A Review of Geothermal Energy Resources for Electricity Generation in Oman

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Abstract:

Oman, like other Arab gulf countries, depends on oil and gas to produce electricity. However, these resources are not guaranteed to last forever and constitute one of the energy security issues in the country. Oman's oil and gas reserves are comparatively low to other Gulf Cooperation Council (GCC) member countries. This article explores the potential of using geothermal energy resources for electricity generation in Oman. Geothermal energy is counted as a type of renewable energy, which means the availability is not affected by the lack of source and the increasing price of fossil oil. The review of geothermal energy shows that cost of electricity generation and greenhouses gases emission is comparatively lower than other form of renewable energy resources. Different types of geothermal plants are discussed with a reference of required temperature for operation of these plants. The binary cycle geothermal power plants are used for low temperature applications (85–175 °C). The temperature of 55 bore holes in Oman is more than 100^{o} C which can be used in binary geothermal plants for electricity generation. The maximum temperature (173.68^{o} C) is at PDO well "Makarem-I" located in the northern part of Oman. There is opportunity for Oman to adopt renewable energy resources and explore the potential of geothermal in more detail. This will help the country to reduce the dependency on oil and gas and compete in the region towards adopting renewable resources.

Key Words: Energy, Natural Resources, Renewable Energy, Fossil Fuels

1. Introduction:

Oman's economy is heavily reliant on oil and gas revenues, which accounted for about 84% in 2014 of the country's export earnings and 47.2% of its gross domestic product (CBO, 2015, NCSI, 2015). All of Oman's domestic energy consumption is supplied by natural gas and oil, reflecting the country's relative abundance of oil and natural gas reserves. In 2011, oil accounted for 71% of Oman's total primary energy consumption, and natural gas made up the remaining 29%. With the exception of 2009, Oman's petroleum consumption rose steadily over the past decade, reaching 154,000 barrels/day in 2013. This further has a significant contribution towards greenhouses gases.

Oman, like other Arab gulf countries, depends on oil and gas to produce electricity. However, these resources are not guaranteed to last forever, and are one of the energy security issues in the country. Some of the gulf countries have diversified their energy resources for example, the Emirates has considered nuclear and renewable energy as part of their electric generation and Qatar aims to generate 20% of its energy from renewables by 2024 with 1800MW of installed green capacity by 2020. As for Oman, the progress of renewable energy development is at a slow pace as currently the electricity generation is still dependant on oil and gas. Omani Vision 2020 seeks to reduce dependence on oil, diversify the economy and create new employment opportunities for all citizens. Omani

Vision 2020 also stresses on the promotion of technology transfer and the increased use of natural and renewable resources, with due regard to the social and natural environment, which gives priority to the main key aspects (NCSI, 2008).

In the last two decades energy consumption in the Gulf Cooperation Council (GCC) member countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arab and United Arab Emirates) has increased rapidly. In 2013, the average electricity consumption in GCC countries was approximately 12370.91 kWh per year per capita while in China this value was 3762.07 (WB, 2016). GCC countries electricity consumption is more than double of the consumption per capita in United Kingdom, which is 5407.29 kWh. In 2013, the electricity consumption per capita in Oman was 5981.45 kWh. The main reasons for the high consumption rate of electricity in GCC countries is high temperature in summer and secondly the cost of electricity is very low compared to other countries. The low cost of electricity for both domestic and industrial users in GCC countries don’t encourage them to avoid the excessive use of electricity. In Oman, the electricity consumption is comparatively low than other GCC countries as Oman is somehow beyond in terms of infrastructures development and industrialization.

Umar and Wamuziri (2016) explore the potential of wind and solar energy in Oman and found that there is a huge opportunity to use these resources. This article provides a review of the geothermal energy resources in Oman by considering the temperature data from the Petroleum Development, Oman (PDO). Geothermal is derived from the Greek word; geo means earth, and thermal means heat, and it can be interpreted as a geothermal heat or energy produced from the earth. The temperatures of the 55 bore holes are more than 100^{0} C which can be used for the electricity generation through binary geothermal energy power plant.

