Simulation of Geothermal Energy obtained from Potential Oil and Gas Wells for Power Production Analysis

Tahir H Soomro[a], Muhammad Ali Abro[b], Zaheer H Zardari[c], Majid Ali Wassan[b]

[a] *Department of Energy Systems Engineering, Mehran University of Engineering and Technology, Pakistan*
[b] *Department of Mechanical Engineering, Mehran University of Engineering and Technology, Pakistan*
[c] *Department Petroleum and Natural Gas Engineering, Mehran University of Engineering and Technology, Pakistan*

Abstract

Energy demand of the World is increasing and fossil fuel based resources of energy generation are declining day by day, hitting a massive burden on energy sector specifically on oil and gas industry. Lots of depleted petroleum wells are to be shut down when they cross their economic limit. So, in order to meet world's energy demand, it is necessary to move towards some modern techniques. To overcome these challenges, the renewable energy is the best option with production optimization in oil and gas industry. However, amongst renewable energy sources, geothermal source of energy is considered to be one of the significant energy resources due to its sustainability and presence. There is presence of massive amount of geothermal energy in the high temperature oil and gas wells which are abandoned/depleted from which geothermal energy could essentially be extracted by different techniques. Geothermal energy literally is the environment friendly; it reduces Carbon dioxide emissions and decreases economic burden on petroleum sector. In this research study, authors deliberate the technical factors of electricity production through producing oil wells especially those oil wells which have high temperature and water production which can be utilized by extracting the geothermal energy of the reservoirs. The key elements that regulate the well head temperature are mass flow rate and formation temperature. In this research study, a theoretical design system i.e Simulation is proposed based on evaluation of oil producing wells in the TAL block region in order to produce power from producing oil wells with the help of Solid Works Software and we have achieved some optimistic results. Ten (10) oil wells from TAL block were chosen with different mass flow rate and insignificant well head temperature difference. We utilized the temperature of primary fluids i.e oil & water coming from oil wells near 72-98° C and this temperature heats up the secondary fluid i.e binary fluid to run ORC (Organic Rankine cycle). Authors obtained the minimum net power output at the oil mass flow rate of 0.624907 kg/s at 77 kW with 8.5% thermal efficiency and maximum net output 113 kW at mass flow rate of oil 3.193 kg/s with 10.53% thermal efficiency. The total net power output generated from ten (10) wells is 947 KW. This produced energy will decrease cost of power utilized at petroleum fields and will decrease the economic burden on the oil industry as well.

Keywords: *Geothermal Energy Binary cycle power plant; Hydrocarbon gas and oil wells; Producing wells.*

1. Introduction

About one third of the world´s population and two billion people, have no approach to modern energy benefits [1]. A primary issue to improve the standard of living is to make clean energy accessible to everyone at prices anyone can afford. Energy impacts all aspects of modern life. The biggest challenge, the energy industry faces today, is how to meet the growing demand for energy on the other hand, reduction in the unconventional energy sources/fossil fuel based generation of energy, as fossil fuel reserves are going to be depleted.

Day to day depletion of unconventional/non-renewable energy sources such as (oil, gas and coal) and increasing energy demands of world putting a great concern. To solve this problem, greater efforts should be done to develop renewable energy resources otherwise our future is to be seen dark [2]. Pakistan needs substantial development to meet its growing current and future demand growth of energy. Total power generation capacity of the country in 2019 stands at 33,554 MW, of which 70% is thermal, followed by hydroelectricity (21%), nuclear stands at (4%) and renewable energy's share is (5%) [3].

Alternative energy/renewable energy resources offer an environmentally friendlier option as compared to unconventional energy sources in particular to the thermal energy. Global trend in renewables energy is growing, whereas renewables in Pakistan is still in its early stages which makes around 5% of total installed capacity. Among

*Corresponding author. Tel.: N/A; fax: NA
E-mail address: tahirsoomro.dgoil@gmail.com

renewable energy sources, geothermal source of energy is considered to be one of the important energy resources [4]. Geothermal energy is found under the surface of earth at the smaller depth and at the temperature of around 50°-60°F (10°-16° C) at the surface of the earth [5]. Geothermal energy helps in reducing the releasing of carbon dioxide. Different types of geothermal operating units are at hand for multiple ranges of temperature. In all the plant units of geothermal, power is obtained through the conversion of thermal energy of the fluid [6].

