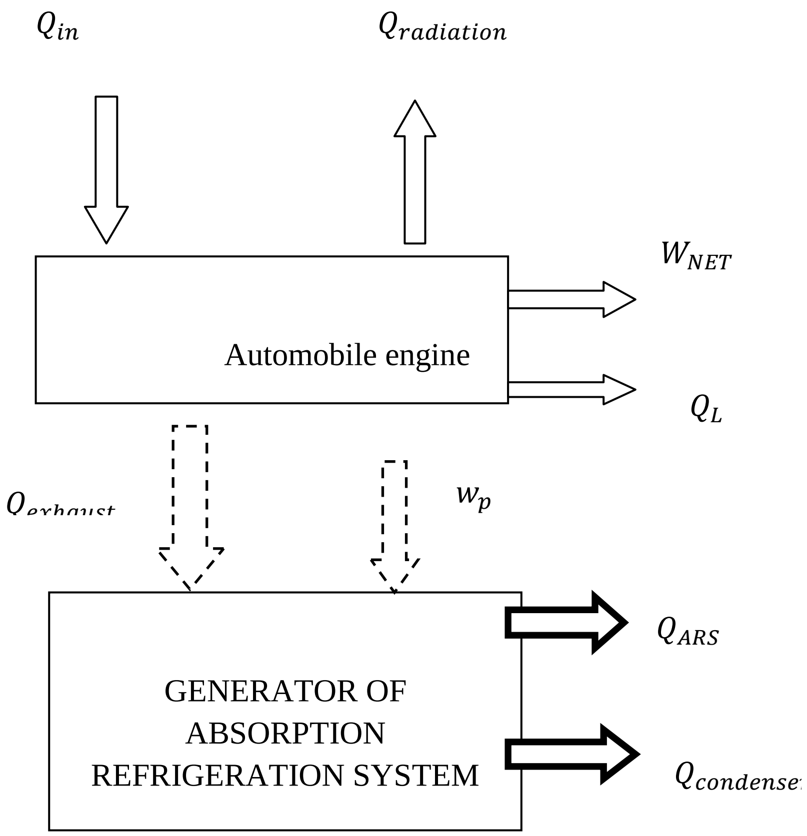

Figure 4.2 System Energy Balance.

Heat extracted from the exhaust of I.C. engine is calculated by using equation 4.3

$$\dot{Q}_{exhaust} = \dot{m}_{dfg}\, c_p\, (T_1 - T_2) \qquad (4.3)$$

Where,

$\dot{m}_{dfg}$ = mass flow rate of dry flue gases of exhaust gas

c_p = specific heat f exhaust gas in kJ/kg-K

T_1 = temperature of outlet of exhaust gas in ^{0}C

T_2 = temperature at exit of heat exchanger in ^{0}C

4.2 COMPOSITION OF EXHAUST GAS

Composition of exhaust gas constitutes of various gases.

Table 4.1 Composition of Exhaust Gas

Components	% (by volume)
CO_2	12.1
O_2	0.3
CO	3.3
H_2	1.3
CH_4	0.3
N_2	82.7

4.3 DESCRIPTION OF PROPOSED SYSTEM AND ITS WORKING

Model of proposed NH_3-H_2O single effect absorption refrigeration system is shown in figure 4.3. In this system evaporator and absorber are maintained at lower pressure level while generator and condenser are maintained at higher pressure level. First start from absorber, saturated vapours of pure NH_3 at state 5 enters into absorber. Ammonia working as a refrigerant absorbed by the binary solution inside absorber followed by rejection of heat. Strong solution coming out from absorber at state 7 is pumped to generator pressure at state 9 after passing through solution heat exchanger. Solution heat exchanger is placed in between generator and pump. Inside generator, strong solution absorbs waste heat recovered from I.C. engine's exhaust gases, causing separation of refrigerant in the form of vapour. Weak solution having less concentration of refrigerant returns to absorber through solution heat exchanger and expansion valve. In case of ammonia water refrigeration system vaporized refrigerant inside generator contains water in form of moisture with it. So to remove moisture rectifier is placed after generator. Pure ammonia exits at rectifier at state 1 and then refrigerant enters into condenser where it rejects its heat to atmosphere and condenses. At the exit of condenser refrigerant is in saturated liquid form and comes out at state 2. Saturated liquid is thus expand to evaporator pressure through expansion valve. In evaporator refrigerant absorbs heat and get evaporated this is called refrigerating effect. Then refrigerant in vapour form exits evaporator at state 5 and enter into absorber to complete cycle.

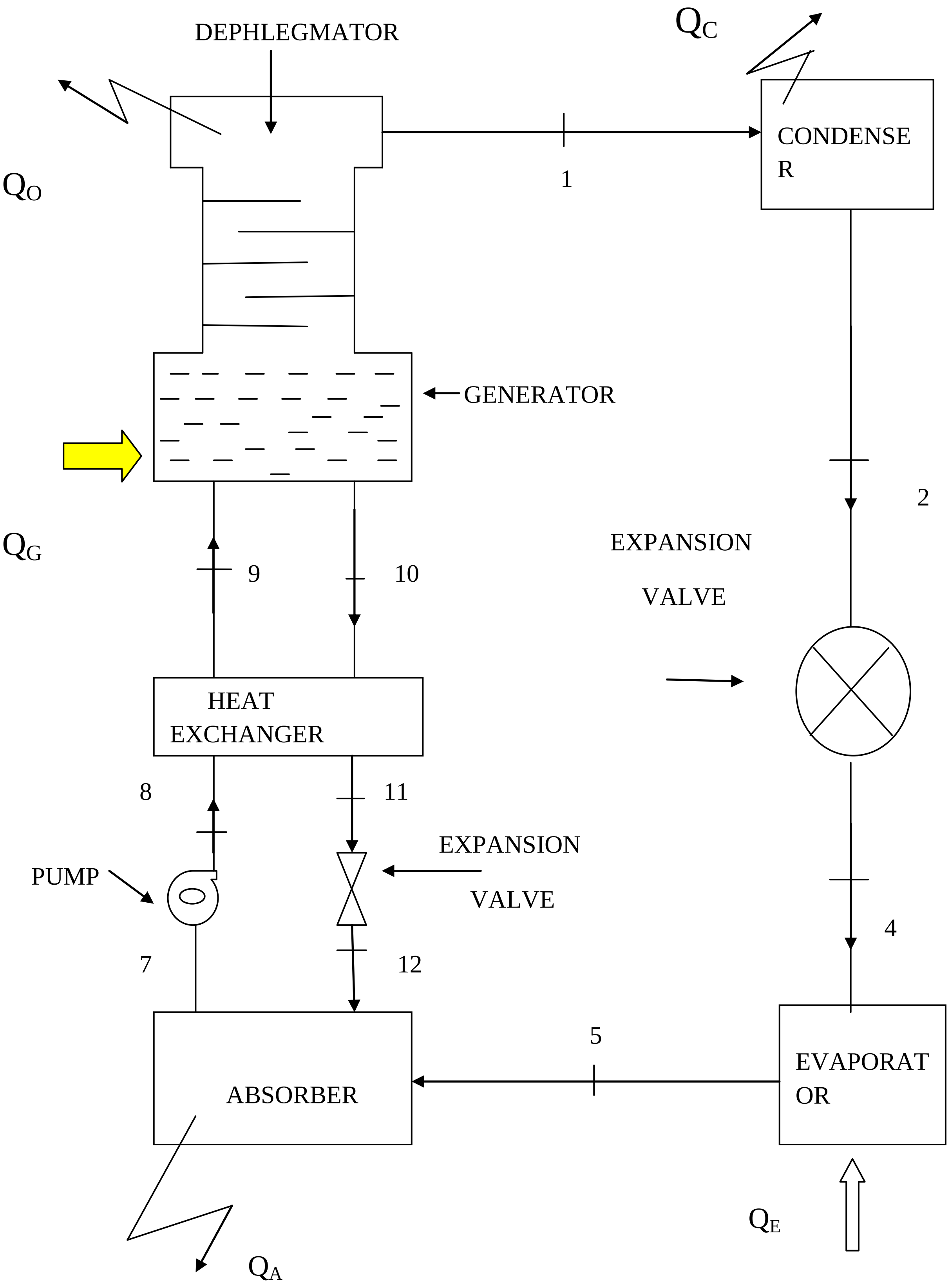

Figure 4.3 Schematic Diagram of Proposed System

Heat exchanger in between absorber and generator increases the coefficient of performance of the entire system. Coefficient of performance of the system is given by ratio of refrigerating effect to the work done by the pump along with heat input at the generator

Mathematically,

$$\mathrm{COP} = \frac{\mathrm{Q_e}}{w_p + Q_g} \tag{4.4}$$

Where

COP = Coefficient of performance

$\mathrm{Q_e}$= refrigerating effect

w_p = work done by the pump

Q_g = heat supplied at generator

CHAPTER 5

FIRST AND SECOND LAW ANALYSIS

5.1 INTRODUCTION

Coefficient of performance of absorption refrigeration system is very low about 0.55 as compared to conventional vapour compression refrigeration. It is necessary to improve the coefficient of performance of proposed refrigeration system to make this technology more competent in the commercial market for that there is need of first and second law analysis of absorption refrigeration system.

