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Study of Economic Feasibility for a Decentralized Small off Grid Geothermal Power Plant Using Slim Boreholes

Taral Patel Manan Shah

Department of Mechanical Engineering, National Institute of Technology, Patna, India

Department of Chemical Engineering, School of Technology, Pandit Deendayal Petroleum University, Gandhinagar-382007, Gujarat, India

Email id: taralpatel1898@gmail.com Manan.shah.@spt.pdpu.ac.in

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ABSTRACT

India's 80% of the electricity demand is fulfilled by exploiting non-renewable fossil fuel. India's dependence on energy imports will exceed 53% of the country's total consumption by 2030. To curtail this alarming increase of dependence on fossil fuels attention towards development of renewable resources like Solar, Wind, Hydropower and Geothermal is needed. Major aggravating factor that flags the development of renewable power plants is 65% of population residing in remote areas. This makes transmission of electricity a major issues for remote areas as most of the power is lost in form of heat over long distances from power plants. This paper shows a case study of Himachal Pradesh, India discussing the feasibility of a decentralised Small off grid Geothermal power plant for providing electricity to remote areas. According to a study, Himachal Pradesh Geothermal Sub- provinces (HPG) is a faction of the large Himalayan Geothermal Province extending up-to 1500 sq. km. High thermal gradients (>260℃/km) and High heat flow(>180mW/m^2) are the characteristics of HPG. Additionally, Surface spring temperature of 57 to 98℃ at Manikaran, Himachal Pradesh corroborates the high potential reserves of geothermal sources beneath the strata. Thermal water flow rates measured from the shallow exploration bore wells, drilled by the Geological Survey of India, varies from 200 L/m (52 GPM) to 1000L/m (264 GPM) is far greater than the 2.5 – 3 GPM required for production of 12000 BTU/hour. Use of slim bore holes (150mm or less) will reduce the drilling cost for extraction of thermal waters further increasing the possibilities of off grid geothermal plants for rural electrification. This paper also present the approximate economic cost required to set up a geothermal plant at remote location and studying the minimum load required for the plant to be feasible for local populace.

1. INTRODUCTION

Developing country like India stands at third position when it comes to electricity consumption. According to Electricity sector of India per – capita consumption in India stood as high as 1208 kWh. For the year 2019-20 the total electricity produced was 374,199 MW. Fossil fuel contributed for 79.8% of the total production where renewable shared a concerning percentage of about 17.3. India's renewable energy basket is filled with Hydro Power, Solar, Wind, Biomass, Tidal and Geothermal Energy (Prajapati et al., 2020). India has been exploiting non - renewable fossil fuels since 18th century with its first oil well in Digboi, Assam. But with increase in the number of factors such as industries, automobiles pollution is rising exponentially (Shah et al., 2020). Researchers along with the government are inclining towards renewable energy and making effort to increase its total share in country's power production (Gothwal et al., 2018).

India takes advantage of its geographical positions and exploits Solar and Tidal energy. But, there is a huge potential for Geothermal Power in India. About 65% of the Indian population resides in remote areas (Sircar et al., 2017). This is the major factor that results in High Transmission losses. 18.5% of the total electricity generation was lost in the form of heat during transmission and distribution. Such losses can be decreased by generating electricity near to the remote areas and distributing it locally. Tidal, wind and Solar energies are geographically constrained due to their requirements. But small scale off decentralized grid geothermal plant can be used for rural electrification where there is geothermal potential (DiPippo, 1999).

India has a geothermal potential of 10,000 MW and majority of which has not been exploited (Chandrasekharam et al., 2008). If large scale flash system plants are established then transmission and distribution losses will curb the development of geothermal power plants. Instead small off grid plants can be more benign. One such province is Manikaran in Himachal Pradesh. Himachal Pradesh Sub Province (HPG) is faction of large Himalayan geothermal province which covers area of 1500 sq. km (Chandrasekharam et al., 2003). High geothermal gradients (>260°C/km) and High Heat flow rates (>180 mW/m^2) can be obtained at very shallow depth (Eliasson et al., 2014).

