Journal of Engineering Science and Technology
Special Issue on SIET2022, May (2022) 107 - 118

USING ABANDONED OIL AND GAS WELLS FOR PRODUCTION OF GEOTHERMAL ENERGY AS A RENEWABLE SOURCE–OVERVIEW OF SOME CASE STUDIES

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Abstract

Geothermal energy is considered a reliable, renewable and abundant source of energy with minimized environmental impact. The extracted geothermal energy can be utilized for direct heating, or electricity generation. This energy source is viewed as a possible alternative to partly replace fossil fuels. One of the main challenges of this strategy is the high capital expenditures required for drilling and completing new wells to be dedicated to geothermal energy production. This paper will discuss and evaluate a commonly proposed solution to this problem. There are many oil and gas wells globally which are not used for production, injection or other purposes. Usually, well abandonment is considered an essential stage at or near the end of a field life to ensure safety and integrity of these wells, which bears huge costs and concerns for the petroleum industry. By converting abandoned oil and gas wells to geothermal wells, it is claimed to be possible to utilize the geothermal energy for power generation. As a crucial stage for evaluation of feasibility or efficiency of this conversion, it is important to be aware of the previous studies. Therefore, in this work, several case studies around the world are generally studied, giving a general evaluation of their success. All the cases were simulation works, which shows the conversion is more like a concept, indicating the great potential for the practice.

Keywords: Abandoned wells, Case studies, Geothermal energy, Production.

1. Introduction

Due to sustainability concerns, limitation of oil and gas reserves, geopolitical reasons, and some environmental concerns about fossil fuels, there is a global trend towards further utilization of renewable energy sources. Some environmental concerns are associated with oil and gas operations, most of which can be eliminated by proper and environmentally friendly planning and execution. Some governments such as USA Biden's administration, have set goals of carbon-free grids by 2035, but mostly the net-zero target is 2050. Among renewable sources, geothermal energy is considered as a viable energy transition way from oil and gas. However, based on International Energy Agency, IEA [1], this technology showed only a 2% annual energy increase in 2020 and is not yet on track with the Net Zero Emissions by 2050 Scenario, which requires 13% annual increases in generation over 2021-2030. One important and feasible method of achieving the aforementioned target is by transforming abandoned oil and gas wells into geothermal ones.

There is a vast number of old and abandoned wells around the world which are not used for production, injection, etc.; in USA, the number of these wells is 2.1 million, based on EPA estimates [2]. Abandonment of oil and gas wells which can no longer produce, has been an integral goal for the oil and gas industry [3]. The cost of plug and abandonment (P&A) ranges from 76 k-USD to 1 million USD; P&A costs are 9% greater for gas wells and increase with depth. In another case study, the P&A cost for a 5,000 m well in Germany rose to 1.27 million USD [4]. In addition, to decommission old wells, there are safety and environmental concerns associated with well integrity issues and subsequent risk of methane or other fluid leakage [5], which can be quantitatively analysed using fuzzy fault tree analysis [6]. Therefore, considering P&A costs, safety and environmental concerns, and potential energy production, conversion of non-activated or useless oil and gas wells to geothermal wells is highly advantageous. Most geothermal power plants have been constructed in the last three decades [7]; however, conversion of oil and gas wells this has occurred mainly in the recent decade. This conversion is an important initiative which is seriously considered and partly implemented by some governments and oil and gas companies. In March 2022, US Department of Energy (DOE) selected four new projects to receive up to $8.4 million to establish new geothermal energy and heat production from abandoned oil and gas wells [8].

Injection fluid selection is an important aspect of geothermal power plant design of abandoned wells. Usually, water is chosen as the injection fluid because of its high heat transmission (contributing to geothermal recovery), its high heat capacity, good heat conductivity and availability. However, for deep and high-temperature abandoned gas reservoirs with very low permeability, for the open-loop production scenario, the application of water as heat carrying media can be limited [9]. Instead, super-critical fluids are proposed [10].

Generally, geothermal energy extraction methods may be categorized into conventional geothermal and abandoned wells geothermal extraction methods. In the conventional method, a well near volcanoes or underground magma sources is drilled and high heat sources are accessed. However, due to the tremendous drilling cost, which accounts for roughly half of the total cost of a geothermal project, abandoned oil and gas wells are considered cost-effective options. These types of projects will have bottomhole temperatures much lower than specific geothermal drilling, which is the reason for being called low temperature sources. Due to the low temperatures of these projects, improving work efficiency and optimization to minimize cost should be followed to the maximum to guarantee economical advantage of the projects. Advances in science in recent years have led to optimization in various fields, to the extent that new surface cycles, working fluids are considered. Due to the importance of exploiting these resources, this work presents a general review of some case studies.

