THERMODYNAMIC ANALYSIS OF VAPOUR ABSORPTION SYSTEM USING WASTE HEAT OF GAS TURBINE PLANT WITH INTERCOOLING

A Major Thesis Submitted in Partial Fulfilment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

IN

THERMAL ENGINEERING

Submitted BY

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SESSION 2013-2016
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DECLARATION

I hereby declare that the work which being presented in the major thesis entitled "**THERMODYNAMIC ANALYSIS OF VAPOUR ABSORPTION SYSTEM USING WASTE HEAT OF GAS TURBINE PLANT WITH INTERCO-OLING "**in the partial fulfilment for the award of the degree of Master of Technology in **"Thermal Engineering"** submitted to Delhi Technological University (Formerly Delhi College of Engineering), is an authentic record of my own work carried out under the supervision of **Dr. R.S MISHRA , Sh. N.A ANSARI** Department of Mechanical Engineering , Delhi Technological University (Formerly Delhi College of Engineering).

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CERTIFICATE

This is to certify that **MAYANK AGARWAL(ROLL NO 2K13/THE/25)**, student of M.Tech, THERMAL ENGINEERING, Delhi Technological University, has submitted the dissertation titled **"THERMODYNAMIC ANALYSIS OF VAPOUR ABSORPTION SYSTEM USING WASTE HEAT OF GAS TURBINE PLANT WITH INTERCOOLING "** under our guidance towards the partial fulfilment of the requirements for the award of the degree of Master of Technology under our guidance and supervision.

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# ACKNOWLEDGEMENT

I do not have words for expressing my sincere appreciation and gratitude to my supervisors **Prof. (Dr.) R.S MISHRA, and Shri. N.A ANSARI Assistant Professor DTU, who helped me to do project work on thermal Engineering** for invaluable inspiration, guidance and continuous encouragement throughout this project work.

I am thankful to **Prof.(Dr.)Vipin** who helped me also provided me moral support at each point.

I also thankful to my family members for suggestions and continuous support during my M.Tech work.

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ABSTRACT

It is rightly been said that necessity is mother of invention same scenario is here in power sector which is in demand for some changes to fulfil the hunger of increasing demand of increasing population , to cater the requirement there are two method either to opt for advance technology or go for optimum use of present resources which could be made possible by reducing the losses , it can be curbed at small level like switching off appliances when not in use , at large scale it can be done my making modification in the present cycle used for power production.

In present work "**thermodynamic analysis of vapour absorption system using waste heat of gas turbine plant with intercooling**" attention is paid to reduce the work input of gas turbine plant in auxiliary equipment, mostly in air compressor by reducing the work input through intercooling and utilising same heat energy for useful purpose using vapour absorption system.

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- w = work done
- v = specific volume
- V = volume
- P = pressure
- T = temperature
- S = entropy
- s= specific entropy
- C = concentration
- c= specific heat
- h = enthalpy
- Q = heat
- COP = coefficient of performance
- VAR = vapour absorption system
- VCR = vapour compression system
- K = kelvin
- (η) = second law efficiency

LIST OF SUFFIX USED

- P = pressure
- V = volume
- Pc = specific heat of cold fluid at constant pressure
- Ph = specific heat of hot fluid at constant pressure
- r = refrigerant
- ws = weak solution
- ss = strong solution
- t_g = temperature of generator
- t_c = condenser temperature
- t_e = evaporator temperature

Chapter 1

INTRODUCTION

1. SYSTEM DESCRIPTION

In this work attention is drawn towards use of better technology and methods to use the energy resources, we have both conventional and non conventional sources in nature which fulfil our day to day needs. We are being a human being always search for better resources and technology. Which could make ours life simple and comfortable, for this we are totally dependent on machine, consuming power and its consumption is increasing day by day. It is also stated and verified by our scientist and scholars that no machine can run without consuming power. Otherwise it would be perpetual machine, second thing no machine can convert energy input into usable form 100% . Presently gas turbine plants solar powered plants are gaining importance Because they are using the clean source of raw material as well raw material Availability is al-so there as both work on renewable resources ,natural gas and Sunlight. Here gas power cycle thermodynamic study is done with modification in intercooling technique used until.

1.1 GAS POWER PLANT

In gas power plant “Brayton cycle” is used for power production. In this there are four fundamental process which completes a cycle. It includes different process as shown in figure 1.1.

Process1 . Compression of gas isentropically.

Process 2. Combustion of fuel and supplying the heat to gas at constant pressure

Process 3. Expansion of gas in turbine isentropically.

Process 4. Exhaust of gases of low grade energy to atmosphere.

All these process are can be accompanied in two ways. Either in closed cycle or in open cycle. In closed cycle same fluid is circulated again heat addition and heat rejection process is carried out with the help of heat exchanger.

LAYOUT OF GAS TURBINE POWER PLANT WORKING UNDER BRAYTON CYCLE

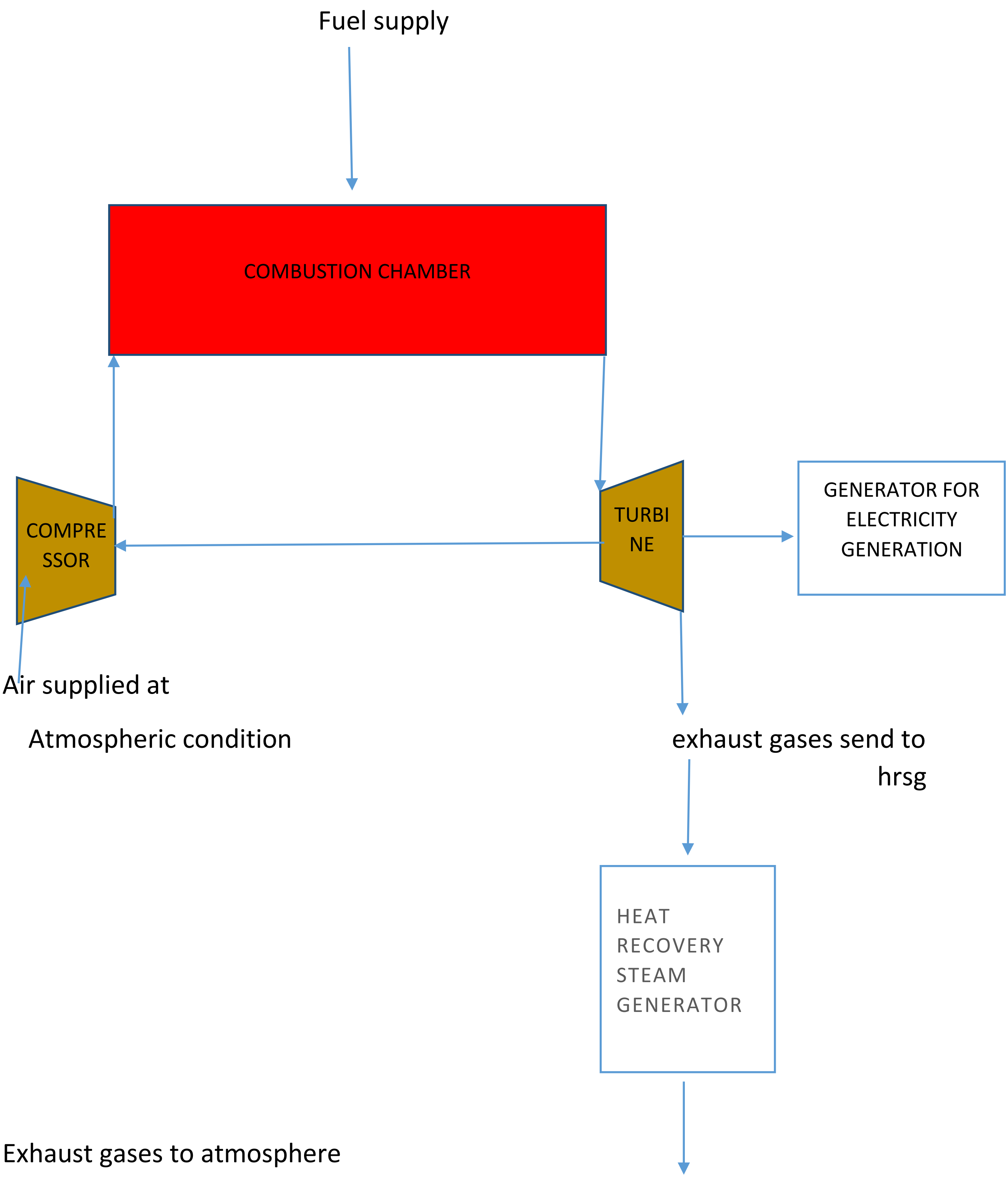


Fig-1.1 Layout of Gas turbine Power Plant working under Brayton cycle [20]

1.2 INTERCOOLING PROCESS

Intercooler are used for absorbing heat generated during the compression process. These are heat exchanger device which uses water, air or any other coolant as the heat carrier of hot gases coming out of compression process.

