THERMODYNAMIC ANALYSIS OF BINARY AND KALINA POWER CYCLE USING BRINE AS THERMAL ENERGY SOURCES AND DEVELOPMENT POTENTIAL IN TATTAPANI

A

DISSERTATION

Submitted in partial fulfilment of the

requirement for the award of the degree

of

MASTER OF TECHNOLOGY

in

THERMAL ENGINEERING

By

MAHBUBUL ALAM LASKAR

Under the guidance of

Mr ARVIND KUMAR CHOUDHARY

DEPARTMENT OF MECHANICAL ENGINEERING

LOVELY PROFESSIONAL UNIVERSITY

PHAGWARA, PUNJAB (INDIA) – 144402

YEAR: 2015

CANDIDATE'S DECLARATION

I hereby certify that the work which is presented in this dissertation entitled, **"THERMODYNAMIC ANALYSIS OF BINARY AND KALINA POWER CYCLE USING BRINE AS THERMAL ENERGY SOURCES AND DEVELOPMENT POTENTIAL IN TATTAPANI"**, in partial fulfilment of the requirement for the award of the degree of Master of Technology in **"Thermal Engineering"**, submitted in **Department Of Mechanical Engineering, Lovely Professional University, Punjab** is an authentic record of my own work carried out under the supervision of **Mr Arvind Kumar Choudhary**, Assistant Professor, Department Of Mechanical Engineering, Lovely Professional University, Punjab.

I have not submitted the matter embodied in this report for award of any other degree.

Dated: 28/04/2015

Place: Phagwara **Mahbubul Alam Laskar**

CERTIFICATE

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

Mr Arvind Kumar Choudhary

Assistant Professor

Department Of Mechanical Engineering

Lovely Professional University

Phagwara, Punjab – 144402

ACKNOWLEDGEMENT

I feel very much honoured in presenting this dissertation report in such an authenticable form of sheer endurance and continual efforts of inspiring excellence from various cooperation and sincere efforts drawn from all sources of knowledge. I express my sincere gratitude to my guide, **"Mr Arvind Kumar Choudhary"** Assistant Professor, Department Of Mechanical Engineering, Lovely Professional University, Punjab, for his valuable guidance and infilling support for the completion of the dissertation work.

I am also grateful to all others faculty members and staffs of Department Of Mechanical Engineering, Lovely Professional University, Punjab.

I extend my thanks to all my classmates and research scholars who have given their full cooperation and valuable suggestion for fulfilment of my capstone report.

Dated: 28/04/2015

Place: Phagwara

Mahbubul Alam Laskar

Regn. No. 11007942

Section: M2013

ABSTRACT

This report presents thermodynamic analysis of Tattapani geothermal field, which is the most promising geothermal field located on Son-Narmada lineament in Central India. Thermodynamic analysis was done considering binary power cycle and kalina cycle. Net power output, net power output per kg of geothermal water, thermal efficiency were calculated for brine inlet temperature. The calculations were made for different brine temperature i.e. 110^{o}C, 100^{o}C, 90^{o}C as well as for different evaporator output temperature i.e. 90^{o}C, 80^{o}C, 70^{o}C.This report also tries to investigate the effect of refrigerant on net power output and efficiency for both binary and kalina cycle. Refrigerant considered for the binary cycle are R134a, R600a, R245fa and R123, which were selected on the basis of high critical temperature, high latent heat, high density, low freezing point. Results shows that the net power output, net power output per kg of geothermal water and thermal efficiency is maximum for R134a. For kalina cycle binary mixture i.e. ammonia-water mixture is used for the analysis of kalina cycle using a concentration ratio of 0.7 on the turbine input. The result shows that the approximate maximum power output is 4.2 MW.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 ENERGY

As per the first law of thermodynamics which states that “Energy can neither be created nor be destroyed it can only be transformed from one form to another”. For example for generating electricity there are lot of energy transformation, such as coal having chemical energy coverted into heat energy which is further converted into mechanical energy by the help of turbine and finally this mechanical energy is conveted into electrical energy by help of generator.

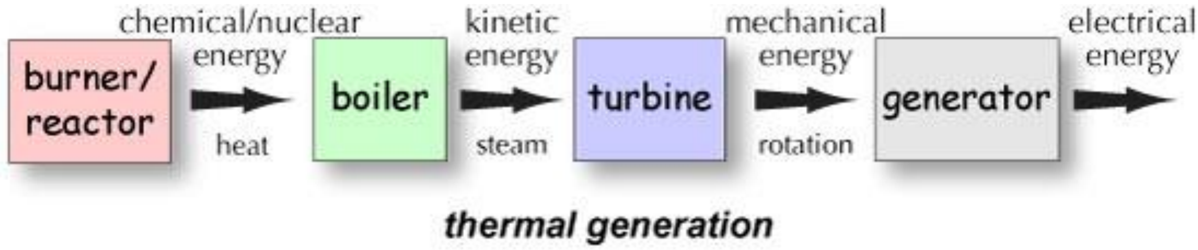


Fig 1.1 Schematic flow chart showing conversion of energy for electricity generation

There are various types of energy for e.g. chemical, electrical, mechanical, nuclear, thermal, radiant energy. These are major six kinds of energy that is part of energy system. But the sources of these energies are different and these are classified into two broad categories “renewable and non-renewable”.

1.1.1 NON-RENEWABLE ENERGY SOURCES:

Non-renewable form of energy are widely used because of the efficiency that we get from these sources are higher than the renewable energy sources.. The definition of these can be quoted as “The type of source which cannot be replenished after a certain interval of time”. Types of non-renewable energy sources are:

1. **Petroleum**: Petroleum is a source of many by product such as petrol, diesel, paraffin etc. Petroleum is also known as crude oil. The process of formation of Petroleum is when the organic matter lost its dissolved oxygen and settles in water and it is compressed for many million years under extreme heat and pressure. All the thermal engines are either based on petrol or diesel hence it’s application is wide as it gives us great output.

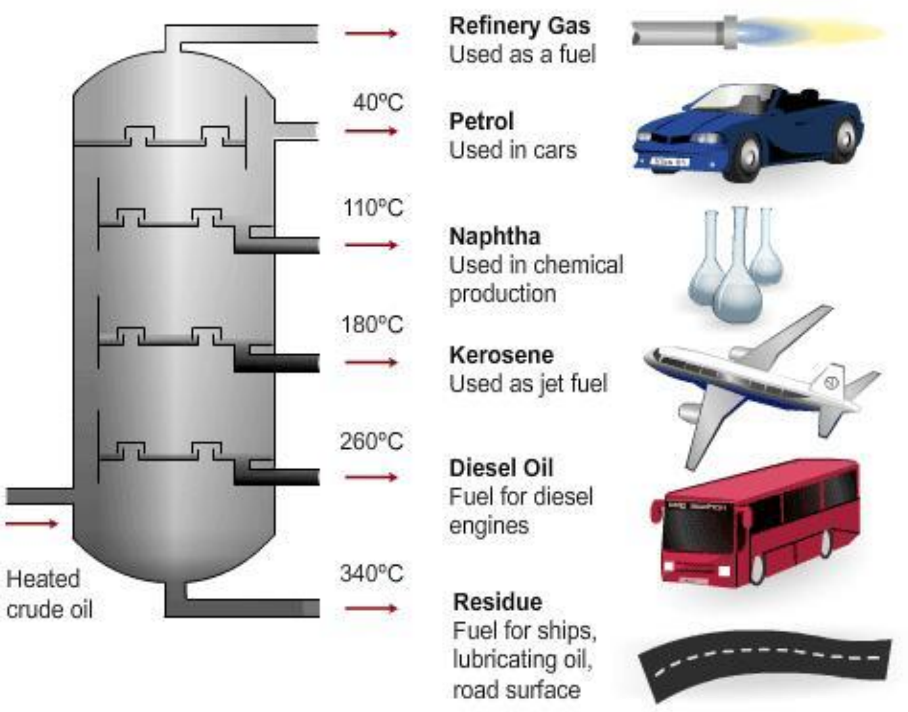


Fig 1.2 Crude oil distillation process

2. **Coal**: Coal is made by dead organic matter which are under extreme pressure for million of years. Coal has high calorific value in past all the engines where based on coal. Now in present days almost all the thermal power plant the main source of heat is coal. The main reason behind that is low cost of coal and easy availability.

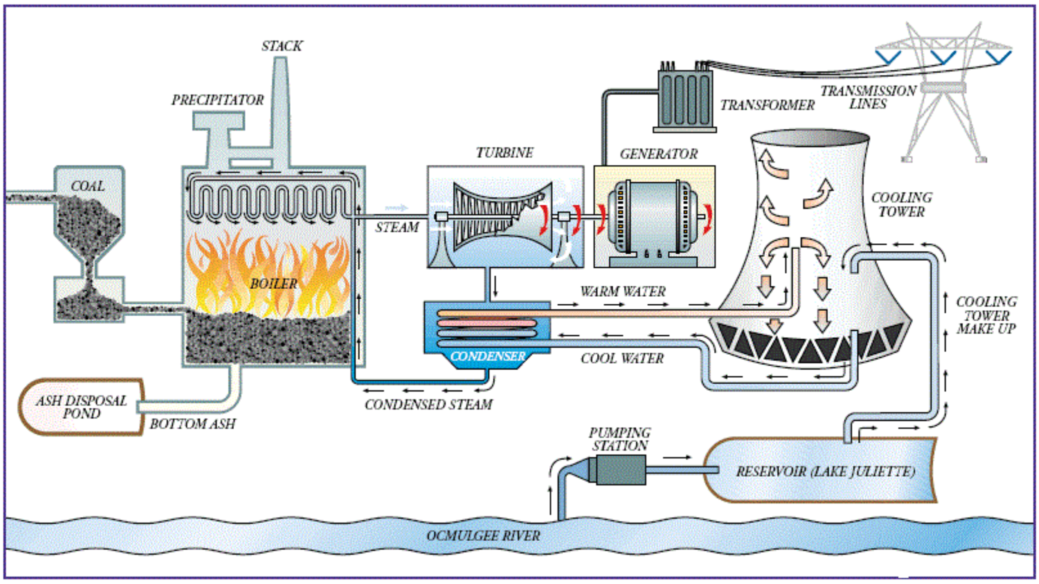


Fig 1.3 Coal power plant

3. **Natural gas**: Natural gas is found in marshy areas. It is methane which is formed from the decomposition of the organic matter.It is extracted and filtered from the organic

matter and we get the clean methane. The formation of methane also requires thousand of years. It is pollution free gas.

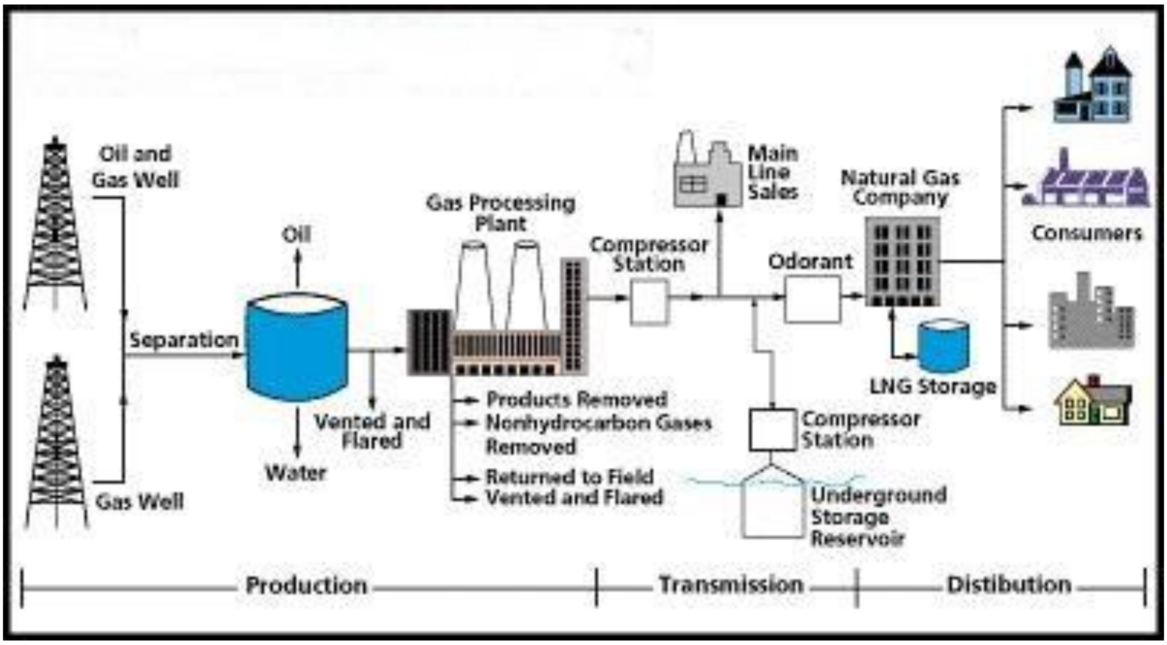


Fig 1.4 Natural gas industry

4. **Nuclear fuel**: The nuclear fuel is uranium which is being extracted and processed from underground mines. In nuclear power plant the water is converted into steam by the uranium fuel.The uranium is melted by firing and passed trough the heat exchanger which exchanges heat with water converts and converts into steam. The steam is used to rotate the turbine.

