European Association for the
Development of Renewable Energies, Environment
and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality
(ICREPQ'12)
Santiago de Compostela (Spain), 28th to 30th March, 2012

Geothermal energy: Present use, Resources and Technology

M. R. Duque[1]

[1] Department of Physics
Évora University
Rua Romão Ramalho,59,7000-671 Évora, Portugal
Phone number:351 266 745372, Fax number:351 266 745394, e-mail:mrad@uevora.pt

Abstract. In this work we use a data-base compiled by the IGA to examine the increase of geothermal energy use in recent years. We speak about electricity produced by different plant types and direct uses of geothermal fluids. We can conclude that the use of geothermal energy has tended to increase in recent years. According to the IGA, there are 233 geothermal plants planned to be in operation in the coming years. The direct use of geothermal fluids is increasing especially the use of geothermal heat pumps.
The last part of the work is dedicated to geothermal resources and future research related to this subject. We discuss different problems related to each type of resource and present the benefits that their exploration can bring to humanity, especially those related to air pollution.

Key words

Geothermal energy, geothermal exploration, geothermal resources, power generation, renewable energy

1. Introduction

With the rise of fossil fuel prices and the increased pollution they produce, there has been an increase in research and investment in renewable energy. In this work we speak about geothermal energy, a renewable energy whose utilization has grown in recent years due to investment and research in new technologies and to the necessity of reducing atmospheric pollutants. Geothermal energy exploration was, in the past, associated with volcanic regions or with boundaries of plate tectonics. Now its exploration is extended to other regions that present high temperatures at depth. Geothermal heat pumps can be used everywhere and their use can be extended to inhabited areas of planet Earth. Another important fact is the cost of energy. An important part of the cost of a geothermal plant is related to the costs of drilling. The holes used in an HDR or an EGS are very deep (several kilometers) and the methods and techniques used to make them are identical to those used in oil exploration.
The values obtained in the latests estimations on heat loss by conduction through the surface of the Earth are 47± 2 TW. This is twice the energy used today by man, but unfortunately, only a small portion of this heat is available. There are efforts to increase the use of geothermal energy prospecting in new regions and attempts to develop the technology needed for this purpose.

2. Electricity production

The data used in this work was retired from the IGA (International Geothermal Association)[1] data base and is related to electricity production by geothermal plants, its distribution throughout the world, and the different types of plants used .We also used the report from 2005 to obtain the increase in electricity production and the number of plants installed since 2005.According to the IGA, in 2005 there were 8,933 MW of installed power capacity in 24 countries generating 55,709 GWh/year of electricity. In 2010 the values increased, and we have an installed capacity of 11, 186.7 MW generating 67,246.4 GWh/year. This represents an increase of 20% in the installed capacity and an increase of 17% in the produced energy. The IGA report from 2010 tell us that this energy was produced by 551 geothermal plants. There were different types of plants in operation: 246 binary plants, 150 single flash plants, 64 double flash plants, 63 dry steam plants,26 black pressure and 2 hybrid plants. Figure 1 shows the percentage associated with different plant

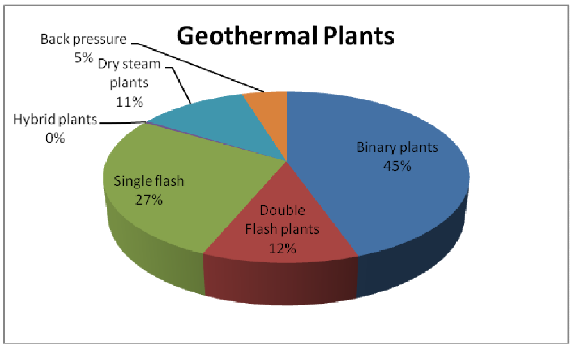


Figure1. The types of plants installed

plant types.

The increase in binary plants is due to the fact that they work at lower temperatures and they do not contribute to atmospheric pollution. In Table 1 we can see the countries with geothermal plants installed and the installed capacity. We can see that the location of the plants is distributed in different locations, all over the world.

