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Technological Review of the Geothermal Energy Systems from Indian Perspective

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Abstracts

Geothermal Power is one of the fastest growing sources of renewable energy in the world and even in India. With an estimated potential of over *10000 MW* India is having a large resource available to be harnessed. Out of the available energy resources geothermal energy has a distinct advantage of being a base load power plant capacity. Technology overview of geothermal energy from its evolution to the current advanced systems of geothermal technology has been discussed in this paper with a view to make the readers and young researchers acquainted with this green source of energy, i.e. Geothermal energy.

Keywords: Geothermal, Renewable, Energy, Technology.

INTRODUCTION

'Geothermal' literally means earth heat energy involves using the high temperatures produced beneath the earth to generate electricity from heated water, as well as for various direct uses like hot springs spas, lumber drying or aquaculture. Therefore geothermal energy means the thermal energy stored beneath the surface of the earth crust. The term geothermal is also applied to the temperatures of the Earth near the surface which are used as a source of consistent temperatures for heating and cooling of buildings. Geothermal applications that involve water heated within the earth are also called hydrothermal processes. [1]

Geothermal Power is one of the fast growing renewable energy source in the world and even in India. With a potential of over *10000 MW* India is having a huge resource available and waiting to be harnessed. As demand of energy is growing at an exponential rate, the world is bound to move towards renewable energy resources. Out of the available energy resources geothermal energy has a distinct advantage of

being a base load power plant capacity, i.e. it can be used as a base load plant for 24 hour power production as other conventional power plants.
In the countries like Unite States of America and Philippines, importance and potential of geothermal energy has been realised and they are moving ahead towards sustainability with the geothermal power as an alternative source of energy.
Technology overview of geothermal energy from its evolution to the current advanced systems of geothermal technology has been discussed and presented in this paper with a view to make the reader and young researchers acquainted with this green source of energy, namely Geothermal energy.

Genesis of Geothermal Technology

The heat from the earth's own molten core is conducted to the adjacent rocks through conduction and convection and eventually is transferred to underground water reservoirs through conduction and convection. Steam/water heated by the geothermal heat can be tapped using different technologies and channelled to various uses. Utilization of geothermal fluid depends heavily on its thermodynamic characteristics. These factors are determined by the geothermal system from which the fluid originated.
Geothermal heat is constantly produced by the Earth from the decay of radioactive material in the core of the planet. The heat is moved to the surface through conduction and convection. In the crust, the temperature gradient is typically 30°C per kilometre but can be as high as 150°C per kilometre in hot geothermal areas. If even a small fraction of the Earth's heat could be delivered to the points of energy demand by humans, the energy supply problem would be solved. The global technical potential of the resource is huge and practically inexhaustible. However, tapping into this tremendous renewable energy reservoir is not an easy task. [2]
Geothermal fluids have been classified differently by different researchers; some have done so by using temperatures while others have used enthalpy. Depending on the enthalpy/ temperature of the geothermal fluid, it can be utilized either for electricity generation or direct applications. Electricity generation is the most important form of utilization of high-temperature geothermal resources while low to medium temperature resources are better suited for direct application.

Table 1: Types and Uses of Geothermal Resources

Resource Availability	**Geographical And Geological Location**	**Use / Technology**
High: > 200°C	Globally around boundaries of tectonic plates, on hot spots and volcanic areas.	Power generation with conventional steam, flash, double flash, or dry steam technology.
Medium: 150-200°C	Globally mainly in sedimentary geology or adjacent to high temperature resources.	Power generation with binary power plants, e.g., ORC or Kalina technology.

