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A Novel Approach for Downhole Power Generation in Geothermal Wells Using Thermoelectric Generator

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ABSTRACT

An account of animated recent technological upgrades, rising demand over the sustainability and the prospect of environment-friendly, sustainable power with adequate proportion; geothermal energy sources have drawn the attention around the globe. In the traditional geothermal field, the hot water produced from geothermal wells are utilized for electricity generation by a binary power plant system. To enhance the thermal recovery, we proposed an innovative downhole power generation method and demonstrate the promising method in terms of operation expenditure, extending the economy of well and influence on the environment. The present method incorporates the integration of well completion, production tube, and thermoelectric generation technology. In this method, the thermal energy is converted to electrical energy in downhole by thermoelectric generator (TEG) installed on the outer side of the production tube. Additionally, the mathematical heat transfer model is demonstrated which gives the temperature distribution profile of well to evaluate the efficiency of TEG. This proposed method capitalizes and implements existing geothermal productions well and retrofit them for electricity generation. This method can be good complementary for a geothermal power plant and extend the economy of wells.

1. INTRODUCTION

Considering the growing demand for replacement of coal-fired energy, the world has drawn attention towards reliable, economical, environment-friendly renewable energy sources. Therefore, renewable energy sources (e.g., solar, wind, geothermal, tide) are being explored and developed as an alternative solution for future energy resources. As a renewable energy resource, geothermal energy offers considerable resource potential, low carbon emission, and widespread distribution (Song et. al 2017). One of the promising technologies that might raise geothermal power growth is the Thermoelectric generation (Li et al., 2015).

The concept of a thermoelectric generator has been explained in this framework with the aim of downhole electric power generation to extend the economics of well and reduce the waste heat in well. Thermoelectric technology directly converts thermal energy into electrical energy by the Seebeck effect. The main advantage of the TEG includes no maintenance because it does not contain any moving parts. Additionally, TEGs operations are clean, environment-friendly and have a long-life span. However, the efficiency of the method is about 5-10% although TEG has great potential. For decades, all the researchers are trying to power generation from the TEG at the surface. However, all attempts are to promote the electric power at the surface and very little attention has been paid on in-situ power generation which gives the highest temperature.

This paper highlighted the downhole power generation in geothermal wells which are applied to harness in-situ geothermal energy for electricity generation. The thermoelectric module converts thermal energy into electric energy. Moreover, the mathematical solution of heat transfer is demonstrated which give temperature distribution profile of well and ultimately efficiency of the TEG can be calculated.

2. WORKING OF THERMOELECTRIC TECHNOLOGY

The basic principle of the TEG system is based on the Seebeck effect (a type of thermoelectric effect) of thermoelectric materials. Thermoelectric (TE) materials are formed by the integration of the p and n-type of semiconductors where p (positive) side contains excess holes and n (negative) side contains a surplus of electrons in outer cells to carry the electric current. When the temperature difference is created between the hot and cold surface of TE material, free charges of semiconductors are in movement through p-n junction and this movement of charges convert heat energy into electric energy. This large number of TE material which contains semiconductors are electrically connected in series and thermally connected in parallel to enhance the output electric power. This chain of connected several TE materials is called the Thermoelectric module. Some standard materials to form a TE module are tellurium (Te), antimony (Sb), bismuth (Bi) or selenium (Se) (Mahalakshmi and Kalaiselvi, 2014). When the temperature difference is created, a created voltage V is given by the following equation,

$$V = \propto (T_H - T_C)$$

Where T_H is the hot side temperature of the thermoelement, T_C is the cold side temperature of the thermoelement and $\propto$ is the Seebeck coefficient (V K^{-1}) of the thermoelement. The generation of electric power will depend on temperature difference, characteristics thermoelectric material, and external load resistance (Wang et al. 2018). The effectiveness of the material to produce a thermoelectric power is given by its figure of merit zT,

$$zT = \frac{\propto^2 T}{KR} = \frac{\propto^2 \ (T_H + T_C)}{2K\sigma}$$

Where T is the temperature (K), $\propto$ is the Seebeck coefficient (V K^{-1}), K is the thermal conductivity (W/mK), R is the resistance (Ω) and σ is the electrical resistivity (Glatz et al. 2009).

The efficiency of the TE module used in TEG can be calculated by the following equation,

$$\eta = \frac{T_H - T_C}{T_H} \frac{\sqrt{1 + ZT} - 1}{\sqrt{1 + ZT} + \frac{T_C}{T_H}}$$

Where T is the average temperature $(T_H + T_C)$/ 2 and zT is the figure of merit.