Table 1.- Number of binary plants per country and installed capacity

Country	Number of plants	Installed Capacity (MW)
Australia	2	1.1
Austria	3	1.4
Costa Rica	4	56.0
El Salvador	1	9.4
Ethiopia	2	7.3
France	1	1.5
Germany	4	7.1
Guatemala	8	52.0
Iceland	8	10.4
Japan	2	2.2
Kenya	4	14.0
Mexico	2	3.0
New Zealand	23	138.2
Nicaragua	1	7.5
Philippines	18	208.8
Portugal	5	28.5
Turkey	4	31.2
U S A	154	687.7
Total	246	1267.3

Africa is the continent with least number of plants but with several projects for the coming years.
The country with the most production was the USA, with 214 plants in operation (39% of the production) and an installed capacity of 3,129.4 MW (28% of the total world installed capacity).

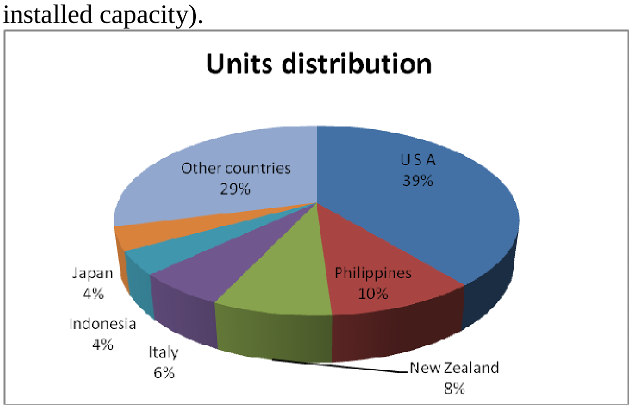
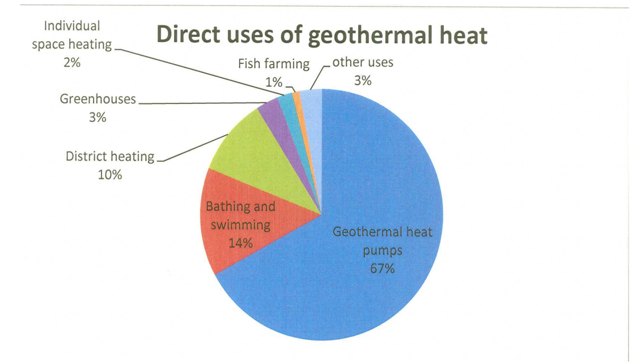


Figure 2. Location of the units and percentage of production

The second country in production was the Philippines with 56 units installed (17% of the world installed capacity and 10% of the production) and in the third place we have New Zealand with 43 units (6.8% of the world installed capacity and 8% of the production).
Unfortunately, there are still 63 dry steam plants working and emitting pollutant gases to the atmosphere.

3. Direct use of geothermal fluids

Direct use of geothermal applications appear to be progressively more commonplace in many countries and are being emphasized in a number of national renewable energy policies as effective measures to decrease greenhouse gas emissions. The worldwide direct utilization of geothermal energy in 2005 [2] was 273,372 TJ/year and in 2010 [1] the values increased to 423,854 TJ/year. This represents an increase of 155%. The main types of direct applications of geothermal fluids can be Fig



3. Direct uses of geothermal fluids

seen in figure 3.
We note that geothermal pumps present a great increase from the use in 2005, occupying now 67% of the total energy used directly. This is due to the fact that they can be installed everywhere and have a low cost of operation. The main use of these pumps is for heating buildings in the winter and refrigeration in the summer.

