Geothermal Energy And Its Applications As Renewable Resource : A Review

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Abstract: *Geothermal energy, is the energy stored within the earth as heat, is a topic which has garnered attention in the recent past because of its potential as a powerful energy resource. Though present technologies for geothermal energy capture are limited to regions with very geologic specific conditions, progress is being made towards technologies which could help to capture a greater portion of this energy resource without the necessity of such geologic conditions. Geothermal energy is often cited as being a 'green' energy source with low environmental impact, and while the environmental impact differs from site to site, this generally holds true when compared to other energy resources.*

Although the earth's stored heat, its theoretically finite, its large amount (12.6 x 10^{24} MJ) makes geothermal energy practically a renewable energy that can theoretically sustain the energy needs of mankind many times.

In this paper, geothermal energy, geologic conditions which concentrate this energy, methods of capturing geothermal energy, and uses of geothermal energy will be discussed.

Index Terms*: Geothermal energy, renewable resource, earth, reservoir, energy uses.*

1. Introduction

Geothermal energy is a clean, renewable resource that provides huge amount of energy whose development and production characterizes an existing and promising international market.

Geothermal energy refers to the energy stored as heat within the Earth. Earth's internal energy is primarily sourced from the energy involved in its formation and the radioactive decay of certain isotopes within it[1]. Together, these factors constitute the Earth's 'heat budget'. Without human intervention, this heat is transferred directly to the atmosphere and from there to the surrounding gas of the solar system. The rate of geothermal energy production by radioactive decay is almost double the present rate of energy use by humans, indicating that this is a resource with potential which should not be ignored[2]. The extraction and harnessing of geothermal energy for human use is a relatively young science with great future potential.

Heat has been radiating from the center of the Earth, at 6437.4 km deep, with temperatures of about 5,500°C. Heat flows through the crust of the Earth at an average rate of almost 59 MW/m² [1.9 x 10^{-2} Btu/h/ft²] and the earth's natural heat reserves are immense. Ninety-nine per cent of planet Earth has a temperature in

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excess of 1,000 degrees Celsius as a result of residual heat inherited from the Earth's primordial origins and the breakdown of radioactive materials[3].

Thermal energy in the earth is distributed between the constituent host rock and the natural fluid that is contained in its fractures and pores. These fluids are mostly water with varying amounts of dissolved salts; typically, in their natural in situ state, they are present as a liquid phase but sometimes may consist of a saturated, liquid- vapor mixture or superheated steam vapor phase[4].

2. Origins of Geothermal Energy

Geothermal energy is defined as heat from the Earth, that provides energy around the world in a variety of applications and resources. The heat of the earth is available everywhere, and we are learning to use it in a broader diversity of circumstances. It is considered a renewable resource because the heat emanating from the interior of the Earth is essentially limitless. The heat continuously flowing from the Earth's interior (Fig. 1), which travels primarily by conduction, is estimated to be equivalent to 42 million megawatts (MW) of power, and is expected to remain so for billions of years to come, ensuring an inexhaustible supply of energy[5,6].

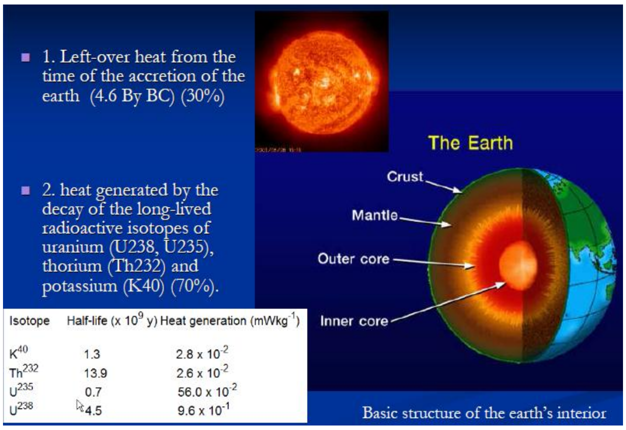
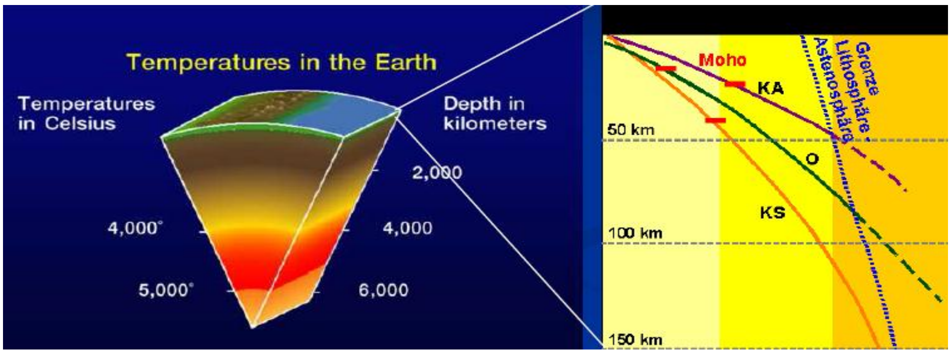