2. GEOTHERMAL POWER PLANT

The use of geothermal energy started to grow exponentially since its first use in Tuscany village of Larderello (Franco and Vilani, 2009). It was used to power a 3/4 horse power engine and that in turn power few bulbs. Today it is used to generate megawatts of energy all across the world. Geothermal power plants uses the thermal waters that is heated due to the internal heat of earth's core. Unlike other sources of power production like fossil fuels heated thermal waters cannot be transferred using pipe lines for power production. So the geothermal plant needs to be established near the resource (Chandrasekharam et al., 2005). It is mainly classified in three types

i. Dry Steam
ii. Flash Steam
iii. Binary System

Dry steam type geothermal power directly uses the heat that is generated from the bore hole. This steam is directly passed to the turbine and power is generated. The steam is then directed towards the cooling tower which converts it to the liquid. The liquid is then injected back into the reservoir to reheat and reuse the steam. Direct use of the steam may generate the problem of scaling on turbines blades. To counter this a development of dry steam system is the flash system. In Flash steam type geothermal power plant hot thermal water from the reservoir is fed to steam separator. Here the thermal fluid in the pressure vessel experience low pressure and it helps the thermal fluid to convert to steam easily. This process is known as flashing. Then the steam is pressurized and passed through turbines for power generation. To increase the efficiency of flash type geothermal plant geo fluid (steam + vapor) is passed through another flash evaporator. Here steam is produced again using flashing and then the remnant of the geo fluid is stored in a storage tank. Flash steam type plant is generally used for the resources where the thermal gradient is more than 180°C (Prada, 2013).

Since the requirement of both dry steam and flash steam is very high fluid temperature they cannot be used for decentralized geothermal power plants. Off grid geothermal plants can be constructed using a binary system. In this system neither the direct steam nor the flashed steam is fed into the turbine. Conversely the hot brine solution from the bore well is fed into the heat exchanger where the heat is transferred to a binary liquid with a very low boiling point. Binary fluids such as isobutene, propane ammonia etc. can be used for heat transfer. Using this method the heat from the thermal fluid with low peak temperatures can be extracted and can be used for power generation. One downside of this system is that it is very complex and can be costly to at first. But if the feasibility of the resources are for the longer period then the binary system can be used for off grid power generation (Legmann, 2003).

3. GEOTHERMAL MANISFESTATION AT MANIKARAN IN HPG

In India there are mainly seven geothermal province i.e. Himalayas, Sohana, West coast, Cambay, Son-Narmada-Tapi (SONATA), Godavari and Mahanadi. Tattapani, Puga, Beas, Parbati, Sutluj, Bhagirathi and Alanknanda are the constituents of Himachal Pradesh Sub Province (HPG). HPG is faction of the greater geothermal province i.e. Himalayan province. A joint research collaboration of Indo – Italian has led to investigation of thermal waters and thermal gases along parbati and kullu valleys consequently providing data to determine feasibility of geothermal power plant. It would be inconsistent to classify a geothermal resource based on single thermodynamic property. At least two independent properties should be used to define the state of the fluid of geothermal resource (Lee, 1996). Based on that geothermal resources can be classified in three categories

i. Low temperature Geothermal Field (< 150℃)

ii. Intermediate temperature Geothermal Field (150℃ - 200℃)

iii. High temperature Geothermal Field (> 200℃)

The temperature of the geothermal fluid in the Manikaran province vary from 200℃ to 310℃. The surface temperature of thermal springs may go from 57℃ as high as 98℃. Currently they are directly used for cooking food and for farming purposes. But the resources are exploited in inefficient way and they can we used for rural electrification. When the water is ejected from the source using feed pump the temperature of the geothermal fluid drops. So seemingly high temperature may give idea that resources at Manikaran should be used for electricity generation using flash and dry steam methods, but those would be rendered futile. Technological advancement have made it possible to combine flash type system with a binary system. First the geothermal fluid at with temperature greater than 200℃ is flash in an evaporator and the steam is used for power generation. If it is a double flash power plant than steam would be generated twice from the geothermal fluid. The residual fluid is then passed through a binary system where heat can be extracted from the fluid even when the temperatures are below 150℃. If the temperatures are reduced any further than problem of silica scaling would occur and would affect the performance of injection pumps. Such a combined system is used at El Salvador geothermal power plants in Central America. Binary system attached at the end of the flash system is called bottoming plants. In case of Manikaran province if one binary system of the capacity ranging from 3 – 10 MW is installed then rural electrification can be made possible.

