KORIŠĆENJE OBNOVLJIVIH IZVORA – PRETVARANJE GEOTERMALNE ENERGIJE U ELEKTRIČNU

UTILIZING RENEWABLE RESOURCES – CONVERTING GEOTHERMAL ENERGY TO ELECTRICITY

Miljan VLAHOVIĆ[1], Milica VLAHOVIĆ[1,2], Zoran STEVIĆ[3],
[1] Public Company Nuclear Facilities of Serbia, Belgrade, Serbia
[2] University of Belgrade, Institute of Chemistry, Technology and Metallurgy, Belgrade, Serbia,
[3] University of Belgrade, Faculty of Electrical Engineering, Technical Faculty Bor, CIK Belgrade, Serbia

https://doi.org/10.24094/mkoiee.020.8.1.101

Prema zvaničnoj definiciji, koju je odobrilo Evropski savet za geotermalnu energiju (European Geothermal Energy Council- EGEC), geotermalna energija je energija akumulirana kao toplota ispod površine čvrstog tla. Geotermalna energija je toplotna energija koja se generiše i skladišti u Zemlji. Generalno se definiše kao deo geotermalne toplote koji se može direktno koristiti kao toplota ili pretvoriti u druge oblike energije. Geotermalni resursi se razlikuju u zavisnosti od lokacije i dubine u odnosu na jezgro Zemlje. Njihova primena moguća je za različite svrhe u zavisnosti od njihove temperature. Ovaj rad prikazuje upotrebu geotermalnih resursa za proizvodnju električne energije. Postoje tri osnovna principa rada geotermalnih elektrana: suva para (dry steam), separisanje pare (flash steam) i binarni (binary cycle). Postrojenja na suvu paru izbacuju vruću paru iz unutrašnjosti Zemlje u turbine, a ona napaja generator koji daje električnu energiju. Postrojenja sa separisanjem pare pumpaju toplu vodu iz iz unutrašnjosti Zemlje u hladniji rezervoar. Nastala para pokreće generator električne energije. Postrojenja sa binarnim ciklusom pumpaju toplu vodu iz unutrašnjosti Zemlje kroz izmjenjivač toplote čime se greje drugi fluid i pretvara u paru koja pokreće generator. U svim pomenutim sistemima korišćeni fluidi se recikliraju. Može se zaključiti da geotermalne elektrane rade slično kao i druge elektrane, ali paru za pokretanje turbine obezbeđuju iz unutrašnjosti Zemlje. Činjenica da se korišćeni fluidi vraćaju u zemlju čini geotermalne izvore energije obnovljivim.

Ključne reči: *geotermalna energija; električna energija; geotermalna elektrana; obnovljivi izvori*

Abstract. According to the official definition, approved by the European Geothermal Energy Council (EGEC), geothermal energy is energy accumulated as heat below the surface of solid soil. Geothermal energy is thermal energy generated and stored in the Earth. It is generally defined as the part of geothermal heat that can be directly utilized as heat or converted into other types of energy. Geothermal resources vary by location and depth towards the Earth's core. Their use is possible for different purposes depending on their temperature. This paper presents the harnessing geothermal resources for electricity generation. There are three main types of geothermal power plants: dry steam plants, flash steam plants, and binary cycle plants. Dry steam plants pipe hot steam from underground into turbines, which powers the generator to provide electricity. Flash steam plants pump hot water from underground into a cooler flash tank. The formed steam powers the electricity generator. Binary cycle plants pump hot water from underground through a heat exchanger that heats a second liquid to transform it into steam, which powers the generator. In all mentioned systems the used fluids are recycled. It can be concluded that geothermal power plants work similarly to other power plants, but providing the steam for starting the turbine from the earth's interior. The fact that used fluids return to the ground makes geothermal energy resources renewable.

