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DIFFERENCES IN ESTIMATING RESERVES BETWEEN GEOTHERMAL AND PETROLEUM RESERVOIRS

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ABSTRACT

The existing volumetric approach was honored by considering the effects of oil and gas saturations on the evaluation of geothermal resources in oil and gas reservoirs. The main reason to do so was that oil and gas phases may not be simply substituted by water because the values of the specific heat of oil and gas are smaller than that of water. We selected an oil reservoir, Hexiwu, from Huabei oil field as an example to apply the method. The effects of oil and gas saturation on the geothermal reserve were investigated at different values of porosity and the results were compared to the existing approaches. It was found that the existing volumetric method tends to overestimate the geothermal reserves in oil and gas reservoirs. The greater the oil or gas saturation is, the more the overestimation of the geothermal reserve is. The results showed that it is necessary to consider the effects of oil and gas saturations on the estimation of geothermal reserve in oil and gas reservoirs.

INTRODUCTION

Much attention has been paid to the direct use of geothermal energy and power generation by using hot fluids co-produced from oil and gas reservoirs because of the high crude oil price (Erdlac, et al., 2006, 2007; Li, et al., 2007; McKenna, et al., 2005; Milliken, 2007). Although the crude oil price dropped significantly in last year, making use of the geothermal energy from oil and gas reservoirs is still an important approach to reducing the green house gas. It is critical to evaluate the geothermal resources in oil and gas reservoirs accurately. There are differences between geothermal and petroleum reservoir engineering (Sanyal, 2003 and 2007). In a geothermal reservoir, there is only single component, water, although there are two phases, steam and water (a very small amount of non-condensate gas such as CO_2 is neglected). In oil and gas reservoirs, however, there are many components in two phases (oil and water) or even three phases (oil, water and gas). This makes the estimation of geothermal reserves in oil and gas reservoirs different from that in geothermal reservoirs.

Yan and Yu (2000) honored the effect of the oil phase on the estimation of geothermal reserves in oil reservoirs. However the effect of gas phase was not taken into account. Water is considered as two phases: liquid water and steam water (Sanyal, and Sarmiento, 2005; Ciptomulyono, 2007). In this study, three phases (oil, water, and gas) were included in the volumetric method. We selected an oil reservoir, Hexiwu, from Huabei oil field as an example to apply this method. The effects of oil and gas saturation on the geothermal reserve were investigated and the results were analyzed.

THEORETICAL BACKGROUND

Volumetric resource estimation approach is most commonly used in the later stages of geothermal exploration after drilling has started, although may be used if good surface indications and geophysical surveys are available (Clotworthy et al., 2006). In terms of this reason, the volumetric resource estimation method is suitable for the estimation of geothermal resource in oil and gas reservoirs because geothermal energy is usually utilized at the later period of oil production. Many wells have been drilled at the later stage of oil production. Volumetric stored heat assessments are well established within the geothermal industry. As Sanyal and Sarmiento (2005) pointed out, volumetric estimation is the only one of the methods consistently applicable for resource estimation at this stage of knowledge. The volumetric method can be described as:

$$Q_R = A \cdot h \cdot (T_r - T_a) \cdot \overline{C} \qquad (1)$$

Where Q_R is the total available heat resource of the geothermal system, A is the area of the reservoir, h is the reservoir thickness, T_r is the initial temperature of the reservoir, and T_a is the abandonment temperature of the reservoir, $\overline{C}$ is the mean specific heat of rock and fluids resided in the rock. In pure liquid (water)-dominated geothermal reservoirs, $\overline{C}$ can be calculated as:

$$\overline{C} = \rho_r \cdot C_r \cdot (1-\phi) + \rho_w \cdot C_w \cdot \phi \qquad (2)$$

Where ρ_r is the density of rock, ρ_w the density of water, C_r and C_w are the specific heat of rock and water respectively, Φ is porosity of rock. Yan and Yu (2000) added the oil phase in Eq. 2 to estimate the geothermal resource in oil reservoirs, and the mean specific heat is then expressed as:

$$\overline{C} = \rho_r \cdot C_r \cdot (1-\phi) + (\rho_w \cdot C_w \cdot S_w + \rho_o \cdot C_o \cdot S_o)\phi \quad (3)$$

Where ρ_o is the density of oil, C_o is the specific heat of oil, S_w is the saturation of water and S_o the saturation of oil.