2.1 Geothermal Energy:

Geothermal energy is counted as a type of renewable energy, which means the availability is not affected by the lack of source and the increasing price of fossil oil. The energy contained in the geothermal fluid is water of which can be in vapor phase, liquid or both as a mixture. The fluid is usually located at a more than 1km depth below the earth's surface. The energy (hot water) comes from the radioactive decay energy from the center of the earth where the temperature can reach 6650 °C, and this energy moves to the earth's surface by conduction and convection (DiPippo, 2007, Gehringer and Loksha, 2012). It is estimated that the energy flowed from this activities reaches up to 42 million MW. Geothermal energy occurs due to three important elements in a specific location within the earth: source of heat, water and permeable layer (Dickson and Fanelli, 2013). The water comes from the rain or melting snow into the earth and trapped in impermeable layer and forming geothermal source, as shown in Figure 1 (Muffler and Cataldi, 1978). Geo-thermal energy can supply the need of the world's energy consumption for100,000 years (Sofyan, 2012).

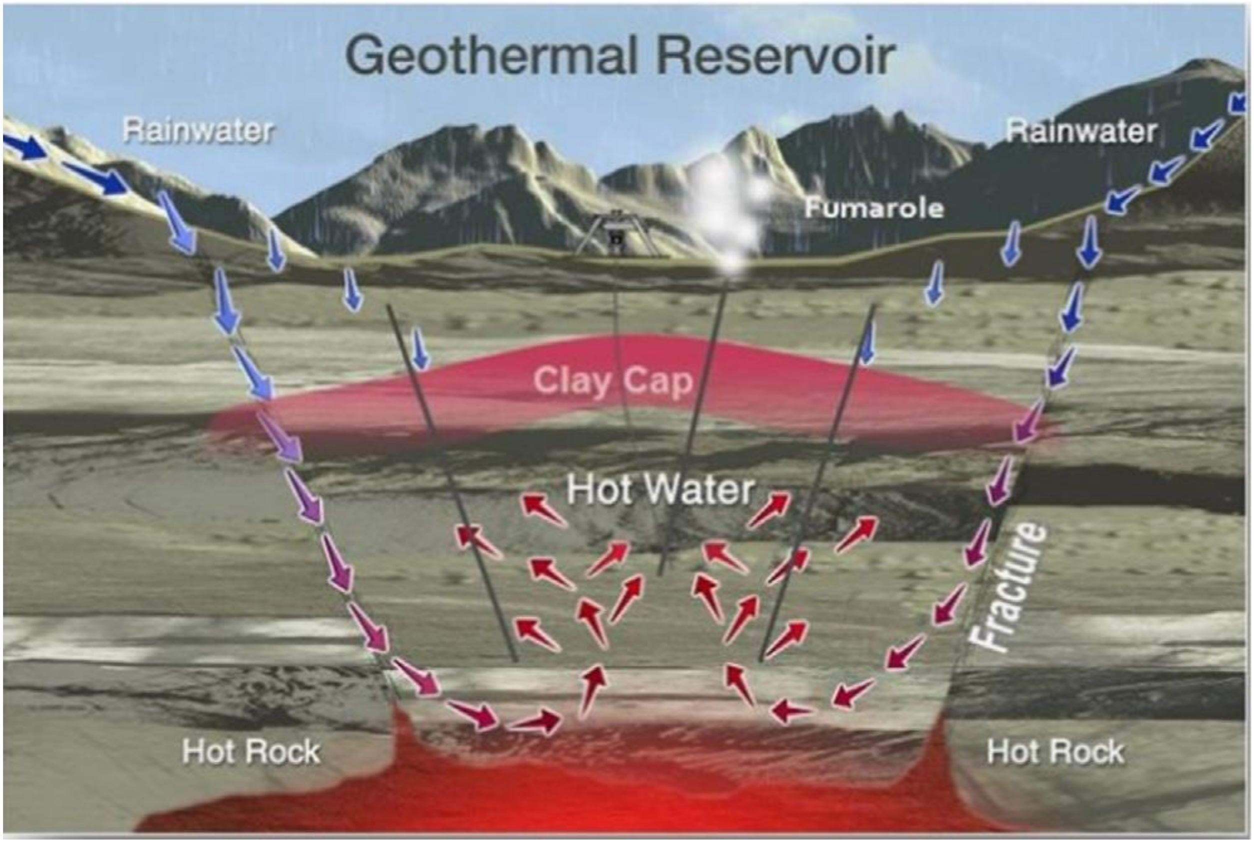

Figure 1: The Schematic of Geothermal (Ngangkham et al 2012)