The main aim of intercooler is reducing the work of compressor which is given as

$$W=h_2 - h_1 = v\ dp$$

Where compressor work depends upon specific volume of working fluid lesser is the volume lesser would be the work supplied to the compressor.

Intercooling process is done with the help of intercooler which is placed between the stages , it removes the moisture when placed at end of compression process and these cooler are called aftercooler but these does not fulfil our requirement of reduction in work input.

Heat exchangers used in intercooling process is mainly of two type parallel flow and counter flow , but selection of Heat exchanger for a particular process depends up-on its effectiveness which in turn depend upon area of contact between two fluids and temperature difference between two fluid.

In this work intercooler has been replaced with the heat exchanger called generator which fulfil two functions simultaneously, firstly extracting waste heat of the compressor to reduce the temperature of air going for second stage compression as well as utilising the same heat to heat the strong solution coming out of absorber to separate pure refrigerant and absorbent.

1.3 VAPOUR ABSORPTION SYTEM OF REFRIGERATION

Refrigeration and air-conditioning is a application of thermodynamics in which comfort is provided to human being as well it aims at protecting the perishable goods at varying environmental temperatures.

Refrigeration is practiced from very early period when we use to store water in earthen pots, in which water at the boundary of pots is evaporated by the surrounding air, the water which evaporates takes the heat of water present in the pot and thus cooling effect is seen .

Today we are facilitated with mechanical refrigeration system which use mechanical energy to carried out refrigeration effect as it includes evaporator, condenser, compressor/pump, expansion device. In vapour absorption system which found lesser application to those of vapour compression system we use low grade energy resources to that of other refrigeration device in this we use generator, pump, absorber working with heat which is low grade energy heat against the compressor which uses high grade mechanical energy.

Refrigeration effect producing capability of a machine is defined with the help of term called coefficient of performance , in heat engine it is termed as efficiency. It is given as ratio of desired effect to work input/ heat input. Difference in vapour compression system and vapour absorption system is shown in table 1.1.

Table 1.1 Difference between VCRS & VARS[22]

VAPOUR COMPRESSION SYSTEM (VCRS)	VAPOUR ABSORPTION SYSTEM (VARS)
COFFECIENT OF PERFORMANCE= DESIRED EFFECT/WORK INPUT TO COMPRESSOR	COEFFECIENT OF PERFORMANCE= DESIRED EFFECT/ HEAT SUPPLIED TO GENERATOR
It uses compressor for creating pressure difference	It uses heat energy and variation of concentration as driving force between evaporator and absorber

1.4 COMPRESSOR

Compressor used in power plant are air compressor as compressed air is having a large no of applications in power plant for example burning of fuel in combustion chamber by providing dense air, for circulating crushed coal in thermal power plants. Compressor takes definite quantity of air/gas and compress and deliver it to desired pressure. It is classified based on method of compression either as a reciprocating and rotary, it may be also classified based on compression stages either single stage or multistage.

In this work aim is to reduce the compressor work compression process through compression work through intercooling [22,21] but instead of direct use of intercooler heat is supplied to the generator of the vapour absorption refrigeration system.

Compression process P-V diagram for single stage compression is depicted in figure 1.2 in this diagram area under the curve represent the amount of work done on the compressor the more the area the more is the work done on the compressor.

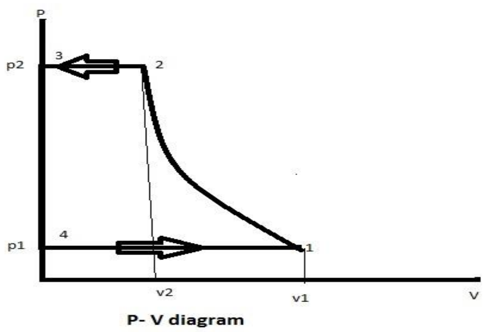


Fig-1.2 Compression process P-V diagram [21]

1.5 TURBINES

Turbines used in gas power plant are more compact in operation to those of turbines used in thermal power plant the difference is that energy to the working substance usually air or gas is supplied within the turbine , it is a combination combustion chamber and expansion part, combustion is provided by burning of fuel supplied through nozzles at varying angle to bring out complete combustion and reduce the exergy losses. But gas turbine have lower efficiencies to those steam turbines .

Gas turbines are classified in two ways based on combustion carried out:

1. constant pressure combustion

2. constant volume combustion

Gas turbine can be run with different types of fuel . it can be run on solid, liquid and gaseous fuel, but it runs more effectively on gaseous fuel like natural gas liquid fuel used for gas turbine are mainly petroleum product which posses proper volatility and calorific value. For the case of solid fuel we uses pulverised coal .

In this work gas turbine under study is working on gaseous fuel and different process occurring in power plant as shown in figure 1.3 with the help of T-S diagram, in this expansion process is shown with the line ‚3-4, for reversible process and ‚3-4’, for irreversible process.

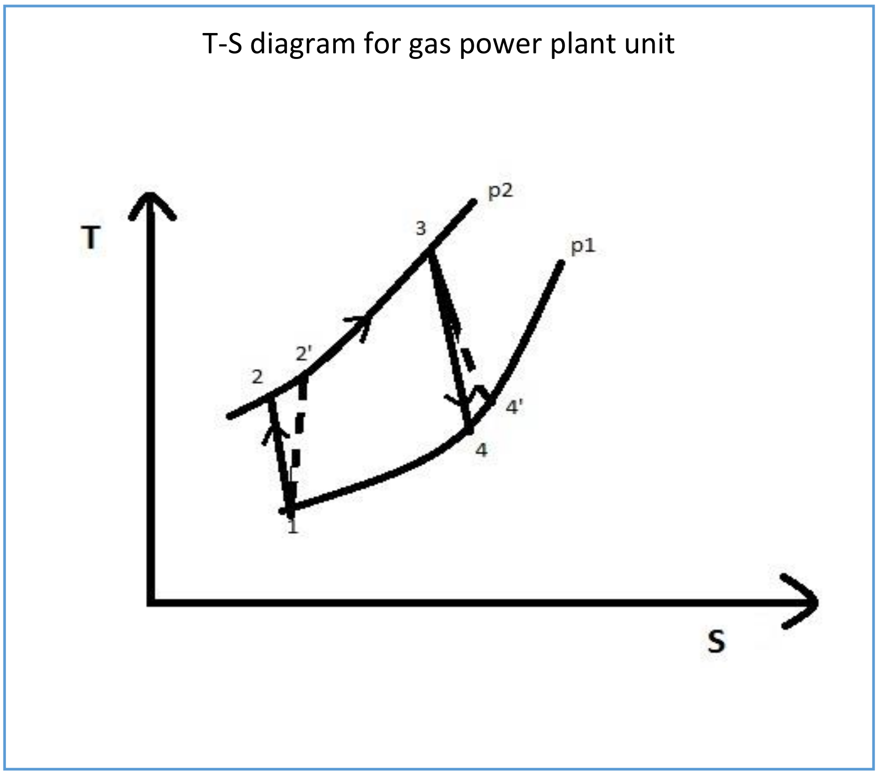


Fig-1.3 T-S diagram of gas power plant unit showing different process[20]

1.6 HEAT EXCHANGER

Heat exchanger is a mechanical equipment which provide the surface for heat transfer between two flowing fluids. Heat exchanger can be classified on different basis, depending upon the direction of fluid flow that is parallel flow, counter flow , cross flow. Another method for differentiating heat exchanger are area of contact of two fluid , whether they are in direct contact or separated from one another.

Analysis of Heat Exchanger :

Performance of heat exchanger is based on various parameters like:

1. "U"= overall heat transfer coffiecient.
2. The total surface area of heat transfer.
3. Inlet and Outlet temperature of fluid.

Heat released by the hot fluid = $m_h *c_{ph} *(t_{h1}-t_{h2})$

Heat gained by the cold fluid = $m_c*c_{pc}*(tc_2-tc_1)$

Total heat transfer in heat exchanger = $U*A*\theta_m$

m   = Logarithmic mean temperature difference.

