POTENTIAL OF GEOTHERMAL ENERGY FOR ELECTRICITY GENERATION IN QATAR

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ABSTRACT

There is general acceptance that climate change, which is the most important challenge facing humanity, is anthropogenic and attributed to fossil fuel consumption. Therefore, improving the performance of our existing energy systems and deploy more renewable energy resources is an urgent issue to be addressed. Geothermal refers to existing of heat energy in deep rock and sedimentary basins. This energy can be used to drive a power turbine to generate electricity. Traditionally, geothermal has been exploited in places with the plentiful hot water at relatively shallow depth. In the light of fact that ground temperature increases with the depth everywhere on the Earth, engineered geothermal systems (EGS) can be installed in any place to exploit the geothermal in generating energy. Unfortunately, the high exploration and drilling costs of boreholes is the main barrier to commerciality of EGS worldwide. In addition, there are technical problems associated with drilling big depth. In oil producing countries such problems can be addressed by utilizing whether active or abandoned oil or gas wells and, consequently, EGS can produce power at profit. The current study presents an analysis of a binary geothermal power generation system for commercial electricity generation in Qatar. For this purpose, two binary cycles are assumed the main difference between them is that the first one is air cooled while the other will be water cooled. The performance of the two cycles and the possibility of improvement has been shown. Economic analysis the power plant shows that the levelized costs of electricity is 3.6US¢/kWh and the pay-back time is less than 8 years.

KEYWORDS

Geothermal energy, electricity generation, organic Rankine cycle, performance, economic viability.

INTRODUCTION

Owning to the awareness of the correlation between the fossil fuel consumption and the ongoing climate changes, the future looks promising for renewable energy development. The main problem encounter the developer is the fluctuation in the availability of renewable energy. Therefore and to overcome this fault, our future energy system of different resource must work together to even out the fluctuations in the available renewable energy.

Geothermal refers to existing of heat energy in deep rock and sedimentary basins. These formations can provide superheated steam or hot fluid that can be used to generate electricity by means of steam turbine. Depending on the state 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 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 . Geothermal energy is a mature technology market around the world with annual electrical generation of 67.2 TWh at capacity factor above 90% (Goldstein et al., 2011) . Nevertheless, the world’s target by 2050 is to reach 1180 TWh annual electricity generation from geothermal resource (Goldstein et al., 2011). Comparison with other renewable energy resources, geothermal energy is independent of the climate. This makes it is suitable for supplying base-load power and can, therefore, synergy with other renewable resource whose alternating availability such as wind and solar .

Usually, geothermal plants have been tied to places with the relatively rare combination of plentiful hot water that is relatively at shallow depth. Unfortunately, such conditions exist in relatively few places around the world. Therefore, according to the US Energy Information Administration, such resources have limited potential for growth. Instead, growth is expected from unconventional resources called enhanced geothermal systems (EGS). Fortunately, the temperature increases with depth below the surface everywhere in this planet. Specifically, the temperature at depths of 3 to 10 km below the surface is enough to be considered as promising future sources of geothermal energy. This fact creates a possibility of exploiting the geothermal energy everywhere by means of binary power plant. In the light of significant improvements of binary organic cycle, harvesting a low percentage of available geothermal heat could replace a substantial percentage of the energy produced by burning fossil fuel. Such energy resource is a readily available domestic source of energy that is reliable, steady, and environmentally friendly.

The depth and temperature of hot rock remain playing the major rule on the commercial viability of enhanced geothermal energy. As a consequence of the availability of such energy at big deep, technical and economic problems associated with deep geothermal energy resource. From economic viewpoint, the high initial construction cost of geothermal power plants, which is still in range of 2130-5200 US$/kW, is the main barrier to commerciality of geothermal energy. Drilling cost of borehole accounts for a considerable portion of construction costs, namely up to 40% of total investment costs of the project (Bromley et al., 2010; Goldstein et al., 2011). Therefore, if the drilling cost of the borehole can be removed from the construction cost, by utilizing the oil wells, the economic feasibility of geothermal power plant would be high.