Key words: *geothermal energy; electricity; geothermal power plant; renewable resources*

[1] Corresponding author, email: mvlahovic@tmf.bg.ac.rs

1 What is geothermal energy

Geothermal energy is the natural heat of the Earth, accumulated in fluids and rock mass, which is estimated to be 5500 °C or even up to 7000 °C in the core. This heat is derived from the original formation of the planet (by exothermic chemical reactions in the Earth's crust such as oxidation of sulfides, by crystallization and hardening of molten rocks, as well as by friction during the movement of tectonic masses) and from the decay of the radioactive elements in the Earth's crust. It is transferred to the subsurface by conduction and convection. The rate of temperature increases with depth, which is called geothermal gradient [1].

In nature, geothermal energy most often appears in the form of geysers, volcanoes and hot springs.

People learnt to use different temperatures and apply them for various purposes. For centuries, geothermal springs have been used for bathing, heating and cooking.

Since ancient times geothermal resources have played a significant role in human societies. Probably the most ancient one is the use of the geothermal hot springs. Nothing can compare to thermal bathing and geothermal waters have been long known for their healing properties. The use of thermal waters dates straight back to 3000 BC when the Indus Valley civilizations used natural hot and mineral springs.

Geothermal waters are highly beneficial, especially for improving health and well-being, treat arthritis, skin diseases, and high blood pressure. Thermal waters contain a lot of minerals. Nowadays, a lot of wellness centers offer a variety of geothermal by-products such as soaps, shampoos, bath powders and facial cremes with thermal water.

In the early 20th century people started to consider the heat from inside the Earth as a practical source of energy with huge potential. Geothermal energy is now used to produce electricity, to heat and cool buildings as well as for other industrial purposes like grain and lumber drying, pulp and paper processing, fruit and vegetable cultivation, soil warming and many others.

Geothermal energy history is presented in Figure 1.

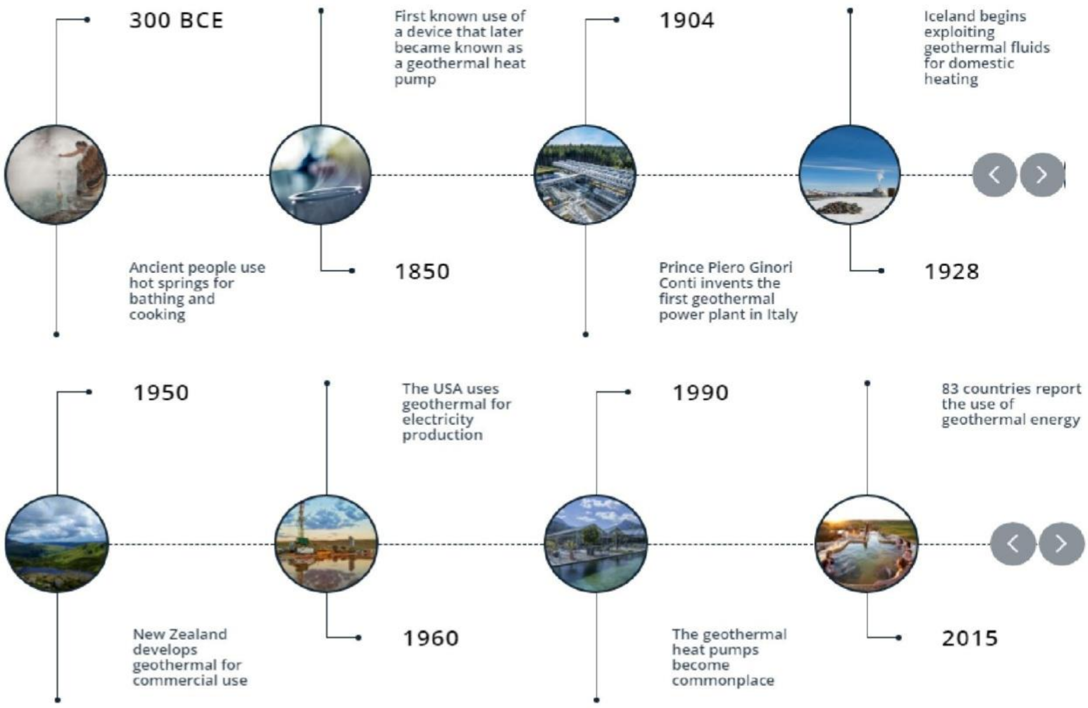

Figure 1. Geothermal energy history [2].

