1. Overview of Advanced Mine Ventilation

Ventilation within any type of underground mine functions in order to introduce fresh air into the workspace of the workers, while simultaneously removing contaminated air from the same location. The removal of such air contaminants is also particularly important in maintaining an overall safe thermal environment that reduces any possible ignitions from occurring within the mine. The basic components of any type of mine ventilation system involve a combination of pipes, ducts, fans, cooling and heating systems, and occasionally air cleaning equipment[1].

The main purpose of mine ventilation is to

- to provide fresh air for personnel to breathe
- dilute mine contaminants
- remove heat from equipment
- maintain thermal comfort of underground personnel, , , and.

Underground mines need to be equipped to accurate, real-time, and intrinsically safe monitoring systems to be able to continuously assess the condition of a mine ventilation system.

2. Importance of Advanced Mine Ventilation

Appropriate mine ventilation

- ➢ improves the productivity of the mine workers,
- ➢ reduced accidents within the mine and
- ➢ fewer chronic conditions associated with contaminant inhalation.

advanced technologies in mine ventilation and monitoring systems with respect to enhanced performance and reliability, health and safety improvements, energy and cost savings, and mine productivity.

Advanced Mine Ventilation Utilizes

1. Mechanical ventilation
2. Sophisticated mechanical ventilators using variable speed drives
3. Takes into account the thermodynamics aspects
4. Considers air as a compressible fluid, hence more accurate

3. Geothermal energy

Earth crust is the infinite reservoir of heat. Geothermal energy is **heat within the earth**. The word geothermal comes from the **Greek words geo (earth) and therme (heat).**

Geothermal energy is a renewable energy source because heat is continuously produced inside the earth.

People use geothermal heat for bathing, to heat buildings, and to generate electricity.

Geothermal energy is the thermal energy in the Earth's crust which originates from the formation of the planet and from radioactive decay of materials.

Geothermal energy comes from deep inside the earth

The slow decay of radioactive particles in the earth's core, a process that happens in all rocks, produces geothermal energy.

The earth has four major parts or layers:

- **An inner core of solid iron**: 2400 km in diameter
- **An outer core of hot molten rock called magma**: 2400 km thick.
- **A mantle of magma and rock surrounding the outer core**: 2900 km thick
- **A crust of solid rock** that forms the continents and ocean floors: 8 to 40 km thick

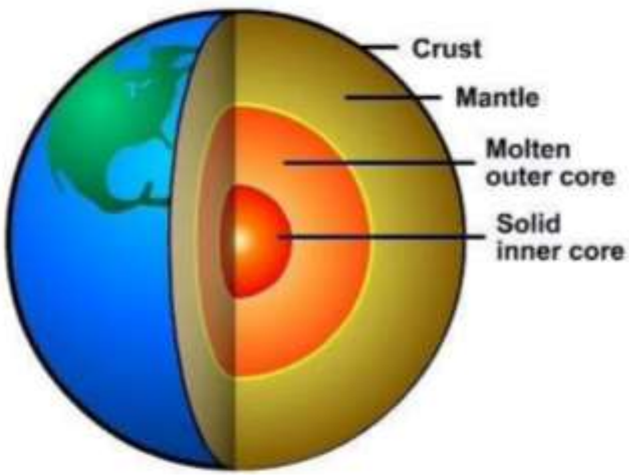


Fig. Interior of earth

The temperature of the earth's inner core is about 10,800 °F (6000°C), which is as hot as the surface of the sun.

Temperatures in the mantle range from about 392°F (200°C) at the upper boundary with the earth's crust to approximately 7,230°F (4000°C) at the mantle-core boundary.

The earth's crust is broken into pieces called ‘tectonic plates’. Magma comes close to the earth's surface near the edges of these plates, which is where many volcanoes occur. The lava that erupts from volcanoes is partly magma. Rocks and water absorb heat from magma deep underground. The rocks and water found deeper underground have the highest temperatures.

Applications of geothermal energy

Some applications of geothermal energy use the earth's temperatures near the surface, while others require drilling miles into the earth. There are three main types of geothermal energy systems:

- Direct use and district heating systems
- Geothermal power plants: for electricity generation
- Geothermal heat pumps

Direct use and district heating systems

Direct use and district heating systems use hot water from springs or reservoirs located near the surface of the earth. Ancient Roman, Chinese, and Native American cultures used hot mineral springs for bathing, cooking, and heating. Today, many hot springs are still used for bathing, and many people believe the hot, mineral-rich waters have health benefits.

Geothermal energy is also used to directly heat individual buildings and to heat multiple buildings with district heating systems. Hot water near the earth's surface is piped into buildings for heat. A district heating system provides heat for most of the buildings in Reykjavik, Iceland.