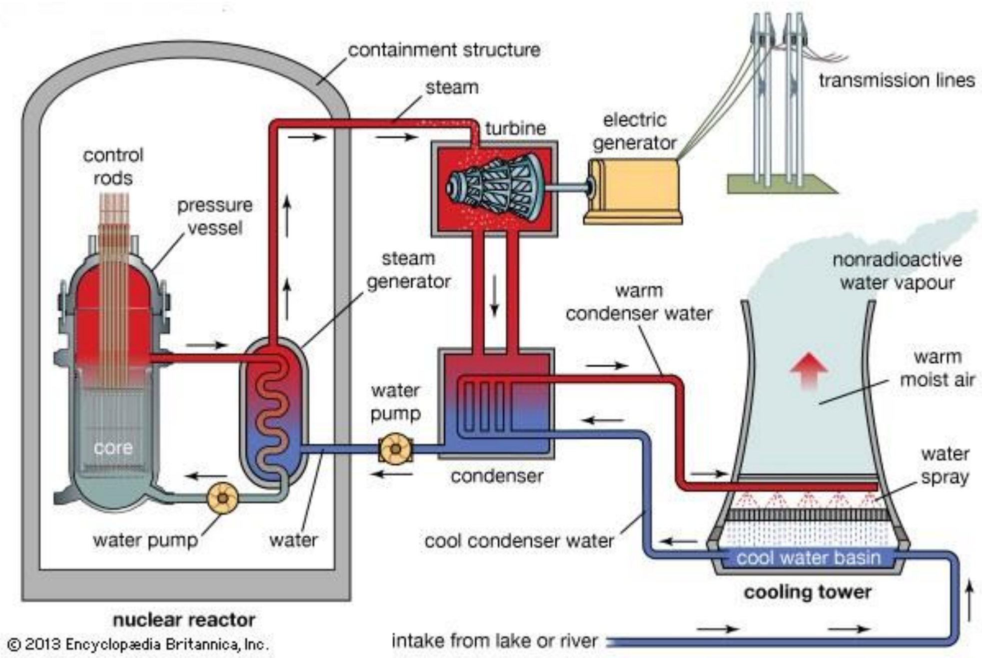


Fig 1.5 Nuclear power plant

Uranium is rarely found hence it make it's cost is very high. U238 is the pure form, which gives by product as U235.

1.1.2 RENEWABLE SOURCES OF ENERGY:

Renewable energy resources are those resources which can be replenished after a short interval of time. These has many advantages as it ecomical and environment friendly. As the non-renewable resources as depleting day by day hence scientist and researcher are concerning on renewable resources.

1. **Wind :** Wind has considerable potential as a global clean energy source, being both widely available,though diffuse, and producing no pollution during power generation. Wind energy has been one of humanity's primary energy sources for transporting goods, milling grain, and pumping water for several millennia. From windmills used in China, India and Persia over 2000 years ago to the generation of electricity in the early 20^{th} century in Europe and North America wind energy has played an important part in our recorded history

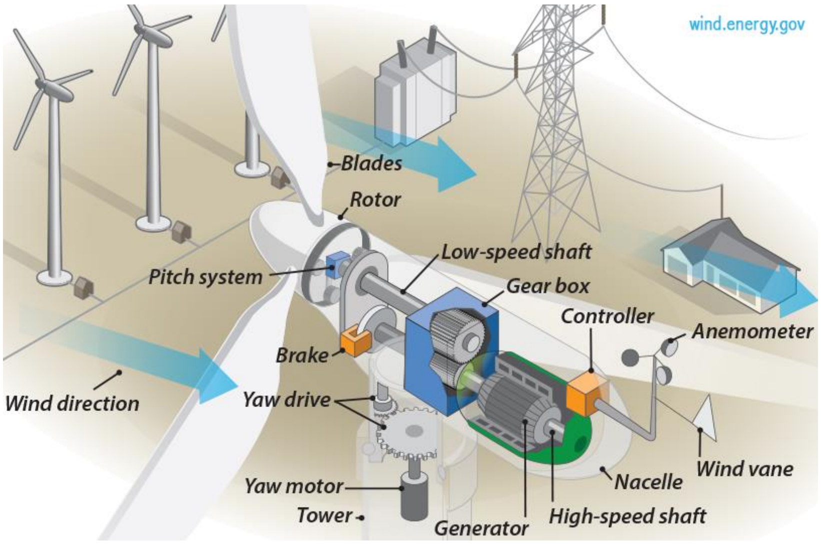


Fig 1.6 Wind powerplant cycle

As industrialization took place in Europe and then in America, wind power generation declined, first gradually as the use of petroleum and coal, both cheaper and more reliable energy sources, became widespread, and then more sharply as power transmission lines were extended into most rural areas of industrialized countries. The oil crises of the 70's, however, triggered renewed interest in wind energy technology for grid connected electricity production, water pumping, and power supply in remote areas, promoting the industry's rebirth [30].

2. **Solar:** Every day the sun radiates an enormous amount of energy. It radiates more energy in one second than the world has used since time began. This energy comes from within the sun itself. Like most stars, the sun is a big gas ball made up mostly of hydrogen and helium atoms. The sun makes energy in its inner core in a process called nuclear fusion.During nuclear fusion, the high pressure and temperature inthe sun's core causes hydrogen (H) atoms to come apart. Four hydrogen nuclei (the centres of the atoms) combine, or fuse, to form one helium atom. During the fusion process, radiant energy is produced. It takes millions of years for the radiant energy in the sun's core to make its way to the solar surface, and then just a little over eight minutes to travel the 93 million miles to Earth.

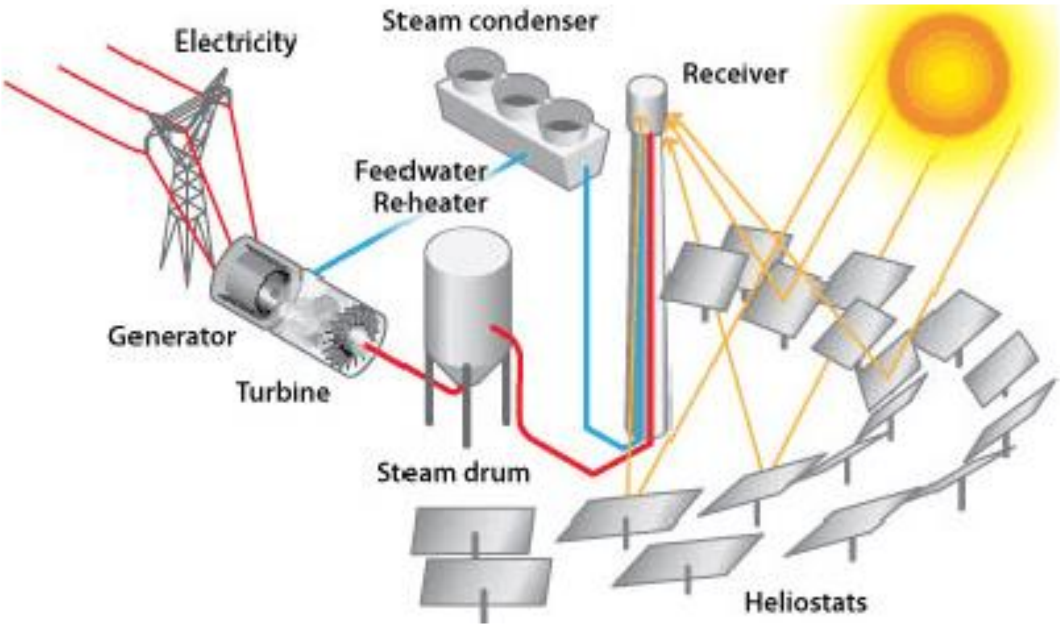


Fig 1.7 Solar powerplant cycle

The radiant energy travels to the Earth at a speed of 186,000 miles per second, the speed of light. Only a small portion of the energy radiated by the sun into space strikes the Earth, one part in two billion. Yet this amount of energy is enormous [31].

3. **Hydro:** Hydropower is generated from water moving in the hydrological cycle, which is driven by solar radiation. Incoming solar radiation is absorbed at the land or sea surface, heating the surface and creating evaporation where water is available. A large percentage—close to 50% of all the solar radiation reaching the Earth's surface—is used to evaporate water and drive the hydrological cycle. The potential energy embedded in this cycle is therefore huge, but only a very limited amount may be technically developed. Evaporated water moves into the atmosphere and increases the water vapour content in

the air. Global, regional and local wind systems, generated and maintained by spatial and temporal variations in the solar energy input, move the air and its vapour content over the surface of the Earth, up to thousands of kilometres from the origin of evaporation. Finally, the vapour condenses and falls as precipitation, about 78% on oceans and 22% on land. This creates a net transport of water from the oceans to the land surface of the Earth, and an equally large flow of water back to the oceans as river and groundwater runoff.It is the flow of water in rivers that can be used to generate hydropower, or more precisely, the energy of water moving from higher to lower elevations on its way back to the ocean, driven by the force of gravity [32].

4. **Geothermal :** Geothermal the name it self suggest that earth heat. Approximately 94% of earth is molten metal.Only the thin outer shell is solidified rock ranges in thickness from 15 to 150 km. the temperature at the centre of the earth is about 3100˚C whereas the temperature between the magma and the crust is about 1200˚C. the crust earth is a great insulator, allowing very little heat to reach the surface.

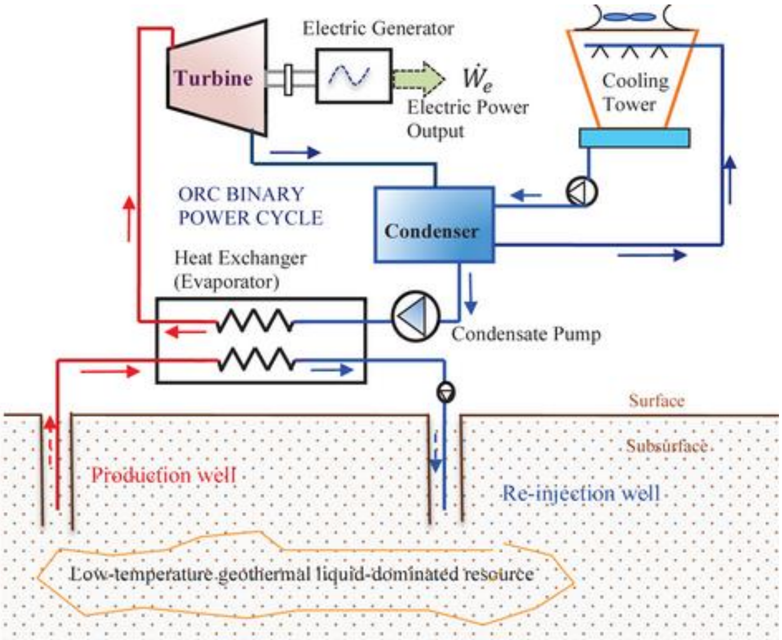


Fig 1.8 Geothermal power plant cycle

Due to which the water below the earth gets heat and gets transformed into high temperature vapour or high temperature water vapour mixture. These high temperature vapour or water vapour mixture are used to generate electricity by using various power plant system. The highest electricity generator by using geothermal source is USA.

CHAPTER 2

GEOTHERMAL ENERGY

2.1 Introduction

Geothermal energy is the energy contained as heat in the Earth's interior. The origin of this heat is linked with the internal structure of our planet and the physical processes occurring there. Despite the fact that the geothermal resources of the earth are huge, practically inexhaustible quantities in the Earth's crust is unevenly distributed and more great thing are to be exploited [1].