Geothermal energy has become established as a reliable and environmentally friendly source of power. High availability and load factors with no dependence on outer sources make geothermal energy one of the key resources in a sustainable energy future. Only a small fraction of the world's geothermal potential has been developed so far, which leaves possibility for growth and development in both electricity and direct use sectors [1].

2 How much geothermal energy is available

Only several kilometres under the Earth's surface temperatures can exceed 250 °C and it increases by 1 °C for every 30-50 metres of depth, pointing to the conclusion that the Earth's geothermal potentials are immense. The estimated stored thermal energy down to 3 km within the continental crust is roughly 43x106 EJ, and that's why geothermal energy is treated as a renewable energy source, and is as such suitable for use in various sectors in an environmentally-friendly manner (World Energy Council, 2016). The main advantage of geothermal energy is its easy use with relatively simple and low-cost technology. However, when it comes to geothermal rock energy, today's technology is limited to a drilling depth of up to 10 km, and therefore exploitation to these depths is possible. Modern technological solutions enable simple and cost-effective use of low-temperature energy sources and, in that context, the European Union redefined the term of geothermal energy as "energy stored in the form of heat beneath the surface of solid earth" under the Directive on renewable energy sources [3].

Hydrogeothermal resources are technically much more usable and cost-effective, although there are fewer of them. If the possibility of using this energy to a depth of 3 km is considered, its global reserves are 2,000 times larger than coal reserves.

In order to assess whether a certain area meets the conditions for the exploitation of geothermal energy, it is necessary to determine the proximity and temperature of the hot mass in relation to the earth's surface. Hot water and steam can be delivered to the surface and used regardless of whether their reservoirs are located in shallow surface layers or at a depth of several kilometers, and the choice of exploitation technology as well as application of the obtained energy primarily depends on the deposit temperature. However, it is most practical to use this energy in areas where the hot mass is close to the earth's surface [4].

Geothermal potential is the amount of energy that can be utilized from a geothermal energy. The potential of geothermal energy in the world is huge, 50000 times greater than the energy that can be obtained from oil and gas.

The geothermal energy of the Earth can be estimated at 12.6×10^{24} MJ, and of the crust at 5.4×10^{21} MJ, which is almost 35 billion times more than today's energy needs, but only a small part of this potential can be used efficiently (only to a depth of 5000 m) [5].

2.1 Geothermal potential of Serbia

Geothermal resources in the Republic of Serbia are divided as follows:

- Classification of geothermal energy according to location in the Earth's crust where it is accumulated and exploited:
- Hydro-geothermal energy (accumulated in water),
- Petro-geothermal energy (accumulated in solid rock mass),
- Aero-geothermal energy (accumulated in gases), and
- Magma-geothermal energy (accumulated in magma).

- Classification of hydro-geothermal resources according to fluid temperature:
- Low enthalpy resources – fluid temperature <100 °C,
- Medium enthalpy resources – fluid temperature 100-200 °C, and
- High enthalpy resources – fluid temperature >200 °C.

All geothermal phenomena identified in Serbia so far are low enthalpy geothermal resources, with fluid temperature below 100 °C.

Geothermal resources of the Republic of Serbia are quantified according to the following subgroups:

- Subgeothermal resources of temperature of up to 30°C (sub-hydro-geothermal and sub-petro-geothermal resources),
- Geothermal resources in the strict sense, of temperature between 30°C and 100°C,
- Geothermal resources of temperature over 100°C (hydro-geothermal resources and hot dry rock energy - HDR) [6].

