Study the Present Scenario of Geothermal Power Generation in the World

A Thesis submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science in Electrical and Electronic Engineering

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CERTIFICATION

This is to certify that this thesis entitled “**Study the Present Scenario of Geothermal Power Generation in the World**” is done by the following students under my direct supervision and this work has been carried out by them in the laboratories of the Department of Electrical and Electronic Engineering under the faculty of Engineering of Daffodil International University in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering. The presentation of the work was held on 31 May 2021.

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MY PARENTS

And

TEACHERS

With Love & Respect

DECLARATION

We do hereby declare that this thesis is based on the result found by ourselves. The materials of the work found by other researchers are mentioned as a reference. This thesis is submitted in partial fulfillment of the requirement for the degree of B.Sc. in Electrical and Electronic Engineering. This thesis neither in whole nor in part has been previously submitted for any degree.

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LIST OF ABBREVIATIONS

BHE	Borehole Heat Exchanger
COP	Coefficient of Performance
CHP	Compression Heat Pump
DTH	Down-The-Hole
EGS	Enhanced Geothermal System
GWh	Gigawatt Per Hour
KWh	Kilowatt Per Hour
MBT	Main Boundary Thrust
OMC	Operation Material Maintenance
Pc	Capillary Pressure
PEC	Purchased equipment cost
PPM	Parts Per Million
SCP	Safeguards Contingency Plan
SExI	Specific Exergy Index
TG	Temperature Gradient
TDS	Total Dissolved Solids
VLH	Very Lightly Hinged
WNA	Western North America
ZK	Capital Cost Rate Unit

ABSTRACT

This thesis is about the present status of geothermal energy in the world. An overall discussion on geothermal energy includes in this thesis. Geothermal energy is part of renewable energy. This geothermal energy is captured into the earth as converted heat energy. It is very cheap, reliable, available over time, and cleanest energy but has some limitations due to the energy extraction requires a high investment, a large land area, insufficient equipment, and insufficient technological progress. The system of producing electricity by the geothermal process, methods using for this energy, geothermal heat pump, geothermal wells are discussed in this paper.

This thesis discusses the different methods of geothermal energy. Where three methods like dry steam, flash steam, and binary cycle are found. Among them, dry steam is the oldest design of geothermal energy and the binary cycle is the newest and advanced design of geothermal energy. The system of producing electricity by geothermal energy first needs to have clear knowledge on Geo heating process which means Ground Source Heat Pumps (GHP) and other one is geothermal wells. This thesis has analyzed and discussed the whole process of geothermal heat pumps and geothermal wells. It also discussed the geothermal potentiality in Bangladesh. Bangladesh has the possibility to produce energy from geothermal resources, with temperatures ranging from 110 to 153°C from 304 kilometers below the surface, the regional geothermal gradient ranges from 19.8 to 29.5°C/km in the southeast, and 20.8 to 48.7°C/km in the north-west. The key sources of geothermal energy are the Rangpur Saddle (700m depth contour), Madhupur Clay (20 m) Single, Kuchma and Bogra (60-125 km), and Thakurgaon warm water area. A private company plans to build Bangladesh's first geothermal power plant, with a capacity of 200MW. The plant will be built at Salandar village in Thakurgaon impoverished northern district. A possible cost calculation for a 200 MW geothermal power plant in Thakurgaon is mentioned in this thesis.

CHAPTER-1

1.1 Introduction

Geothermal energy is a part of thermal energy that is stored under the earth's surface. It is the safest energy and also good for the climate. Recently, more than 26 countries are using geothermal resources mainly to produce electricity. It can be an effective and faithful choice for the whole world. The first geothermal production started in the United States. It began in 1960. The concept "Geothermal" is derived from the Ancient Greek words "geo," which means "earth," and "therme," which means "heat." The heat contained in the earth's crust is known as geothermal energy. Geothermal energy generates heat that comes from deep inside the earth. This heat comes from a mixture of two sources: the initial heat generated by gravitational collapse during the creation of the earth, and the heat generated by radioactive decay of different isotopes such as potassium-40 and thorium-232. The earth is taking billions of years to cool due to its poor thermal conductivity [1].

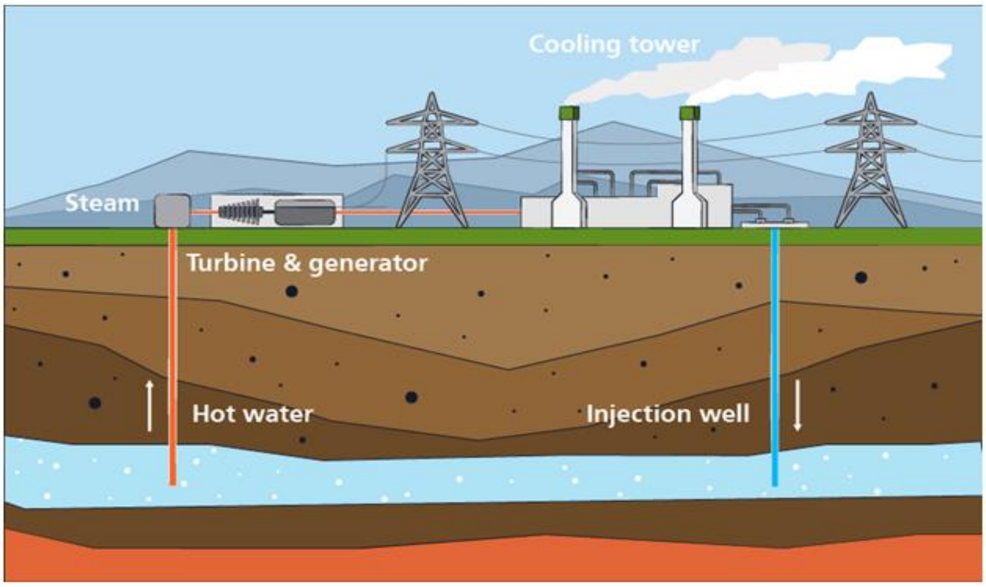


Figure 1.1**:** Geothermal Power System

These Isotopes are variations of an element's atom that have a different number of neutrons than standard versions. The nucleus of potassium, for example, has 20 neutrons. Potassium-40, on the other hand, has 21 neutrons. The nucleus of potassium-40 transforms as it decays, releasing immense quantities of energy (radiation). The most common isotopes of potassium-40 are calcium (calcium-40) and argon (argon-40), (argon-40). In a geo system, three types of geothermal plants are commonly used. Dry steam power plants, flash steam power plants, and binary cycle power plants are all examples of systems. Dry steam is the oldest form of geothermal energy, and the binary cycle is the newest and most recent style. Figure 1 shows a sample of geothermal power systems.

1.2 Background

There is lots of energy on our earth that can be extracted. Geothermal energy has been founded from the beginning of our planet. North American – Paleo Indians were the first user of geothermal energy since 10000 years ago. Since ancient Paleolithic times, the people used water from hot springs only for cooking, bathing, and cleaning but now it is well known for electricity generation. The first commercial geothermal power generation started in Pisa, Italy, in the late 18th century.

Figure 1.2: First Geothermal Power Plant in Larderello. Italy

Boric acid was extracted from the Larderello fields' hot pools using steam from natural vents (as well as from drilled holes). In 1830, Asa Thompson was the first one to commercialize geothermal energy. He produced three spring-fed baths in a wooden tub and paid one dollar for each one. Warm Springs Avenue in Boise, Idaho, was the first street to receive geothermal heat in 1892, and Italian scientist Piero Ginori Conti generated the first geothermal electric power in Larderello, Italy, in 1904. John D Grant drills a well in 1921 at the Geysers for generating electricity but he was not successful in that. After one year later he drilled a second well and this time he was successful [1]. He invented the first geothermal power plant in 1922 and the name of the power plant is “The Geysers Geothermal Power Plant”. The capacity of the power plant was 250 kilowatts. The project was canceled for lacking advanced pipes and turbines. The first geothermal power plant was started commercially in the Geysers in California in September 1960. [2]

1.2.1 Geothermal Energy's Emergence Over Periods

1. **1807:** When a European settler named John Colter visited Yellowstone, he came across hot springs, earning the name "Colter's Hell." In 1807, Hot Springs, Arkansas was founded as well.
2. **1830:** Asa Thompson charged one dollar per person for three spring-fed baths in a wooden tub, making it the first commercial use of geothermal energy.

3. **1847:** William Bell Elliot encounters a steaming gorge just north of what is now San Francisco, California. He misnamed the location "The Geysers" and thought he had found the entrance to Hell. The Geysers were converted into a spa in 1852, and future presidents Ulysses S. Grant and Theodore Roosevelt, among others, stayed there.

4. **1892:** Water was piped from hot springs to townhouses in Boise, Idaho, to create the world's first district heating system. Boise now has four district heating systems that provide heat to over 5 million square feet of residential, commercial, and government buildings. The same method is used in 17 districts across the United States and dozens more around the world at the same time.
5. **1904:** In the Larderello dry steam field in Tuscany, Italy, Prince Piero Ginori Conti invented the first geothermal power plant.
6. **1948:** Professor Carl Nielsen of Ohio State University invented the first ground-source heat pump for his home, and Portland, Oregon engineer J.D. Krocker was the first to use a groundwater heat pump in a commercial building.

7. **1970:** The Geothermal Resources Council was formed to encourage the development of geothermal resources around the world. The Geothermal Steam Act was passed in the United States, which allows the Secretary of the Interior to lease public and other federal lands for geothermal exploration.
8. **1972:** The Geothermal Energy Association (GEA) is a non-profit organization dedicated to the advancement of geothermal energy. Geothermal energy for electricity generation and direct-heat applications is developed by the organization all over the world.
9. **1977:** The Department of Energy of the United States of America was created.
10. **1984:** A 20MW plant in Roosevelt Hot Springs, Utah, has begun to generate electricity. A 1.3MW binary power plant in Nevada and a 50MW power plant in Imperial Valley, California have both gone online. A 25MW geothermal plant was built in Hawaii in 1992, and a 23MW binary power plant in Steamboat Springs, Nevada, was built in 1993.
11. **1994:** To encourage the use of geothermal energy and eliminate greenhouse gas emissions, the Department of Energy developed two industry-government successfully installed. One initiative focused on accelerating the use of geothermal resources for electric power generation, while the other focused on accelerating the use of geothermal heat pumps.
12. **2000:** More legislation was passed. In 2005, the Energy Policy Act was passed, which included tax breaks and loan guarantees for various forms of energy production. In the same year, 14,800 GWh of electricity was provided, enough to power 1.3 million homes for a year. The Energy Independence and Security Act of 2007 was enacted in 2007, and it provided authorization and guidance for activities.
13. **2009:** The Geothermal Technologies Office awarded $368.2 million in grants to 149 geothermal projects across 38 US states and the District of Columbia.
14. **2011/2012:** In the first portion of 2012, the geothermal industry in the United States grew steadily, with capacity growing from 3102MW to 3187MW.
15. **2013:** The Department of Energy put a lot of money into a project that allowed it to produce zero-emission electricity for less than 6 cents per kWh using closed-loop geothermal electricity generators.

16. **2015:** Geothermal energy was used in China, Turkey, Iceland, Japan, Hungary, and, of course, the United States. According to Britannica, the world's total installed direct-use capacity was around 73,290 megawatts thermal (MWt), with 163,273 gigawatt-hours used each year (587,786 terajoules per year).
17. **2016:** The total installed capacity for electrical power generation in the world was around 13,400 MW, producing around 75,000 gigawatt-hours per year for a utilization factor of 71%, or 6,220 full-load operating hours per year.
18. **2019:** Geothermal power plants were discovered in seven US states, producing baseload power that accounted for 4% of all utility-scale generation in the country, or 16 billion kilowatt-hours.

1.3 Exploration of geothermal resources

Exploration is an important step in the geothermal resource utilization process. Its goal is to find geothermal reservoirs that can be exploited and to choose the best options for drilling production wells with the highest level of technology. Geothermal exploration employs a variety of methods and techniques drawn from various fields of Earth science to locate reservoirs, characterize their conditions, and optimize well placement (geology, geophysics, geochemistry, drilling technology, and so on). In geothermal resource exploration, geologic mapping, geochemical analysis of water from hot springs, and mining-related geophysical techniques are frequently used. Reflection seismic surveys are becoming more popular as seismic techniques advance. Reconnaissance, pre-feasibility, and feasibility are usually the first steps in the exploration process. During each of these phases, we gradually eliminate the less interesting areas and concentrate on the most promising ones. As the program progresses, the methods used become increasingly sophisticated and detailed. To achieve these goals, a variety of methods and technologies are available. Many of these techniques are currently in use and have been extensively tested in other fields of research. Techniques and methodologies that have proven successful in mineral and oil or gas exploration may not be the best solution in geothermal exploration. Techniques not commonly used in oil exploration, on the other hand, could be ideal for finding natural heat.

1.3.1. Geochemical Methods in Geothermal Exploration

Surface fluids (aqueous solutions or gas mixtures) are thought to reflect physicochemical and thermal conditions in the geothermal reservoir at depth, according to the basic premise of geochemical exploration.

Subsurface waters: A genetic classification of subsurface waters has proven difficult to come by. Water flows away from its source and interacts with rocks along the way, making it more difficult to figure out where it came from. White (1986) proposed the following classification:

1. Meteoric water circulates in the atmosphere, coexisting with near-surface, un-cemented sediments, and has the ability to circulate in subsurface rocks and dissolve constituents like evaporates.
2. Ocean water is made up of partially evaporated meteoric water.
3. Evolved connate water can be found in young marine sediments. Salinity varies, possibly due to filtration, evaporation, or evaporate dissolution.
4. Rocks contain metamorphic water or are driven by metamorphic dehydration reactions. Because it is over pressured at depth, it may escape in response to litho-static load.
5. Magmatic water is formed when oceanic and evolved connate waters are subducted into the mantle with the oceanic crust. It is mostly due to the metamorphism of rocks at the deep crustal level.
6. Water that has never been exposed to the atmosphere is known as juvenile water. It must be extremely uncommon if it exists. Juvenile 3He and CO_2 from the mantle have been discovered, implying that juvenile H_2O exists as well, though it has yet to be definitively identified.

Geothermal waters: Geothermal waters are divided into four categories by major ions, according to Ellis and Mahon (1978).

Alkali-chloride water: Alkali-chloride water has a pH range of 4 to 11, and is most common in young rocks, such as Iceland. Although Ca concentrations in brines are often significant, sodium and potassium chloride fluids are the most common.

Acid sulfate water: The majority of the constituents of these waters are dissolved from the surface rock as a result of the oxidation of H_2S, SO_4 near the surface. As a result, this type of water is rarely used to predict subsurface qualities.

Acid sulfate-chloride water: Such water can be a mixture of alkali chloride and acid sulfate water, or it can be the result of the oxidation of H_2S SO_4 in alkali-chloride water, or it can be the result of S dissolution followed by oxidation. Sulfate-chloride waters do not need to be acidic to reflect subsurface equilibrium or predict subsurface properties.

Bicarbonate water: When CO_2-rich steam condenses or combines with water, bicarbonate water is generated; it's found in old geothermal waters and outflows on the edges of geothermal sites. They're usually in a condition of equilibrium and can be utilized to determine the qualities of the subsurface. Geothermal water's dissolved constituents come from meteoric or oceanic water to some extent. However, interactions between water and rock, as well as the addition of magmatic gases, can alter geothermal solutions further. The dissolved components are separated from rock-forming materials such as Si, Al, Na, K, Ca, Mg, Fe, Mn, and incompatible constituents such as Cl, B, Br.

1.3.2. Geophysical Methods in Geothermal Exploration

Geophysical methods used in geothermal exploration can be divided into four groups based on the physical parameters measured:

1. Methods based on rock density and magnetic properties, as well as two Earth potential fields: magnetic and gravitational;
2. Electrical and electromagnetic (EM) methods are used to study the electromagnetic properties of rocks (conductivity, permittivity) and the Maxwell equations.
3. Seismic methods based on rock elastic properties and wave propagation equations in continuous media.
4. Radiometric methods are based on rock radioactivity and atomic physics equations. The most common application of these techniques is in good logging.

1.4 Recent Geothermal Activities

Nowadays geothermal energy is lucrative and environmentally friendly. It depends on tectonic plate boundaries for producing electric power. The magma is produced in the boundary of tectonic plates which contains heat. This heat comes from a combination of two processes.

The first one is ‘Gravitational fall’ and the second one is ‘Radioactive decay’. In the case of gravitational falls, the heat produced from the construction of the earth, and in the case of radioactive decay the heat is produced by several isotopes. For this reason, geothermal plants take advantage of this volcanic activity. The geothermal resources are of four categories: magma, pressure, hydrothermal, and hot dry rock. For power generation, the hydrothermal resource is mainly used. To produce electricity the temperature of these resources should be greater than 90^oC. But if the temperature rises above 100^oC then it is called the darkest regions of hydrothermal resources which are suitable for electricity generation. All of this heating process is maintained by the Geo-Heat Center [2]. Geothermal energy is used by digging the wells deeply for a mile. Then with the help of a hot pump, electricity is generated by turning steam and hot water through a turbine. The main three types of geothermal power plants are dry steam, flash steam, and binary cycle.

1.5 Thesis objectives:

1. To study the different types of geothermal power plant systems.
2. To study the effects of geothermal energy.
3. To analysis the geothermal exploration resources and methods.
4. To discuss the reservoir formation, exploration methods, and efficiency.
5. To analysis the operation of heat pumps, their applications, and various systems.
6. To discuss the geothermal wells, well design, and drilling methods.
7. To talk about global geothermal energy production, installed capacity, environmental impacts, economics, and extraction.
8. To describe and analyze the potential areas in Bangladesh, including a possible cost analysis of a 200MW power plant in Thakurgaon.

CHAPTER-2

Methods in A Geo-System

2.1 Introduction

This chapter looks at the different methods of geothermal energy and analyzes how to work in these various methods. It also discussed several types of geothermal methods in this paper. The methods of geo-systems are:

1. Dry Steam Power Plant
2. Flash Steam Power Plant.
3. Binary Cycle Power Plant.

Among these methods, the dry steam power plant is the oldest design of geothermal energy and the binary cycle is the advance and newest design of geothermal energy. All of the subsections of every method are discussed in this chapter.