5.2 ASSUMPTIONS INVOLVED IN THE ANALYSIS

There are various assumptions which are involved in the analysis of first and second law of thermodynamics of the proposed system as shown in figure 4.3. These are very helpful while calculating the properties at various points during analysis of the system. Various assumptions have been considered to simplify the equations during analysis of the system, laws of conservation of mass ,energy, exergy and concentration have been applied to each component and each component is considered as control volume exchanging heat, work etc. Various assumptions are:

- It is assumed that all points are in thermodynamic equilibrium.
- Flow is assumed to be steady.
- Ammonia at the dephlegmator and evaporator outlet is assumed to be in saturated vapour state.
- In the condenser, the refrigerant condenses to a saturated liquid state.
- In the evaporator refrigerant evaporates to a saturated state.
- Pressure drop due to friction along the fluid flow through system and heat exchanger is assumed to be negligible.
- Heat exchange between system and surroundings, other than that prescribed by heat transfer at the generator, evaporator, condenser, and absorber are assumed negligible.
- Simulations and analyses are carried out for a constant refrigerant capacity.
- In the analyses calculations were performed for 10kW cooling load.
- Specific heat of exhaust gas is approximated to specific heat of air.

5.3 ANALYSIS OF EACH COMPONENT USING FIRST LAW

First law of thermodynamics deals with law of conservation of energy and it deals with the quantity of energy involved in the thermodynamic system. In the ammonia water absorption refrigeration system various components are used like evaporator, generator, condenser, solution heat exchanger, pump, generator, expansion valve, dephlegmator, absorber etc. These are connected with each other through pressure lines in which working fluid is flowing. Thermodynamic analysis of each component will give the scope of improvement of the COP of system. Analysis of each component is equally important and it become more important during second law analysis of the system where entropy generation in each component are calculated that we will be discussed in detail during the second law analysis. In first law of analysis we will calculate magnitude of energy transferred through each component.

5.3.1 STEADY FLOW PROCESS WITH BINARY MIXTURE

5.3.1.1 Adiabatic mixing of two streams

Consider two fluids of different concentration brought together adiabatically in a mixing chamber as shown in figure 5.1 after balancing masses, concentration, enthalpies balance in mixture we can write

$$m_1 + m_2 = m_3 \tag{5.1}$$

$$m_1\, h_1 + m_2 h_2 = m_3 h_3 \tag{5.2}$$

$$m_1\, C_1 + m_2 C_2 = m_3 C_3 \tag{5.3}$$

Eliminating m_3 using above equations we get,

$$\frac{m_1}{m_2} = \frac{C_2 - C_3}{C_3 - C_1} = \frac{h_2 - h_3}{h_3 - h_1} \tag{5.4}$$

So the concentration C_3 and enthalpy h_3 after mixing are given by

$$C_3 = C_1 + \frac{m_2}{m_1}(C_2 - C_1) \tag{5.5}$$

$$h_3 = h_1 + \frac{m_2}{m_1}(h_2 - h_1) \tag{5.6}$$

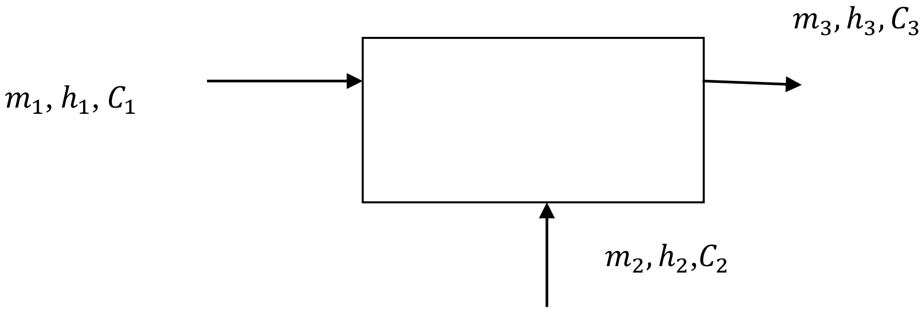

Figure 5.1 Mixing of binary fluid under steady flow

5.3.1.2 Mixing of two streams with heat exchange

In case of absorption of absorber refrigeration system heat transfer takes place, heat is generated while mixing of two streams thus we can again write fundamental equations for the mixing with heat generation.

$$m_1 + m_2 = m_3 \tag{5.7}$$

$$m_1 h_1 + m_2 h_2 = m_3 h_3 + Q \tag{5.8}$$

$$m_1 C_1 + m_2 C_2 = m_3 C_3 \tag{5.9}$$

Using above equations eliminating m_1 we get,

$$C_3 = C_1 + \frac{m_2}{m_3}(C_2 - C_1) \tag{5.10}$$

$$h_3 = h_1 + \frac{m_2}{m_3}(h_2 - h_1) - \frac{Q}{m_3} \tag{5.11}$$

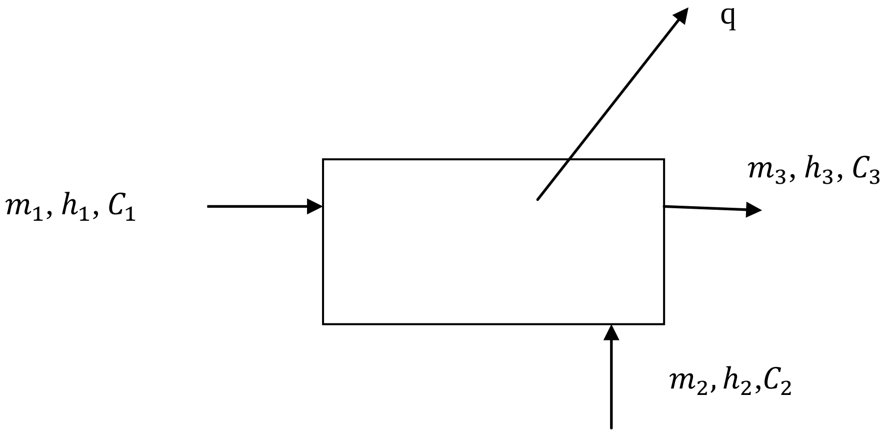

Figure 5.2 Mixing of binary fluid under steady flow with heat exchange

Subscript 1 and 2 denotes states before mixing and subscript 3 denotes the state after mixing and m, h & C represents mass, specific enthalpy and concentration respectively as shown in fig 5.2.

5.3.1.3 Throttle

Using steady flow energy equations we can write throttling is an isenthalpic process in which enthalpy at inlet and exit is same.

Mathematically,

$$h_2 = h_1 \tag{5.12}$$

Where $h_1 \ and \ h_2$ represents enthalpies at section 1 and 2

5.4 ANALYSIS OF RECTIFIER OF BINARY MIXTURE

The vapour generated after distillation in the generator always carries water along with ammonia refrigerant and it is necessary to remove the water from the vapour otherwise if it will reach the evaporator it may offset the system and performance of the system decreases. So to remove moisture we attach dephlegmator at the exit of generator as shown in figure 5.3. It is a combination of number of perforated plates and the purpose of these plates is to establish immediate contact between ascending vapour and descending liquid. Thus the concentration of ascending vapours increases and descending fluid becomes weaker and weaker in concentration.