The environmental impact from geothermal energy is lower than that caused by conventional energy sources. If there is any problem in pollution regarding the extraction of fluids then reinjection of used brine back into the earth will solve the problem. Reinjection may also help to maintain reservoir pressure [2].

Geothermal energy can be applied for different purposes according to temperature range. Low-temperature geothermal energy would generally utilized for greenhouse heating and aquaculture, high-temperature applications, including absorption chillers for refrigeration and air conditioning and power generation e the highest grade and most useful form of energy known to humankind [3]. Geothermal fluid that is present beneath the surface are present in two form one is water dominated and other is steam dominated. If the fluid does not contain any water then it is called as steam dominated and water if present then it is called water dominated.

2.1.1 Geothermal Potential in World

USA is on the top of list in extracting geothermal potential. About 77% power plant till 2010have been installed capacity of 3086 MW. The Philippines leads the second position in geothermal electricity production with 1904 MW installed capacity. In USA the largest geothermal power plant are located in Geysers, California. The total installed geothermal capacity in the world is 11765 MW

Table 2.1 World Leading Geothermal Producers

Country	2010 (MW)	2013(MW)
USA	3086	3389
Philippines	1904	1894
Indonesia	1197	1333
Mexico	958	980
Italy	843	901
New Zealand	628	895
Iceland	575	664
Japan	536	537
Kenya	167	215
Costarica	166	208

2.1.2 Geothermal Potential in India

Geological survey of india has identified 340 hot springs in india. They categorizes these into six groups which are [4]:

1. Himalayan Province - Tertiary Orgenic belt with Tertiary magmatism
2. Areas of Faulted blocks - Aravalli belt, Naga-Lushi, West coast regions and Son-Narmada lineament.
3. Volcanic arc - Andaman and Nicobar arc.
4. Deep sedimentary basin of Tertiary age such as Cambay basin in Gujarat.
5. Radioactive Province - Surajkund, Hazaribagh, Jharkhand.
6. Cratonic province - Peninsular India.

Geothermal potential of India is about 10000 MW which can be tapped from Himalaya, Naga Lushai, Andaman-Nicobar Islands, West Coast, Cambay Graben, Aravalli, Son-Narmada-Tapi, Godavari and Mahanadi, South Indian Cratonic geothermal provinces in India. However, the geothermal reservoirs in India are of low to medium enthalpy type [5].

2.1.3 Indian Geothermal Sites

In India geologist has discovered 340 hot srings which are present at various regions around the country. The various sites are

1. **Puga Geothermal Field:** The Puga area is located at a distance of about 180km from Leh in Ladakh Region of J&K across the Great Himalayan Range at an altitude of

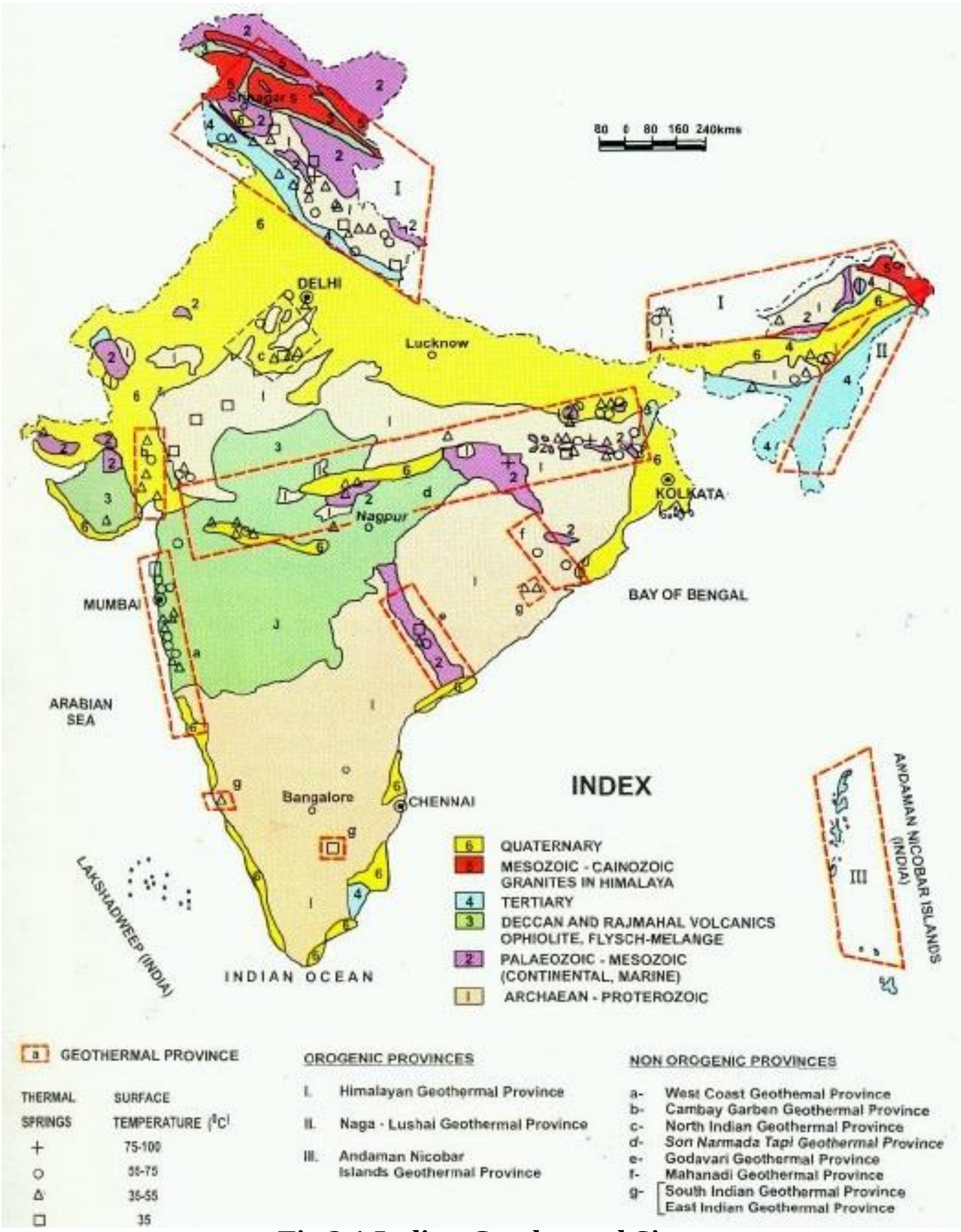


Fig 2.1 Indian Geothermal Sites

4400m. The temperature varies from 30˚C to 84˚C. The maximum discharges is 5 litre per/sec. Geochemical thermometers, based on the concentration of Na, K, Ca and Mg, have pointed to the possibility of having thermal fluids of 220˚C-260˚C temperatures at deeper levels whereas the oxygen isotope thermometry places this estimate at 180˚C.

2. **Chhumathang Geothermal Field**: Chhumathang field is about 40 km north of Puga. Hot springs has a temperatures range between 30˚C to 87˚C. the discharge for all the spring is 200litre/sec. Geochemical studies have indicated the existence of thermal fluid in the reservoir of about 150°C temperatures.
3. **Manikaran Geothermal Field:** Manikaran geothermal field is located about 50 km east of Kulu, Himachal Pradesh at an altitude of about 1700 m. The temperature range between 34˚C to 96˚C at the right side of the bank and at the other side temperature ranges between 28˚C-37˚C.
4. **Tapoban Geothermal Field:** Tapoban Geothermal area is located in Dhauli river valley, a major tributary to Alaknanda River. The maximum temperature at this ste is 65˚C having a discharge of 0.83-9.22 litre/sec.
5. **Sohana Geothermal Field:** The Sohana Hot Spring is located close to Gurgaon, Haryana, the temp range are found to be between 40˚C to 60˚C.
6. **Tattapani Geothermal Field:** The tattapani hot sring is located in chattisgarh. The temperature ranges from 80˚C to 120˚C.

2.1.4 Tattapani Geothermal Site

The Tattapani geothermal field is located 100 km northeast of Ambikapur, Sarguja district, Chattisgarh. Tattapani is most promising geothermal field in the Peninsular India. Geothermal activity is seen in the east of the Tattapani and in the west of the Jhor, which are located 50 km apart. Thermal manifestation at Tattapani is very intense in an area of 0.05 sq. km with several hot spots, hot water pools and a marshy land

Twenty six boreholes have been drilled to depths ranging from 100 m to 620 m. Blow out conditions occurred in five wells as shown in the Table. Bore hole GW-6 is the deepest well drilled to a depth of 500m. The shut-in temperature of the thermal fluids is around 112° C. The cumulative discharge from wells is 1600 liters/min. About 4 kg/cm^2 pressure has been measured by ONGC in all the five bore holes. The surface manifestations show occurrence of white to dirty white deposit (identified as silica) and moderate to low gas activity. The temperature of the hot water varies from 50°C to 98°C.

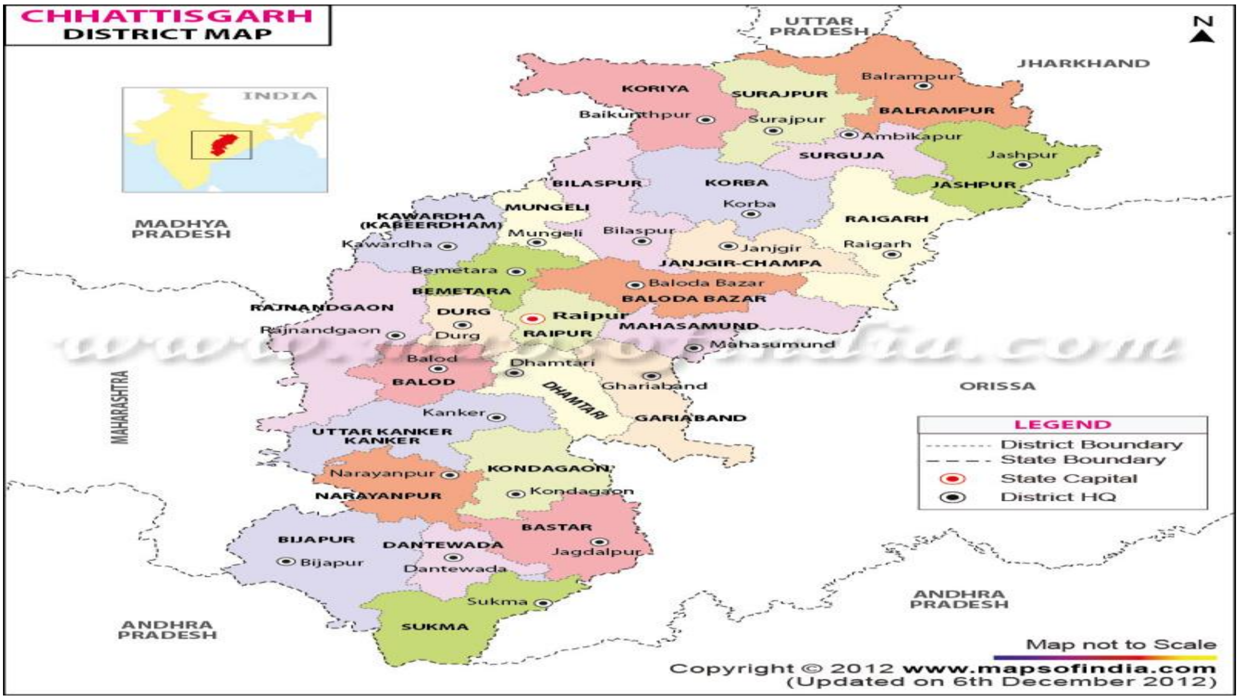


Fig 2.2 Tattapani geothermal field, Sarguja district, Chattisgarh

Surface flow of the individual springs is very low while the cumulative discharge is around 60 liters/minute. Fig. 5.7 shows the geothermal water blowing out of the geyser at Tattapani geothermal field. The AMT surveys specified a conductive zone in the sub-surface close to the hot spring area, which may correspond to the hot water comportment development. Sub-surface temperature by means of different thermometry found to be in the range of 120° C to 150°C. Based on the cumulative discharge of 1600 lit/min of thermal water (100° C) from five drill holes at Tattapani a joint project of ONGC-GSI-MPUVN (Madhya Pradesh UrjaVikas Nigam) to install a 300 kW binary cycle power plant is under consideration.