2.2 Dry Steam Power Plant

It is the oldest system that directly pulls the underground reservoir's steam and this steam travels directly to the turbine to produce electricity. To turn this turbine, it uses a minimum of

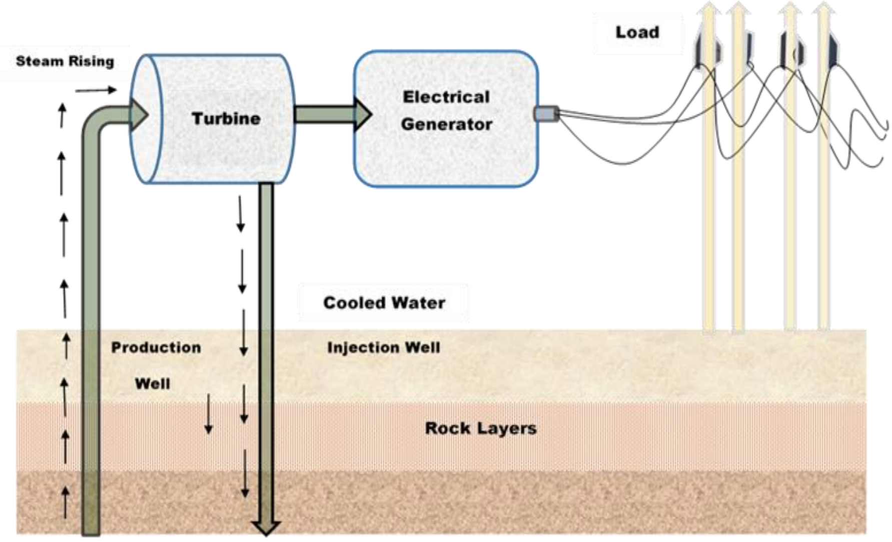


Figure 2.1: Dry Steam Power Plant [3]

150^oC of geothermal steam. The activity of the dry steam power plant is presented in Figure 2.1. Two wells are dug for this plant. The wells which pulled steam are called production well and the wells which injected steam are called injection well. Using this process, the steam travels to the surface by the production well through the turbine. After that when transferring its energy to the turbine is condensed and is injected back to the underground reservoirs by the injection well.

2.2.1 Non-Condensing Dry Steam Geothermal Power Plant

The most convenient and cost-effective way to generate geothermal energy is through the direct non-condensing cycle. There are no condensers at the turbine's outlet, so the steam from a geothermal well is simply passed through it and released into the atmosphere. Plants that use a direct non-condensing cycle require 15 to 25 kg of steam per kWhel of electricity generated. [4].

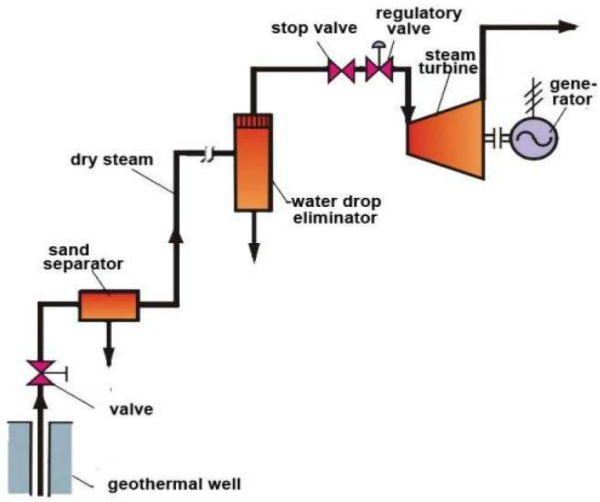


Figure 2.2: Non-Condensing Dry Steam Geothermal Power Plant [4]

2.2.2 Condensing Dry Steam Geothermal Power Plant

Since almost all geothermal energy is delivered in the form of dry steam, which dissolves 2 to 10% non-condensing gases, the geothermal plant must have a system in place to remove these gases. In most cases, a two-stage ejector is used, but vacuum pumps or turbochargers may also be used in some cases. In a geothermal dry steam power plant with vapor condensation, the vapor at the turbine exit is not discharged directly into the atmosphere, but rather passes through a condenser where a constant temperature is maintained, typically 35 to 45^oC [4].

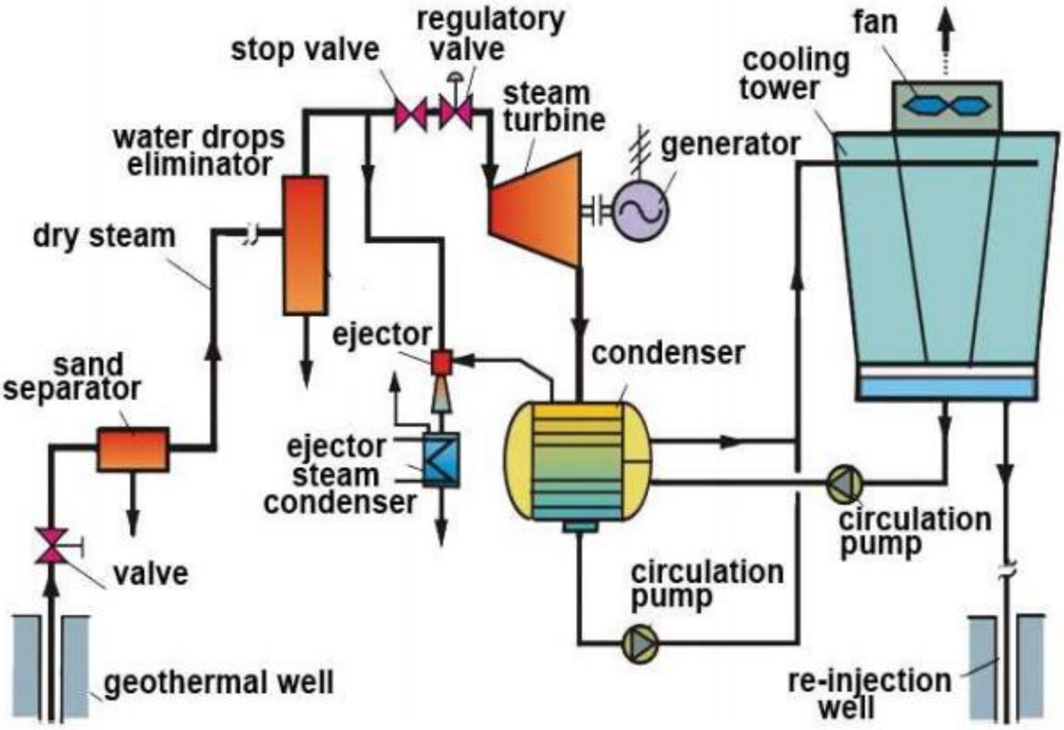


Figure 2.3: Condensing Dry Steam Geothermal Power Plant [4]

The advantage of SCPs over non-condensing plants is that they make more effective use of geothermal steam and eliminate the possibility of environmental noise emissions during steam discharge. After all, higher investments, higher maintenance costs, more complicated efficiency, and the need to cool geothermal steam make construction more costly and less favorable.

2.3 Flash Steam Power Plant

In this process, the hot water is pumped into the surface by the flash tank. A Flash tank is used for pulling the water from beneath to the surface. When this water comes to the surface, the pressure is reduced and is reduced and for this reason, some of the water goes through is reduced and for this reason, some of the water goes through the steam and this produces a blast of steam. After that, the cooled water is backed to the reservoirs by the injection well. The temperature that contains this steam is greater than 182^0C [3]. Generally, single flash and dual flash are the two Categories of flash steam power plants.

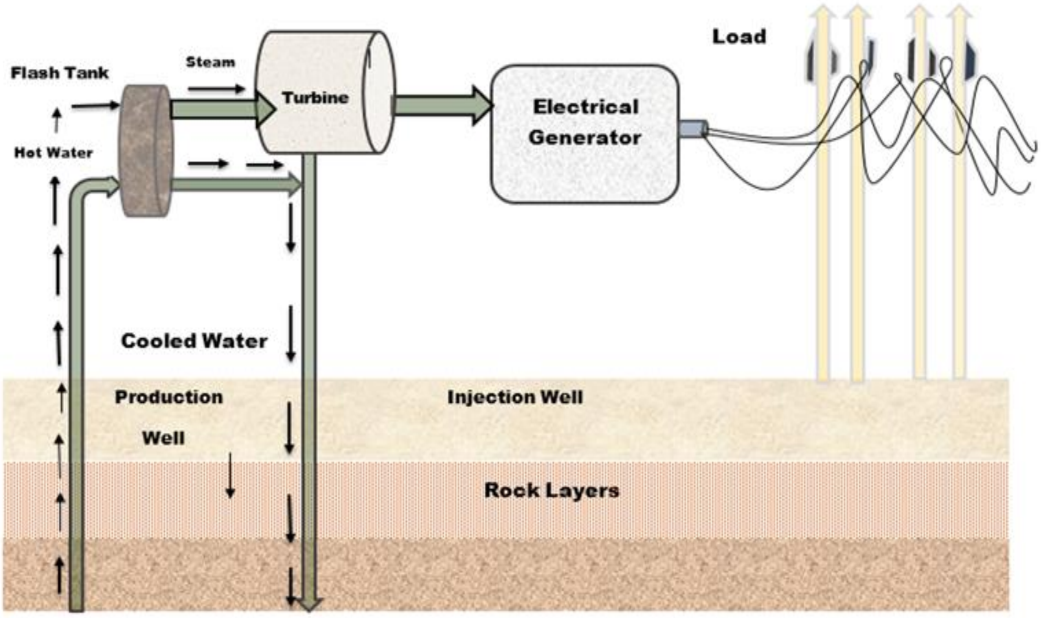


Figure 2.4: Flash Steam Power Plant [3]

2.3.1 Single Flash Steam

It is known as the most affordable flash steam power plant. The temperature in this plant is always maintained above 190^o C. Two steps occur here. One step produces steam and the other step for producing liquid (brine). These two steps are occurred by the separator. The steam goes through the turbine and the brine goes through the condenser pump by the separator. Then the steam leaves the turbine and is connected with the condenser.

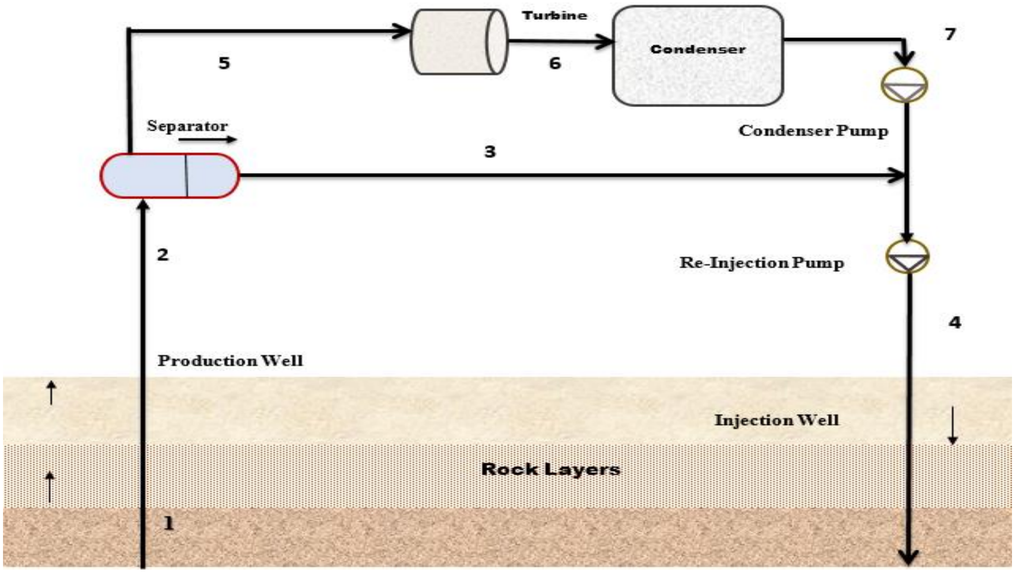


Figure 2.5: Single Flash Steam Power Plant [3]

The condenser is also connected with the condenser pump. For this reason, the steam then leaves the turbine and goes to the condenser pump. After all of this process, the steam and brine go back to the underground reservoirs by connecting with the re-injection pump. This power plant is used for 32% of all geothermal plants and the average capacity of this plant is slightly less than 28MW [3].

2.3.1.1 Single Flash Condensing System

The direct contact condenser or a heat exchanger-style condenser is usually used to condense the steam.

Each MW of electrical power needs between 6000 and 9000 kg of steam per hour. When resource temperatures exceed 150o C, flash has traditionally been used [4].

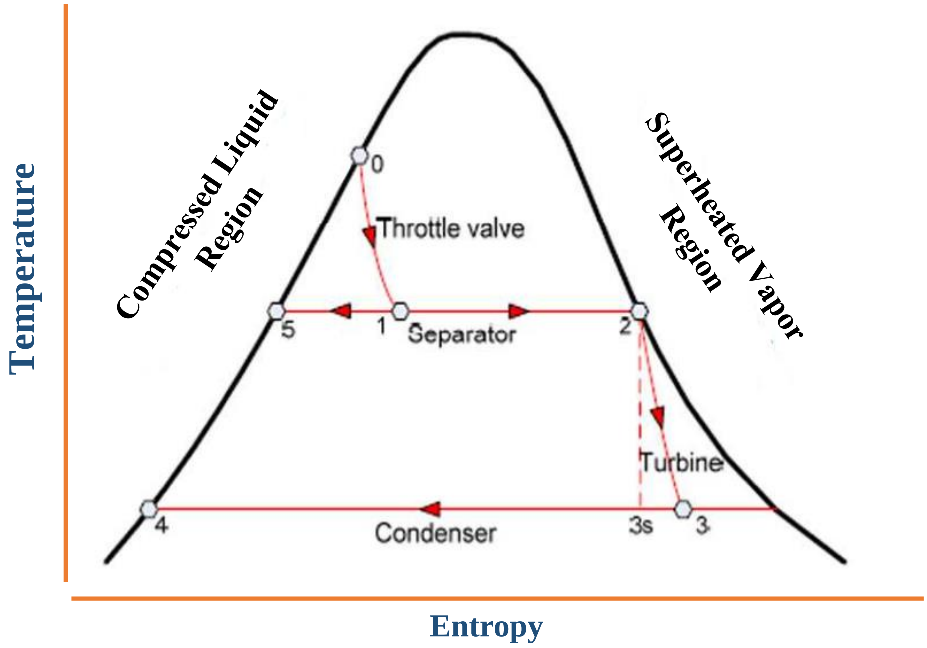


Figure 2.6: Single Flash Condensing System [4]

2.3.1.2 Single Flash Back Pressure System

The name "back pressure" is used because the turbine's exhaust pressure is much greater than that of the condensing system. There is no condenser in this device. At the same flow rate, the steam consumption per unit of power output is nearly double that of the condensing type. Back pressure units are inexpensive and easy to build, but they are inefficient (typically 10-20 tons of steam per hour for every M).

The Back pressure systems are cheap and simple to mount, but they are inefficient (typically 10-20 tons of steam per hour for every MW of electricity) and can have negative environmental consequences.

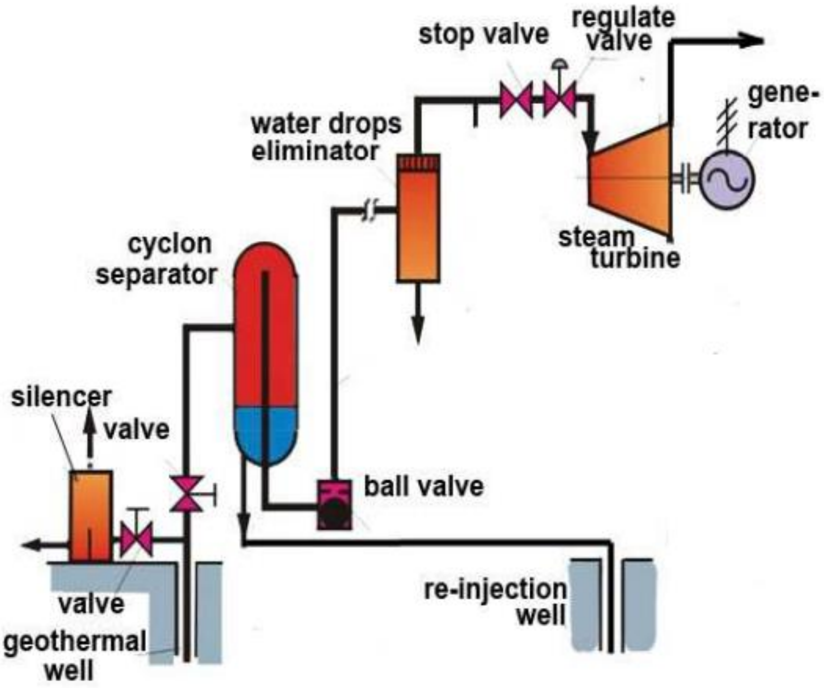


Figure 2.7 Single Flash Back Pressure System [4]

2.3.2 Dual Flash Steam

These types of plants are very much close to single flash steam power plants in case of operation. But the difference is that there are two separators are used in this power plant for producing more steam than a single flash. One is called a High-pressure separator and the other one is called a Low-pressure separator. A throttling valve that is shown in Figure 2.8, is used for connecting these two separators. This plant generates 15 to 25% more power than a single flash power plant, with a capacity range of 47 to 110 MW [3].