2. Case Studies

2.1. Case from the USA

In a case study in Texas, USA [11], a double pipe was used in a vertical well with the depth of 4,200 m with a general schematic shown in Fig. 1. Water, as the geothermal fluid, was injected or circulated through the annulus (between the 9 5/8-in casing and the outer pipe) and returned to the surface through the inner pipe. The outlet fluid flowed into a binary organic Rankine cycle power plant, where the hot water flows through heat exchanger getting in contact with the organic fluid (here R134-a) which was evaporated (due to its low boiling point) to turn the turbine to generate electricity. The double-pipe system comprises outer pipe, insulation layer, inner casing/pipe for hot fluid extraction. An insulation was installed between the inner pipe (without any mentioned diameter) and outer pipe (without any mentioned diameter). The casing was 9 5/8-in casing, which is also the fluid inlet diameter, is 0.222 meters (8 7/8 inch), and the inner diameter of the well (fluid outlet diameter) is 0.0507 meters (2 inch).

The geothermal gradient is 31.1 degrees ºC/km (the bottomhole temperature of 130 ºC at the depth of 4,200 m), the inlet temperature is zero ºC, the average outlet temperature is 72 ºC, and the mass flow rate is 2.5 kg/s. The maximum power (net) output was 109 KW. The thermal and whole power efficiencies were not mentioned in this work. However, for cycle efficiency, it was generally mentioned that it ranges from 9-13% [12].

In the simulations in the study, some properties of the working fluid were considered on greater heat generation: a) higher the thermal conductivity, b) the lower the specific heat capacity, c) the greater its viscosity. They also noted that increasing the inlet temperature from zero to 60 ºC would lead to linear outlet temperature increase and generated heat power. It is noted that the density of the working fluid has very little effect on magnitude of the generated heat.

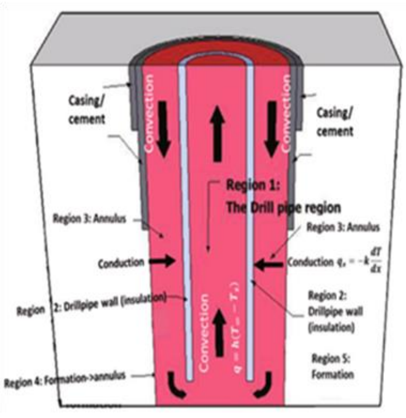

Fig. 1. Schematic of closed-loop production [11].

2.2. Case from Croatia

According to Macenic and Kurevija [13], a deep oil well (called Pcelic-1) was drilled to the depth of 4,772 m in 1989 for purpose of oil production. However, during drilling, the drill string was stuck at the bottom of the well. Therefore, the well was plugged and abandoned by setting cement plugs and a packer, and it was converted to a 4,500-m well for geothermal energy production (Fig. 2). Considering the geothermal gradient of the formation (41 ºC/km) and the surface temperature of 21.7 ºC, the bottomhole temperature is 206.2 ºC. For completion, a tapered inner pipe (5-in / 3 ½-in) was run inside the 9 5/8-in casing and the 7-in casing respectively. Water was injected through the inner pipes and returned to the surface through the casings (or called outer pipes in the work). Their way of production is unusual as it is a common practice to inject the cold fluid from the annulus and the return through the inner pipe. In addition, no insulation of the casings and the inner pipe was performed. These have adverse effects on the rate of heat generation.

The outlet fluid (with the temperature of 97.5 ºC) entered a binary cycle power plant (most likely organic Rankine cycle, though not mentioned in the work). The working fluid used to turn the turbine to generate electricity, was not mentioned. The effect of different circulation rates of water was investigated. It was inferred that the higher the flow rate, the greater the energy produced though the lower the temperature of the returning fluid (see Table 1). Thus, the highest heat with the value of 1,750 MWh can be obtained with flow rate of 12.5 l/s. However, the work brings up on a term called SPF (ratio of heat extraction to consumed energy by the circulating pump) to indicate that this flow rate may not necessarily be the optimum one due to high circulating pump energy.