3.1 BINARY GEOTHERMAL POWER PLANT

Since the thermal properties of geothermal fluids at Manikaran are not feasible for flash or dry steam type power plants, it is more adequate to discuss about binary type geothermal power plants. We use a Rankine cycle for power production in flash type geothermal power plant whereas we use a modification i.e. Organic Rankine Cycle (ORC) for binary type system. A typical ORC is formed by two cycles namely the primary cycle that contains the geothermal fluid and a secondary cycle that contains the organic working fluid. The primary cycle begins at the production wells and it ends at the reinjection well. The geothermal fluid can be in the form of water or steam. But during the heat exchange process the temperature and pressure of the fluid is maintained to avoid flashing. During the process of reinjection the temperature should be not drop the silica scaling point to avoid any long term maintenance issues. The main components of the binary system are

i. Preheater

ii. Evaporator

iii. Turbine

iv. Condenser

v. Working fluid pump

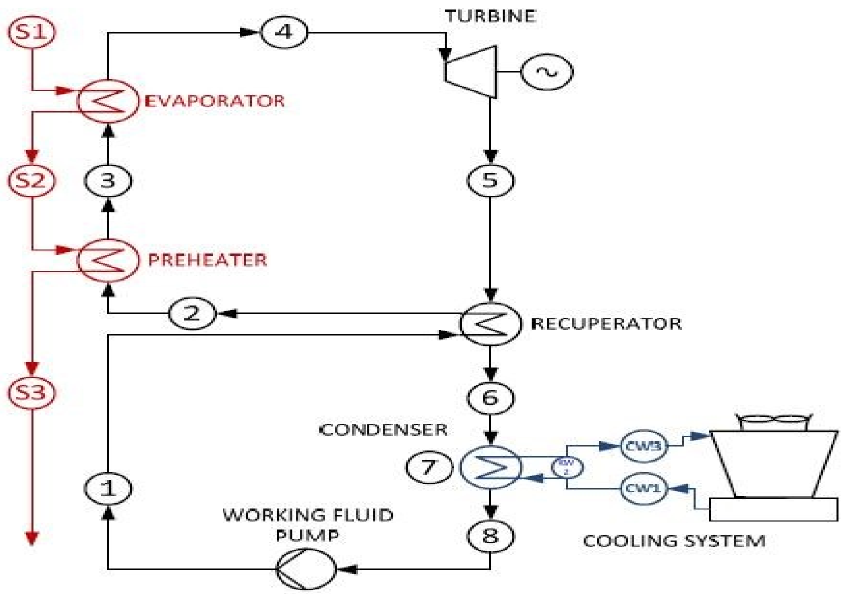

Figure 1: Schematic Diagram of Binary cycle Geothermal Power Plant

The binary cycle process can be represented on the graph with temperature and entropy on its axes. The process for the organic working fluid is plotted which is used to calculate the work output of the turbine. Figure 2: shows the secondary cycle on T-s diagram. It consist of mainly four processes.

6 – 1	Isentropic Compression in Pump
1 – 2 – 3	Constant pressure heat addition in Preheater and Evaporator
3 – 4	Isentropic expansion in turbine
4 – 5 – 6	Constant pressure heat rejection in condenser.

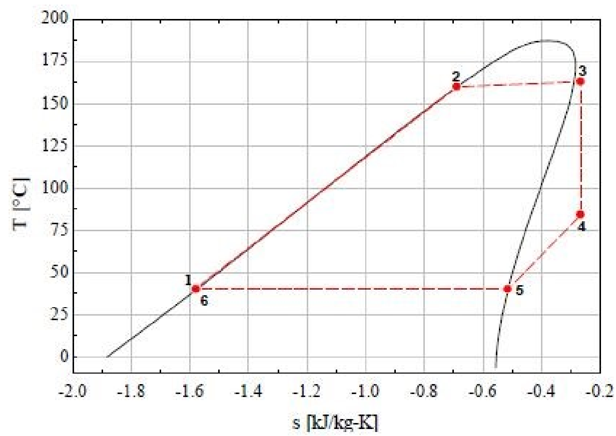

Figure 2: T-s diagram for binary cycle using organic working fluid.