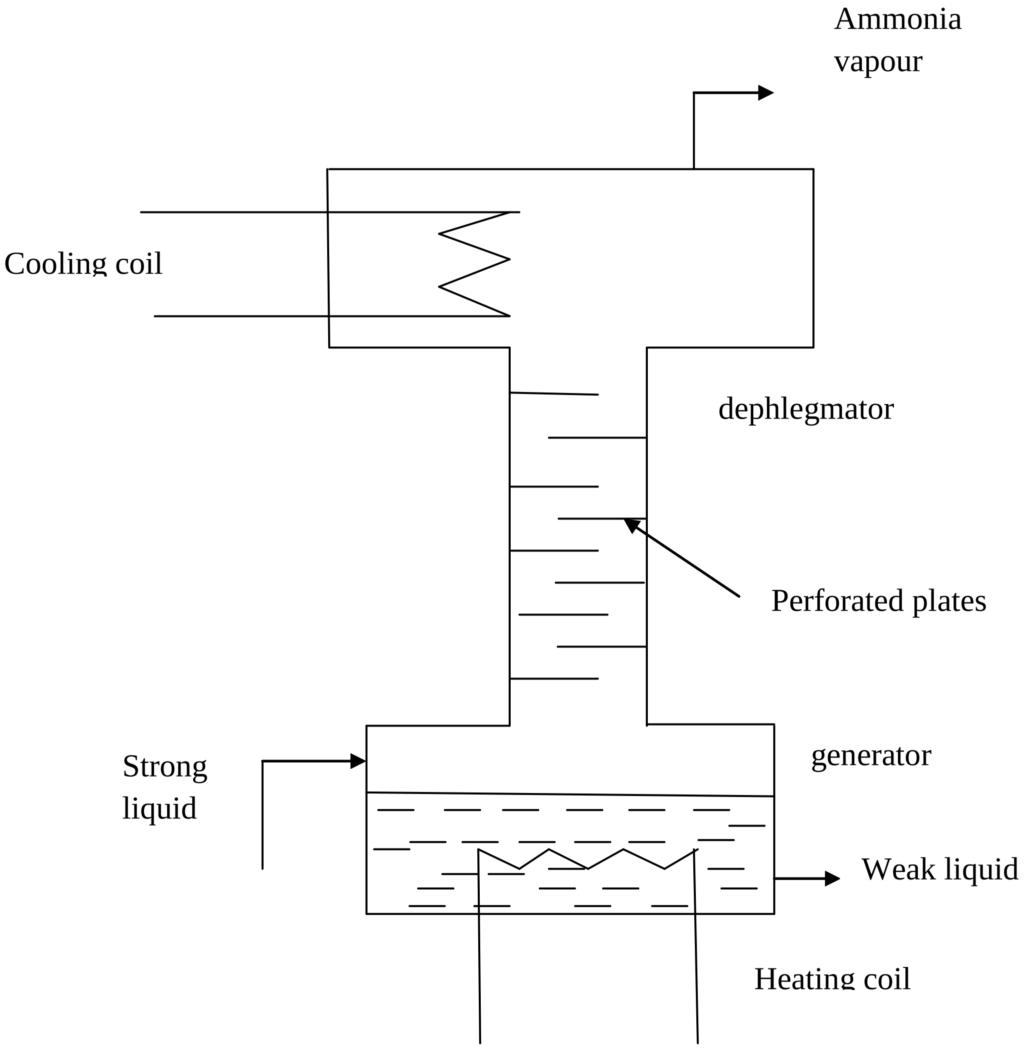

Figure 5.3 Rectifier

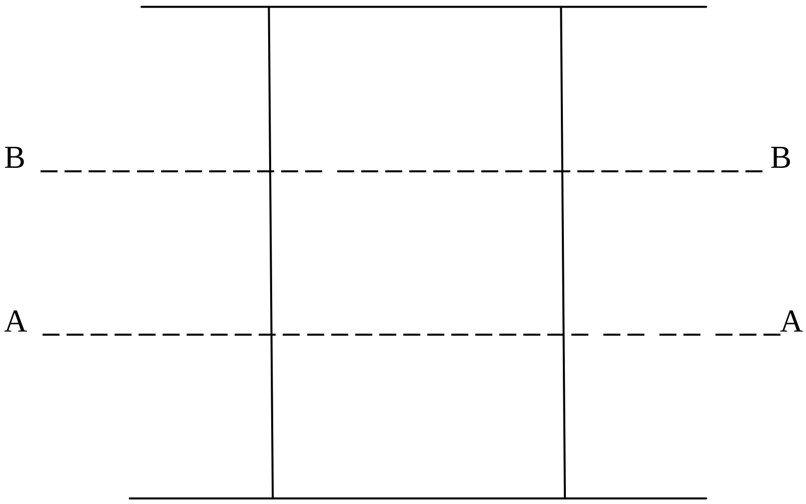

Figure 5.4 Showing Locations of the Rectifier

Consider two locations of the rectifier one section is at vapour and another is at liquid level as shown in figure 5.4.

Using mass conservation and after balancing masses we can write

$$m_{v_a} + m_{l_b} = m_{v_b} + m_{l_a} \tag{5.13}$$

$$m_{v_a} - m_{l_a} = m_{v_b} - m_{l_b} \tag{5.14}$$

This states that at any cross section along rectifier.

$$m_v = m_l = m_3$$

$$m_v\, C_v - m_l C_l = m_3 C_3 \tag{5.15}$$

And $m_v\, h_v - m_l h_l = m_3 h_3 + Q_d$ (5.16)

Where, Q_d is the heat lost during ascending along the rectifier.

From the above equations we get

$\frac{m_v}{m_3} = \frac{C_3 - C_l}{C_v - C_l}$ and (5.17)

$$\frac{m_v}{m_3}(h_v - h_l) = (h_3 - h_l) + \frac{Q_d}{m_3} \tag{5.18}$$

Where

m_v , C_v = mass and concentration at vapour state

m_3 , C_3 = mass and concentration at state 3

m_l, C_l = mass and concentration at liquid state

m_{v_a} , m_{v_b} = mass of vapour at section A and B

m_{l_a}, m_{l_b} = mass of liquid at section A and B

h_v , h_l = enthalpy at vapour and liquid state

5.5 ENRGY BALANCE AND MATHEMATICAL MODEL

Thermodynamics analysis of proposed system as shown in figure 4.3 is done with the help of mass balance, energy balance and composition balance:

- Mass balance: $\sum m_i = \sum m_e$ (5.19)
- Concentration or composition : $\sum m_i X_i = \sum m_e X_e$ (5.20)
- Energy conservation: $\sum Q - \sum W = \sum m_e h_e - \sum m_i h_i$ (5.21)

Condenser

$m_1 = m_2 = m$ (5.22)

$Qc = m (h_7 - h_8)$ kg/min

Or

$Qc = (h_7 - h_8)$ kJ/kg of ammonia vapour (5.23)

Expansion value

$m_2 = m_5 = m$ (5.24)

$h_2 = h_5$ (as process is isenthalpic) kJ/kg (5.25)

Evaporator

$m_5 = m_4 = m$ (5.26)

$Q_e = m(h_5 - h_4)$ kJ/min (5.27)

Or

$Q_e = (h_5 - h_4)$ kJ/kg vapour (5.28)

Circulation ratio

$f = \frac{m_9}{m_1}$ (5.29)

$m_9 = m_1 + m_{10}$ (5.30)

$m_9 X_9 = m_1 + m_{10} X_{10}$ (5.31)

Using above two equations we get

$m_{10} = (1- X_9) / (X_9 – X_{10})$ (5.32)

$m_{10} = (1- X_{10}) / (X_9 – X_{10})$ (5.33)

$m_1 = m_9X_9 – m_{10}X_{10}$ (5.34)

$f = \frac{m_9}{m_1}$ (5.35)

Absorber

$Q_a = mh_5 + mfh_{12} – (1+f)mh_7$ (5.36)

Solution pump

$m_7 = m_8 = m_{WS}$ (5.37)

$w_p = (1+f)mV_{solution}(p_c - p_e)$ kJ/min (5.38)

where $V_{solution} = 7.2 \times 10^{-3}\ m^3/kg$ (5.39)

Solution Heat Exchanger

$m_2 = m_3$ (5.40)

$m_3 = m_5$ (5.41)

$Q_{HX} = (1 + f)m(h_9 – h_8) = mf(h_{10} – h_{11})$ (5.42)

Generator

$m_9 = m_1 + m_{10}$ (5.43)

Heat input to generator is

$Q_g = m_1h_1 + m_{10}h_{10} - m_9h_9$ (5.44)

And finally using the above equations systems performance is measured in terms of coefficient of performance and COP is the ratio of desired effect to the net energy input to the system

Mathematically,

$$\text{COP} = \frac{Q_e}{w_p + Q_g} \tag{5.45}$$

From the analysis we can satisfy first law of thermodynamics

According to first law of thermodynamics we can write,

$$q_k = q_a + q_c = q_o + q_h + q_p \tag{5.46}$$

Equation 5.46 is satisfied from calculated value of magnitude of heat.

Where

COP = Coefficient of performance

Q_e= refrigerating effect

w_p = work done by the pump

Q_g = heat supplied at generator

Parameters fixed and assumed in the first and second law analysis is given at the end of the second law analysis.

5.6 ANALYSIS OF EACH COMPONENT USING SECOND LAW

Second law of thermodynamics came in existence when first law of thermodynamics failed to explain the quality of energy and the direction in which energy transfer takes place. First law of thermodynamics explained the coefficient of performance of the system. COP obtained using first law is low, so identifying actual component responsible for low COP is not possible with the first law of thermodynamics. Then number of questions arises like where maximum irreversibility exists? Which system is responsible for low coefficient of performance? Which system requires extra attention? And so on. To answer these questions second law analysis is very useful because second law deals with the concept of available energy, availability and exergy. It is the second law of thermodynamics which deals with the quality of energy and tells the direction in which energy flows. Second law of thermodynamics introduces very important property called entropy which is measure of randomness or disorderness of a system.

In real life none of the process is reversible. All the natural and artificial processes are irreversible in nature because of friction and it is main cause of entropy generation. Thus unlike energy, entropy is not conserved so second law provides where the real inefficiencies in a system lie. Entropy generation is associated with thermodynamic irreversibility which takes place in all the devices associated with heat transfer.