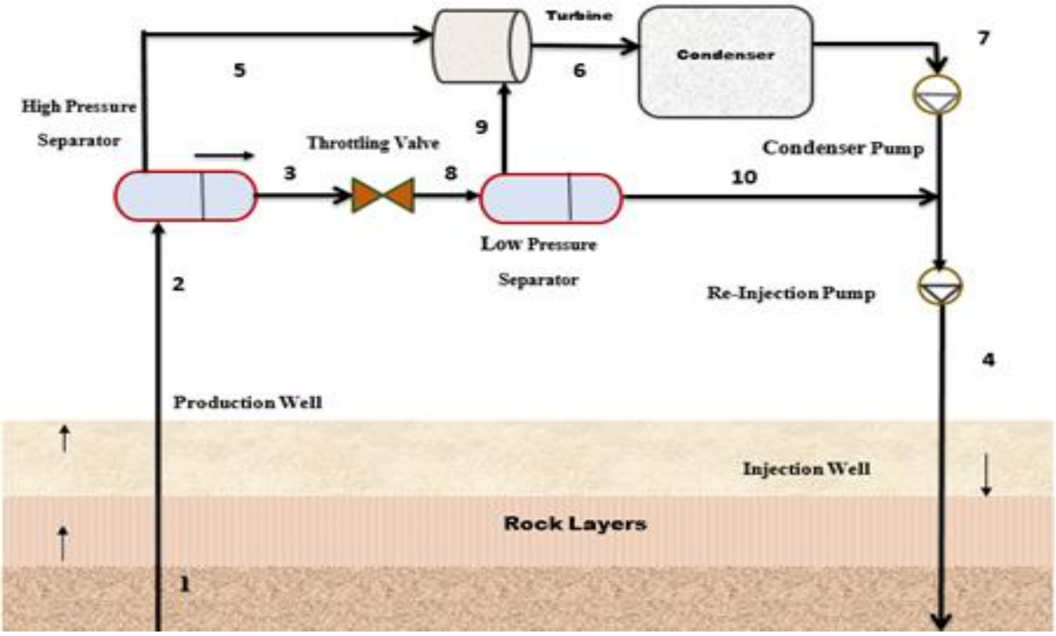


Figure 2.8: Dual Flash Steam Power Plant

Steam from the high-pressure turbine is combined with steam from the low-pressure separator before being transferred to the low-pressure turbine to generate additional power. A low-pressure separator delivers the brine to the reinjection wells.

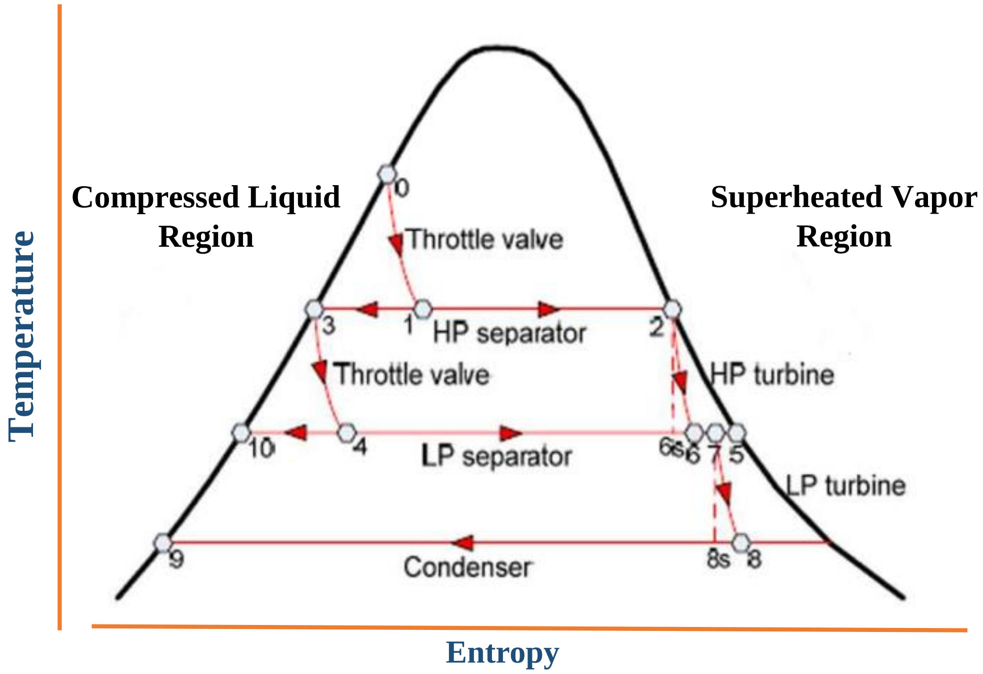


Figure 2.9: Double Flash Condensing System's Temperature-Entropy Connection [4]

2.3.3 Triple Expansion System

Designed to withstand situations where the EGS geofluid arrives at the plant at super-critical temperatures and pressures, such as 374°C and 22 MPa. A temperature of more than 374°C and a pressure of more than 22 MPa are needed.

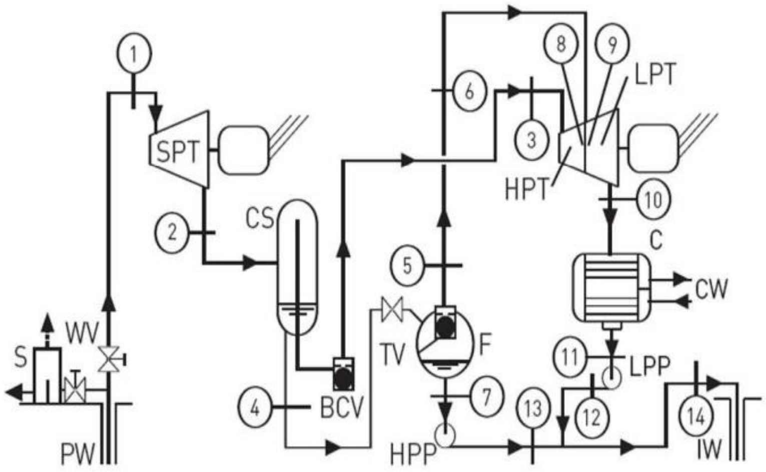
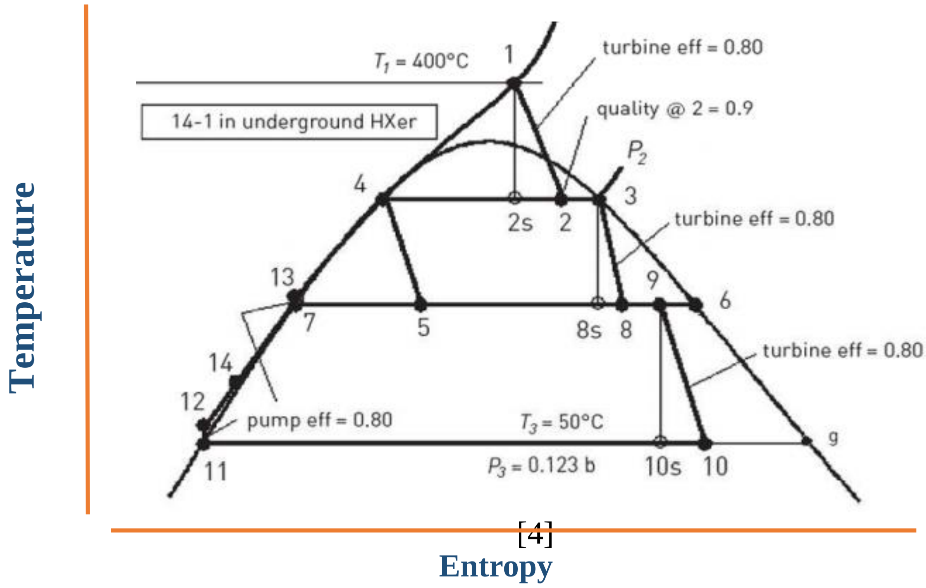


Fig 2.10: The Power plant of triple expansions for supercritical EGS fluids [4]

The turbine was designed to withstand extreme pressures. Processes for a triple expansion power plant with a utilization efficiency of approximately 67 percent and a thermal efficiency of approximately 31 percent. In either case, it would only take about 15 kg/s of EGS fluid flow to generate 10 MW due to the high specific net capacity.



[4]

Figure 2.11: Processes for A Power Plant with Triple Expansions [4]

2.4 Binary Cycle Power Plant

The binary cycle power plant is the recent development of geothermal generation. Because in this process the turbine is not directly connected with the geothermal reservoirs. There is a connector called the Heat exchanger that separates the turbine from the geothermal reservoir. In this system, the geothermal fluid is moderately heated from the lower boiling point and the temperature contains below 204^0 C. The fluid is vaporized which passed through a heat exchanger. After that, the secondary fluid drives the turbine and subsequently, the generator. The temperature range of this power plant is $100\text{-}200^0$ C.

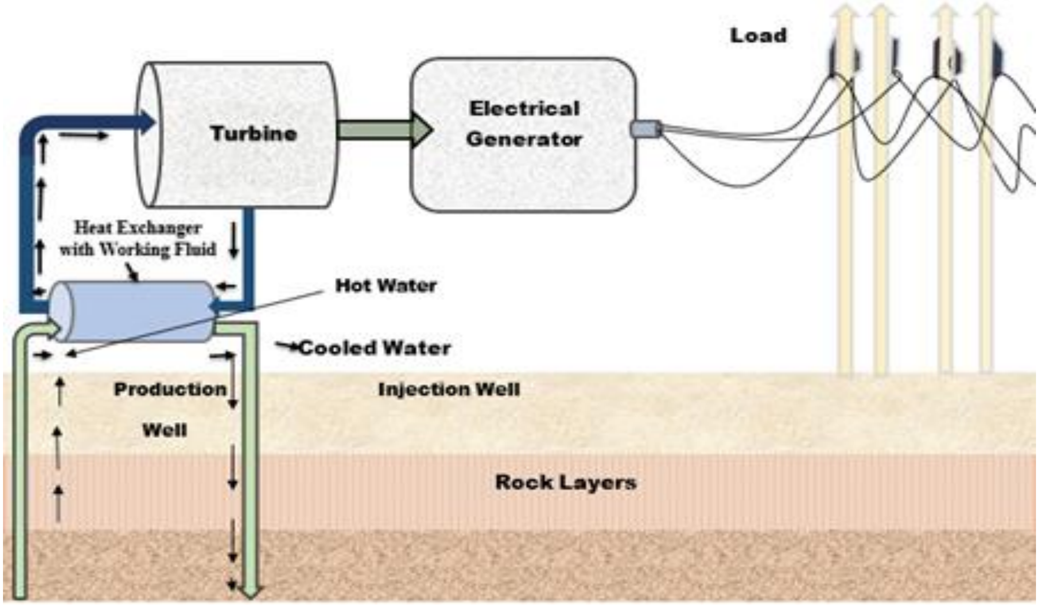


Figure 2.12: Binary Cycle Power Plant [3]

CHAPTER-3

Geothermal Reservoirs

3.1 Introduction

Geothermal energy is the energy that exists naturally within the earth's crust. In a subsurface porous, a geothermal reservoir is formed when a large amount of hot water and steam is trapped, and also a convective circulating current and permeable rock structure is established. Hochstein (1990) defined a geothermal system as "convective water in the Earth's upper crust that transfers heat from a heat source to a heat sink, usually the free surface" in a confined space. There are three main components in a geo system. They are a heat source, a reservoir, and a fluid. Figure 3.1 depicts a schematic diagram of a typical geothermal reservoir system with power plants, production, and injection wells [5].

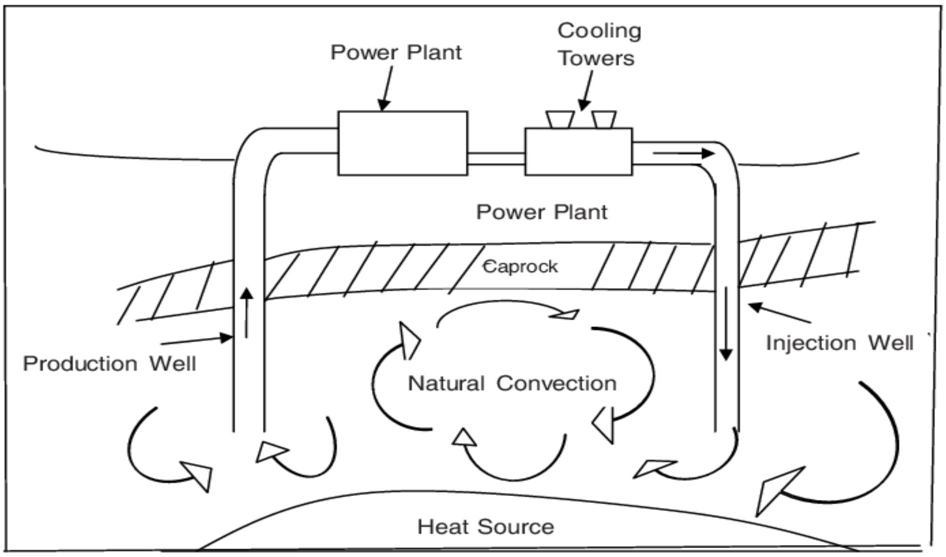


Figure 3.1: System of Geothermal Reservoirs [5]

Researchers have been looking into geothermal energy as an alternative source of energy for a long time. The reason for this is that geothermal energy is a clean and renewable source of energy with significant environmental benefits, as there are no chemical pollutants or wastes produced because of a reliable geothermal emission, and the power resource. As a result, research has been focused on a variety of topics, including geothermal resource exploration, characteristics models of various types of geothermal reservoirs, and technologies for extracting energy from them. The goal of these models was to predict the production of hot water and steam.

3.2 Nature of Geothermal Reservoir Formations

Granite, granodiorite, quartzite, greywacke, basalt, rhyolite, and volcanic tuff are some of the most common rock types found in geothermal reservoirs. When contrasted to the sedimentary formations that make up most oil and gas reservoirs, geothermal formations are hot (producing ranges from 160°C to above 300°C), abrasive (quartz percentage above 50%), heavily fractured (fracture apertures of millimeters), and under-pressured. They frequently contain corrosive fluids, and some formation fluids contain a large number of solids (TDS in some Imperial Valley brines is above 250,000 ppm). Drilling is typically difficult under these conditions because of the low penetration and bit life, corrosion is common, lost circulation is common and severe, and the majority of these issues are exacerbated by high temperatures.

Carbon dioxide (CO_2) and hydrogen sulfide (H_2S) gases are almost always present in common geothermal systems, whether dissolved or free. While all of these gases contribute to the corrosion problem, H_2S in particular limits the materials that can be used for drilling equipment and casing to lower strength steels due to sulfide stress cracking. During the drilling process, H_2S poses a significant safety risk. The cost of drilling geothermal wells rises as a result of these material limitations and the associated safety risks.

When water is heated by the earth's heat, hot water or steam can be trapped in permeable and porous rocks beneath a layer of impermeable rocks, resulting in the formation of a geothermal reservoir. A geothermal reservoir is a natural collection of hot water. Figure 3.2 shows the formation of the geothermal reservoirs.

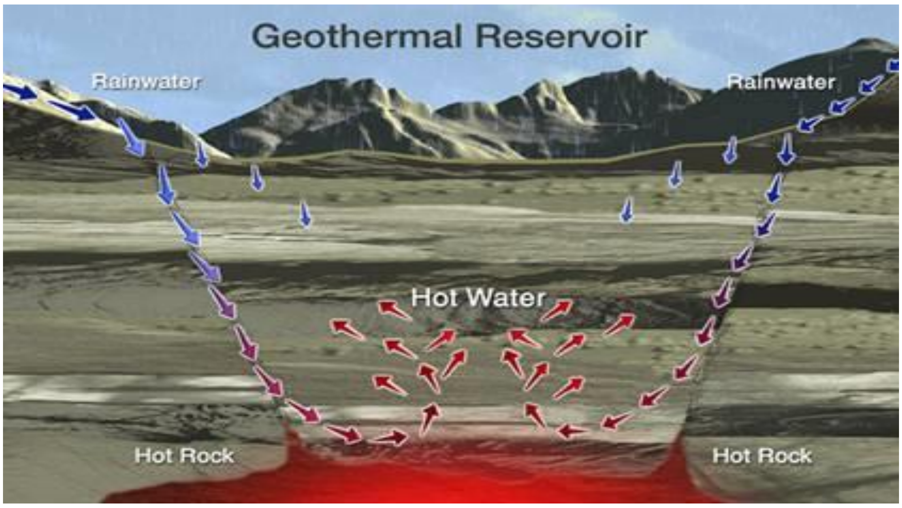


Figure 3.2: Geothermal Reservoir Formation [5]

3.3 Aspects of Mathematical Equations

The simulation of a geothermal reservoir requires a mathematical model which is well-constructed. This process is an acceptable numerical solution of the system. To create this acceptable solution of the system, you'll need to know or understand:

1. The reservoir is undergoing physical and chemical changes.
2. The system's initial conditions and the boundary conditions at the system's edges.
3. The spatial variation of hydrogeologic parameters (porosity, permeability, and so on).
4. Density, viscosity, enthalpy vapor pressure, and other fluid properties.
5. The flow rates and locations of sinks and sources.

The governing equations for geothermal reservoirs can be written with various sets of variables. As examples, density-internal energy, pressure-temperature-saturation pressure enthalpy, and pressure-temperature-saturation enthalpy. The partial differential equations that govern the system are listed below [5].

3.3.1 Mass Balance

Water (w), the wetting phase, and steam (s), the non-wetting phase, both of which are commonly found in geothermal systems, have mass conservation equations.

$$\text{Steam:}\quad \frac{\partial(\phi S_s \rho_s)}{\partial t}+\nabla\cdot(\rho_s \vec{v}_s)-q_s-\dot{m}=0 \qquad \text{................ (1)}$$

$$\text{Water:}\quad \frac{\partial(\phi S_w \rho_w)}{\partial t}+\nabla\,(\rho_w \vec{v}_w)-q_w+\dot{m}=0 \qquad \text{................ (2)}$$

Here φ represents the porosity, S is the saturation, ρ is the density, q is the source term, ν is the averaged phase velocity and m represents the mass transfer rate from liquid to vapor [5].

3.3.2 Momentum Balance

Newton's second law is commonly used to express momentum conservation equations. Darcy's Law is applied in this case to multiphase flow through porous media. It should be noted that it is only applicable to a fractured system. A single fracture cannot be used to describe the flow. It can be used as a momentum or dynamic equation for fluid flow analysis in a geothermal reservoir medium that consists of a system of fractures. The equations are as follows:

$$\vec{v}_s=-\frac{\mathbf{K}k_{rs}}{\mu_s}(\nabla p_s-\rho_s g\nabla D) \qquad \text{................ (3)}$$

$$\vec{v}_w=-\frac{\mathbf{K}k_{rw}}{\mu_w}(\nabla p_w-\rho_w g\nabla D) \qquad \text{................ (4)}$$

Where K is the intrinsic permeability tensor or relative permeability, D denotes depth, p denotes phase pressure, and g denotes gravitational constant. [5].