In the current work, the thermodynamic and economic analyses are presented of a geothermal power plant that uses oil well as heat source for organic Rankine cycle.

SYNERGY WITH OIL INDUSTRY

The obvious similarities between geothermal and oil extraction operations creates the possibility of use the advanced technology and the experience from the petroleum industry in geothermal. This means geothermal exploitation has the potential to shift from natural resources extraction to the enhanced geothermal energy. Exploiting the oil wells represents the geothermal energy's low hanging fruit in oil states. Recently more and more attention has been paid to geothermal power generation by utilizing hot fluids co-produced from oil and gas reservoirs. Since the oil and gas wells in many cases go to high depth below the ground surface, temperature of the produced water is high enough to generate electricity. Electricity generation from the produced water will give new life to low yield oil and gas producers because of high water cut. It is worth mention that the water cut in many mature oil and gas fields, which is very high up to 98% of the flow rate of the well, is usually considered a nuisance to oil and gas producers because they are required to dispose or re-inject the water into reservoirs . This process costs a lot and reduces the net profit value of the oil and gas producers. The water cut oil and gas reservoirs can be used as an electricity generation source.

In oil states, beside the relevant wild experience there are many abandoned wells that can be used as energy resource for energy generation. In active wells, it is also possible to exploiting the hot water produced with oil and gas to run binary plant. Besides getting rid of the drilling cost of deep borehole, using oil wells means that all required data for geothermal plant are available.

METHODOLOGY

Geothermal system design means the determination of the thermodynamic performance and the economic viability. To estimate the expected thermal power and exergy of a given site, two important parameters are required:

- Geofluid temperature at the outlet of the well, ^{o}C
- The mass flow rate, kg/s

Thermodynamic Performance

There are chemical and technical problems associated with geothermal utilizing for electricity generation. From chemistry viewpoint, most of geothermal fluids of high temperature contain non-condensable gases, hazardous compounds, corrosive ions, and insoluble materials. From the technical viewpoint and in the case of geothermal temperature relatively low, non-aqueous secondary fluids of low boiling point are needed. In this study and to overcome these problems, a binary cycle will be considered. The schematic of suggested unit is illustrated in *Figure 1*.

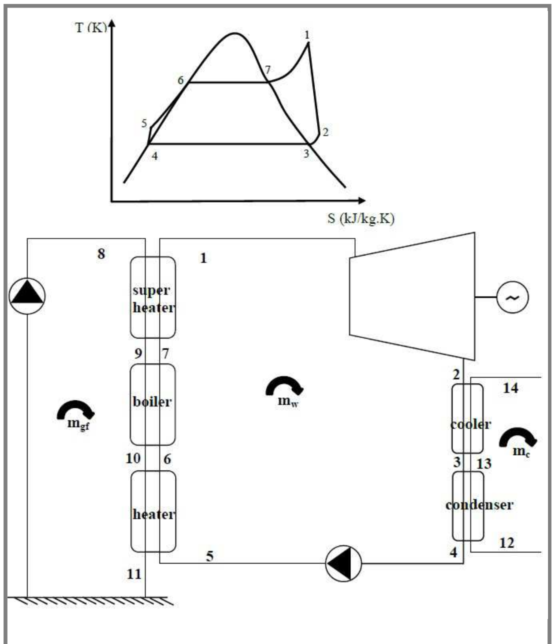

Figure 1- Schematic of the plant and the thermodynamic cycle on T-S map

The geofluid, which is the extracted fluid from the wells, passes through the heat exchanger system that consists of three counter flow heat exchangers where heat transfers to the working fluid. After that the geofluid is driven to continue its ordinary way.in the current study, the heat exchanger will be considered as three parts; the first one is used for preheating, the second one is used for evaporating and the last one is used for super-heating. Similar technique was used for condensing side but with two parts. The working fluid is found superheated at the heat exchanger exit. The vapor then drives a turbine. The working fluid is condensed at the other side of turbine via exchanging heat with a cooling medium and returns to the heater by means of a feed pump to complete the cycle.

