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Utilization of oil wells for electricity generation: Performance and economics

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ABSTRACT

There is a general agreement that the climate change, which is the most important challenge facing humanity, is anthropogenic and attributed to fossil fuel consumption. Therefore, deploying more renewable energy resources is an urgent issue to be addressed. Geothermal refers to existing heat energy in deep rock and sedimentary basins. Traditionally, geothermal energy has been exploited in places with plentiful hot water at relatively shallow depth. Unfortunately, the high exploration and drilling costs of boreholes is the main barrier to the commerciality of geothermal worldwide. In oil producing countries, such problems can be overcome by utilizing oil or gas wells. The current study presents thermodynamic and economic analyses of a binary geothermal power generation system for commercial electricity generation. Two different source temperatures (100 and 120 °C) and constant sink temperature (29 °C) were considered. The optimal working fluid and optimal design that improve the performance of the plant are determined. For the current costs in Qatar, the economical analysis of 5 MW geothermal plant shows that the levelized cost of electricity for the plant varies from 5.6 to 5.2 ¢/kW. Whereas, the payback period of such plants lies between 5.8 and 4.8 years.

1. Introduction

Owning to the awareness of the correlation between fossil fuel consumption and the ongoing climate changes, the future looks promising for renewable energy development. The main problem encountered by the developer is the fluctuation in the availability of renewable energy. To overcome this issue, the future energy systems, which exploit energy from different resources, must work together to even out the fluctuations in available sources of renewable energy.

Geothermal refers to existing heat energy in deep rock and sedimentary basins. These formations can provide superheated steam or hot fluid that can be utilized to generate electricity using any work producing device. Depending on the condition of the geothermal fluid in the reservoir, different power producing cycles may be used, including direct steam, flash-steam (single and double-flash), binary, and combined flash–binary cycles. Although the direct steam cycle is the simplest geothermal cycle, binary power plants have been proven to have greater efficiencies than flashing plants for liquid-dominated low-temperature geothermal resources in the range of 100 °C and 170 °C.

Compared to other renewable energy resources, geothermal energy is a stable resource and independent of the climate. Therefore, geothermal energy is suitable for supplying base-load power. Geothermal energy is a mature technology market with total installed capacity worldwide about 10700 MW [1]. The annual electrical generation from such plants is 67.2 TWh at a capacity factor above 90% [2]. Nevertheless, the world's target by 2050 is to reach 1180 TWh of annual electricity generation from geothermal sources (about 6% of current global electricity consumption) [2]. Although the design of binary plants has been addressed in different studies, it is still an area of active research. To be exact, the low First Law efficiency (<10%) and low Second Law efficiency (25–45%) and the large required heat exchanger [1,3] means more research are required.

Usually, geothermal plants are located in places characterized with the relatively rare combination of large reservoirs of hot water at shallow depth. Unfortunately, such conditions exist in relatively few places around the world. Therefore, according to the U.S. Energy Information Administration, geothermal resources have limited potential for growth. Instead, growth is expected from

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unconventional resources called EGS (enhanced geothermal systems). Fortunately, temperature increases with depth below the surface everywhere on the earth. In most hydrocarbon-producing areas, the gradient is usually in the range of 11–30 °C per 1000 m of depth increase [4]. Consequently, the temperature at depths of 3–10 km below the surface is enough to be considered as promising future sources of geothermal energy. This fact creates a possibility of exploiting geothermal energy everywhere by means of binary power plants. In the light of significant improvements in binary ORC (organic Rankine cycles), harvesting energy from a low temperature source becomes possible. The analysis and the improvement of the performance of ORC were widely addressed in the literature [1,3,5–9]. Franco, for instance, investigated the exploitation geothermal energy of low temperature in the range 100–130 °C [1]. In his study, Franco showed possibility to improve the ORC by using recuperated cycle configurations [1]. Another study showed the exergy analysis of a 12.4 MW existing binary geothermal power plant [3]. Kanoglu showed that about 70% of exergy of the geofluid can be utilized by ORC, while the corresponding thermal efficiency for the plant is 5.8% [3]. Thermal and utilization efficiencies were calculated for 35 MW geothermal power plant of high resource temperature (160–254 °C) [6]. Due to the high resource temperature, DiPippo et al. showed that the thermal efficiency of 15.1%, while the Second Law efficiency of 37.2% [6].