According to available data, Serbia has 360 springs of thermal and thermo-mineral waters with a temperature of 14 to 98 °C. With the amount of geothermal heat- heat that erupts on the Earth's surface, calculated per m^2 per second, which averages 100 MW/m^2, Serbia exerts with significant hydrogeological and geothermal resources compared to the average values in Europe of 60 MW/m^2. However, although experts state that the total amount of heat of geothermal resources in Serbia is about twice greater than the heat that would be generated from domestic coal reserves, this potential has not been exploited at all. Water from geothermal springs or wells is mainly used for therapeutic purposes in numerous thermal spas and sports and recreation centers, although in an irrational and inefficient way. On the contrary, in Iceland and El Salvador, more than 25 % of total electricity is produced in geothermal plants, and many other countries are increasingly taking advantage of this energy source (USA, Italy, Germany, France, New Zealand, Mexico, Nicaragua, Costa Rica, Russia, Philippines, Indonesia, China, Japan) [7].

Figure 2 presents hot water flowing artesian well in Jošanička Banja spa.

Figure 2. Hot water flowing artesian well in Jošanička Banja spa of temperature of 78 °C [6].

3 Utilizing geothermal resources

There is a natural source of power found below the surface of the earth that has been around for centuries. Underground, far below, there are pools of water, geothermal reservoirs, heated by magma (or molten rocks). Water or steam can escape from cracks in the earth in the form of geysers or (or sometimes as magma from a volcano). Harnessing the power of the earth’s temperatures to power, heat or cool homes and businesses is the essence of geothermal power.

Geothermal power does not require the burning of any fossil fuels. The hot water or steam used is returned to the ground after it is used where it can be used again, which makes it a renewable energy source as well [8].

The use of geothermal resources is possible for various purposes.

Modern conversion technologies enable the use of geothermal resources in electricity generation, district heating in cities, at industrial plants, for the heating of buildings, sports and recreation facilities and spa resorts, in family homes and in agriculture.

High-temperature geothermal sources (>150 °C) are suitable for electricity generation. Medium and low temperatures of resources (<150 °C) are suitable for various applications (in balneotherapy, agriculture, industry, tourism etc), while resources with temperatures below 20 °C are used with heat pumps (Figure 3) [6].