Fig.1 Earth's internal structure and temperatures in the Earth (from Geothermal Energy Association)

2.1. Temperature Distribution in the Earth

Figure 2 illustrates the distribution of temperature from internal core until earth crust, and geothermal gradient in the upper 150 km, dT/dz ~ 30°C/km



Temperature in the earth

Geothermal gradient in the upper 150 km dT/dz ~ 30°C/km

Fig. 2 Temperature distribution in the earth(Geothermal Energy Association)

2.2. Mechanisms of Heat Transport in the Earth

(1) *Heat transport by conduction*: Figure 3 depicts the transport of heat by conduction according to Fourier's law.

$$\frac{dQ}{dt} = -\lambda A \, \frac{dT}{dx} \quad (1)$$

where

$\frac{dQ}{dt}$ = Heat flow, A = area, T = transport time,

λ = constant

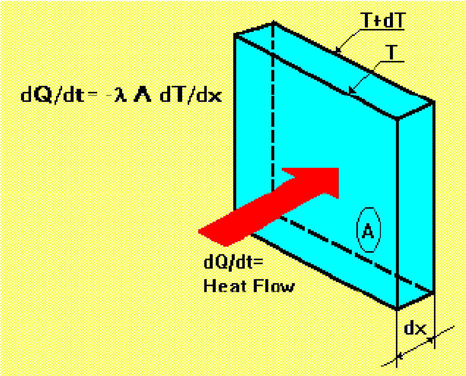


Fig. 3 Heat transport by conduction

(2) *Heat transport by convection*: Mantle convection currents driving the plates of earth crust as shown in Figure 4.

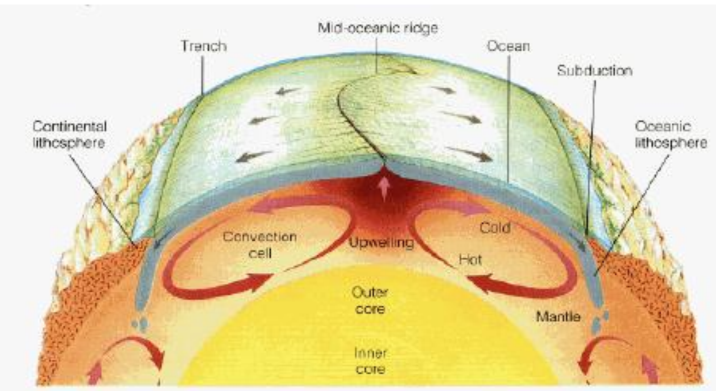


Fig. 4 Transportation of heat by convection

2.3. Heat Flow at the Earth's Surface

Local and regional geologic and tectonic phenomena play a major role in determining the location (depth and position) and quality (fluid chemistry and temperature) of a particular geothermal resource, but certain conditions must be met before claiming a viable geothermal resource:

1. Reservoir accessibility: achieved by drilling to depths of interest.

2. Reservoir productivity.

Thermal energy is extracted from the reservoir by coupled transport processes (convective heat transfer in porous and/or fractured regions of rock and conduction through the rock itself). Figure 5 shows heat flow at the earth's surface.