Pakistan's electricity generation is largely dependent on unconventional sources (fossil fuels), presently contributing around 62% of power capacity generation, with most of the fuel being imported [7]. Pakistan has immense potential for renewable energy due to its extensive landmass & a diverse geography. Geothermal source of energy will contribute to meet the power/energy requirements of Pakistan as well as will accomplish the power demand of field or plant available there [8].

Geothermal is reliable source of energy due to its availability. Utilization of oilfield thermal energy is not only reducing the use of oil, gas but could also provide new path for oilfield diversification and future development. Use of thermal energy has bright future in oil field [2]. Geothermal source of energy has manifested authentic, feasible, reliable, secure and clean; therefore, it is sustainable source of energy. Power generation, cooling and heating is also achieved [4]. More polluting fossil fuel and nuclear energy sources will also be replaced in the upcoming time period as well as in present scenario of lack of fossil fuel, their huge cost factor and environmental impact will also be diminished. The Authors stated that, throughout the world, countries are increasingly heading towards alternative energy for power generation. Wind power and Solar technology have made splendid success in decreasing cost and increasing efficiency [9].

Pakistan has been relying heavily on expensive imported oil to fuel its thermal power plants. However, now a reduction in imported oil-fired power generation and increase in coal and RLNG based generation is seen [10]. This trend shift has reduced the cost of generation, but it's just one form of fossil fuel imports being replaced by others [11]. Amongst sources of renewable, geothermal energy source is more reliable source of energy due to its availability.

Despite having renewable resources, Pakistan has lagged behind in installing geothermal power plant. Pakistan should utilize excellent renewable energy resources by increasing energy security through more hydrogenation. Pakistan has large number of a geothermal reservoir containing hot fluid [11]. Moreover, geothermal energy is one of the plentiful, feasible, cleanest, authentic as well as known to be sustainable source of energy. Thus, it emits less emissions of CO2 as compared to fossil fuels like coal, oil, and gas [4]. Moreover, availability of the geothermal energy throughout the day is one of its fundamental advantage, so called base load energy resource, while other renewable sources like solar works only in day time in presence of sun light and wind turbines are dependent on the condition that they work only in the suitable wind speed [12].

The motive of the research is to propose a method by which electrical power output could be produced with the help of binary cycle power plants to generate geothermal energy from conventional methods such as use of moving oil and gas wells by drawing out geothermal capability of the geothermal reservoir under the surface of earth. [13]. This technique will permit generation of geothermal energy in the presence of moving hydrocarbons in wellbore. With the help of this approach, a large quantity of power can be generated through utilizing moving fluid during the oil and gas production from the oil and gas wells.

This research work will provide appropriate understanding for choosing suitable type of geothermal power generation plant depending on the temperature of fluid available in the reservoir or well. Moreover, Maximum power generation techniques will also be helped out. There are numerous techniques are used to explore the geothermal energy from the earth's subsurface. (i) Dry-steam power plant (ii) flash steam power stations (iii) Binary Cycle Power Plant. Binary cycle power plant is recent and widely used technique for power production form low temperature wells which uses low temperature geothermal fluid about 55° C to heat the organic fluid of lower boiling point and turns turbines to generate Power. In binary cycle power plant different cycles are used to generate power from hot fluid. Rankine cycle is also one of them which is categorized into various classes such as water Rankine, organic Rankine, and other multi-fluids cycles. Working fluids for the Rankine cycle are formed of water, organic fluids of different kinds, or combination of multi-fluids or binary fluids. Refrigerants or any other organic working fluids are utilized in the Organic Rankine Cycle which inter-alia smaller boiling points as working fluid is widely utilized in power production technique from a wide range of low and intermediate temperature heat forms with geothermal, solar thermal, ocean thermal and industrial excess heat. The working fluid chosen based on the temperature of the heat sources on the basis of the temperature of the reservoir. We are suggesting organic Rankine cycle for power production. The organic Rankine cycle is a thermodynamic cycle that works on the similar Rankine cycle but uses R134a as the working fluid, due to the specific thermodynamic properties of the working fluid.

2. Organic Rankine Cycle Proposed Model

The fundamental constituents of organic rankine cycle are heat exchanger, turbine, pump & condenser. In order to overcome the expanses of well drilling oil wells are planned for extracting geothermal energy. Proposed technique seen in Fig. 1 uses the heat energy of oil wells for the production of eletrical power to decrease the economic burden of oil and gas industry and meet power requirement and to supply power for surrounding societies as well.