In order to determine the net electrical power and the performance of the thermodynamic cycle following variables are assumed to be specified and known, see *Figure 2*:

1. The geofluid flow rate, m_{gf}
2. The extracted geofluid temperature, $T_{gf,i}= T_8$
3. The outdoor temperature (i.e. environment temperature), T_o
4. Temperature of the cooling medium at the inlet of the condenser, $T_s= T_{12}$
5. The isentropic efficiency of the turbine, η_{is}
6. The turbine-generator efficiency, $\eta_{t\text{-}g}$
7. Mechanical efficiency of the circulating pump, η_p

Thermal effectiveness of each part of the heat exchangers, i.e. the boiler ε_b, the condenser ε_c, the heater ε_h, the cooler ε_c, and the supper heater ε_s.

In current work different cooling temperature will be analyzed. Note that the net power output strongly depends on the condenser temperature. Thus, in air-cooled condenser the net power changes throughout the year in response to the changes in ambient air temperature. It is shown that the major exergy losses in a binary Rankin cycle occurs in the condenser (EIA (Energy Information Administration), 2010; Kanoglu & Dincer, 2009; Kanoğlu & Çengel, 1999; Kynoch, 2010; Li et al., 2007; Mishra, Glassley, & Yeh, 2011) . The thermal effectiveness of the heat exchangers depends on its size, i.e. bigger heat exchanger leads to a better effectiveness and, probably, better performance of the cycle, but higher cost of the project. Therefore, in the current work the impact of the effectiveness of heat exchanger will be analyzed.

The mechanical power extracted from the turbines is converted to electrical power in generators, which will be referred to as gross power. The turbine-generator efficiency depends on the turbine design. It will be assumed 80% (Kanoglu & Dincer, 2009) . Parasitic power, including circulation and production pumps, condenser fans, and auxiliaries, typically consumes in an air-cooled binary geothermal about a quarter of the gross power generated (Kanoğlu & Çengel, 1999). In the case of water-cooled condenser the parasitic power will be assumed essentially constant since the power to pump the water and the fan power saved in the condenser will likely cancel each other.

The methodology and thermodynamics behind the model, assumptions, and data sources are available in the literatures (Gouri Shankar Mishra, William Glassley, & Sonia Yeh, 2010; Kanoglu & Dincer, 2009; Yunus A. Cenel & Michael A. Boles, 2001). In current work the Engineering Equation Solver EES-based model was developed to simulate the operating conditions. First and second law efficiencies can be used as two criterions to assess and analyses the performance of the proposed power plant.

The working fluid used in the plant should have the following advantage: low boiling point, low critical temperature, high critical pressure, saturated vapor line on the T-s diagram of sufficient slope angle, and the saturated pressure above atmospheric pressure for the expected range of the condenser temperatures. In order to select the working fluid that provides the best performance at working conditions of Qatar, the evaluation of the unit performance is calculated for different fluids. Among different working fluids commonly used in binary geothermal power plants six fluids have been studied, including R134a, R-114, isobutane , isopentane and n-pentane (Saleh, Koglbauer, Wendland, & Fischer, 2007) .

Economic viability

The economic performance results in determination the investment and operating costs, the net annual profit and the payback time. The investment costs, in USD, are composed of four components:(1) exploration and resource confirmation; (2) drilling of wells; (3) surface facilities and; and (4) the power plant (Gerber & Maréchal, 2012) .

Each component has its impact on the total cost of the project as follows (Bromley et al., 2010; Goldstein et al., 2011): The first component stands for 10-15%. The second component stands for 20-35%. The third component represents 10 to 20%. Finally, the fourth component represents 40-81%.