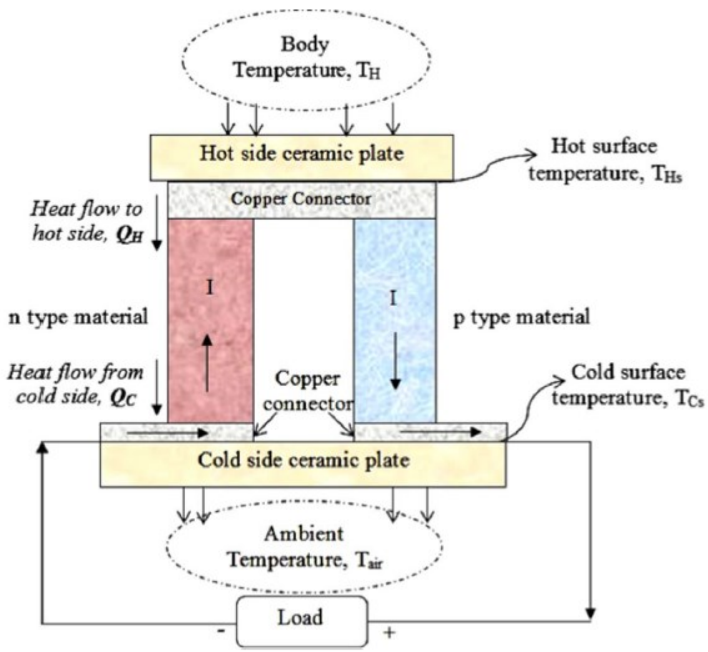

Figure 1: Schematic of thermoelectric module containing n-type and p-type semiconductors (Siddique et al. 2017).

3. THE STRUCTURE DESIGN OF DOWNHOLE POWER GENERATION

Typically, the geothermal field contains high-temperature water in the reservoir and thus, these fields are a good candidate to employ downhole power generation by TEG. For maximizing downhole power generation, it is important to create a high-temperature difference between the thermoelectric module. The TEGs are designed to employee on a production tubing without disturbing the continuous stream of production. The higher temperature difference is created when one side of TEG is in contact with the hot fluid and another side is in contact with a cold fluid. In downhole conditions, one side of the TEGs is in contact with production tubing through which hot water is flowing act as a heat source and another side is in contact with circulated cold water in annulus act as a cold source. The generated electricity is either transmitted to the surface or used to power the downhole tools.
The pictorial view of the downhole power generation with a dynamic production well is shown in fig. 2. In this structure design, TEGs are mounted on the production tubing and annulus containing a small diameter pipe for the circulation of cold fluid. Packers that are installed at the end of tubing near the production zone provides complete isolation between the annulus filled with cold fluid and the tubing with hot fluid. For maximizing the temperature difference, the temperature at the heat side is maintained by producing hot fluid from the formation and cold side temperature is maintained by continuous injection of cold water in the annulus from the surface to kept temperature as low as possible.

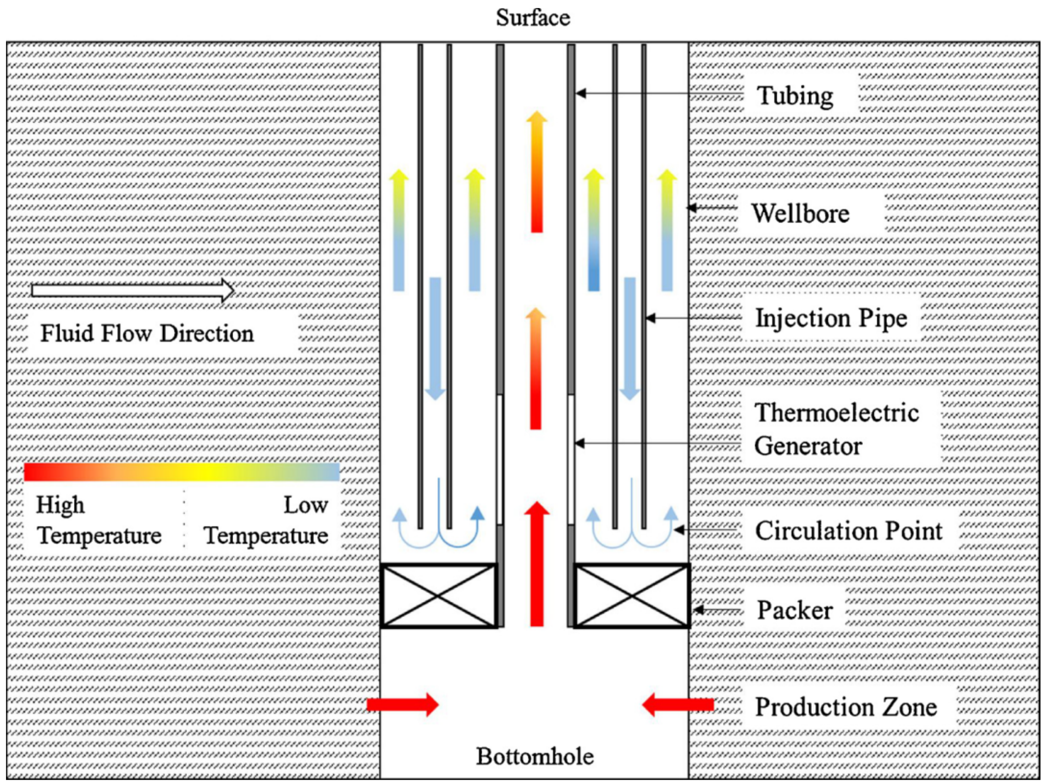

Figure 2: Pictorial view of the downhole power generation in the production well (wang et al. 2018).

