Modeling of the Geothermal Energy Flow for Optimized Power Conversion based on the Diffusion Equation of Fluid Flow for Porous Rocks

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Resumen

Recientemente se han realizado muchos esfuerzos concretos en el diseño de plantas para la conversión de energía geotérmica en electricidad. Este documento se centra en el modelado del flujo de energía geotérmica para la conversión de energía optimizada basada en la ecuación de difusión del flujo de fluido para rocas porosas, para optimizar el uso de la energía geotérmica, además de discutir el papel de los parámetros: la velocidad de rotación del par, el flujo de fluido tasa, la velocidad del fluido, el ángulo de incidencia y el radio de la turbina para la conversión eficiente en potencia. Se ha presentado una breve descripción de la dependencia de la variación de la temperatura en la profundidad del océano y la eficiencia térmica teórica del ciclo de Rankine en la diferencia de temperatura entre el agua del océano profundo y el agua superficial.

Palabras clave: Educación, flujo de energía, epistemología.

Abstract

Many concrete efforts have recently been made on designing plants for conversion of geothermal energy into electricity. This paper focuses on Modeling of the Geothermal Energy Flow for Optimized Power Conversion based on the Diffusion Equation of Fluid Flow for Porous Rocks, for optimizing the use of the geothermal energy, besides discussing the role of the parameters - torque rotational speed, the fluid flow rate, the fluid velocity, the incidence angle, and the turbine radius for the efficient conversion into power. A brief description of the Temperature variation dependence on the depth of the ocean, and theoretical thermal efficiency of Rankine cycle on the temperature difference between deep ocean water and surface water, has been presented.

Keywords: Education, energy flow, epistemology.

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I. INTRODUCCIÓN

Geothermal energy is the thermal energy generated and stored in the Earth, and determines the temperature of matter. The Geothermal energy of the Earth's crust is originated from two factors: (i) The original formation of the planet (1/5th), and (ii) The radioactive decay of minerals (4/5th). The earth consists of three parts – core (innermost), mantle (middle), and earth's crust (outermost).

The top layer of mantle is a hot liquid rock (magma), on which the earth floats. During the eruption of volcanoes, magma breaks through the surface of the earth in the form of lava. The temperature differential below the earth is formed in such a way, that for every 100 meters below the ground, the temperature of the rock increases by ~ 3 degrees Celsius, and thus near the surface of the rock, it becomes ~ 150 degrees Celsius. . However, due to the fact that it is not in contact with air, it does not form steam. This difference in temperature can be used for the generation of electricity. This geothermal gradient i.e. the difference in temperature between the core of the earth and its surface, results in the continuous conduction of heat energy from the core to the surface. However, efficient technology for extracting and using this energy is still not developed. It is well known that around the world, people have been using the hot springs for rest and relaxation. Recently, for the well known reasons, a lot of research and development work is going on for finding ways of utilizing the sources of renewable energy. Chopra [1, 2, 3, 4] has made some investigations on various forms of renewable energy including solar energy, and Biophotonics and Optofluidics. With the increasing importance of the sources of renewable energy, a lot of interest has been shown in the studies connected with geothermal energy. Glassley [5] has given a very exhaustive account of geothermal Energy as the renewable energy, and its effect on the environment. Fridleifsson [6] has presented a detailed review of the renewable and sustainable energy. Fridleifsson et al [7] have discussed the possible role and contribution of geothermal energy to the mitigation of climate change.

Bertan [8] has presented the results of global geothermal generation for the year 2007. Bloomquist [9] has given a detailed account of the use of the geothermal heat pumps in the last four decades of the 20th century. Lund [10] has discussed in detail the characteristics, development and utilization of geothermal resources. Dickson and Fanelli [11] have discussed the different aspects of geothermal energy.