A = Effective Heat transfer area

U =overall heat transfer coefficient between two fluids

1.7 Expansion Valve

Expansion valve used in refrigeration and air conditioners are the devices which circulates correct mass through the evaporator according to the load of cooling it also reduce the pressure from condenser pressure to the pressure at which evaporator is working.

There are five different type of expansion device:

1. Capillary tube
2. Float Type
   - 2.1 High side float
   - 2.2 Low side float
3. Expansion Valve operated electronically
4. Automatic Expansion Valve
5. Thermostatic Expansion Valve.

The figure 1.4 shows the automatic expansion valve used in vapour compression system in this refrigerant coming from condenser is passed through the strainer followed by an orifice whose opening is adjusted with help of adjustment spring .

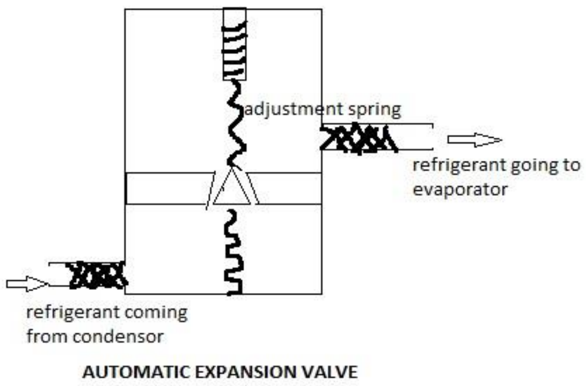


Fig-1.4 Automatic Expansion Valve [22]

1.8 ABSORBER

Absorber is a mixing chamber in which hot weak solution coming out of generator mix with the vapour of pure ammonia coming out of evaporator and mix adiabatically. Heat of solution formed, can be negative or positive is taken from or released to the atmosphere.

Thermodynamic relation for absorber;

$m_1+m_2=m_3$

$m_1h_1+m_2h_2=m_3h_3$

$m_1C_1+m_2C_2=m_3C_3$

Absorber used in vapour absorption system is shown in figure 1.5 representing stream of pure refrigerant shown with parameters m_1,h_1,c_1 and weak solution entering with parameters m_2,h_2,c_2 ,strong solution leaving the absorber m_3,h_3,c_3 .

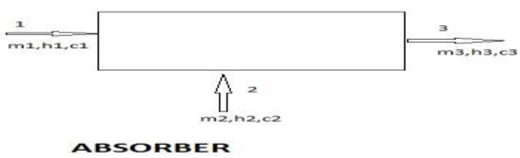


Fig-1.5 Absorber Used in absorption system [22]

1.9 CONDENSER

Condenser is also a heat exchanger which is used to change the state of the one liquid by absorbing its latent heat in condenser two process takes place one is de-superheating of the liquid followed by condensation of saturated liquid. The heat is rejected either to air or water directly with the help of cooling towers. There are different type of condenser these are:

1. air cooled
   1.1 forced flow air cooled
   1.2 free flow air cooled
2. water cooled
3. evaporative condenser.

Heat rejection ratio = heat rejected in condenser/ heat absorbed in absorber.

So condenser affect the coefficient of performance of the refrigerating machine. in this work counter flow heat exchanger is opted for better results.

Equations of condenser

$M_r *(h_{incoming\ refrigerant} - h_{outgoing}) = U_{condenser} *$ area of contact $* \Delta T_{logarithmic\ for\ condenser}$

1.10 Evaporator

Evaporator is also a type of heat exchanger in which refrigerant boils and absorb heat of the substance which is required to be cooled. It is termed so because the refrigerant undergoes evaporation process in the heat exchanger. Refrigerant in the evaporator produce cooling effect either by forced convection or free convection. In forced convection the substance to be cooled is forcefully passed over the cooled surface with the help of fan. In free convection fluid flow is seen due to density difference.

Evaporators can also be differentiated on basis of flow of refrigerant inside or outside tubes. In case of natural convection refrigerant is forced to flow in tubes and air to be cooled flow over it as in case of window air conditioners.

Equation of evaporator

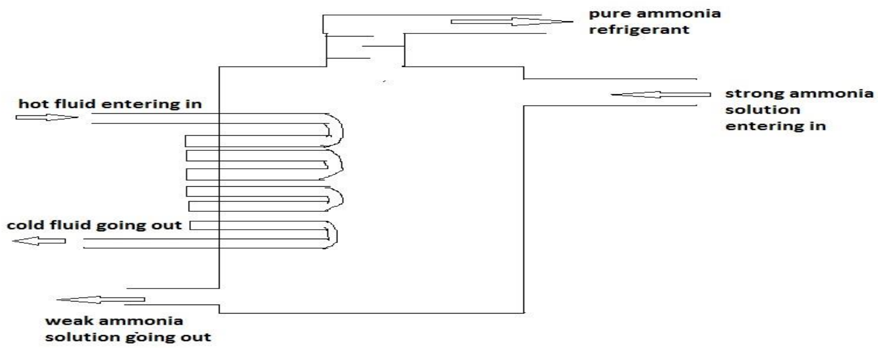
M_r*($h_{saturatedliquid} - h_{saturatedvapour}$) = cooling load (heat supplied from atmosphere)

In this work evaporator used for two type of loading one is refrigeration when analysis is done with help of vapour absorption system using ammonia water solution where waste heat is used for purpose of refrigeration purpose and other is for air conditioning purpose when lithium bromide double effect system is used.

1.11 GENERATOR

Generator is a special mechanical equipment used in vapour absorption refrigeration system in which there are two process occurring simultaneously. Firstly it act as fractionating chamber where strong solution of ammonia coming from absorber passing through pump separate into strong solution of ammonia and weak solution of ammonia water solution which is send back to the evaporator after passing through the pressure reducing valve. Secondly it act as a heat exchanger where low grade waste heat is supplied to it through external source like solar, biogas, waste heat of automobile, waste heat of sugar industry etc.

The pictorial view of generator used is shown in figure 1.6 which shows that different path of entering and leaving, it shows that strong solution entering the generator from one side and weak solution leaving the other, ammonia refrigerant vapour being lighter escape from top of generator after passing through analyser. The heat is supplied for heating of strong solution from the compressed air of the compressor as shown below.



GENERATOR USED IN VAPOUR ABSORPTION SYSTEM

Fig-1.6 Generator used [22]

Equation of generator

Mass balance : $M_{ws} + M_r = M_{ss}$

Net heat supplied to generator $Q_{generaor} = M_{ws}*h_{ws}+ M_rh_r - M_{ss}*h_{ss}$

In generator heat transfer between hot fluid which is supplying its waste heat to the strong solution coming from absorber through both modes of sensible and latent heat transfer for generator overall heat transfer coefficient lies in range of 1600-2300 W/m^2 K.

Chapter -2

LITERATURE REVIEW

2.1 LITERATURE

K.Cheung et al.[1] carried out Performance assessment for multistage absorption cycles of 11 multistage multi-effect absorption cycles which include water lithium bromide, ammonia water and their cascade configurations, increment in no of stages is done by them to increases the no of absorption cycle and by increasing the effect they made maximum use of available energy from a stage, in this work evaluation is made for air conditioning applications with the help of energy balance and mass balance across each component taking temperature of evaporator to be 4°C and temperature of condenser 35°C. A no of cycle 8 in no were selected for a detailed simulation. The result shows that highest COP was obtained for approach temperature of 0°C in which three stage water lithium bromide cycle was cascaded with two single stage ammonia water cycle.

J. M.GORDON et al[2]conducted a design and analysis of a general thermodynamic model for absorption chiller, in this they derive the relation to show the effect on coefficient of performance due to varying cooling rates. Model analysis results are compared with performance data of already published works and found model analysis was useful when chiller performance and coefficient of performance of chiller varies with time.

GUANGMING CHEN et al [3]carried out evaluation of a refrigeration cycle working on solar energy as well as electricity further to improve efficiency of combined cycle principle of a heat transformer is applied because solar energy can only be fruitful if it is continuously available so for this thermal reservoir is required but here a source of electricity is used in place of it when solar energy is not available. A thermodynamic model was formed and with help of computer program its performance is evaluated. Present work COP, and parameters were compared with those of traditional vapour absorption system. Which shows that present work overcome shortcoming of currently running vapour absorption system.

I. Horuz[4] did theoretical study on performance comparison between water ammonia and lithium bromide water based vapour absorption system the study include the comparison of system using two different refrigerants that is lithium bromide water and ammonia water solution and parameters COP , the cooling capacity and other parameters are studied and concluded that ammonia water solution is less efficient than lithium bromide water solution but it is free from effect of crystallization.