Table 2.2 Temperature and discharge of boreholes at Tattapani

Borehole number	Depth(m)	Discharge(lpm)	Maximum temperature flowing (^{o}C)
GW/Tat/6	320	255-288	111.2
GW/Tat/23	350	282-380	111
GW/Tat/25	230	218	112
GW/Tat/26	210	356-380	111.7

2.2 TYPES OF GEOTHERMAL ENERGY RESOURCES

There are various types of geothermal energy resources which have been identified by the geologist. These are presnt at various temperature and pressure according to there state. Every resources have there unique application. Some are very useful and quite few method has not yet developed to extract the energy from these resources. Types are given below:

1. **Hot Water Reservoir:** This the most prominent source of geothermal energy which is generally used to produce electricity and in mostly every where in world. It has a temperature below 200˚C and it is liqid dominated.most of the geothermal power plant are based on hot water reservoir for eg. Binary power plant, binary flash power plant, single flash steam power plant, dual flash steam power plant.

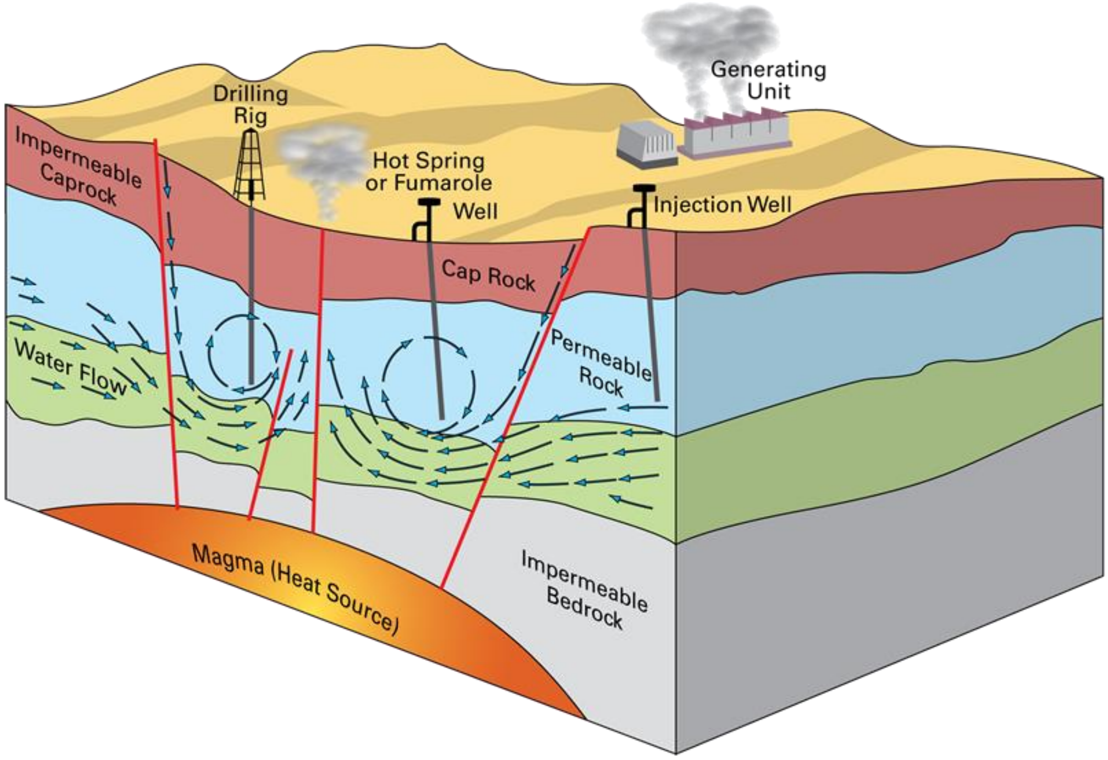


Fig 2.3 Geothermal energy reservoir

2. **Dry Steam Reservoir:** In this type the geothermal fluid is present in the form of steam. Due to high temperature present beneath the earth the water gets converted into steam and when we creates a hole by drilling the pressurised steam comes to the surface due to the difference in pressure. The temperature of the steam is above 200˚C. For this type dry steam power plant is present in which we directly rotate the turbine with the help of the steam.

3. **Hot Dry Rocks:** The rocks present beneath the earth gets heated because of thehigh temperature present at the core. This high temp rocks are used to convert water into steam. The method involves drilling a hole upto where the dry rock is present and then pipe takes water to the dry rock the another hole is drilled which brings the steam formed trough a pipe. As the water passes through the hot dry rock heat is transferred and the water gets converted into steam and this steam is used to run the turbine or for other activities.
4. **Geo-Pressured Reservoir:** In this type of reserve, under the overlying rock brine completely saturated with natural gas in stored under pressure. This type of resource can be used for both heat and for natural gas. Geo-pressured reservoirs are characterized by three important properties that make them potentially attractive for geothermal exploitation these are very high pressure, high temperature and dissolved methane. The first property allows the use of a hydraulic turbine to extract the mechanical energy stored in the form of high pressure; the second property allows the use of a heat engine of some kind to extract the thermal energy; and the last property allows for either the combustion of the gas on site for power generation or for sale to enhance the economics of a development project.
5. **Molten Magma:** Magma is present in molten form beneath the earth and comes during volcanic eruption. To extract it energy the method used is to drill a well into the magma, insert an injection pipe and pump cold water down the well under great pressure. The molten magma will solidify in the presence of cold fluid into a glassy substance that should crack under the thermal stress imposed on it. If the water can be made to return to the surface by passing upward through the cracked, extremely hot glassy material, it would reach the surface hot and ready for use in a Rankine-type power plant.

2.3 GEOTHERMAL POWER PLANT

All the power plant system takes up the geothermal water from the reservoir, exchanges heat, generates electricity and injects the geothermal water back to the reservoir. The most common type includes dry steam power plant and single flash steam plant and nowadays binary cycle.The basis of thermodynamic analysis of every geothermal power plant is second law of thermodynamics with assumption. For designing purpose exergy analysis is most important.

2.3.1 Single Flash Steam Power Plant

The single-flash power plant is first geothermal that has been installed. From the overall geothermal power plant installed in world near about 32% of them are single flash steam power plant. The power generation ranges between 3 to 90MW and the average power rating is 25.3MW per unit.

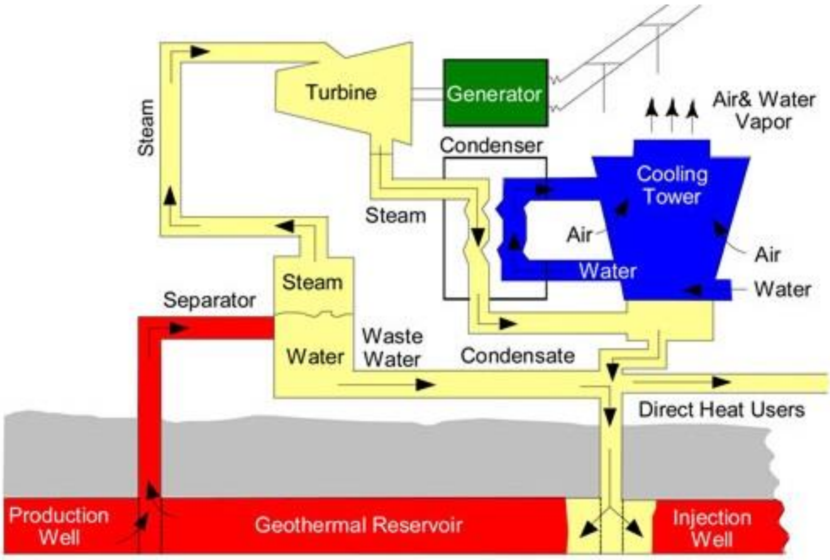


Fig 2.4 Single flash geothermal power plant

The process of single flash steam power plant involves a flash tank in which geothermal water is passed. The pressure inside the flash is very less due to which the liquid that is present in the brine gets vapourizes anr then this vapourized brine is sent to the turbine which rotates the turbine and turbine drives the generator. And after flashing process if there remains some what amount of water then it is again flashed to another flash tank this cycle is called as dual flash steam power plant.

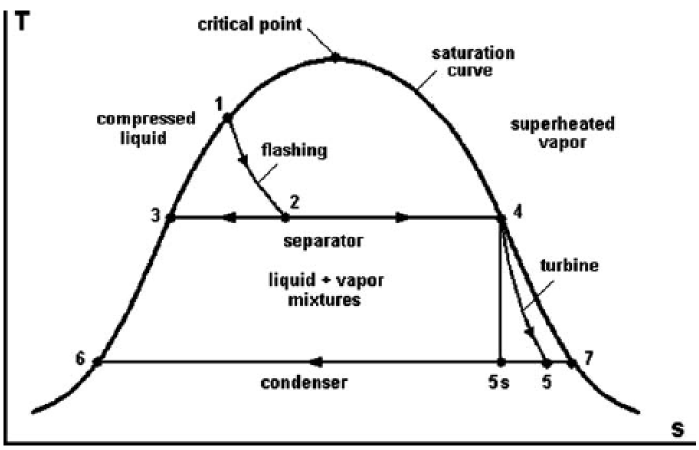


Fig 2.5 T-S diagram of single flash cycle

2.3.2 Dry Steam Power Plant

Dry steam power plant is used for the brine which is vapour dominated. The temp of the vapour is above 200˚C. The percentage of dry steam power plant in all over the world is 12%. The power generation ranges over 40MW.

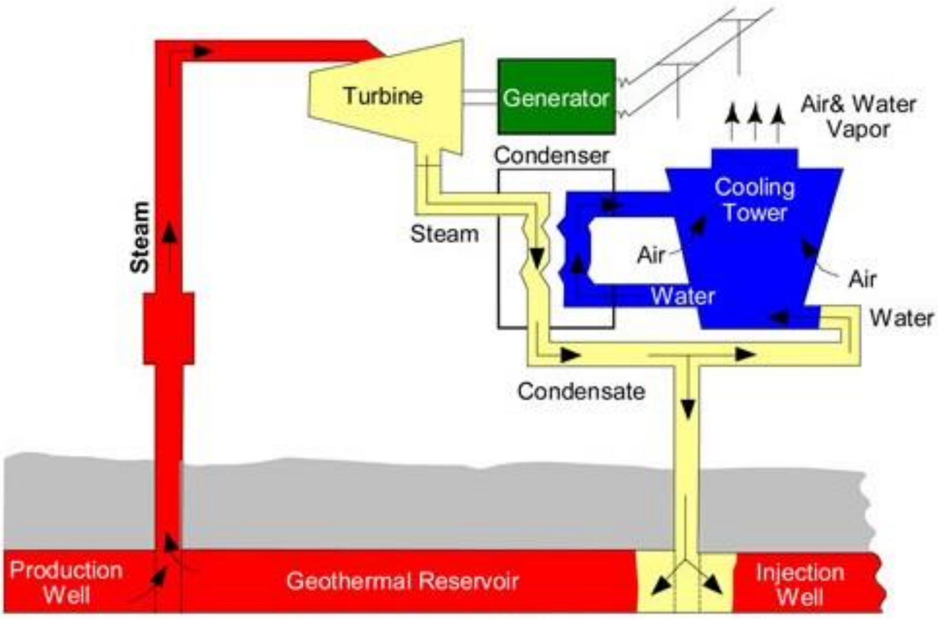


Fig 2.6 Dry steam power plant

In dry steam power plants the steam is directly fed into the turbine as it is already in vapour form. This runs the turbine and so the generator drives.

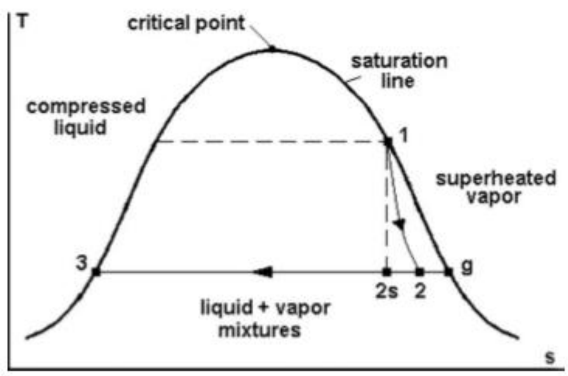


Fig 2.7 Temperature-Entropy diagram of dry steam power plant

2.3.3 Binary Cycle Power Plant

The binary cycle is same in aprinciple to rankine cycle.The first binary cycle based geothermal power plant was at Paratunka, Russia in 1967 having a potential of 670kW. The power rating is very small about 2.3 MW per unit. The percentage of binary cycle power plant are about 32%.The process involves four major components that is heat exchanger, turbine, condenser, pump. By installing binary cycle power plant thermal efficiency of about 50% or more is achievable. In binary cycle powerplant refrigerant is used to rotate the turbin. Selection of refrigerant is based on the property of brine.

