SARDAR PATEL UNIVERSITY

Vallabh Vidyanagar-388120

B.Sc. (Semester - 5) Subject: Physics Course: US05DPHY26

Renewable Energy Sources

(Two Credit Course –2 Hours per week)

(Effective from June-2020)

UNIT- II Geothermal Energy and Wind Energy-Fundamentals and Applications

Geothermal Energy: Introduction, Application, Geothermal Energy Resources, Origin of Geothermal Resources, Hydro Geothermal Resources.

Wind Energy- Fundamentals and applications: Introduction of Wind Energy, Wind power density, Power in a wind stream, Wind turbine Efficiency, Power of a wind Turbine for given incoming Wind Velocity, Types of wind turbine –Generator Units, Mono- Blade Horizontal axis Wind turbine (HAWT), Twin- Blade Horizontal axis Wind turbine (HAWT) and Three-Blade Horizontal axis Wind turbine (HAWT).

Introduction:

The thermal energy contained in the interior of the earth is called the geothermal energy. The geothermal energy is enormous and will last for several millions of years and is therefore called renewable.

The important aspects about the geothermal energy have been summarized in Table 6.1.

Table- 6.1 Important Aspects about Geothermal Energy

Characteristics	Remarks
Form of Energy	-- Thermal energy in the form of hot water, steam, Geothermal brine, mixture of these fluids.
Availability	-- Generally available deep inside the earth at a depth more than about 80 km. Hence, generally not possible to extract. -- In a few locations in the world, deposits are at depths of 300 m to 3000 m. Such locations are called the Geothermal Fields.
Method of Extraction	-- Deep production wells are drilled in the geothermal fields. The hot steam/water/brine is extracted from the geothermal deposits by the production wells, by -- pumping or -- By natural pressure.
Geothermal fluids	-- Hot water, -- Hot brine -- Wet steam, -- Mixture of above.

Countries which have known Geothermal Resources	-- Chile --New Zealand --EI Salvador -- Philippines --Hungary --Indonesia -- Iceland --Turkey --Italy -- U.S.A. --Japan --USSR -- Mexico
Application of Geothermal Energy	-- Hot water for baths, therapy -- District heating, space heating -- Hot water irrigation in cold countries -- Air conditioning -- Greenhouse heating -- Process heat -- Minerals in geothermal fluid -- Electrical power generation.
Engineering Criteria for applications of geothermal hot water.	

Application	Temperature (more than) ˚C	Depth (less than) km	Discharge (more than) m^3/day
Electrical power generation by steam water cycle	100	3	10000
Electrical power generation by binary cycle	70	2.5	25000
District heating	70	2.5	1000

Range of Geothermal Power plant installed capacity	-- 5 MW to 400 MW
Average geothermal gradient	-- 30°C per 1000 m depth
Geothermal energy released through earth's crust	-- 0.06 W/mn^2 About 1/1000th of solar energy on earth's surface
Total geothermal reserves in the earth	-- 4x 10^{12} EJ (EJ = exa-joule = 10^{18} joule)
Renewable energy deposits available for Use in upper 3 km Zone	-- 4000 EJ (EJ = exa-joule = 10^{18} joule)
Rate at which the renewable can be tapped for production of electricity	-- 2 to 10 EJ/yr (EJ = exa-joule = 10^{18} joule)
Types of Geothermal	

energy deposits	
-- Hydrothermal	-- Hot water and steam, hot brine
-- Petro thermal	-- Hot dry rock (HDR)

Evidence of the enormous geothermal energy stored deep inside the earth is apparent only n a few countries and a few locations in the world in the form of

-- Hot water springs:

-- The geysers (gusher): Hot water and steam released periodically from small vents in the ground in volcanic region or geothermal fields.

-- Fumaroles: Hot steam and gases released from small vents in the ground volcanic regions or geothermal fields.

-- Volcanic eruptions: Eruption of geothermal energy eruption in large quantities releasing hot lava, rocks, ash, mud, forming a typical conical hill or mountain.

Applications:

Until 1904, the use of naturally available geothermal energy had been limited for the use of warm water baths, therapeutic treatments etc. After 1904 the geothermal energy is being used for many electrical power generation and non-electrical applications (refer table 6.2).

The non-electrical applications include

-- Space heating -- Air-conditioning
-- Greenhouse heating -- Process heat
-- Medical therapy -- Mineral extraction

Geothermal water is used for heating green houses, heating houses, agricultural water, aquaculture water, medical therapy, mineral extraction (calcium chloride, boron etc.), desalination plants etc.

Table 6.2 Applications of Geothermal Energy for Various Purposes

Countries	Utilization	
	Electrical Power Production	Non-electrical Applications
Chile	√	--
El Salvador	√	--
Hungary	√	√
Iceland	√	√
Italy	√	--
Japan	√	√
Mexico	√	--
New Zealand	√	√
Philippines	√	--
Turkey	√	--
USA	√	√
USSR	√	√
France		√

Important criteria for engineering applications geothermal water are:

-- Temperature of geothermal fluid, °C
-- Discharge rate, m^3/day
-- Useful life of production well, years.