Survey Studies show that the investment costs for typical binary geothermal plant varies between $ 2130 and 5200 per kW electricity(Bromley et al., 2010; Goldstein et al., 2011) or in average $3665/kWe. It should be noted that in the case of utilizing the existing oil wells, the first and second components costs (i.e. about 40% of total investment costs) are zero. Thus the total investment costs, C_{inv} becomes $2200/kWe. This way the total cost of geothermal power plant in USD is:

$$C_{inv} = 2200 \cdot P_{net} \quad (1)$$

Where P_{net} stands for the net power. The total investment costs can be converted into annual investment cost, $C_{inv,an}$ as follows:

$$C_{inv,an} = C_{inv} \cdot \frac{ir \cdot (ir+1)^{ny}}{(ir+1)^{ny}-1} + C_{OM} \quad (2)$$

Where *ir* represents the interest rate; *ny* is the project lifetime; C_{OM} is the annual total operating and maintenance (O&M) costs of the plant, in USD/y. O&M costs depend on many parameters in USA , for example, this costs vary between $152 and 187/kW (Bromley et al., 2010; Goldstein et al., 2011) (average $169/kW). Thus, C_{OM} becomes:

$$C_{OM} = 169 \cdot P_{net} \quad (3)$$

If C_{oil} is the price of oil in $/barrel, then the annual production of the geothermal plant $C_{p,an}$ in USD is

$$C_{p,an} = \frac{8760 \cdot P_{net} \cdot C_{oil}}{1900 \cdot \eta} \quad (4)$$

Where 1900 stands for oil energy contain, kWh/barrel; η represents the average energy conversion efficiency of conventional power plant. In Qatar and for gas power plants η is about 38%. Finally, the payback time of the installation in years is calculated by:

$$t_{pb} = \frac{ny \cdot C_{inv,an}}{C_{p,an}} \quad (5)$$

RESULTS AND DISCUSSIONS

For simplicity sake the thermal capacity of the wells was assumed a specified, i.e. the outlet temperature and the flow rate of the geofluid were assumed 100 °C and 100 kg/s, respectively. In water-cooled condenser plant, the cooling medium temperature was assumed to be constant and equals the mean annual air temperature. In air-cooled condenser case, the cooling medium temperature was assumed to be equals to ambient temperature.

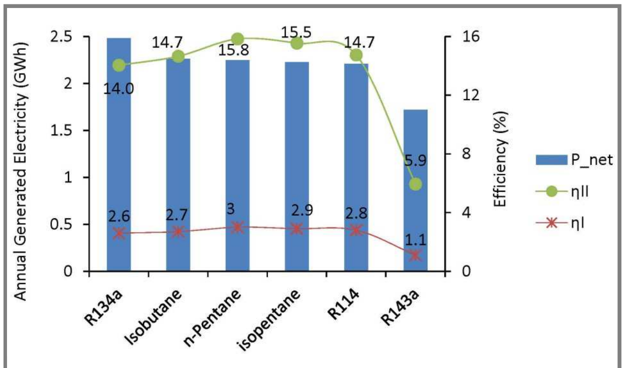

Figure 2- The performance of ORC of different working fluids for geofluid flow rate 100 kg/s and temperature 100 °C, and the effectiveness of the heat exchangers are 80%

In order to select the working fluid that provides the best performance, the performance units were calculated for selected fluids and the results illustrated in Figure 2. As shown, R134a is the best working fluid at the specified working conditions. Thus, R134a was assumed as the working fluid in the next calculations. In these calculations, the cooling medium temperature in the condenser equals the mean annual air temperature.

Figure 3 shows the performance of air-cooled geothermal plant for the thermal effectiveness of all heat exchangers is 80%. The calculations show that the annual electrical energy generation 2500 MWh.

To show the possibility of improving the performance of the cycle, the impact of the effectiveness of each part of the heat exchangers on the performance was examined. It was found that the improvement of different parts has different impact on the performance of ORC. For instant, the calculations show that improving the overall heaters' effectiveness by 18 % results in increasing the annual net electrical energy by 24 %. The same increase in the effectiveness of the heater and cooler part results in increasing in the annual net electrical energy by 45% and 139%, respectively. The hourly simulations are illustrated in Figure 4. This difference in benefit gained from improving the overall effectiveness and individual parts implies that the improvement of some part of the heat exchangers must lead to reducing in the performance of the cycle. Therefore, the impact of improving individual part of heat exchanger on the performance has been investigated as follow. The effectiveness of the concerned part was increased from 80 to 95 %, while the effectiveness of other parts was kept constant at 80 % and increasing. The process was repeated for each part, namely, heater, boiler, super-heater, cooler and condenser. As shown in Figure 5, improving the effectiveness of the heater and cooler has positive impact on the performance, while improving the effectiveness of the boiler, super-heater and the condenser has negative impact.

