CHAPTER

7 Geothermal Energy

7.1 INTRODUCTION

Geothermal energy is *primarily heat energy from earth's own interior.* The word "Geothermal" comes from the Greek words 'geo' meaning earth and 'thermal' meaning heat.

- It is classified as **renewable** *because the earth's interior is and will coutinue in the process of cooling for the indefinite future.* Hence, geothermal energy from the earth's interior is *almost inexhaustible* as solar or wind energy, so long as its sources are actively sought and economically tapped.
- As we travel down earth's surface radially, there exists a temperature gradient of *0.03°C per metre*. Thus a 30°C increase in temperature can be obtained per kilometre depth from the earth crust. There are *many local hot spots just below the surface where the temperatures are much higher than expected.* Ground water, when comes into *contact* with hot spots, *either dry or wet steam is formed.* By *drilling holes* to these locations, hot water and steam can be tapped and these can be *used for power generation or space heating.*
- Geothermal energy is present over the entire earth's surface except that it is *nearer* to the surface in the *'volcanic areas'*.
- Heat transfer from the earth's interior is by *three primary means :*
  1. Direct heat conduction,
  2. Rapid injection of *ballastic magma* along natural rifts penetrating deep into earth's mantles.
  3. Bubble-like magma that buoys upwards towards the surface.

7.2 IMPORTANT ASPECTS OF GEOTHERMAL ENERGY

Following are the *important aspects* about geothermal energy:

1. **Form of energy:**
   — *Thermal energy'* in the form of *hot water, steam, geothermal brine, mixture of these fluids.*
2. **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 to 3000 m.* Such *locations are called **Geothermal fields**.*
3. **Method of extraction:**
   — *Deep production wells* are drilled in the geothermal fields. The hot steam/water/brine is *extracted* from the geothermal deposits by *production wells*, by *'pumping'* or by *'natural pressure'*.
4. **Geothermal fluids:**
   — Hot water;
   — Hot brine;
   — Wet steam;
   — Mixture of above.
5. **Range of geothermal power plants installed capacity:**
   — 5 MW to 400 MW.
6. **Average geothermal gradient:**
   — 30°C per 1000 m length.
7. **Geothermal energy released through earth's crust:**
   — About 0.06 W/m^2.
8. **Total geothermal reserves in the earth:**
   — 4×10^{24} MJ(Estimated).
9. **Renewable energy deposits available for use in upper 3 km zone:**
   — 4×10^{15} MJ (Estimated).
10. **Rate at which the renewable energy can be tapped for production of electricity:**
    — 2×10^{12} to 10×10^{12} MJ/year (Estimated).
11. **Types of geothermal energy deposits:**
    — Hydrothermal: Hot water and steam, hot brine.
    — Petrothermal: Hot dry rock (HDR).

7.3 STRUCTURE OF EARTH'S INTERIOR

The earth consists of the following *parts (concentric shells)*:

1. Crust; 2. Mantle; 3. Core.

1. **Crust.** It is the uppermost shell of earth that extends to variable depths below mountains, continents and oceans. The thickness of crust is believed to be 0.90 km and several substances like limestone, coal, gold, petroleum etc. are found in the crust.

2. **Mantle.** It is the second concentric shell of earth that lies below the crust. The upper *rigid* part of the mantle extends up to 100 km below the separating crust and contains mainly iron and magnesium. The crust and upper mantle form the

'lithosphere'.

Substances like limestone, coal,
petroleum, gold etc. found in this part.
Crust
Upper mantle
Continental: 35 km deep
Lower mantle
Ocean: 5–10 km deep
Zone (Rigid part)
Outer core (Liquid)
separating crust and mantle

Inner
core (Solid)
Surface

6370 5200 2900 90019090 0

Distance from
the surface, km

Fig. 7.1. Structure of eath's interior.