4. Geothermal resources

An important point related to geothermal energy is the different types of resources. In some regions with high temperature gradients, there are deep subterranean faults and cracks that allow groundwater to seep underground. There, the water is heated by the hot rock and circulates back up to the surfaces forming hot springs, mud pots, geysers or fumaroles. If the ascending hot water meets an impermeable rock layer, the water is trapped and fills the pores and cracks existing underground, forming a geothermal reservoir that can reach temperatures of more than 350ºC, and are powerful sources of energy. Hot water or steam can ascend (or be pumped to the surface) through production wells drilled from the surface to the reservoir. If the temperature of the fluids are around 120-370ºC, they are used to produce electricity. Shallower reservoirs of lower temperatures are used directly for district heating, geothermal heat pumps, health spas, greenhouses, etc. The available heat in a region cannot be increased, but the permeability and water content can be enhanced. An example of water reinjection is The Geysers in the USA. In 1969, wells that were marginally productive were reconfigured as injection wells and the fluid was injected through them into the reservoir. The mass of the injected fluid was equivalent to 25-30% of the extracted steam. In 1995 another project was initiated to inject treated wastewater from the city of Santo Rosa. A pipeline was constructed that was capable of providing 29.5 million liters. This injected water stabilizes the steam production.

Water injection also has the benefit of reducing H_2S in the fluid.

Hot Dry Rock geothermal systems are found in regions where geothermal heat is stored in hot and poorly permeable rocks without any fluid available to store or transport heat. To exploit the heat stored in these regions, it is necessary to artificially create a fracture system at depth, which acts as a heat exchanger. Water circulates from the surface into a drilled well (injection well) to the cracks and goes back to the surface through another drilled well (production well). Hydraulic fracturing involves injection of water at high pressures into a reservoir, to create new fractures or enlarge pre-existing cracks. Generation of large heat exchangers at depth and controlling the loss of circulating fluids present the biggest technological problems in exploitation of HDR geothermal energy [3].

Geopressured geothermal resources are deeply buried reservoirs of fluid confined by impermeable rock and clay that inhibit fluid exchange with the surroundings. They are found in sedimentary basins subjected to subsidence. The process of subsidence subjects the poorly consolidated sediments to intense heat and enormous pressure. Such reserves typically are found between 3 and 6 km depth, with fluid temperatures between 150 and 180ºC at pressures up to 130 MPa [3].

Extraction of thermal energy from magma was tested during the 1980s by drilling into a lava lake in Hawaii. Magma is molten rock material, a hot viscous liquid, which retains fluidity until solidification. Typically , magma crystallizes to form igneous rock at temperatures varying from 600 to 1400ºC. At its site of generation, magma is lighter than the surrounding material, and it rises as long as the density contrast between the magma and the surrounding rocks continues. At several volcanic locales, magma is present within the top 5 km of the crust.

5. Present research

A.Exploration and drilling

The natural hydrothermal resource is ultimately dependent on the coincidence of substantial amounts of heat, fluids and permeability in reservoirs, and the present state of knowledge suggests that this coincidence is not commonplace on the Earth. Many high enthalpy systems are yet to be developed.

Exploration efforts today are often related to blind geothermal systems and low enthalpy resources, which commonly require enhancement in permeability. Exploration of potential EGS reservoirs requires a wide variety of approaches, often a combination of several methods. EGS targets include deep sedimentary basins (historically used for hydrocarbon exploration). There has been considerable improvement in both technology and methods used by the hydrocarbon industry and driven by increasing activity in the geothermal sector. For example, seismic methods often considered to be expensive, have increased in popularity in the geothermal sector. Magnetotellurics (MTs) are a primary tool for the detection and characterization of geothermal reservoirs.

Enhancing a geothermal system generally involves drilling wells with large diameters. These wells are used to stimulate the reservoir by hydraulic fracturation, originating or detecting fault zones. A parameter essential for EGS development is knowledge of the stress field in the region and understanding geomechanics in the subsurface. The characterization of a reservoir must include several methods that constrain the stress field of a reservoir and elucidate the stress states along faults chosen for stimulation.

Drilling is the most expensive part of geothermal exploration. Cost reduction for geothermal drilling must be considered in a geothermal project. Geothermal reservoirs may have highly corrosive fluids with high temperature at great depth. Special tools and techniques are required to minimize this effect. In addition to these problems, geothermal wells must have large diameters because large flow rates are necessary. Drilling requires the interaction of geology and engineering of rock materials and techniques. Both fields are complex and need to be integrated theoretically and practically.