The equations of second law of thermodynamics to calculate entropy generation in each component during analysis is expressed as

Absorber

$$\dot{S_a} = \dot{m}\,[\ \mathrm{f}s_7 - s_6 - (\ \mathrm{f} - 1\ )\, s_{11}\ ] + \dot{m_a}(\ s_{18} - s_{17}\ ) \tag{5.47}$$

Where f represents circulation ratio and $\dot{S}$ represents entropy generation in kWK^{-1}

Condenser

$$\dot{S_a} = \dot{m_R}(\ s_2 - s_1\ ) + \dot{m_a}(\ s_{20} - s_{19}\ ) \tag{5.48}$$

Generator

$$\dot{S_a} = \dot{m}\,[\ s_1\ + (\ \mathrm{f} - 1\ )\, s_{10} - \ \mathrm{f}s_9\ ] + \dot{m_{wv}}(\ s_{15} - s_{13}\ ) \tag{5.49}$$

Evaporator

$$\dot{S_E} = \dot{m_R}(\ s_5 - s_4\ ) + \dot{m_a}(\ s_{16} - s_{15}\ ) \tag{5.50}$$

Solution Heat Exchanger

$$\dot{S_{SHE}} = \dot{m_R}(f-1)\,(\ s_{11} - s_{10}\ ) + \dot{m_R} f(\ s_9 - s_8\ ) \tag{5.51}$$

Pump

$$\dot{S_p} = \dot{m_R} f(\ s_8 - s_7\ ) \tag{5.52}$$

Solution Expansion Valve

$$\dot{S_{SEV}} = \dot{m_R}(f-1)\,(\ s_{12} - s_{11}\ ) \tag{5.53}$$

Refrigerant Expansion Valve

$$\dot{S}_{REV} = \dot{m}_R\ (s_5 - s_3\ ) \qquad (5.54)$$

Where

$\dot{S}$ Represents entropy generation kWK^{-1}, f represents circulation ratio, $\dot{m}_R$= m represents mass flow rate of refrigerant and $\dot{m}_a$ = m represents mass flow rate of absorbent.

Second law efficiency is given by

$$\eta_{II} = \frac{\dot{Q}_{evaporator}\ (1 - {T_0}/{T_{cold}})}{\dot{Q}_{generator}\left(1\ -\ {T_0}/{T_{hot}}\right) + \dot{W}_p} \qquad (5.55)$$

5.7 PROCESS SIMULATION

A computer program has been developed using engineering equation solver (EES) & is used to solve intensive equations. Enthalpy – Concentration chart is also analysed to get desired properties.

Table 5.1 Operating parameters used in the analysis

Generator temperature	70-130^{0}C
Condenser temperature	20-40^{0}C
Absorber temperature	20-40^{0}C
Heat exchanger effectiveness	0.5-1
Generator pressure = condenser pressure	10 bar
Evaporator pressure = absorber pressure	3.6 bar
Temperature leaving dephlegmator	50^{0}C
Temperature at the exit of exhaust	480^{0}C
Temperature at the exit of heat exchanger	273^{0}C
Mass flow rate of exhaust gas	360 kg/hr

Table 5.2 Parameters that are fixed in the analysis

Generator temperature	90^0C
Condenser temperature	25^0C
Absorber temperature	25^0C
Heat exchanger effectiveness	0.8
Temperature leaving dephlegmator	50^0C
Strong solution entering column	75^0C
Ton of refrigeration	10

Table 5.3 Heat transfer rate of components of the system

Component	**Heat transfer (kJ/Kg of vapour)**
Generator	1895
Condenser	1250
Evaporator	1200
Pump	39.051
Absorber	1885

Table 5.4 Thermodynamic property at each point

State point	Pressure (bar)	Temperature (^{0}C)	Concentration of ammonia per kg of mixture	Enthalpy (kJ/kg)	Flow rate (kg/min)	Entropy (kJ/kg-K)
1	10	50	1	1650	1.76	4.559
2	10	25	1	500	1.76	0.4175
4	3.6	-5	1	500	1.76	0.07
5	3.6	10	1	1600	1.76	4.826
7	3.6	32	0.39	17	32.32	0.3485
8	10	32	0.39	17.73	32.32	0.3479
9	10	75	0.39	230	32.32	0.9309
10	10	90	0.318	290	30.57	1.144
11	10	50	0.318	57.35	30.57	0.4959
12	3.6	50	0.318	57.35	30.57	0.4964

CHAPTER 6

RESULTS AND DISCUSSION

Table 5.1 shows the range of thermodynamic properties used in the analysis where as table 5.2 shows the fixed thermodynamic property used to calculate the performance of the system. Thermodynamic properties are calculated at all points with the help of EES software and enthalpy concentration chart shown in table 5.4. In this simulation, calculations are performed for 10 ton of cooling load.

Table 5.4 shows calculated values of mass flow rate, concentration, temperature, enthalpy and entropy. Table 5.3 shows calculated values of heat transfer in kJ/kg of vapour of evaporator, generator, condenser, absorber and pump. It clearly shows that heat transfer in generator is very high as compared to other components and In pump it is very low. Thus effect of pump on total energy supplied to the system is neglected.

From figure 6.1 and 6.2 it is observed that at fixed absorber, condenser and evaporator temperature with increase in generator temperature coefficient of performance of the system increases because with increase in generator temperature more refrigerant will evaporate from the strong solution. With further increase in generator temperature beyond 120-130^{0}C COP starts decreasing because of increase of irreversibility. On the other hand it is observed that with increase in generator temperature circulation ratio (ratio of strong solution to the refrigerant solution) decreases because with the increase in generator temperature refrigerant solution remain unaltered but from strong solution refrigerant starts evaporating inside generator. Thus there is decrease in strong solution concentration which results in decrease in circulation ratio.

From figure 6.3 and 6.4 it is observed that at fixed parameters as shown in table 5.2. COP of system decreases with increase in absorber temperature because with increase in absorber temperature its absorbing capacity decreases this result in decrease of COP. While circulation ratio increases with increase in absorber temperature because flow rate is inverse to concentration difference. With rise in temperature, concentration of refrigerant becomes equal to concentration of weak solution thus flow rate increases and this satisfies the result obtained after analysis.