The lower mantle extending up to 2900 km below the earth's surface is *less rigid* and is *hotter.* This is known as *'asthenosphere'* and is capable of being deformed. The movement of lithosphere over the asthenosphere results in the *'phenomenon of plate tectonics' i.e.* movement of the earth's crust.

3. **Core.** It is the innermost concentric shell of the earth. The core boundary begins at a depth of 2900 km from the surface and extends to the centre of the earth at 6370 km. This layer is further subdivided into *outer core* and *inner core.* The outer core comprises the region from a depth of 2900 km to 5200 km below the earth's surface and behaves mere like a *liquid*. The inner core with a thickness of around 1170 km is believed to be a *solid* metallic body, containing nickel-iron alloy.
   - *The hot molten rock of the mantle is called* **Magma.**

7.4 ENERGY OF EARTH – HEAT FLUX

Earth is in a state of *thermiol equilibrium.* The *energy received from sun is lost at night.* The small amount of energy generated by the decay of unstable isotopes of uranium, thorium etc. is *dissipated* from earth's interior to oceans and atmosphere. The heat generated within earth is around 2700 GW.

- *The heat energy in earth's interior is due to* **radioactivity**. Regions of higher radioactivity have *higher heat flux* and are *potential geothermal sites.*
- Earth's surface consists of about one dozen **tectonic plates** (*e.g.*, American plate, Arabian plate, Indian plate, Philippine plate, Pacific plate etc.). Each of these plates has *thickness around 100 km* and *thousands of kilometres area.* Earth's interior is *unable to lose heat, by conduction, as rapidly as it is generated by 'radioactivity'*. This leads to *"convective instabilities"* which means that these *plates are continuously in motion with respect to each other.* A variety of processes along the margins of the plates lead to *partial melting* at depths between 15 and 200 km. The molten masses penetrate the surrounding rocks and rise towards earth at rates varying from a few cms per day to a few cms per year, thus resulting in **volcanic activity**. The molten masses which *do not reach earth's surface* come to *rest in the middle or upper part of earth's crust at depths less than 20 km.* These **liquid magmas** may have temperatures around 1000°C.

The crystallisation of these liquid magmas produces *intrusive igneous bodies.* The cooling and crystallisation of igneous bodies give rise to *local heat flux*. This **heat flux** *constitutes the geothermal energy* which may be used for a variety of purposes including generation of electricity.

*The local heat fluxes continue for thousands of years and form an '**inexhaustible** source of energy'.*

- The majority of active geothermal areas *tend to concentrate around the margins of major lithospheric plates.*

7.5 GEOTHERMAL SYSTEM – HOT SPRING STRUCTURE

Fig. 7.2, shows a schematic diagram depicting how *"hot springs (geysers)"* are produced through hot magma (molten mass), the fractured crystalline rocks, the permeable rocks and percolating ground water.

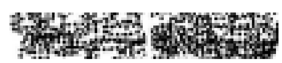

Fig. 7.2. Geothermal system – hot spring system structure.

At a depth of 5000 m or so lies an *impermeable magma.* Above the magma are the *'impermeable rocks'* which are *overlain by localised pockets of 'permeable rocks'*. One such localised pocket is shown in this figure. The localised pockets are bounded by *fracture zones or faults* along which some relative motion of rocks has occurred. *Water circulates along the fault lines.* As it goes down and moves in earth's interior it is *heated by the permeable layer which is in turn heated by conduction of heat from the magma*. The hot water comes out through another fault and forms a hot spring.

7.6 EARTHQUAKES AND VOLCANOES

Geothermal systems/fields need a *combination of* the following *three geological conditions:*

1. A natural underground source of water,

2. An impermeable layer that traps water and allows formation of steam, and 3.

A large mass of hot rock in vicinity of water system.

Earthquakes and **volcanoes** *are largely located in the "plate boundaries"*. Most of the world's volcanic activities and geothermal sites are located in the *circum pacific belt* known as **rim of fire**. It starts from New Zealand, encompasses Philippines, Japan, West Coasts of North America & Mexico; another belt runs from Iceland touching the British Isles, through Azores across the Atlantic to the West Indies, with a branch running through the Mediterranean Sea.