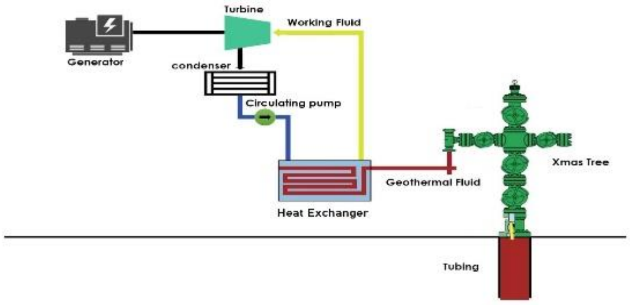

Fig. 1: Proposed Model of Organic Rankine Cycle

The high temperatures of the geothermal fluid extracted from the oil producing tank pass from the separator, the heat exchanger and return to the water storage area by injection well. Geothermal liquids with temperatures below 50° C are difficult to dissipate with the help of a light steam power station that can supply electricity efficiently and efficiently. In the lower geothermal enthalpy system, it is usually best to use a binay energy cycle plant based on the Kalina Cycle Kalina cycle to extract electricity. A mixture of ammonia-water (organic matter) is used as an active liquid in the Kalina-based binary cycle. Geothermal heat taken from high-temperature liquids is transferred from high-temperature liquids to binary (active fluids) as the hot liquid reaches the temperature change. The heating fluid relaxes one stage, yet its temperature gradually decreases between the outlet and inlet of the heat exchanger as it transports heat. The active fluid raises the temperature to room temperature and becomes isothermal until it evaporates completely.
After removing the heat, the high-temperature liquid remains cool and condensed to flow underground by injection thoroughly. Picture. 1 shows a diagram of the system of the binary cycle process. Binary fluid passes through a turbine and then moves to a liquid phase in the condenser while the liquid moves to a separator where oil, gas and water are dispersed and in the proposed model the liquid system structures of the R-134a can be shown in Table 1.

Table 1: Properties of R-134a

Properties	R-134a
Critical temperature	252° F or 122° C
Ozone depletion level	0
Solubility in water	0.11% by weight at 25° C
Boiling point	-14.9° F or -26° C
Auto Ignition Temperature	1418° F or 770° C
Global warming potential	1200

3. Modeling and Simulation

Model of the temperature switch below as shown in Fig. 2, designed by SOLIDWORKS according to the size taken from the book review consisting of seven tubes each 2540 mm long and 2.5 mm wide. Although, the inner diameter of the tube and shell are 85 mm and 132 mm, the six baffles and the inner diameter and outer diameter are 381 and 386 mm respectively, however, the material used for the heat exchanger is copper due to its thermal properties.

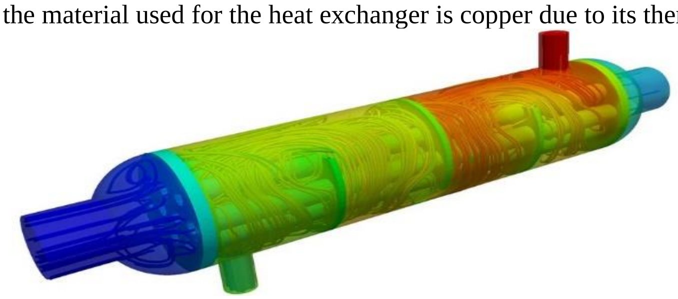

Fig. 2: View of Copper 3D Model Heat Exchanger

Initial Boundary conditions for the proposed model layout are tabulated in below Table. 2.

Table 2: Boundary Conditions for Heat Exchanger

Well No.	m (Oil) [kg/s]	T (Oil) [K]	m (R134a) [kg/s]	T (R134a) [K]
1	0.624907	332.4492	3	237
2	0.708333	334.116	3	237
3	1.810185	334.6716	3	237
4	2.211574	336.3384	3	237
5	2.5925	339.1164	3	237
6	2.633426	339.1164	3	237
7	2.850648	343.0056	3	237
8	3.023796	344.1168	3	237
9	3.148148	346.3392	3	237
10	3.193796	346.3392	3	237

The basic thermodynamics processes of Binary Cycle are presented by the equations (1) to (6).
The heat transferred in heat exchanger to the working fluid is

$$Qe = m_{NG}(h_{S1} - h_{S2}) = m_{R134a}(h_2 - h_1) = m_{NG}Cp_{NG}(T_{S1} - T_{S2}) \quad (1)$$