-- Depth of Aquifer (m)
-- Mineral Contents gram/m^3

Typical range of parameters of present geothermal power plants is given in Table 6-3.

Table 6.3 Engineering Criteria for Resources for Geothermal Power Plants

Type of Power	Average temperature of geothermal fluid °C	Discharge of production well m^3/day	Depth of drill hole m	Mineral content g/kg
Electrical power plant with steam-water cycle	185 to 255	10,000	650 to 3000	3 to 20
Electrical power generation with binary fluid cycle (Ammonia/water or Hydrocarbon//water, Freon/water)	70 to 150	25000	500 to 2500	6 to 40

Geothermal Energy Resources: The temperature of earth increases with the depth rather non-uniformly with average increases of 30°C per 1000 m (Geothermal Gradient). It is therefore; generally necessary to drill 10 km deep production wells to obtain geothermal fluids at significant temperatures and deep wells generally exclude the exploitation of this geothermal energy. Hence though immense geothermal energy may be available at great depths, they are not considered as potential geothermal resources. (Refer figure 6.1). The layers of aquiferous permeable rocks (4), impermeable rocks (5) and upper surface (6) of the earth are non-uniform. There are a few favourable geothermal deposits at relatively less depths (300 m to 3000 m). The geothermal energy deposits in such locations may contain large quantum of energy or low quantum of energy. However, such deposits at lesser depths have geothermal fluids at relatively low temperatures and the energy cannot be transported economically over long distances and must be used at the site locally. Such sites are called the geothermal fields. Some twenty geothermal sites are already known and a few others are yet to be discovered.

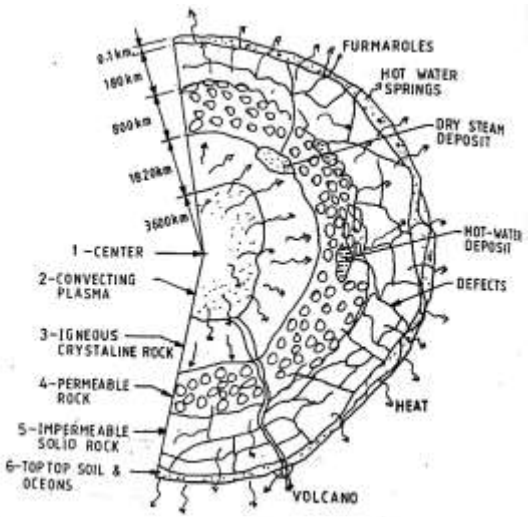


Figure: 6.1 Cross section of the earth with geothermal energy deposits, various types of modes, volcanoes, furmoroles, hot springs etc.

There are two types of geothermal energy deposits. These are called
-Hydro-geothermal energy resources.
(*Hydro = Water or fluid*)
-Petro-geothermal energy deposits.
(*Petro = Rock*)

Hydro-Geothermal Energy Resources: These are the deposits of hot water and steam at relatively lesser depths (3000 m). Hot

water, hot brine and steam can be extracted from such deposits by means of the production wells.

Petro-Geothermal Energy Resources [Hot Dry Rock (HDR)]: The hot dry rocks at temperature around 200°C and depth about 2000 m form important deposits of geothermal energy. Two types of wells are drilled in HDR sites. These are called production wells and injection wells.

Water is pumped in through the injection well into the Hot Dry Rock fracture.

The injected water collects heat from the hot dry rock and forms a deposit of hot water and steam in the fracture within the rock.

Production well extracts the hot water and steam from the geothermal deposits in the hot dry rock.

Petro Geothermal Energy Deposits may deliver mixture of hot water and steam of temperatures up to about 200°C for several decades.

Origin of Geothermal Resources: The planet earth originated from the sun several millions years ago and is cooling slowly. The earth was originally a mass of hot liquids, gases and steam. As cooled by loosing heat to the atmosphere, the outer solid crust, oceans, lakes were formed. The average thickness of cooler outer crust is about 30 km. Hot dry rocks, hot gases and liquids are deposited in the region below average depth of 2800 km. The temperature range of the magma (molten mass) is of 1250°C to 1500°C. The centre of the earth is at temperature 4500°C. The inner core of the earth has several minerals including iron, nickel, silicon, magnesium.

The earth is losing heat slowly through the outer crust with average energy loss of about 0.025 W/m, which too small compared with average solar radiation on the earth's surface (25 W/m^2).

The average increase in temperature with the depth is about 25 to to 30°C per kilometer. This is called average geothermal gradient.

The normal thermal radiation from earth is only about 25 kW per square kilometer and about 3 x 10^{10}kW for the entire earth.

The earth's outer crust and internal rock formation is non-uniform. The liquid magma in the upper mantle approaches earth’s surface at some points resulting in higher thermal gradients and higher heat flows through surface of the earth.

Fig. 6.1 shows a cross section of the globe indicating following zones.