Low: < 150°C	Exist in most countries (average temperature gradient of 30°C/km).	Direct uses and depending on location and power tariff offered, power generation with binary power plant

(Source: Gehringer, M., Loksha, V., Geothermal handbook: Planning and financing power Generation, ESMAP World Bank, 2012)

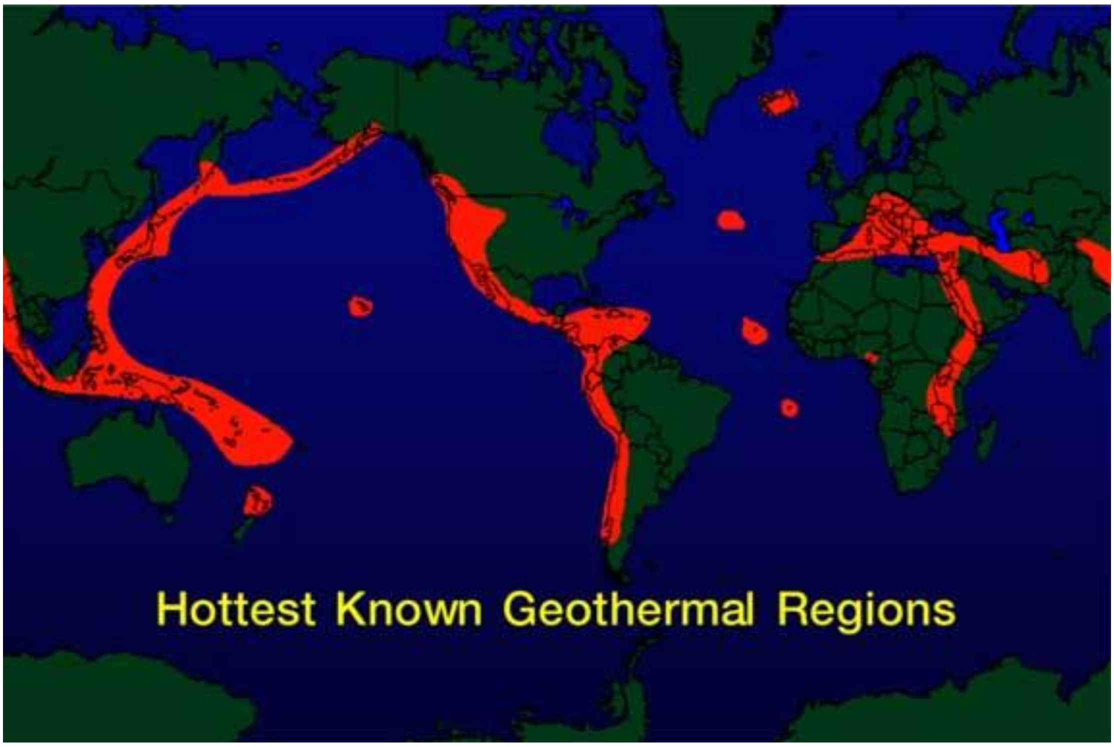

Figure 1: Ring of Fire
(Source: http://www.greenibis.com/edu/geo/frames/where.html)

Humans have been utilizing this geothermal energy ever since pre historic era. Up until a century ago, geothermal energy was known mostly as a source of heat for spa and bathing purposes. The use of geothermal steam for electricity production began in the 20th century-with the first experimental installation built in Larderello, Tuscany, Italy in 1904 [2]. Ever since then there has been a great improvement in technology for harnessing geothermal energy, either for producing electricity or for any other process heating / cooling application. A 250 kWe geothermal power plant began operation there in 1913. [2] Geothermal features are not common geological features. They occur in clusters, in a few widely separated locations of the world where the conditions are right for their occurrence.
We can find some of the most active geothermal zones of the world around "Ring of Fire" are as: Yellowstone (USA), North Island (New Zealand), Iceland, Kamchatka (Russia), and Japan.[3]

Like any other energy resources in the world, geothermal energy has its own set of advantages and disadvantages, some of these merits / challenges are enumerated as follows [2]:-

