GEOTHERMAL ENERGY

Octavian BOLOGA[1], Mihai CRENGANIS[2]
[1]Full Member of the Academy of Technical Sciences in Romania
[2]Engineering Faculty of Sibiu

Rezumat. Populația lumii consumă o cantitate neconceput de mare de energie. Sursa principală de energie electrică rămâne arderea combustibililor fosili, care are o contribuție majoră la producerea de gaze cu efect de seră. Găsirea surselor regenerabile de energie și a soluțiilor de eficiență energetică sunt cheia pentru un viitor durabil. În acest fel energia geotermală poate juca un rol important, datorită faptului că poate satisface nevoile actuale ale societății, fără a compromite mediul și resursele energetice ale generațiilor viitoare. Lucrarea de față prezintă avantajele energiei geotermale și tipurile de centrale geotermale existente în zilele noastre. În prezent, există trei tipuri de centrale: dry steam, flash steam și binary cycle. Primul tip de centrală utilizează ca materie primă aburul, al doilea apa și al treilea căldura. Acestea sunt diferite constructiv, dar oarecum înrudite ca procedură; ele pun în mişcare turbine care, la rândul lor, generează electricitate. Tipurile de centrale geotermale utilizate în prezent maximizează producția de electricitate, dar cu un impact minim asupra mediului înconjurător.

Cuvinte cheie: energie geotermală, abur uscat, centrală cu vaporizație, schimbător de căldură.

Abstract: The world population consumes an inconceivable amount of energy. The primary source of electricity remains the burning of fossil fuels which have a major contribution to greenhouse gases. Finding renewable sources of energy and solutions for energy efficiency are the key to sustainable future. This is where geothermal energy can play an important role, due to the fact that it can meet the present needs of society without compromising the environmental and energetic future of the next generations. The present paper concentrates on the advantages of geothermal energy and on the types of geothermal power plants existent nowadays. There are currently three types of plants: dry steam, flash steam and binary cycle. The first type of plant makes use of the steam, the second of the water and the third of the heat. These are different but somewhat related procedures which power turbines, which in turn generate electricity. The used methods maximize production with minimum environmental impact.

Keywords: geothermal energy, dry steam, flash steam, binary cycle.

1. THE CONCEPT OF GEOTHERMAL ENERGY

Our planet consists of a crust, which reaches a thickness of about 20-65 km in continental areas and about 5-6 km in oceanic areas, a mantle, which is roughly 2900 km thick, and a core, about 3470 km in radius. The physical and chemical characteristics of the crust, mantle and core vary from the surface of the Earth to its center. Earth's temperature increases gradually with depth, at the center reaching more than 4.200°C (7600°F).

As heat naturally moves from hotter to cooler regions, so Earth's heat flows along a *geothermal gradient* from the center to the surface, where an estimated 42 million thermal megawatts (MWt) are continually radiated into space. The amount of heat supply cannot be practically captured, because it arrives at the surface at a too low temperature. Fortunately, the fundamental geologic process known as *plate tectonics* (responsible for seismicity, mountain building, and volcanism) ensures that some of this heat is concentrated at temperatures and depths favorable for its commercial extraction [2, 3, 14, 15].

Geothermal systems can therefore be found in regions with a normal or slightly above normal geothermal gradient, and especially in regions around plate margins where the geothermal gradients may be significantly higher than the average value.

A geothermal system is made up of three main elements: a *heat source*, a *reservoir* and a *fluid*, which is the carrier that transfers the heat. *The heat source* can be either a very high temperature (> 600 °C) magmatic intrusion that has reached relatively shallow depths (5-10 km) or, as in certain low-temperature systems, the Earth's normal temperature. *The reservoir* is a volume of hot permeable rocks from which the circulating fluids extract heat. The reservoir is generally overlain by a cover of impermeable rocks and connected to a recharge area through which the meteoric waters can replace or partly replace the fluids that escape from the reservoir through springs or are extracted by boreholes. *The geothermal fluid* is water, in the majority of cases meteoric water, in the liquid or vapor phase, depending on its temperature and pressure. This water often carries with it chemicals and gases such as CO_2, H_2S etc. Figure 1 shows a simplified representation of an ideal geothermal system [16].