7.7 GEOTHERMAL GRADIENTS

The temperature difference within the earth depends on :

1. The thermal properties of earth's interior and their radial and lateral variation. 2. Movement of fluids or solid rock materials occurring at rates of more than a few millimetres per year.

A potential geothermal source region should have *high thermal gradient.*

Thermal gradient is *defined as the ratio of heat flux* and *thermal conductivity.*

i.e., $\text{Thermal gradient} = \dfrac{\text{Heat flux}}{\text{Thermal conductivity}}$

Fig. 7.3 shows the Geothermal gradients. The figures are based on measurements within a few km of earth's surface.

Fig. 7.3. Geothermal gradients.

- **Curve 1:** It represents average uniform gradient.
- **Curve 2:** It represents theoretical *increase in the boiling point* of water at increasing depths *due to higher pressures,* allowing for reduced density due to higher temperatures.
- **Curve 3:** It represents thermal gradients of such regions in which water percolates through upper crust into lower hot region and hot water flows vigorously upwards forming 'hot springs'.
- **Curve 4:** It represents the effect of solid impermeable rock. The rock forms insulating cap on geothermal reserves and does not allow heat flow to upper part.

- **Curve 5:** It represents leaks in the solid impermeable rocks in the form of springs of hot boiling water discharged in large quantities to ground surface. In some locations production of steam occurs at lower depths and the steam is released to the surface in the form of *furmaroles* and *geysers* as shown in curve 5. Such locations are *very few in number.*

7.8 GEOTHERMAL RESOURCES

Geothermal resources are of following *five* types:

1. *Hydrothermal or hydro-geothermal energy resources:*

(*i*) Vapour-dominated or dry steam fields;

(*ii*) Liquid-dominated system or wet steam fields;

(*iii*) Hot-water fields.

2. *Geopressured resources.*
3. *Petro-thermal systems* or hot dry rocks (HDR) resources.
4. *Magma resources (Molten-rock-chamber systems).*

- The *"hydro-thermal convective systems"* are *best resources* for geothermal energy exploitation at present. 'Hot dry rock' is also considered.

7.8.1 Hydrothermal Resources

Refer to Fig. 7.2. In hydrothermal convective system water is heated by contact with hot rocks. These are wet reservoirs containing steam and hot water or only hot water. If the temperature is *high* enough then *'steam' generates electricity,* otherwise *'hot water'* is used for *space heating and process heating*. The water present in the porous medium is heated by convection process and convective heat flow occurs across hot rocks to water present in porous rock.

"Examples" of *hydrothermal resource sites* are :

(*i*) Landerello field in Italy; (*ii*) Wairakei field in New Zealand; (*iii*) Geyser geothermal field in California etc.

1. **Vapour-dominated or dry steam fields:**

The vapour-dominated reservoirs produce dry saturated steam of pressure above atmosphere and at high temperature about 350°C.

Fig. 7.4 shows a dry-steam open system.

Fig. 7.4. Dry-steam open system.

— Steam extracted from the well is cleaned in *centrifugal separator* which removes solid matters.

— The cleaned steam is then supplied directly into the *'steam turbine'*. The exhaust steam from steam turbine is wet steam, (*i.e.,* mixture of water and steam) which passes through the *condenser.* The condenser condenses wet steam into water (through a cooling tower).

— The *non-condensable gases* present in wet steam are removed by *'steam jet injection method'*.

— The condensed steam is reinjected deep into the ground/well. •

This system is used in Landerallo (Italy) and Geyser (USA)

Environmental aspects*:*

- The steam from hydrothermal resources may contain 0.5 to 5% by weight of non condensable gas (mainly CO, CH_4 and NH_3) which are *largely harmless* in the quantities present. Gases also contain H_2S (hydrogen sulphide) which is *harmful to plant and animal life.*
- The withdrawal of large amount of steam from the source may result in *surface subsistence,* mainly occursin'oilfields', is *dealt with by injecting water into the ground.* The re-injection of excess water is done at some distance from a ground fault. 2.