Geothermal wells often have to be stimulated, in order to increase well productivity. Techniques used to improve the near-wellbore region up to a distance of few tens of meters, are chemical treatments and thermal fracturing. The method used to improve the far field, up to several hundred of meters away from the borehole, is hydraulic fracturing.

Drilling for geothermal exploration and production wells is one of the most expensive and risk-intensive aspects of the development of a geothermal field. It is estimated that the construction of a geothermal steam field may be nearly half of the total cost of developing a geothermal resource. Industry and governments are continually developing technologies designed to improve the success rate of drilling geoexploration and production wells.

In order to increase geothermal use it is necessary to implement alternatives. The actual research in geothermal energy production is related to EGS reservoir development, and the study of Geopressured Reservoirs. In order to explore HDR (Hot Dry Rock Reservoirs) immediate technology improvements are needed in reservoir predictive models, zonal isolation tools, monitoring and logging tools and submersible pumps. The primary challenges that are faced when trying to develop an economically viable power generation system for a geopressured resource are: Separating dissolved solute load from the aqueous phase while minimizing the loss of thermal energy; separating and capturing the dissolved methane gas phase from the aqueous phase; efficiently extracting the thermal and kinetic energy from the fluid while maintaining sufficient pressure and flow rates [4].

B. Geothermal plants

The single-flash steam plant was widely used, by geothermal power industry, several years ago. In September 2011, there were 150 units of this kind in operation around the world. This type of plant accounts for 27% of all geothermal plants. These plants are used when geothermal wells produce a mixture of steam and liquid. A typical 30 MW single-flash power plant needs 5 or 6 production wells and 2 or 3 injection wells. The wells may be drilled at sites distributed across the field or several wells may be drilled from a single padd using directional drilling to intercept a wide zone of the reservoir.

The terminology single-flash system indicates a process of transitioning from a pressurized liquid to a mixture of liquid and vapor, by lowering the geofluid pressure below the saturation pressure corresponding to the fluid temperature. The flash processe may occur in the reservoir, in the production well or in the inlet to the cyclone separator. The turbines used in geothermal applications must be made of corrosion-resistant materials due to the presence of gases such as hydrogen sulfide that can attack ordinary steel.

Geothermal steam contains non-condensable gases such as hydrogen sulfide, H_2S, carbon dioxide, CO_2,methane, CH_4, and other gases in very small amounts. Uncontrolled venting of steam releases all these gases into the atmosphere. Under normal conditions, the gases are isolated in the condenser , drawn into the ejectors, and treated before release to the atmosphere. The CO_2 that is released from flash plants is not abated, but constitutes a relatively minor source of greenhouse gases.

The separated brine contains practically all the dissolved minerals that existed in the geofluid in the reservoir but at higher concentrations. Some of the elements typically found in brines would affect surface or groundwater if allowed to mix with them.

A single flash plant is relatively economical in terms of land required to build the plant when compared to other means of generating electricity. A flash plant needs 1.200m^2/MW, including well pads, pipe routes, power plant and substation.

The double-flash steam plant is an improvement on the single-flash plant and can produce 15-25% more power output for the same geothermal fluid conditions. The plant is more complex, more costly and requires more maintenance. In September 2011 there were 64 double flash plants in operation, 12% of all geothermal plants. The fundamental new feature is a second flash process imposed on the separated liquid leaving the primary separator in order to generate additional steam.

Double flash plants have the same potential environmental impacts as single flash plants. In the matter of water pollution, the waste brine from a double flash plant will in general carry more highly concentrated contaminants than single-flash plants.

Dry-steam plants were the first type of geothermal power plant on the market. Dry-steam plants tend to be simpler and less expensive than flash-steam plants. In September 2011, there were 63 plants of this type in operation, 11% of all plant types.