3.3.3 Energy Balance

Pressure and enthalpy are used as primary variables in energy balance equations. Here, we use the assumptions of zero capillary pressure and local thermal equilibrium [5].

$$\frac{\partial}{\partial t}[\phi\rho h' + (1-\phi)\rho_r h_r'] - \nabla\cdot[\frac{\mathbf{K}k_{rs}\rho_s h_s'}{\mu_s}(\nabla p - \rho_s g\nabla D)] -$$

$$\nabla\cdot[\frac{\mathbf{K}k_{rw}\rho_w h'_w}{\mu_w}(\nabla p - \rho_w g\nabla D)] - \nabla\cdot[K_m\left(\frac{\partial T}{\partial p}\right)_h \nabla p$$

$$+K_m\left(\frac{\partial T}{\partial h'}\right)_p \nabla h'] - q_h = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

T represents the temperature and q_h is the source/sink term.
where ρ is the density of the total steam-water mixture, given by

$$\rho = S_w\rho_w + S_s\rho_s \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

with the sum of the individual phase, saturation equals to 1

$$S_w + S_s = 1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

h_w', h_s' and h_r' are the enthalpies of water, steam, and rock respectively and h' is the enthalpy of water-steam mixture and is given by

$$h' = \frac{Ss\rho sh's + Sw\rho wh'w}{\rho} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

The numerical complexity of the governing equations of geothermal reservoirs is affected by the capillary pressure (Pc) and relative permeabilities of the phases (Kr). Constitutive relations are the relationships that characterize this dependency and are required to fully explain the structure. The capillary pressure can be expressed as

$$p_c = p_s - p_w \qquad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where p_s is the non-wetting phase pressure of steam and pw is the wetting phase pressure of water.

The Brooks and Corey (1964) p_c-S_w, k_r-S_w relations are given by

$$p_c = p_d S_e^{-\frac{1}{\lambda}}$$

$$k_{rw} = S_e^{\frac{2+3\lambda}{\lambda}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(10)}$$

$$k_{rnw} = (1-S_e)^2 (1-S_e^{\frac{2+\lambda}{\lambda}}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(11)}$$

Where λ is the pore size distribution index, and pd is the entry or displacement pressure for the fracture media. Se denotes the wetting fluid's effective saturation and is calculated as follows:

$$S_e = \frac{S_w - S_{rw}}{1 - S_{rw} - S_{rnw}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(12)}$$

The residual saturations for the wetting (water) and non-wetting (steam) phases are Srw and Srnw, respectively. The relative permeabilities of the wetting and nonwetting phases are krw and krnw [5].

3.4 Conceptual Models

3.4.1 Geothermal Conceptual Models

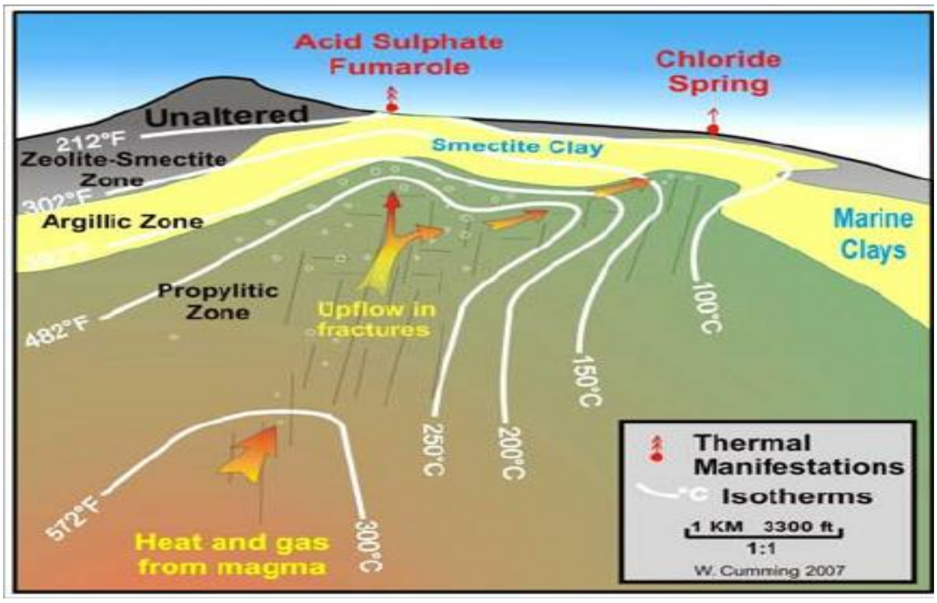


Figure 3.3: A Cross-Section of a 250 to 300°C Geothermal Reservoir as a Conceptual Model [6]

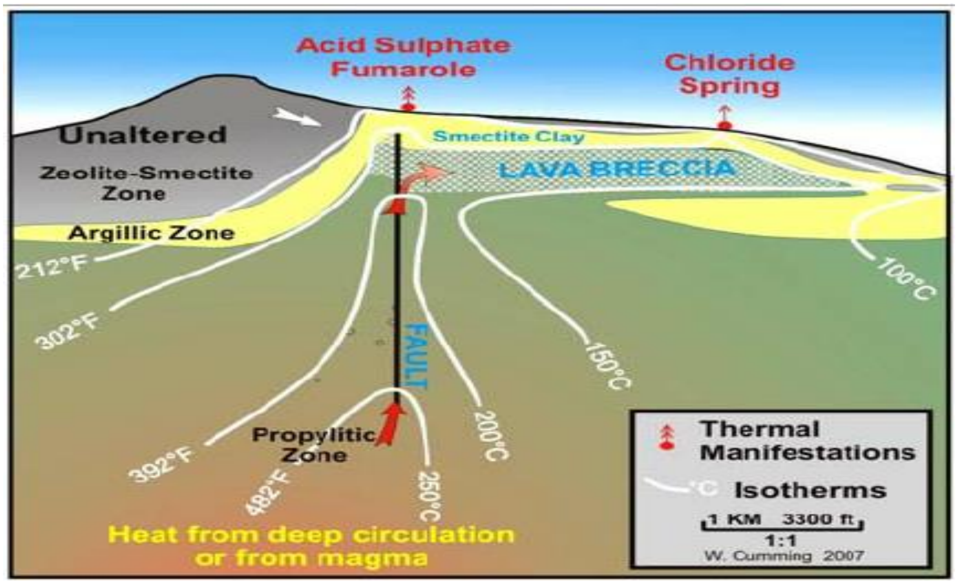


Figure 3.4: A Cross-Section of a 150 to 200°C Geothermal Reservoir in a Conceptual Model [6]

The most prominent surface data sets in constraining reservoir parameters at the exploration stage over the last decade have been cation and gas geochemistry from thermal manifestations, as well as MT resistivity evaluated in the context of basic geology and hydrology. It’s also important to map active surface alteration. As systems, temperature gradient wells, and structural mapping methods have become more popular with more modest surface manifestations in structural situations like the US Basin and Range receiving increased attention. Cross-sections and maps are used to integrate these data sets into a conceptual model [6].

3.4.2 Interpreting Isotherms on Cross-Sections

Cross-sections are a more intuitively attractive format than maps for evaluating how the buoyant flow of higher temperature water would interact with a geothermal reservoir's permeability distribution. The isotherm pattern in Figures 3.3 and 3.4 is strongly related to the permeable and impermeable portions of the conceptual models.

1. **Upflow and Outflow**

The upflow zone, for this paper, is the reservoir zone where flow is primarily vertical and the temperature rises with depth. Like on the right side of the upflow in Figure 3.4, the outflow is mostly horizontal, and the temperature drops as you go deeper into the major outflow zone. The outflow is still buoyant at temperatures above 100°C, so there is some upward movement.

2. Realistic Isotherm Patterns

The top limit on isotherm values at any given depth is the boiling point of water as a function of depth, assuming a hydrostatic pressure gradient defined by the water table. According to thermodynamics and fluid flow principles, isolated high and low-temperature zones are either transients or flow in and out of the plane of a cross-section. In exploration models, an arrow head or tail should be utilized to illustrate the interpreted flow direction. Because the isotherms are related to heat transfer via conduction and fluid flow, with fluid flow being more essential, arrows indicating the direction of fluid movement, as illustrated in Figures 3.3 and 3.4, are useful.

3. Permeable Zones

The temperature gradients in permeable zones will be reduced, as shown by the contour spacing of 250 to 300^{0}C in Figure 1 and 150 to 200^{0}C in Figure 3.4. The two models depict two different permeability distributions. Fluid upflow in fractures is the ultimate source of heat in both. In many reasonably high-temperature volcanic systems, cracks are associated with practically all permeability that is relevant to optimal deliverability (see Figure 3.3). Figure 3.4 shows a Basin and Range system with upflow in a small fault zone. [6].

4. Impermeable Zones

Permeability is low Where isotherms are regularly and densely spaced, implying a large linear gradient. This does not rule out the possibility of fluid movement, but it is likely to be less than in areas with more widely spaced isotherms.

5. Juxtaposed Permeable and Impermeable Zones

Permeability is low where isotherms are near together, signifying a large temperature differential, as shown in Figures 3.3 and 3.4 by the clay cap colored yellow. Both sides of the impermeable zone have permeable zones, signifying a steep gradient. The top of the impermeable clay cap in Figure 3.3 is kept cool by a cool meteoric aquifer, while the bottom is heated by permeability reservoir upflow and outflow.

6. **Cooler Water Entering an Upflow**

Cooler water can enter a geothermal upflow zone, but to keep the geothermal system stable, most cold inflows must be minor leaks or permeable channels with limited linkages to the upflow. Cooler water can enter from either side and due to the cooler water column's higher density outside the reservoir, it may be at a higher pressure. Figures 3.3 and 3.4 depict isotherm patterns that indicate deep convective return flow toward reservoir upflow, but conductive heat loss could account for much of the pattern, therefore no arrows are given.

3.4.3 Blind Geothermal Systems

As exploration continues in a region and top-ranked prospects are developed, the types of manifestations utilized to constrain the isotherms of the conceptual models in Figures 3.3 and 3.4 become less plausible. The conceptual elements of blind geothermal systems can be effectively constrained using traditional geothermal geoscience data sets. Another benefit of this method is that the process of constructing a conceptual model typically reveals another benefit: it both characterizes uncertainty and identifies techniques for efficiently dealing with the higher risk of exploring such prospects. The following synthetic scenario is a compromise between real-world circuitous thinking and real case histories' results-oriented orientation. This scenario is for a blind prospect in which sediments cover broken Paleozoic metamorphic rocks, which can be found all over the world, notably in the US Basin and Range and Turkey. [6].

1. **Exploration Data**

The findings of a typical exploration program, which included thermal manifestation, MT resistivity, geology, and structure investigations, are depicted in Figure 3.5. A steeply dipping normal fault has Paleozoic schist on the left and Recent sediments on the right. The sediments have a low resistivity, as one would expect if there was a lot of clay in them, but from below, a greater resistivity zone appears to intrude into the sediments. At a depth of over 2000 m on the left (upthrown) side of the fault, an isolated, massive low resistivity zone occurs. Aside from an inactive sinter deposit, there are no thermal manifestations at the surface.

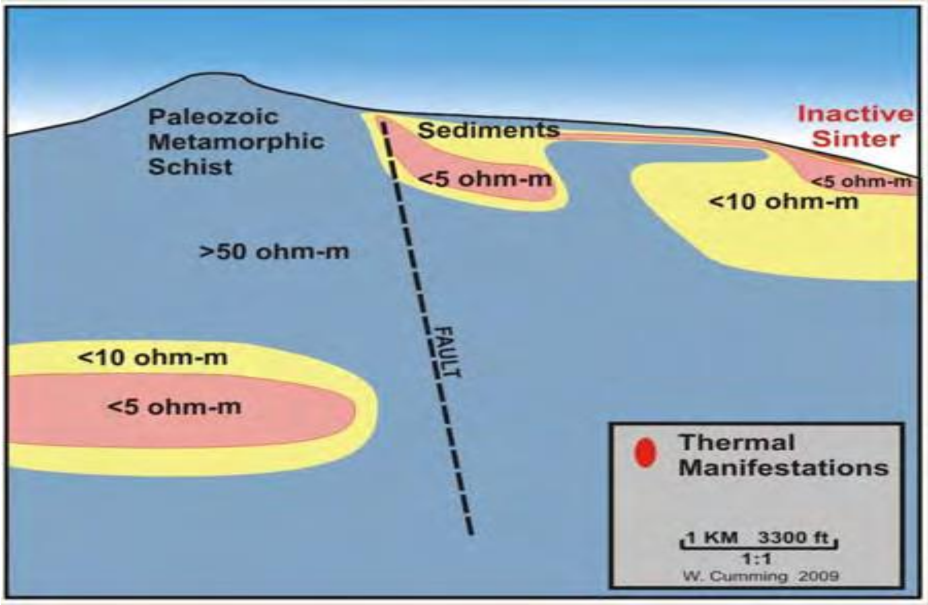


Figure 3.5: MT Resistivity Cross-Section of a Blind Geothermal Prospect annotated [6]

2. **Exploration Scenario**

The upflow is thought to occur between the fault and a location about 800 meters to the right, underneath the area where the clay cap's 5 ohm-m portion (red) extends to a depth of about 500 meters. It's realistic to predict increased upflow where the resistive (blue) zone continues into the sediments. It looks to be a structure that hosts an upflow, which encounters an almost flat aquifer (blue) that spans over 1000 meters to the right and finishes near the sinter at around 250 meters depth. That geometry fascinates me. Despite the fact that the sinter is no longer functioning, it shows that temperatures of around 180°C were once extremely close. The flat-lying resistive (blue) zone is about 200 meters below the water table and is appropriate for hosting an aquifer with a temperature of 180 degrees Celsius without boiling (and creating gas that is not visible). The sinter's inactivity could be caused by a slight dip in the water table. Because temperature is still the largest concern, a 250 m narrow hole close to the right of the final "s" in the label "Sediments" could be a cost-effective test of this idea. It would be built to extract a clean sample of water from a high-resistivity aquifer. To continue with this scenario, after digging Well A, the aquifer is discovered to be a silicified sandstone at a depth of 250 meters with a temperature of 100°C. The temperature lowered as a result of the small production enabled by a slim opening. The cation geothermometric is 200 degrees Fahrenheit, on the other hand [6].

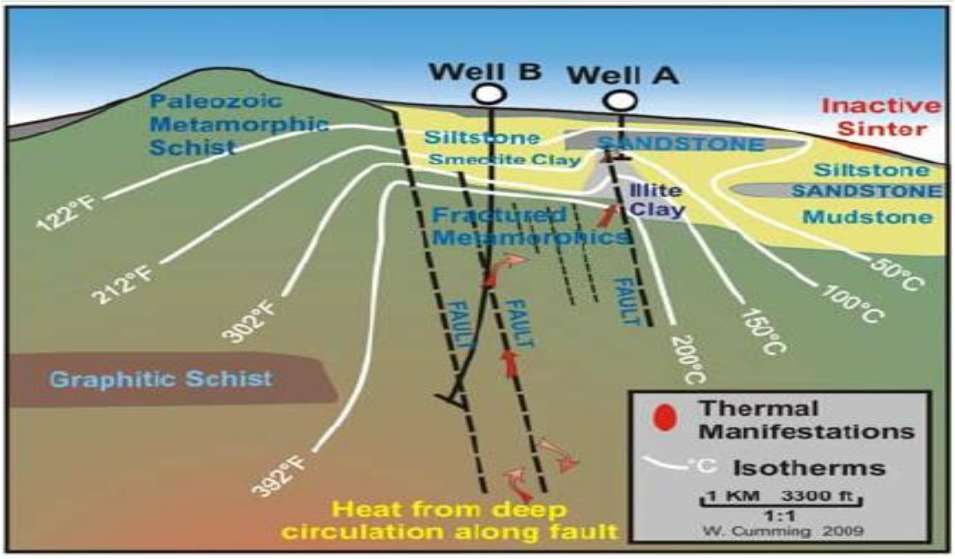


Figure 3.6: A 200°C Blind Geothermal Reservoir Cross-Section Conceptual Model [6]

The conceptual model in Figure 3.6 could be assembled using the data from the first Well A, and a Well B could be targeted directionally across as many structures as possible between Well A and the main fault. In a conceptual model for a blind system without surface manifestations, a method to prevent fluid and gas from leaking to the surface must be incorporated. In this situation, the clay cap is extremely thick.

3.4.4 2D and 3D Models

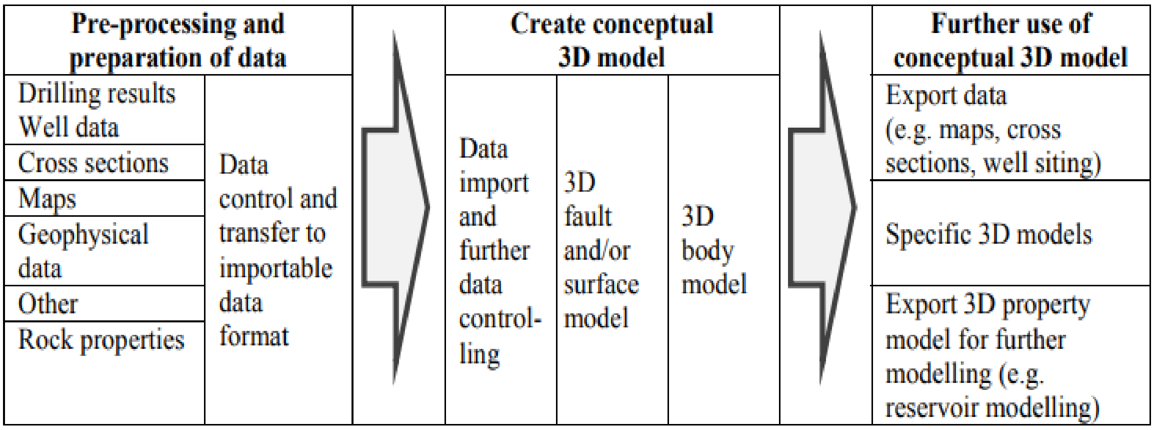
The relevant data and interpretation results for the various disciplines involved in geothermal research and development are described in various presentations during the current short course, but the development of conceptual models, particularly in 3D, will be outlined in the following section.