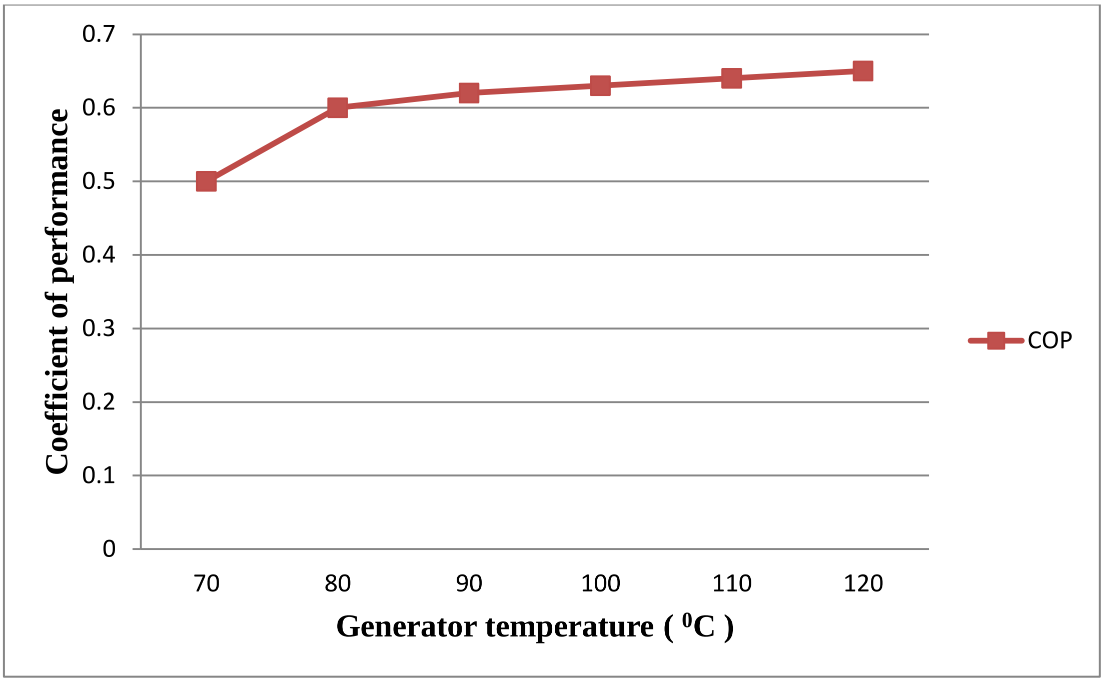

Figure 6.1 COP vs Generator Temperature

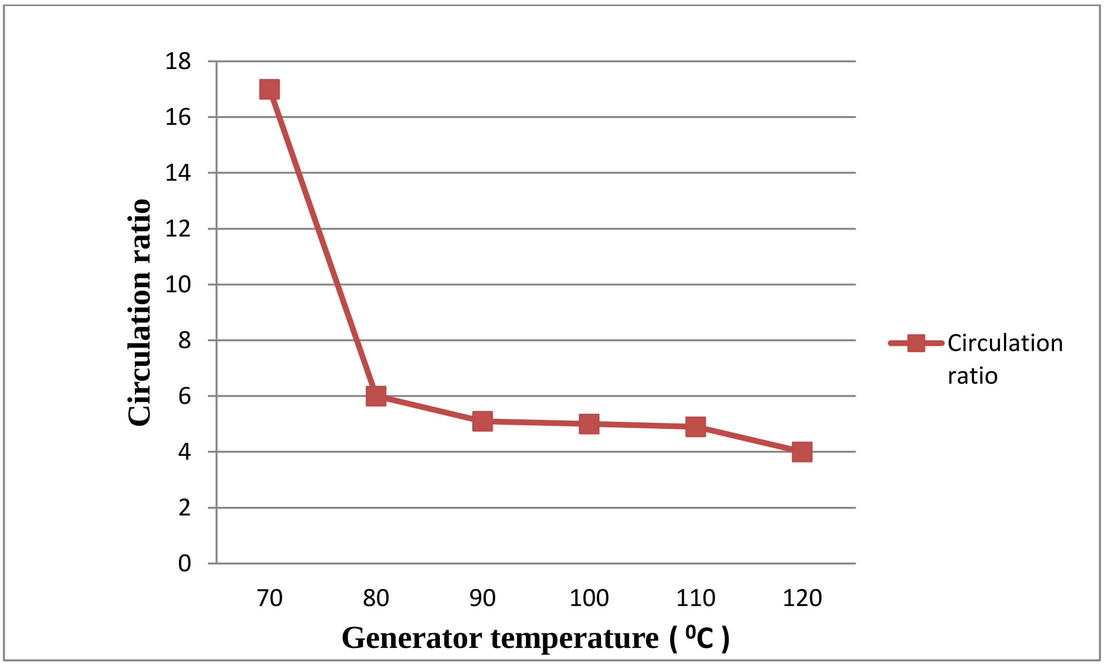

Figure 6.2 Circulation Ratio vs Generator Temperature

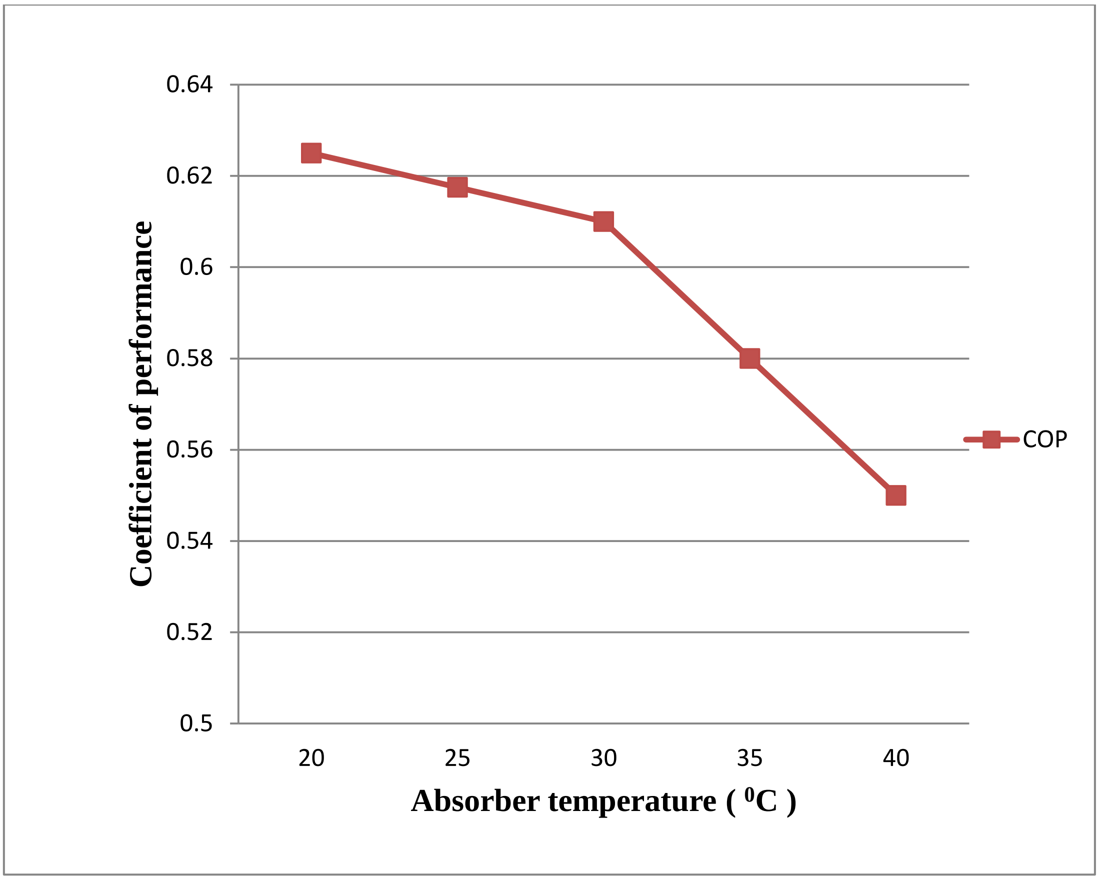

Figure 6.3 COP vs Absorber Temperature

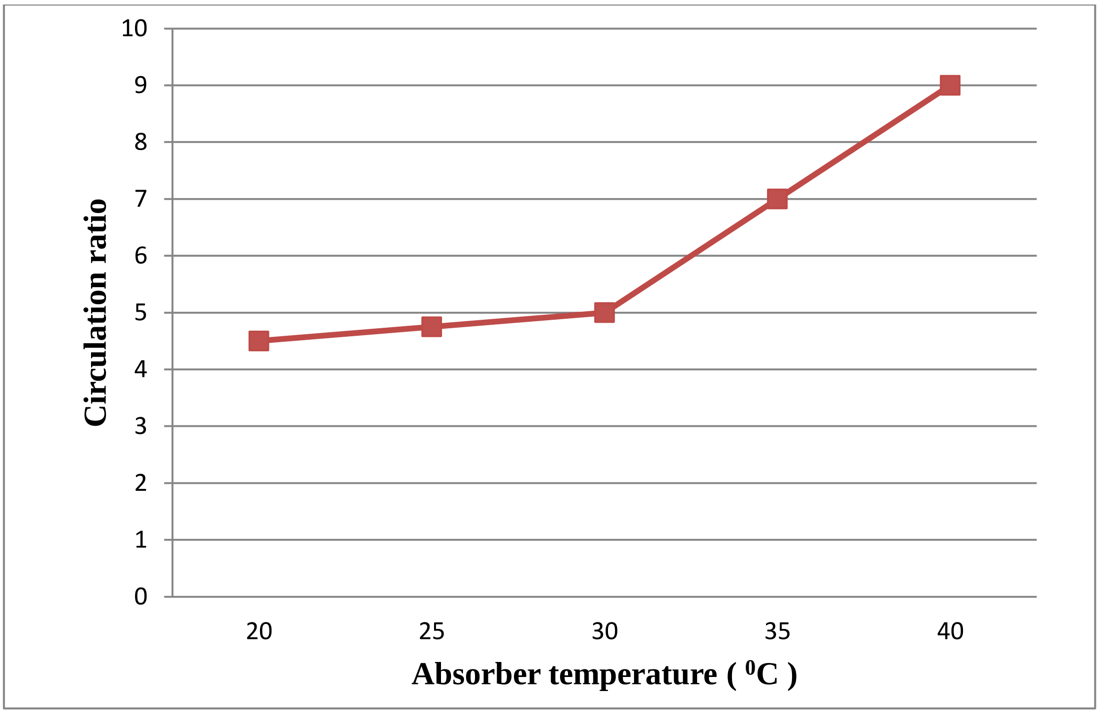

Figure 6.4 Circulation Ratio vs Absorber Temperature

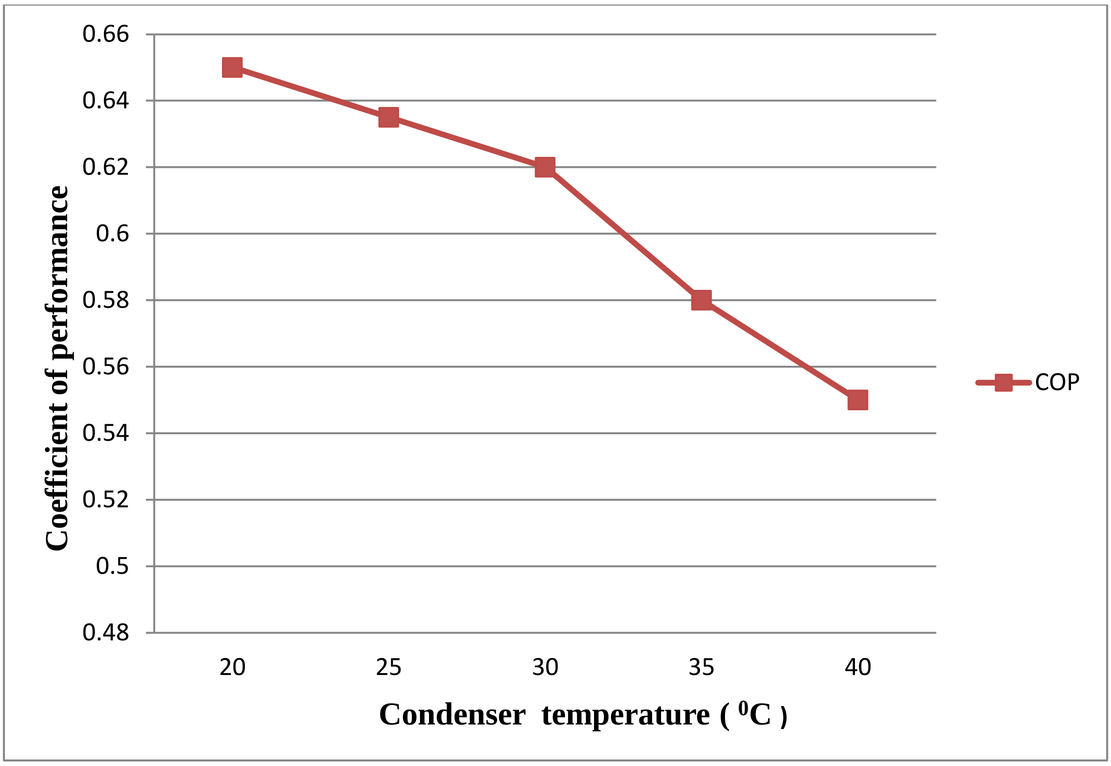

Figure 6.5 COP vs Condenser Temperature

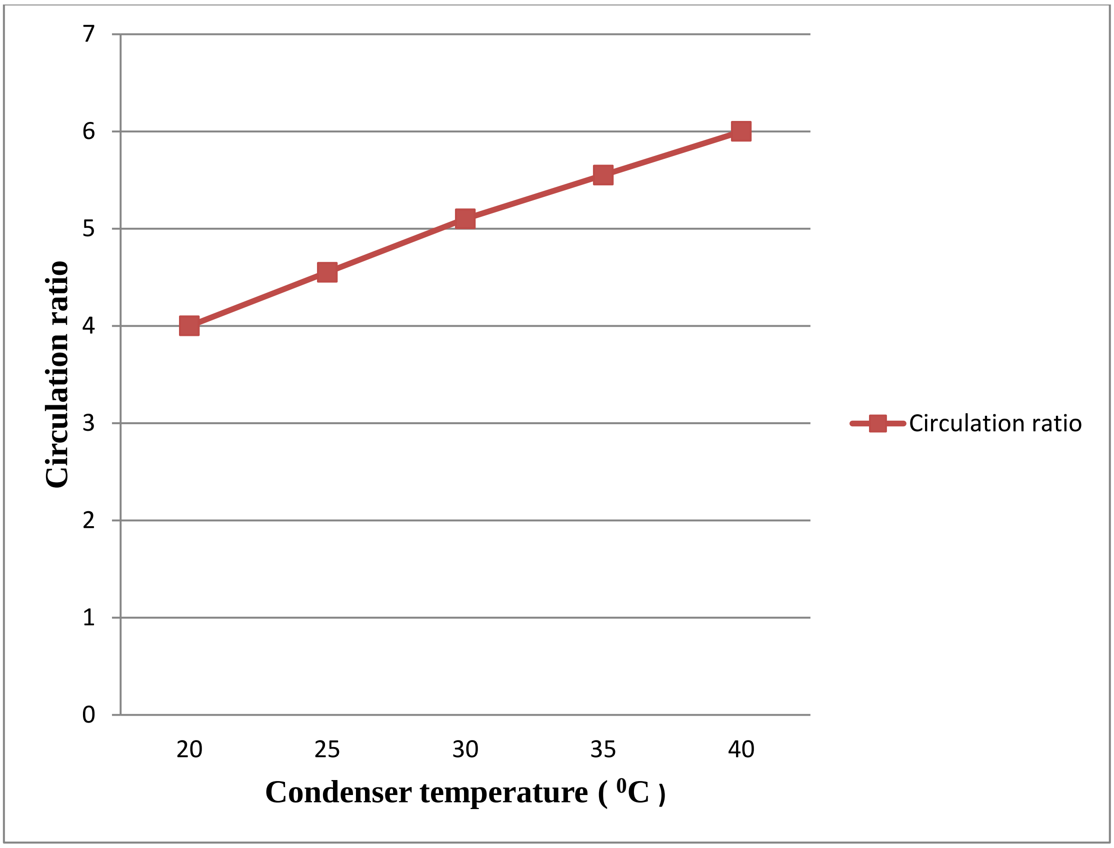