The general characteristics of a dry-steam reservoir is that it comprises porous rocks, fissures or fractures, that are filled with steam. The steam contains gases such as carbon dioxide, hydrogen sulfide, methane, and others in trace amounts. Little or no liquid is present.

The mechanism of fluid behavior in a dry-steam reservoir is complex. There are three sources for the steam that is seen in the production wells. The first contribution comes from the steam residing in fissures and fractures existing in rock. The second comes from the vaporization of liquid that forms as condensate from steam that has come in contact with the cooler lateral and upper boundaries of the reservoir. The third arises from evaporation of the top of a deep brine reservoir over a prolonged period of steam production that causes a decrease in reservoir pressure.

Dry-steam geothermal plants have very low potential impact on the environment. The geofluid consists of only steam, so there is no mineral brine to dispose of. The The non-condensable gases in the steam are isolated in the condenser and removed by means of vacuum pumps or steam-jet ejectors, and they can be treated to remove hydrogen sulfide.

Today, binary cycle power plants are the most widely used type of geothermal power plant with 246 units in operation in September 2011. They constitute 45% of all geothermal units in operation. The installed capacity is 1267.3 MW (11% of the world installed capacity).Basic binary plants have low thermal efficiencies mainly due to the small temperature difference between the heat source and the heat sink. Binary systems work when geofluid temperature is 150ºC or less and it is impossible to build a flash-steam plant that can efficiently and economically work with this geofluid. At such low temperatures it is unlikely that the wells will flow spontaneously, and if they do, there is a strong likelihood of calcium carbonate scaling in the wells. One way to prevent the scaling problem is to produce the geofluid as a pressurized liquid using down-well pumps.

In the design of this type of plant, the selection of the working fluid is important because it has great implications for the performance of the plant. There are many choices available for the working fluid but there are also many constraints on that selection due to the thermodynamic properties of the fluids as well as considerations of health, safety, and environmental impact. These include flammability, toxicity, ozone depletion potential (ODP) and global warming potential (GWP). Some refrigerants, like ammonia, are toxic. All of the hydrocarbon candidate fluids are flammable and necessitate appropriate fire protection equipment onsite, over the usual requirements for any power plant.

Geothermal binary plants are the most benign of all power plants regarding environmental impact. The geofluid is pumped from the reservoir and returns entirely to the reservoir after passing to the heat exchangers without seeing the light of day. The cycle working fluid is contained completely within pipes, heat exchangers and the turbine, so that it never comes in chemical or physical contact with the environment.

The only possible form of pollution from a binary plant might be called thermal pollution [5] caused by the heat that must be rejected from the cycle. In the case of a binary plant, the amount of thermal power that needs to be absorbed by the surroundings is about nine times the useful power delivered by the plant. This effect can be minimized if there is a use for waste heat, such as soil or greenhouse heating.

6. Unsolved problems related to the existence of geothermal plants in one region

A.Land subsidence

It is difficult to draw generalizations about subsidence because there exists fields like Larderello (Italy) that has been in operation for over 100 years with negligible subsidence and other fields like Wairakei (New Zealand) where subsidence reached nearly 500mm/year. The maximum depression in this field now exceeds 15 m and is located 1.5 Km from the center of the production field.
This occurs because geothermal reservoir production works at rates much greater than recharge. Subsidence is more likely to occur in formations where the fluid in place is under lithostatic, rather than hydrostatic pressure. The risk of subsidence can be avoided doing fluid reinjection.

B.Induced seismicity

Induced seismicity is due to a change in fluid pressure within a stressed rock formation leading to movement of fractured rocks. This may happen, for example, when fluids are injected underground at high pressure. This can be a serious problem in HDR (Hot Dry Rock) or EGS (Enhanced Geothermal Systems).As injection of waste fluids is one of the critical features associated with the maintenance of an EGS reservoir, the induced seismicity can be a problem.
The acoustic noise generated may be monitored with high-precision instruments to provide real-time information regarding the behavior of the reservoir and to make possible the location of fractures and faults in the formation. In 2007, in Basel (Switzerland) an earthquake of magnitude 3.3 caused considerable alarm among residents. This problem remains unsolvable.
The site of a future HDR or EGS system must be monitored for any unexpected natural or induced microseismic events after field work begins. If there are residents near the site, an educational program should be put in place to inform people about the possibility of seismic events.