M. Talbi et al[5] conducted theoretical study of energy recovery from exhaust gases of diesel engine for air conditioning and its effect on performance. Earlier the exhaust from such resources have been utilized for combined heat and power applications here in this work performance of four different configuration of a turbocharger diesel engine and absorption refrigeration unit is studied. They examines the interfacing of Vapour Absorption Refrigeration system with diesel engine and estimate the performance enhancement. It is found that pre-intercooled turbocharger engine configuration cycle offers considerable benefits.

Paul Kalinowskia,et al.[6] did study for application of vapour absorption which is used for waste heat recovery from low temperature in the LNG recovery process. They found Liquefied natural gas recovery process require low temperature cooling which commonly uses vapour compression system but due to high power consumption it is substituted by vapour absorption system which is powered by waste heat of electric power generating gas turbine reducing overall energy consumption. In their study a potential replacement of propane chillers with absorption refrigeration was analysed and found that single effect ammonia water vapour absorption system could replace propane chillers.

M.Engler et al.[7] carried out a simulation and comparative investigation of ammonia water absorption cycle for heat pump applications. They found that in residential and small commercial ammonia water cycle can be used for winter heating and summer cooling throughout the year with better COP then other alternatives. Several cycle were analysed from a single effect generator absorber heat exchange with variations. Their objective was a comprehensive study of various ammonia water cycles, with varying operating conditions and varying design parameters for comparing their performance by starting from single effect system to varying its components and analysing effect of each component which showed COP has increased from 0.5 to 1.08.

DA-WEN SUN [8] carried out performance comparison of the ammonia water and ammonia sodium thiocyanate and NH_3 –$LiNO_3$ absorption refrigeration system. he compared the three on the basis of air conditioning application where he found that ammonia water solution can be replaced with the above two mentioned substitutes with the help of a computer program.

Also he found performance of sodium thiocyanate was better than other two.

André Aleixo Manzela et al. [9] did experimental study for vapour absorption system using engine exhaust gas as energy source. In their work they represented experimental study of the exhaust gas energy availability and the effect of absorption system on the engine performance, the exhaust emissions and the power economy of the vehicle. For this they tested a productive automotive engine in bench test dynamometer and absorption system connected at the exhaust pipe. They tested engine at varying opening of a throttle valve that is 25%, 50% and 75% respectively. The refrigerator reached a steady state after operating for 3 hours, but it depends upon engine throttle valve opening. Results showed that Addition of vapour system reduced the carbon monoxide emission but it increases the emission of hydrocarbons.

Shenyi Wu et al.[10] carried out experimental study that can be seen in vapour absorption cycle. In their work they opt for multistage multi effect vapour absorption system compared to those of single effect and double effect, in this multi stage they use generator at high pressure after double effect to run the double effect system with the moto to utilize input heat three times to improves the efficiency.

R. Fathi et al.[11] carried out study of an irreversible model of solar operated absorption refrigerator. General solar refrigerator uses the solar collector and refrigeration system and operates between two limits that is maximum COP and providing maximum cooling capacity. They work for a new system in which not only irreversible effect due to heat conduction would be considered but also friction, eddy and other effects would be analysed, as these affect the working of absorption system when it operates continuously. They derived the analytical relations of the optimal refrigeration COP and maximum cooling capacity of the system. Also comparison was made with the earlier results of single stage absorption system. They obtained results which describe the optimal performance of varying temperature values to 4 different level thus absorption refrigeration affected by irreversibility.

Jose´ Ferna´ndez-Seara et al [12] carried out mathematical analysis of crucial matter of water effect in ammonia water absorption system of refrigeration effect with flooded evaporators. They analysed the effect of the ammonia purification and liquid entrainment and blowdown from evaporator, for this they developed mathematical model based on single stage vapour absorption system with complete condensation. For the purification of ammonia analysis is done through murphee efficiencies of the stripping and rectifying sections of distillation column.

M. Mostafavi, B. Agnewt [13] carried out thermodynamic analysis of diesel cycle combined with absorption refrigeration unit for naturally aspirated diesel engine. The analysis was made on the basis of laws of thermodynamics which help to formulate mathematical relations amongst net work, the exhaust gas temperature of the diesel engine as a function of pressure ratio and temperature ratio of the cycle. These relations helped in calculations of magnitude of thermal energy available and the amount of thermal energy required for running of vapour absorption system. The variations in work output of diesel engine and its efficiency at different configurations as a function of cycle pressure are given and a diagram has also been plotted for cooling capacity required for air conditioning purpose.

Alberto Vales et al. [14] did design and modelling for heat recovery from trawler chiller fishing vessels to run an on board ammonia water absorption system. In this synthetic oil was used as a heat transfer medium and worked in closed cycle as it is recirculated. It used two heat exchangers fluid to solution heat exchanger and gas to fluid heat exchanger. Modelling is done and verified using computer programs, these help in study of influence of geometric design parameters and thermal operating condition on the heat exchanger and thermal performance of system.

Ahmed Ouadha et al· [15]carried out the study based on thermodynamic parameters for integrated ammonia water absorption refrigeration system and marine diesel engine. In their study they found marine diesel engine utilises only 48% of the energy supplied rest was released to atmosphere as a waste to water which is used as an coolant now they integrate the diesel engine with vapour absorption refrigeration system to utilize this waste energy also reducing load on coolant.

S.S.Mathapati1 et al.[16] carried out study on vapour absorption system using LiBr-water solution for air conditioning of the automobile using the waste heat of same automobile which was earlier going into waste in the atmosphere. They did mathematical modelling for the utilization of the exhaust coming out of the internal combustion engine. Cooling load of the vehicle is estimated and feasible study is carried out for calculating energy available in exhaust gas of the automobile.

K.BALAJI et al.[17] carried out study on utilising waste heat of sugar industry in their study through use of vapour absorption system. They work with the aim to reduce the dependence of industries on fossil fuels as fuel price is increasing day by day by exploiting maximum to its waste exhaust, as in sugar industry turbine exhaust carry a large amount of waste heat. This amount of energy which was earlier going in waste now employed to run the vapour absorption system using LiBr-water solution in single effect and describe various parts of vapour absorption system.

V.K.Bajpai[18] carried out design and analysis of solar operated vapour absorption system. In his work he aim to produce the cooling effect in which he opt for both vapour compression system and vapour absorption system but found that vapour absorption system to be better alternative because of low power consumption as well as lesser moving parts. Then he calculated the parameters required for solar panel to fulfil the heat requirement of the generator.

Ketan Bhore et al. [19] did designing for experimental analysis of heat recovery using Vapour Absorption system of waste heat of internal combustion engine. They have opted for ammonia water solution for waste heat recovery and utilising this system for the air conditioning process.

2.2 Conclusions from literature Review

After going through rich literature it is found that the vapour absorption system has been a topic of research from very early period because of increasing dependence on fossil fuels and reduction in fossil reserves day by day, also cycle and process presently used such as vapour compression system for refrigeration, rankine cycle in power plants, Brayton cycle in gas power plants, internal combust-ion engine of automobile all of these uses high grade of energy and due to irreversibility in the process they reject large amount of heat which is discharged in the atmosphere as a part of low grade energy.

Also second law statement given by kelvin-planck and clausius also emphasis that no heat engine or machine can produce power by consuming 100% of the available energy. Also to maximum energy can be obtained from the energy source when it reaches its dead state according to the availability postulates. For day to day process surrounding environment is supposed to be the dead state but the energy carrying fluid which leave the device is not at dead state and posses some amount of thermal energy, kinetic energy and pressure energy, many device had been invented by our great scholar till date like organic rankine cycle which work on the principle of rankine cycle but uses organic fluid like R134a for waste heat recovery from the cycle, it is mostly used as bottom cycle coupled with rankine cycle which is used as top cycle in combined cycle plant. In present work waste heat recovery is done for the purpose of air conditioning and refrigeration which is in present demand because the device presently in use are vapour absorption system single stage, cascaded vapour absorption system which make use of compressor, consuming large amount of power. So to reduce the power consumption in our day to day life and increasing efficient use of present resources and reducing wastage, air conditioning and refrigeration process is carried out with the help of vapour absorption system.

2.3 Research Gap Identified

In terms of gap identified, all the cycle studied and analysed till date worked mostly with LiBr-H_2O solution , also till now no one worked for gas turbine power plant waste heat recovery using vapour absorption system though models have been formulated with the organic rankine cycle using as a bottoming cycle in waste heat recovery accompanied with heat recovery steam generator.

2.4 Objective of Project Work

The main objective of this work is to utilize waste heat of gas turbine plant for the purpose of providing human comfort using vapour absorption system, and to reduce the thermal load on the atmosphere which was due to use of water as a coolant in thermal and gas plant which releases waste heat to ponds and atmosphere.