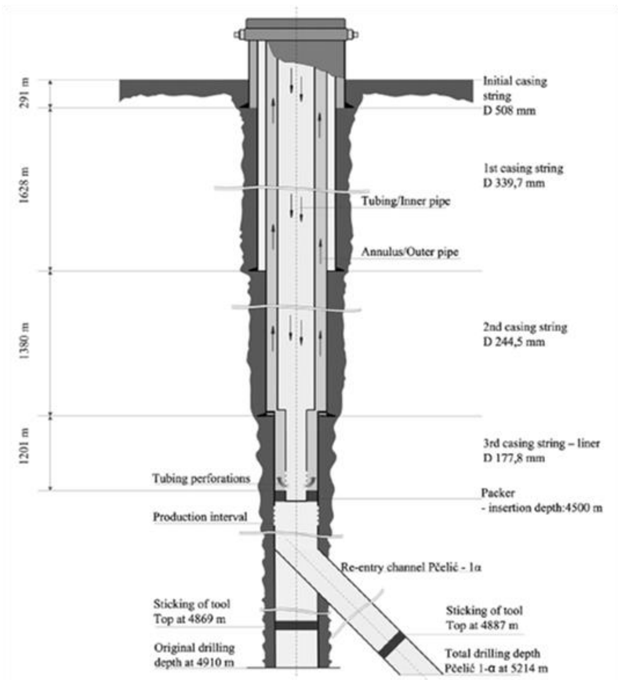

Fig. 2. Schematic of a well in Croatia used for geothermal energy production [13].

Table 1. Information about different mass flow rate.

Mass flow rate (l/s)	Temperature (ºC)	Extracted Heat Production (MWh)
5	10	670
7.5	10	1090
10.5	10	1460
12	10	1750

2.3. Case from Pakistan

Mehmood et al. [14] simulated using two abandoned wells a gas field in Pakistan for geothermal energy production. Figure 3 shows the cross-section of one of the wells. Considering the open-loop system, one well was the injector and the other one was the producer. Both wells had 4,500 m vertical depth and the distance between the two wells was 200 m. The thickness of the limestone reservoir was 500 m.

Water was injected with the injection flow rate of 50 kg/s, the injection pressure of 25 MPa (high enough to ascertain circulation) and the injection fluid temperature of 60 °C. The outlet pressure (in the producer well) was 10 MPa, the bottomhole temperature was estimated to be 197 ºC, and 85-90 % of the producing fluid from the well was water, with the rest being gas.

According to numerical reservoir simulations, the highest achievable stable heat production and power generation were 49.4 MWe and 12.6 MWe respectively. It was simulated that after 40 years of production, due to the expected temperature drop in the reservoir, the heat production would drop from 49.4 MWe to 43.8 MWe, and the power generation would drop from 12.6 MWe to 5.6 MWe. As a result, considering the commercialization target for this system (i.e., 25 MWe of heat and 3.5 MWe of electricity, based on Evans [15], the well lifespan of the geothermal system would be 40 years which is beyond expectation. As drilling generally constitutes about 44% of the total project investment [16, 17], reusing the abandoned oil wells would significantly improve the feasibility of the project. However, the energy efficiency of the system after 40 years is still low (33.5%), which requires modifications of the production system.

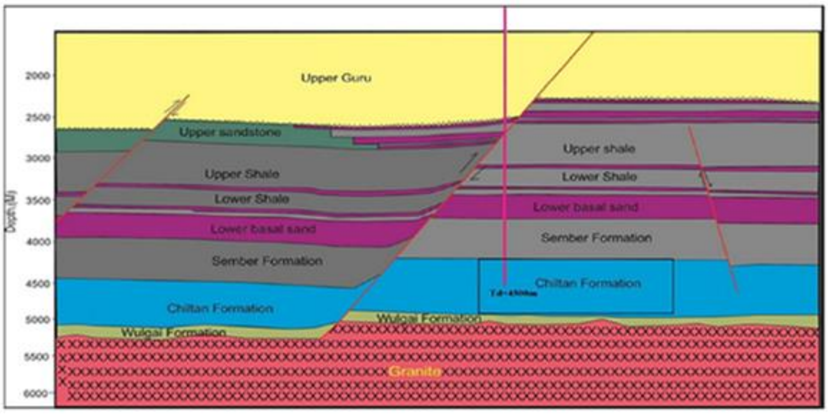

Fig. 3. Structural cross-section of Shan-X1 field with the Chiltan formation being the reservoir [14].