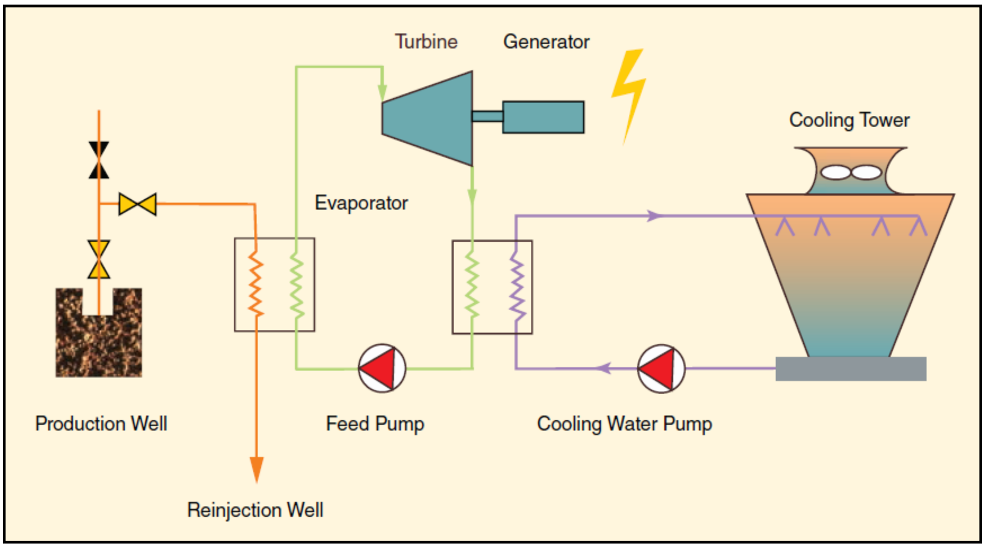


Fig 2.8 Binary cycle geothermal powerplant

The refrigerant exchanges heat from the heat exchanger and get gets converted into vapour and vapour drives the turbine to generate electricity. After the turbine the refrigerant enters the condenser where the vapour gets condenses and again it comes into liquid form. The it is passed to pump where the pressure increases and the refrigerant is passed to evaporator agai

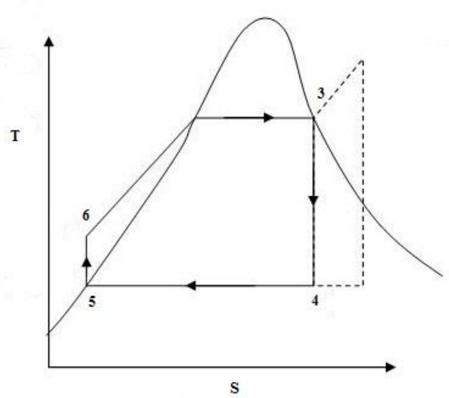


Fig 2.9 T-s diagram of Binary cycle geothermal power plant

Refrigerants have an important role in system performance. There are few physical and chemical properties while selecting refrigerant such as non-toxicity, non-corrosiveness, non-flammability and stability [29]. For having a high power output refrigerant should have this following characteristics:

1. High critical temperature should be higher than maximum operating cycle temperature
2. Low freezing point should be lower than the lowest cycle operating temperature.
3. Density and latent heat of refrigerant should be high

Viscosity should be low and thermal conductivity should be high

The thermodynamic processes undergone by the working fluid are shown in fig 2.4. The analysis is done as follows

Turbine Analysis:

By assuming negligible potential and kinetic energy along with steady flow processand adiabatic process the net work done by the turbine is :

$$\mathbf{W_{turbine} = m_{ref}\,(h_3 - h_4)} \qquad \mathbf{(1)}$$

Condenser analysis:

The heat rejected by the working fluid water or airWork done by the pump:

$$\mathbf{Q_c = m_{ref}\,(h_4 - h_5)} \qquad \mathbf{(2)}$$

Pump analysis:

The net work given to the working fluid from the pump

$$\mathbf{W_{pump} = m_{ref}\,(h_5 - h_6)} \qquad \mathbf{(3)}$$

Evaporator analysis:

The analysis of the evaporator where the brine transfers its heat energy to the working fluid, assuming steady flow process and having negligible potential and kinetic energy.

$$\mathbf{m_{brine}(h_1 - h_2) = m_{ref}\,(h_3 - h_6)} \qquad \mathbf{(4)}$$

The above equation can be used to calculate the mass flow rate of refrigerant, which is give by:

$$\mathbf{m(ref) = \frac{m(brine)[(h1 - h2)]}{h3 - h6}} \qquad \mathbf{(5)}$$

Overall cycle analysis:

After analysing each component the results is used to calculate the net power output and efficiency.

Net power output:

$$P_{net}= m_{ref}\ [(h_3-h_4)-(h_5-h_6)]*\eta_t*\eta_m*\eta_{gen} \qquad (6)$$

And thermal efficiency is given by:

$$\eta = \frac{Pnet}{mref(h3-h6)} \qquad (7)$$

2.3.4 Kalina Cycle Power Plant

Dr. Alexander Kalina developed the kalina cycle.Different plants based on kalina cycle includes Tokyo bay oil refinery, Kashmira steel works, Husavik oil facility and etc.It produces high power output and thermal efficiency than binary cycle.The kalina cycle is used is refrigeration cycles,but it is now used in power generation. It shows advantages such as improved thermodynamic properties of heat exchanger by reducing irreversibilities associated with heat transfer across a finite temp difference. The heaters are arranged in such a way that better heat transfer is maximised. The cost of turbine used in ammonia cycle is less than the other refrigerant based cycle.

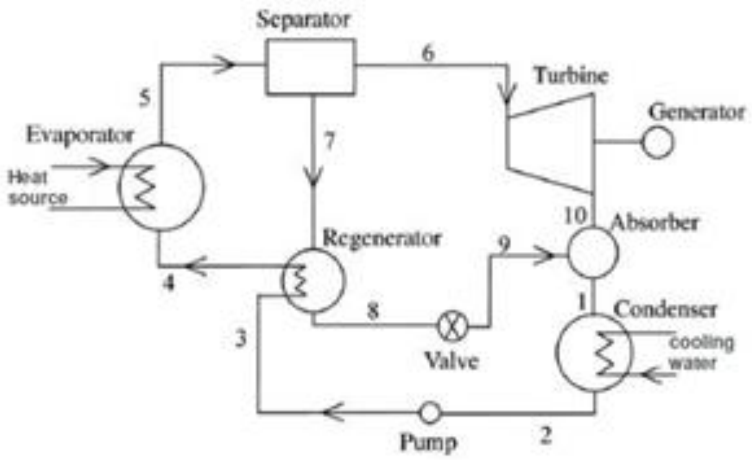


Fig 2.10 Kalina Cycle

The recuperator is to recover waste heat from the ammonia after the expansion process in turbine. The separator allows to flow rich ammonia in the turbine. The process of kalina starts with giving heat to the NH_3-H_2O mixture from the heat source. By giving the NH_3-H_2O mixture starts boiling after that it is passed through the turbine as the mixture rotates the turbine blade which is coupled with generator. After that the mixture has high concentration of ammonia and to condense it will require very less temperature which is impossible to achieve. Hence we add a separator which will add lean mixture to the high concentration mixture decreasing the concentration of ammonia. The separator is added up between the turbine and evaporator. After that the mixture is condensed and passed through the pump. A regenerator is used before the evaporator to preheat the mixture. Thermodynamic analysis of kalina cycle is same as that of binary cycle. The thermodynamic analysis is as follows:

Turbine Analysis:

By assuming negligible potential and kinetic energy along with steady flow processand adiabatic process the net work done by the turbine is :

$$\mathbf{W_{turbine} = m_{mix}\,(h_3 - h_4)} \qquad \textbf{(8)}$$

Condenser analysis:

The heat rejected by the working fluid water or airWork done by the pump:

$$\mathbf{Q_c = m_{mix}\,(h_4 - h_5)} \qquad \textbf{(9)}$$

Pump analysis:

The net work given to the working fluid from the pump

$$\mathbf{W_{pump} = m_{mix}\,(h_5 - h_6)} \qquad \textbf{(10)}$$

Evaporator analysis:

The analysis of the evaporator where the brine transfers its heat energy to the working fluid, assuming steady flow process and having negligible potential and kinetic energy.

$$\mathbf{m_{brine}(h_1 - h_2) = m_{mix}\,(h_3 - h_6)} \qquad \textbf{(11)}$$

The above equation can be used to calculate the mass flow rate of refrigerant, which is give by:

$$\mathbf{m(mix) = \frac{m(brine)[(h1-h2)]}{h3-h6}} \qquad \textbf{(12)}$$

Overall cycle analysis:

After analysing each component the results is used to calculate the net power output and efficiency.

Net power output:

$$P_{net} = m_{mix}\,[(h_3-h_4)-(h_5-h_6)]*\eta_t*\eta_m*\eta_{gen} \qquad (13)$$

And thermal efficiency is given by:

$$\eta = \frac{Pnet}{m(mix)(h3-h6)} \qquad (14)$$

CHAPTER 3

LITERATURE REVIEW

Subir K. Sanyal [7] presented that for 10 years if we drill make wells then the power cost is reduced.another way of reducing the power cost is to run the plant beyond its amortization; the method is not for larger capacity plant. The Power cost depends upon O&M cost and by unit capital cost.

Carlos Atli Cordova Geirdal et al. [8] presented that for the wellhead power plant production time is more..The well head proction rate depends upon the time of drilling of well.

Cedric Nathanael Hance [9] presented that the important factors affecting the power development cost is site and characteristic of resources.Maintanence cost also cause the rise in capital cost. Most parameters affecting capital costs also impact O&M costs. The factor that the O&M costs are resource charecteristics, size of the project, geothermal brine chemical composition and resource depth.

P.B.Sarolkar et al. [10] presented the different parameters of tattapani geothermal site the result were the reservoir is located under proterozoic rocks at a depth of 70m. The maximum temperature at a depth of 200m is 112.°C. A conductive cooling region is identified at a depth of 175 to 275m.

P. N. Razdan et al. [11] presented that 300 hot springs available in india are studied and examined. From the 300 areas 31 areas have been studied in details.The drilling was done in 16 areas. The maximum depth bore hole was drilled in Puga (385m), Manikaran (700m), Tattapani (620m), Tapoban (728m), West Coast (500m) and Chhumathang (220m). temperature variation is found to be 90°C to 140°C.

Efstathios E. Michaelide et al [12] presented that 20% more work output is generated by binary flashing plant than conventional plant. Maximum work output is shown by binary flashing plant is with Freon, isobutane and ammonia.

Aleksandra Borsukiewicz-Gozdur [13] presented that the Geothermal energy can be utilised more by using hybrid and dual-fluid hybrid plants. By using cyclohexane a hybrid power plant will have maximum thermal. The main factor between the exchanges of heat between the brine and the biomass depends on the plant type and temperature of geothermal water. R236fa shows maximum geothermal energy utilization in dual fluid hybrid power plant.

Huijuan Chen et al. [14] presented that the Conversion efficiency can be affected by various factor which are design of system, content of NCG, loss of heat from equipment, efficiency of turbine and generator. All conventional thermal power plants have higher conversion efficiency than geothermal power plant(12%). Conversion efficiency for binary power plant is 1% and for dry steam is 21%

Mortaza Yari [15] presented that the geothermal power plant can have a maximus outputs with regenerative organic Rankine cycle with an Internal heat exchanger. During the reinjection process certain of available energy of brine is lost

Ronald DiPippo [16] presented that geothermal binary plants have less capability to covert heat into work. Binary power plant have thermal efficiency around 8 to 12%.1, whereas for kalian cycle having brine specific exergies of 200kJ/kg shows 15 to 50% more power output as in comparision with binary cycle based power plant .