Chapter -3

THERMODYNAMIC STUDY OF GAS POWER CYCLE

3.1 Gas Power cycle

Gas power plant have got rich history in electricity generation from gas turbine was carried out using natural gas in early 1930/1940 in Switzerland with the output of 4 megawatts then reheat gas turbine was developed in 1945 with a world record of 10 MW with increasing its capacity to 40 MW in Switzerland. Then development in gas power production increases just like fire in forest. In1961 the first combined cycle plant began operation in Austria. Its generative capacity was 75MW after that gas power plant working on combined cycle increased exponentially. One reason seen was that of its greater efficiency and lower emission then any other plant.

Gas power plant is a compact in working to that of thermal plant because it accommodate compressor, combustion chamber and turbine in a single part. Combustion and expansion process is assumed to be isentropic and work on fundamental law of expansion and compression

$$PV^N = \text{constant}$$

Where N= varies from 0 to 1.4 for air

Here air is reference because gas power cycle woks on atmospheric air as a working which is supplied energy through burning of fuel , natural gas is used as fuel in gas power plant.

In this work the above relation is not taken into consideration for compression and expansion process. Because it work on an assumption that specific heat is constant for air with varying temperature, but in actual practice specific heat of air vary with temperature, also compression process is always accompanied with change in temperature of air between two states.

For isentropic process in which specific heat varies with the temperature then for that case

$$P_1/P_2 = P_{relative1}/P_{relative2}$$

$$P_{\text{relative }1} = \text{exponential}\ (s_1/R)$$

After compression fluid that is air in compressed form pass to air pre heater it is also a type of heat exchanger in which heat of exhaust gases leaving the turbine is utilized to preheat the air this preheated air is passed through combustion chamber where by burning of fuel which is mostly gaseous fuel (natural gas) , chemical energy is changed to heat energy in the presence of the dense air. So this high pressure and kinetic energy carrying gas impinges the turbine fixed and moving blades arranged alternatively. Thus passing over the blade of the turbine the pressure energy of gas is transformed to kinetic energy imparted to the rotor also kinetic energy of the gas is delivered to the rotor of the turbine.

3.2 T-S diagram of gas power cycle

T-S diagram for gas power plant working cycle is shown in figure 3.1 showing the process occurring in the gas power cycle. In this diagram process 1-2 represent the isentropic compression process followed by isobaric heat addition process 2-3 at this point gas is taken out from turbine and send for reheating process 4-5 after reheating of gas it is again impinged on the blades of turbines , reheating is mainly done to remove moisture attack on the blades of turbine which is due to condensation of gas (gas contains water vapour after process of combustion as a by-product) . After leaving reheater it is expanded isentropically during process 5-6. In T-S diagram it is clearly shown that work of expansion is more to that of work of compression and at last exhaust gas is released in atmosphere for open cycle and in case of closed cycle it reach at its original state.

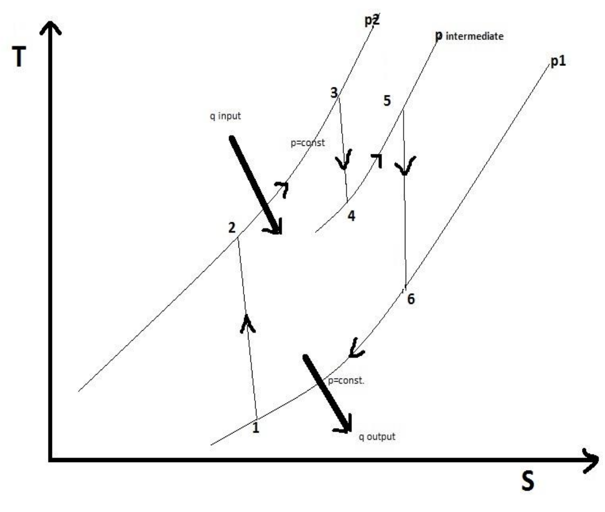


Fig-3.1 T-S diagram for gas power plant[21]

3.3 Intercooling

Intercooling is a process of heat transfer from hot fluid coming out of first stage of compression to the fluid which circulates the heat absorbed and released in atmosphere. Intercooling is required for compression process for reduction in compressor work and increase the overall work output of the cycle because a large portion of turbine work goes in compression process. Heat rejection in intermediate stages of compression is beneficial with use of intercooler but use of aftercooler is not required to fulfil any purpose.

Intercooling is done to reduce the specific volume of the fluid, as with increase in pressure temperature of fluid also increases due to which its specific volume increases significantly and compressor has to handle a large volume of fluid thus increasing the overall work input. For pressure regulated devices such as pressure hammer, pressure regulated valve, compression is carried out in single stage and there is no need for intercooling, whereas for axial compressor used in gas turbine compression is done for a large amount of fluid which is circulated per second so in this case intercooling is done. The cooling Process is isobaric process that is it takes place at constant pressure, and the gas is cooled to the initial temperature at each stage of intercooling. Multistage compression with intercooling is especially attractive when a gas is to be compressed to very high pressures.

In the P-V diagram and T-s diagram drawn below shows the effect of intercooling on work done on the compressor, in this air is taken at inlet condition of pressure p_1 and temperature t1 and undergoes to compression process thereby attaining pressure p_x and temperature t2. So to minimize the work done expression for work done equated to zero and this results in intermediate pressure;

$P_x = (P_1*P_2)$^0.5

The temperature of the fluid is reduced to initial condition as that of the inlet to calculate the minimum work done.

3.4 T-S diagram and P-V diagram for intercooling

In figure 3.2 T-S diagram is shown in which process 1-2 which was earlier following straight line follows zig-zag path showing that at intermediate pressure fluid temperature is reduced to its initial value

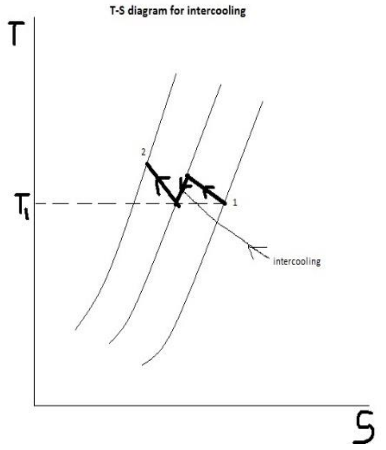


Fig-3.2 T-S diagram for Intercooling[21]

The P-V diagram showing compression process following polytropic process with and without intercooling is depicted in figure 3.3 it shows this shows that area under the curve is reduced when the process is followed by intercooling as in P-V diagram area under the curve gives the amount of work done on compressor and it is our aim in this work to reduce the work done.

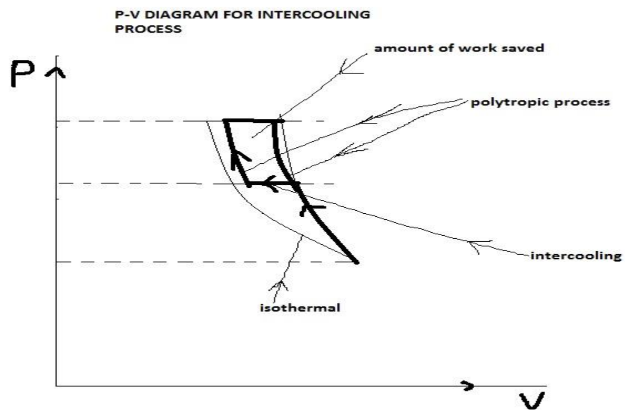


Fig-3.3 P-V diagram for intercooling process[21]

3.5 Entropy

Entropy measure the degree of randomness, for a process entropy is always associated and entropy change of isolated system is always positive. Entropy concept was originated from the clausius inequality which is given as;

$$\oint \frac{\delta Q}{T} \leq 0$$

In which equality sign is for reversible process and inequality for irreversible process. Entropy change is always equal to net transfer for a process across the boundary to the temperature of boundary. A process is said to be carried out when there is change in state of system from one state to another. Entropy change can be calculated for both reversible and irreversible process for irreversible process entropy change is equated to that of entropy change for reversible process if both the process are carried out at same end states hence entropy is property which depend on the states not on the path followed.