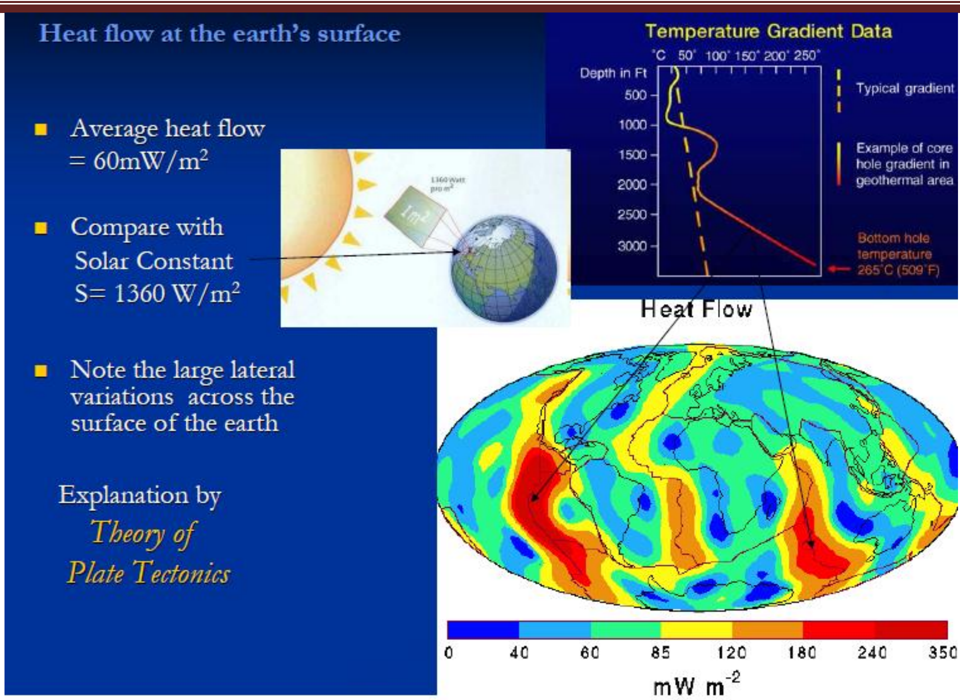


Fig. 5 Heat flow at the earth's surface[6]

The geothermal heat extraction process must be designed with the constraints imposed by prevailing in situ hydrologic, lithologic, and geologic conditions.

The use of geothermal resources is strongly influenced by the nature of the system that produces them.

1. Resources of hot volcanic systems are utilized primarily for electric power generation

2. Resources of lower temperature systems are utilized mostly for space heating and other direct uses.

Consideration of a number of factors is required to determine the optimal use of a geothermal resources.

1. the type (hot water or steam) of geothermal fluid
2. the rate of flow
3. the temperature and chemical composition
   the pressure of the geothermal fluid and depth of the geothermal reservoir

Currently, researches in geothermal energy exploitation are aimed to explore greater depths with the objective of finding supercritical fluids: a condition which can be reached when temperature is greater than 374°C and the pressure above 220 bars, the critical point.

Overall the geothermal share of global power generation remains very small (0.3%), but in certain countries it plays a significant role, for example, Kenya (44% of power), Iceland (27%), El Salvador (26%), and New Zealand (18%)[7].

3. The Main Geothermal Energy Concepts

Earth emits energy in the form of heat, which propagates from deeper ground towards the surface, the so-called flow of heat or geothermal flow

The heat flow is due to two primary processes:

1. Upward convection and conduction of heat from the Earth's mantle and core (original heat).

2. Heat generated by the decay of radioactive elements, particularly isotopes of uranium, thorium, and potassium.

Due to the different thicknesses of the Earth's crust and the different geological situations which can cause the rise of warmer materials from deeper zones, the geothermal gradient (i.e. the increase in temperature, due to greater depth) is not equal all over the earth.

On average, the temperature increases 2-3°C per 100 m in depth, but the increase can vary from 1° up to 5°C/100 m.

4. Geothermal Areas and Fields

With reference to the "plate tectonics" theory (according to which the earth's crust can be divided into approximately 20 micro-areas called "plates" continuously interacting), the hottest geothermal areas of the globe are generally positioned along the breaking and collision margins of the plates. The flow of heat is greater where the thickness of the lithosphere is less, as for example on the ocean ridges or in the continental rifting zones or in volcanic areas where different geological processes lead to rock melting, or in areas where there is slowly cooling magma in the subsoil.

The breaking of a plate causes long cracks on the earth's crust, through which the magma reaches the surface (the Iceland Rift, The Red Sea/Rift Valley system, the Baikal Lake). Such regions might encompass several geothermal fields (Fig. 6).

5. The Geothermal Systems

"A geothermal system is any localized geologic setting where portions of the Earth's thermal energy may be extracted from a circulating fluid and transported to a point of use.

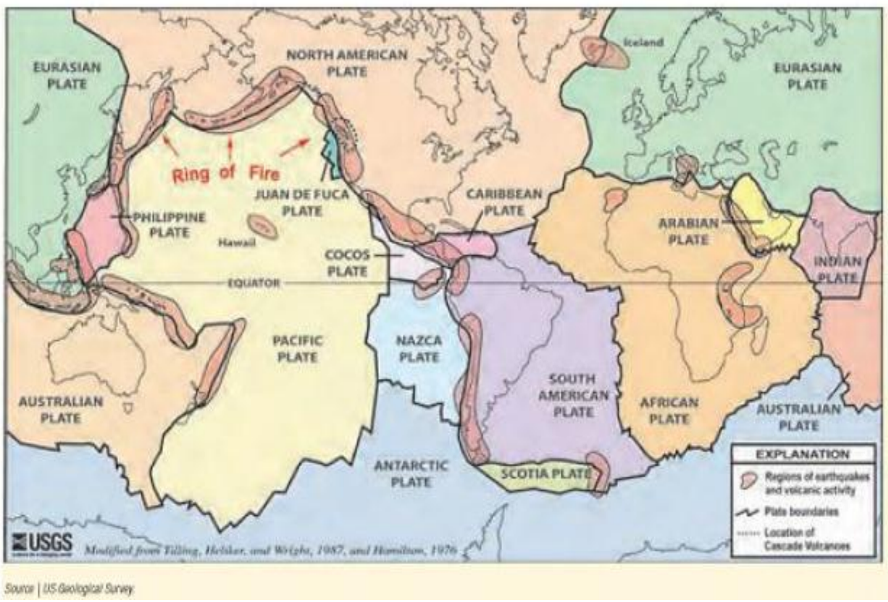


Fig. 6 Map of tectonic plate boundaries (Unites States Geological Survey, USGS)

A geothermal system includes fundamental elements and processes, such as fluid and heat sources, fluid flow pathways, and a caprock or seal, which are necessary for the formation of a geothermal resource." (USGS) (Fig. 7).