Liquid-dominated systems or wet steam fields:

In such a system water temperature is above the normal boiling point (100°C). Due to the pressure inside the reservoir, water does not boil but remains in liquid state. When the water comes on the earth surface its *pressure reduces* resulting in *rapid boiling* and the liquid water *'flashes into a mixture of hot-water and steam'*. The *steam is separated from mixture and used to generate electricity.*

(a) **Liquid-dominated high temperature systems:**

For such systems, the following two methods are used :

(*i*) The flash steam open system.

(*ii*) The binary cycle system.

(i) **The flash steam open system:**

Fig. 7.5 shows a schematic diagram of flash steam open system.

Generator

Steam

Steam turbine

Brine

Condenser

Flash chamber
and brine separator

Brine and condensate

Hot brine

re-injection well

Pump

Geothermal zone

Reservoir

Fig. 7.5. Flash steam open system.

— Hot brine from the reservoir reaches the well head at lower pressure by *throttling process*. This low quality mixture is then throttled in *flash separator* which *improves the quality of mixture.* Now steam is separated as a dry saturated steam and supplied to the *'steam turbine'*, which *produces electric power* through a *'generator'.*

The *'power generation' from such system can be made more economical by associating chemical industry with power plant to make use of brine and gases effluent.* • This system is used in Cerro Prietol Mexico, Otake (Japan).

Limitations. Following are the *limitations* of flash steam open system as compared to vapour-dominated system:

1. *Much larger total mass flow rates* through the well required.
2. Owing to large amount of flows, there is a great degree of ground surface subsidence.
3. A greater degree of *precipitation* of minerals from the brine results in the necessity for design of valves, pumps, separator internals, and other equipment for operation under *scaling conditions.*

(ii) The binary cycle system:

The binary cycle concept *isolates the steam turbine from corrosive or non-corrosive materials and/or to accommodate higher concentration of non-condensable gases.* This is basically a **Rankine cycle** with an organic working fluid.

Generator
Vapour
Turbine
Condenser
Secondary
working fluid Pump
Heat exchanger
Geothermal zone
Hot brine

Fig. 7.6. Hot water closed (binary) system.

Fig. 7.6 illustrates a hot water closed (binary) system. About 50 per cent of hydrothermal water is in the temperature range of 153°C to 205°C. In this system, a '*heat exchanger*' is used to transfer a fraction of the brine enthalpy to vaporize the secondary working fluid. Expansion through a '*turbine*' to a lower pressure is fixed by the heat rejection temperature which provides the means for power generation. In this system there are *no problems of corrosion or scaling in the working cycle components,* such as the turbine and condenser. Such problems are confined only to the well casing and the heat exchanger. The '*heat exchanger*' is a shell-and-tube type so that *no contact* between brine and working fluid takes place.

- This system was first installed in the Soviet Union in 1967 on Kamchatka Peninsula having capacity of 680 kW. The firs binary cycle built in U.S.A. is of 11 MW capacity in California and second one at Raft-river-Idalio, is of a capacity of 10 MW.

Total flow concept system:

In such a system, both *'kinetic energy' and 'heat energy of the steam-liquid mixture,* produced by *flashing* the geothermal brine, *are utilised.* The *overall efficiency for conversion into 'eletrical energy'* should be *greater* than other methods (described earlier) in which *only the heat content of the brine is utilised.*

This system *utilises the principle of the 'Lysholm machine'*, known in this connection as the *helical (or screw) expander* or *mixed phase expander.*

Fig. 7.7 shows the schematic diagram of a liquid-dominated total flow concept.

Fig. 7.7. Schematic diagram of a liquid-dominated total flow concept system.