But for reversible process also there need some relation between heat transfer and temperature at the system boundary, some relation are ;

$dQ_{int\ rev} = T*dS$

$Q_{int\ rev} = T*(S_2-S_1)$

$dQ_{intrev} = dU + PdV$ (for reversible work)

$T*dS = dU + PdV$

$dS = (dU/T) + (PdV/T)$------------------------(1

Also,

$dH = dU+PdV+VdP$

$dH = T*dS + VdP$

$T*dS = dH – VdP$

$dS = (dH/T) – (VdP/T)$-----------------------------(2

3.6 Air Properties

Properties of air utilised in this work are taken from thermodynamic table 3.1 with initial condition of air at temperature of 300K and 1bar pressure

Table-3.1 Air properties

Temperature in degree Celsius	Enthalpy in KJ/Kg	Relative pressure P_r	Entropy s^0
300	300.19	1.3860	1.70203
400	400.98	3.806	1.99194
410	411.12	4.153	2.01699

Chapter-4

THERMODYNAMIC STUDY OF VAPOUR ABSORPTION CYCLE

4.1 Vapour Absorption cycle

Vapour absorption system was developed by a French scientist to overcome shortcoming of vapour compression system in which compressor is used to extract the vapour from the evaporator and compress the large volume of the vapour, so the vapour absorption system was invented which uses heat energy instead of work for producing high COP. Vapour absorption system work on a principle of chemistry " like dissolve like" in which some liquids which have great affinity of absorbing large quantity of vapours and converting their state from vapour to liquid, reducing their volume significantly.

A vapour absorption system is a heat operated device in which the refrigerant is continuously absorbed and liberated from the absorbent. In absorption system refrigerant is absorbed by the weak solution of refrigerant in water which is coming out of generator. This weak solution absorb the vapours of ammonia and hence lowers the pressure in the absorber to absorb more and more refrigerant, absorption of ammonia refrigerant by weak solution is exothermic process so some cooling is also provided to increase cooling capacity.

This strong solution formed in the absorber is pumped to the generator with the help of a pump, which is then heated by some external means to remove the refrigerant vapours, these vapours passed to the condenser where it is converted to a high pressure liquid ammonia then this ammonia pass through throttle valve to the evaporator where it absorb heat of substance to be cooled in form of latent heat of vaporization and produce the required cooling effect.

But in addition to above process there is need for some auxiliaries to increase the efficiency of the system and make it economical it includes analyser, a rectifier and two heat exchangers. Such that vapour generated in the generator contains some amount of water vapour in addition to ammonia refrigerant which would choke the flow passage in the condenser, in order to remove these vapours rectifier is used. Before reaching the rectifier it is passed through analyser where removal of water takes place in analyser vapours of ammonia are brought in contact to the aqua richest in ammonia and by cooling the vapour with water as a coolant.

<u>Analysis of aqua-ammonia using concentration chart and tables</u>

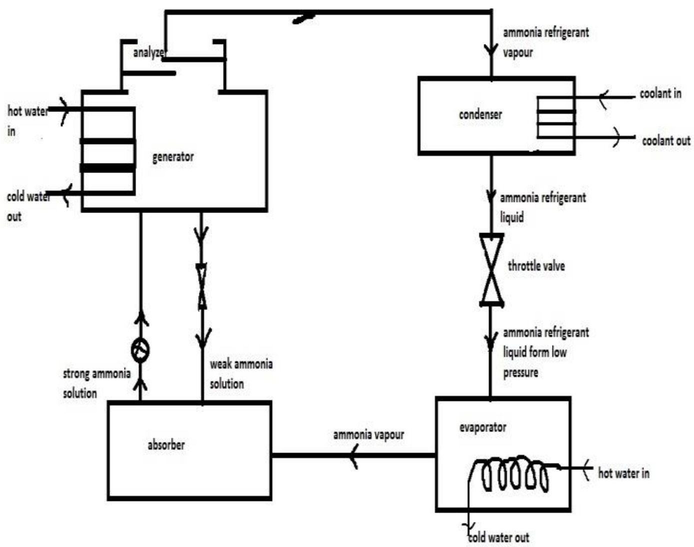
As in this work aqua ammonia absorption system is being used for waste heat recovery. So for design and analyses it is necessary to represent the process on the concentration enthalpy chart, for design 1st parameter to be selected is the temperature and pressure of condenser and evaporator. In present work water is taken as a coolant in condenser at a temperature of 25^{0}C so for this saturation temperature pressure to be calculated as 10 bar.

In evaporator considering condition of positive pressure and protecting from condition of vacuum pressure is assumed to be 1 bar and for this saturation pressure temperature for "R717" found to be -33^0 C. secondly for heat load estimation from gas plant it is found that refrigeration effect of 14 TR is required in evaporator so for these values calculation is done.

In this work analysis is done with the help of tables generated from the (Ziegler and Trepp,1984; Patek, 1995; Xu and Goswami, 1999 and Alamdari, (2007)correlations solution made available by "Shankar Ganesh, N" in his phd work.

4.2 Flow chart of vapour absorption system

The figure 4.1 shows the flow chart of single effect vapour absorption system following the path of ammonia refrigerant passing through different components like evaporater, condenser, generator, pump, analysis is started with condition of condenser and evaporater load.



<u>Fig-4.1Vapour Absorption System flow chart [22]</u>

4.3 Relative pressure

Entropy as defined in above discussion shows that it is function of internal energy and enthalpy, internal energy is a function of specific heat at constant volume and temperature similarly enthalpy is a function of specific heat at constant pressure and temperature. It is the property of specific heat that it vary with temperature so with variation in temperature specific heat would also vary and thus entropy which is dependent factor of both internal energy and enthalpy would vary with temperature so entropy is analysed in two ways .

Entropy change for constant specific heat

$$s_2 - s_1 = c_{v,avg} \ln(t_2/t_1) + R \ln(v_2/v_1)$$

$$s_2 - s_1 = c_{p,avg} \ln(t_2/t_1) - R \ln(p_2/p_1)$$

Entropy change for variable specific heat

$$s_2 - s_1 = s^0{}_2 - s^0{}_1 - R \ln(p_2/p_1)$$

where $s^0{}_1$= entropy with respect to zero degree reference temperature

for isentropic process $s_2 - s_1 = 0$;

and thus

$$p_2/p_1 = \exp(s^0{}_2 - s^0{}_1 / R)$$

$$p_2/p_1 = \exp(s^0{}_2 / R) / \exp(s^0{}_1 / R)$$

$$\exp(s^0{}_2 / R) = p_{rel,1}$$

$$\exp(s^0{}_1 / R) = p_{rel,2}$$

$p_{rel,1}$= relative pressure at 1st state

$p_{rel,2}$= relative pressure at 2nd stage

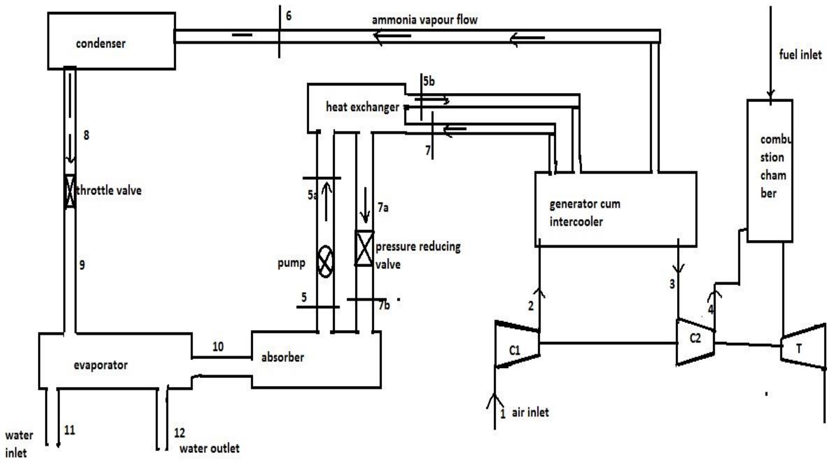
4.4 Calculation Work

Assumptions made;

1. steady state condition.
2. friction in pipes is neglected
3. compression process is carried out at entropy change zero
4. pure refrigerant is flowing through condenser and evaporator in vapour absorption system
5. effectiveness of heat exchangers used is 100%
6. mass flow rate is unity in gas turbine operation

With the help of figure 4.2 analysis is done

it is seen that gas power plant is operating without intercooling process with following conditions



<u>Fig-4.2 Pictorial representation of used ammonia VAR system[22]</u>

Assuming air is taken from atmosphere which is available at temperature of 298k and at this value enthalpy of the air is calculated with the help of table which is 298.18kj/kg. in this work assuming compression is taken to be isentropic as mentioned above also taking condition of variation of specific heat with the temperature so for this condition, using concept of relative pressure in which condition at another state is calculated as follows, definition of relative pressure is already made in chapter 3 of this work.