To honor the effects of oil and gas saturation on the geothermal resource in petroleum reservoirs with both oil and gas phases, Eq. 3 can be expressed as:

$$\overline{C} = \rho_c \cdot C_r \cdot (1-\phi) + (\rho_w \cdot C_w \cdot S_w + \rho_o \cdot C_o \cdot S_o + \rho_g \cdot C_g \cdot S_g)\phi \quad (4)$$

Where ρ_g is the density of gas, C_g is the specific heat of gas, S_g the saturation of gas. Obviously:

$$S_w + S_o = S_g = 1 \quad (5)$$

The electric energy (power) generated from geothermal energy is expressed as follows:

$$E = Q_R \cdot \eta \quad (6)$$

Where η is the efficiency factor, E the electric energy generated from geothermal energy.

RESULT

In this study, we chose Hexiwu reservoir in Huabei oilfield as an example to study the effects of oil and gas saturation on the estimation of geothermal reserve. Hexiwu oil reservoir is located in Hexiwu structural belt in Lang-gu depression. It is one of the main water flooding carbonate reservoirs of the palaeogene Huabei oilfield. The area of Hexiwu reservoir is about 452 km^2, the thickness is 117 m, and the porosity is about 30%. The density and the specific heat of rock are 1,956 kg/m^3 and 857 J/(kg·℃); the density and the specific heat of oil are 850 kg/m^3 and 2,468 J/(kg·℃); the density and the specific heat of water are 1,000 kg/m^3 and 4,190 J/(kg·℃); the density and the specific heat of gas are 0.717 kg/m^3 and 2,227 J/(kg·℃) respectively.

We calculated the geothermal resource, energy and the possible income from Hexiwu reservoir using the volumetric approach (Eqs. 1 and 4). It was assumed that the efficiency factor is equal to 12% and the price of energy is 0.5 Yuan/kW.h (1 dollar = 7 Yuan approximately).

Fig. 1 shows the effect of water saturation on the geothermal resource in the case in which only oil and water phases exist in the oil reservoir. One can see from Fig. 1 that the geothermal resource increases with water saturation and decreases with the increase in oil saturation. This observation is reasonable because the specific heat of oil is less than that of water. As the temperature of the reservoir increases, the geothermal resource increases and the effect of water saturation on the geothermal resource is more significant. We can also see from Fig. 1 that the geothermal reserves in oil and gas reservoirs are overestimated if the oil phase is substituted simply with water.

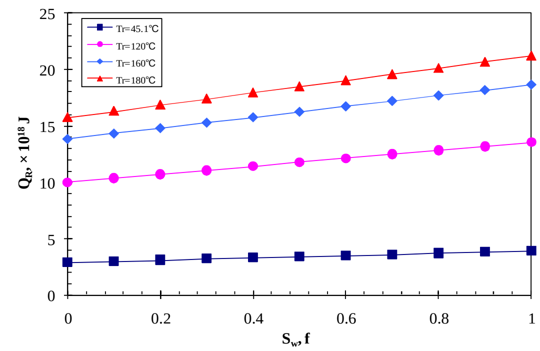

Fig. 1: Effect of water saturation on the geothermal resource in the case in which only oil and water phases exist in the oil reservoir.

One can see from Fig. 2 that the energy generated increases with water saturation and the temperature of the reservoir. The effect of water saturation on the power is more significant at higher reservoir temperature.

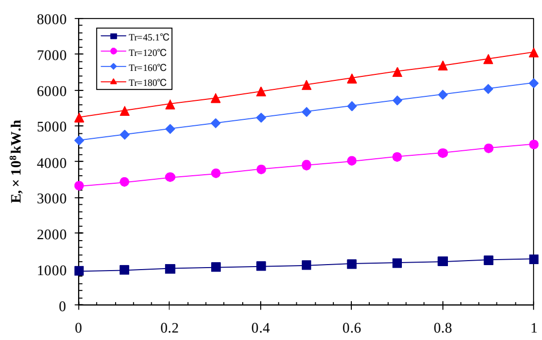

Fig. 2: Effect of water saturation on the power in the case in which only oil and water phases exist in the oil reservoir.