Based on the fluid temperature, the enthalpy of geothermal energy can be classified into low, medium and high .Although sometimes classifying it can be confusing, it can be known by at least two variables to determine its thermodynamic state of the water (Lee 2001). Geothermal classification is still not standardized; some classifications separate geothermal in five categories based on its characteristics of reservoir. In order to provide the geothermal categories, table 1 can be used as the reference to obtain the five categories of geothermal such as hot water systems, two phase, liquid dominated systems, low enthalpy systems, two phase, liquid dominated, medium enthalpy system, two phase, liquid dominated high enthalpy system and two phase, vapor dominated systems (Eylem Kaya and O'Sullivan Michael 2011). Lower temperature (120–200 °C) requires pumping. They are common in extensional terrains, where heating takes place via deep circulation along faults, such as in the Western US and Turkey. Water passes through a heat exchanger in a Rankine cycle binary plant. The water vaporizes an organic working fluid that drives a turbine. These binary plants originated in the Soviet Union in the late 1960s and predominate in new US plants. Binary plants have no emissions. Heat pumps extract energy from shallow sources at 10–20 °C in 43 countries for use in space heating and cooling. Home heating is the fastestgrowing means of exploiting geothermal energy, with global annual growth rate of 30% in 2005 and 20% in 2012.

Category		**Temperature (T)**	**Production enthalpy (h)**
Hot-water		T < 220˚C	h < 943 kJ/kg
Two-phase, liquid-dominated	Low-enthalpy	220˚C < T < 250˚C	943 kJ/kg < h < 1100 kJ/kg
	Medium-enthalpy	250˚C < T < 300˚C	1100 kJ/kg < h < 1500 kJ/kg
	High-enthalpy	250˚C < T < 330˚C	1500 kJ/kg < h < 2600 kJ/kg
Two-phase, vapour-dominated		250˚C < T < 330˚C	2600 kJ/kg < h < 2800 kJ/kg

Table 1: Categories of geothermal systems (Eylem Kaya and O'Sullivan Michael 2011)

2.2 Geothermal Power Plants:

According to Mehmood et al (2016) Geothermal resources are available in three temperature ranges: (a) Low Temperature, (b) Moderate Temperature, and (c) High Temperature. Temperature greater than 150 °C is high temperature while, temperature more than 90 °C and less than 150 °C is moderate temperature and temperature lower than 90 °C considered as low temperature. For different ranges of temperature, separate geothermal plants are used for electric power generation. Geothermal energy used as power generation is usually referred as geothermal power plant and the power plants are environmental friendly, renewable and sustainable due to the characteristics of the energy source (Duffield and Sass, 2003; Jennejohn and Blodgett, 2012). CO2 emissions from coal fired power plants is12 times greater than the geothermal power plant, while the CO_2 emission from gas power plants produces 6 times larger than geothermal power plant (Nasruddin et al 2016). In addition, the area required for geothermal power plant is smaller than the area required by conventional power plant (Risch 2012). Another advantage of geothermal power plant is the ability to sustain base load electricity, since the energy produced does not fluctuate against the weather or season, hence continuous electricity production is possible Edrisi and Michael 2013; EPRI, 2010).

There are three types of geothermal power plants in use today, namely dry steam, flash steam and binary cycle. The dry type or direct steam power plant (figure 2) is the typical geothermal plant with steam vapor dominated (dry-steam). Dry steam generated from several production wells are circulated by pipes to the turbine. The high temperature and pressure steam rotates the turbine. This approach to utilize geothermal energy is restricted because dry-steam hydro thermal resources are very rare.