$P_{relative1} = r*P_{relative\ 2}$

Where r = pressure ratio for compression process it is taken from 6-20 for optimum values of operation . in this work compression ratio taken is 8.

$P_{relative1} = 1.3543$

So $P_{relative2} = 8 * 1.3543$

For this value of $P_{relative2} = 10.834$

Temperature and enthalpy is found with the help of interpolation

Temperature = 536k

Enthalpy= 540.51 kj/kg

So

<u>work done for this process = enthalpy after compression – enthalpy at inlet of compression process</u>

(formula is valid with assumption of unit mass flow rate of air and flow work in open system as mentioned in introduction earlier)

Work done = 540.51-298.18

= 242.33 kJ/kg

Case 2nd as this done in this work with modification of present cycle and shown in figure -4.2 in case intercooling process is carried out for compression process so calculation of work input in this case is given as;

Intermediate pressure for compression process is given as , $P_{intermediate}$= (P_{inlet}*P_{outlet})*0.5

Work supplied to compressor = 2* work supplied in single stage

But P_{outlet} / P_{inlet}= 8 ;

So

$P_{intermediate}$ / P_{inlet}= 8^0.5

$P_{relative\ intermediate}$= (8^0.5)*1.3543 = 3.8305

For this value of intermediate pressure $T_{intermediate}$ and $h_{intermediate}$ is calculated

$T_{intermediate}$ = 400.69k

$h_{intermediate}$= 401.60kJ/kg

workdone = 2*($h_{intermediate}$- h_{inlet}) = 2*103.4

= 206.8 kJ/kg

Amount of heat rejected = mass flow rate of air* Cp*change in temperature

= 1*1.005*(400.69-298)

= 103.20 kJ/kg

Calculations for vapour absorption system For absorption system calculation is started from condenser liquid and temperature of the coolant in this work water has been taken as a condenser coolant which is available at a temperature of 25^0C so for this temperature pressure is taken to be 10 bar From figure -4.2 above at point 6 with condition of pure ammonia refrigerant vapour with quality 100% enthalpy is given by

H_6= 1480 kJ/ kg ("from EES software after defining parameters")

Point 8 in fig-4.2 shows the condition of pure ammonia refrigerant in liquid which loses its latent heat in the condenser to the water flowing through it. So enthalpy at condenser outlet is;

H_8= 316.8 kJ/kg

Point 9 is the state of the refrigerant after passing through throttle valve.so enthalpy at this point is

H_9= 316.8

After that it passes through the evaporator and absorb the heat of substance to be cooled and change itself from liquid to vapour state by absorbing heat in form of latent heat.

H_{10}= 1418 kJ/kg

For the calculation of mass flow rate of ammonia refrigerant in the evaporator assuming refrigerant load of 14TR.with the given heat input at generator

So for producing refrigeration effect of 14TR amount of refrigerant circulated is

$M_{ammonia}$* (h_{10}-h_9) = 14TR

$M_{ammonia}$= 0.0447 kg/s

= 0.45kg/s

Temperature of air at inlet of generator which is supplying heat to the generator is 127.54^0C

The concentration of weak solution leaving generator is calculated with the use of tables and chart given in the references.

Using method of interpolation at 10 bar pressure, with taking values of temperature at different concentration using enthalpy concentration chart

So from method of interpolation it is found that value of concentration; that is X=0.186

Now calculation of concentration of strong ammonia solution leaving the absorber is found as follows

Concentration of strong solution = concentration of weak solution + gassifying factor

Gassifying factor in this work = 0.044

So concentration of strong solution is given = 0.186+0.044 = 0.23

From table and chart and with interpolation enthalpy at this values found to be =355.637 kJ/kg = h_5 =h_{5a}

In figure-4.2 it is found at point 5 solution is strong solution whose enthalpy is calculated using chart and tables at pressure of 1 bar which is evaporator pressure at which it is maintained as mentioned earlier in the previous discussion .From point 5 strong solution pass through the pump at a higher pressure with condition of 5a. but enthalpy at this point is same to that of point 5.Similarly enthalpy of weak solution leaving the generator h_7= 423.36 using chart and tables.

Heat given by the generator is;

Overall mass balance for absorber

$M_{ammonia}$+ M_{7b}= M_5;

Ammonia mass balance for the absorber

$M_{ammonia}$+ (0.186) M_{7b}= 0.23* M_5

Heat supplied to the generator, M_{5b}* h_{5b} + Qg = M_{7b}*h_7 + M_6*h_6

4.5 Analysis of system using lithium bromide absorption system

In above method coefficient of performance of vapour absorption system was found low using single effect vapour absorption system using ammonia water solution so work is further done with the recovery of waste heat of system using vapour absorption system with lithium bromide in double effect operating mode using ees software with the following pictorial representation.

In figure 4.3 analysis made using double effect lithium bromide system is shown, this figure shows that waste heat of intercooling in compression process is going in high pressure generator of double effect VAR system, it helped in analysing the problem and solving the problem using software, in the software programming was done starting with evaporator and various input parameters used was waste heat gas temperature, evaporator pressure, evaporator working temperature & temperature of condenser.

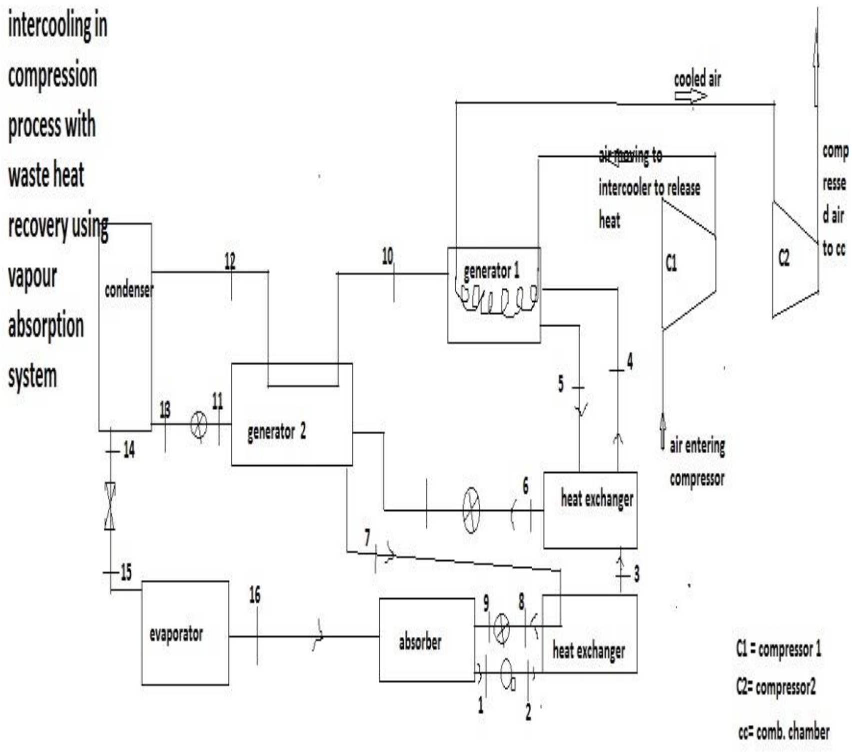


Fig-4.3 Combined cycle with intercooling using liBr-H2O VARs [22]

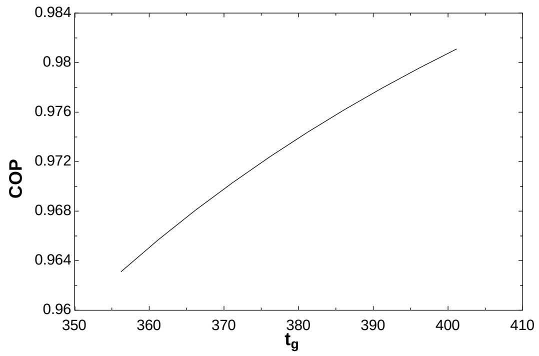
Chapter -5

RESULT AND DISCUSSION

5.1 VARIATION OF COEFFICIENT OF PERFORMANCE WITH TEMPERATURE OF GENERATOR, EVAPORATOR & CONDENSER

5.1.1 variation of COP with generator temperature

Figure 5.1 shows that COP of the double effect vapour absorption system firstly increases with generator temperature and then become constant and at higher temperature it decreases.