Fig. 3 shows the possible income at different water saturation and reservoir temperature in the case in which only oil and water phases exist in the oil reservoir. Obviously the income also increases with water saturation and reservoir temperature.

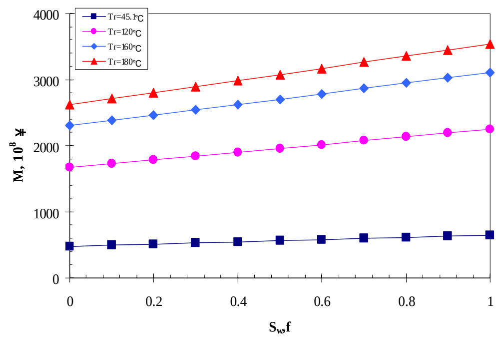

Fig. 3: Effect of water saturation on the possible income in the case in which only oil and water phases exist in the oil reservoir.

One can see from Figs. 1-3 that the rates of geothermal resource, power, and the possible income increasing with water saturation are greater at high temperatures than that at low temperatures.

Figs. 4, 5, and 6 show the effects of water saturation and the reservoir temperature on the geothermal resource, power, and possible income in the case in which only gas and water phases exist in the gas reservoir. We can see that the geothermal resource, power, and possible income increase with water saturation and reservoir temperature.

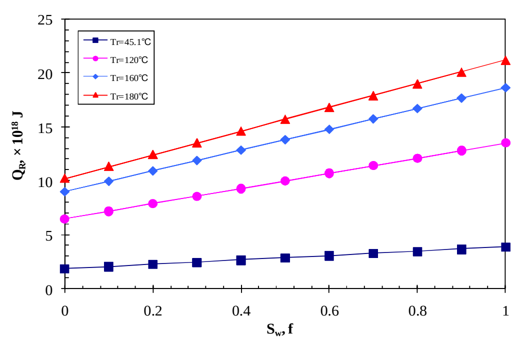

Fig. 4: Effect of water saturation on the geothermal resource in the case in which only gas and water phases exist in the gas reservoir.

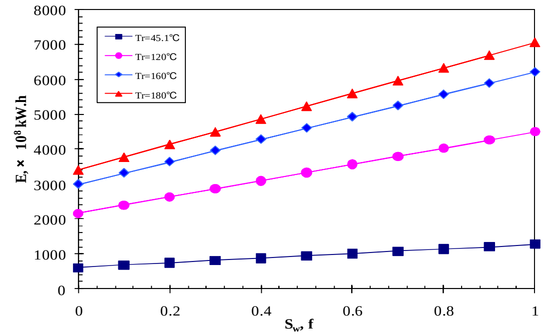

Fig. 5: Effect of water saturation on the power in the case in which only gas and water phases exist in the gas reservoir.

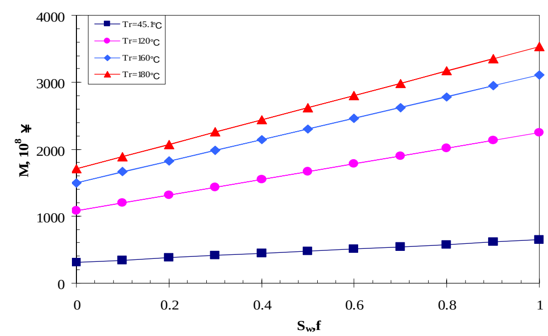

Fig. 6: Effect of water saturation on the possible income in the case in which only gas and water phases exist in the gas reservoir.

Compared with Figs. 1, 2, and 3, one can see that the geothermal resource, possible power generated, and the possible income in the case in which oil and water two phases exist are all greater than those in the case in which gas and water two phases exist at the same reservoir temperature and the same water saturation. Fig. 7 shows the comparison of the effect of water saturation on the geothermal resource between oil-water and gas-water systems at a temperature of 180°C. The difference shown in Fig. 7 is significant and is because of the lower specific heat of gas than that of oil. The difference approaches to zero when the water saturation approaches to 1, as expected. We can also observe that the rate of geothermal resource increasing with water saturation in gas-water systems is greater than that in oil-water systems.