2.4. Case from China

You Daqing oilfield (Fig. 4), located in south eastern China, is one of the largest oilfields in China. The reservoir formation is Mesozoic Cretaceous sandstone field of continental facies. In this field, geothermal energy has been extracted using a hot dry rock (HDR) system which usually requires an open-loop or enhanced geothermal system (EGS) extraction system. This system is usually used when water is not naturally available [18]. The geothermal gradient of the region is 38.7 °C/km which is abnormally high caused by development of a mantle pillow due to upwelling of the upper mantle [19, 20]. With this gradient and surface temperature of 34 ºC, at the depth of 3–5 km, the formation temperature reaches 150–230 °C. It is noted that to take possibility of precipitation issues into account, the produced heavy crude oil from this field contained 20–30 % wax content. It is noted that the temperatures measured by drill stem test (DST) provided more accurate results. The heat content within 3–5 km is 24.28×1021, wherein 68.2% exceeded 150 ºC. If the recovery factor was given by 2%, the most conservative estimate for recoverable HDR geothermal resource was 0.33×1021 J.

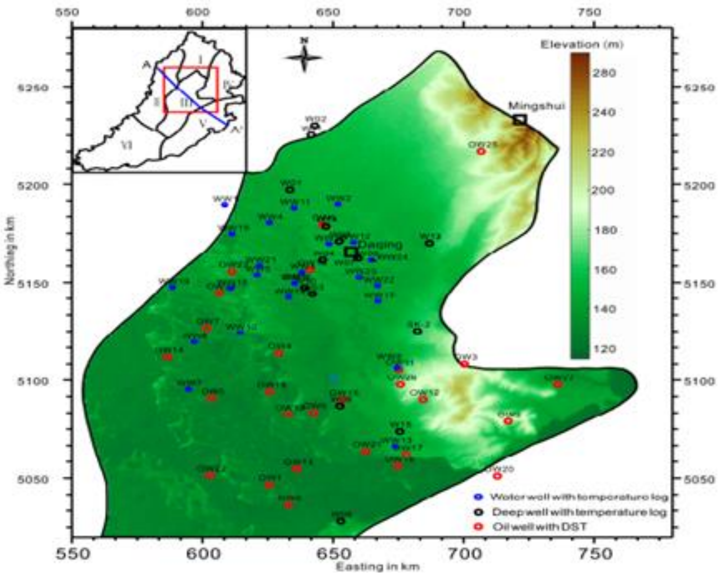

Fig. 4. Daqing oilfield in China [18].

2.5. Case from Indonesia

There is a recent initiative in Indonesia and specifically in Arun oilfield to convert approximately 60% of abandoned wells in this area (equivalent to 13,000 wells) to a source of geothermal energy [21]. In their study, they chose a closed geothermal loop because of its advantages. First, it does not require a water management system, compared to a compulsory water management system for open loop configurations. Second, a closed loop configuration needs less pumping power compared to an open loop configuration which requires considerable power to overcome gravitational head. Moreover, closed loop configurations create a potential to use a non-aqueous fluid (such as supercritical CO_2) to increase the rate of heat exchange with the earth. Next, a closed system prevents contamination of underground water resources and the environment as no fluid would be injected into underground formations. Indeed, in this method, just the heat is obtained from the depth of the earth. In this field, the geothermal gradient is considerably high, i.e., 58 ºC/km.

Syarifudin et al. [21] simulated one of the 13,000 wells with the vertical depth of 3,048 m. considered a new type of heat exchanger (i.e., spiral) in the bottom of the wellbore, which prevented loss of heat due to its greater length of the pipe and thus increased the outlet temperature (see Fig. 5). This type of heat exchanger has proven to be the best configuration compared to W-type, 2U-type or U-type heat exchanger, in case of efficiency. Average heat exchange rates for 100 hours of U, W 2U, and spiral type GHEs were 35.71 W/m, 40.76 W/m, 39.03 W/m, 76.80 W/m respectively, [22]. At the surface, the power generation cycle in this region is an ORC, the organic fluid boiling point was lower than that of pure water. Finally, in Arun field, it is possible to get the returning fluid with 170 ºC temperature with circulation rate of 2.65 kg/s, and to generate more than 2900 kW per well of electricity. The estimation was done using analytical solution after making three assumptions about heat flow.