Table 2: Merits and Challenges of Geothermal Resources

Advantage / Merit	**Disadvantage/Challenge**
Globally inexhaustible (renewable)	Resource depletion can happen at individual reservoir level
Low/negligible emission of CO2 and local air pollutants	Hydrogen sulphide (H_2S) and even CO_2 content is high in some reservoirs
Low requirement for land	Land or right-of-way issues may arise for access roads and transmission lines
No exposure to fuel price volatility or need to import fuel	Geothermal "fuel" is non-tradable and location constrained
Stable base-load energy (no intermittency)	Limited ability of geothermal plant to follow load/respond to demand
Relatively low cost per kWh	High resource risk, high investment cost, and long project development cycle
Proven/mature technology	Geothermal steam fields require sophisticated maintenance
Scalable to utility size without taking up much land/space	Extensive drillings are required for a large geothermal plant

Some of the major highlights of a geothermal energy systems as observed by the author *Gehringer, M. and Loksha, V. in their book "Geothermal handbook: Planning and financing power Generation" published by ESMAP World Bank in the year 2012* are listed below [2]:-

i. Geothermal fields are generally found around volcanically active areas that are often located close to the boundaries of tectonic plates. Nearly 40 countries worldwide possess sufficient geothermal potential that could, from a technical perspective, satisfy their entire electricity demand with geothermal power.
ii. Electricity from geothermal energy is produced by 24 countries. The United States and the Philippines have the largest installed capacity of geothermal power, about 3,000 MW and 1,900 MW, respectively. Iceland and El Salvador generate as much as 25 percent of their electric power from geothermal resources.
iii. Geothermal power generation from hydrothermal resources can be expected to grow from 11 GW in 2010 to 17.5 GW by 2020 and to about 25 GW by 2030. Most of this increase is expected to happen in Pacific Asia, mainly Indonesia; the East-African Rift Valley; Central and South America; as well as in the United States, Japan, New Zealand, and Iceland.

iv. Geothermal is a commercially proven renewable form of energy that can provide relatively cheap, low carbon, base-load power and heat, reducing a country's dependence on fossil fuels and CO_2 emissions.
v. The development of geothermal power generation cannot be regarded as a quick fix for any country's power supply problems, but should rather be part of a long term electricity generation supply strategy.
vi. Geothermal power projects are best developed in steps of 30 MW to 60 MW in order to reduce concentration of resource risk and to minimize the risk of unsustainable exploitation of the geothermal reservoir.
vii. Investment costs per installed megawatt can vary widely, from US$ 2.8 million to US$ 5.5 million per MW installed for a 50 MW plant, depending on factors such as the geology of a country or region, quality of the resource (e.g., temperature, flow rate, chemistry), and the infrastructure in place.
viii. Despite its high upfront costs, geothermal power can be competitive and complement other sources of generation thanks to high capacity factors, long plant lifetimes, and the absence of recurring fuel costs.
ix. Levelized costs of energy from hydrothermal resources are usually found to be between US$ 0.04 and 0.10 per kWh.

Based on the above observations we can clearly deduce the fact that geothermal energy is available in abundance in the world, but its extraction needs focus of the global community to propagate this renewable source of energy.

INDIAN GEOTHERMAL POTENTIAL

India has a good potential for geothermal resources and all the geothermal zones of India are located in areas with high heat flow and geothermal gradients. The heat flow and thermal gradient values in India varies from 75-468 m W/m2 and 59-234°C respectively. The estimated power generating capacity of the geothermal energy is about 10,600 MW. [15]

The seven major geothermal provinces of India, *as shown in figure 2*, which encloses nearly 400 thermal springs, are in the region associated with the mid continental rifts, subduction, sedimentary basins and Cretaceous-Tertiary volcanic zone.These provinces include: [15]

i) The Himalayas,
ii) Sohana,
iii) Cambay,
iv) Son-Narmada-Tapi rift zone (SONATA),
v) West coast,
vi) Godavari, and
vii) Mahanadi.