In flash steam power plant, hydrothermal fluids above 182 °C can be used 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”, also termed as “Wet Steam Power Plant”. The vapour 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. Hot water is collected in a vessel and as water pumps to the generator water is released from hot geothermal reservoir and abrupt change in pressure force some water to be converted in to steam. The steam rotates the turbine and finally electrical output received by generator that is operated by turbine action as presented in figure 3.

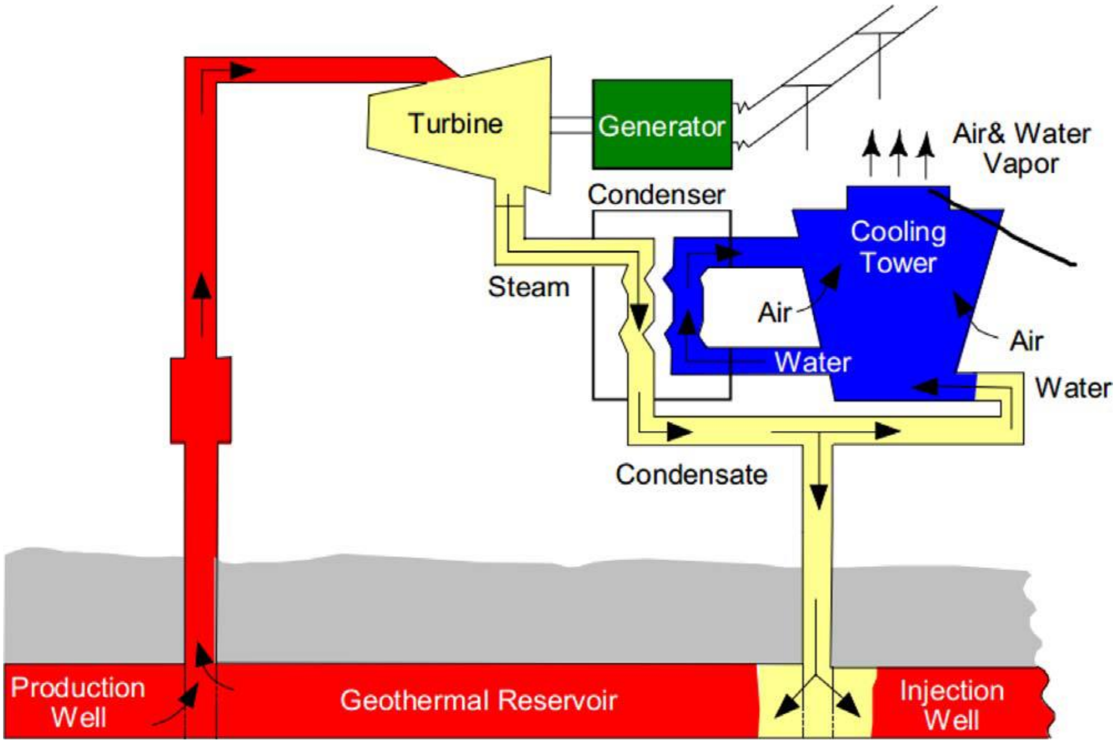

Figure 2: Dry or Direct Steam Power Plant (GSE, 2011; Kagel, 2009; Lund, 2009)