Figure 6.6 Circulation Ratio vs Condenser Temperature

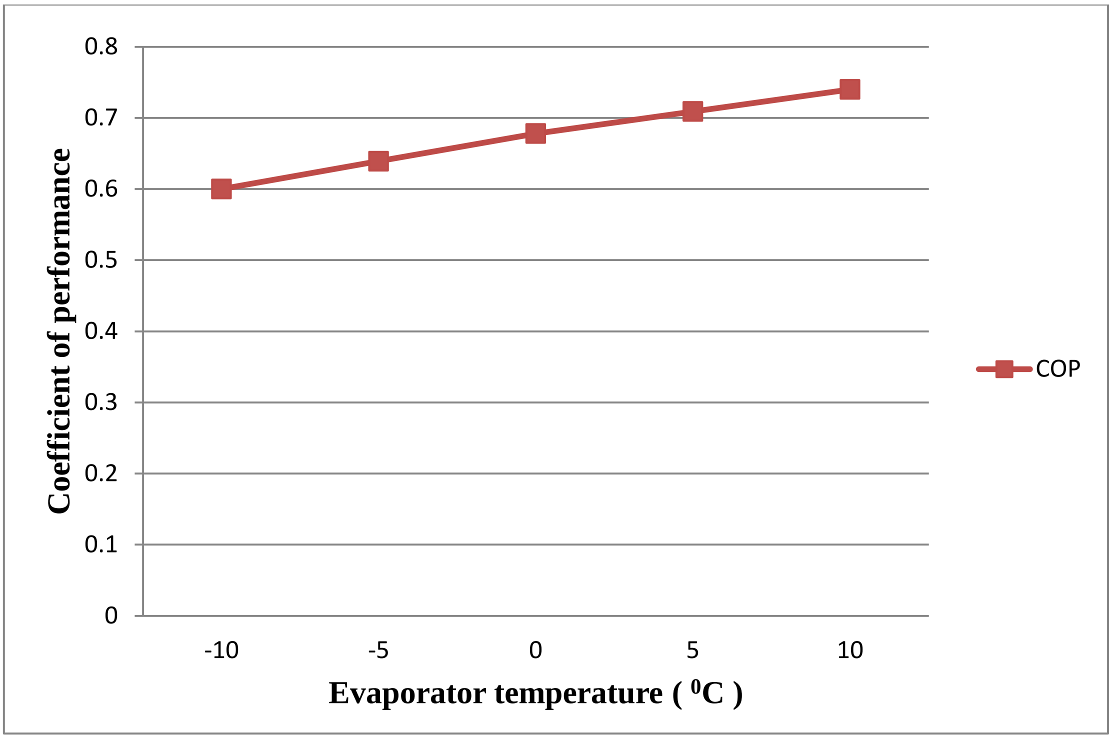

Figure 6.7 COP vs Evaporator temperature

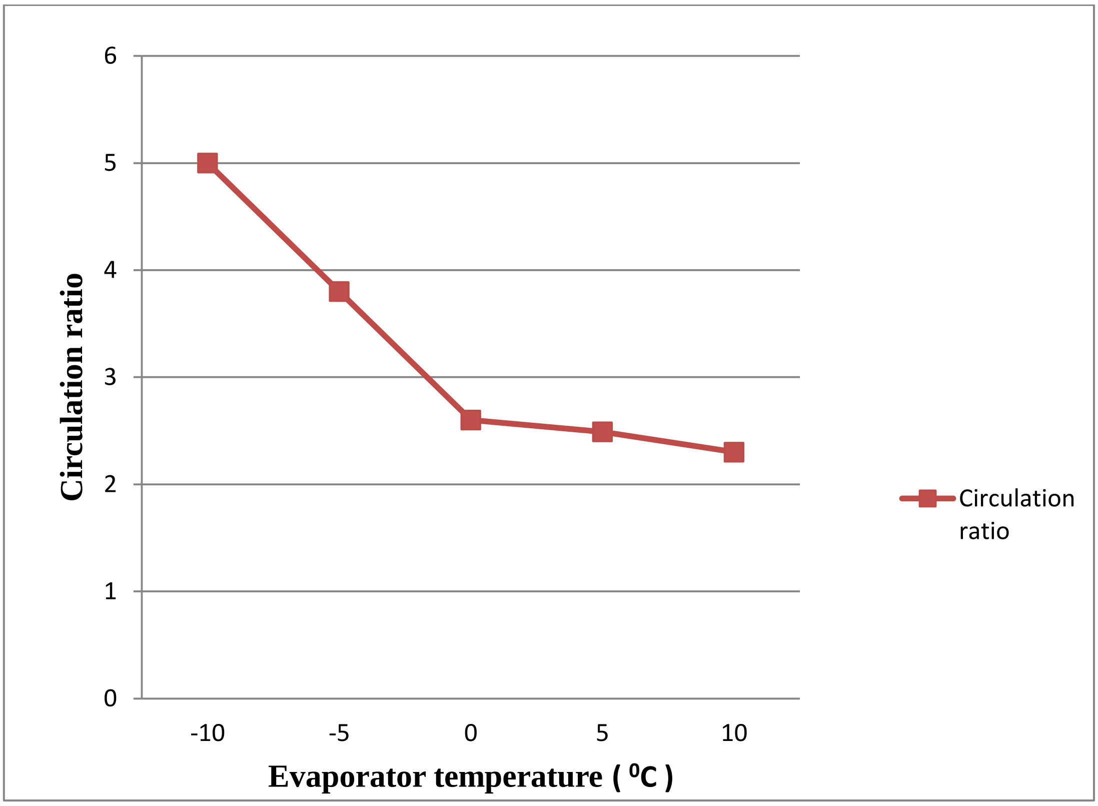

Figure 6.8 Circulation Ratio vs Evaporator Temperature

From figure 6.5 and 6.6 it is observed that at fixed generator, absorber, evaporator temperature with decrease in condenser temperature coefficient of performance increases while circulation ratio increases with increase in condenser temperature.