The *hot brine* from geothermal well is throttled where it becomes a *two-phase mixture of low quality.* The two phases at this point are *not separated* and the *full flow* is expanded in the *'mixed phase expander' (turbine)* which is coupled with generator which generates *electrical power.* The mixture from the expander/turbine is discharged into condenser. Then the brine condensate is re-injected into the well.

Following are the *requirements* of mixed phase expanders:

(*i*) They should be able to *overcome the losses* associated with the impingement of liquid droplets on blades (the efficiency of the turbine decreases with the decrease in quality).

(*ii*) They must be able to *withstand the corrosive and erosive effects* of the significant quantities of dissolved solids in the brine.

(**b**) **Liquid-dominated low temperature systems (Geothermal fluids):** The hydrothermal reservoirs of this system are available at moderate temperature range of 90°C to 175°C.

Due to low temperature, *little mineral water is extracted.* If there is danger of corrosion then it can be passed through a *heat exchanger* to transfer heat from the natural hot water.

The main *uses* of this system include the following:

(*i*) To provide heat for homes, commercial and agricultural buildings including greenhouses and animal shelters.

(*ii*) Hot water may also be used for air-conditioning and refrigeration.

7.8.2 Geopressured Resources

The geopressured resources contain moderate temperature brines (160°C) containing dissolved methane. These are trapped under high pressure (nearly 1000 bar) in a deep sedimentary formation sealed between impermeable layers of shale and clay at depths of 2 to 10 km.

At geopressure, dissolved methane gas is usually 1.9-3.8 m^3 per cubic metre of water. The methane gas is released from water on the earth surface because pressure at earth surface is lower. Therefore, methane gas is separated from brine by simple and economical gravity separation technique and burning of CH_4 also *produces energy*.

When tapped by boring wells, *three sources of energy* are available :

(*i*) Thermal;

(*ii*) Mechanical-as pressure; and

(*iii*) Chemical-as methane.

- The major resource area is along the Texas and Louisiana coast of the Gulf of Mexico which is about 1200 km in length. The potential of geopressured energy in this area is maximum 240 GW of electricity for 30 years.

7.8.3 Petro-thermal Systems or Hot Dry Rocks (HDR) Resources

These systems are composed of hot dry rock (*HDR*) *but no underground water.* They represent by far the largest geothermal resources available.

The rock, occurring at moderate depths, has very low permeability and needs to be fractured to increase its heat transfer surface.

The *recovery of heat from HDR* involves drilling deep into hot rocks, then cracking it to form cavity or fractures. This can be achieved by: (*i*) using high explosives at the bottom of the man-made well, (*ii*) using nuclear explosion, and (*iii*) by hydraulic fracturing (pumping water at high pressure into the rock).

The *thermal energy* of the HDR is *extracted by pumping water or fluid* through a well at the lower part of the fractured rock and *withdrawn by another well at a distance.* The temperature of the rock at a depth of 5 km is about 200°C. To achieve steady flow of high temperature water, the injection and extracting wells are joined to form a circulating loop. When heat is extracted through water, the rock cools down and due to temperature gradient between rocks, new cracks are developed.

- HRD technique is in operation near Valles Caldera, U.S.A., where fractures are made at a depth of 2.76 km and temperature at the location is about 185°C.

7.8.4 Magma Resources (Molten-rock-chamber Systems)

At some places, especially in the vicinity of relatively recent volcanic activity, molten or partially molten rock (*i.e. magma*) occur at a moderate depth (less than 5 km). The very high temperature above 650°C and the large volume make magma a substantial geothermal resources.

This resource has *not* been used yet due to the reason that the existing technology does not allow recovery of heat from these resources (Magma technology requires *special* manufacturing technology).

7.8.5 Hybrid Geothermal Fossil Systems

Such a system *utilises the relatively low-temperature heat of geothermal resources in the low temperature end of a conventional cycle and the high temperature heat from fossil-fuel combustion in the high temperature end of that cycle.*

Fig. 7.8 shows the schematic diagram of a geothermal **preheat hybrid system**, in which *low-temperature geothermal energy is used to heat feed water of a conventional fossil fuel system*.