More data is obtained from the subsurface as geothermal field exploration progresses with the start of drilling. Despite the spatial relationship of the data, 2D cross-sections have been the main form of presentation of subsurface data and models for many years.

As mentioned previously, 3D software programs must be capable of integrating a wide range of geological, geophysical, and geochemical data[7]. Table 1 shows the steps involved in creating a 3D model, but they can be broken down into at least five categories:

a. Data preparation and quality control,
b. Data import and quality control,
c. Creating a surface and/or fault model (e.g., Stratigraphic boundaries in a geological model),
d. Creating a 3d property model, and
e. Model presentation in 2d and 3d.

Table 3.1:The Work Method for Developing 3D Models [7]



Pre-processing and preparation of data			**Create conceptual 3D model**				**Further use of conceptual 3D model**
Drilling results Well data	Data control and transfer to importable data format		Data import and further data controlling	3D fault and/or surface model	3D body model		Export data (e.g. maps, cross sections, well siting)
Cross sections							
Maps							Specific 3D models
Geophysical data							
Other							Export 3D property model for further modelling (e.g. reservoir modelling)
Rock properties							

The first step after importing data into the software program is to create a surface model, which will define the data boundaries, such as strata boundaries, faults, and aerial coverage of data, whether it is well locations or the extent of surface exploration (Figure 3.5). Because faults and fractures control permeability in volcanic-hosted geothermal fields, there is a strong emphasis on characterizing faults in the geological model through correlation of good data, seismic data, and surface geology. Many geological models are so-called deterministic models, which fully acknowledge the data. As a result, the fault and strata boundaries define the geological model (Figure 3.6)

The next step is to create a 3D body (property) model once the model's boundaries have been defined, but this is a three-step process. The first step is to draw a grid within the model's boundaries. The second step is up-scaling, which involves averaging data (such as well data) into the grid model's layers, but Figure 3.7 shows an example of comparing the formation temperature log with up-scaled formation temperature in the preparation of the temperature model.

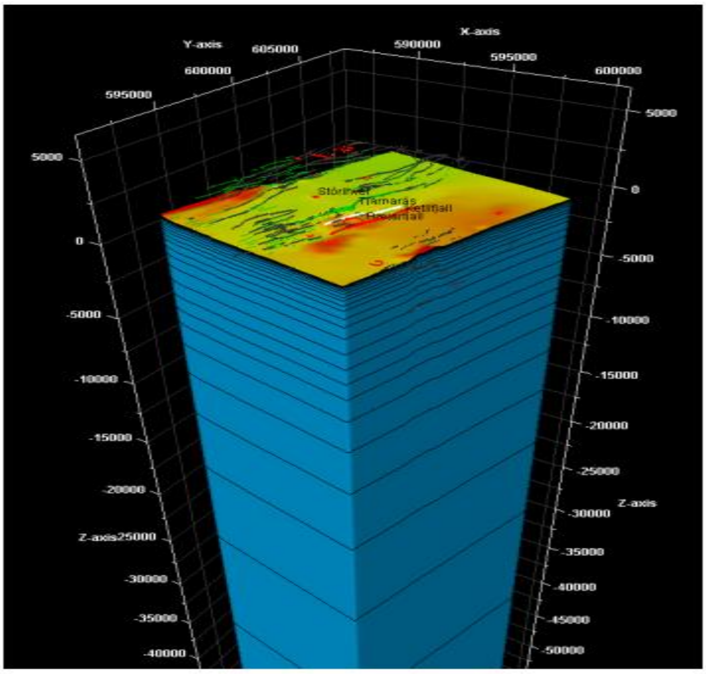


Figure 3.7: Building Blocks of the 3D Body/Property Model [7]

Because up-scaling reduces the resolution of the data, it's critical to make sure the up-scaled data maintains a statistically acceptable distribution in comparison to the input data to avoid introducing errors into the model [7].

CHAPTER-4

Analysis of Geo-Heat Pumps & Wells

4.1 Introduction

Geothermal heat pumps are also known as ground source heat pumps (GHPs) since the late 1940s. It is also known as Geo-Exchange, water-source, and earth-coupled heat pumps. It has been in operation since the late 1940s. They use the earth's constant temperature instead of using the outside air temperature as the exchange medium. It regularly utilizes the earth as either a heat source (in the winter) or a heat sink (in the summer).

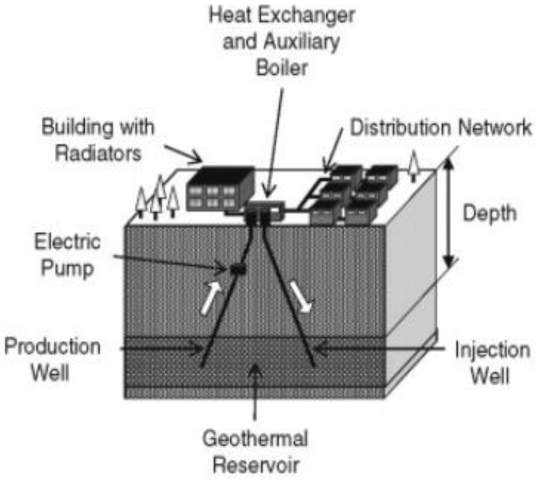


Figure 4.1: Geothermal Heating Process [3]

The design of these GHP systems is used to increase performance and lower operating costs of heating and cooling systems by taking the ground's moderate temperatures advantage, and it can be combined with solar heating to create a geo-solar system with even higher efficiency. Geo-exchange, earth-coupled, and earth energy systems are some of the other names for them. Engineers and scientists prefer the terminology "geo-exchange" or "ground source heat pumps", for producing electricity to avoid the conventional geothermal power confusions. This conventional geothermal power uses as a high-temperature heat source.

heat pumps." Heat is absorbed in the Earth's surface by ground source heat pumps, which are driven by solar energy. The ground temperature is approximately equivalent to the local mean annual air temperature below 6 meters (20 feet). Figure 4.1 shows the heating process of geothermal power generation. The four categories of a geothermal heat pump. Among them, three categories are based on the closed-loop system and one category is based on the open-loop system.

If we talk about Geothermal wells, they are different from any other wells of other industries. The shallow well's depth is normally 1000 m and the deep geothermal well's depth is 2000m. For wells depth, three types of diameters like 95/8, 113/4, 133/8 are used and 95/8 is standard for 1000 m shallow wells. But 133/8 is standard for 2000 m deep wells. Figure 4.2 shows the design of geothermal wells. The geothermal wells are designed based on the types of geothermal systems. Two types of geothermal wells are used in geo-energy. They are self-discharging and non-discharging. Self-discharging is used for producing mass flow rates and non-discharging is running by the downhole pump, airlifting, etc.

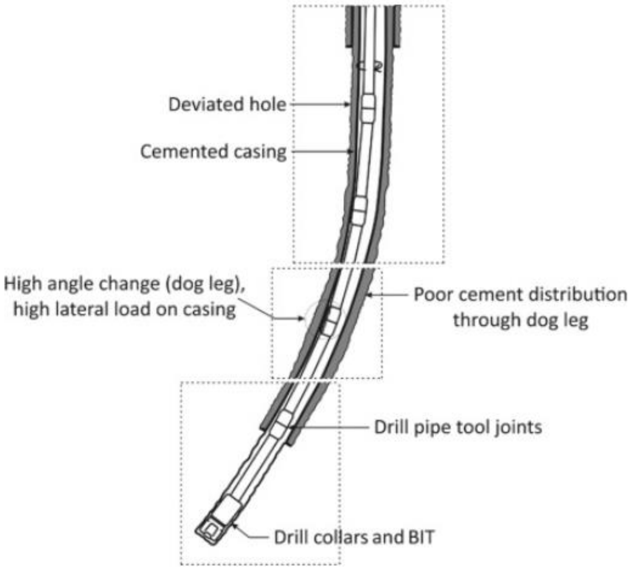


Figure 4.2: Geothermal Wells

4.2 The Status of the GHP Systems

The system of GHP is divided into three categories based on the objective or method of heat extraction.

- A heat pump system with an earth heat exchanger (also known as an earth-coupled heat exchanger). It can be installed vertically in boreholes or shallow trenches and t's up to 2 meters in depth.
- The system of heat pump uses groundwater as the primary source of heat.
- This system uses surface water (lake, marsh, or river) directly or as a heat source. A coil tube set must be installed in the acceptable lake, lake, or river for this device to work.

This survey will look at a system that uses a vertical ground heat exchanger-style heat pump system, as seen in Figure 4.3. Depending on the heat exchanger's configuration, it may be of the type of vertical installation (vertical ground heat exchanger type) or horizontal installation (horizontal ground heat exchanger type).

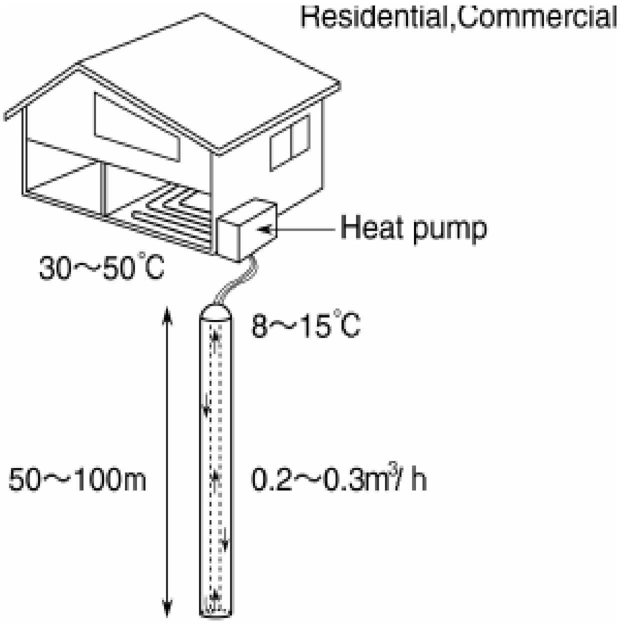


Figure 4.3: Borehole Heat Exchanger in a GHP System [9]

4.2.1 Closed-Loop System

Closed-loop systems are used as a horizontal approach, vertical approach, and as a Lake. Among them, the closed-loop horizontal approach is costly for residential areas. Nowadays large commercial buildings often used vertical approach systems. But water lake systems are the cheapest system for residential areas.

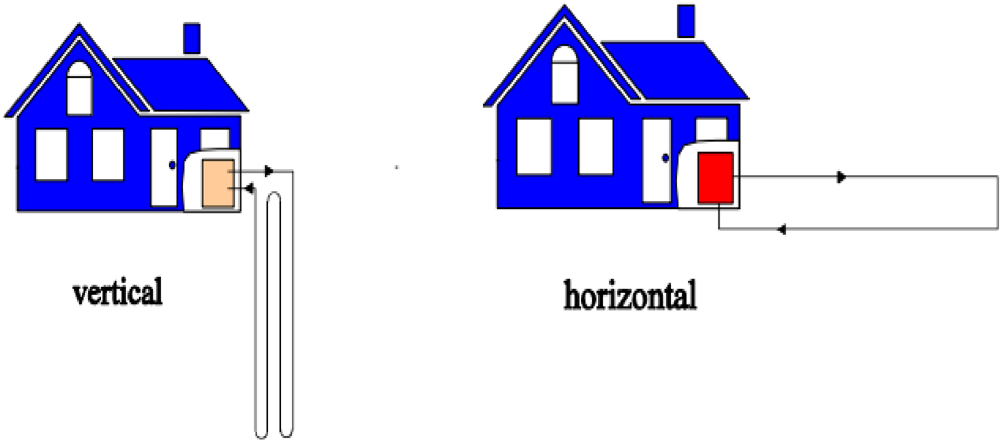


Figure 4.4: Closed-Loop System (Ground Coupled) [9]

4.2.1.1 Closed Vertical Loop

One or more boreholes in which BHE is installed make up this system. Boreholes can reach depths of up to 200 meters.

The following are two possible BHE fundamental concepts:

1. U-pipes, for starters.

2. Pipes that are coaxial (concentric).

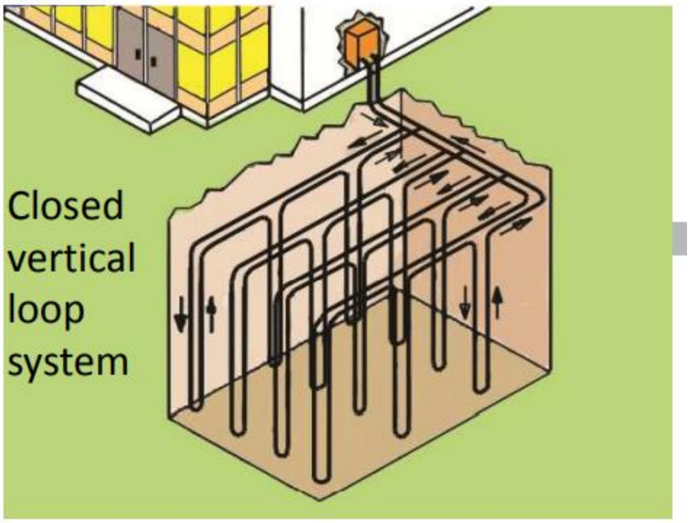


Figure 4.5: Closed-Loop Vertical System [8]

4.2.1.2 Closed Loop Horizontal Systems

The system with the smallest depth. Compared to vertical loops, they require less capital investment and are slightly less efficient due to the fluid's lower working temperature. For all horizontal systems, solar radiation is the principal source of thermal recharging.

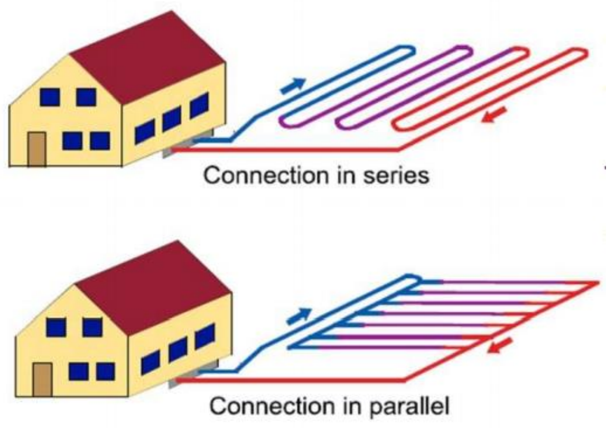


Figure 4.6: Horizontal Closed Ground Heat Exchanger [8]

The so-called "slinky" system is more compact horizontally. Horizontal systems perform best in fine-grained, water-rich soils like clay and silt. The direct expansion system is an alternative to the horizontal ground source heat pump.

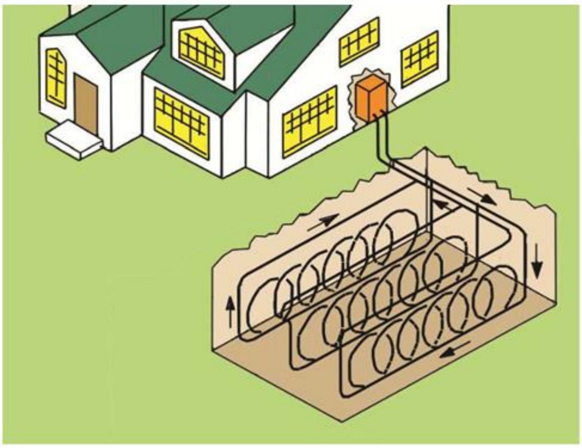


Figure 4.7: Slinky-Loop System with A Closed Horizontal Loop [8]

The temperature of the fluid and the borehole environment, as well as the heat pump COP, will gradually decrease during the winter season. In a properly designed system, the temperature will not be low enough to cause the heat pump to shut down. When compared to air as a heat source, this is a significant benefit of GSHPs. These systems may provide free cooling in the summer. The distance between the boreholes is the distance between the boreholes.

4.2.1.3 Surface-Immersed Closed-Loop Systems

The cheapest geothermal heat pipe system could be built if surface water is available. Coils should be fully submerged in water at least 2.4 meters below the surface.

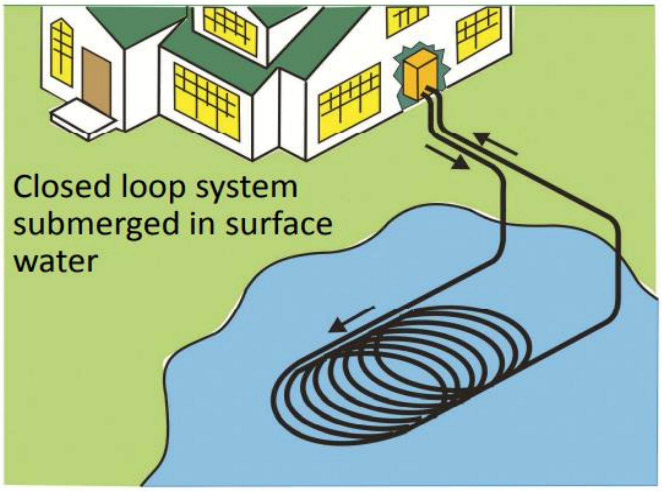


Figure 4.8: Surface-Immersed Closed-Loop Systems [8]

4.2.2 Open-Loop System

In an open-loop system, water is taken directly from the water source and after that, it recycles to another water source. In this system heat exchange fluid is used by applying the GHP technique. Once it has pulled through the system, the water back to the ground through the production well or surface discharge.