Qiang Liu et al. [17] presented that with decrease in condensation temperature the power output of the organic rankine cycle increases. Avoid scaling and fouling problems the reinjection temperature should be maximum in the heat recovery heat exchanger and in the pipes.by applying IHE only reduces the inlet temperature of the turbine but also increases the net power output low temperature brine having fixed temperature of reinjection. Maximum net power output is shown by R600, R600a, R245fa

Aleksandra Borsukiewicz-Gozdur et al. [18] presented that the cycle with return mass flow has greater net power than the cycle without return mass flow. The parameter on which the net power output depends is brine initial parameter and refrigerant thermodynamic properties. Refrigerant having low critical temperature have high power output.

Florian Heberle et al. [19] presented that by using CHP the efficiency can be increase up to 20%. The circuit in series chp has the most efficiency. For circuits in parallel and power generation the favourable refrigerant is isobutane and R227ea.

Zhang Shengjun et al. [20] R123, R600, R245fa, R245ca and R600a shows high exergy and thermal efficiency. R218, R125 and R41 shows high recovery efficiency.for low temperature organic rankine cycle R125 with transcritical power cycle shows cost effective. 45% and 15.7% is the thermal efficiency and exergy efficiency of R125 whereas R123 shows 20.7% higher recovery efficiency.

Mehmet Kanoglu et al. [21] presented that The plant operation and heat exchange process depend upon the parameter of cycle performance and the corosponding information can be used in the design, analysis, and performance improvement of binary geothermal power plants.

Oguz Arslan et al. [22] presented that because of the non-linearity of the neural networks a highly unique flexible ANN algorithm was proposed to evaluate the organic rankine cycle Binary systems. The results obtained analytically were used to train several ANN algorithms, such as CGP, LM and SCG. CoV, PRMS and R^2 are the algorithm method used. The best algorithm is LM was seen fron the result. Optimization of Supercritical ORC-Binary was done by ANN. For the output in training and testing steps the value of R^2 for s1 and s2 types was obtained as 0.9999, ANN can be applied for optimization problems of power cycles

Sergio Arosioa et al. [23] presented that TG system has higher thermal efficiency than compared with Organic Rankine Cycle. Plants operating with the inverse cycle (TGHP) exhibit features that are particularly suitable for geothermal applications when working with a regenerative thermodynamic cycle.The use of a feed pump conventional plant results in lower costs, noise levels and reduced vibration

T. Harinarayana et al. [24] presented that The lateral and vertical variation in resistivity structure. The one-dimensional and two-dimensional inversion results reveal the occurrence of surficial conductive zone extending upto a depth of about 400 m underlain by a resistive structure.The surface conductive region centered in the anomalous part of the area could be possibly due to the combined effect of top alluvial cover filled with geothermal deposits and fractured breccia/bedrock in which hot water is circulating.The presence of partial melts in the region is indicated from geophysical studies. This zone was subjected to intense basic to ultrabasic, plutonic to submarine volcanism of Cretaceous age and several phases of wide spread acid igneous activity from Upper cretaceous to Upper Tertiary times.

Cesar R. Chamorro et al. [25] presented that exergy efficiency is increased with double flash system instead of a single flash system. At 180˚C to 220˚C the increases is greater than 25% whereas at 200˚C is 25.4% .with Triple Flash technology the exergy efficiency can further be increased. the increasein exergy efficiency is 10% for at 230˚C. The exergy efficiency is maximum at 290 ˚C at saturated vapour.

C. Coskun et al. [26] presented that the mean exergy efficiency cames 45.2% on taking outdoor temperature distribution that is 4.77 times more than the exergy efficiency.If reinjected brine is used then 16.37 for purpose of heating , 3.2 for cooling, 28.3 for heating of green house.The system with air-cooled condenser which are affected by the weather conditions the efficiencies changes

Deniz Yildirim et al. [27] presented that net power generated from plants varies of depending on the air temperature for air cooling was carried out the both in DORA 1 and DORA 2 plants. Cooling process differs in summer and winter condition, the air temperature increases for cooling. Losses of percent of the turbine and pump also differ in the DORA1and DORA2. In this differences are indicators vary depending on daily operating conditions of the plant concerned.

John W. Lund [28] presented that Geothermal fluid consumption is increased in year 1995, 2000 and 2005. The reason behind the lag of consumption is the low cost of fossil fuels and high investment cost of geothermal power plant. Geothermal energy can now be developed anywhere as geothermal heat pumps are easily availabe. Temperature which is low and moderate can be used in power plants for generation of electricity and below 100 °C are binary cycle power plant and then used for other purposes.

CHAPTER 4

OBJECTIVE, SCOPE AND RESEARCH METHODOLOGY

4.1 OBJECTIVE OF THE STUDY

Thermodynamic Analysis of Binary and Kalina Power Cycle using Brine as Thermal Energy Sources and Development Potential in Tattapani.

Geothermal power plant system on which calculation will be based:

1. Binary cycle
2. Kalina cycle

Main objectives:

1. Net power output of the geothermal system
2. Net power output per kg of the geothermal system
3. Thermal effieciency of the geothermal power plant system.

4.2 SCOPE OF THE STUDY

The main source of energy in India is coal. The reason behind the large use of coal is cheapcost and large availability. But if the coal reserve diminishes we have to rely on the renewable energy sorces. I think it is a step toward toward the adaption of geothermal energy which economical and environment friendly.

One day we have to rely on these renewable resources because our country need to be stronger and developed day by day and we need energy to fulfil these needs. And what if these non renewable resources reserves diminishes, hence we have to adapt on renewable resources.These renewable resources has many advantages over disadvantages. Geothermal energy is one of the type under renewable energy. Geological Survey of India has identified about 340 hot springs and these hot springs have the capability to generate 10000 MW [6].

As India’s first geothermal power plant is going to establish in Tattapani, Chattishgarh, hence in this study the parameter of the sites like mass flow rate, brine temp (geothermal water) and pressure of the brine and apply it to different power plant system and will try to find which refrigerant and parameter will be appropiate for the parameters of the geothermal sites.

4.3 RESEARCH METHODOLOGY

Step 1: Collection of data from Tattapani geothermal site, Chattishgarh

Step 2: Selection of refrigerant on the basis of lowest critical temperature.

Refrigerant used in the thermodynamic analysis are given below in the Table 3.2.

Table 4.1 Refrigerants with their critical temperature and critical pressure

Refrigerant	Critical Temperature(˚C)	Critical Pressure(bar)
R134a	100	40
R600a	134.66	36.290
R245fa	154.01	36.510
R123	183.68	36.618

Step 3: On the basis of the data and the selected refrigerant analysis will be done for Binary and Kalina cycle

1. Net power output
2. Net power output per kg of geothermal water
3. Thermal efficiency

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Binary Cycle

The parameter of geothermal site is used to calculate the net power output, the net power output per ton of the brine, and the overall efficiency. The parameter are applied on binary cycle and refrigerant used are R134a(1,1,1,2-tetrafluoroethane), R600a(isobutane), R-245fa (1,1,1,3,3-pentafluoropropane), R123(2,2-dichloro-1,1,1-trifluoroethane).

Assumption made for the analysis of binary cycle:

1. At the inlet of turbine the condition of steam is taken as saturated vapor and super saturated vapor.
2. The pressure at the outlet of the turbine is taken as 1 bar
3. Temperature of the working fluid after the heat exchange between brine and working fluid is taken as 90˚c, 80˚c, 70˚c
4. As temperature of the brine fluctuates between 80˚c to 120˚c, hence the temperature of the brine is taken as 90˚C, 100˚C, 110˚C.

Tattapani geothermal power plant site, Chhattisgarh has been investigated for different brine temperatures which are 110^{o}C, 100^{o}C and 90^{o}C for the refrigerants R134a, R600a, R245fa and R123. The reason behind the selection of these refrigerants is that they are suitable for the brine condition. The mass flow rate of the brine is 40kg/s. Assumption were taken that the temperature of refrigerant after it exchanges heat with the brine is 90^{o}C, 80^{o}C and 70^{o}C. The pressure at the outlet of turbine kept constant and the pressure at the inlet of the turbine is varied along with temperature. The calculation were done analytically for calculating the net power output, net power output per kg of geothermal water and thermal efficiency. First the brine heat (Q_{brine}) is calculated for different temperature for the refrigerants. Brine heat is is given by Q_{brine} and Q_{in} is the heat input to the refrigerants. As we know, Q_{brine}= Q_{in}, from this M_{ref} is calculated and Mref is used to calculate the net power of the cycle and thermal efficiency from the equation (6) and (7). The results of the calculation for refrigerants are given in the table below.

R143a

Table 5.1. Net power output, net power output per kg of geothermal water and thermal efficiency for R134a

T_1(°C)	T_2(°C)	Pnet(kW)	Pnetg (kWs/kg)	η_t (%)
110	90	3507.463	87.68658	16.09814
	80	3410.045	85.25114	15.65103
	70	3270.295	81.75739	15.00962
100	90	3261.747	81.54368	16.0983
	80	3171.127	79.27818	15.6511
	70	3041.167	76.02918	15.0097
90	80	2931.635	73.29086	15.6511
	70	2811.49	70.28724	15.0097

Table 5.2 Net power output, net power output per kg of geothermal water and thermal efficiency for R600a

T_1(°C)	T_2(°C)	Pnet(kW)	Pnetg (kWs/kg)	η_t (%)
110	90	3273.345	81.83363	15.0236
	80	3085.726	77.14316	14.1625
	70	2892.89	72.32226	13.2774
100	90	3043.995	76.09988	15.0236
	80	2869.517	71.73793	14.1625
	70	2678.432	66.96079	13.2775
90	80	2652.803	68.14629	14.1625
	70	2487.028	62.17569	13.2775

Table 5.3 Net power output, net power output per kg of geothermal water and thermal efficiency for R123

T_1(°C)	T_2(°C)	Pnet(kW)	Pnetg (kWs/kg)	η_t (%)
110	90	2182.673	54.56684	10.0178
	80	1927.81	48.19526	8.848
	70	1653.363	41.33408	7.5884
100	90	2029.475	50.73687	10.0165
	80	1792.767	44.81918	8.8482
	70	1537.5	38.4375	7.5883
90	80	1657.372	41.43431	8.8482
	70	1421.384	35.53459	7.5883

Table 5.4. Net power output, net power output per kg of geothermal and thermal efficiency for R245fa

T_1(°C)	T_2(°C)	Pnet(kW)	Pnetg (kWs/kg)	Ƞt (%)
110	90	2505.255	62.63137	11.4983
	80	2286.465	57.16162	10.4941
	70	2041.828	51.04571	9.3713
100	90	2329.73	58.24325	11.4984
	80	2126.279	53.15699	10.4942
	70	1898.773	47.46933	9.3714
90	80	1965.697	49.14242	10.4942
	70	1755.372	43.88431	9.3714

From the tables we can desist that R134a shows the maximum power output and thermal efficiency. R134a at 110°C and 100°C brine temperature as the temperature of the refrigerant at the outlet of the heat exchanger increases the mass flow rate also increases. Whereas at 90°C brine temperature it is found that as the temperature of the R134a at the outlet of the heat exchanger increases the mass flow rate decreases.

R134a shows the maximum efficiency at 110°C brine temperature and 90°C refrigerant temperature in the turbine inlet which is about 16.098 and the efficiency decrease with decrease in the turbine inlet temperature as shown in table below.

5.2 Kalina Cycle

Assumptions made for the analysis of kalina cycle:

1. The condition of steam is taken as saturated vapour at the inlet of turbine.
2. Temperature of the mixture is taken as 90°C, 80°C and 70°C after the heat exchanger.
3. The temperature of the brine is taken as 90°C, 100°C, 110°C as temperature of the brine at Tattapani geothermal site fluctuates between 80°C to 120°C.
4. The concentration of NH_3-H_2O at the evaporator to turbine side is taken as 0.7.

The calculation were done analytically for calculating the net power output, net power output per kg of geothermal water and thermal efficiency. First the heat energy for geothermal water is calculated (Q_{brine}) is calculated for different temperature for the refrigerants and enthalpy at the inlet of the evaporator and at the outlet of the evaporator is calculated. After that both the heat energy i.e. from the geothermal water and at the evaporator is equated:

$Q_{brine} = Q_{mix}$

From this equation mass flow rate of the NH_3-H_2O mixture is calculated M_{ref} is calculated. M_{ref} calculated at different brine temperature and corresponding temperature at the outlet of the evaporator is used to calculate the net power output and and thermal efficiency is calculated using equation (13) and (14).