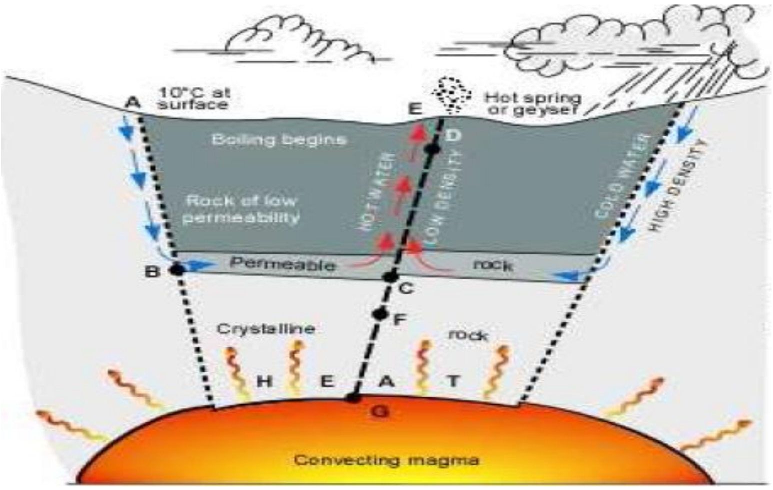


Fig. 7 Sketch of a geothermal system (USGS)

A geothermal field consists of three elements:

1. Thermal source: a magma penetration or a normal heat flow

2. Reservoir: a thermally permeable rock formation

3. Fluids which act as heat carriers: meteoric, surface or magma origin; in liquid or vapor state with dissolved solid substances and gases

The mechanism underlying geothermal systems is largely governed by fluid convection. When water is heated by the earth's heat, hot water or steam can be trapped in permeable and porous rocks under a layer of impermeable rocks and a geothermal reservoir can be created and this natural collection of hot water is properly called a "geothermal reservoir" as shown in Figure 8.

"Geothermal reservoir indicates the hot and permeable part of a geothermal system that may be directly exploited".

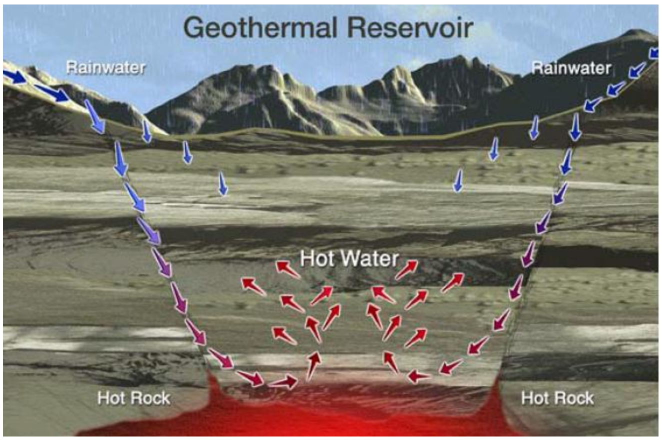


Fig. 8 Formation of geothermal reservoir (from Geothermal Communities –GEOCOM)

Table 1 lists the geothermal resources.

Table 1 Geothermal resource types

No.	Resource Type
1	Convective hydrothermal resources
2	Vapour dominated
3	Hot-water dominated
4	Other hydrothermal resources
5	Sedimentary basin
6	Geopressured
7	Radiogenic
8	Hot rock resources
9	Solidified (hot dry rock)
10	Part still molten (magma)

Convective hydrothermal resources according to the predominant fluid phase are categorized as vapor dominated (steam) or liquid-dominated (hot water) (Fig. 9).