It is well known that the he earth's internal energy comes from: (i) the decay of radioactive nuclei embedded within the earth, having long half lives, (ii) the residual heat left over from the earth's formation, and (iii) the impacts of meteorites. The various geothermal energy sources are: (i) Hot water resources, which are the huge reservoirs of hot underground water, more useful for space heating than for the generation of electricity; (ii) Natural stem reservoirs, which are formed by digging a hole into the ground, resulting in coming of steam to the surface; and (iii) Geopressured reservoirs, in which the brine fully saturated with natural gas is stored under pressure by the weight of the covering rock, and can be used for heating and for the natural gas. It is interesting to note that tens of thousands of megawatts (MWs) of geothermal power is now available online in many countries. Some tens of gigawatts of direct geothermal heating capacity is used for space heating, spas, industrial processes, and agricultural applications. The direct use of the geothermal energy is suitable for the sources with temperature below 1500 degrees Celsius.

These are: space heating, drying, snow melting, air conditioning, industrial processes, hot water, Agriculture, Greenhouses, and resorts and pools. The functioning of direct sources is simple: First, the water is sent down into a well, and heated by the earth's warmth. Thereafter, a heat pump is used to take heat from the underground water to the substance being used for heating the house. Finally, the water is cooled, and injected back into the earth. The generation of electricity is suitable for the sources having temperature greater than 150 degrees Celsius. This is done by various types of plants: (i) Dry Steam Plants, which use the underground steam to directly turn the turbines; (ii) Flash Steam Plants, which pull out the deep water at 2000 degrees Celsius and high pressure to the surface, which is then transported to low pressure chambers, and the resulting steam is made to drive the turbines, with the remaining water and steam being injected back into the source from which they were originally taken; and (iii) Binary Cycle Plants, which pass moderately hot geothermal water past an organic fluid with a lower boiling point, and use the resulting steam to drive the turbines, the process being free from any emissions. In this case, the hot water is made to go through heat exchanger, to heat up another fluid like isobutene in a closed loop system, so that the later fluid boils at lower temperature than the hot water, and hence is converted into steam much faster, which is finally made to drive the turbine, because of the fact that the hot water is much more common than water at extremely high temperatures. The optimization of the use of the geothermal energy is done by considering its flow in a huge reservoir, and making these assumptions: (i)

II. OPTIMIZATION AND MODELING OF GEOTHERMAL ENERGY

The reservoir has different porous rock formations, in which the pores are filled with fluid, mainly water, existing in liquid phase, gas phase, or as a two phase mixture, and the solid rock material has elastic properties, but not moving as the fluid; (ii) The reservoir is surrounded by Earth's surface and the outer boundaries within the crust. In the mathematical flow analysis, the conditions have to be specified for the main variables at all the points on the boundary; (iii) The concerned variables and parameters are functions of position in a 3-D space, and (iv) The state of the reservoir in general varies with time, though in certain cases a steady state solution can also be found. The flow of the liquid through the porous medium i.e. rock is studied by the well known Darcy's law, which is surprisingly based on some of the experimental results on the flow of water through sand beds, and also explains fluid permeability used in the earth sciences like hydrogeology. Darcy's law is just a proportional relationship between the instantaneous discharge rate through a porous medium, the viscosity of the fluid and the pressure drop over a given distance, and is given by the following equation:

$$Q = (\frac{-kA}{\mu})(\frac{P_b - P_a}{L}), \tag{1}$$

where Q is the total discharge in units of volume per time (m^3/s), which is equal to the product of the permeability of the medium, k (m^2), the cross sectional area of flow, A (m^2), and the pressure drop, P_b in pascal, divided by the viscosity, U (Pa·s) and the length over which the pressure drop is taking place (m). The negative sign appears because the fluid flows from high pressure to the low pressure. For the negative change in pressure i.e. $P_a > P_b$, the flow is in the positive x direction. Dividing both sides of the equation by A and using more general notation, we can write:

$$q = (\frac{-k}{\mu})\nabla P. \tag{2}$$

$$v = \frac{q}{n}. \tag{3}$$

Darcy's law is a simple mathematical statement which explains many properties exhibited by the flowing groundwater, like: (i) In absence of any pressure gradient over a distance, no flow of the fluid takes place; and (ii) In presence of a pressure gradient, fluid flows from high pressure towards low pressure i.e. opposite to the direction of increasing gradient; which explains the negative sign in Darcy's law.