In the recent event of last decade the volcanic eruption in the Barren islands has become one the most important geothermal provinces in the Indian subcontinent. The estimated energy from one third of these springs is of the order of 40.9x1018 calories.

This is equivalent to the energy that can be obtained from 5.7 billion tons of coal or 28 million barrels of oil. If these energy resources are developed for a medium to low temperature application it will substitute about 10,600 MW of power. [15]

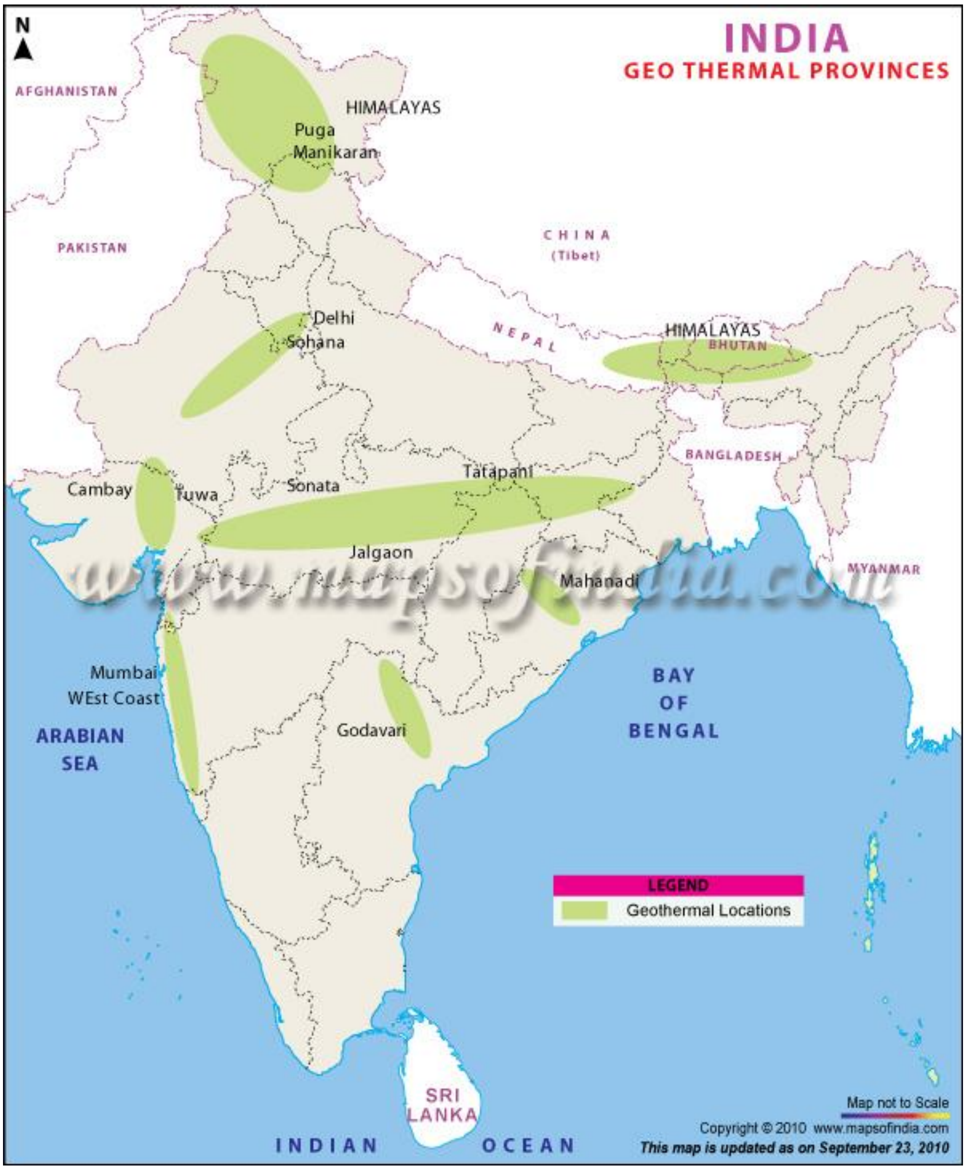

Figure 2: Geothermal Potential Map of India[15]
(Source: http://www.mapsofindia.com/maps/nonconventional/geothermal.htm#)