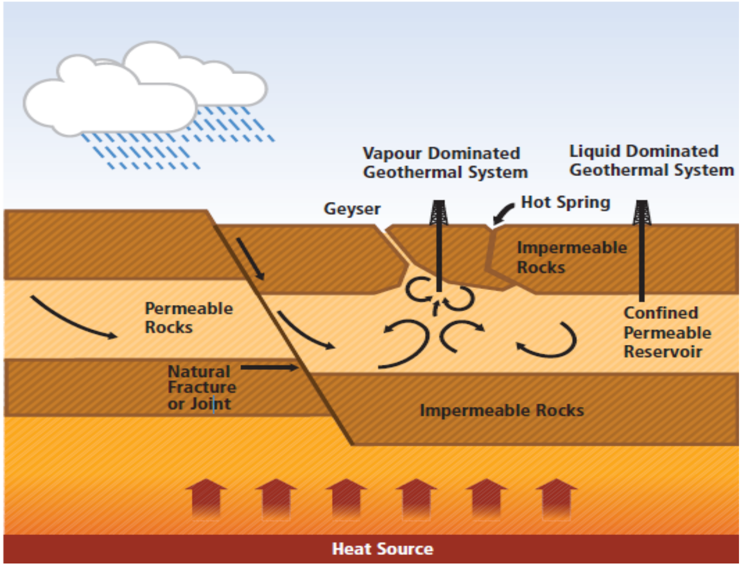


Fig. 9 Illustration hot water dominated and vapor dominated geothermal resources

6. Classification of Geothermal Systems

The most common criterion to classify geothermal resources is based on the enthalpy of the geothermal fluids (Table 2).

Geothermal resources have been classified by their reservoir temperatures into: *low, intermediate and high enthalpy resources*.

The ideal geothermal reservoir = high temperatures + water = steam

Table 2 shows a general classification based on temperature, typical reservoir fluid, common use and technology used.

Table 2 Classification of geothermal systems (from Geothermal Systems and Technologies, Geothermal communities)

Reservoir temp.	Reservoir fluid	Common use	Technology common chosen
High temperature > 220 ˚C	Water and/or Steam	Power generation Direct use	Flash steam Combined (flash and binary) cycle Direct fluid use Heat exchangers Heat pumps
Intermediate temperature 100-220 ˚C	Water	Power generation Direct use	Binary cycle Direct fluid use Heat exchangers Heat pumps
Low temperature 50-150 ˚C	Water	Direct use	Direct fluid use Heat exchangers Heat pumps

6.1. Deep Geothermal Energy Reservoirs

Table 3 Different classifications of deep geothermal reservoirs in relation to the temperature ˚T.

Table 3 Classifications of deep geothermal reservoirs

Low enthalpy resources	< 90	< 125	< 100	≤ 150	≤ 190
Intermediate enthalpy resources	90-150	125-225	100-200	-	-
High enthalpy resources	< 150	< 225	< 200	< 150	< 190

6.1.1 High Enthalpy Reservoirs

Characterization of high enthalpy-systems

1. Mostly in regions with volcanic activity (Fig. 10)
2. Use for generation of electricity (flash-method) and of process heat
3. Temperature range: 90 – 300°C
4. Depending on pressure reservoirs have more steam or water
5. Steam is reinjected (Fig. 12)

- no negative environmental impact
- higher productivity

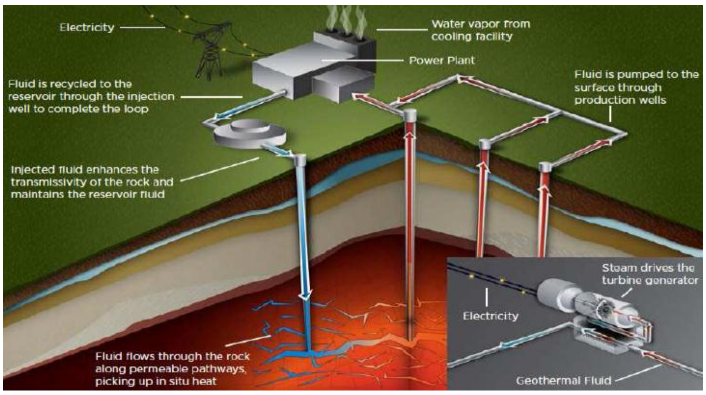


Fig. 10 Shows volcanic activity and reinjection of fluids[7]

6.1.2 Low Enthalpy Reservoirs

6.1.2.1 Hydrothermal Systems

The geothermal energy can be used to produce electricity and the steam or the hot water can directly be fed into the power plant for production of electricity. The different components of a geothermal power plant can be summarized as below:

Production well: These are the wells used to extract the Geothermal fluids, such as hot water and steam and are brought to the surface and directly connected by pipe to the power plant.

Power plant: This comprises of turbine wherein the geothermal fluid rotates the turbine blades and produced electricity as a steam turbine.

Injection Well: It is used to inject the used geothermal fluid and hence fed into the reservoir again without evacuating the earth interior crust.

Thermal power extraction can be expressed by Equation 2.

$$p_{therm} = \rho C_p Q_{flow} \Delta T \qquad (2)$$

where

ρ = water density, C_p = specific heat

Q_{flow} = flow rate , $\Delta T = T_{hot} - T_{cold}$

Typical layout of a geothermal power plant is shown in the Figure 11.