Industrial applications of geothermal energy include food dehydration (drying), gold mining, and milk pasteurizing.

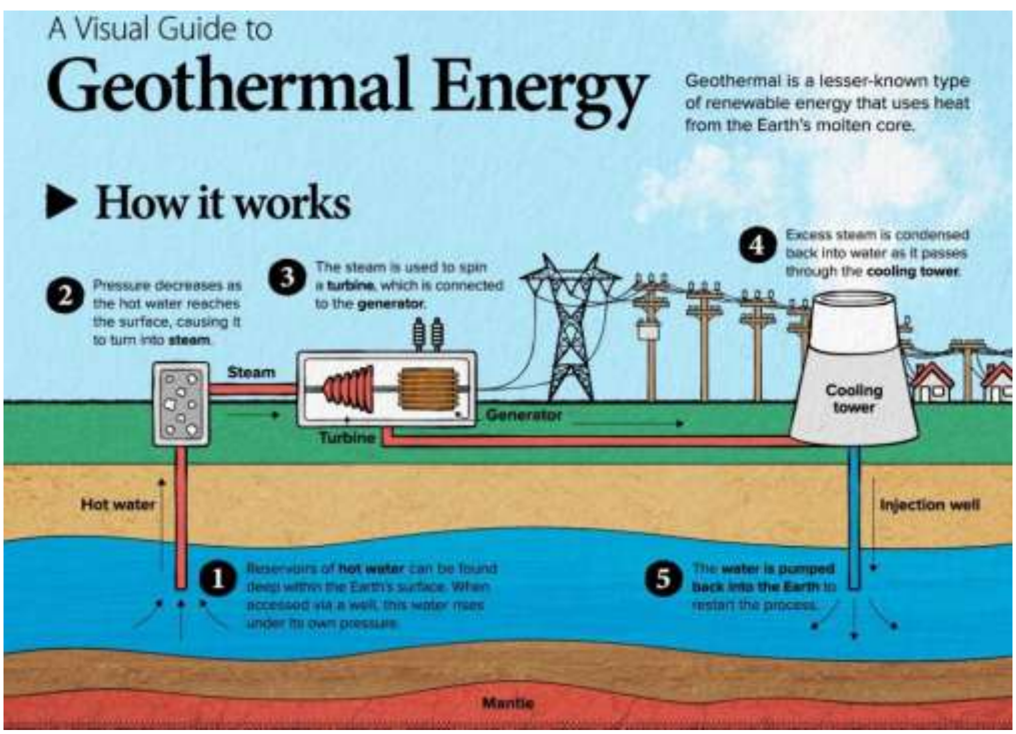
Generation of geothermal power

Geothermal electricity generation requires water or steam at high temperatures (300° to 700°F). Geothermal power plants are generally built where geothermal reservoirs are located, within a mile or two of the earth's surface.

Geothermal power production involves:

- Tapping into underground reservoirs of hot water and steam. Wells are drilled into geothermal reservoirs to bring the steam or hot water to the surface, where it is used to drive turbines connected to electricity generators.

- The cooled water is then re-injected into the Earth to sustain the reservoir pressure and temperature, creating a sustainable loop.



The United States leads the world in the amount of geothermal electricity generation. In 2021, there were geothermal power plants in **seven states**, **which produced about 16 billion kilowatthours (kWh) (or 16,238,000 megawatthours), equal to about 0.4% of total U.S. utility-scale**

electricity generation. Utility-scale power plants have at least 1,000 kilowatts (or 1 megawatt) of electricity generation capacity, equal to 0.4% of total U.S. utility-scale electricity generation.

States with geothermal power plants in 2021

	State share of total U.S. geothermal electricity generation	Geothermal share of total state electricity generation
California	70.5%	5.8%
Nevada	24.2%	9.4%
Utah	2.2%	0.8%
Oregon	1.3%	2.2%
Hawaii	1.0%	0.3%
Idaho	0.5%	0.5%
New Mexico	0.3%	0.1%

International geothermal electricity generation

- In 2019, 27 countries, including the United States, generated a total of about 88 billion kWh of electricity from geothermal energy.
- **Indonesia was the second-largest geothermal electricity producer after the United States**, **at nearly 14 billion kWh of electricity**, which was equal to about 5% of Indonesia's total electricity generation.
- **Kenya was the eighth-largest geothermal electricity producer at about 5 billion kWh**, but it had the largest percentage share of its total annual electricity generation from geothermal energy at about 46%.

Geothermal heat pumps

Geothermal heat pumps use the constant temperatures near the surface of the earth to heat and cool buildings. Geothermal heat pumps transfer heat from the ground (or water) into buildings during the winter and reverse the process in the summer.