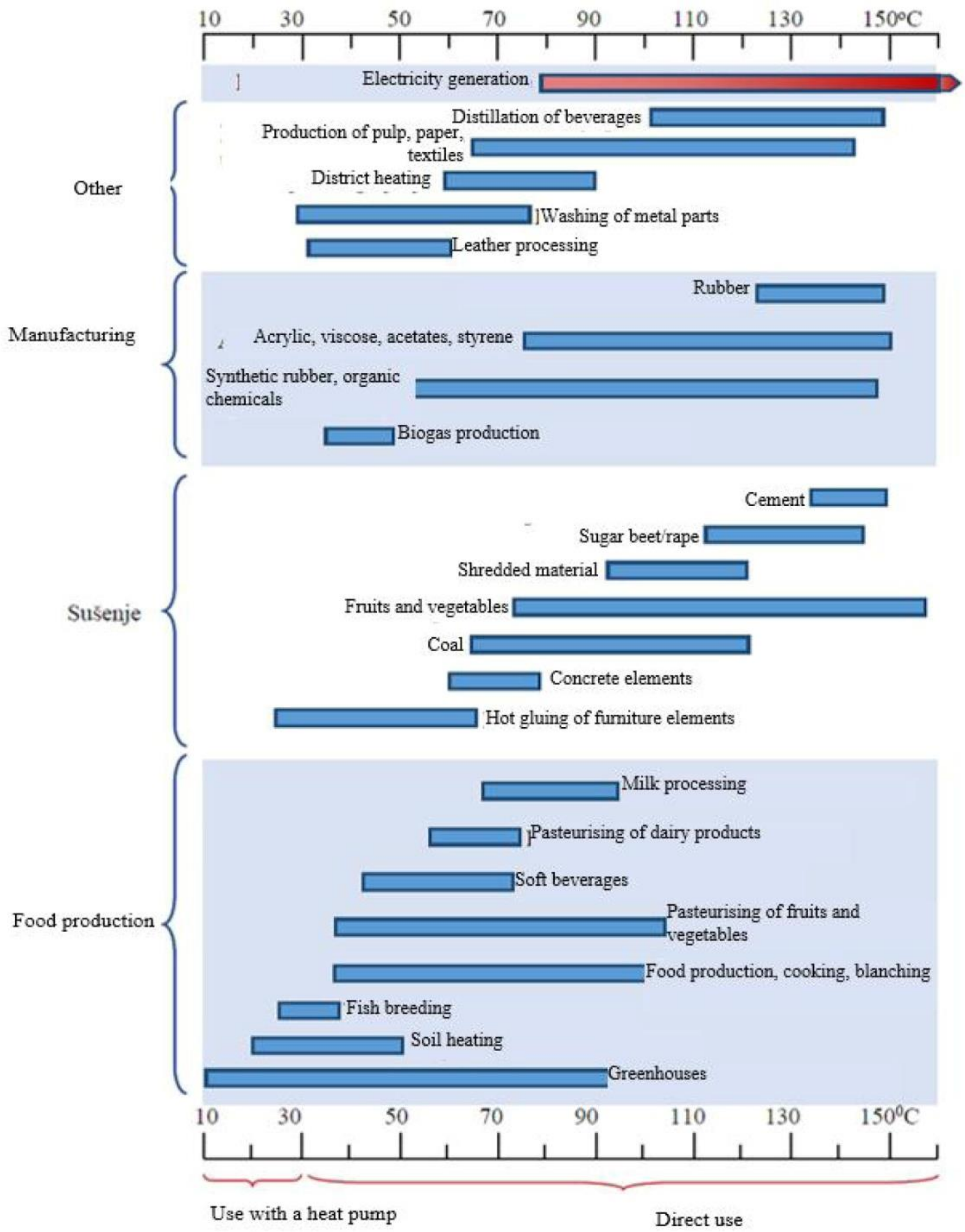

Figure 3. Use of geothermal resources [6].

There are also numerous classifications of these resources in relation to usability. One of the basic classifications divides geothermal resources according to the possibility of utilization depending on the temperature into two groups [9]:

- Geothermal resources for electricity generation;
- Geothermal resources for thermal energy production.

The most important way of using geothermal energy is the production of electricity whereby hot water and steam from the Earth are used to power the generator, which means that there is no burning of fossil fuels and subsequently no emission of harmful gases into the atmosphere, only water vapor is released. Also, an advantage is that such power plants can be implemented in a variety of natural environments.

4 Geothermal resources for electricity generation- geothermal power plants

By the end of the 19th Century, Prince Piero Conti conceived an idea to harness the natural steam of the Larderello geothermal field in Italy to produce electric energy; he started technical experiments in 1903, and a year later, the first geothermal-electric energy that lighted five 5-watts-lamps was produced.

In 1913, Conti put in commercial operation a power plant of 250 kW fed by pure steam, and in 1916 two power units of 3.5 MW each. This is how geothermal power production was born [2].

There are currently geothermal plants in over 80 countries according to the Geothermal Energy Association and although the United States is currently the global leader of geothermal power, other countries like Indonesia, Turkey and Kenya are all in the process of expanding their power capacities as well. The first geothermal plant in the United States was built in 1960 at an area called The Geysers, in the Mayacamas Mountains north of San Francisco. Today, California is the world's largest geothermal field with 22 geothermal power plants, known as The Geysers Complex.

Geothermal power plants function in a similar way as any other power plant, with the difference that the steam needed to start the steam turbine is obtained from the earth's interior. Existing power plant technologies enable generation of electricity either directly from high temperature steam, from steam-water mixtures, or from geothermal water with intermediate temperature. After passing through the turbines, the steam goes to the condenser, turns into a liquid state, and returns to the underground or is further cascaded.