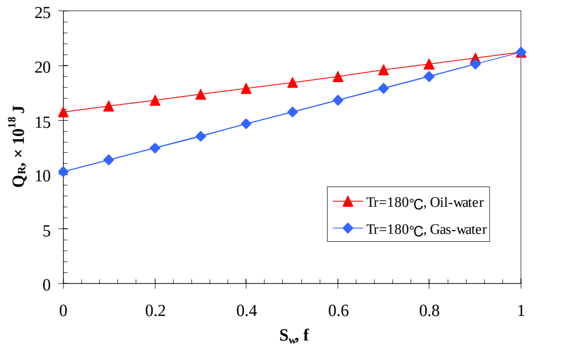

Fig. 7: Comparison of the effect of water saturation on the geothermal resource between oil-water and gas-water systems.

The effects of water saturation and reservoir temperature on the geothermal resource, power and the possible income in the case in which oil, gas, and water phases exist in the reservoir are shown in Figs. 8, 9, and 10.

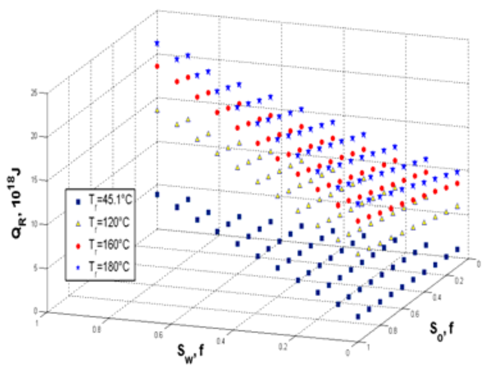

Fig. 8: Effect of water saturation on the geothermal resource in the case in which oil, gas, and water phases exist in the reservoir.

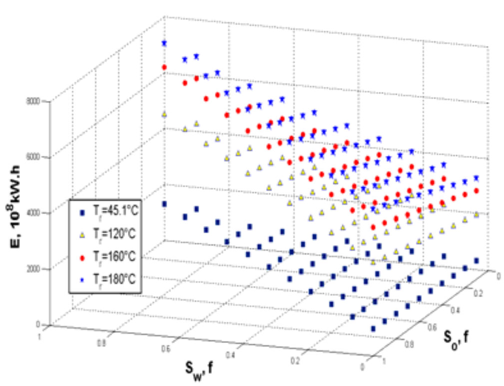

Fig. 9: Effect of water saturation on the power in the case in which oil, gas, and water phases exist in the reservoir.

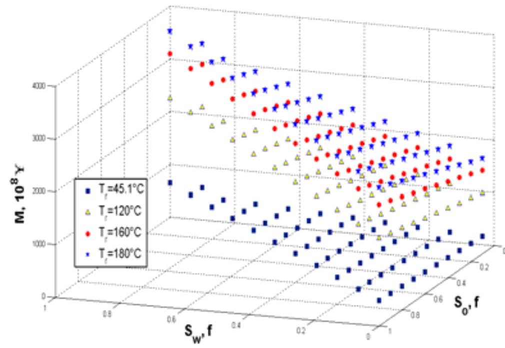

Fig. 10: Effect of water saturation on the possible income in the case in which oil, gas, and water phases exist in the reservoir.

The effects of water saturation and the reservoir temperature on the geothermal resource, power, and possible income in the case in which oil, gas, and water phases exist in the reservoir are similar to those observed in Figs. 1-6. Summarizing the results presented previously, the sequence (from great to small) of the geothermal resource, power, and possible income is listed as follows: pure water (liquid) reservoir > oil-water reservoir > oil-gas-water reservoir > gas-water reservoir under the same water saturation and reservoir temperature.