It must be noted that the Darcy's law holds true only for slow, viscous flow; which is usually the case with the most groundwater flows. Any flow with a Reynolds number less than unity is laminar, and is valid for applying the Darcy's law. In fluid mechanics, the Reynolds number is a dimensionless quantity, used to help predict similar flow patterns in different fluid flow situations, and is defined as the ratio of inertial forces to viscous forces and consequently quantifies the relative importance of these two types of forces for given flow conditions. This number for the porous media flow, and is expressed as:

$$R_e = \{\frac{V\rho drg}{\mu}\}, \quad (4)$$

Where *p* is the density of water (mass per unit volume), *V* is the specific discharge, drg is a representative grain diameter for the porous media, (generally taken as 20% to 40%) as the 30%, and *u* is the viscosity of the fluid. The basic law governing the flow of fluids through porous media is given by Darcy's law, which as pointed out earlier, is based on experimental results on vertical water filtration through sand beds. The data is found to fit in the following equation:

$$Q = \{\frac{CA\Delta(P-\rho gz)}{L}\}. \quad (5)$$

Where P is the pressure in, *pascal*, *P* is the density in $\frac{kg}{m^3}$, *g* is the gravitational acceleration in $\frac{m}{s^2}$, *Z* is the vertical coordinate (measured downwards) in *m*, *L* is the length of sample in *m*, *Q* is the volumetric flow rate in $\frac{m^3}{s}$, *C* is the constant of proportionality in $\frac{m^2}{Pascals.s}$, and *A* is the cross.

Sectional area of sample *in* m^2. It is interesting to know that the Darcy's law is analogous to some important laws like - Ohm's law for electrical conductivity, Fick's law for solute diffusion in a solvent, and Fourier's law for conduction of heat. Let us understand as to how the term *(P – pgz)* governs the flow rate. We know that in the fluid mechanics, the Bernoulli's equation, which is based on the principle of conservation of energy, contains the terms.

$$(\frac{P}{\rho} - gz + \frac{v^2}{2}), \quad (6)$$

Where *P*/*ρ* is related to the enthalpy per unit mass, *gz* is the gravitational energy per unit mass, $\frac{v^2}{2}$ is the kinetic.

Energy per unit mass and gradient of (*P – pgz*) is the driving force for flow, since the velocity of the fluid in the reservoir is very less, and the third term is consequently zero. Sometimes, the volumetric flow per unit area, $q = \frac{Q}{A}$, is considered for the computational work, and so the Darcy's law can be write in the form:

$$q = \frac{Q}{A} = \{\frac{k\Delta(P-\rho gz)}{\mu L}\}. \quad (7)$$

Where *q* is the flux in $\frac{m}{s}$, or in $\frac{m^2}{m^2 s}$, which is easier to follow. The volumetric flow rate *Q* is inversely proportional to the fluid viscosity, *u* in *Pascal.second*, and so if we put $C = \frac{k}{\mu}$, then *k* is known as the permeability, with dimensions m^2. It is important to note that the permeability is a function of rock type, and varies with the change in the parameters like stress and temperature, but is independent of the nature of the fluid. Permeability has units of m^2, but in geothermal engineering, Darcy units are used, which are defined by 1 Darcy = 0.987 ×10−12 m^2 ≈ 10−12 m^2. This unit is defined so that a rock having a permeability of one Darcy transmits 1 cc of water with viscosity 1 c *Pascals* second, through a region of 1 sq. cm. cross sectional area, for the pressure drop along the direction of flow equal to 1 atm per cm.

For the transient processes in which the flux varies from point to- point, the differential form of Darcy's law has to be considered, which is written as:

$$q = \frac{Q}{A} = \{\frac{kd(P-\rho gz)}{\mu dZ}\}. \quad (8)$$

For the case of the fluid in static equilibrium, *q*= 0, and the Eq. (8) leads to:

$$\{\frac{d(P-\rho gz)}{dZ}\} = 0 \text{ i.e. } (P-\rho gz), = \text{constant} \quad (9)$$

where *Z* is the vertical distance. For the case of the sea level, *Z* can be taken as zero, and the fluid pressure is just the atmospheric pressure, and therefore, the static pressure P_{stat} *i*s given by:

$$P_{stat} = (P_{atm} + \rho gz). \quad (10)$$

We can see by comparing the Eq. (7) and (9), that only the pressure above and beyond the static pressure given by Eq. (9) contributes in driving the flow. Hence, *pgz* can be neglected since it only contributes to the static pressure, and not to the driving force for flow. In order to take this extra term into consideration, a new term corrected pressure Pcorr is defined as:

$$P_{corr} = (P - \rho gz) \quad (11)$$

Hence, the Darcy's law given by Eqn. (1) can be written as:

$$Q = CA\Delta(\frac{P_{corr}}{L}) \quad (12),$$

which relates the total discharge Q in terms of the parameters $C; A; P_{corr}$, and L.