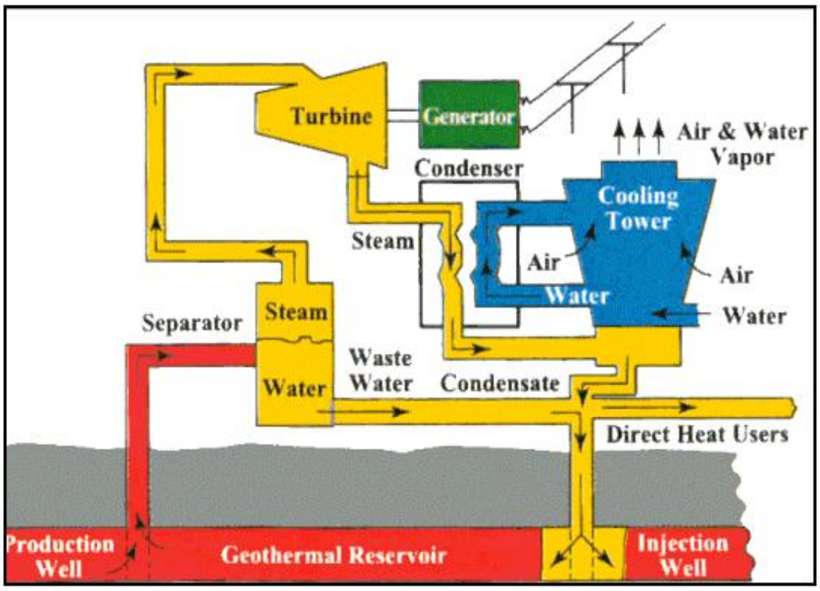


Fig. 11 Typical layout of a geothermal power plant[8]

6.1.2.2 Petrothermal Systems /HDR/EGS

The petrothermal systems of geothermal reservoir are represented by hot dry rock technology (HDR) and enhanced geothermal system (EGS) are represented in Figure 12.

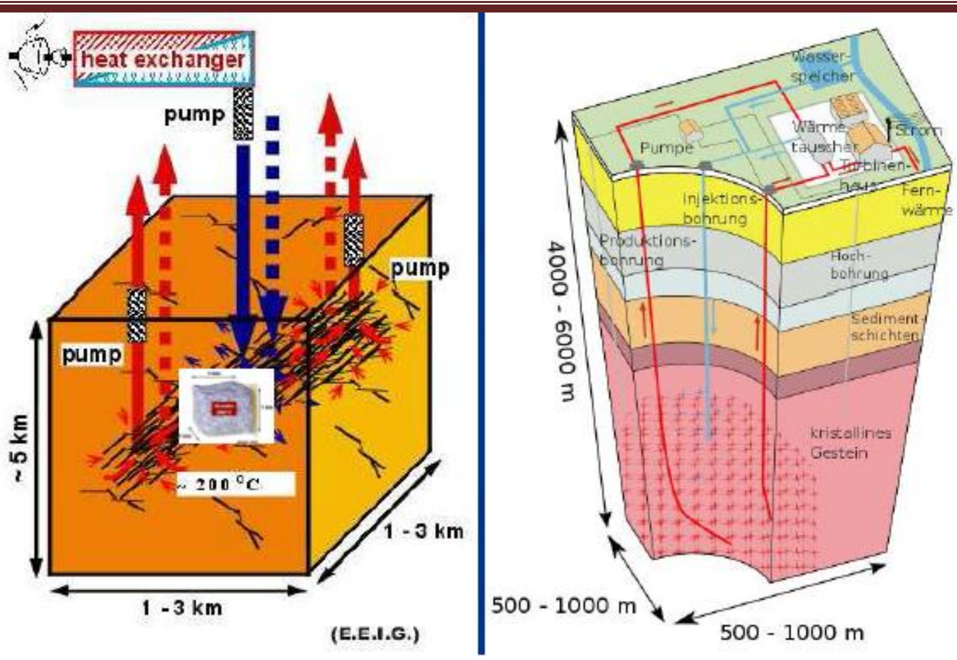
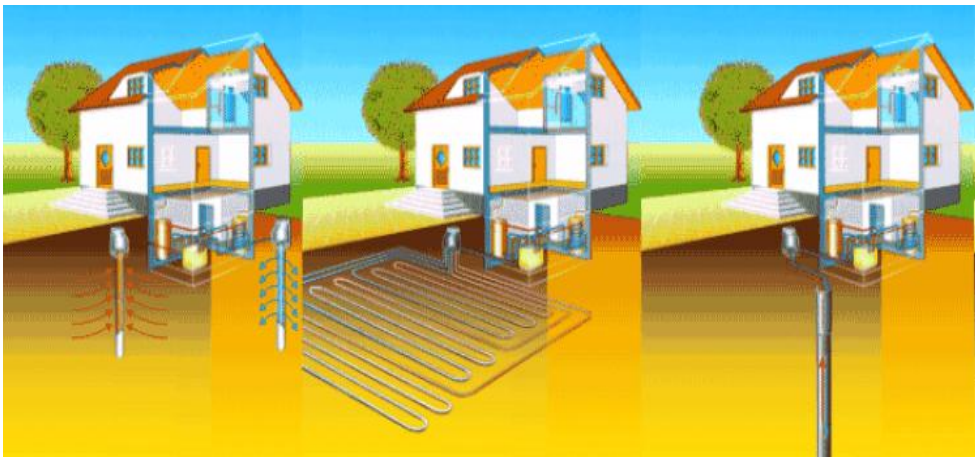