However, high depth for such energy creates technical and financial problems. The economic viability of utilizing geothermal for power generation was addressed in literature capacity [2,10–17]. The perspectives of development of geothermal power plants of medium-low temperature were discussed by Franco [10]. Based on investment costs of 1250 €/kWel for the ORC, Preiβinger et al. showed that the payback period can be reduced by 10% and the cash flow can be increased by 8% by using a transcritical ORC [17]. Still, the high initial capital cost of geothermal power plants, which is currently in the range of 2130–5200 US$/kW [2,11], is the main barrier to commerciality of geothermal energy. Borehole drilling accounts for up to 40% of the total cost of the project [2,11]. Considering the fact that oil wells are usually drilled to big depth and, consequently, the wells bottom is of high temperature. Hence, oil wells can be economically used as geothermal wells. This way, drilling cost can be eliminated from the initial cost of geothermal plants and, accordingly, the economic feasibility of geothermal power plants can be improved effectively.

The current work discusses the thermodynamic and economical analyses of utilizing abandoned oil wells for power generation. Qatar was selected as a case study and, therefore, the source and sink temperatures were selected according to the local conditions. Thermodynamic and economic performances of Organic Rankine cycles are analyzed and optimal design criteria are defined. It is important to note that despite the fact that this study is limited to the selected working conditions, it is expected the approach can be successfully applied for other conditions. This study can be extended to any waste heat source other than oil well.

2. Synergy with oil industry

The similarities between geothermal and oil extraction operations create the possibility of using the advanced technology and experience from the petroleum industry in geothermal operations [18]. This can facilitate the transition from natural resources to enhanced geothermal energy. Exploiting the oil wells represents the low hanging fruit in geothermal energy production in oil countries. Recently, more and more attention has been paid to geothermal power generation by utilizing hot fluids co-produced from oil and gas reservoirs. The geothermal gradient varies from basin to basin. In most hydrocarbon-producing areas, the gradient is usually in the range of 11–30 °C per 1000 m of depth increase. Since the oil and gas wells in many cases are drilled to a big depth below the ground surface, the temperature of produced geofluid is high enough to generate electricity. In addition, the water-cut of an oil well, which is very high and up to 98% of the flow rate of the well in some cases, increases with time [19]. The temperature of the produced geofluid, in the water-cut period of the well's life, increases with time as well. It is worth mention that the water-cut in many mature oil and gas fields, is usually considered a nuisance to oil and gas producers because they are required to dispose or reinject the water into the reservoirs. This process costs a lot and reduces the net profit of the oil and gas producers. Thus, the exploitation of oil wells for electricity generation gives a new opportunity to low yield oil and gas producers.

In oil producing counties, there are many abandoned wells that can be used as sources for energy generation. Obviously, active wells can also be used as energy source for binary plants. In addition to eliminating of the drilling and exploration costs associated with deep boreholes, the use of oil wells implies that all required data for the geothermal plant are available.

3. Methodology

Geothermal system design requires the determination of thermodynamic performance and economic viability. A computational model was built in order to simulate thermodynamic and economic performances of organic Rankine cycles. In Qatar, high-temperature wells have been successfully drilled into reservoirs where temperatures exceed 149 °C [20]. To be more realistic the source temperature will be taken as 100 and 120 °C [21]. The sink temperature was assumed to be 29 °C, which is equal to the annual mean air temperature. From the thermodynamic analysis the optimal design of the geothermal power plant was obtained. Also, the economic analysis was carried out at current conditions in Qatar and resulted in determination of different figures of merit including NPV (net present value), IRR (internal rate of return), the PBT (payback time), and LCOE (levelized cost of electricity).

3.1. Thermodynamic analysis

There are chemical and mechanical problems associated with the use of geothermal sources for electricity generation. From a chemical perspective, most geofluid of high temperature contain non-condensable gases, hazardous compounds, corrosive ions, and insoluble materials. From a mechanical viewpoint and in the case of a relatively low geothermal temperature, non-aqueous secondary fluids with low boiling points are needed. To overcome these problems, a binary cycle is considered. The schematic of the suggested unit is illustrated in Fig. 1.

The geofluid, which is extracted from the well (state 8), passes through the heat exchange system where heat is transferred to the working fluid. After the heat exchanger system (state 11), the geofluid either is used in oil/gas process cycle or reinjected into the well again. The working fluid will be superheated vapor at turbine inlet (state 1). The working fluid is condensed upon exiting the condenser via exchanging heat with a coolant (state 4), and returns to the heater (state 6) by means of a feed pump to complete the cycle. The mechanical power extracted from the turbine is converted to electrical power in a generator, which is referred to as gross power.

The following thermodynamic analysis is available in the literature [22–24]. Keep in mind that the current study is investigating the utilizing the abandoned oil well, a part of generated energy will be lost as parasitic power. In binary organic cycle, the parasitic