In figure 6.7 and 6.8 it is observed that with increase in evaporator temperature coefficient of performance of proposed system increases whereas with the increase in evaporator temperature circulation ratio decreases.

In second law analysis, entropy generation and non dimensional entropy generation number of each component is calculated. Non dimensional entropy generation is the ratio of entropy generation in each component to the total entropy generation of the system. Figure 6.9 shows entropy generation in each component whereas figure 6.10 shows non dimensional entropy generation of each component.

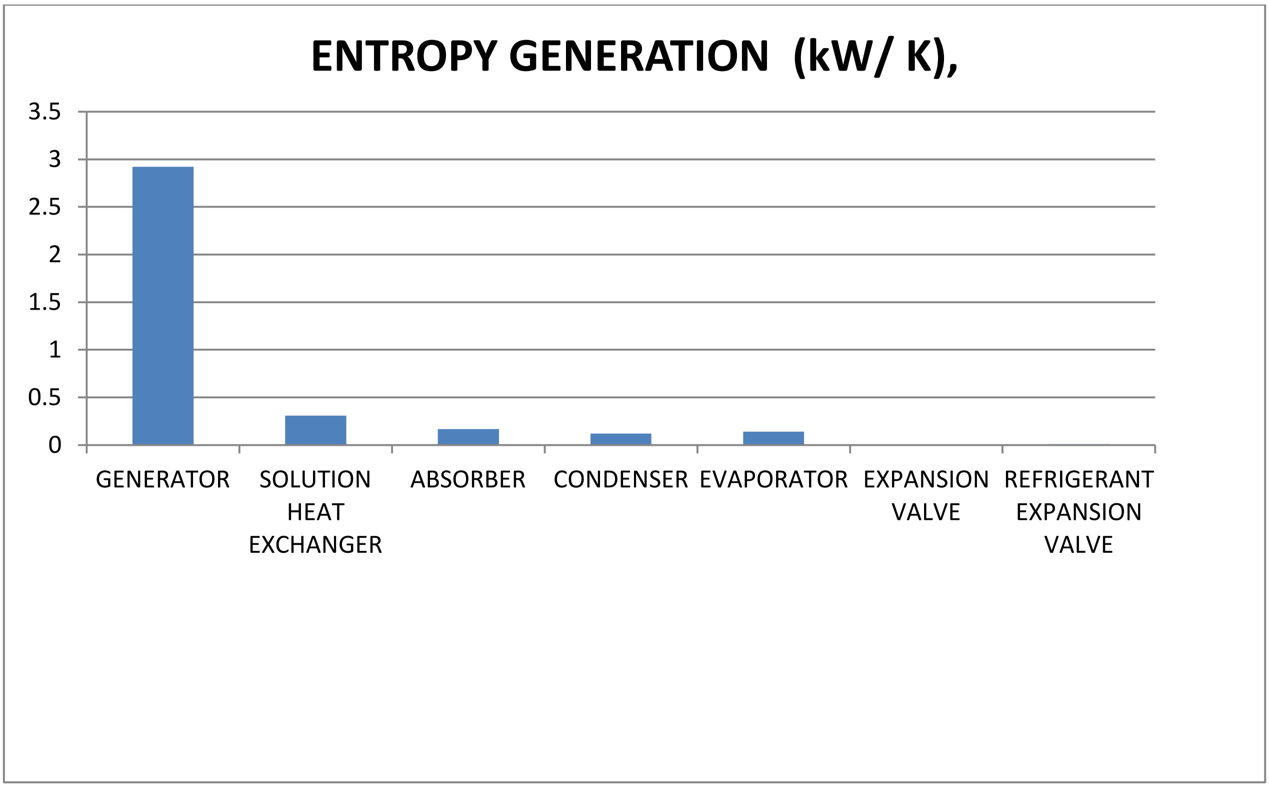

Figure 6.9 Entropy Generation

From the result it is observed that in the proposed system generator has highest entropy generation about 2.92 kW/K followed by solution heat exchanger, absorber, evaporator and condenser. The reason for large entropy generation in absorber is due to mixing of two fluids working pair and cooling stream this large temperature difference is responsible for entropy generation. Since heat transfer in pump and expansion valve is very small so entropy generation in these components are also negligible. On the other hand entropy generation number in generator is highest about 79.85%.

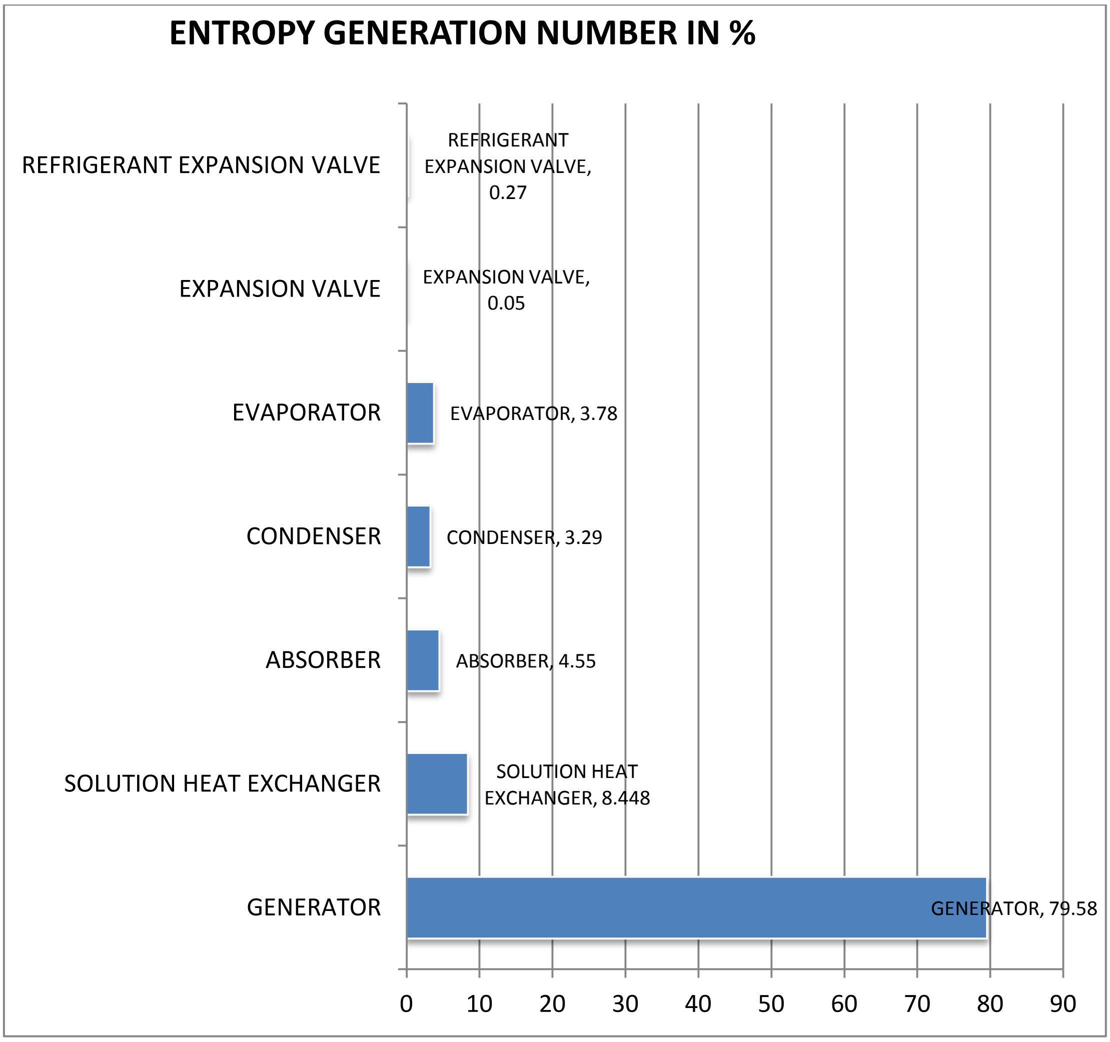

Figure 6.10 Entropy Generation Number

Thus we can say that generator and absorber plays very important role in degradation of second law. These data obtained in the analysis can be very useful in further improvement of the system performance.

From figure 6.11 it is observed that with increase in generator temperature second law efficiency decreases at fixed input parameters listed in table 5.2. This is because of large temperature differences between working pair and heating fluid, results in irreversibility and this leads to large entropy generation as a result second law efficiency decreases.