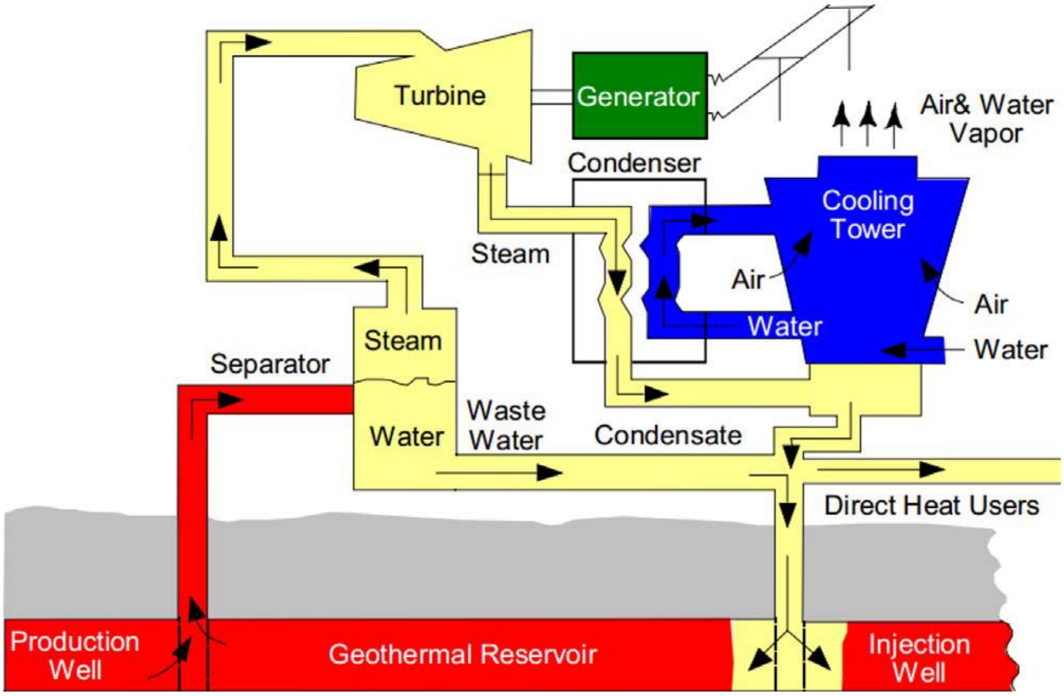

Figure 3: Flash Steam Geothermal Power Plant (GSE, 2011; Kagel, 2009; Lund, 2009)

Binary Cycle Geothermal Power Plants are used for low temperature applications. The hot water heat up another fluid having low Boiling Point (BP) organic compound, fluid like butane (BP=-0.5) by heat exchanger. Steam of that fluid is used to rotate the turbine and further turbine operate generator for electrical output. Two fluids in binary cycle power plant are:

a) Geothermal Fluid (Extracted from geothermal reservoir).
b) Working Fluid (Low boiling Point).

Geothermal fluid transfer its energy to working fluid using heat exchanger and working fluid is converted in to steam. The steam operates the turbine; steam is then condensed and prepared for the next cycle. Geothermal fluid is sent back to reservoir for maintaining internal temperature of the geothermal reservoir. Furthermore, binary cycle plant operated at temperature 85–175 °C. The temperature has very less carbon emission (Kose, 2007). The typical structure of the Binary Cycle Geothermal Power Plant is shown in figure 4.