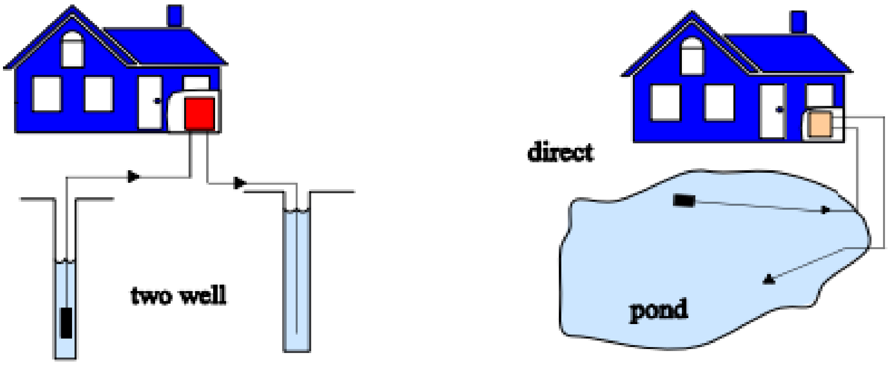


Figure 4.9: Open-Loop System (Groundwater Type) [9]

4.3 Benefits of GSHP Systems

There are several advantages to using geothermal heat sources, including:

1. Low-cost operations.

2. Affordability.

3. Low upkeep.

4. There is no need for additional heat.

5. Integrated low-cost water heating.

6. No outdoor equipment is required.

7. Minimal negative impact on the environment.

8. Standardize seasonal electric demand.

9. Increased life expectancy.

4.4 Geothermal Wells

4.4.1 Types of Geothermal Wells

Three types of geothermal wells are used in geo-energy.

1. Wells with a Temperature Gradient (TG).

2. Stratigraphic (also known as "Slim") Wells.

3. Wells of Commercial Quality.

4.4.1.1 Comparing Costs

1. TG wells are less expensive than slim wells, costing about 10% to 20% less. Slim wells are inexpensive in comparison to a full-scale commercial well – typically 30-50 percent less expensive.
2. Commercial-grade geothermal wells are very expensive, ranging from \$1.5 million to more than \$5 million.

3. Drilling and completion costs for the most expensive commercial-grade wells could exceed $10 million.

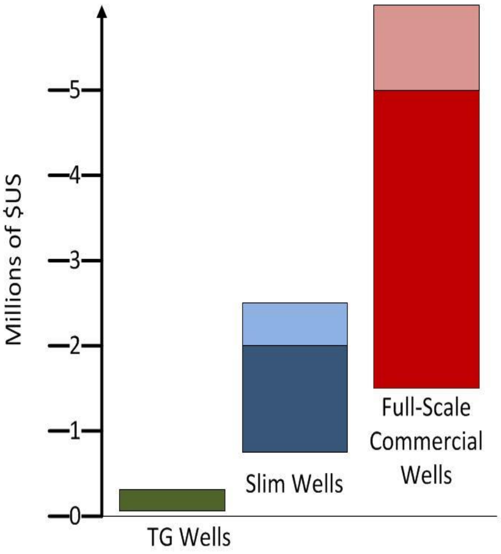


Figure 4.10: Costs Comparing [10]

4.4.2. TG Well Features

1. Shallow.
   i. Less than 500 meters
   ii. Most often 150 meters or less
2. Small circumference.
3. Drilled with rotary or diamond core rigs mounted on light trucks.
4. Drilled without BOPE – Drilling comes to a halt when the temperature of the flow line reaches 75°C.

4.4.2.1 TG Well Drilling

1. A hole is drilled in the ground.
2. A conductor is driven or a surface casing is cemented.
3. Drill a hole with a smaller diameter.
4. The tubing with a small diameter is returned to the surface.

5. The surface conductor that has been driven is yanked.

6. Cement is pumped back to the surface through the tubing.

7. A wiper plug is pumped into the tubing to displace the cement.

8. A valve is installed to allow survey tools to access the tubing.

9. Fill the tubing with water, then fill the top 10 meters with vegetable oil or antifreeze.

4.4.2.3 Two Products of Temperature Gradient Wells

1. The geology of the shallow subsurface is the first step.

2. Post-drilling temperature data.

    I. Short-term conductivity data.
    II. TG data over time.
    III. Seasonal effects.

Figure 4.11: Well Drilling [10]

4.4.2.4 Design Advantages

1. Low-cost; can be drilled with readily available rigs.

2. Fully cemented tubing quickly equilibrates.

3. No need for large-scale surface production equipment

4. Simple temperature-logging equipment is used in the testing.

5. Abandonment is straightforward.

4.4.2.5 Disadvantages of Design

1. Impossible to produce

2. Provides only the most basic information

4.4.3 Stratigraphic Or “Slim” Wells

1. Wells has a larger diameter than TG wells.

2. In most cases, a hole is drilled into the reservoir.

3. Drilled with light-medium range oilfield rigs using BOP equipment.

4. Drilled during the intermediate exploration phase

5. Drilled to determine the viability of the resource

6. Give details on:
    i. Reservoir fluid chemistry
    ii. Structural data
    iii. Lithological data.
    iv. Data on deep temperature gradients.

4.4.3.1 Slim Well Drilling

1. A conductor is permanently attached.
2. A hole is drilled in the surface.
3. The surface casing is installed and cemented in place.
4. A temporary wellhead and blowout prevention equipment are installed.
5. A hole is drilled in the middle.
6. Geophysical logs are collected and analyzed (SP, Gamma, Resistivity), and

7. The casing is reinstalled and cemented to the surface.
8. A permanent wellhead with a master wellhead valve is installed.
9. A hole is drilled that is open (uncased). Geophysical logs (often including imaging logs) are run, and a perforated liner is placed on the bottom
10. Finally, a flange with a small valve is installed on the wellhead, allowing future logging access to the wellbore.

4.4.3.2 Advantages of Slim Well Drilling

1. Low cost compared to commercial-grade wells – typically 30% to 50% of the cost of a full-sized well.
2. Designed and built to be low-cost, with no need for special casings or cement slurries.
3. In environmentally sensitive areas, a smaller footprint may be advantageous.
4. Provide the majority of the information that a commercial-grade well does.
5. Can be used as disposal wells during subsequent production testing.
6. Can be used as reservoir monitoring wells.

Figure 4.12: Slim Well Drilling [10]

4.4.3.3 Disadvantages of Slim Well Drilling

1. Requires much more powerful equipment than is typically available locally.

2. Because the wells are not as durable as commercial wells, they have a shorter life span and must be abandoned after only a few years.
3. Normally, except in the case of extremely good, hot resources, not commercially producible.

4.4.4 Commercial Grade Wells

1. Production and Injection are the two primary categories.
2. Made to be extremely durable and long-lasting
3. Use the same design as often as possible, especially early in the development of a good field. Early on in the wells, it is not always clear which service will be provided.
4. Oilfield rigs that can drill large diameter holes and handle large-diameter casing strings are used to drill commercial-grade wells.

Figure 4.13: Typical Land Conventional Rig [10]

4.4.4.1 Testing Commercial Grade Wells

Slim wells, as well as production and injection wells, are tested in the same way.

1. Recording of pressure and temperature.

2. Pump or Flow Testing.
3. Pressure/Temperature/Spinner logging while injecting.
4. Wellhead pressure buildup or falloff testing.

4.4.4.2 Production Well Drilling

1. A conductor is permanently attached.
2. Using bentonite-based mud or air, a large diameter surface hole is drilled.
3. The annulus is fully cemented and the surface casing is installed.
4. A makeshift wellhead is erected.
5. The BOP equipment has been installed and is being tested.
6. Drill a section of the intermediate hole.
7. The annulus is fully cemented and an intermediate casing is installed.
8. If more than one intermediate casing string is needed, the process can be repeated, or liner strings can be used instead of a full string to save money on the cost of running it to the surface and cementing it. Pumped-well liners are also beneficial.
9. The master valve and the permanent wellhead are both installed.
10. In the reservoir, a hole is drilled.
11. Liquid water/polymer drilling fluid
12. Reservoirs that are dominated
13. In vapor-dominated reservoirs, air or foam
14. A perforated liner is run and the well is logged. Injection wells in some hard rock reservoirs are only required to have a liner.

4.4.4.3 Injection Well Testing

The mechanical integrity of injection wells can also be checked to ensure that injected fluid does not flow into surface water zones. The following are some of MIT's:

1. Noise and temperature logs
2. Caliper logs for casing
3. Logs with a cement bond
4. Logs of ultrasonic casing imaging

4.5 Designing of Geothermal Wells

In several ways, geothermal wells vary from those drilled for oil and gas exploration:

- The potentially active formation is exposed in the open hole area.
- A slotted liner is used to finish the well.
- The pressure in a geothermal reservoir is hardly hydrostatic for the temperature of the reservoir.
- The permeability observed by wells in the volcanic geothermal setting found in most high-temperature geothermal resources exists as distinct regions.
- In a well, there are typically multiple permeable areas, which are spaced hundreds of meters apart.

One of the most notable differences between geothermal and oil/gas wells is that in geothermal wells, potentially productive formations are exposed to the wellbore across the entire open-hole section, while in oil and gas wells, the producing zone is typically limited to a narrow, well-defined vertical interval. In geothermal wells, the open-hole section can be as long as 2000 meters. Wherever the well intersects a broken zone, this long open-hole section allows contact between the well and the formation, and where many permeable areas are found, there are normally internal flows. Circulation cells inside the wellbore, which are normally guided by a combination of well completion design (variation of casing size and perforation details) and the diameter of the drilled hole, further complicate the analysis of downhole pressure-temperature data. A wide range of data is desirable to begin designing the well, but it is impossible to obtain the complete package always. While it is worthwhile to obtain as much information as possible, the designer must sometimes rely on the best data available. The listed below parameters are the sample of the desired data, however, they are not all-inclusive.

1. Well, purchase.
2. Conditions of Surface or shallow borehole.
3. Conditions of Reservoir.
4. Logistical requirements
5. Likely problems in drilling
6. Casing requirement.

CHAPTER-5

The Present Scenario of Geo System

5.1 Introduction

Globally geothermal installed capacity is increasing day by day. This is the cleanest and good for the climate. The geothermal power capacity increasing gradually since 2000. Since solar, wind, and hydro, geothermal energy is often known as the third or fourth most powerful renewable energy source. It only makes up a small portion of the world's power capacity; in 2010, it had about 10,709.7 MW of installed capacity. Global geothermal installed capacity was 12.7 GW in 2016. It generated nearly 80.9 TWh in 2015, accounting for about 0.3 percent of global electricity production. Built geothermal power capacity is led by the United States (2.5 GW), the Philippines (1.5 GW), and Indonesia (1.5 GW). In 2016, the world's installed capacity increased by 901 megawatts (MW), most in ten years, with projects in Kenya (518 MW), Turkey (197 MW), and Indonesia (95 MW) contributing to the total. As the demand for geothermal energy grows, a growing number of countries are expressing interest in developing geothermal projects. These systems' installed capacity is steadily growing day by day. We can easily see the difference in geothermal energy installed capacity from 2007 to now if we look at the graph below. Geothermal installed capacity was 9731.9 MW in 2007, but by 2020, it will have increased to 21443 MW. Fig. 6.1 is a graphical chart of the installed geothermal capacity from 2007-2020 of the world. Several countries like the United States, Mexico, Philippines, New Zealand, Iceland, etc. are producing electricity with the help of geothermal energy.

At this moment, United States is the world's largest geothermal energy producer. Despite this, geothermal accounts for less than 1% of total energy consumption in the United States. Surprisingly, the Philippines is ranked second, with Mexico in the third position as we see in figure 5.1. In figure 5.1, we show a global breakdown of geothermal electricity production. In the United States, China, Hungary, Mexico, Iceland, Australia, and New Zealand, geothermal energy has a lot of promise, but that doesn't mean it's being fulfilled.

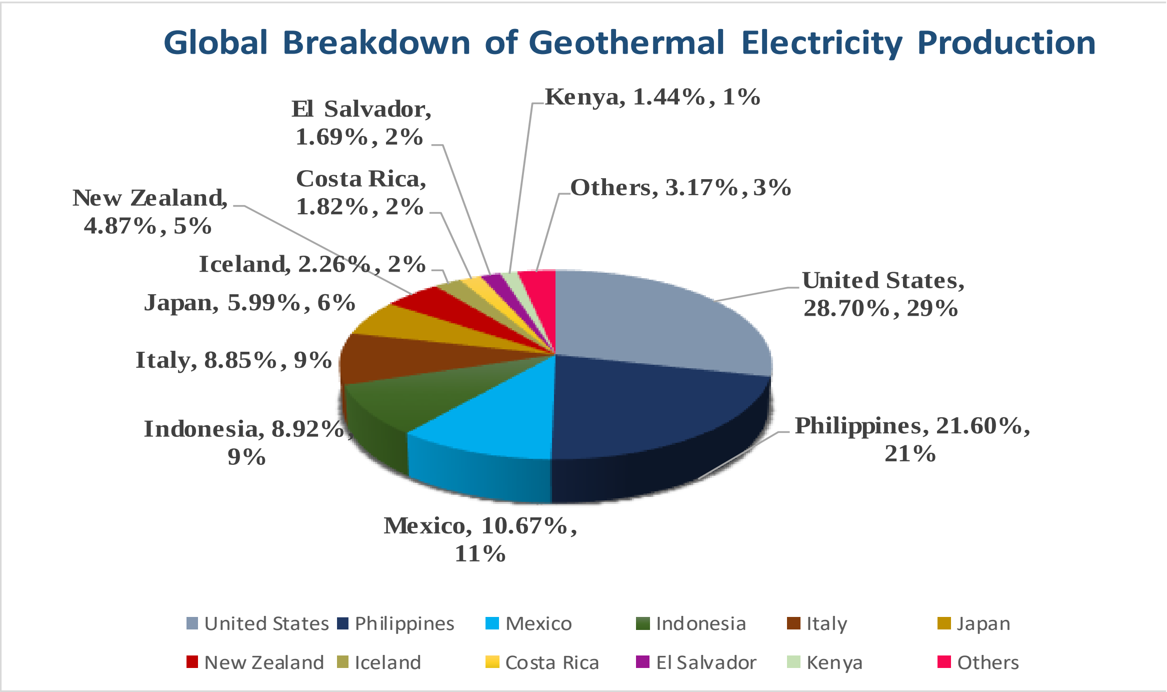


Figure 5.1: Global Breakdown of Geothermal Electricity Production [3]

5.1.2 Installed Capacity

Geothermal power is used in 26 countries, and geothermal heating is used in 70. Global geothermal power capacity is 15.4 gigawatts (GW) as of 2019 schedule, with 3.68 GW (23.86 percent) deployed in the United States. The present scenario of top countries geothermal energy is given below:

1. **United States:** Geothermal power stations are only located in western states of the united states, where geothermal energy potential is greatest. The Mayacamas Mountains and Imperial Valley in California, as well as Western Nevada, have the highest concentrations. At least 29 geothermal power stations are located in the united states. Among them "Geysers" is the largest geothermal power plant in the world and with a current installed capacity of 1,590 MW.
2. **Mexico:** In Baja California, Mexico, the Cerro Prieto Geothermal Power Station is a complex of geothermal power stations. Its installed capacity is 820 MW, it is the world's largest geothermal power station complex in terms of total size and the second- largest in

terms of energy production. The plant, which is located just south of Mexicali, is made up of five separate units referred to as CP1 through CP5.

3. **Italy:** “Larderello” is a fraction of the comune of Pomarance in Tuscany, central Italy, and is well-known for its geothermal activity. This is the world's oldest geothermal power station. Its installed capacity is 769 MW. “Valle Secolo & Nuova Serrazzano” geothermal power stations are also located in Italy.

4. **Kenya:** Olkaria I, II, III, IV, V are some of the examples of geothermal power stations in Kenya.

5. **Indonesia:** The Darajat Geothermal Power Plant Complex is located in Pasirwangi, Garut, West Java, about 150 kilometers south of Jakarta. The complex is located in the Mt Kendang district, which is 2000 meters above sea level and is surrounded by volcanic mountains. The Darajat geothermal field is a valuable resource that produces dry steam at the wellhead. The asset is one of the world's few dry steam fields.

6. **Philippines:** In the Philippines, there are almost 8 geothermal power stations. Among them, Tiwi Geothermal Power Plant is one of them. It is located near Malinao Volcano, Bicol Region with an installed capacity of 330 MW.

7. **Iceland:** Nesjavellir Geothermal Power Station is the largest geothermal power station in Iceland. The plant is near the Hengill volcano in southwest Iceland. And its installed capacity is 300 MW.

8. **New Zealand:** In New Zealand, geothermal power is a small but important part of the country's energy generation capacity, accounting for around 17% of the country's electricity generation capacity, with over 900MW of installed capacity. There are eight commercial geothermal power stations currently operating in New Zealand (Kawerau, Nga Awa Pura, Ngatamariki, Ohaaki, Poihipi, Te Huka, Te Mihi, Wairakei).

9. **Nicaragua:** San Jacinto Tizate is the only geothermal power station in Nicaragua. It is located 20km west of Leon, Leon, Nicaragua and its installed capacity is 74 MW.

10. **Costa Rica:** Miravalles is the only geothermal power station in Nicaragua. It is located in Bagaces, Guanacaste and its installed capacity is 100 MW.

11. **El Salvador:** Two geothermal power stations used in El Salvador, Ahuachapán & Berlín geothermal power stations. Each of the power stations has 95 MW & 109.4 MW installed capacity.

12. **Papua New Guinea:** Lihir Geothermal Power stations are located in Papua New Guinea with 55 MW installed capacity.

13. **Russia:** In Russia, geothermal energy is the second most common renewable energy source, but it only accounts for about 1% of total energy output. In 1966, the first geothermal power plant in Russia, as well as the world's first Binary cycle power station, was installed in Pauzhetka, Kamchatka, with a capacity of 5 MW.

14. **Turkey:** In Turkey, there were 53 geothermal power plants in service at the end of 2018. According to JESDER, Turkey is ranked fourth in the world in terms of installed capacity.

15. **Japan:** Japan has attractive geothermal power sites because of its proximity to the Izu–Bonin–Mariana Arc. Hatchōbaru is one of the geothermal power stations of japan & its installed capacity is 112 MW.