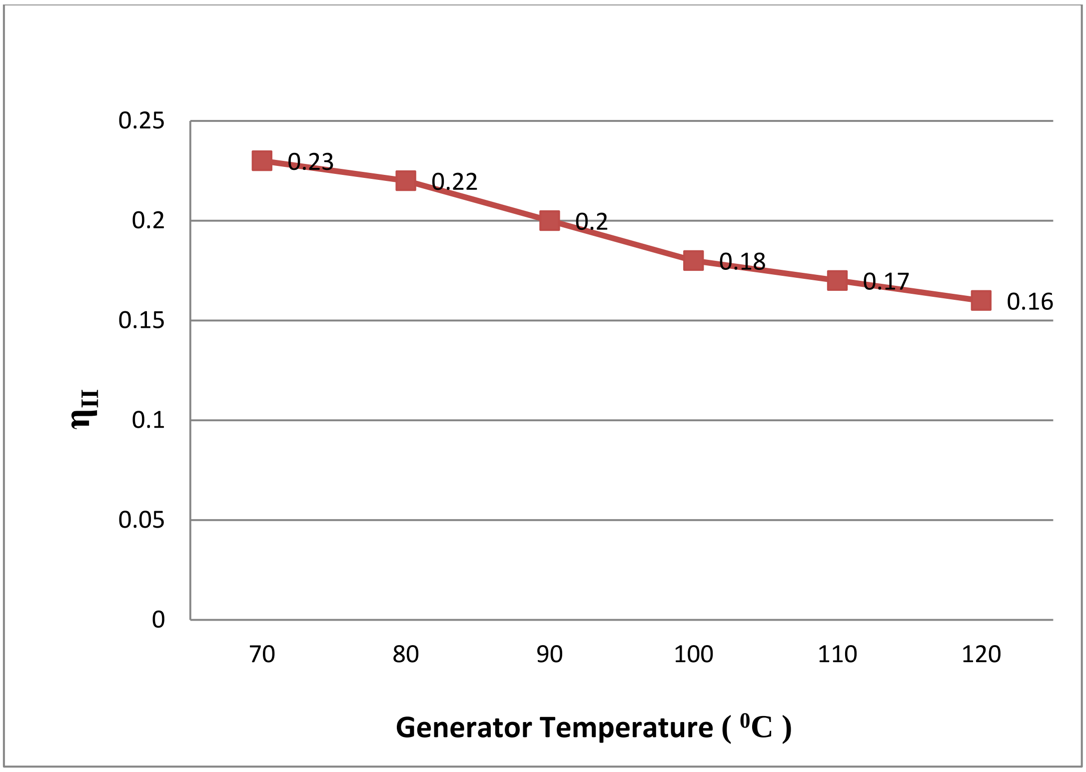

Figure 6.11 Second Law Efficiency vs Generator Temperature

From fig 6.12 it is observed that with increase in absorber temperature second law efficiency increases because of decrease in temperature difference. And from figure 6.13 it is observed that with decrease in evaporator temperature second law efficiency increases.

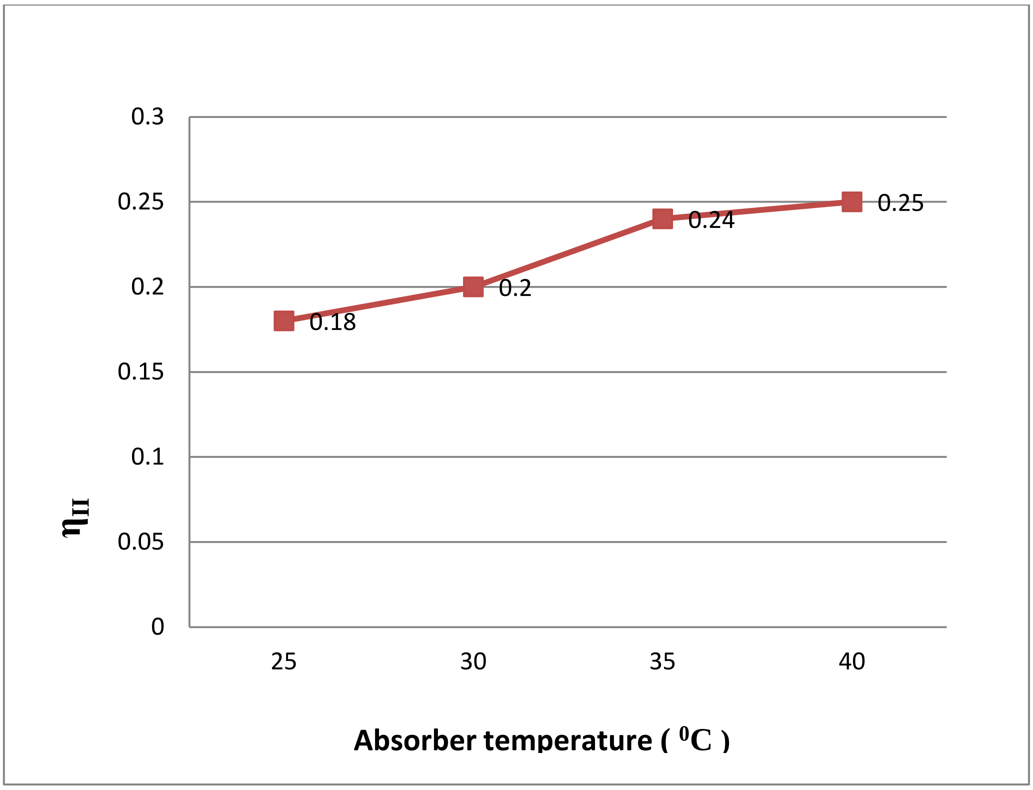

Figure 6.12 Second law Efficiency vs Absorber Temperature

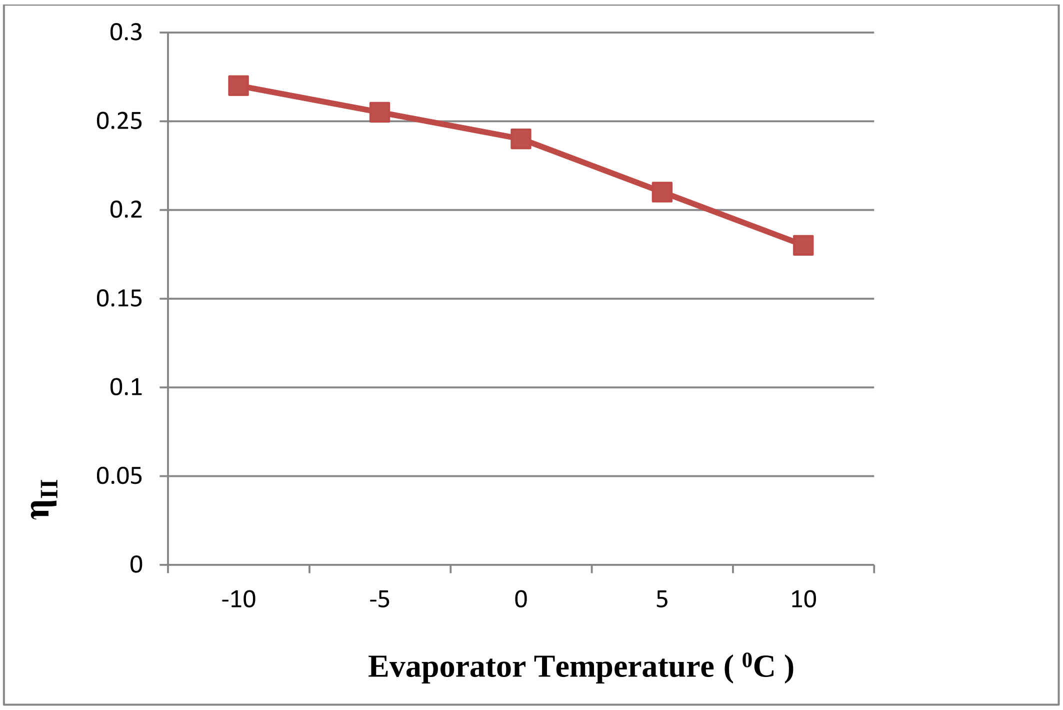

Figure 6.13 Second Law Efficiency vs Evaporator Temperature

CHAPTER 7

CONCLUSION

The present study applies the first and second law of thermodynamics using constituted mathematical model to study performance of Ammonia-Water ARS, where some operating parameters are varied. The computational model of based on first and second law of thermodynamics is presented to investigate the effects of evaporator, condenser, absorber, and generator temperature on the COP and circulation ratio of the system. Solution procedures and application steps are clearly presented and results are comprehensively discussed.

- It is observed that COP of system increases with increase in generator and evaporator temperature while it decreases with increase in condenser and absorber temperature.
- Circulation ratio increases with increase in condenser and absorber temperature while it decreases with increase in generator and evaporator temperature.
- Maximum possible COP obtained is 0.68, when generator temperature is maintained at 100^0C, absorber and condenser temperature is 22^0C and evaporator temperature is 7^0C.
- Results shows that entropy generation in the refrigerant expansion valve, solution pump are small fractions of total entropy generation in ARS. The non dimensional in generator, absorber, SHE is very high and constitutes 96% of total entropy generation.

Since the generator has greater effect on COP and entropy generation in the system. Thus it can be clearly stated that generator is most important component of ARS.

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