Fig. 7.8. Geothermal preheat hybrid with conventional plant.

In this system geothermal heat heats the feed water throughout the low-temperature steam end prior to an open-type deaerating heater. It is followed by a boiler feed pump and two closed-type feed water heaters with drains cascaded backward. These receive heat from steam bled from H.P. (high pressure) stages of turbine. *No steam is bled from L.P. (low pressure) stages because 'geothermal brine' fulfills this function.*

7.9 ADVANTAGES AND DISADVATAGES OF GEOTHERMAL ENERGY OVER OTHER ENERGY FORMS

Advantages of Geothermal Energy:

1. Geothermal energy is *cheaper*.
2. It is *versatile* in its use.
3. It is the *least polluting* as compared to other conventional energy sources. 4.
It is amenable for *multiple uses* from a single resource.
5. Geothermal power plants have the *highest annual load factors* of 85 per cent to 90 per cent compared to 45 per cent to 50 per cent for fossil fuel plants. 6. It *delivers greater amount of net energy* from its system as compared to other alternative or conventional systems.

7. Geothermal energy from the earth's interior is *almost as inexhaustible as solar or wind energy*, so long as its sources are actively sought and economically tapped.

Disadvantages:

1. *Low overall power production efficiency* (about 15% as compared to 35 to 40% for fossil fuel plants).
2. Drilling operation is *noisy*.
3. *Large areas are needed* for exploitation of geothermal energy.
4. The withdrawal of large amounts of steam or water from a hydro-thermal

reservoir may result in *surface subsidence or settlement*.

7.10 APPLICATIONS OF GEOTHERMAL ENERGY

The various *applications* of geothermal energy are:

3. Industrial process heat

1. Generation of electric power.
2. Space heating for buildings. Main applications

4. Crop drying.
5. Plastic manufacture.
6. Paper manufacture.
7. Mushroom culture.
8. Timber seasoning.
9. Production of salt from sea.
10. Sewage heat treatment
11. Greenhouse cultivation using discharge from a geothermal field. • **Geothermal plants** *have proved useful for "base-load power plants". These kinds of plants are primarily entering the market where medium-sized plants are needed with low capital cost, short construction period and life-long fuel (i.e. geothermal heat).*

7.11 ENVIRONMENTAL PROBLEMS

Geothermal power plants *create some environmental problems* which are peculiar to them alone. The effluent will be salty and may contain sodium and potassium compounds. Additionally, in some cases lithium, fluorine, boron and arsenic compounds may be present. Such effluents cannot be discharged into the existing water courses unless properly treated without risking severe pollution problems. Some effluents contain boron, fluorine and arsenic. All these are *very harmful to plants and animal life in concentrations as low as two parts per million. Suitable waste treatment plants to prevent degradation of water quality will have to be installed to treat these new and increased sources of pollution.*

7.12 GEOTHERMAL ENERGY IN INDIA AND ABROAD

Some progress has been made in India on tapping geothermal energy on a commercial scale. Engineers from the Geological Survey of India have drilled about 50 shallow wells for steam in the Puga valley of the Ladakh region in Jammu and Kashmir. It may be possible to operate a 5 MW power station at the site. The Puga valley at an altitude of 4500 metres above sea level has the most promising geothermal field. The area extends to about 40 square kilometres out of which 5 sq. km is active. A combination of wet and dry steam to the tune of 170 tonnes of hot water per hour and 20 tonnes/hour of dry steam

(superheated steam suitable for running steam turbines) is available. This is enough to run a small power station to light the homes of local population. The geothermal heat can also be used for space heating in the Puga valley as the temperature in this area, especially during winter months, goes down to 35 degrees below freezing point. There are no other energy sources in Ladakh region and coal, petroleum etc. have to be transported from Srinagar. It can also be used for poultry farming, mushroom cultivation and pashmina wool processing which need a warmer climate. In addition, there are good deposits of borax and sulphur in this area. Sulphur in elemental form is found only in this region in the whole of India.