1. Centre,
2. Magma,
3. Conducting (Permeable) Rock
4, Aquiferous rock (Porous, permeable rock through which water can percolate),
5. Solid impermeable rock.
6. Outer soft soil and water.

-- The thicknesses of the zones vary widely due to non-uniform formation of layers. Some layers overlap on adjacent layers. Some layers have defects.

-- The layers of outer and inner layers experience slow or violent geological movements.

Strong violent seismic movements are 'earthquakes'. Violent out-bursts ejecting magma, hot ash; hot rocks, lava etc. are called volcanoes. Earthquakes and volcanoes occur in some spots occasionally. There are several potential geothermal fields in the neighborhood of dead volcanoes.

Geothermal fields are regions in which energy deposits are available at a depth less than 1500 to 3000 m.

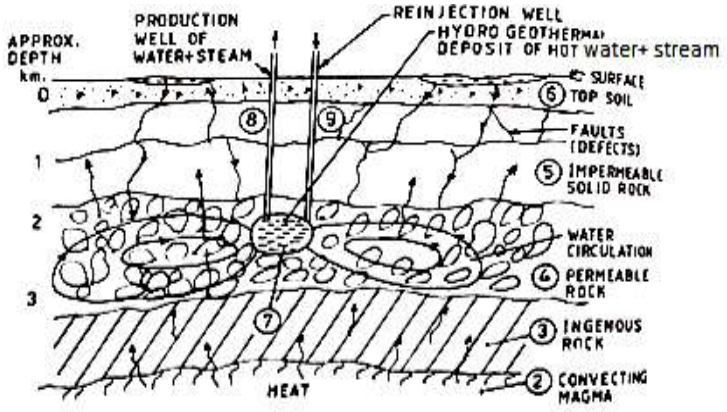
Hydro Geothermal Resources: These are reserves of hot water, wet steam and dry steam. Fig.6.3 shows a cross section of earth below a geothermal field. The geological layers of earth's crust, semi permeable rocks and permeable rocks are non-uniform and have several fractures and defects.

A few locations on the earth's surface have potential hydro thermal resources in the form of hot water, wet steam and mixture hot water and steam of medium temperatures (below 200°C).

Hot water and steam deposits are located in the fractures within the hot aquiferous permeable rocks. The water from rain, lakes, ocean etc. over several tens or hundreds of kilometer surface area percolates into the earth through upper crust and the defects (fissures) in the permeable rocks to the depths of 2 to 10 km. The water gets heated and rises through defects in the solid impermeable rocks and gets
Rain water, lake water, sea water percolates through top soil and fractures.

The water gets heated in contact with geothermal heat, rises and gets collected in the fractures within the permeable rocks. The upper impermeable rock provides insulating covering to the hot water deposits.

The hot water deposits without much steam content called liquid dominated hydro geothermal deposits. The temperature of water in such deposits is usually in the range of 100°C to 310°C.



When wells are drilled in the ground over such deposits, there are three possibilities:

-- The hot water and steam rises naturally through production well (Geo-pressure system).

Figure: 6.2 Hydrothermal and Geothermal Deposits
(Reserved)

-- The hot water should be pumped up through the production well.

-- Geothermal brine rises through the production well (Calcium chloride, boron, clay, etc.) is called geothermal brine.

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QUESTIONS

Part-1: Multiple Choice questions:

1. The thermal energy contained in the interior of the earth is called the _____.

   (a) Geothermal energy (b) Thermal energy (c) Geothermal power (d) Volcanic energy

2. The Geothermal energy is generally available deep inside the earth at a depth more than about _____km.

   (a) 20 (b) 40 (c) 60 **(d)** 80

3. Average value of geothermal gradient is _____.

   (a) 30°C per 500 m depth **(b)** 30°C per 1000 m depth (c) 30°C per 2000 m depth (d) 30°C per 10000 m depth

4. Hot steam and gases released from small vents in the ground volcanic regions or geothermal fields is called_____.

   (a) hot water springs (b) gusher **(c)** fumaroles (d) volcanic eruptions

5. The earth is losing heat slowly through the outer crust with average energy loss of about 0.025 W/m.

   (a) 0.025 W/m (b) 0.022 W/m (c) 0.020 W/m (d) 0.035 W/m

6. Hydro Geothermal Resources are reserves of _____.

   (a) magma **(b)** hot water (c) rocks (d) minerals

Part-2: Short answer questions:

i. Define: (1) The geysers, (2) Fumaroles and (3) Volcanic eruptions
ii. Enlist non-electrical applications of geothermal energy.
iii. Explain in short-The Petro-Geothermal Energy Resources.
iv. Explain in short-hydro-Geothermal Energy Resources.
v. Give the brief details of engineering Criteria for Resources for Geothermal Power Plants.

Part-3: Long answer questions:

1. Write a note on the important Aspects about Geothermal Energy.
2. Write a note on the applications of Geothermal Energy.
3. Write a note on the Geothermal Energy Resources.
4. Write a note on origin of Geothermal Resources.
5. Write a note on the hydro Geothermal Resources.

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