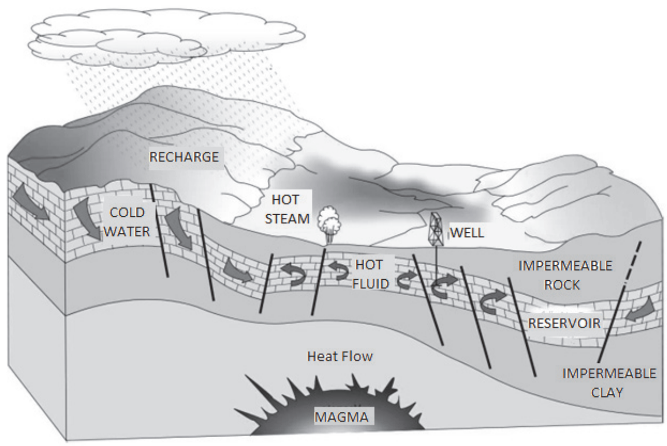

Fig. 1: Schematic representation of an ideal geothermal system.

The mechanism underlying geothermal systems is governed by *fluid convection*. Convection occurs because of the heating and consequent thermal expansion of fluids in a gravity field; heat, which is supplied at the base of the circulation system, is the energy that drives the system. Heated fluid of lower density tends to rise and to be replaced by colder fluid of high density, coming from the margins of the system. Of all the elements of a geothermal system, the heat source is the only one that has to be natural. Providing conditions are favorable, the other two elements could be 'artificial' [3, 7, 9].

Geothermal resources are classified based on the enthalpy of the geothermal fluids that act as the carrier transporting heat from the deep hot rocks to the surface [1, 3, 10].

The determination of the resource type is necessary in order to establish the adequate technology for its exploitation.

2. GEOTHERMAL ENERGY ADVANTAGES

Geothermal Energy is *clean.* Other forms of renewable energy impact the environment on some level by generating waste either directly or indirectly. During extraction there is no burning of fossil fuels because plants are powered by steam. From flash steam plants raise vapor emissions, not smoke. Binary plants release zero emissions. Everything that is brought to the surface is injected back into the ground to be used again.

Table 1

Classification of geothermal resources (°C)

	(a)	(b)	(c)	(d)	(e)
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

Source: (a) Muffler and Cataldi (1978).
(b) Hochstein (1990).
(c) Benderitter and Cormy (1990).
(d) Nicholson (1993).
(e) Axelsson and Gunnlaugsson (2000)

Geothermal energy is incredibly *reliable*. The Earth provides a constant source of heat, power production can vary depending upon the available hydrothermal resources but a typical geothermal plant operates at 95 percent to 99 percent operating availability. This means that in comparison with a coal plant which operates at 75 percent of operating ability the geothermal power plant can produce a steady stream of power with little or no interruptions. Wind turbines are dependent on wind, photovoltaic modules on sun. No wind or a cloudy day can mean no energy.

Geothermal energy has *many uses*. It is used to heat water for winter crops, to heat and humidify greenhouses, to dehydrate food, to heat homes, swimming pools and commercial buildings. Communities use it to melt snow and ice on sidewalks and roads.

3. GEOTHERMAL ENERGY TECHNOLOGY

The three types of commercial geothermal power plants are dry steam plants that use resources of pure steam, flash steam and binary cycle plants that tap reservoirs of hot water [3, 7, 8, 9].

3.1. Direct Steam Plants

Direct Steam Plants are used at vapor dominated (or dry steam) reservoirs. This type of geothermal power plant is very effective and it was first used at Lardarello in Italy in 1904. However this technology for utilizing geothermal energy is limited because dry-steam hydrothermal resources are extremely rare. For example, the Geysers, in northern California, are the only dry steam field in the United States. Dry, saturated or slightly superheated steam is produced from wells. The steam carries non-condensable gases of variable concentration and composition. Steam from several wells is transmitted by pipeline to the powerhouse where it is used directly in turbines of the impulse/reaction type. The turbine drives a generator that produces electricity [11, 12, 13].

The used turbines are either exhaust turbines or condensing steam turbines. Atmospheric exhaust steam turbines are the simplest and the most cost effective of all geothermal cycles. The obtained geothermal steam either directly from dry steam wells, or after flash separation from wet wells, is inserted through a conventional axial flow steam turbine which exhausts directly to the atmosphere.

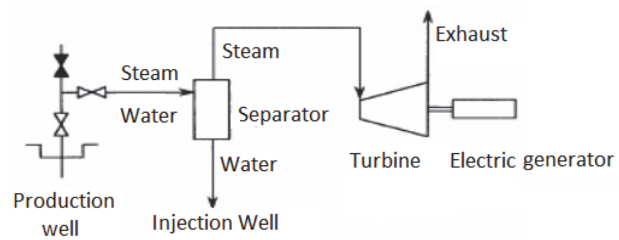

Fig. 2. Direct steam plants schematic.