4. MATHEMATICAL SOLUTION OF TEMPERATURE DISTRIBUTION PROFILE

To estimate the downhole electricity generation, temperature distribution in the wellbore is one of the key parameters. The mathematical model is developed by wang and his co-workers (2018) with the following assumptions. 1) Wellbore geometry is taken two dimensions by neglecting azimuth direction. 2) Injected and produced fluid are incompressible. 3) Geothermal gradient is constant. 4) Production and injection flowrates are constant 5) Steady state heat transfer in wellbore 6) Due to high thermal conductivity of material of tubing and casing, small temperature drop across the wall occurs which is neglected. 7) Cold fluid injection pipe should be thermally insulated to avid heat transfer.

The temperature distribution along the tubing and annulus is represented by following equation:

$$T_t(z) = me^{\lambda_1 z} + ne^{\lambda_2 z} + T_{surface} + g_G(z + \xi)$$

$$T_a(z) = (1 - \lambda_1 B)me^{\lambda_1 z} + (1 - \lambda_2 B)ne^{\lambda_2 z} + T_{surface} + g_G(z + \xi - B)$$

Where T_t, T_a and $T_{surface}$ are the temperature in tubing, annulus and surface respectively. Z represents depth and g_G stands for constant geothermal gradient. Parameter A, B, C, m, n, $\lambda_1, \lambda_2,$ and ξ are constant.

$$A = \frac{C_{pa}\, W_{inj}}{2\pi}\left(\frac{K_e + r_c U_a T_D}{r_c U_a K_e}\right) \qquad B = \frac{C_{pt} W_t}{2\pi r_t U_t} \qquad C = \frac{C_{pa} W_{inj}}{2\pi r_t U_t}$$

$$\xi = \frac{AB + BC + AC}{C}$$

$$\lambda_1 = \frac{AB + BC + AC + \sqrt{(AB + BC + AC)^2 - 4ABC^2}}{2ABC}$$

$$\lambda_2 = \frac{AB + BC + AC - \sqrt{(AB + BC + AC)^2 - 4ABC^2}}{2ABC}$$

$$m = \frac{(1-\lambda_2 B)\left[T_r - T_{surface} - g_G(L+\xi)\right] - e^{\lambda_2 (L-L_c)}\left[T_{inj} - T_{surface} - g_G(L_c+\xi-B)\right]}{(1-\lambda_2 B)e^{\lambda_1 L} - (1-\lambda_1 B)e^{\lambda_1 L_c + \lambda_2 (L-L_c)}}$$

$$n = \frac{(1-\lambda_1 B)\left[T_r - T_{surface} - g_G(L+\xi)\right] - e^{\lambda_1 (L-L_c)}\left[T_{inj} - T_{surface} - g_G(L_c+\xi-B)\right]}{(1-\lambda_1 B)e^{\lambda_2 L} - (1-\lambda_2 B)e^{\lambda_2 L_c + \lambda_1 (L-L_c)}}$$

$$T_D = \ln\left[e^{-0.2t_D} + (1.5 - 0.3719e^{-t_D})\sqrt{t_D}\right]$$

Where, $C_{pa,}$ C_{pt} are the specific heat capacity of annulus and tubing, respectively. W stands for fluid mass flow rate, and subscript t, a, and inj are standing for tubing, annulus and injection. r_c and r_t are the casing and tubing radius, respectively. U_t stand for heat transfer coefficient of tubing & U_a is overall heat transfer coefficient of heat through cement, casing and annulus fluid. At the boundary condition, inlet of tubing z = L ➔ T_t = T_r and circulation depth z =L_c ➔T_a = T_{inj}. K_e is the formation thermal conductivity. T_r, $T_{inj,}$ T_{wb} are the reservoir, injected cold fluid and wellbore temperature, respectively. T_D is the dimensionless temperature which depends on dimensionless producing time t_D. From the above data, ultimately, we can find the figure of merit and efficiency of TEG.

5. CONCLUSION

To overwhelm the demand for sustainable power, instead of making more use of fossil fuel; the clean, environment-friendly, cost-effective prospect of renewable energy resources should have been developed and harnessed that on real field application. This paper demonstrated one of the promising methods for downhole power generation in geothermal wells by TEG using thermoelectric technology to enlarge the economy of well. Not Solely the downhole power generation is working in the well, but together with conventional binary plant at the surface are also used for extra power generation. However, the high temperature difference at TEG is one of the crucial parameter for better electricity generation. The appropriate selection of TEG material, maximum temperature difference at TEG, and better production & injection rate ultimately lead to efficient power generation. High adaptability, reliability, and environment-friendly technology are the key features of the technology that excite the industry and promote it into the real field.

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