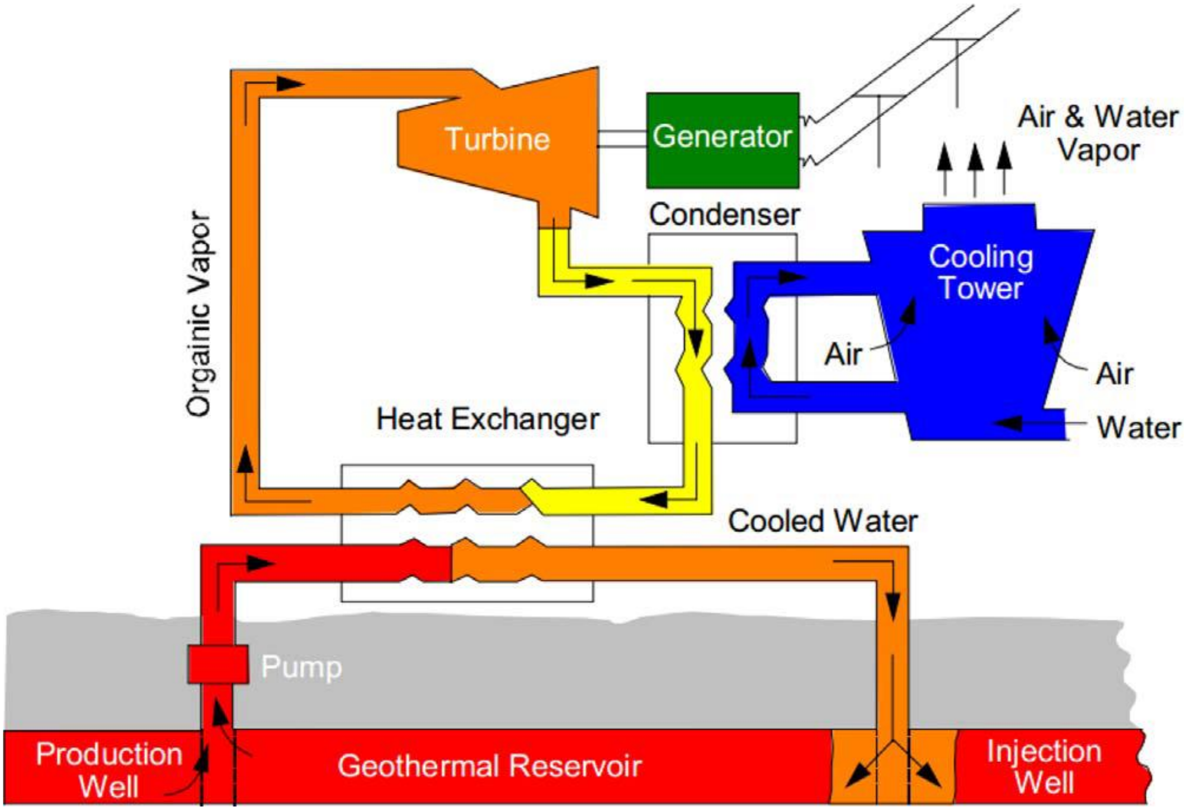

Figure 4: Binary Cycle Geothermal Power Plant (GSE, 2011; Kagel, 2009; Lund, 2009)

Research conducted by Shevenell (2012) on Nevada geothermal wells reported that geothermal projects cost might be expected to range from $835,000 to $3.4 million per MW if the drilling of well will be successful. Similarly, drilling costs per MW were estimated using all drilled wells (successful or not) and indicate costs could range from $341,000 to $1.1 million per MW. A typical breakdown of costs of completing a geothermal power production facility from beginning to end has been presented by GEA (2005) and Hance (2005) as shown in figure 5. Although the data presented here is more than 10 years older, however it helps to understand the cost of different stages of a geothermal power project. It is needed to note that the percentage of such cost may vary from country to country.

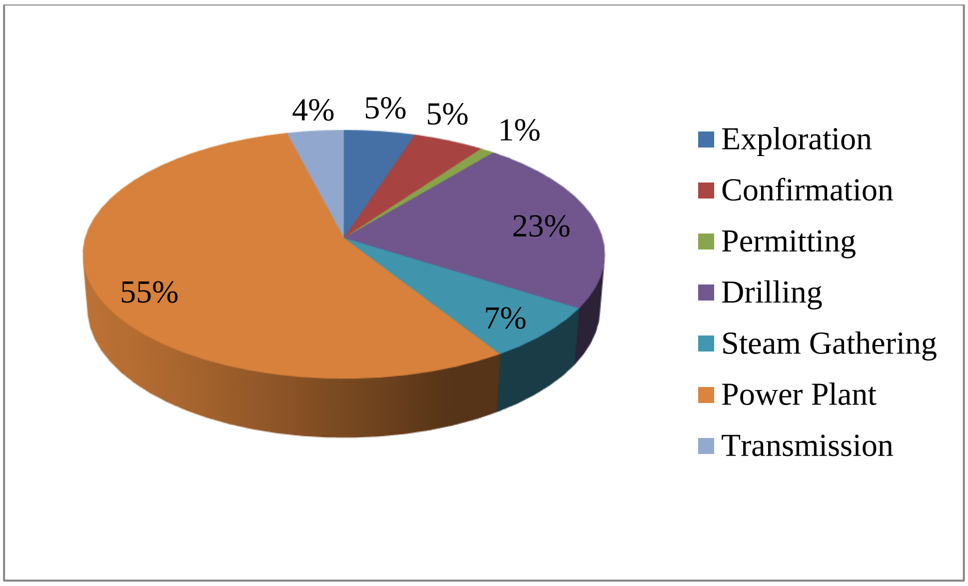

Figure 5: Typical cost breakdown of geothermal power projects (Hance 2005)