III. ANALYSIS OF THE DESIGN PARAMETERS

Geothermal power plants are used to capture the geothermal energy by tapping underground into the special type of systems called - Hydrothermal Convection Systems, by which the heat energy is transferred to the Earth's surface. The water becomes hot, and rises to the Earth's surface, mostly in the form of steam, which is captured from drilling in the warm underground rocks; and made to come up through wells and piping systems, and is finally pumped out of the earth. Subsequently, the steam is used in the power plants for running the generators, and the water is sent back underground for the further use. The generators are used to produce electricity for various uses. The other method of capturing the geothermal energy is by using the 'Hot Dry Rock' System, in which the hot rocks underground break apart due to the high pressure of the water pumped from the surface, the water being then carried up to the earth's surface through piping systems, and finally driving the turbines for the generation of electricity. The turbine is based on converting the kinetic energy of the working fluid into the rotational motion of the turbine shaft. According to the well-known Euler's Turbine Equation, the torque *(T)* on the shaft is equal to the change in angular momentum of the water flow, deflected by the turbine blades, and the power *(P)* generated is equal to the product of the torque on the shaft and the rotational speed of the shaft. The concept of power generation has been explained on the basis of the following equations:

$$\text{Torque} \quad T = \rho Q(\tau_{in}.V_{in} - \tau_{out}.V_{out}), \tag{13}$$

and

$$\text{Power} \quad P = \omega T = \omega\,\rho\,Q(\tau_{in} q_{in} \cos\beta_{in} - \tau_{out}\, q_{out} \cos\beta_{out}), \tag{14}$$

Where Q is the fluid flow rate, p is the fluid density, q is the fluid velocity, β is the incidence angle, V is the tangential fluid velocity $(V = q\cos\beta)$, τ is the turbine radius, ω is the turbine rotational speed, T is the torque, and P is the power output. It is clear that the power output is independent of the turbine configuration, and depends only on the change in angular momentum of the fluid between the turbine's input and output.

The parameter k is quite significant in the study of the geothermal energy, and its numerical value for a given rock depends on (i) the diameter d of the pores in the rock, and (ii) the degree of interconnectivity of the voids, and is ~

$k \approx \frac{d^2}{1000}$. The computations of k for some of the common rocks give the values as; (i) fine sand,silt - k (Darcies) in the range 10^{-4} - 10^{0}; and $k(m^2)$ in the range 10^{-12} – 10^{-10} (ii) limestones - K (Darcies) in the range 10^{0} - 10^{2}; and $k\ (m^{2})$ in the range 10^{-12} – 10^{-10}, and (iii) sandstones - k (Darcies) in the range 10^{-5} – 10^{1}; and and $k(m^2)$ in the range 10^{-17} -10^{-11}. The exact knowledge of k is very useful for the designers of the plants for the energy extraction and power generation. In most of the cases, there are differences between the calculated values and the achieved values, and thus the corrections have to be made on the basis of this feedback, which requires a lot of experience and expertise of the designers.

IV. OCEAN THERMAL ENERGY CONVERSION (OTEC) TECHNOLOGY BASED ON OPEN/CLAUDE CYDLE

In Open/Claude Cycle scheme, warm surface water at around 27°C is admitted into an evaporator, where the pressure is maintained at a value slightly below the saturation pressure. The working is based on the fact that temporarily superheated water undergoes volume boiling, different from the pool boiling in conventional boilers having the heating surface in contact. In this case, the water partially flashes and converts into steam with a prevailing two phase equilibrium. The OTEC Plant has many important components like- The heat source is the 27°C surface water in the tropical oceans., and the heat sink or the cold bottom water is nearly 900 m below the surface i, which is ~ 4.5°C. It can be easily seen that this temperature difference is sufficient to operate vapor turbines, which drive generators for producing not only electricity, but also fresh water as a byproduct.