The work of the turbine (WT) is

$$W_T = m_{R134a}(h_2 - h_3) = m_{R134a}\eta_t(h_2 - h_{3s}) \quad (2)$$

The heat transfer in the condenser is given by

$$Qc = m_{cw}(h_{CW3} - h_{CW1}) = m_{R134a}(h_3 - h_4) \quad (3)$$

The work of the pump can be calculated as follows

$$\mathrm{W_p} = m_{\mathrm{R134a}}(\mathrm{h_1} - \mathrm{h_4}) = m_{\mathrm{R134a}}\eta_{\mathrm{t}}(\mathrm{h_1} - \mathrm{h_{4s}}) \quad (4)$$

The work net output is

$$W_{net} = W_T - W_p \quad (5)$$

The thermal efficiency is

$$n_{th} = \frac{W_{net}}{Q_e} = \frac{(W_T - W_p)}{Q_e} \quad (6)$$

4. Results & Discussion

The ultimate aim of this research study is to propose a model of heat exchanger and execute thermodynamic study of organic rankine cycle such as heat exchanger inlet mass flow rate (m) and temperature (T). The consequences of these constraints on turbine inlet temperature, net output and thermal efficiency is inspected. Thermodynamic evaluation of R134a under fluctuating state of turbine inlet temperature is carried out using above six (1-6) energy equations. R134a used in the system was in liquid state at the heat exchanger inlet and no need of preheating due to its low boiling temperature. Input parameter for the heat exchanger simulation is given in Table 2. Values indicated in the Table 3 are inlet factors & outlets parameters of turbine. Ten (10) oil wells were examined and considered as geothermal wells for the analysis having different mass flow rate and pressure however, temperature is assumed as normal temperature. Study determines that the impact of mass flow rate of oil and is observed form Fig.3 that increasing mass flow rate of oil increases the turbine inlet temperature values and mass flow rate has directly impact on heat transfer rate. At minimum mass flow rate of 0.624907 kg/s temperature achieved at turbine inlet is 25.9° C and at maximum mas flow rate of 3.193 kg/s achieved turbine inlet temperature of 38.5° C.
This graph is based on estimation that the working fluid arrives in the turbine which is at saturated state and the condensation temperature is keot -10° C. Variation in output work of turbine with rise in turbine inlet temperature is obtained in Fig. 4. The output work of turbine is rising from 87 kW to 123 kW with rise of temperature at turbine inlet from 25.9° C to 38.5° C.
It is analyzed from the simulation that there is direct impact on heat transfer by mass flow rate of primary fluid and temperature correlation amongst oil mass flow rate in heat exchanger and output work of turbine as shown in Fig. 5. Above graph in rising trend indicates that the increase in turbine work output by increasing the oil mass flow rate in heat

exchanger. At 0.624907 kg/s mass flow rate the output achieved is 87 kW by rising the mass flow rate up to 3.193 kg/s the output obtained is 123 kW.

Table 3: Turbine Inlet and Outlet Parameters

Well No.	m(R134a) [kg/s]	T_2 [K]	P_2 [MPa]	T_3 [K]	P_3 [MPa]	h_2 [KJ/kg]	h_3 [KJ/kg]	W_T [kW]
1	3	298.9	0.105	262	0.06	274	245	87
2	3	300.6	0.105	262	0.06	276	245	93
3	3	302.7	0.105	262	0.06	278	245	99
4	3	303.3	0.105	262	0.06	279	245	102
5	3	304.8	0.105	262	0.06	280	245	105
6	3	305.2	0.105	262	0.06	280	245	105
7	3	305.5	0.105	262	0.06	280	245	105
8	3	306.2	0.105	262	0.06	281	245	108
9	3	310.3	0.105	262	0.06	285	245	120
10	3	311.5	0.105	262	0.06	286	245	123