3 Geothermal Resources in Oman:

The underground fluid temperature is the key element and need to be considered to evaluate the potential of geothermal energy for electricity generation and other uses. Knowing the temperature will further help to use the appropriate geothermal plant for energy generation. The Oman hot water springs is one of the main prediction which justify that the lower temperature of the fluid could be comparatively high than the temperature of the water of these springs. According to the Oman Water Society (OWS, 2016), there are more than more than 360 water springs; most of which are in Musandam, Muscat and Dhofar Governorates and are non- traditional sources for fresh water. 23 springs are classified as hot water springs which are very famous for tourism and natural therapy. For instance the temperature of the spring at Al Kasfah (figure 6), located in Wilayt Ar Rustaq in Al Batinah South Governorate is 45 degree Celsius (MOT, 2016). To further explore the potential of underground temperature and to see the possibility of using geothermal energy in Oman, it was necessary to examine the fluid temperature at certain depth in Oman. Such exploration required boring to obtain sample from earth and examine to temperature and as such involve huge cost. The geothermal gradient can be used to estimate the depth of the desired temperature, however as the thickness of the crust varies around the world therefore using an average value of geothermal gradient (25°C/km) would not give an accurate results.

Figure 6: Al Kasfah Spring in Oman (MOT, 2016)

The only organization which conducts underground exploration in Oman is the Petroleum Development of Oman (PDO). The main purpose of PDO exploration is to search for new oil and gas reserve, however, measurement of sample temperature at certain depth is part of such exploration. PDO operates over 5000 well drillings in more than 120 oil fields in Oman. PDO is producing 7 barrels of well water per barrel of crude oil (5 to 6 million barrels of water a day). Most of the produced well water is re-injected in the same or new wells. The average temperature of the well water was estimated to 86° C (AERO, 2008). The latest data obtained from PDO show significant temperature (table 2) at different location of Oman, which could be used for energy generation. The 55 bore holes which have a temperature of more than 100° C are located in block 6 as shown in figure 7.

Well Name	**Temperature (° C)**	**Well Name**	**Temperature (° C)**
ABU THAYLAH	102.70	YIBAL IV	131.10
AL BASHAIR	157.00	ZALZALA	107.10
AL FAISAL	116.51	AL HUSAIN	125.00
AL NOOR	101.40	AL HUWAISAH I	126.40
AMBRAH	100.92	AL HUWAISAH II	110.00
ASEEL	100.48	AL HUWAISAH III	114.00
ASFOOR	117.74	AL HUWAISAH IV	124.00
BARIK	124.38	DHULAIMA I	104.00
DAFIQ	103.00	DHULAIMA II	157.80
FAAL	120.74	FAHUD	130.00
FAHUD SOUTH EAST	163.00	FUSHAIGHA	110.00
FAHUD SOUTH	106.60	HASIRA I	103.30
FAYROUZ	101.63	HASIRA II	103.00
INAAM	153.84	LEKHWAIR I	101.70
KHAZZAN I	157.65	LEKHWAIR II	160.00
KHAZZAN II	145.74	LEKHWAIR III	147.00
LAHAN	129.64	SAIH NIHAYDA	111.00
MABROUK I	121.10	SAIH RAWL I	100.60
MABROUK II	114.40	SAIH RAWL Ii	133.00
MAKAREM I	173.68	SHUWAIQI	118.90
MAKAREM II	170.00		
MUSALLIM	147.54		
NIBRAS	142.84		
QARN NIHAYDA	110.00		
QASHOOB	115.40		
RABAB	117.00		
SABEEL	114.00		
SAKHIYA	107.33		
SUWAIHAT	106.40		
TIBR	140.13		
YIBAL I	137.20		
YIBAL II	123.00		
YIBAL III	111.00		

Table 2: Temperature of 55 Bore holes (Temperature above 100^{o} C)