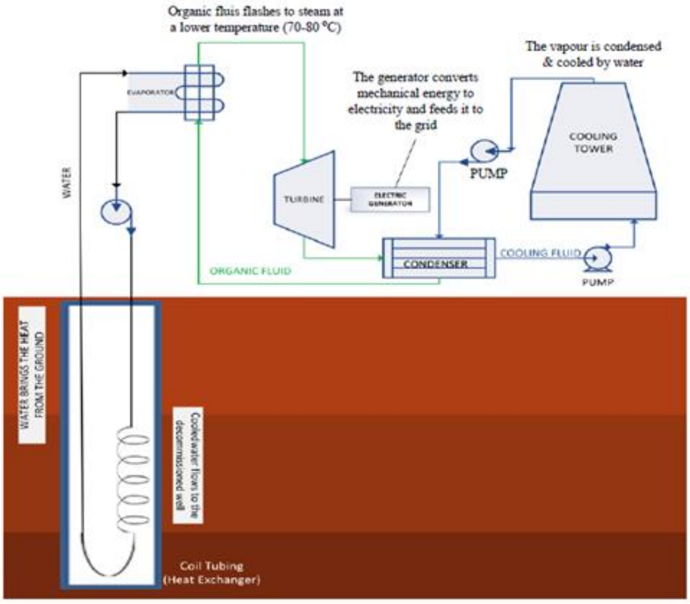

Fig. 5. Process flow schematic for closed-loop binary cycle [21].

2.6. Case from Malaysia

In a case study conducted in Malaysia [23], a double pipe was used in a vertical well with the depth of 1,500 m (Fig. 6). The cold geothermal fluid (water) was injected or circulated through the annulus (between the 9 5/8-in casing and the outer pipe) and returned to the surface through the inner pipe. The insulation is located between the inner pipe (0.0603 m/ 2 3/8-in) and outer pipe (0.1143 m / 4 ½-in) with the insulation thickness (1 inch). The inside diameter of the 9 5/8-in casing, which is also the fluid inlet diameter, is 0.222 meters (8 7/8 inch), and the inner diameter of the well (fluid outlet diameter) is 0.0507 meters (2 inch).

In this case, the geothermal gradient is 51.8 degrees ºC/km, the inlet temperature is 30 ºC, the average outlet temperature is 73 ºC, and the mass flow rate is 1800 kg/s. Due to the low outlet fluid temperature at the surface, an ORC cycle is used. The selected organic/working fluid in the cycle is R245-fa and the maximum power (net) output was 0.71 kW. According to the study, 1800 kg/s is the optimal circulation rate because increasing the flow rate to 1800 kg/hr will increase the net production capacity; however, exceeding the mentioned flow rate would cause reduction of the net production capacity.

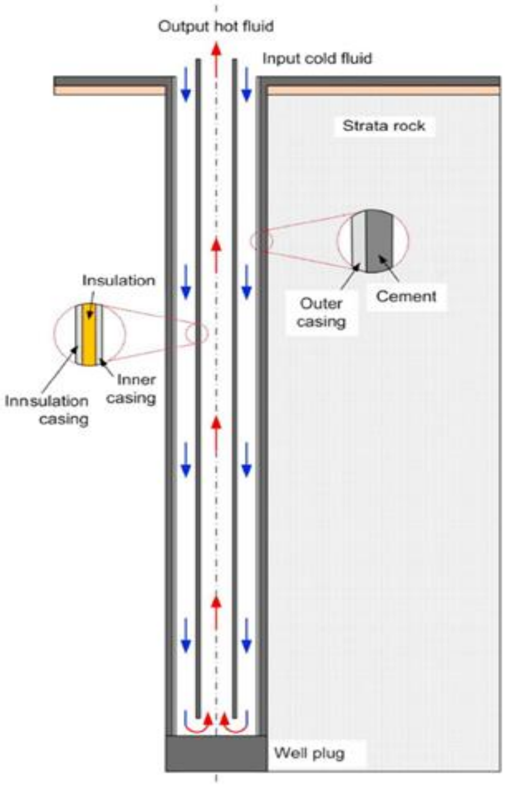

Fig. 6. Schematic of the retrofitted oil well considered in this study [23].