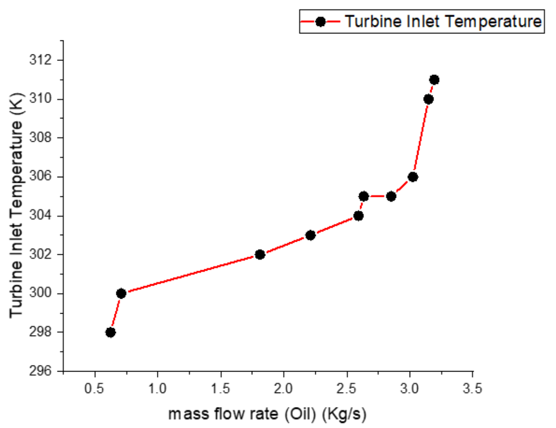

Fig. 3: Mass flow rates of Oil Viz a Viz Turbine Inlet Temperature

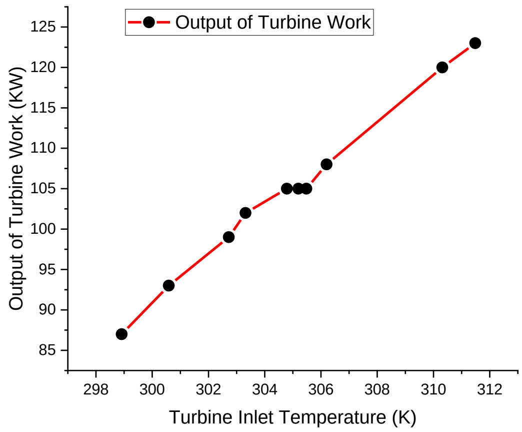

Fig. 4: Output of Turbine inlet temperature Viz a Viz Turbine Output

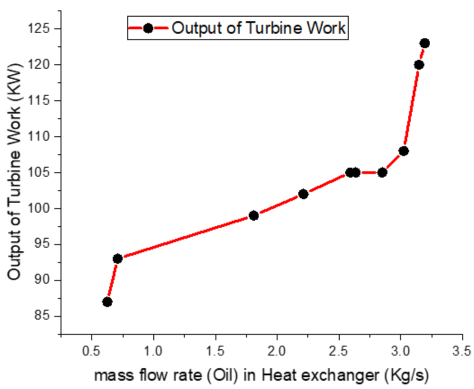

Fig. 5: Output of Turbine Viz a Viz mass flow rate of oil in heat exchanger

This analysis shows the correlation between the average flow rate of an oil well i.e. the total turbine output capacity and the thermal efficiency of the plant. The trend for this graph is shown in Fig. 6 shows that the increase in the flow rate of the oil source weight based on the pressure of the main fluid has the effect of the output of the residual energy obtained on the turbine and the thermal efficiency also increases. The maximum net power produced in the turbine is 123 kW and the maximum thermal efficiency is 10.53% with a maximum oil source flow rate of 3.193 kg /s.

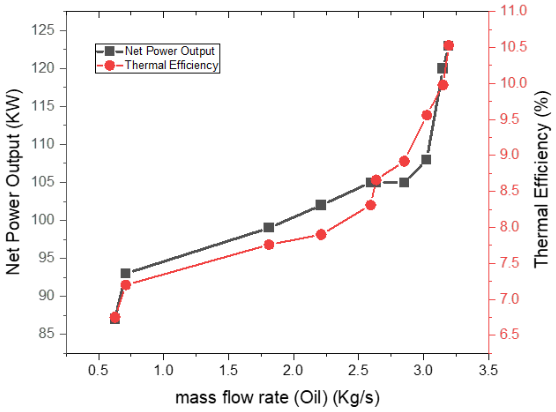

Figure 6: Oil well mass flow rate Viz a Viz net output of power & thermal efficiency

There is direct correlation amongst geothermal oil well and the output power obtained by each well at normal flowing temperature and distinct pressure is indicated in Fig. 7. Well No. 1 having minimum mass flow rate and normal temperature of reservoir around 59° C produced 87 kW power and well no. 10 having maximum mass flow rate and slightly increase in temperature generates 113 kW of net power.

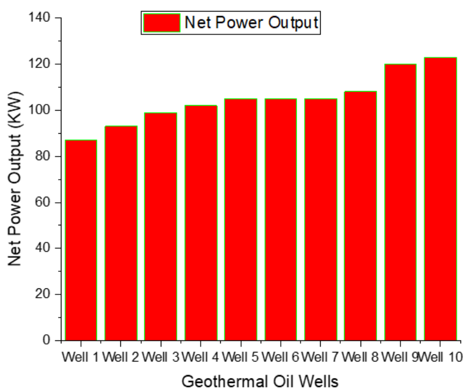

Fig. 7: Geothermal Oil well and net power from each well

5. Conclusion and Recommendations

In this research study, authors have conducted analytic approach based on binary cycle power plant for oil wells as geothermal well and concluded as under:

i. Unavailability of energy and massive economical burden on oil and gas industry can be curtailed by employing this method.
ii. This technique uses high temperature oil extracted from oil well to produce electrical power.
iii. Net Power of 113 kW can be produced by using geothermal fluid i.e., with mass flow rate (oil) of 3.193 Kg/s
iv. With increasing mass flow rate of fluid impacts rise in working fluid temperature but also increase output of electrical power.
v. Total gross electrical power production from ten (10) wells is 1047 kW and Net power is 947 kW at average temperature of 67° C at varying mass flow rates of ten different wells.