There are different ways to get electricity from geothermal resources. The method that will be chosen in the construction of the geothermal power plant in the certain region depends on the characteristics of the geothermal energy source- temperature, depth and quality of water and steam. In all cases, the condensed steam is returned to the well, which increases the abundance of the geothermal source.

Three main types of geothermal energy plants that generate power in slightly different ways are as follows:

- Geothermal power plants with dry steam,
- Geothermal power plants with flash steam, and
- Geothermal power plants with binary cycle.

Geothermal power plants with dry steam

This is the simplest and oldest system, and at the same time the cheapest, applied for the first time in Lardarello, Italy. Fluids above 220 °C are used. Dry steam geothermal power plants are the most common types of geothermal power plants, accounting for about half of the installed geothermal plants. This direct method works by piping hot steam from underground reservoirs into turbines from geothermal reservoirs, which powers the generators to provide electricity. After powering the turbines, the steam condenses into water and is piped back into the earth via the injection well.

Schematic presentation of a dry steam geothermal power plant is given in Figure 4 and photograph of one of 22 dry steam geothermal power plants in the Geysers (Northern California) is shown in Figure 5.

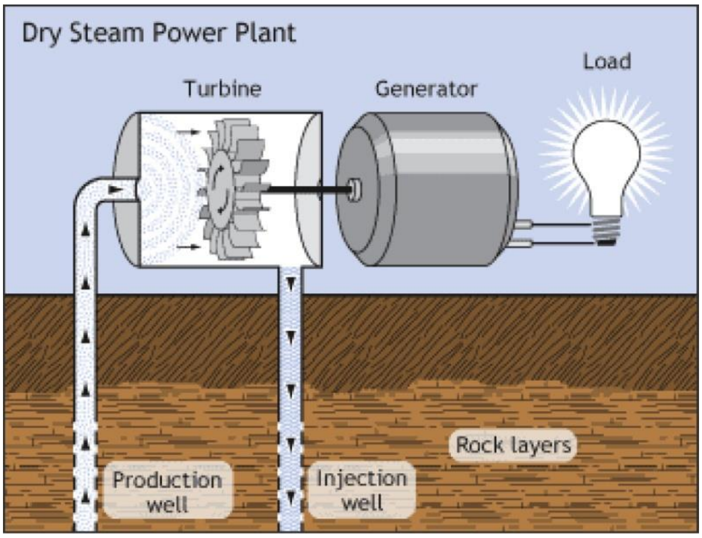

Figure 4. Dry steam geothermal power plant [10].

Figure 5. Dry steam geothermal power plant, The Geysers, California, USA [11]

Geothermal power plants with flash steam

This indirect method is characterized by the double use of water and steam. Fluids above 180 °C are used. Flash steam geothermal power plants differ from dry steam because they pump hot water, rather than steam, directly to the surface. These flash steam plants pump hot water at a high pressure from below the earth into a "flash tank" on the surface. The flash tank is at a much lower temperature, causing the fluid to quickly "flash" into steam. The steam produced powers the turbines. The steam is cooled and condenses into water, where it is pumped back into the ground through the injection well. Most modern geothermal power plants work on this principle.

Schematic presentation of a flash steam geothermal power plant is given in Figure 6 and photograph of one flash steam geothermal power plant in Iceland is shown in Figure 7.