The top countries installed capacity from 2011 to 2020 is shown in table 5.1

Table 5.1: Top Countries Installed Capacity from 2011 to 2020 [3]

COUNTRY	**GEOTHERMAL INSTALLED CAPACITY (MW)**									
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Australia	.1	.1	.1	.1	.1	.1	.1	.12	.31	0.62
Austria	.91	.91	.91	1	1	1	1	1.2	1.2	1.25
China	26.15	26.15	27	26	27	25.75	25.75	25.75	34.89	34.89
Costa Rica	217.5	217.5	217.5	217.5	217.36	206.86	206.86	206.86	261.86	262
El Salvador	204	204	204	204	204	204	204	204	204	204
Ethiopia	7.3	7.3	8	7.3	7.3	7.3	7.3	7.3	7.3	7.30
France	16.3	15.3	16.3	16.3	16.3	15.51	15.90	16.7	15.90	17
Germany	6	16	26	29	29	33	32	38	42	43
Guatemala	54.2	54.2	49.2	49.2	49.2	49.2	49.2	49.2	52	52
Iceland	665	665	665	665	665	665	710	755.6	755.6	755
Indonesia	1226	1336	1343.5	1403.5	1438.5	1643.5	1808.5	1945.5	2130.5	2289
Italy	728	728	729	768	768	767	767.19	767.19	800	916
Japan	537	512	512	508	516	526	481	482	525	550
Kenya	198	205.5	205.5	366.1	618.9	662.9	672.9	663	823	1193
Mexico	887	824	823	813	906	926	925.7	950.6	935.6	1005.8
New Zealand	726	726	798	924	941	941	941	941	941	1064
Nicaragua	87.5	164.5	154.5	154.5	154.5	154.5	154.5	154.5	153.24	159
Papua-New-Guinea	56	56	56	56	50	56	56	56	56	11
Philippines	1846.7	1846.7	1846.7	1916.1	1916.1	1916.1	1916.1	1928.1	1928.1	1918
Portugal	25	25	28	25	29	25	29.1	26	29.1	33
Russia	81	81	82	78	82	78	74	74	74	82
Thailand	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Turkey	114	162	311	405	624	821	1064	1282.5	1515	1549
USA	2409	2592	2607	2514	2542	2517	2483	2540.5	2555.3	3700

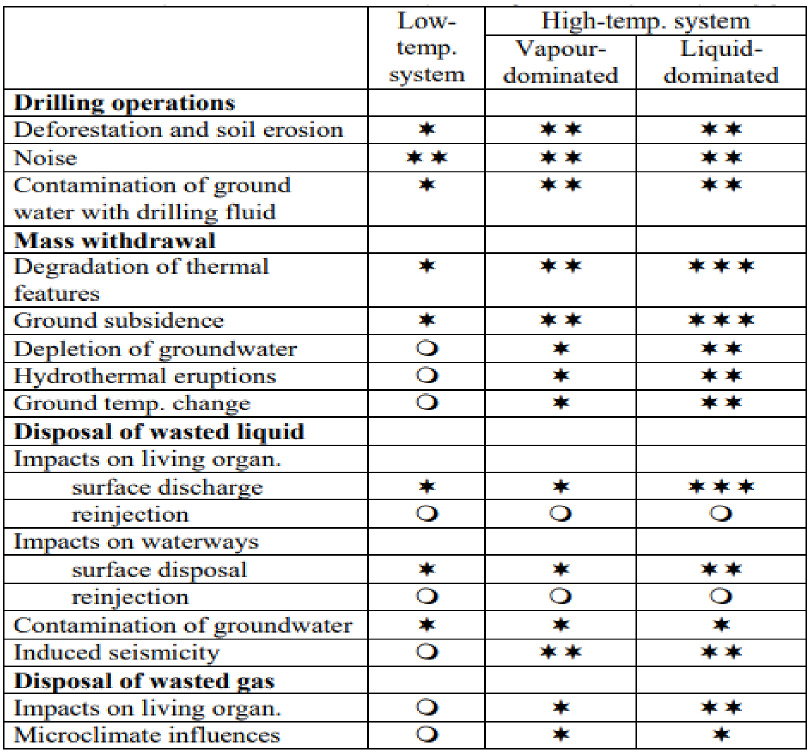
5.2 Environmental Impacts

There are several types of environmental impacts of geothermal power generation like:

1. Large portions of agricultural land have been destroyed.
2. A lot of noise or sound pollution.
3. Depletion of groundwater level.
4. The fertilizer rate is reduced as a result of soil digression.
5. Landslide occurs due to wells drilling.
6. Ground waste dissolves the underlying limestone bedrock, resulting in depression.

Since geothermal energy is growing in popularity in Europe and Croatia, It is critical to understand the environmental impacts of geothermal power plants and the new technological solutions for controlling those impacts. In comparison to fossil fuels, geothermal energy is commonly thought to be a more environmentally sustainable source of energy. However, over the last 40 years, the use of geothermal energy has shown that it has negative effects on the environment. There is a growing interest in these effects, which may be a limiting factor for

Table 5.2: The Potential Environmental Impacts Of Geothermal Power Plant [11]



	Low-temp. system	High-temp. system	
		Vapour-dominated	Liquid-dominated
Drilling operations			
Deforestation and soil erosion	✶	✶✶	✶✶
Noise	✶✶	✶✶	✶✶
Contamination of ground water with drilling fluid	✶	✶✶	✶✶
Mass withdrawal			
Degradation of thermal features	✶	✶✶	✶✶✶
Ground subsidence	✶	✶✶	✶✶✶
Depletion of groundwater	❍	✶	✶✶
Hydrothermal eruptions	❍	✶	✶✶
Ground temp. change	❍	✶	✶✶
Disposal of wasted liquid			
Impacts on living organ.			
surface discharge	✶	✶	✶✶✶
reinjection	❍	❍	❍
Impacts on waterways			
surface disposal	✶	✶	✶✶
reinjection	❍	❍	❍
Contamination of groundwater	✶	✶	✶
Induced seismicity	❍	✶✶	✶✶
Disposal of wasted gas			
Impacts on living organ.	❍	✶	✶✶
Microclimate influences	❍	✶	✶

the use of geothermal energy in the future. Ignoring or neglecting such issues, as history has shown, can harm industry growth by causing a lack of trust from the public and financial sectors. If the intention is to enhance geothermal energy applications, all environmental impacts should be identified, as well as preventive steps to prevent or reduce their environmental impact. An environmental impact assessment should be conducted to define and measure both potential and real impacts, as well as to ensure adequate plant monitoring and accident protocols. During the project planning, plant design, and start-up phases, special attention is needed. Table 5.2 shows the potential environmental impacts of the geothermal power plant [11] .

Water Use and Consumption, Waste Liquid Disposal, Solid Waste Production, Waste Liquid Disposal, Ground Deformation, Ground Temperature Changes, Groundwater Depletion, and Waste Gas Emissions such as Carbon Dioxide, Hydrogen Sulfide, NOx, and others are all potential environmental impacts. The potential environmental impact of the geothermal power plant is shown visually in Figure 5.2.

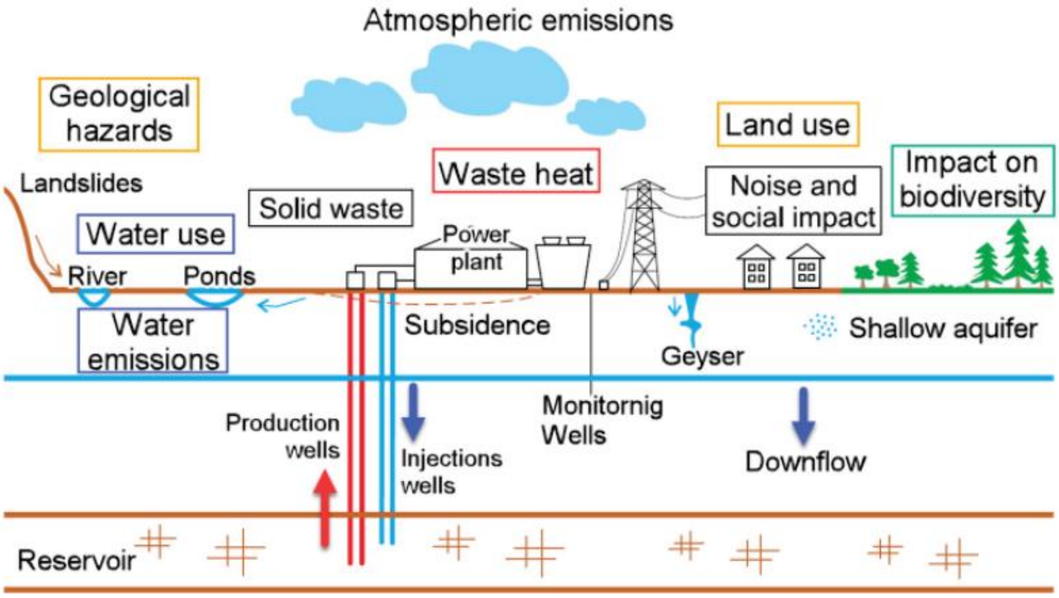


Figure 5.2: Environmental impacts of geothermal power production [11]

5.3 Economic Impact

The main advantage of geothermal energy is that it is available 24 hours per day and 7 days per week. But, renewable energies like solar and wind are only available for one-third of the day. The cost of geothermal energy is almost 5 to 10 cents per kilowatt. For this reason, this energy can be competitive with other energy sources, like coal and natural gas. Geothermal energy is also used for commercial flower farming, snow melting system, restaurant, and local business.

5.4 Geothermal Extraction

Geothermal energy depends on the temperature of the central earth's core which is created from the original structure of the planet and the radioactive decay. This energy is found in areas with high thermal gradients (difference in temperature between the core of the planet and its surface) where gradients arrive in regions affected by recent volcanism activity, in areas located along plate boundaries (such as along the Absolute Ring of Fire), or in areas marked by thin crustal hotspots. Figure 5.3 shows the Temperatures on Earth. The 4000 km in the earth's core is situated to melt rock (magma) and perfect for thermal energy to use [12].

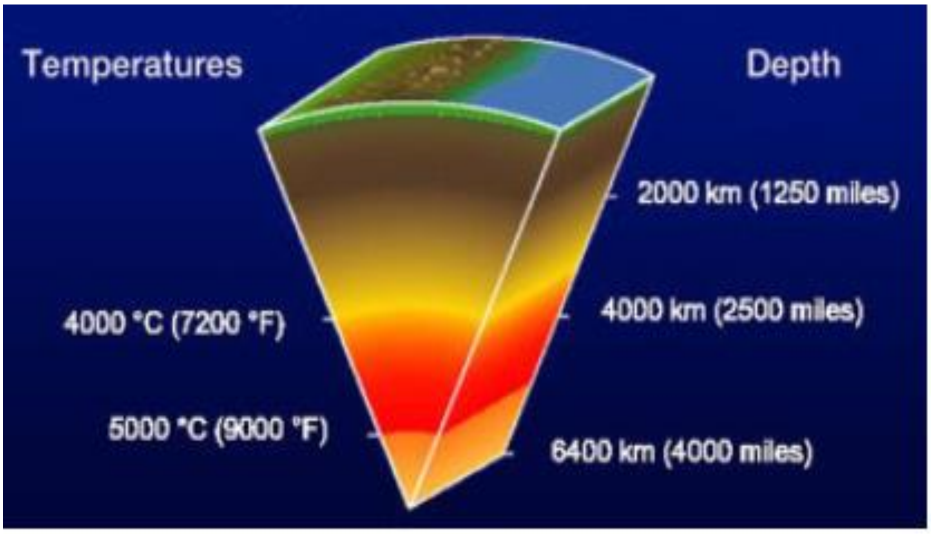


Figure 5.3: Temperatures in Earth

The specific exergy index (SExI) is a parameter that including the Mollier diagram uses to find a map of a geothermal field. It is the parameters of the line between 0.5 to 0.05, which classify and evaluate the geothermal resources [12].

- $SExI < 0.05$ for low-quality geothermal resources
- $0.05 \leq SExI < 0.5$ for medium-quality geothermal resources
- $SExI \geq 0.5$ for high-quality geothermal resources.

5.5 Geothermal Sustainability

The geothermal power systems can be sustainable for many years if all of the activities of geothermal energy are managed correctly. We need to manage a proper place for making this energy sustainable. It can be sustainable if provident resource management techniques are in the exact place. The pressure/water level, temperature, and flow rate of the geothermal resource should be monitored all the time. Otherwise, the system should be redesigned if any of these changes. Hot dry rock resources can be found anywhere beneath the Earth's surface, at depths of 3 to 5 miles, and lower depths in some areas. These resources are obtained by injecting cold water down one well, passing it through hot fractured rock, and then extracting heated water from another well. This technology has yet to find commercial use. Existing technology also prevents direct heat recovery from magma, geothermal energy's deepest and most powerful source. Many technologies have been developed to utilize geothermal energy, which is heat from the earth.

CHAPTER-6

Potentiality in Bangladesh

6.1 Introduction

Geo-energy is the most sustainable and clean energy source on the planet. Different geological features of the northwest, such as hydrogeological settings, seismicity and earthquakes, basement fault clustering, and surface thermal anomalies, point to the possibility of geothermal reservoirs at a depth of a few kilometers beneath the earth's surface. Bangladesh, on the other hand, has the potential to produce energy with the help of geothermal sources, with a localized geothermal gradient ranging from 19.8 to 29.5°C/km in the southeast and 20.8 to 48.7°C/km in the north-west, with temperatures ranging from 110 to 153°C from 304 kilometers below the surface. The key sources of geothermal energy are the Rangpur Saddle (700m depth contour), Madhupur Clay (20 m) Single, Kuchma and Bogra (60-125 km), and Thakurgaon warm water area.

A private company plans to build Bangladesh's first geothermal power plant, with a capacity of 200MW. The plant will be built at Salandar village in Thakurgain's impoverished northern district, according to Anglo MGH Energy. The Dhaka-based firm intends to dig 28 deep tube wells to transport hot steam with a minimum temperature of 12 degrees Celsius.

The raised and stressed steam will be directed into a turbine, which will then be connected to a generator, which will turn to generate electricity. The company claims to have found ideal sites in Thakurgaon for generating 200 MW, which they say would significantly reduce acute power shortages in the northern districts.

6.2 Geothermal Resource Prospective Areas in Bangladesh

Geologists' investigations of various deep relinquished wells excavated for natural gas and oil have shown the possibility of geothermal reservoirs in Bangladesh. Because of the country's varying geo-tectonic conditions, potential geothermal energy resources are divided into two regions:

I) The northwest, known as the "Shield areas of the country," and

II) The southeast, known as the "Bengal foredeep zone," is located in the deep sedimentary basin.

Different geological features of the northwest, such as hydrogeological settings, seismicity and earthquakes, basement fault clustering, and surface thermal anomalies, point to the possibility of geothermal reservoirs at a depth of a few kilometers beneath the earth's surface. The geothermal gradient in this area varies between 20.8 and 48.7 degrees Celsius per kilometer. Mizanur Rahman's research revealed that the Thakurgaon district has the potential for geothermal energy. The Singra-Kuchma-Bogra sections of the Bogra shelf region look promising for inspection; the Singra well, with a temperature of above 150^{o}C in the bottom hole, is the most promising of the three. Two more locations to be concerned about are the Barapukuria coal basin and the Madhyapara hard rock mine. The temperature was found to vary between 67°C and 153°C in water samples from the Madhyapara hard rock mine area's basement aquifer, indicating the presence of a possible low-temperature geothermal reservoir in this area [13].

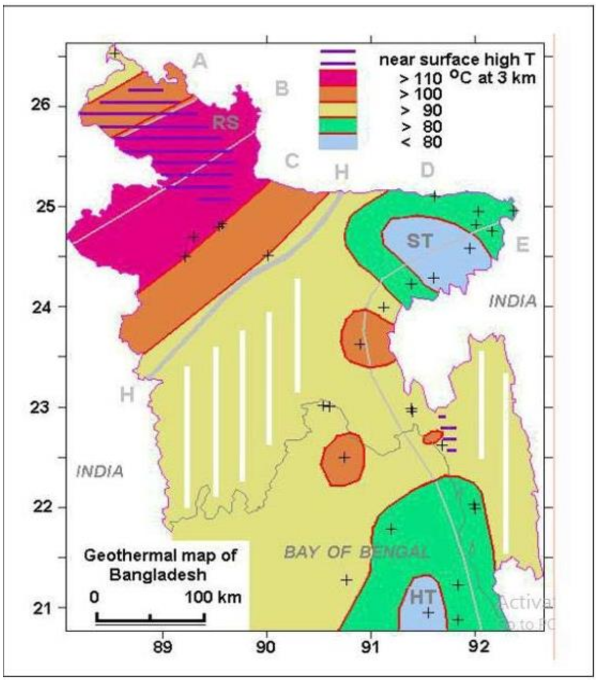


Figure 6.1: Temperatures At 3 Km on A Geothermal Map of Bangladesh [13]

The geothermal gradient in the southeast area ranges from 19.8°C to 29.5°C/km. The hilly region of Sitakund is interesting because it has a few thermal springs. The Hatiya trough at the Shahbajpur 1 well has the maximum gradient in this area, at 29.5°C/km, followed by Saldanadi 1 at 27.2°C/km.

6.3 The Geothermal Prospects of The Tectonic Units

Bangladesh is at the head of the Bay of Benga. Padma and Brahmaputra are two great rivers that flow from delta systems that follow one another. The mountains of Himalayan ranges were elevated as a result of a collision with a northerly-flowing Indian plate. Bangladesh is divided into four sections by the Indian platform. The Rangpur Saddle, also known as the Dinajpur Slope. The Bogra Slope and the Hinge Line are two points on the Bogra Slope that are linked by the Hinge Line.

6.3.1 Sub-Himalayan Foredeep

The Himalayan Foredeep which is located south of the Main Boundary Thrust (MBT), runs the length of the Himalayan foothills. The basement is located at a depth of 2500 meters in Salbanhat, Bangladesh's northwest corner. At this depth, the temperature is 79 degrees Celsius. In his tectonic scheme of Bangladesh, Reiman (1986) included the Rangpur Saddle which is the North Slope of the Himalayan Foredeep. The Neocene of the Siwaliks is well-formed in the Himalayan Foredeep, with sandstones, subordinate shales, clay and gravel beds, and a thickness of 3 to 4.5 km. The gradient of heat is too low to allow a geothermal potentiality in conjunction with Salbanhat's only deep well, despite the high porosity of the sedimentary units [15].