Condensing steam turbine plants instead of discharging steam from the turbine to atmosphere, it is discharged to a condensing chamber. This chamber is maintained at a very low absolute pressure, typically 0.12 bar. Due to the greater pressure drop across a condensing turbine much more power is generated from a given steam flow, at typical input conditions, compared with an atmospheric exhaust turbine.

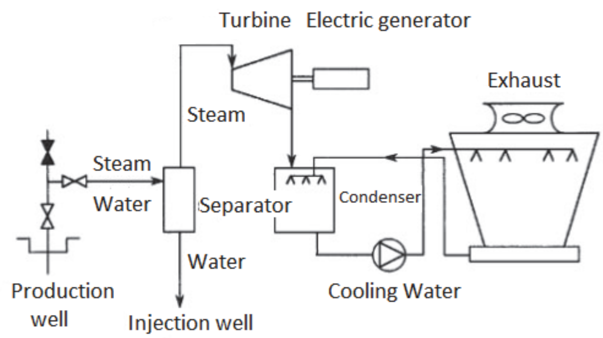

Fig. 3. Direct steam with condenser plants schematic.

3.2. Flash Steam Plants

A lot of systems are dominated by hot water with temperatures in the range 150-300°C (300-700°F). For these systems, flash-steam power plants are most suited for harvesting the energy. The geothermal fluids are brought to the surface through production wells located at 4-5 km depth. At these depths, the hot waters are highly pressurized. Through the transfer to the power plant the pressure is reduced and 30% - 40% of the water *flashes* (explosively boils) to steam. The steam is separated from the remaining hot water and is delivered to a turbine to produce electricity. The residual water is returned to the reservoir through injection wells to help maintain pressure and lengthen productivity [11, 12, 13].

Hydrothermal fluids above 182°C can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or „flash”. The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank to extract even more energy.

Flash power plants can be categorized in single flash and multiple flash plants. The use of one or the other technology depends upon the temperature of the resource and other reservoir characteristics.

In a single flash plant the liquid dominated brine steam mixture will be flashed in a separator before the dried steam will be fed to the condensing steam turbine. Condensing cycles have more auxiliary equipment compared to atmospheric exhaust units. This significantly increases the costs of the total plant as well as construction and installation time. Furthermore, the presence of non-condensable gases in the geothermal steam, which accumulate in the condenser, requires the installation of a gas extraction system, which will in smaller quantities emit NO_2 and CO_2 (compared to a fossil fired power plant these are very small quantities).

Multi-flash systems are similar to the single-flash apart from additional flash tanks for the production of further steam from the hot water coming from the separator. The steam produced during the first flash stage is sent to the first stage of the turbine, while the steam produced from the following flashes is admitted in intermediate turbine stages. The decision regarding the use of a multiple flash system is a simple economic one. Investors must balance the increased generation against the increased capital cost of the additional flash separation plant [11, 12, 13].

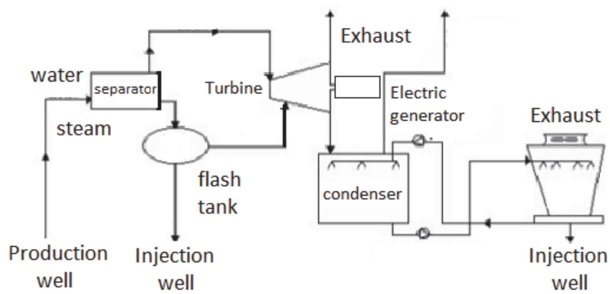

Fig. 4. Flash steam plants schematic.

Dual-flash plants differ from single-flash plants in that they capture the earliest and hottest spent steam (i.e., condensate) and then allow it to flash in a different part of the generator. This process allows extra energy to be extracted from the steam that would otherwise have been lost. Dual-flash systems require a series of turbines specifically designed to operate within relatively narrow pressure and temperature intervals, and they are highly efficient.

3.3. Binary Plants

For reservoirs with lower temperatures between 100°C up to 150°C, binary-cycle power plants are the favored systems. These are called binary because of the two different kinds of fluids – a geothermal resource as a heating source which evaporates a low boiling point and a fluid which drives a turbine.

Geothermal waters are passed through a heat exchanger to heat the secondary working fluid (for example, isopentane) that vaporizes at a lower temperature than water [11, 12, 13]. The working fluid vapor spins the power producing turbine, and then is condensed back to liquid before being re-vaporized at the heat exchanger. The heat-depleted geothermal water exiting the binary plant is injected back into the reservoir. This type of geothermal plant has superior environmental characteristics compared to the others because the hot water (which tends to contain dissolved salts and minerals) is never exposed to the atmosphere before it is injected back into the reservoir.