The OTEC Plant plant is based on using advanced turbines and heat exchangers for the Geothermal Energy Flow for Optimized Power Conversion based on the Diffusion Equation of Fluid Flow. The plant uses multiple heat exchangers (evaporators and condensers), pumps, vapor turbines, compressors and generators, the whole system being charged with propylene, a refrigeration fluid. Interestingly, this refrigerant boils at low temperatures (~ 19.5°C) under a pressure of 150 psi. The 27°C solar heated surface water, allows propylene to convert from a liquid to a gas or vapour. Also, the warm water pumped through the boilers (heat exchangers) boils the propylene into a vapour, which expands through vapor turbines that drive the generators. Another important step is to complete the cycle, which is done by pumping cold water (~ 4.5°C) from the lower depths of the ocean. Finally, the cold water is used to condense the propylene vapuor back into its liquid state, which is again pumped into the boiler to complete the cycle. Interestingly, in most of the systems, electricity is transmitted from the plant-ship to shore via underwater cable. An added advantage of the technology is that in addition to electricity, large quantities of fresh water can be produced.

A. Temperature variation with the depth of the ocean

The Temperature variation with the depth of the ocean has been experimentally measured for different oceans. The results, as available in the literature have been reproduced below:

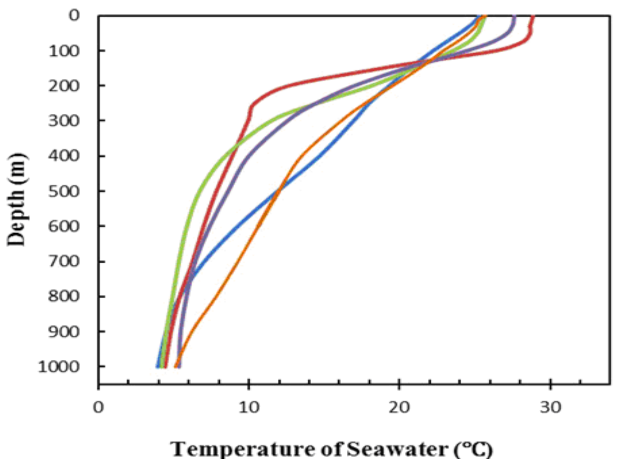

FIGURE 1 Ocean depth vs. Depth curves. At T=10°C, the curves are respectively, from top to bottom, for the oceans – Okinawa, Micronesia, Hawaii, Caribbean, and Reunion. Figure courtesy www.otec.ws/otec_principle.htm.

It is observed that at great depths ~ 1000m, temperature in all oceans is nearly the same (~5°C), the shape of the curves being dependent on the weather conditions prevailing near the ocean.

A lot of work has been reported on studying the dependence of the theoretical thermal efficiency of Rankine cycle on the temperature difference between deep ocean water and surface water. (The Rankine cycle is a model used to predict the performance of steam turbine systems, and is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work, the heat being.

B. Dependence of the theoretical thermal efficiency of rankine cycle on the temperature difference between deep ocean water and surface water

Supplied externally to a closed loop, which usually uses water as the working fluid.) The most reliable results, available in the literature kave been repdoducrd below.

It may be noted that because of the small temperature difference between deep ocean water and surface water, it is possible to increase the theoretical thermal energy of the Rankine cycle by heating the surface water to a higher temperature. In fact the Solar and Ocean Thermal Energy Conversion (SOTEC) technology is for attaining this objective by passing the surface water through solar collectors, which increases the theoretical thermal efficiency.