In the secondary cycles the working fluid enters the process at state 6 in the form of the saturated liquid. After isentropic compression by working fluid pump its pressure increases to the level of working pressure of preheater. The working fluid enters the preheater as a compressed liquid and exits the evaporator as saturated steam at state 3. The saturated state of the steam ensures that there are no liquid droplets present in the steam and it will cause no erosion to the turbine blades. It then enters the turbine and generates electricity by isentropic expansion till state 4. Preheater is a huge heat exchanger which is used to bring the working fluid to a boiling temperature. It ensures that the evaporator has to input less work in order to increase the efficiency of the cycle. The exiting steam still has energy left before it enters the condenser for further cooling. The exiting steam can be used to preheat the entering working fluid and reduce the heating load on the preheater further decreasing the energy demand of the cycle. This process of reusing the exiting the steam can be done using a recuperator. After reusing the heat of exiting steam it is still in the vapor form and needs to be cooled for further use. It then enters the condenser and it is condensed to liquid at constant pressure. The cycle is then repeated and the liquid enters the working fluid pump. The condenser that is used for cooling purpose can be of two type i.e. air cooled and water cooled which are known as air and wet cooling systems respectively.

3.1.1 PREHEATER AND EVAPORATOR

Preheater and evaporator are the first system in a binary cycle that a geothermal systems comes in contact with. These are heat exchangers where the heat energy from geothermal fluid is transferred to the organic working fluid. In these heat exchangers the two fluids never come in direct contact. Point S1 in figure 2 is the entry point for geothermal fluid into the evaporator and S3 is the exit of the geothermal fluid from preheater. Constraints are applied on the geothermal fluid exiting the preheater at S3 such that its temperature and pressure should be enough to avoid scaling.

Point 1 is the entry of the organic working fluid from the fluid working pump and point 3 is the exit from the evaporator. The steam properties depends on the turbine requirements however at the exit it should be saturated or superheated. It is assumed that the heat exchanger is completely insulated and the only heat is supplied to working fluid. Energy balance equation is given by

$$\dot{m}_{gf}(h_{s1} - h_{s3}) = \dot{m}_{wf}(h_3 - h_1)$$

$\dot{m}_{wf}$ = Working Fluid mass flow rate

$\dot{m}_{gf}$ = Geothermal Fluid mass flow rate

h = Enthalpy values at specific points

Values of the enthalpy and mass flow rate depends on the resource at particular place. In Manikaran flow rates up to 1000 L/m can be observed. The least temperature difference between the geothermal fluid and working fluid is known as the pinch point. The pinch point temperature difference is often specified by the manufacturer and it can be used to find sT_{s2}.

3.1.2 TURBINE

It is component that is used to convert the thermal energy stored in steam into electric energy using vanes, turbine shaft and electric generator (Gabbrielli, 2012). The major advantage of binary system is that the direct steam from geothermal fluid containing harmful gases and moisture never interacts with the turbine. This results in prolonged turbine life and greater power plant life cycle. Also, to control the temperature the working fluid steam using preheater is much more convenient compared to flash system. Steam undergoes isentropic expansion from point 3 to point 4 and rotates the shaft generating electricity. The ideal power generation depends on the mass flow of the steam and actual output can be obtained using the turbine efficiency n_t.

$$\dot{W}_T = \dot{m}_{wf} n_t (h_3 - h_{4s})$$

$\dot{W}_T$ = Turbine work output

3.1.3 CONDENSER

Condensers are the heat exchanger that is used to remove the residual heat from the working fluid steam (Combs et al., 1997; DiPippo, 2012). But before the steam enters condenser it is redirected into the preheater where it is used to preheat the entering working fluid reducing the heat withdrawn from the geothermal fluid. Condenser energy balance equation is given as

$$\dot{m}_{CF}(h_{CW3} - h_{CW1}) = \dot{m}_{wf}(h_4 - h_6)$$

$\dot{m}_{CF}$ = Cooling Fluid mass flow rate

It is classified in three systems.

i. Water cooling system

ii. Wet air cooling system

iii. Air cooling system

Water cooling system has a shell type heat exchanger where the heat from the steam exiting recuperator is extracted into the cooling fluid i.e. water. The heated water is then introduced back into the reservoir and the cycle is repeated. Over the prolonged years the temperature of the water body can increase affecting the aquatic life of the locality. But such a system can only be used when there is huge availability of water source in vicinity of the power plant. In case of Manikaran and HPG there is abundance of water available from Pārbati River.

Wet air cooling system also has the same structure that of a wet cooling system but it is more environmentally benign. Conversely when the water extracts the heat from the steam it is then sent to the cooling tower where the heat from water is rejected to the surroundings.

Air type cooling system uses forced convention to cool the entering steam. The fan blows the air around the condenser tubes and the heat is extracted. No source of water is used for such type of condenser and it is feasible to install it irrespective of the terrain and resource availability.