6.3.2 Rangpur Saddle and the Garo

The Indian Platform is represented by the Rangpur Saddle. The Indian Shield's Shillong Massif is a big thrust block. The basement is most elevated and full of thin sedimentary strata in the Rangpur Saddle. The approximately 700 m depth contour on the north and south slopes has been seismically established as the provisional boundary of the Saddle of Rangpur. The basement in the Madhyapara region is only 130 meters deep and is overlain by Plio-Pleistocene

Dupi Tila Sandstone and Madhupur Clay. In 1963-64, the Corporation of Oil and Gas Development (OGDC) in the Rangpur - Dinajpur collected seismic data. According to this seismic data, they said that the north and south slopes of Rangpur Saddle are both very gentle. Figure 6.2 shows an expansion of the Tectonic Map of Bangladesh to include NW Bangladesh, as well as some additional structural features. A generalized thermal segment across the Rangpur Saddle is visualized in Figures [15].

Table 6.1: Possible Geothermal Sites in Bangladesh [14]

SI	Divisions	Subdivisions	Comments
1	Sub-Himalayan Foredeep	• Salbanhat • Panchagarh District • Northern Slope of Rangpur Saddle	• Thermal gradients are relatively low. • Barely Feasible
2	Rangpur Saddle and the Garo-Rajmahal Gap	• Rangpur District • Dinajpur District • Malda • Western part of the Rangpur Saddle • Barakupuria • Thakurgaon.	• High surface Temperatures • Reasonable drilling depth.
3	Bogra Slope	• Singra • Kuchma • Bogra	• Potentially favorable
4	Deep Sedimentary Basin	• Sylhet • Mymensingh • Pabna • Faridpur Trough • Barisal • Chandpur High	• Loaded with cool sediments • Geothermal gradients are very low, Barely feasible

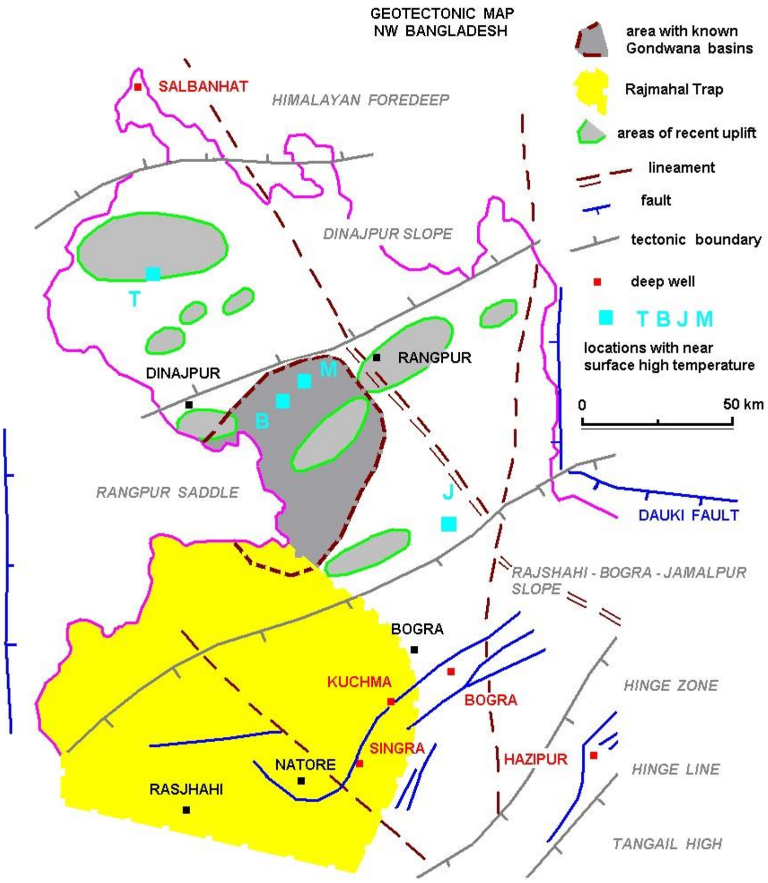


Figure 6.2: Geotectonic Map of NW Bangladesh [15]

Several graben and half-graben structures with Gondwana sediments have been discovered in the western part of the Rangpur Saddle, some of which contain coal seams. At a depth of 400 m, the Gondwana sandstone series underneath the coal seams in the Barakupuria coal mine has a 50^{o}C temperature. The basement below temperature is increasing for the coal seems function which is known as an insulator. Figure 6.3 shows a set of shallow temperature profiles along with their lithostratigraphy.

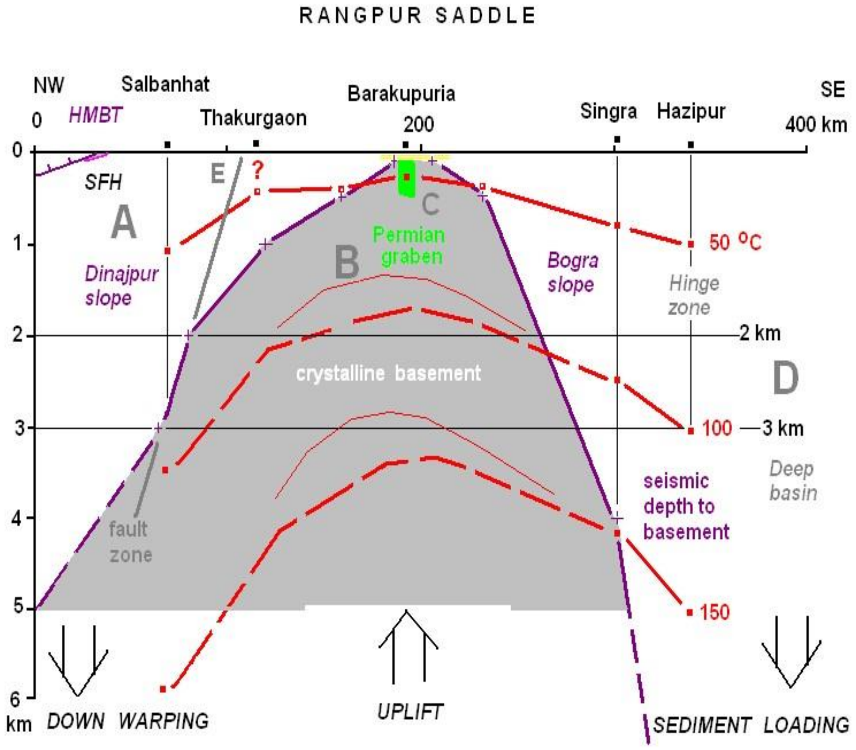


Figure 6.3: Generalized Segment NW-SE Around the Rangpur Saddle's Crystalline Basement Rise (Gray) [15]

6.3.3 Bogra Shelf

The Bogra Shelf (Bogra slope) is a regional monocline that gently descends to the Hinge zone on the southern slope of the Rangpur Saddle in the southeast (Figure 6.1). From a depositional and structural standpoint, this zone indicates the changeover between the Rangpur Saddle and the Bengal Foredeep, up to the Hinge Zone, the Bogra Shelf varies in breadth from 60 to 125 kilometers, and the thickness of the sedimentary sequence increases towards the southeast.

In the mid-1950s, the Stanvac Oil Company (SVOC) conducted aeromagnetic and seismic surveys, followed by the drilling of two wells in Kutchma and Bogra. The top of the Eocene Limestone (Bogra Limestone) shows a regional dip of 2-3 degrees, according to seismic contours as well as a range of NE-SW trending faults, the most prominent of which is the Bogra fault. The Sylhet Limestone's attitude most probably conforms to the basement floor. Singra to the southwest, Bogra to the northeast, and Kuchma in the middle have all been drilled deep in the Bogra slope at distances of 22–26 kilometers. These wells have a litho-stratigraphic connection.

The Hinge Zone is a regionally significant tectonic feature that has influenced the creation of the Bengal Basin. It's a limited zone that runs from Sylhet to Mymensingh to Panda to Calcutta, and further southwest along the coast of Orissa. The peak of the Eocene Sylhet Limestone is 3500 meters below sea level according to the seismic data, Bangladesh's and West Bengal's most prominent sedimentary reflector is bound by the Bogra Shelf (or south slope of the Rangpur Saddle).

The Faridpur Trough is characterized by a widespread gravity low and the creation of Neocene sequences and is located adjacent to the Hinge Zone. The Sylhet Limestone is 6500 meters deep in the region south of the Padma and Jamuna rivers' confluence.

6.3.4 Folded Belt

Depending on the strength of folding and other structural characteristics, the Folded Belt is divided into two zones: Western and Eastern. The Western Zone contains a huge number of simple anticline systems, including 27 in Bangladesh, 10 in India's neighboring areas, and 3 in Myanmar. According to the strength of folding and other structural features, the Folded Belt is divided into two zones: Western and Eastern.

The folds are described by ridges with a box-like cross-section, variable width, and high amplitude, which are oriented in the same echelon as the neighboring structures. In Bangladesh, the elongated anticline folds' elevation varies from 100 to 1000 meters. There are faults and thrusts in several of the structures, and the folding force steadily rises from west to east. As a result, the eastern systems are strongly folded, faulted, and thrusted, with narrower synclines connecting them. Table 6.2 shows that the Neogene sedimentary sequence created here is generally non-fossiliferous and largely primarily of shales, clays, claystone’s, siltstones, and sandstones being altered, with some intra-formational conglomerates.

Table 6.2: Stratigraphic Units and Lithologies [15]

Group	Formation	Rock Types	Thickness (m)
Dupi Tila	Dupi Tila	Sandstone (SSt.) & Clay	150-1000
Tipam	Girujain Clays	Clays with SSt.	100-300
	Tipam Sandstones	SSt. with shales (Sh.)	400-1200
Surma	Upper Boka Bil	Shales	300-400
	Middle Boka Bil	SSt. and Sh. Alternation	700-900
	Lower Boka Bil	Shales	300-400
	Upper Bhuban	SSt. and Sh. Alternation	1200-1500
	Middle Bhuban	Shales	800-1000
	Lower Bhuban	Sh. and SSt. Alternation	1000-1200

6.4 Cost Analysis For 200 MW Power Plant in Thakurgaon

As one private company plans to build Bangladesh's first geothermal power plant, with a capacity of 200MW, so we discussed a possible cost for making this power plant. In table 7.3 we discussed the surface costs, known field costs, and unknown field costs.

Table 6.3: Geothermal Energy Investment Cost for a 200 MW Power Plant

	Value of Expectance (USD/KW)	Range Within One Standard Deviation (USD/KW)
Cost of Surface	110000	10062-140092
Known Field Cost (Total)	160000	150062-190092
Unknown Field Cost (Total)	180000	170022-240000

So, the total amount is 450000$

In table 7.4, we also discussed the Operation and Maintenance Costs for the Subcomponent of the Plant. There are different kinds of components in a geothermal power plant like turbine, condenser, pump, heat exchanger, preheater, cooling pump, etc. Each of the components has different individual costs. A binary geothermal power plant is the new design of geothermal power generation. Dry steam, flash steam both are the oldest design of geothermal power generation. To build a binary cycle geothermal power plant we need 2 turbines,2 condensers,2 pumps,2 heat exchangers,2 preheaters, etc. A partial cost for making a binary cycle geothermal power plant is shown in table 7.4. All of the subcomponent's costs are divided into four sections. PEC ($), $Z^{IC}{}_{k}$ ($/h), $Z_{k}{}^{OMC}$($/h), $Z_{K}{}^{T}$($/h). The meaning of these four sections is:

PEC -Purchased equipment cost, $
Z_K - capital cost rate unit, $/h
OMC- Operation Material Maintenance
T-temperature
I- Interest Rate C- Cost rate associated with exergy, $/

Table 6.4: Operation and Maintenance Costs for the Subcomponent of the Plant

Component	PEC ($)	$Z_{k}{}^{IC}$ ($/h)	$Z_{k}{}^{OMC}$($/h)	$Z_{K}{}^{T}$($/h)
Turbine	18006000	715.27	135.81	851.96
Condenser	24000000	953.38	181.02	1135.57
Pump	21052000	836.27	158.78	996.09
Heat Exchanger	10301880	409.23	77.70	487.44
Preheater	30000500	1191.74	226.28	1419.49
Cooling Pump	10000000	397.24	75.42	473.15
Other Plant Equipment's	50050000	1988.20	377.50	2368.15
Total PEC	10020000	398.03	75.57	474.10

Now, the total amount is 173430380 $ + 450000$=173880380$. If we want to the potential cost for making a 200 MW Geothermal Power Plant in Bangladesh then the cost can be almost (173880380*84.77) = 14739.83981 million tk.

CHAPTER-7

7.1 Conclusion

This thesis covers direct and indirect geothermal energy utilization technologies, electricity generation methods, reservoirs, heat pumps, geothermal wells, and data from around the world. Illustrative examples with thermodynamic aspects of several geothermal electricity applications are also compared to shed light on the performance characteristics of such systems with their energy and exergy efficiencies. This thesis analyzes the different country's usable total installed cost of geo-energy from 2011-2020. Finally, In Bangladesh, there are some possible fields to start the geo-energy project. This thesis describes and tries to find the possible fields for starting this project. One private company already planned for a 200MW geothermal power plant in Thakurgaon, Bangladesh. But they couldn't research the cost calculation for this project. So, the possible cost for starting this project is clearly described in this thesis. It analyzes the surface cost, known and unknown field cost. This thesis also calculates an operation and maintenance cost for the subcomponent of these 200 MW power plants. According to this research, the cost can be almost 14739.83981 million tk.

7.2 Recommendation for Future Research

Recommendations for Addressing Technical Issues in Geothermal Development:

i.) Develop better standards for monitoring and reporting geothermal operations and resource exploitation;

ii.) Develop open interaction and cooperation to enhance complementary research into geothermal energy.

iii.) Reduce induced seismicity in geothermal power plants;

iv.) Improve power plant designs

v.) Develop appropriate technologies in project life cycle assessment to reduce water use.

vi.) Improve heat flow prediction techniques and anticipate the drilling bit.

vii.) Improve the EGS technology by developing better equipment and tools for hard rock.

REFERENCES

[1] Askari Mohammad Bagher, Mirzaei Vahid and Mirhabibi Mohsen (2014), "Geothermal Energy", J. of Engg. and Tech Res., Volume 6, Issue 8, pp. 146-150, Available at: https://www.researchgate.net/publication/269106480_Geothermal_Energy.

[2] Charles F. Kutscher (2000), “The Status and Future of Geothermal Electric Power”, National Renewable Energy Laboratory, Presented at the American Solar Energy Society (ASES) Conference, Available at: https://www.nrel.gov/docs/fy00osti/28204.pdf

[3] Mohammad Tawhidul Alam, Foysal Dhali, Al-Amin (2020), “Present Scenario of Worldwide Geothermal Power Generation”, Journal of Electrical and Power System Engineering, Volume 6, Issue 3, pp. 21-30, Available at: http://matjournals.in/index.php/JOEPSE/article/view/5862

[4] Case study on “Geothermal Systems and Technologies”, Available at: https://geothermalcommunities.eu/assets/presentation/2.Course_GT.pdf

[5] Sayantan Ganguly and M. S. Mohan Kumar (2012), “Geothermal Reservoirs – A Brief Review”, Journal Geological Society of India, Volume 79, pp. 589-602, Available at: https://www.researchgate.net/publication/249322509_Geothermal_reservoirs-A_brief_review

[6] William B Cumming, “Geothermal resource conceptual models using surface exploration data”, Available at: https://www.researchgate.net/publication/228643656

[7] Anette K. Mortensen and Gudni Axelsson, “Developing A Conceptual Model of a Geothermal System”, Presented at “Short Course on Conceptual Modelling of Geothermal Systems”, Available at: https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-16-29.pdf

[8] Case study on Shallow Geothermal Systems, Available at: https://geothermalcommunities.eu/assets/presentation/5.Course_GT.pdf

[9] Lund, John W. "Geothermal Heat Pumps - An Overview", Geo-Heat Center, Volume 22, Issue 1, pp 885-1750, Available at: https://www.researchgate.net/publication/242159982

[10] Case study on “DRILLING AND TESTING GEOTHERMAL WELLS- 2012”, https://www.esmap.org/sites/esmap.org/files/Bailey_Exploration%28Day1%29_0.pdf

[11] Mladen BOŠNJAKOVIĆ, Marinko STOJKOV (2019), Mate JURJEVIĆ, "Environmental Impact of Geothermal Power Plants", Portal Hrvatskih Znanstvenih I Strucnih Casopisa, Volume 26, Issue 5, Pp 1515-1522, Available at: https://www.researchgate.net/publication/336375677_Environmental_Impact_of_Geothermal_Power_Plants

[12] Case Study on Exergy Analysis of Renewable Energy System,2007. Available at: https://www.researchgate.net/publication/279871121

[13] Asif Bin Karim, Sakib S. Avro, Saquib Shahriar (2018), "Prospect of Geothermal Energy Resources in Bangladesh”, International Journal of Renewable Energy Resources, Volume 8, Issue 2, Pp 22-28 Available at: https://www.researchgate.net/publication/330114996_PROSPECT_OF_GEOTHERMAL_ENERGY_RESOURCES_IN_BANGLADESH

[14] Md. Akramul Alim, Md. Momtazur Rahman, Nafiul Islam, Md.Mahmudul Hasan(2017), "Geothermal Power Generation possibility and Geothermal sites in Bangladesh: A Review" BAUET JOURNAL, Volume 01, Issue 01, pp 67-81, Available at: http://journal.bauet.ac.bd/

[15] Debendra K. Guha, Herbert Henkel, Badrul Imam (2010), "Geothermal Potential in Bangladesh - Results from Investigations of Abandoned Deep Wells", Bali, Indonesia, Publisher: Proceedings World Geothermal Congress, Available at: https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0172.pdf