Finally, the economic analysis shows that for the base case, namely average capacity of 283 kW, and for oil price of $100/barrel the payback time is less than 8 years. It is worth mentioning that the levelized cost of geothermal electricity (installation costs divided by expected life time energy output) is 3.6US¢/kWh.

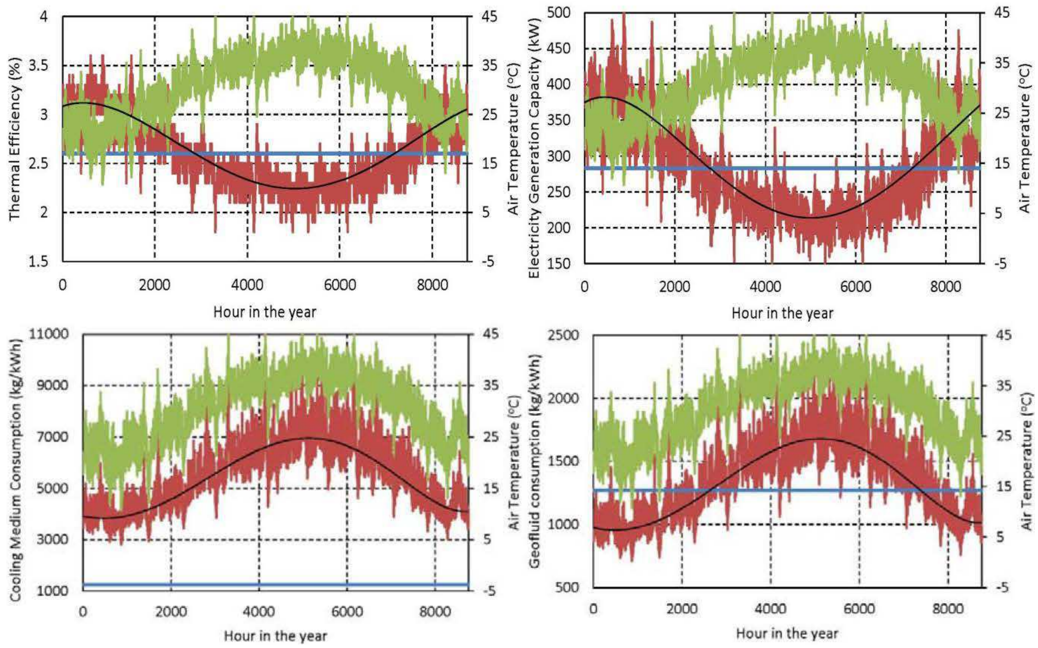

Figure 3- The calculation results of ORC at Qatar local conditions for geofluid flow rate 100 kg/s and temperature 100 ^{o}C, and the effectiveness of the heat exchangers are 80%

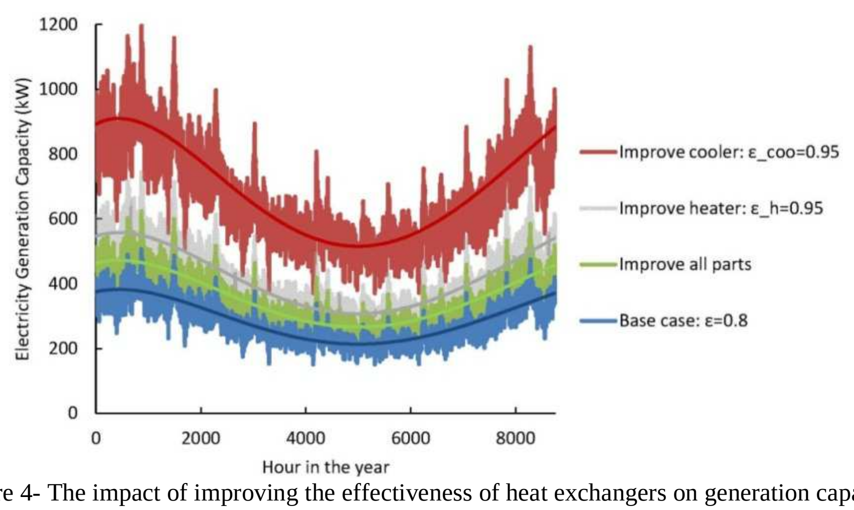

Figure 4- The impact of improving the effectiveness of heat exchangers on generation capacity