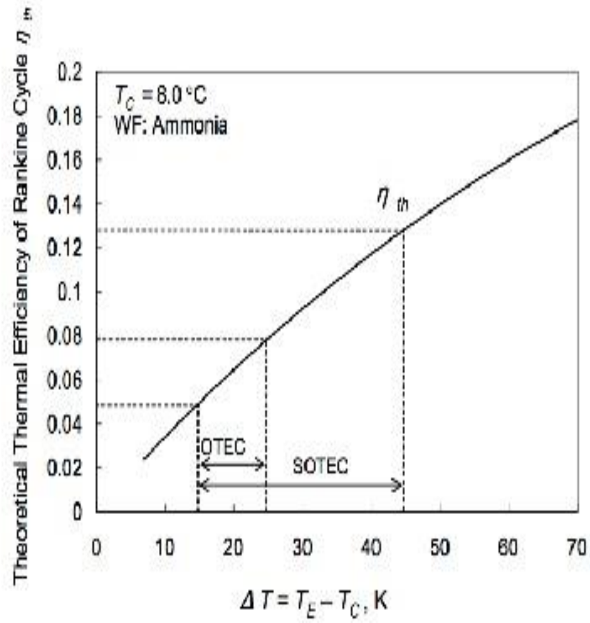

FIGURE 2 Illustration of the theoretical thermal efficiency of Rankine cycle on the temperature difference between deep ocean water and surface water.Figure courtesy otec.fsu.angelfire.com

V. DISCUSSION AND CONCLUDING REMARKS

The underlying principle of the OTEC technology is very simple – When the cool water from underground is absorbed by hot crust and magma layers of the earth, an endothermic reaction takes place, as the water absorbs heat energy from the earth, which results in an increase of the kinetic energy of water due to the increase in temperature, and no change in the potential energy, which remains constant because no phase change takes place. In the second step, water heats up to high temperatures and forms steam at the Earth's surface, and the reaction is exothermic, as the system releases heat to the earth in the form of steam. The kinetic energy in this case remains constant since there is no temperature change between water and the steam; and there is an increase in the potential energy because of the change in the liquid form to the gaseous form, which results in the water molecules overcoming the attractive force holding them and hence becoming apart. When the steam is captured by drilling underground rocks, it rises up through a well, and is finally pumped into the power plant. When the steam is transferred into the power plant, it condenses in a condenser to form hot water, which is finally pushed back down into the earth for reusing. This is an exothermic reaction since the steam releases heat energy which is gained by the surroundings. Here, there is a physical change, as the steam is converted from gas into liquid form.

As both the phases are at the same temperature, the kinetic energy remains constant. However, there is a decrease of the potential energy, because the gas molecules move closer together to form liquid by the attractive force.

Next, moving down of the hot water into the earth is an endothermic reaction, since it absorbs the heat energy, which results in an increase of its kinetic energy due to an increase in temperature, but at the same time with no change in its potential energy. The geothermal energy is converted into the power by the usual technique of using the turbine. The steam is used to spin a turbine in a power plant, connected to a generator, containing an electric conductor, which interacts with a magnetic field to create an electric current that is made to flow through the internal wiring. This electricity is sent to the places of use by the distribution power lines attached to the generator. As the electrons move at very high speeds within the copper wire, their kinetic energy increases on hitting a magnetic field, and this results in a flow of current throughout the wire.

However, the potential energy remains constant as there is no change in the state of the particles. It is clear that the mechanical energy within the wire is converted into the electrical energy, which is carried through the distribution wires to the respective places of their use.