Table 5.5 Net power output and Net power per kg of geothermal water of kalina cycle

Brine temperature	Refrigerant temperature at turbine inlet	P_{net}(kW)	P_{netg}(kWs/kg)
110^{o}C	90^{o}C	4266.817	106.6704
	80^{o}C	3814.217	95.35543
	70^{o}C	3466.273	86.65682
100^{o}C	90^{o}C	3259.443	81.48607
	80^{o}C	3223.4	80.585
	70^{o}C	3083.26	77.0815
90^{o}C	80^{o}C	2979.964	74.49909
	70^{o}C	2850.4	71.26

The maximum thermal efficiency is calculated which is at 110^{o}C and shown in table 3 below

Table 5.6 Thermal efficiency of kalina cycle

Refrigerants temperature at turbine inlet	η_t
90^{o}C	19.58333
80^{o}C	17.50605
70^{o}C	15.90909

The maximum thermal efficiency of the cycle at 90^{o}C is 19.58 and corresponding net power output is 4266.817.

CHAPTER 6

CONCLUSION

The thermodynamic analysis of Tattapani geothermal site, Chhattisgarh has a good potential for binary cycle as well as for kalina cycle based geothermal power plant. The brine condition is low temperature and water dominated which is a suitable condition for binary cycle as well as for kalina cycle based geothermal power plant.

For binary the calculations were made for different brine temperature by using R134a, R600a, R245fa and R123 as refrigerants. The selections of refrigerant were made on the basis of high critical temperature, high latent heat, high density, low freezing point. The analysis shows that for different brine temperature R134a shows the maximum net power output which is 3.5 MW and thermal efficiency of 16.098 among all refrigerant.

Analysis of kalina cycle is also done the results shows that the power output is maximum at 110^{o}C brine temperature which can be 4.2 MW and a thermal efficiency of 19.58 which is greater than the net power output of binary cycle.As kalina cycle has high efficiency and net power output compared with binary cycle. Therefore the cycle can be considered in Tattapani geothermal site for maximum heat extraction.

To exploit the low temperature brine more and to maximise the power output it will be useful to use advanced optimisation and design methods for the binary cycle and kalina cycle.

FUTURE SCOPE

The is lot of future work left in the thermodynamic analysis of Tattapani geothermal site, Chattishgarh which includes the following:

1. Insatead of binary cycle we can adapt for binary flash cycle it is so beacause binary flash shows more conventional work than binary cycle that is about 20%.
2. Advanced optimisation and design methods on various equipments of the cycles can be done to exploit more energy.

Nomenclature

m_{ref}	mass of refrigerant, kg s^{-1}
m_{mix}	mass of NH_4-H_20 mixture
m_w	mass of brine, kg s^{-1}
h_1	enthalpy of the brine at the inlet of heat exchanger, kJ kg^{-1}
h_2	enthalpy of the brine at the inlet of heat exchanger, kJ kg^{-1}
h_3	enthalpy of the refrigerant at the inlet of turbine, kJ kg^{-1}
h_4	enthalpy of the refrigerant at the outlet of turbine, kJ kg^{-1}
h_5	enthalpy of the refrigerant at the inlet of pump, kJ kg^{-1}
h_6	enthalpy of the refrigerant at the outlet of pump, kJ kg^{-1}
h_6	enthalpy of the refrigerant at the inlet of turbine, kJ kg^{-1}
h_{10}	enthalpy of the refrigerant at the outlet of turbine, kJ kg^{-1}
h_2	enthalpy of the refrigerant at the inlet of pump, kJ kg^{-1}
h_3	enthalpy of the refrigerant at the outlet of pump, kJ kg^{-1}
P_{net}	net power output, kW
P_{netg}	net power per kg of geothermal water, kWs/kg
η_t	thermal efficiency

References

[1] Barbier Enrico. Geothermal energy technology and current status: an overview review article.

[2] Anil Basaran, Leyla Ozgener, Investigation of the effect of different refrigerants on performances of binary geothermal power plants.

[3] Cerci Y., Performance evaluation of a single-flash geothermal power plant in Denizli.

[4] Geological Survey of India, Geothermal fields of India (2014)

[5] S. K. Sharma, Geothermal, A viable eco-friendly source of energy for India (2005)

[6] Geological Survey of India, Geothermal fields of India (2014)

[7] Subir K.Sanyal, Cost of geothermal power and factors that affect it (2004)

[8] Carlos Atli Cordova Geirdal, Maria S. Gudjonsdottir, Pall Jensson, Economic comparison between a well headed geothermal power plant and a traditional geothermal power plant (2013)

[9] Cedric Nathanael Hance, Factors Affecting Costs of Geothermal Power Development (2005)

[10] P.B.Sarolkar, S.N.Shukla, D.K.Mukhopadhyay, Shallow level sub surface characters of Tatapani Geothermal field, India (1995)

[11] P. N. Razdan, R.K. Agarwal and Rajan Singh, Geothermal energy resources and its potential in India (2008)

[12] Efstathios E. Michaelide and Gregory J. Scott, A binary-flashing geothermal power plant (1983)

[13] Aleksandra Borsukiewicz-Gozdur, Dual-fluid-hybrid power plant co-powered by low-temperature geothermal water (2010)

[14] Huijuan Chen, D. Yogi Goswami, Elias K. Stefanakos, A review of thermodynamic cycles and working fluids for the conversion of low-grade heat(2010)

[15] Mortaza Yari, Exergetic analysis of various types of geothermal power plants (2010)

[16] Ronald DiPippo, Second Law assessment of binary plants generating power from low-temperature geothermal fluids (2004)

[17] Qiang Liu, Yuanyuan Duan, Zhen Yang, Performance analyses of geothermal organic Rankine cycles with selected hydrocarbon working fluids (2013)

[18] Aleksandra Borsukiewicz-Gozdur, Dual-fluid-hybrid power plant co-powered by low-temperature geothermal water (2010)

[19] Florian Heberle, Dieter Bruggemann, Exergy based fluid selection for a geothermal Organic Rankine Cycle for combined heat and power generation (2010)

[20] Zhang Shengjun, Wang Huaixin, Guo Tao, Performance comparison and parametric optimization of subcritical Organic Rankine Cycle (ORC) and transcritical power cycle system for low-temperature geothermal power generation (2011)

[21] Mehmet Kanoglu, Ali Bolatturk, Performance and parametric investigation of a binary geothermal power plant by exergy (2008)

[22] Oguz Arsla, Ozge Yetik, ANN based optimization of supercritical ORC-Binary geothermal power plant: Simav case study (2011)

[23] Sergio Arosio, Roberto Carlevaro, Non-conventional thermodynamic converters for low temperature geothermal applications (2003)

[24] T. Harinarayana, K.K. Abdul Azeez, K. Naganjaneyulu, C. Manoj, K. Veeraswamy, D.N. Murthy, S. Prabhakar Eknath Rao, Magnetotelluric studies in Puga valley geothermal field, NW Himalaya, Jammu and Kashmir, India (2006)

[25] Cesar R. Chamorro, Maria E. Mondejar, Roberto Ramos, Jose J. Segovia, Maria C. Martin, Miguel A. Villamanan, World geothermal power production status: Energy, environmental and economic study of high enthalpy technologies (2012)

[26] C. Coskun, Z. Oktay, I. Dincer, Performance evaluations of a geothermal power plant (2011)

[27] Deniz Yildirim, Leyla Ozgener, Thermodynamics and exergoeconomic analysis of geothermal power plants (2011)

[28] John W. Lund, Direct Utilization of Geothermal Energy (2010)

[29] Anil Basaran, Leyla Ozgener, Investigation of the effect of different refrigerants on performances of binary geothermal power plants, (2013)

Appendix

Properties of refrigerant

R134a

Temp °C	Density Kg/m^3	Pressure MPa	Enthalpy, kJ/Kg		Entropy,kJ/Kg K		Specific Heat, kJ/Kg K	
			Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
90	837.8	3.2442	342.93	425.42	1.4390	1.6662	2.756	3.121
80	928.2	2.6332	322.39	428.81	1.3836	1.6850	2.065	2.012
70	996.2	2.1168	304.28	428.65	1.3332	1.6956	1.804	1.605

R600a

Temp °C	Density Kg/m^3	Pressure MPa	Enthalpy, kJ/Kg		Entropy,kJ/Kg K		Specific Heat, kJ/Kg K	
			Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
90	451.1	1.6420	434.54	667.86	1.7283	2.3708	3.110	2.625
80	469.9	1.3438	404.73	657.31	1.6469	2.3621	2.942	2.409
70	487.0	1.0875	376.17	645.77	1.5664	2.3520	2.812	2.252

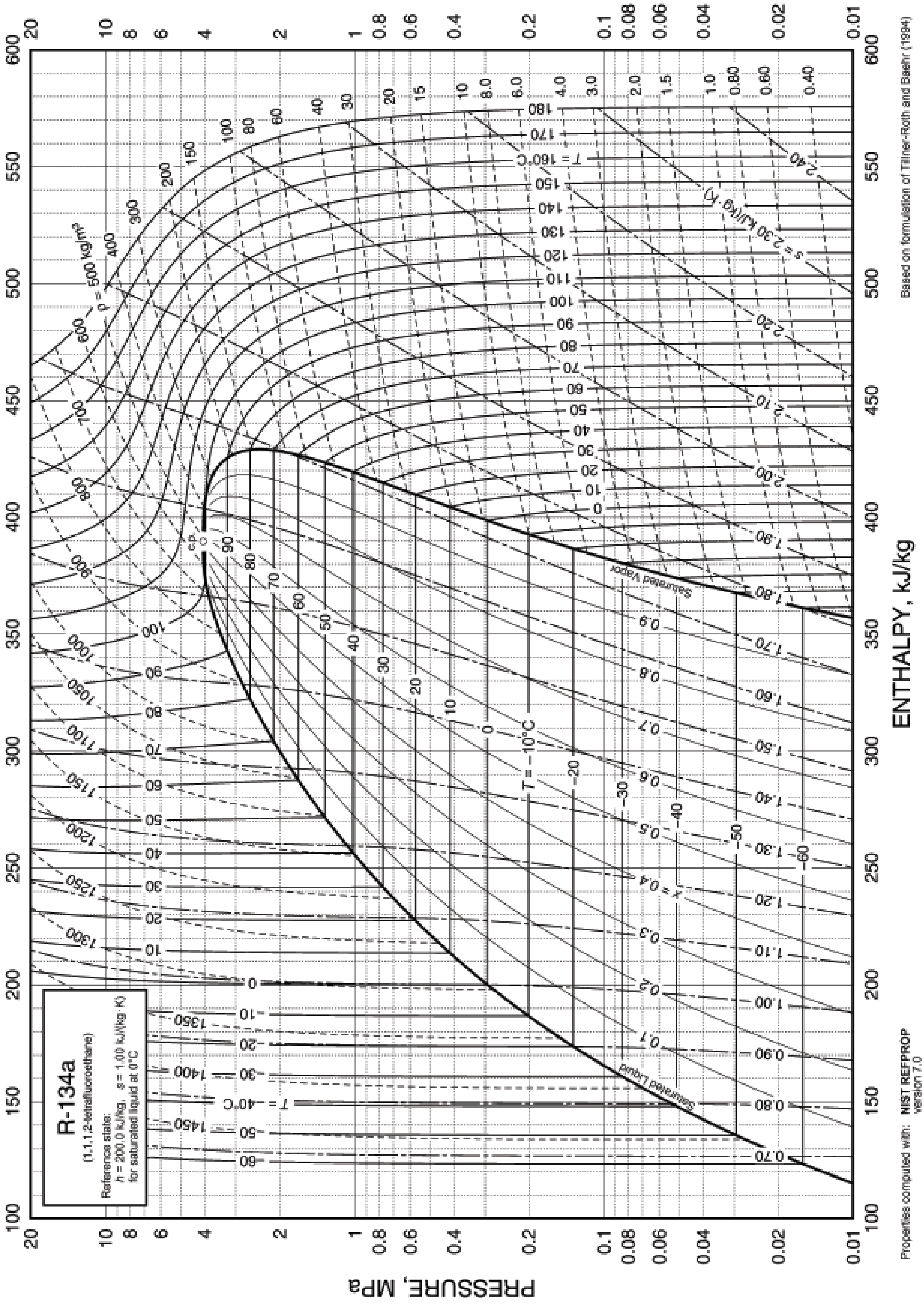
R123

Temp °C	Density Kg/m^3	Pressure MPa	Enthalpy, kJ/Kg		Entropy,kJ/Kg K		Specific Heat, kJ/Kg K	
			Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
90	1279.9	0.62423	294.45	434.43	1.2967	1.6822	1.120	0.845
80	1311.2	0.48909	283.35	428.89	1.2660	1.6781	1.100	0.816
70	1341.2	0.37722	272.42	423.20	1.2349	1.6743	1.082	0.790