All of the above results are computed with a porosity of 30%. The values of porosity vary in different geothermal and petroleum reservoirs. For example, the porosity of rock from The Geysers geothermal field is about 5%. However the porosity in most of the oil reservoirs is greater than 5%. We repeated some of the above calculations using two different values of porosity: 5% and 15% in order study the effect of porosity. The results are presented and discussed as follows.

The effects of water saturation and reservoir temperature on the geothermal resource at the different values of porosity in the case in which only oil and water phases exist in the reservoir are shown in Figs. 11 and 12 respectively. Fig. 11 shows the results calculated with a porosity of 15% and Fig. 12 shows the results calculated with a porosity of 5%. One can see from Figs. 11 and 12 that the effects of water saturation and reservoir temperature on the geothermal resource are less significant as porosity decreases.

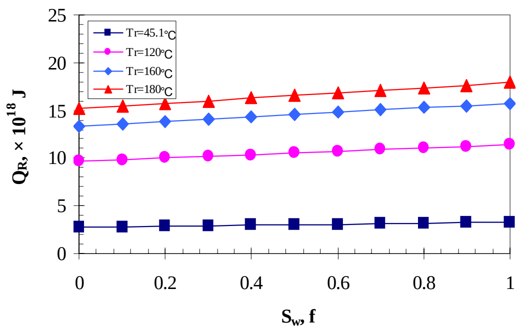

Fig. 11: Effect of water saturation on the geothermal resource in the case in which only oil and water phases exist (Φ =15%).

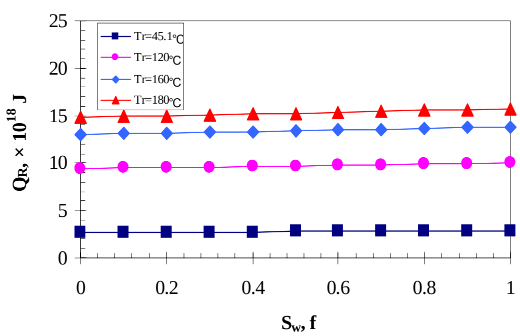

Fig. 12: Effect of water saturation on the geothermal resource in the case in which only oil and water phases exist (Φ =5%).

Fig. 13 shows the effect of water saturation on the geothermal resource at different values of porosity in the case in which only oil and water phases exist in the reservoir at a temperature of 180^{o}C. The smaller the porosity is, the smaller the effect of water saturation on the geothermal resource is.

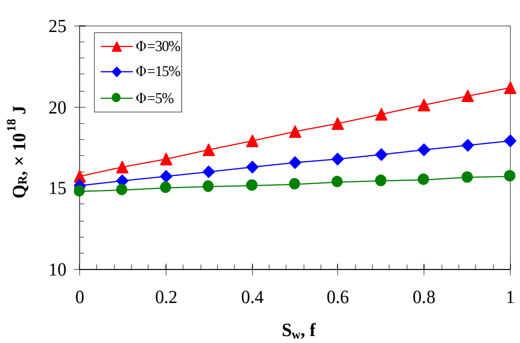

Fig. 13: Comparison of the effect of porosity on the geothermal resource in oil-water system (T_r =180^{o}C).

We also conducted the calculations at different values of porosity for gas-water systems. The similar phenomenon as shown in Fig.13 was observed in the case in which only gas and water phases exist.

According to the above results, the effect of water saturation on the geothermal resource may be neglected when the porosity is small enough.

CONCLUSIONS

The following conclusions may be drawn according to the present study:

1. Geothermal resource, energy, and possible income increase with water saturation and reservoir temperature in oil and gas reservoirs;
2. The sequence (from great to small) of the geothermal resource, power, and possible income is: pure water (liquid) reservoir > oil-water reservoir > oil-gas-water reservoir > gas-water reservoir under the same water saturation and reservoir temperature;
   The rate of geothermal resource increasing with water saturation is greater in gas-water systems than that in oil-water systems;
3. The rate of geothermal resource increasing with water saturation is greater at high temperatures than that at low temperatures;
4. The difference in the estimation of reserves between geothermal and petroleum reservoirs is significant and the effects of oil and gas saturation should be considered;
5. The effects of water saturation and reservoir temperature on the geothermal resource become less significant as porosity decreases.

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