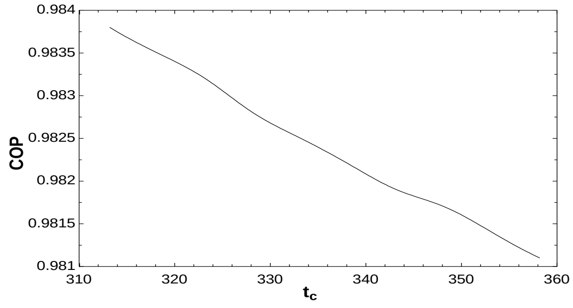


tg = generator temperature(K)

Fig-5.1 showing variation of COP with generator temperature

5.1.2 Variation of COP with temperature of condenser

Figure 5.2 showing variation of COP with the condenser temperature it shows that as the temperature at which heat is rejected into atmosphere increases from the present work data of 40^0 C to higher values COP of the system starts decreasing.

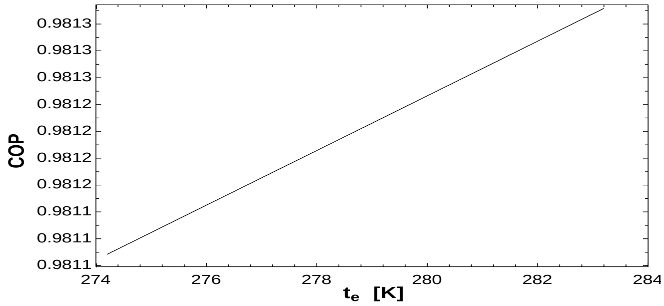


tc = condenser temperature (K)

Fig-5.2 Variation of COP with condenser temperature

5.1.3 Variation of COP with evaporator temperature

Figure 5.3 shows that with increase in temperature of the evaporator i.e the temperature at which heat is absorbed by the system increases there is simultaneous increase in the COP of the system.



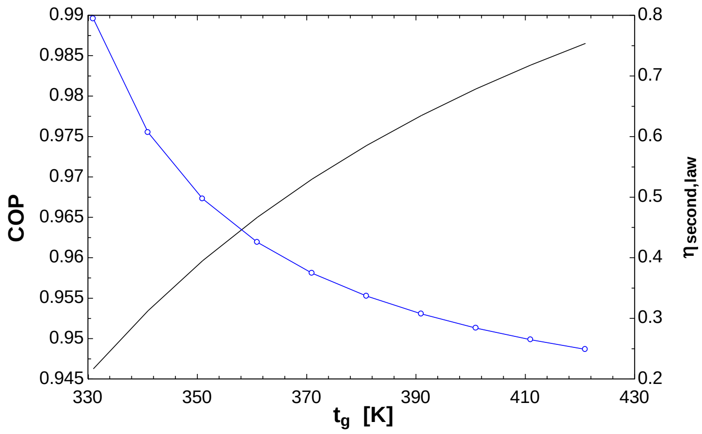
$\mathbf{t_e}$ = evaporator temperature (K)

<u>Fig-5.3 variation of COP with evaporator temperature</u>

5.2 SIMULTANEOUS EFFECT ON COEFFICIENT OF PERFORMANCE AND SECOND LAW EFFICIENCY OF THE SYSTEM DUE TO TEMPERATURE OF GENERATOR,TEMPERATURE OF EVAPORATER & TEMPERATURE OF CONDENSER

5.2.1 Effect of temperature of generator on first and second law efficiency of the system

Figure 5.4 shows that COP increases with generator temperature to a particular point then become stagnant and after that decreases where as second law efficiency of the system is more at lower temperature of generator.

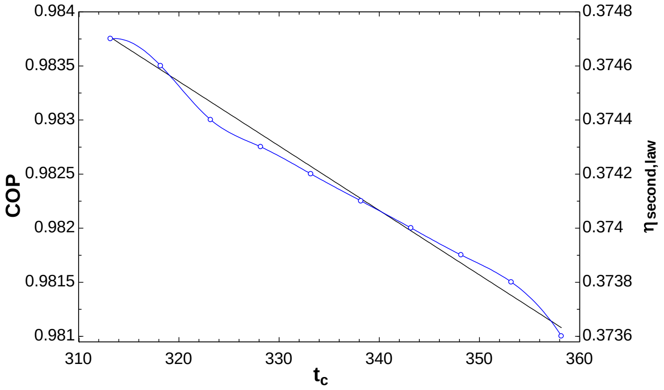


$\mathbf{t_g}$ = temperature of generator (K)

<u>Fig-5.4 variation of first law efficiency (COP) and second law efficiency (</u>η_{second}<u>) with the temperature of generator</u>

5.2.2 Effect of temperature of condenser on first and second law efficiency of the system

Figure 5.5 shows the variation of condenser temperature on COP and second law efficiency of the double effect system, showing that as the temperature at which heat is rejected to atmosphere increases it would lead to decrease in COP and second law efficiency.

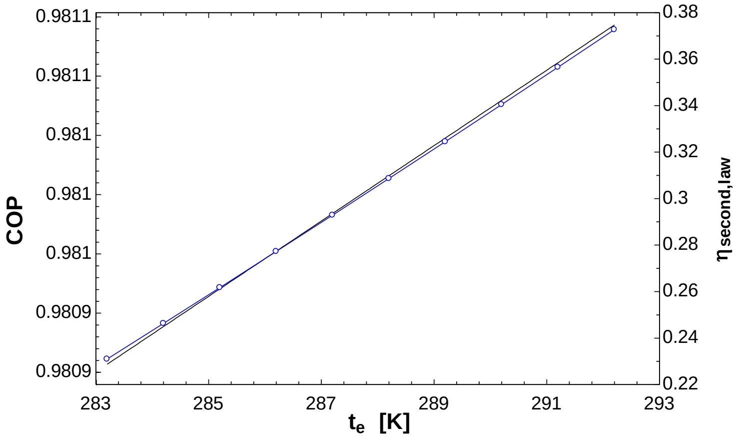


t_c = temperature of condenser (K)

<u>Fig-5.5 variation of first law efficiency and second law efficiency with temperature of condenser</u>

5.2.3 Effect of temperature of evaporator on first and second law efficiency of the system

Figure 5.6 shows effect of variation of evaporator temperature on first law efficiency(COP) and second law efficiency, showing that both first law and second efficiency increases with increase in evaporator temperature i.e more the refrigerating effect with given heat input more would be efficiency of the machine according to first and second law.



t_e = evaporator temperature (K)

<u>Fig-5.6 variation of first law and second law efficiency with evaporator temperature</u>

5.3 Tabular Representation of variation of COP, COP_{carnot} , Exergy destruction ratio, second law efficiency, generator heat and evaporator heat with temperature of generator, temperature of condenser and temperature of evaporator

This table shows that with decrease in temperature of generator first law efficiency of the system decreases where as second law efficiency increases when refrigeration load is kept same because at lower temperature exergy destruction reduces as shown in the table above.

Table-5.1 Showing variation of VAR parameters with tg

COP	**COP_{carnot}**	**EDR**	**η second law**	**Q_a (kJ/kg)**	**Q_g kJ/kg**	**R kJ/kg**	**T_g Kelvin**
0.9865	3.963	3.017	0.2489	83.06	1719	2351	421
0.9839	3.715	2.776	0.2648	83.06	1632	2351	411
0.9809	3.455	2.522	0.2839	83.06	1545	2351	401
0.9776	3.181	2.254	0.3073	83.06	1459	2351	391
0.9739	2.893	1.97	0.3367	83.06	1373	2351	381
0.9697	2.589	1.67	0.3745	83.06	1287	2351	371
0.965	2.269	1.351	0.4254	83.06	1203	2351	361
0.9596	1.93	1.011	0.4972	83.06	1119	2351	351
0.9535	1.571	0.6482	0.6067	83.06	1035	2351	341
0.9462	1.191	0.2589	0.7944	83.06	952.8	2351	331

Chapter-6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

The following conclusions can be drawn from above result

1. Temperature of generator and heat supplied to generator greatly affect the cop of performance of the system in this double effect libr water vapour absorption system accompanying two heat exchangers shows that COP increases with temperature of generator and heat supplied till a particular value of COP then decreases.

2. It shows exergy destruction ratio is less at lower temperature of generator

3. Second law efficiency of system decreases with increase in temperature of generator.

4. It shows that COP was decreasing its value from 0.981 as the temperature of condenser increase so it shows that with increase in temperature at which heat is rejected to atmosphere it will decrease system COP.

5. It was found that COP of single effect system was lesser than COP of double effect.

6. Temperature increase of condenser lead to decrease in second law efficiency.

6.2 Future work

In this work following variable are not analysed which could become part of future research

1. Exergo-economic analysis is not carried out of above system

2. The optimization using GA methods was not done .

Chapter -7

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