Finally, the future recommendations for electrical power productions can be defined as under:

i. Appropriate selection of binary fluid.
ii. Selection of oil wells with high temperature & mass flow rate
iii. Producing oil & gas wells with thermal potential
iv. Abandoned oil & gas wells with thermal potential.

Acknowledgment

The authors are thankful to Mehran University of Engineering & Technology and MOL Oil & Gas Co B.V (Upstream Oil & Gas Industry) for their support regarding this research study.

References

[1] Pakistan Energy Outlook (PEO), 2019, Petroleum Institute of Pakistan.
[2] Moya, D., Aldás, C., & Kaparaju, P. (2018). Geothermal energy: Power plant technology and direct heat applications. Renewable and Sustainable Energy Reviews, 94, 889-901.
[3] Hou, J., Cao, M., & Liu, P. (2018). Development and utilization of geothermal energy in China: Current practices and future strategies. Renewable Energy, 125, 401-412.
[4] W. Johnston, (2019). Emerging Geothermal Energy Technologies, KSCE Journal of Civil Engineering (2011) 15(4):643-653 DOI 10.1007/s12205-011-0005-7.
[5] Gondal, I. A.; Masood, S. A.; Amjad, M. J. R. and Reviews, S. E. (2017) Review of Geothermal Energy Development Efforts in Pakistan and Way Forward. 71, 687-696.
[6] Aniko N. Toth (2020). Direct Utilization of Geothermal Energy 2020 Worldwide Review, Proceedings World Geothermal Congress 2020 Reykjavik, Iceland, April 26 – May 2, 2020.
[7] Wang, S., Yan, J., Li, F., Hu, J., & Li, K. (2016). Exploitation and utilization of oilfield geothermal resources in China. Energies, 9(10), 798.
[8] Muhammad Wakeel, et.al., (2015), Overview of energy portfolio in Pakistan, CUE2015-Applied Energy Symposium and Summit 2015: Low carbon cities and urban energy systems, Energy Procedia 88 (2016) 71 – 75.
[9] Jefferson Tester, et.al., (2011), The Future of Geothermal Energy, Review of Title II, Subtitle B- Geothermal Energy of EPAct; and other renewable programs and proposal for public resources" Thursday, April 19, 2011
[10] Derek H. Freeston, et.al., (2013), Direct Utilization of Geothermal Energy 2010 Worldwide Review, Proceedings World Geothermal Congress 2010 Bali, Indonesia, 25-29 April 2010.
[11] Javed Ahmad, et.al., (2014), The Geothermal Energy Potential of Pakistan Clean Sustainable Solution for Our Energy Future, GRC Transactions, Vol. 38, 2014.
[12] Derek H. Freeston, et.al., (2013), Direct Utilization of Geothermal Energy 2010 Worldwide Review, Proceedings World Geothermal Congress 2010 Bali, Indonesia, 25-29 April 2010.
[13] Nayyer Alam Zaigham, et.al., (2010). Renewable hot dry rock geothermal energy source and its potential in Pakistan, Renewable and Sustainable Energy Reviews 14 (2010) 1124–1129
[14] Wang, K., Liu, J., & Wu, X. (2018). Downhole geothermal power generation in oil and gas wells. Geothermics, 76, 141-148.
[15] Mehmood, A., Yao, J., & Fun, D. Y. (2017). Future Electricity Production from Geothermal Resources Using Oil and Gas Wells. Open Journal of Yangtze Oil and Gas, 2(04), 191.
[16] Ahmad, I., & Rashid, A. (2010). Study of geothermal energy resources of Pakistan for electric power generation. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 32(9), 826-838.
[17] Abbas, T., Bazmi, A. A., Bhutto, A. W., & Zahedi, G. (2014). Greener energy: Issues and challenges for Pakistan-geothermal energy prospective. Renewable and Sustainable Energy Reviews, 31, 258-269.
[18] Barbier, E. J. R. and reviews, s. e. (2002) Geothermal Energy Technology and Current Status: An Overview. 6, 3-65.