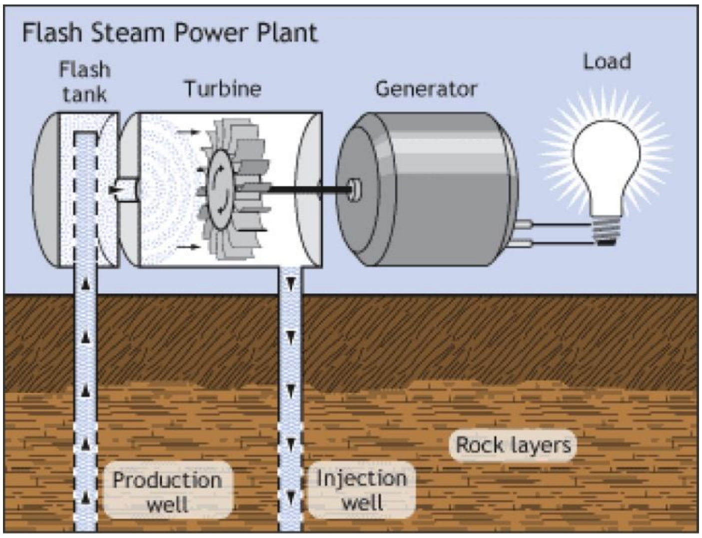

Figure 6. Flash steam geothermal power plant [10].

Fluid temperatures for such mixed method range from 100 °C and above. In these binary cycle geothermal power plants, the main difference is that the water or steam from below the earth never comes in direct contact with the turbines. Instead, water from geothermal reservoirs is pumped through a heat exchanger where it heats a second liquid- like isobutene, freon, ammonia, alcohols (with a lower boiling point than water). This second liquid is heated into steam, which powers the turbines that drives a generator. The hot water from the earth is recycled into the earth through the injection well, and the second liquid is recycled through the turbine and back into the heat exchanger where it can be used again. The advantage of this principle is higher efficiency and greater availability of the required geothermal reservoirs. Also, an advantage is the complete closure of the system since the used water is returned back to the reservoir, so heat loss is reduced, and there is almost no water loss. Most of the planned new geothermal power plants will use this principle.

Figure 7. Flash steam geothermal power plant in Iceland [11].

Geothermal power plants with binary cycle *(ORC Rankin cycle)*

Schematic presentation of a binary cycle geothermal power plant is given in Figure 8 and photograph of one binary cycle geothermal power plant in Nevada, USA is shown in Figure 9.

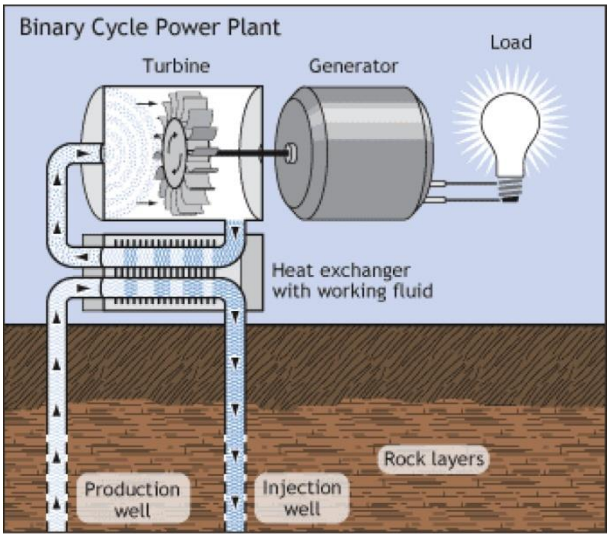

Figure 8. Binary cycle geothermal power plant [10].

Figure 9. Binary cycle geothermal power plant in Nevada, USA [11]

In addition, there are combined or hybrid plants that comprise two or more of the above basic plant types to improve versatility, increase overall thermal efficiency, and improve load-following capability. Cogeneration plants, or Combined Heat and Power plants (CHP), produce both electricity and hot water for district heating at significantly higher efficiency than can be achieved by just generating electricity or supplying heat [1].

5 Advantages and disadvantages of geothermal power plants

Advantages are as follows:

- **Renewable, sustainable and permanent source**

Geothermal energy is end-less, it will always exist and geothermal power will work. It can provide a constant supply of energy unlike other renewable energy sources.

- **Ecologically clean**

Geothermal power plants use a renewable heat source with a constant supply unlike coal-fired power plants and emit only 5% of greenhouse in the contrary with coal-fired power plants.

- **Low operating costs, more electricity with stable prices**

Geothermal power stations require minimal maintenance compared to conventional power plants, thus being reliable and cheap in operation. They have the great capacity that can meet the growing energy demand and offer stable electricity price because it does not depend on varying fuel costs.