4. ECONOMICS AND COST ESTIMATION OF POWER PLANT

The variable components of the power plant are the heat exchangers that are used to withdraw the heat from geothermal fluid. If the size of such heat exchangers increases for the small scale geothermal power plant then it would be rendered futile. For that purpose proper sizing of preheater and evaporator becomes pivotal design parameter for such small scale plants. During the design consideration the constraints that controls the sizing is the reinjection temperature of geo fluid. The reinjection temperature should always be greater than the dew point of geo fluid to avoid silica scaling. If excess of heat is removed from geo fluid and transferred to working fluid then power plant life cycle can be affected largely (Rajda and Saragih, 2003).

One parameter that defines the size of the heat exchanger is the area required in m^2 to exchange the specific heat. Principles of conduction through heat exchangers tubes and principles of convection through the geo thermal fluid are used for area calculation. Since this would result in very complex analysis it is more convenient to use overall heat exchange co-efficient U. Also, the Log Mean Temperature Difference (LMTD) method is used to determine the area.

$$A = \frac{Q}{U*LMTD}$$

$$LMTD = \frac{\Delta T1 - \Delta T2}{\log(\frac{\Delta T1}{\Delta T2})}$$

A = Heat exchanger surface area

Q = Rate of Heat Transfer

U = Overall Heat Transfer coefficient

$\Delta T1$ = Temperature difference between the fluids at the inlet of heat exchanger

$\Delta T2$ = Temperature difference between the fluids at the outlet of heat exchanger

When a recuperator is added to the power plant to increase its overall efficiency then cost of establishment increases due to addition of a surplus heat exchanger. If an investment is made in heat exchangers for a binary power plant with recuperator, considering the energy cost at 560 INR/MW along with the operations and maintenance cost at 5% of the annual income the estimated payback time can be of 1.71 years [10]. Such short payback time can be feasible for a power plant with geothermal potential that can last up to 25 years and provide rural electrification.

5. CHALLENGES AND FUTURE SCOPE

Establishing a geothermal power plant is not just dependent on the availability of the resource but also on the thermal chemistry of geo fluid. If harmful gases dissolved in the geo fluid then irrespective of the type of anti-corrosion materials used for turbine and heat exchangers they would be prone to scaling and contamination. Consequently during the life cycle of power plant replacing and maintenance of heat exchangers is feasible but the same frequent procedure for the turbine would result in increased down time and reduce in annual income. For off grid power plants when there is production of electricity on small scale such hindrances can affect largely. Geothermal fluid with temperatures 90℃ to 130℃ are injected back into reservoir. The remnant heat from the fluid can be used for other purposes like space heating, food industry and many more. Especially cold climates like at Manikaran can reuse the heat from geothermal fluid. Costs are significantly increased when recuperator is added to increase the overall efficiency but proper plant design can help reduce this cost. Geothermal power plant has a huge environmental impact on surroundings of its location. Land occupancy, water resources exploitation, and increase in ambient air temperature etc. are some of the factors that should be considered before establishing the power plant. With proper survey and design methodologies India can fully exploit its geothermal potential in near future.

6. CONCLUSION

If the plot of world geothermal resources is made with reference to temperature then the lines are steeper towards the medium and low temperature geothermal resources. This implies that further development of binary geothermal power plants would empower greater exploitation of geothermal fields at low temperature. Also using the organic fluid helps to increase the life cycle of the power plant by reducing the corrosion of the turbine blades and heat exchangers. Addition of recuperator unit does not increase the turbine efficiency but rather it prevents the heat that was previously used in preheating the working fluid. But a major drawback for adding the recuperator is the increased cost that only can be justified by power plant life which is dependent on the geothermal resource. The state of the geothermal fluid can be either steam or fluid. The major advantage of using the steam is avoiding the scaling problems in heater and evaporator and also reducing the risk of scaling while reinjection. Various environmental factors are considered while choice a condenser system depending on the water availability and ambient air temperature. Manikaran has both cold air and water resource to ease the process of condenser choice. However dry cooling systems are preferred over wet due to less complexity and easy maintenance. India has a rich potential of geothermal it can be exploited by either binary or a combined system for power generation. Manikaran has a geothermal topology that supports the establishment of a power plant and since it is the area where rural electrification is still a needed such establishments could achieve that goal.

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