Fig. 12 Petrothermal systems of geothermal reservoir[9]

6.2. Surficial Geothermal Energy Use with Heat Pumps

The Surficial geothermal energy use with heat pumps are illustrated in Figure 13.



Open doublet system Horizontal ground loop Vertical U-tube loop (most common)

Fig. 13 Surficial geothermal energy use with heat pumps[9]

6.3. Surficial Geothermal Energy Use with Heat Pumps/Principle

On the other hand, the surficial geothermal energy use with heat pumps/Principle are illustrated in Figure 14.

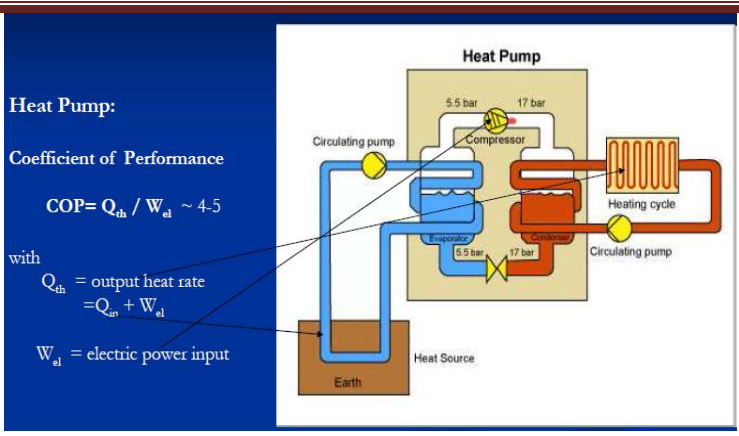


Fig. 14 Surficial geothermal energy use with heat pumps/principle[9]

6.4. Geothermal Energy Use from Tunnels

The geothermal energy can be used from tunnels as in Switzerland.

6.5. Geothermal energy use from old mining shafts

The old mining shafts can also be used for geothermal energy by extraction of warm water from mining shaft as in Figure 15.

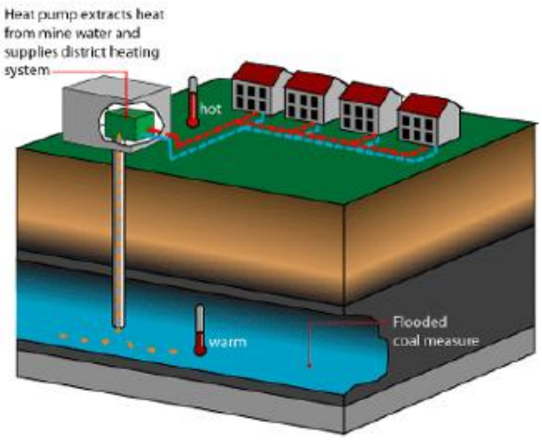


Fig. 15 Extraction of warm water from mining shaft[10]

6.6. Geothermal Energy use for Seasonal Storage

Moreover, this energy can be use for seasonal storage in both summer and winter as depicted in Figure 16.

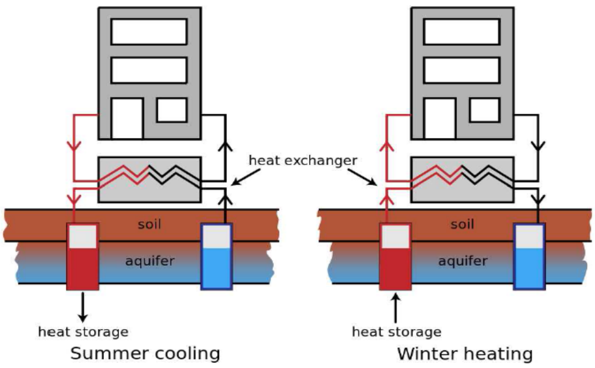


Fig. 16 Geothermal energy use for seasonal storage[10]

7. Use of geothermal energy

Geothermal use depend on the temperature of the geothermal reservoir.

7.1 Direct use

There are many direct uses of geothermal energy can be categorized as following:

1. Balneology (hot spring and spa bathing).
2. Agriculture (greenhouse and soil warming).
3. Aquaculture (fish, prawn, and alligator farming).
4. Industrial uses (product drying and warming).
5. Residential and district heating.

7.2 Heating and cooling

Geothermal energy can be used in other purposes such as heating and cooling as depicted in Figure 17.