The most common geothermal resource has a moderate temperature between 75 °C and 180 °C. Dry steam or flash steam plants were not been able to exploit this low and medium temperature resource. The first binary cycle on ORC technology was already prototyped in 1961, the first binary cycle on Kalina technology in 1967. These demonstration projects were a breakthrough as they allowed the use of much lower temperature geothermal fields that were previously unrecoverable [11, 12, 13].

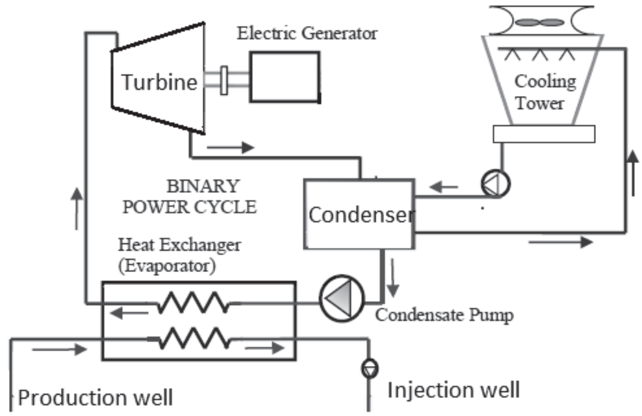

Fig. 5. Simplified flow diagram for a binary cycle geothermal power plant.

Conducted as a cogeneration plant with cascade use of the geothermal resource the binary plant is also able to use the geothermal resource for direct uses like heat production, greenhouses, spa, drinking water, spirulina growing, etc. This cascade use of energy leads to an efficient exploitation of the geothermal source. For binary plants two different systems currently are state of the art, the Organic Rankine Cycle (ORC) and the Kalina Cycle: An ORC uses an organic, high molecular one component mass fluid with a liquid-vapor boiling point, occurring at a lower temperature than the water-steam phase change. The working fluid in a Rankine Cycle is in a closed loop and is circulated and re-used constantly. Lowest possible temperature for ORC heat recovery is about 95 °C. With the pilot developed within the Low-Bin project, this temperature was lowered in 78°C. The Kalina Cycle, invented by the Russian engineer Alexander Kalina and firstly demonstrated in 1967 in Paratunka, Kamchatka, Russia, is a thermodynamic cycle for converting thermal energy to mechanical power, optimized for use with low to medium temperature geothermal sources. The cycle uses a two component working fluid and a ratio between those components is varied in different parts of the system to increase thermodynamic reversibility and therefore increase overall thermodynamic efficiency. Multiple variants of Kalina cycle systems are specifically applicable for different types of heat sources.

The two systems differ especially in the used working fluid. As ORC uses a one component mass fluid, mostly butane or pentane hydrocarbon, the Kalina cycle uses a working fluid with at least two components (typically water and ammonia) that makes it possible to adjust the ratio between the two components in order to increase the thermodynamic efficiency of the Kalina system. The Kalina system shows higher efficiency in the use of the geothermal resource.

4. CASE STUDIES

The Geysers is the largest complex of geothermal power plants in the world and is located north of San Francisco in the Macayamas Mountain. Here the magma is believed to exist at least 6.4 km below the earth’s surface. The heat radiates to the layers of rock heating the water. Part of the heated water rises to the surface creating geysers and hot springs. A plant at The Geysers consists in a steam turbine, a generator, a condenser, cooling tower, gas removal system and a hydrogen sulphide abatement system. Pressurized steam flows from wells, enters through the turbine, expands and is converted into mechanical energy. The generator converts then the mechanical energy into electrical.

The Geysers complex consists in 15 operating geothermal plants, with 335 steam wells and 53 injection wells. The complex generated in 2012 approximately 6.1 million net megawatt hours, amount which satisfies nearly 60% of the electricity demand in the North Coast region of the US.

Due to the accelerated development and rising needs, by 1989 the steam pressure in the reservoir had decreased. This threatened the sustainability of the power generation. The Geysers needed therefore a reliable water supply to sustain the reservoir pressure and the steam production. The solution was the injection of wastewater from Lake County and City of Santa Rosa. The approximately 7 million liters of wastewater sustain the production of the original reservoir and contributes to a sustainable power generation.