Classification of Geothermal Technology

In order to extract geothermal heat from the earth, water is used as the working medium. Generally the naturally occurring groundwater is available for this task in most places but more recently technologies are being developed to even extract the energy from hot dry rock resources. The underground temperature of the resource is a major determining factor of the technologies required to extract and utilize the available thermal energy. The *Table 3* given below enlists the basic technologies normally used in accordance to the available resource temperature. *Energy conversion technology* for geothermal applications can be broadly classified into three types, as given below:

- Dry steam power plants
- Condensing power plants
- Binary plants.

Table 3: Basic Technology Commonly Used For Geothermal Energy

Reservoir temperature	**Working Fluid**	**Technology commonly chosen**	**Application**
High temperature, > 220°C	Dry Steam	**Dry steam plant**	Power generation, Heat exchangers, Heat pumps
Intermediate temperature 100-220°C	Hot Water or Steam	**Flash Steam Plant**	Power generation, Heat exchangers, Heat pumps
Low temperature 30-150°C	Hot Water	**Binary fluid plant**	Power generation, Heat exchangers Heat pumps

(Source: Martha, M., Geothermal Energy Utilisation, Short Course IV on Exploration for Geothermal Resources, Kenya, 2009)

On the whole we could say that the geothermal power generation has the following positive features:

- Lower emission of CO2, which is a main source of global warming
- Higher availability factor
- Use of more sustainable energy

But due to the variable steam conditions at source and larger equipment size, geothermal power generation tends to involve higher capital costs per output compared with fuel-fired power systems. We need to plan to improve the economic efficiency by improving turbine efficiency and increasing unit capacity. We will have to continue to extend efforts for the further deployment of geothermal power technology, which is an effective option to mitigate global warming, through the continuous development of anticorrosion technology to increase equipment reliability.[6]

Basic Geothermal Power Cycle Technology

Geothermal energy is the heat energy stored beneath the surface of the earth. Wherever there is heat then always there is thermodynamics involved in it to extract or harness the heat energy. So in order to harness the thermal energy of the earth we need to understand the technology and the thermodynamics involved in it. Heat is the energy transferred between a system and its surroundings due to a temperature difference that exists between them, from a body at higher temperature to a body at lower temperature.

The Zeroth law of thermodynamics states that if two bodies, independently, are in a thermal equilibrium with a third body, then both of them must be in thermal equilibrium with each other. In the case of geothermal energy, this can be used to explain the process of the vaporization of the working fluid / refrigerant. The water and the refrigerant are not in thermal equilibrium initially, so anything in contact with them will be at a different temperature. The heat will flow from the hot water carrying heat from the geothermal reservoir up to the / turbine or any refrigerant until those two bodies are in thermal equilibrium.

Similarly the First law of thermodynamics could be applied to the geothermal energy, as the law states that the internal energy of a system will increase if heat is added and decrease if work is done by the system, i.e. this law depicts the law of conservation of the internal energy of a system.

In the case of geothermal energy, heat is added to the system of the refrigerant and turbine by the temperature difference between the refrigerant and the water. If heat is added, the internal energy of the system must either increase, or be offset by the work being done in the form of electricity by the turbine or in the form of direct application of heat in any process. Thus the energy is conserved as per the first law of thermodynamics.

According to the Second law of thermodynamics, for any process in a closed system, the entropy never decreases. In the case of geothermal energy, we can assume that the system between the ground, the mixing chamber, and the turbine is a closed system. This can be assumed because the process of pumping up the water and returning it to the earth requires a fair amount of energy that cannot be regained. Since, it is clear that the first three laws of thermodynamics can be applied to the geothermal process, so now it is also relevant to know the efficiency of this system.