Figure 7: Location of Boreholes with Temperature more than 100° C

Considering the temperature data of different bore holes in table 2, the binary cycle geothermal power plant which operate at a temperature of 85 – 175° C, can be used for power generation. According to Parada (2013), the binary power plants are 44% of the world total geothermal power plants. A comparison of cost for electricity generation using different renewable sources is shown is figure 9. It is clear that the cost of electricity generation from geothermal binary plant is comparatively low than solar, hydro, wind and nuclear. Electricity generation costs for a 50 MW geothermal binary plant is $ 92 per megawatt hour (GEA, 2016). Such comparison provides a guideline to adopt an appropriate source of renewable energy in Oman. The maintenance of binary cycle power plants is highly influenced by different factors such as: the nature of the geothermal fluid used in the primary loop, the nature of the working fluid, the technology and location of the plant, climate and weather. Corrosion and scaling are the most common problems in binary power plants (Parada, 2013).

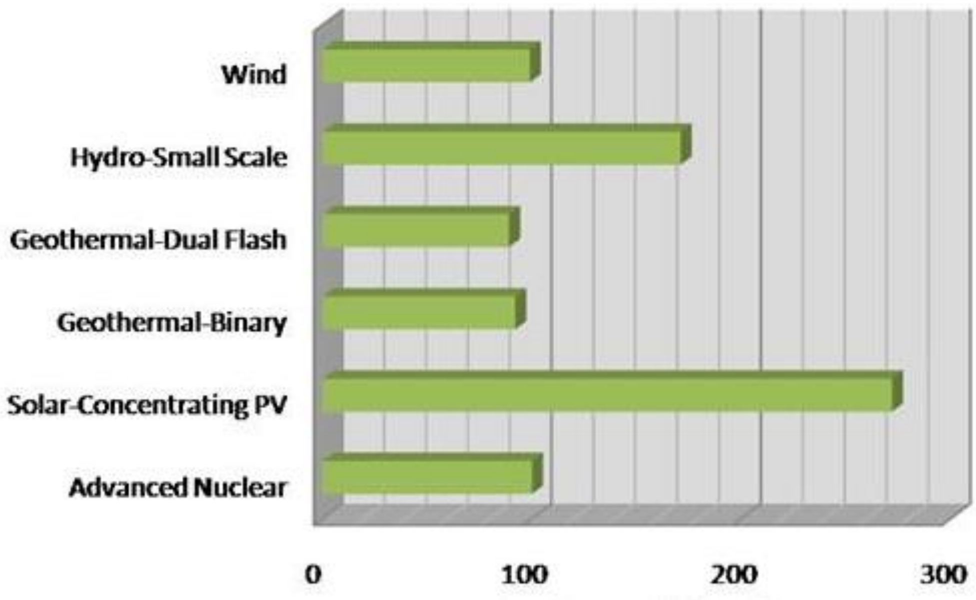

Figure 9: Electricity Generation Cost in US $ per 50 MWh from Different Renewable Energy Resources (GEA, 2016)

4 Conclusion:

The temperature data obtained from PDO of 55 bore holes indicates that there is potential of utilization geothermal energy resources in Oman. Considering the temperature of these bore holes, the binary geothermal plant can be used to produces electricity. Energy production cost of binary geothermal is low compared to solar and wind. The initial cost of the geothermal project is high while the success of drilling is the main contributing factor. The maintenance of binary cycle power plants is highly influenced by different factors including the nature of the geothermal fluid, the technology and location of the plant, climate and weather. Other issues with binary geothermal plants are corrosion and scaling. In GCC region, Emirates is has set the target to produces 25% of power by renewable sources by 2030 and Qatar aims to generate 20% of its energy from renewables by 2024. Emirates have recently started the feasibility study on the use of geothermal resources. There is an opportunity for Oman to consider geothermal energy resources and to reduce the dependency on oil and gas. This research is exploratory in nature and considers the temperature data for the potential use of geothermal resources in Oman. The data presented in this article is from the PDO, keeping in mind that the main focus of PDO is on the oil and gas resources. The depth of required temperature to use the geothermal resources will be a factor that will contributes towards the cost and needs to be considered during the feasibility study. While planning for using geothermal resources, Lund (2009) suggest that several environmental impacts including emission of harmful gases, noise pollution, water use and quality, land use, and impacts on natural phenomena, wildlife and vegetation needs to be considered.

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