The electricity produced by the geothermal plants has already reached a level, where more than 100 million barrels of fuel are saved from burning every year around the world. In addition, more than 50 million tons of CO2 are prevented from being emitted into the atmosphere. The Earth, on an average emits ~1.2, and this number is much larger at places in the region near volcanoes and hot springs; and ~ 1 of hot rock yields 30MW of electricity in three decades, on being cooled by 1000 degrees Celsius. It is considered that the heat radiated from the centre of the Earth is sufficient to look after the requirements of the humans for the whole of the biosphere's lifetime. Another important point to be noted is that the geothermal energy is 3rd highest among the renewable energies, after the hydro energy and biomass energy. Interestingly, Iceland is very successful in using the geothermal energy, with emphasis on using this energy for space heating, and also ~ 1/6th of their electricity generation by using geothermal energy. Geothermal power has many advantages like - cost effective, reliable, sustainable, and environmentally friendly. In earlier times, it was limited to areas near tectonic plate boundaries, but now the recent technological advances have made it possible to use it in other areas, along with the expansion of the size of viable resources, especially for applications like home heating. The useful minerals like zinc and silica can be easily extracted from underground water. The cost per unit of energy is competitive with the conventional energy resources. The flash and dry steam plants emit ~0.1% to 0.2% CO2 of that produced by fossil fuel plants, no NO and NO2, and very little SO2, and the Binary and hot dry rock plants produce no gas emissions. One disadvantage is that the geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are much lower than those of fossil fuels, and hence the geothermal power has the potential to reduce the global warming if used in place of the fossil fuels. Advantage in geothermal power is that it is sustainable, because the heat extraction is small compared with the Earth's heat content. The disadvantages of the geothermal power are: (i) Salination of the soil by the brine, if the water is not injected back into the reserve after the extraction of heat; (ii) land subsidence can take place as a result of the extraction of large amounts of water, unless the cooled water is injected back into the reserve so as to keep the underground water pressure constant; and (iii) the release of the H_2S gas, if the cooled water is not injected back into the ground, which is a real problem if large quantities are emitted, as it is poisonous in nature.

It is thus observed that the knowledge of the various parameters like the fluid flow rate, the fluid density, the fluid velocity, the incidence angle, the tangential fluid velocity, $V = q\cos\beta$, the turbine radius, the turbine rotational speed, the torque, the power output, the density in $\frac{kg}{m^3}$, the gravitational acceleration in $\frac{m}{s^2}$, the vertical coordinate (measured downwards) in *m*, length of sample in *m*, the volumetric flow rate in $\frac{m^3}{s}$, the constant (*C*) of proportionality in $\frac{m^2}{Pascals.s}$., and the cross sectional area *A*of sample in m^2, is very useful and helpful for the designers and engineers of the plants for the extraction and conversion of the geothermal energy for the optimization of this energy and its conversion into power. It is important to note that the geothermal energy is a reliable and sustainable source of energy; and the sustainability depends upon (i) the initial amount of heat, (ii) the water obtained, (iii) the rate of regeneration of the geothermal energy, and (iv) the production rate. Clearly, a lower production rate implies a longer lasting source of energy.

Geothermal energy is useful in the sense that it prevents global warming and some of the health problems because of the great reduction of the emission of the harmful gases.

The production of geothermal energy does not require extremely large geological production rates, and also large areas of land. It is much cheaper than other sources of energy, and does not create environmental problems and waste, since it involves the direct use, and also the production process is very controllable. The other good point about this source is that the geothermal sources can be replenished quickly. It is well established that the distribution of induced-earthquake magnitudes in deep geothermal reservoirs is a classical tool for monitoring reservoirs, which shows some important fluctuations through time and space. Though being very crude information (*i.e.*, a scalar quantity) of very complex mechanical stress evolution, understanding these variations can still be useful for studying the mechanics of the reservoir. Stormo et al [12] have analyzed the output of a simple quasi-static physical model of a single fault, and have proposed a new way to describe bursts that could be compared to seismic events. They have proposed a new definition of bursts in a fault model, based on the local fracture front velocity, and have studied geothermal reservoir in terms of fault asperities and normal stress evolution.

Recently, a global geothermal energy summit [13] has taken place, which provided a unique peer-to-peer learning platform with plenty of networking opportunities with key decision makers in the geothermal power industry. It focused on some topics including Investigating best methods, tools and strategy in geothermal exploration drilling, detailed design and construction, and Optimized operations and maintenance of geothermal power plants. Burns *et al*. [14] have used a heat and mass transport model (SUTRA) to evaluate the potential impact of groundwater flow on heat flow alomg two different regional groundwater flow paths. It has been reported that limited on situ permeability data from the Columbia River Basalt Group (CRBG) are compatrible with a steep permeability decrease at 800-900 m depth and approximately 40°C. The annual IEEE PES General Meeting [15] is going to focus on the technical sessions, administrative sessions, super sessions, poster sessions, on various topics associated with geothermal energy. Recently, the software [16] for designing geothermal ground source heat pump systems has been made commercially available, which is being utilized in a very large number of countries. Hence, it can be safely concluded that in the coming years, the technology will continue to be explored by the newer and more developed plants and processes.

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