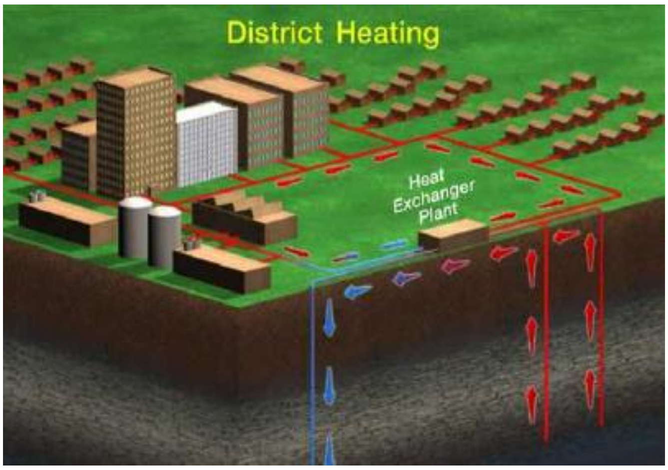


Fig. 17 Geothermal use in heating and cooling[12]

7.3 Electric power generation

On the other hand, geothermal energy can be also used in electric power generation as shown in Figure 18

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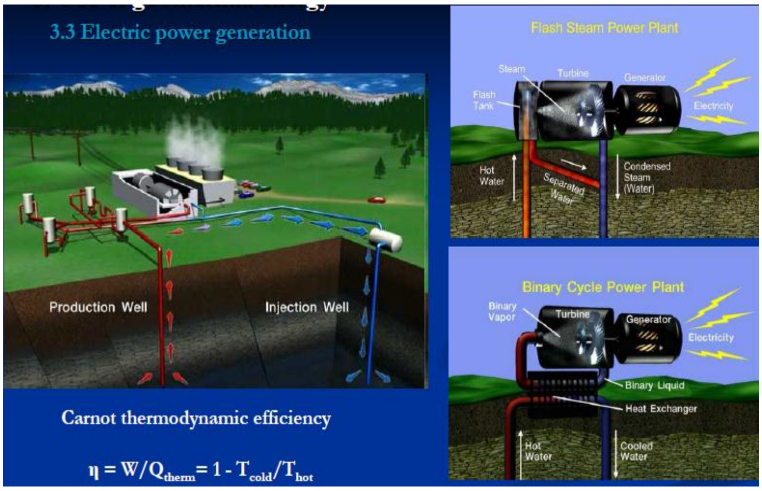

Fig. 18 Geothermal use in Electric power generation[13]

8. Conclusion

Geothermal energy is a powerful natural resource with the potential to shape the future of human society. It is relatively clean and environmentally friendly when compared to present energy sources such as fossil fuels. Its possible applications are numerous and its ubiquitous nature means that it is not limited to any physical location for extraction or use, especially given that methods are being developed to access non-ideal systems such as hot dry rock systems. As the technology used to harness and extract geothermal energy becomes less cost-prohibitive and more regions are able to be developed for economically viable geothermal energy capture, geothermal energy has the potential to become a greater and more important contributor to global human energy use.

المستخلص: الطاقة الحرارية الأرضية ، هي الطاقة المخزنة داخل الأرض كحرارة ، وهي موضوع جذب الانتباه في الماضي القريب بسبب إمكاناتها كمصدر طاقة قوي. على الرغم من أن التقنيات الحالية لالتقاط الطاقة الحرارية الأرضية تقتصر على المناطق ذات الظروف الجيولوجية المحددة للغاية ، إلا أنه يتم إحراز تقدم نحو التقنيات التي يمكن أن تساعد في الحصول على جزء أكبر من مورد الطاقة هذا دون الحاجة إلى مثل هذه الظروف الجيولوجية.
غالبًا ما يُشار إلى الطاقة الحرارية الجوفية على أنها مصدر طاقة "أخضر" له تأثير بيئي منخفض ، وبينما يختلف التأثير البيئي من موقع إلى آخر ، فإن هذا صحيح عمومًا عند مقارنته بموارد الطاقة الأخرى.
على الرغم من أن حرارة الأرض المخزنة ، محدودة نظريًا ، فإن مقدارها الكبير (12.6 × 1024 ميغا جول) يجعل الطاقة الحرارية الأرضية عمليا طاقة متجددة يمكنها نظريا الحفاظ على احتياجات الطاقة للبشرية عدة مرات.
في هذا البحث ، سيتم مناقشة الطاقة الحرارية الأرضية ، والظروف الجيولوجية التي تركز هذه الطاقة ، وطرق التقاط الطاقة الحرارية الأرضية ، واستخدامات الطاقة الحرارية الأرضية.
الكلمات الدالة : الطاقة الحرارية الأرضية ، الموارد المتجددة ، الأرض ، الخزان ، استخدامات الطاقة.

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