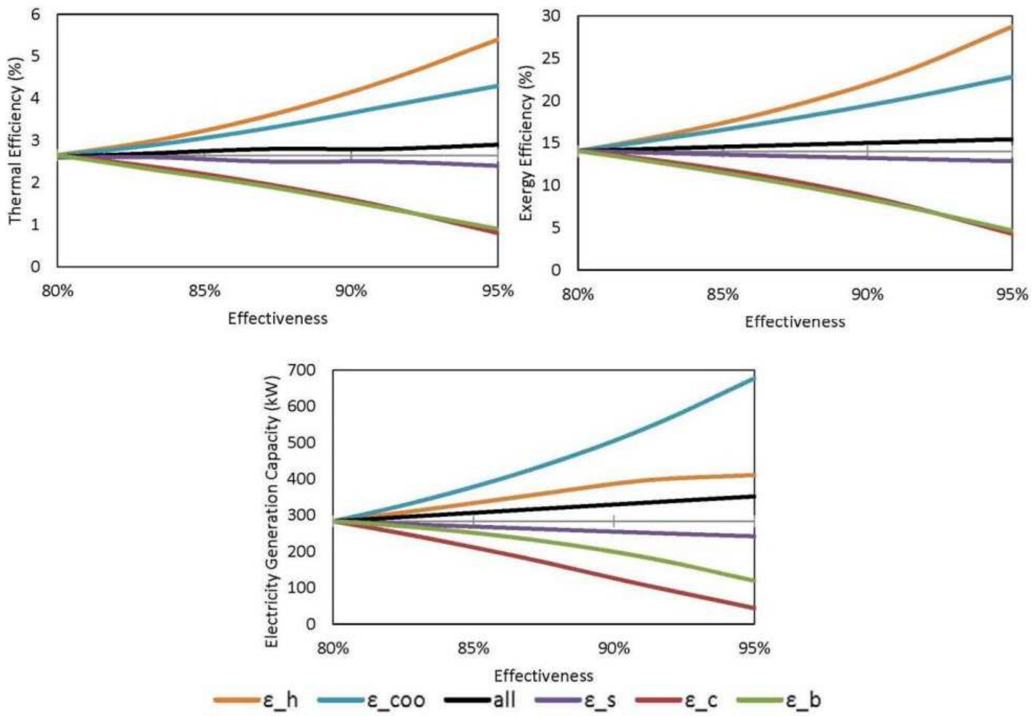

Figure 5- The impact of improving the effectiveness of individual parts of heat exchangers on thermal efficiency, exergy efficiency and generation capacity.

CONCLUSIONS

Traditionally, geothermal has been exploited in places with the plentiful hot water that is relatively shallow. In the light of fact that ground temperature increases with the depth everywhere on this planet, enhanced geothermal systems (EGS) can be installed everywhere to exploit the geothermal in generating energy. In oil producing states active or abandoned oil wells can be used as heat source of organic Rankin cycle. This way about 40 % of total investment cost of geothermal plants can be removed.

Performed calculations show:

- At working conditions of Qatar, R134a seems to be the best working fluid among examined ones.
- No benefit from using ground water for cooling the condenser from annual energy output viewpoint. Consequently, it is recommended to use air-cooled condenser to reduce the initial installation costs.
- Only the improvement of the heater and the cooler part of the heat exchanger have positive impact on the performance of the cycle.
- The improvement of the cooler has the biggest potential to improve the plant's energy output
- The improvement of the heater has the biggest potential to improve the plant's efficiency.
- Utilizing the oil wells as the heat source for organic Rankin has economical potential with the payback time less than 8 years and the levelized cost of electricity is 3.6US¢/kWh.

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