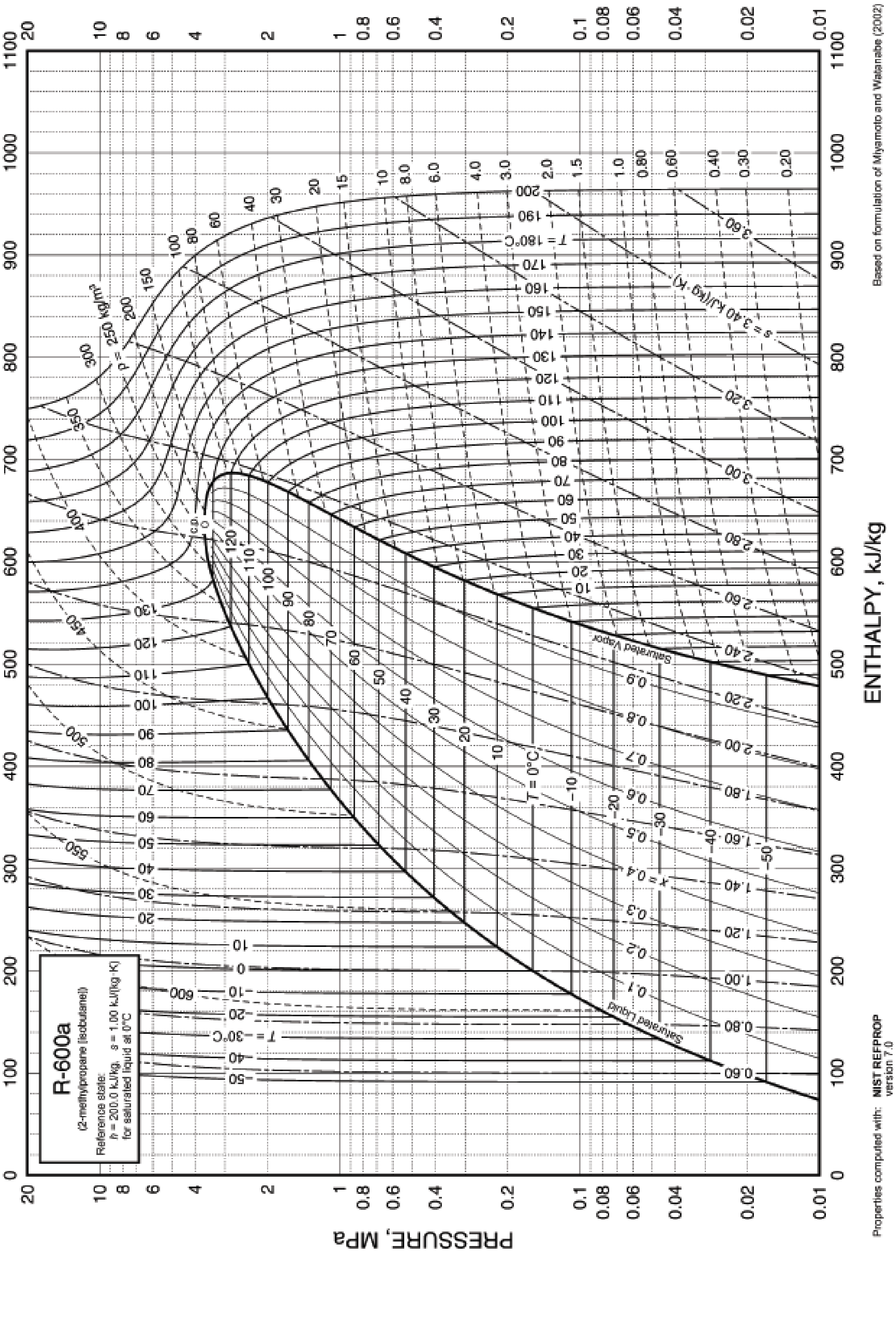
R245fa

Temp °C	Density Kg/m^3	Pressure MPa	Enthalpy, kJ/Kg		Entropy,kJ/Kg K		Specific Heat, kJ/Kg K	
			Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
90	1133.3	1.0061	324.28	468.20	1.3893	1.7856	1.532	1.272
80	1170.1	0.78931	309.24	461.75	1.3478	1.7797	1.486	1.204
70	1204.4	0.60960	294.59	455.00	1.3062	1.7736	1.447	1.147

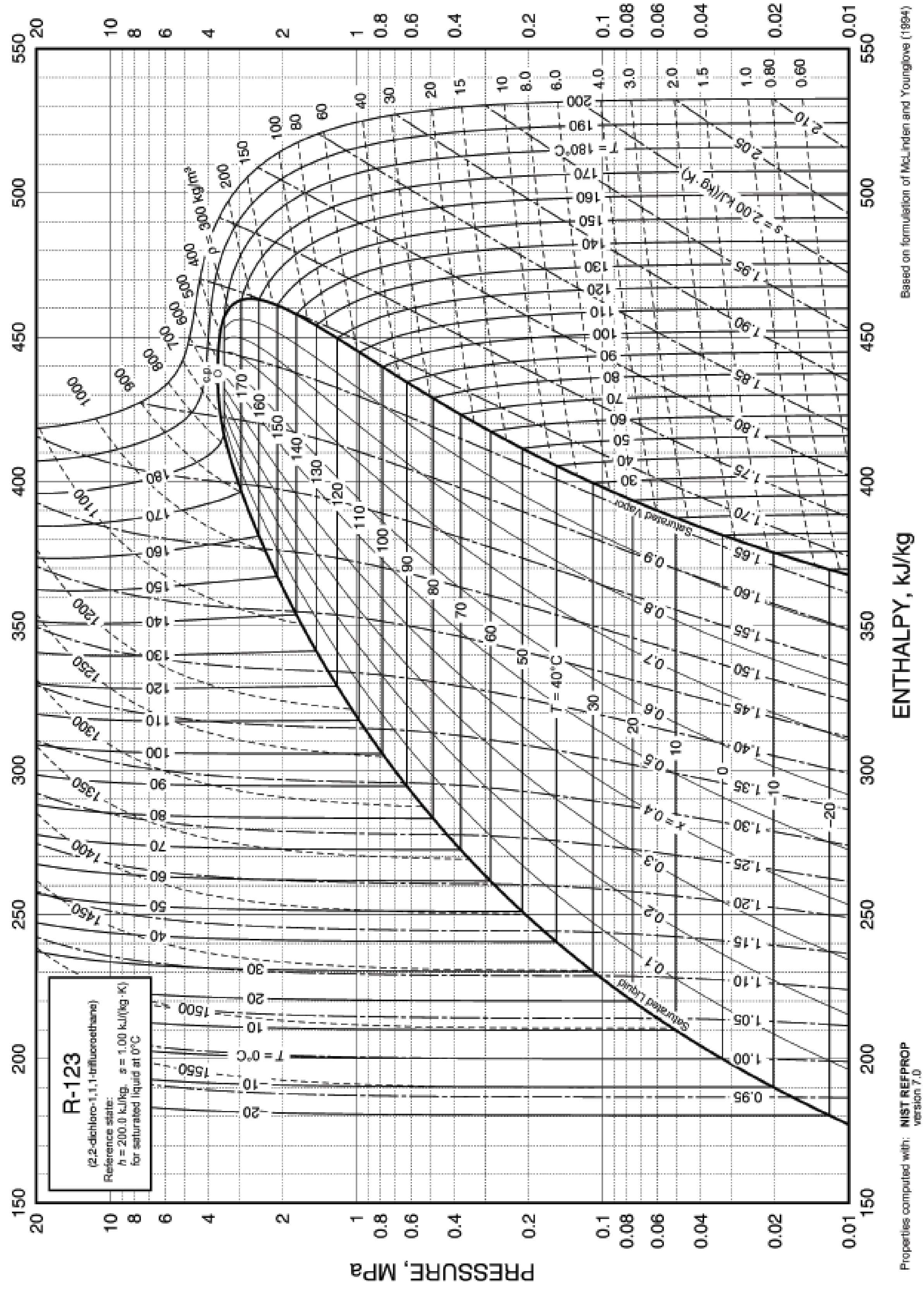
Pressure-Enthapy chart of R134a



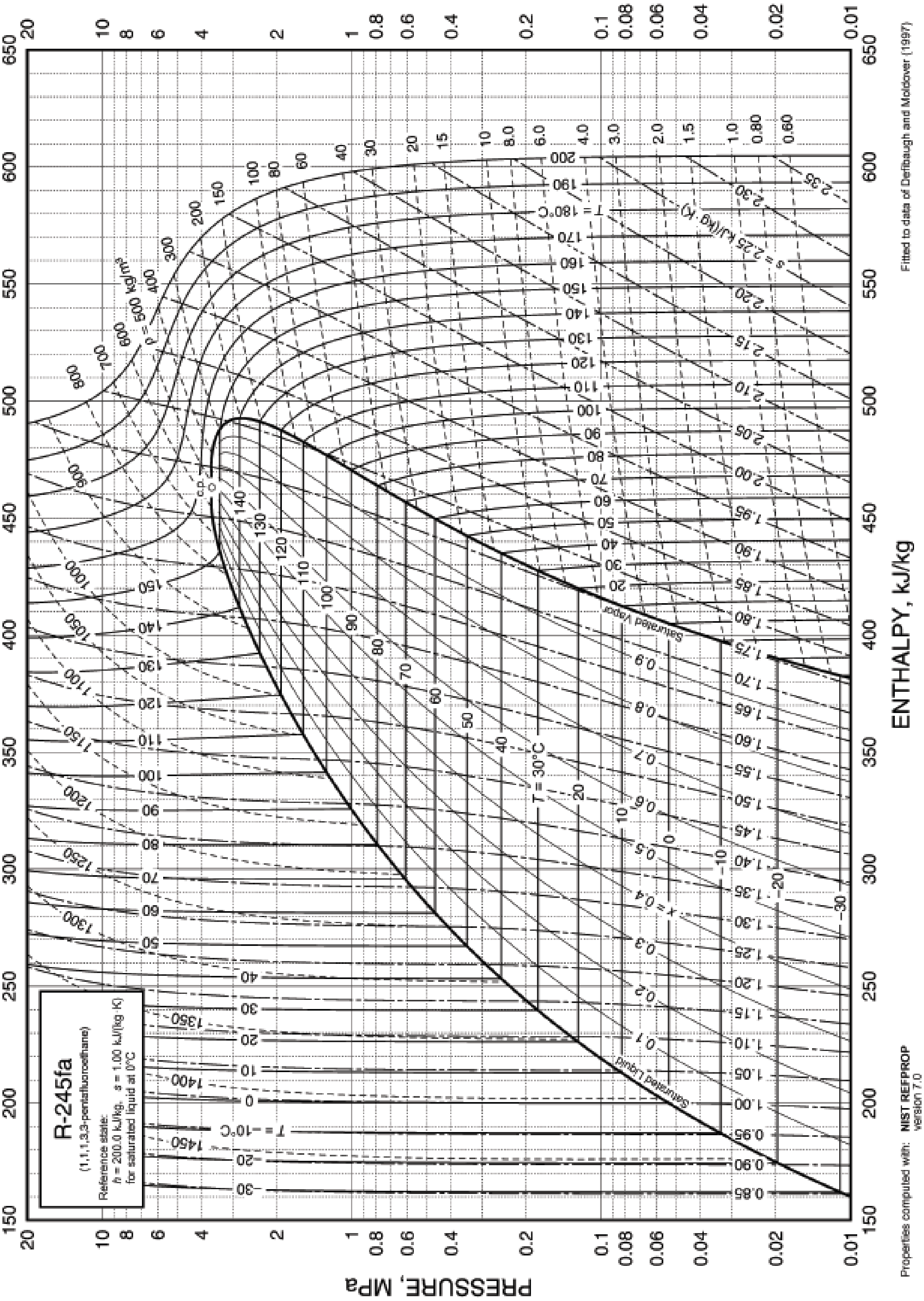
Pressure-Enthapy chart of R600a



Pressure-Enthapy chart of R123



Pressure-Enthapy chart of R245fa



Temperature-Concentration diagram of ammonia-water mixture