C.Induced landslides

Landslide have occurred at geothermal fields but the cause is often unclear. The worst disaster happened in Guatemala in 1991 in which at least 23 people were killed. Recommendations for the prevention of similar catastrophes include development of an hazard map identifying all potential landslide areas, slope monitoring instruments, monitoring of springs to detect possible changes in flow rate, temperature, chemistry and clarity, installation of drains in slopes to remove moisture and avoidance of unstable areas for wells, roads, and other construction activity.

D.Noise pollution

In the development stage of a geothermal project, noise is generated during road construction, excavation for drilling sites, well drilling and well testing. These sounds are of limited duration. During normal plant operations, transformers, generators, water cooling towers, motors, pumps and fans, brine and steam flowing through the pipes, may be heat sources.
The highest noise levels occur during the drilling and testing of the wells. Noise levels can reach 114 decibels.

E.Disturbance of natural hydrothermal manifestations

The drawdown or lowering of the hydrostatic water level from production wells perturbs the natural thermohydraulic balance that gives rise to surface manifestations like hot springs, mud pots or geysers. This effect can destroy such manifestations but it can also create or enhance such manifestations. This occurred in Wairakei where geothermal development increased the boiling of hot springs at several sites and created or enhanced others.

7. Geothermal energy in the future

Geopressured systems have been found in regions that are usually associated with oil and gas fields. They are attractive as a potential geothermal resource because they have temperatures suitable for power generation using binary plants. They appear in regions where industrial demand for power is high, as in the oil and gas industry. Sometimes, such areas are also near major electric load centers, thus making them potential resources for municipal power.
There are, however, significant challenges that must be overcome before this resource can be economically utilized. One significant factor is related to the salinity of these fluids sometimes as high as 200,000 mg/l. They often contain significant concentrations of CO_2. These solutes must be removed before the fluid enters the turbine and undergoes a reduction in temperature and pressure. This is required because the dissolved load will precipitate on the turbine blades. Additionally, the complex chemical properties of these solutions affect the amount of heat in the solution that is available to do work. This results from the fact that dissolution of many of the compounds that makeup the dissolved load requires energy. For example, if one mole of NaCl, a common salt, is added to a kilogram of water at 25ºC,approximately 3836 joules of heat must be added to the water to keep the temperature at 25ºC. However, the heat of solution varies with the amount of salt added. This fact can be very complicated because geothermal solutions contain many different solutes, each with their heat of solution.

8 Conclusion

The use of geothermal energy has increased in the recent years. According to the IGA, there are 233 geothermal plants planned for the coming years. The installed capacity associated with these plants is 8925.8 MW. Geothermal reservoirs associated with hydrothermal resources are currently being explored, but other types of reservoir whose exploration requires the solution of several technical problems (Hot Dry Rock, Enhanced Geothermal systems, Geopressured resources) are under study. Another field of study is related to the increase of geothermal plant performance and to the solution of environmental problems associated with geothermal plants.

References

[1]**http://vmigg.iit.cnr.it/SpagoBI/servlet** **retrieved 14.10.2011**

[2] J.W.Lund, D.H. Freeston, T.L. Boyd, " Direct Application of Geothermal Energy: 2005 Worldwide Review", Geothermics, vol 34,(2005) pp691-727.

[3]H.Gupta, S. Roy, Geothermal Energy. An alternative resource for the 21st century, Elsevier, Amsterdam (2007),pp 49-59.

[4]W.E. Glassley, Geothermal Energy. Renewable Energy and the Environment, CRC Press, Boca Raton, pp:263-274.

[5]R. DiPippo,Geothermal Power Plants. Principles, Applications, Case Studies and Environmental Impact, Elsevier,Oxford (2008),pp 81-184.