In Romania over 200 wells were drilled in the 70s, mostly to search for oil resources. The drilling has revealed there was no oil but geothermal resources. The exploration from the last 15 years has led an estimation of the heat resources to about 200,000 TJ of heat for a period of 20 years. The capacity of the existing operating wells is about 320 thermal MW, of which only about 137 thermal MW are currently used and provided by 60 wells which produce geothermal water with temperatures between 55-115 ° C.

Most geothermal reservoirs are located in the western part of Romania, namely in the eastern part of the Pannonian Basin.

One of the biggest is the Pannonian geothermal aquifer, located between 800 – 2,100 m depth, located on an area of approximately 2.500 km^2 from Satu Mare to Timişoara. Geothermal potential has been exploited by 80 wells of which 37 wells are currently operated. The fluid surface temperature varies between 50 and 85 ° C and natural gradient is between 45-55 °C/km. The energy provided by these probes is used to heat greenhouses in an area of 34 ha, to heat almost 2,460 apartments, to create hot water for 2,200 apartments and for various processes such as drying grain, wood.

Another geothermal aquifer of great importance is in Oradea. The installed capacity is currently of about 30 MWt through 11 artesian production wells and one injection well. The geothermal energy is used for heating the district campus, about 2,000 apartments, creating hot water for 4,000 apartments, pasteurization of 80.000 l milk / day and drying 5.000 m^3 of wood.

5. CONCLUSIONS

As a result from the above presented examples, in Romania the existing energetic geothermal potential makes possible the realization of new projects for electricity generation, heat production and its use in applications such as, heating of greenhouses and livestock farms, aquaculture, fish farming, drying wood, grain, heating swimming pools etc.

However the costs of projects that are based on geothermal resources are relatively high and discourage potential investors. The cost of such projects depends on temperature and pressure of the geothermal deposit, the depth and permeability of the reservoir; it also depends on fluid chemistry and the type of technology used. For example, capital costs for a "flash plant" is between 2000-4000 USD / kW. 10-15% of this amount are the costs of exploration, 20-35 % represents the drilling costs, 10-20 % the surface facilities costs and 40-60% the costs of the geothermal plant.

Although investment in geothermal projects is high, sustainability and profitability are very high also so that the investment effort is worth doing. Compared to other renewable energy sources, geothermal energy capacity factor is 98 % as opposed to wind power whose capacity factor is below 35% and in the case of photovoltaic around 25 %.

Bibliography

[1] Chandrasekharam, D., Bundschuh, J., *Low-enthalpy geothermal resources for power generation*, CRC Press Taylor & Francis Group, New York, 2008.
[2] Dickson, M. H., Fanelli, M., *Geothermal energy: utilization and technology*, Earthscan, an imprint of James & James (Science Publishers) Ltd. in Association with the International Institute for Environment and Development, 2005.
[3] DiPippo, R., *International Development in Geothermal Power Production*, Geothermal Resource Council Bulletin, 1988.
[4] Frick, S., Kaltschmitt, M., Schröder, G., *Life cycle assessment of geothermal binary power plants using enhanced low-temperature reservoirs*, Energy, Elsevier, 2010.
[5] Galanis, N., Cayer, E., Roy, P., Denis, E. S., Desilets, M., *Electricity generation from low temperature sources*, Journal of Applied Fluid Mechanics, 2009.
[6] Grasby, S. E., Allen, D. M., *Geothermal energy resource potential of Canada*, Geological Survey of Canada, Open File 6914.
[7] Gupta, H., Roy, S., *Geothermal energy: an alternative resource for the 21st century*, Elsevier, New York, 2010.
[8] Kestin, J., *Sourcebook on the Production of Electricity from Geothermal Energy*, United States Department of Energy, 1980.
[9] Lund, J., W., *Characteristics, development and utilization of geothermal resources*, Geo-Heat Center, Oregon Institute of Technology, GHC bulletin, 2007.
[10] Shulman, G., *Low temperature flashed steam power generation*, Geothermal Power Company, Inc., New York.
[11] ***http://energyinformative.org. Energy informative. How enhanced geothermal systems (EGS) work.
[12] ***http://www.geo-energy.org Geothermal Energy Association, GEA, Geothermal: International market overview report.
[13] *** http://www1.eere.energy.gov/geothermal/powerplants.html U.S. Department of Energy, Energy Efficiency & Renewable Energy, Geothermal Technologies Office.
[14] ***www.iea.org Renewable Energy Essentials: Geothermal, International Energy Agency, OECD, 2010.
[15] *** http://egi.utah.edu/research/geothermal/ Energy & Geoscience Institute, University of Utah.
[16] *** www.rise.org.au .