Efficiency is the ratio of input to output, a performance measure for the process. The thermal efficiency is seen as the ratio of produced power to the heat transferred to the power plant. The power plant thermal efficiency is the ratio between power produced and the heat flow to the power plant. The heat input is then the heat input to the power plant, and takes no notice of how much heat is available from the wells. The power plant thermal efficiency is traditionally defined as:[16]

[*]Efficiency = [Power produced / Heat supplied to the power plant]

[*]**Thermal Efficiency (ἡ) = [W / Q]**

[*]Where,

W-Power / work produced by the power plant

Q-Heat energy supplied to the power plant.

[*]*Source:http://ffden-2.phys.uaf.edu/212_fall2009.web/Nathan_Burke.dir/contentpage4.html*

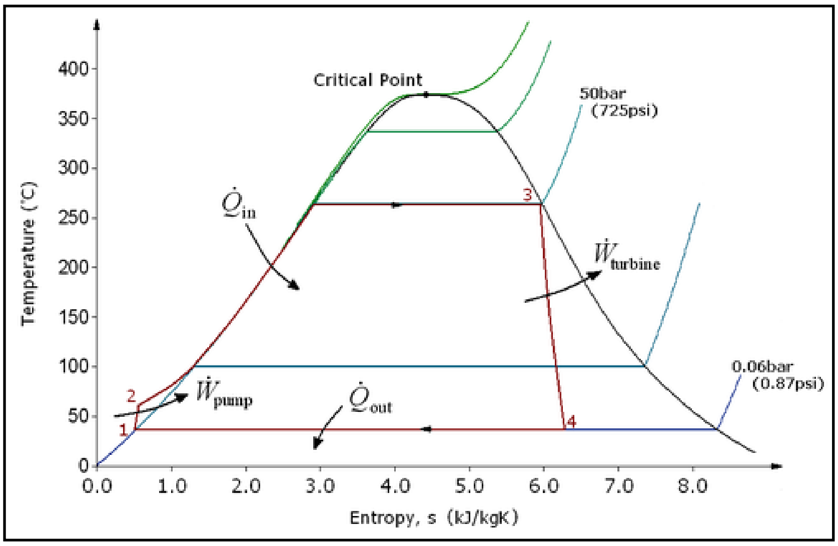

Figure 3: T-S diagram of typical Rankine cycle

Source: http://en.wikipedia.org/wiki/Rankine_cycle

Conclusion

Geothermal energy is a vast source of energy available beneath the earth crust, ready to be harnessed. Geothermal energy has gone through a lot of evolution from the naive thermal application to the complex technology for power production. Though this power is dependent on the geographic features and lithosphere composition of the region, but wherever it is available there it can be a good source of power if harnessed properly with the aid of right kind of technology. If energy prices continue to rise, direct use of geothermal resources could provide an economical, clean and renewable source of thermal energy. We have learnt that one of the most efficient modes of energy conversion for indirect use of geothermal energy is through dry steam power plant. But this power plant requires dry steam at high temperatures, which is unfortunately not available easily. Therefore this technology is limited to only those geothermal sites where high potential thermal energy is available at our disposal. With the available technology we are not able to harness this energy potential of earth to the fullest. But sooner or later we will need to develop those customized and efficient technologies which are able to extract maximum energy from the deep surfaces of the earth.

India's ambitious energy program focuses on proliferation and propagation of its Renewable Energy Sources. The Policy makers hope that India will be generating substantial quantity of power through these green sources in future. If the geothermal energy potential is exploited to the fullest then India can have self sustainability in electricity production. In the very near future India may appear on the geothermal map of the world with the proposal of generating power and direct utilization of geothermal energy from the existing bore wells. We can conclude by observing that geothermal energy has a lot of potential to develop into sustainable and clean source of energy, all it needs is the collaborative efforts of the entire human community, especially in rural India.

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