4. Geothermal gradient: Variation of strata temperature with depth

The increase of strata temperature as a function of depth is known as "geothermal gradient". Mine ventilation engineers often face difficulty in keeping the underground temperature below 30^{o}C due to unavoidable geothermal gradient. In upper crust of the earth surface, the geothermal gradient varies from 15 to 40^{o}C/km. As per Donoghue et al. (2000), in metal mines with rectagular opening, which are operating below 1200 m depth have 3.17 times higher heat related incidence rate than the mines operatig above 1200m [29]. Geothermal gradient depends on the thermal conductivity of rock. Strata heat increases at a higher rate in lower thermal conductive rocks, like coal measure.

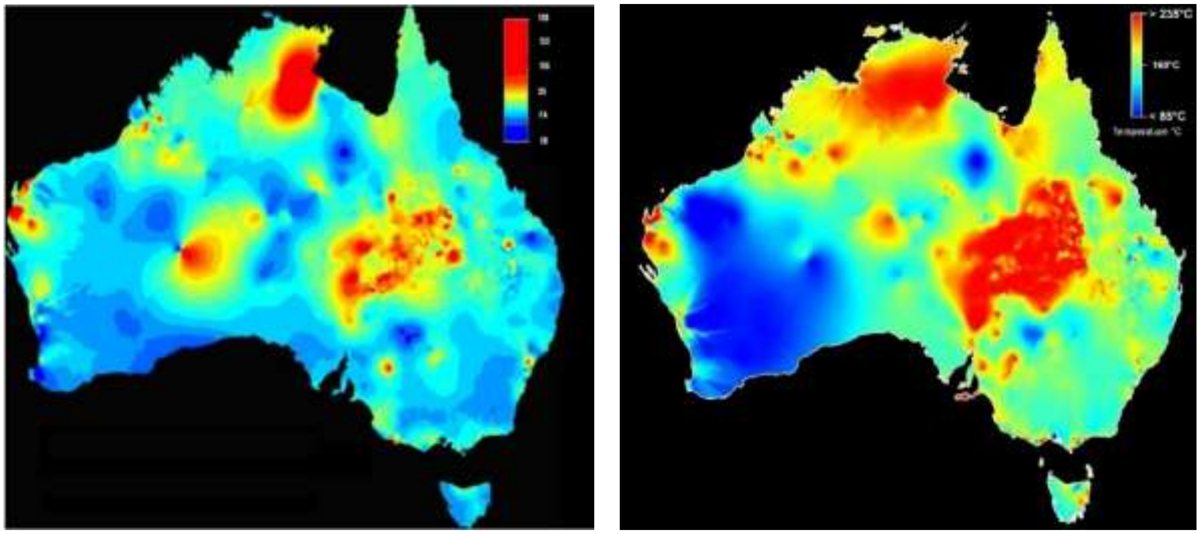
- Heat flow from underground wall rock is a major contributing source to the rise in mine air temp.
- Amount of heat transfer from the rock, in a given mining condition, requires the knowledge of thermal properties of rock.
- Heat flows out of the hot core of the earth at almost a constant rate of 0.05 W/m^2 over most of the earth's surface.
- As a result, the temp. of the ground rock increases steadily as we go deeper down the earth's crust.
- The rate of increase of temp. with depth is called **geothermal gradient**.

$$\text{The geothermal gradient, gg} = \frac{0.05\ (\text{w/m}^2)}{\text{thermal conductivity (w/m.}^{o}C)} ({}^{o}C/m)$$

- Geothermal gradient varies from place to place and it dependent on the following physical properties of the rock which govern the rate of heat transfer in the rock as
  - Thermal conductivity: In rocks of lower thermal conductivity such as coal-measure rocks, the geothermal gradient is steeper or the rise in temp. with depth is faster.
  - Specific heat and
  - Density.
- The typical values of geothermal gradient (°C/100m) are as follows:

Ontario, Canada	1.22
Hungary	5.00
KGF, India	1.10
Wit Waterstrand, South Africa	0.80
UK and Europe	1.00 – 3.00
Broken hill, NSW, Australia	1.97

Geothermal gradient is very site specific. For instance, in some volcanic area, geothermal gradient could be significant and some mines in Japan, China and Arizona. For example, Resolution Copper mine of Arizona, is a large, deep copper ore body and is hosted by Laramide volcano-sedimentary rocks and close to Magma Vein [33]. The VRT in the mine at a depth of 2000 m is more than 80 °C [34]. Geothermal gradient in some specific area in China reaches 70-80°C per 1000 m depth [35]. Geothermal heat mapping of Australia shows the variation of geothermal gradient in different places. The Figure 4 presents the geothermal heat at 2 km depth and 5 km depth in Australian map [18,36].



(a) (b)

Figure 4. Geothermal mapping at depth of (a) 2km and (b) 5km in Australia.