- **Small area**

They occupy less space than their fossil fuels equivalents.

- **Low noise work**

Geothermal energy is produced with a little noise; the main is by the fans in the cooling systems which can easily be reduced.

- **Energy security**

Using local geothermal resources, supplying from other countries reduces, thus lowering dependence on external influences and helping in increasing energy security.

Disadvantages are as follows:

- **Geographical limits and seismic instability**

Geothermal activity is the highest along the tectonic fault lines in the earth's crust where the geothermal energy has the greatest potential. Therefore, only few countries can use geothermal resources: the USA, Iceland, Kenya, Indonesia, the Philippines, Mexico. Geothermal structures can cause seismic activity which is usually insignificant.

- **Expensive construction**

Although they have low operating costs, the construction costs of geothermal power plants are high. Much expenses concerns the exploration and drilling of geothermal energy resources as well as special heating and cooling systems and other equipment resistant to high temperatures.

- **Ecological problem**

High consumption of fresh water can be a loss for the environment, which can lead to its deficit. Liquids extracted from the earth during drilling contain toxic chemicals (including arsenic and mercury), as well as greenhouse gases (such as hydrogen sulfide, carbon dioxide, methane, ammonia and radon) that have to be properly treated.

- **Possible exhaustion**

Without careful management, geothermal sources can be exhausted thus making the geothermal power plant unnecessary until the tank restoration. The only inexhaustible option is to get geothermal energy directly from the magma, but this is still in the developing stage [11].

6 Conclusion

Geothermal energy has a rather serious potential and will play an important role in the future. In Europe, geothermal heat is used for different needs, but most of all for electricity generation, heating, and cooling of buildings.

With the estimated total amount of geothermal energy that could be used significantly higher than the total amount of energy sources based on oil, coal, and natural gas, more importance should certainly be given to geothermal energy, especially having in mind that it is cheap, a renewable energy source and also environmentally friendly. Since geothermal energy is not easily available everywhere, accessible places, such as edges of tectonic plates, should definitively be used and thus the pressure on fossil fuels would be at least slightly reduced, which would help the Earth to recover from harmful gases.

Serbia's current energy strategy does not treat geothermal energy as a significant resource several times larger than the total coal reserves in Serbia, which is present in every place at all times.

The whole of Europe is striving to reduce energy dependence and is trying to increase its energy production; the only possibility for that is to significantly increase the share of renewable energy sources in the overall energy balance. Serbia is in a similar energy dependence on imports and that is why it is very important to urgently start increasing the use of geothermal energy.

7 Acknowledgments

This work was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant Nos. 451-03-68/2020-14/200026)

8 References

[1] *** Geothermal Quick guide, International Geothermal Association Inc., 2018.

[2] *** https://www.geothermal-energy.org/explore/what-is-geothermal/

[3] *** Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (European Council. 5 June 2009. Retrieved 19 September 2016).

[4] *** https://www.energetskiportal.rs/obnovljivi-izvori-energije/geotermalna-energija/

[5] *** https://www.gradjevinarstvo.rs/tekstovi/1828/820/geotermalna-energija-osnovni-pojmovi

[6] *** http://zelenaenergija.pks.rs/ZelenaEnergija.aspx?id=140&p=4&

[7] *** Energy Sector Development Strategy of the Republic of Serbia for the Period by 2025 with Projections by 2030 (Official Gazette of RS No. 101/15)

[8] *** https://www.saveonenergy.com/how-geothermal-energy-works/

[9] **Milenić, D., Vranješ, A.,** Istraživanje i valorizacija subgeotermalnih energetskih resursa, University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia, 2015.

[10] **Mohr, M.,** Geothermal power in the Long Valley Caldera and Beyond, Student research, Indiana University Geological Sciences G188, Collings Living-Learning Center L130, 2014.

[11] *** https://avenston.com/en/articles/geothermal-pp-pros-cons/