2.7. General case

Al-Khawaja et al. [24] considered converting abandoned oil and gas wells for geothermal energy production using complex systems. The well is a 4-km vertical depth one, with geothermal gradient in the underground formation being 34 ºC/km which is considered above normal gradient of 25 ºC/km. With the ambient temperature of 16 ºC, the bottomhole temperature is 152 ºC which is considered the upper boundary of medium temperature source [25]. A closed-loop system was considered using two concentric pipes of 3.1 cm and 3.6 cm with the insulation thickness of 2.5 mm to prevent heat transfer between the two pipes. As the simulation, water was injected through the injector well with flow rate of 32 m3/hr and with the temperature of 80 ºC whereas the producing fluid temperature (at the producer wellhead) was simulated to be 114 ºC.

The produced hot water vapor is allowed to enter a cycle unit used called thermo-mechanical refrigeration (TMR) where it enters a heat exchanger (called "Heater" in Fig. 7). The working fluid of R1234ze was selected (after using genetic algorithm optimization) in both power and cooling loops. The evaporated working fluid flows to the expander compressor units (ECUs) to push a piston and compress fluids, i.e., do work. Next, the fluid flows to the condenser where it is cooled down. Part of the cooled working fluid flows back to the power loop and the rest goes through the cooling loop to the evaporator, following which it flows again to the UCUs and does some further work by again compressing the fluid. A special loop system has been devised for the condenser using an underground heat exchanger to cool the water as the condenser's cooling fluid. Using this special complex system, the power efficiency was increased for 23.5 % compared with normal cycle systems due to not using air and water cooling, etc. Using 20 expanders, a cooling load of 100 kW could be generated.

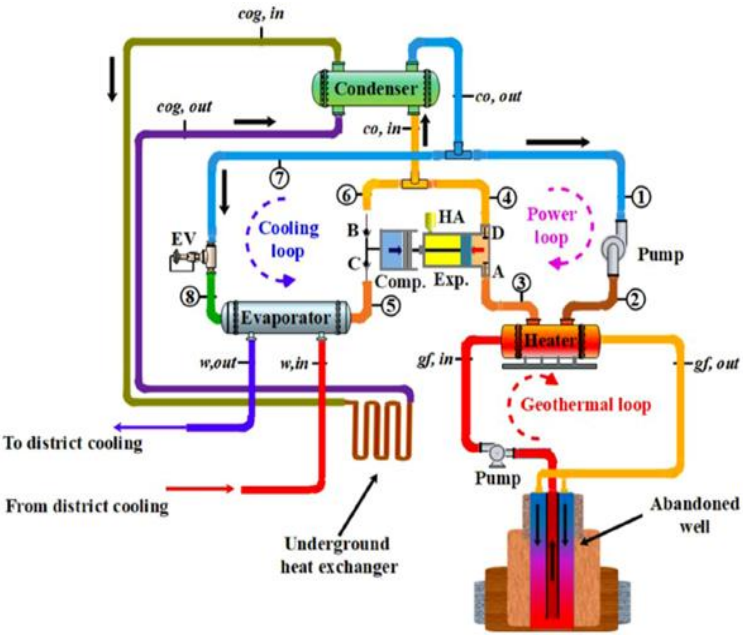

Fig. 7. Three-loop cycle layout of the geothermal mechanical refrigeration (GTMR) system for energy conversion of heat from abandoned oil wells to mechanical refrigeration [24].

It is noted that in all case studies, except for one, water was considered as the circulation fluid. As confirmed in the case studies, most power plants for conversion of oil and gas wells to geothermal wells are organic Rankine cycle (ORC), which suffer from low thermal efficiencies of around 10% , compared with Kalina cylces [26-29].

3. Conclusion

This paper generally presented a review of several case studies of conversion of oil and gas wells for utilization of geothermal resources. All the cases were simulation works, which shows the conversion is more like a concept, indicating the great potential for the practice. This is due to the fact that this conversion can yield considerable energy production while eliminating drilling costs, and deferring plug and abandonment costs. Huge drilling cost is considered a serious barrier to using conventional geothermal energy sources.

In brief, based on the promising results of heat production simulation seen in the review, using abandoned wells is expected to become a more widespread method of sustainable energy supply, particularly in oil and gas producer countries.

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