There are many *hot water springs* in India. Hot water springs represent heat energy coming out of the earth from a large body of molten rock that has been pushed up into upper crust of the earth by geological forces. In North they occur in *Ladakh* and *Himachal Pradesh.* In western parts they are found in the *Cambay region of Gujarat and Maharashtra.* They are also found in the *Singhbhum region of Bihar* while there are some in *Assam.* The water from a hot spring at *Garampani, near Jawai, in Assam* is so hot in summer that rice kept in muslin bag gets worked in no time.

The Geological Survey of India has so far identified about *350 hot spring sites* which can be explored as sources of geothermal energy. The engineers have commissioned an experimental 1 kW generator running on geothermal energy in the Puga area. This is the first production of electricity from a hot water spring in India.

- Many countries with hot springs in their territories have realised their potential for power and heat production. Countries like *Italy, Iceland, New Zealand, the USA and the USSR have achieved remarkable progress in the application of geothermal energy.*

The Italian power plant at Landerello was started in 1904 on a small scale but now it produces 540 MW of electricity. This is equivalent to burning 1.5 million tonnes of oil in a year. New Zealand started exploration in 1950 and the Wairakei power station now produces 175 MW, which is equal to 0.7 million tonnes of oil per year. The power production in California, USA, began in 1960 and has already touched 50 MW. In the Philippines the drillers struck high pressure, high temperature steam at about 200 m only at Tiwi, a tiny sleepy village nestled at the base of the volcano Malino, in 1967. By January, 1976, the first geothermal power plant at Tiwi began producing 55 MW. A geothermal plant with a capacity of 11 MW has been in operation for nearly 20 years in USSR. The construction of another power plant at Mutnovsky with a capacity of 200 MW is in progress.

- At present, *35 countries* of the world use about 15000 MWe geothermal energy for *space heating, industrial and agricultural applications* whereas 21 countries utilise geothermal energy for electricity generation.

The following countries have installed generating **geothermal units** *(above 20 MWe)* up to the year 2005:

Country	**Installed up to 2005 (MWe)**
Mexico	953
Indonesia	793
Italy	790
Costa Rica	163

EI Salvador	161
Kenya	127
Russia	79
Nicaragua	77
Guatemala	334
Portugal	20
Turkey	20

THEORETICAL QUESTIONS

1. Is geothermal energy renewable? Explain briefly.
2. What are the various means by which heat transfer from earth's interior takes place?
3. Explain briefly the various parts of the earth's interior.
4. Explain with a neat diagram the following parts of the earth's interior:
(*i*) Crust; (*ii*) Mantle; (*iii*) Core.
5. What do you mean by 'Heat flux'?
6. Describe with a neat sketch the 'Hot Spring structure'.
7. What is geothermal system? Explain briefly.
8. Discuss briefly 'Earthquakes and Volcanoes'.
9. What is thermal gradient? Explain briefly.
10. How are geothermal resources classified?
11. Give the examples of hydrothermal resources.
12. Describe within a diagram the 'Dry-steam open system'. State its environmental aspects.
13. Explain with the help of a schematic diagram the 'Flash steam open system' used for power generation.
14. Explain the principle of the Binary cycle system' employed for power generation.
15. Draw a schematic diagram of a liquid-dominated 'total flow concept system' and explain it briefly.
16. Write a short note an 'liquid-dominated low temperature system (geothermal fluids)'
17. What are 'Geopressured resources'? Explain briefly.
18. What are 'Hot dry rocks (HDR) resources? Explain.
19. Write a short note on 'Magma resources'.
20. Explain clearly with a neat schematic diagram the working of a 'Hybrid geothermal fossil system.
21. List down the advantages and disadvantages of geothermal energy over other energy forms.
22. What are the applications of geothermal energy?
23. Write a short note on 'Geothermal energy in India and abroad'.
24. What are the environmental problems associated with geothermal energy?