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Low Temperature Geothermal Resources at Huabei Oilfield, China

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ABSTRACT

Water cut in many mature oil and gas fields is very high, up to 97%. The produced water is usually considered a nuisance to oil and gas producers because it is 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. In many of the high water cut oil and gas reservoirs, the temperature of the produced water is over 100°C, high enough to generate electricity using modern power generation technology. Electricity generation from the produced water will give new life to low yield oil and gas producers because of high water cut. In this paper, feasibility of generating electricity using the hot fluids (oil, gas, and water) produced from Renqiu oil reservoir at Huabei oil field, China was investigated. The current daily production of water from Renqiu oil reservoir is about 18000 m^3 with a temperature of over 100°C. The estimated gross electrical power potential is about 4 MW and may be enhanced to 110 MW by increasing the production of water. A pilot binary power plant of 300 KW was proposed. The pay back time is about 5 years.

Introduction

The concentration of green house gases in the atmosphere is increasing because of the soaring consumption of fossil energy. For example, the concentration of carbon dioxide in the atmosphere around the earth has increased by a third from its pre-industrial value. Carbon dioxide and other greenhouse gases are changing the climate of the earth, posing significant threats to our environment, economy, health, and etc. The global community (especially the community of developed countries) has become seriously concerned about the anthropogenic climate change caused by the increase in the concentration of green house gases in the atmosphere. Under this situation, technologies and energy resources with very low CO_2 emissions are being sought desperately by scientists. One of the energy resources is geothermal energy, with extremely low CO_2 emission.

Oil and gas resources are traditionally considered as high CO_2 emissions. A significant portion of crude oil is burning to provide heat for transportation of oil in some oil fields with cold whether. For example, about thirty thousand tons of crude oil is burned for heating each year in Huabei oilfield, China. However there is a huge amount of geothermal energy co-existed with oil and gas in these petroleum reservoirs. As Erdlac et al (2007) reported, Texas has thousands of oil and gas wells that are sufficiently deep to reach temperatures of over 250°F (121°C) and sometimes 400°F (204°C) (also see the reports by Swift et al, 1999; Erdlac et al, 2004; McKenna et al, 2005; Erdlac et al, 2006). The possible electricity generation from the hot water, estimated by Erdlac, was about 47-75 billion MWh (equivalent to about 29-46 billion bbls of oil).

Milliken (2007) reported that the geothermal resources at Naval Petroleum Reserve #3 located at Teapot Dome field in Natrona County, Wyoming. Fractured Precambrian basement granitic rocks at depths of 7000 ft and more may yield large volumes of water at temperatures exceeding 250° F. Gross power potential at NPR-3 from 130 MBWPD at 220° F would be 76 MW (Milliken, 2007).

Actually there is great geothermal energy potential in many oil and gas fields with low to medium temperature. Either the direct-use or electricity generation of the geothermal energy co-existed in these oil and gas reservoirs may reduce the CO_2 emission significantly by substituting the consumption of crude oil and gas. However the investigation on the application of geothermal energy in oil and gas fields is limited. To our best of knowledge, there have been no geothermal power plants installed in oil and gas fields to generate electricity before this paper was prepared. In this study, the geothermal resources in Renqiu oil reservoir, Huabei oil field were estimated. Both the technical and economical feasibilities for electricity generation were appraised.

Geological Background of Renqiu Oil Reservoir

Huabei oilfield is located 150 kilometers south of Beijing, China (See Figure 1). Huabei oilfield is composed of many naturally fractured carbonate oil reservoirs (the so-called Ancient Buried Hills). These reservoirs are fractured naturally. A large water system exists in these Hills. Some of the produced water, with a temperature of over 100°C, has been used directly for crude oil transportation and space heating but not for electricity generation. One of these naturally fractured reservoirs is Renqiu oil reservoir, located in Renqiu County, Hebei province, northern China. Renqiu oil reservoir, operated by Huabei Oilfield Sub-Company of PetroChina, is the largest carbonate reservoir in China. The location of Renqiu oil reservoir at Huabei oilfield is shown in Figure 2.

Renqiu has an oil bearing area of 56.3 km^2 and has an average depth ranging from 2596 to 3510 m (see Figure 3). Renqiu oil reservoir is also a typical buried hill fractured carbonate reservoir with partial bottom water drive. The reservoir is cut by a well developed fault system. Its west side is cut vertically by the major Rensi fault and its inner-portion is cut laterally by four secondary faults to form four V-shaped hills (see Figure 4). Three groups of north-eastern, north-western and east-west faults inside these hills are developed, and these faults are tensional faults. The infrastructures of the reservoir are monoclinal structures plugged north-eastward.

The formation temperature of Renqiu oil reservoir is about 120°C and the average temperature gradient is about 3.5°C/100m. The initial reservoir pressure is 32.5 MPa. The fractured reservoir has a unified pressure system with a pressure coefficient of 1.02-1.05 and the natural drive is mainly the bottom water encroachment. The original oil/water interface was at the depth of 3510 m.

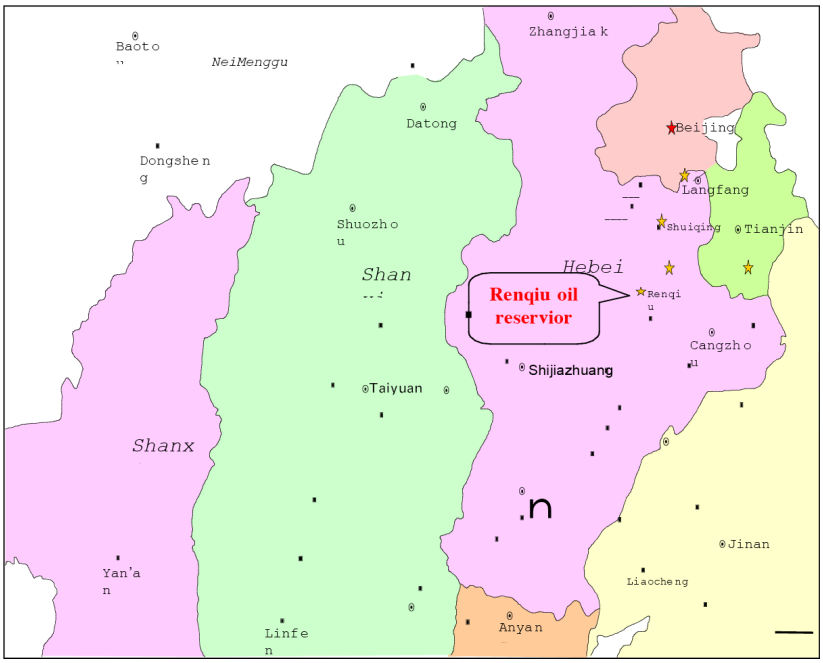

Figure 1. Location of Huabei oilfield.

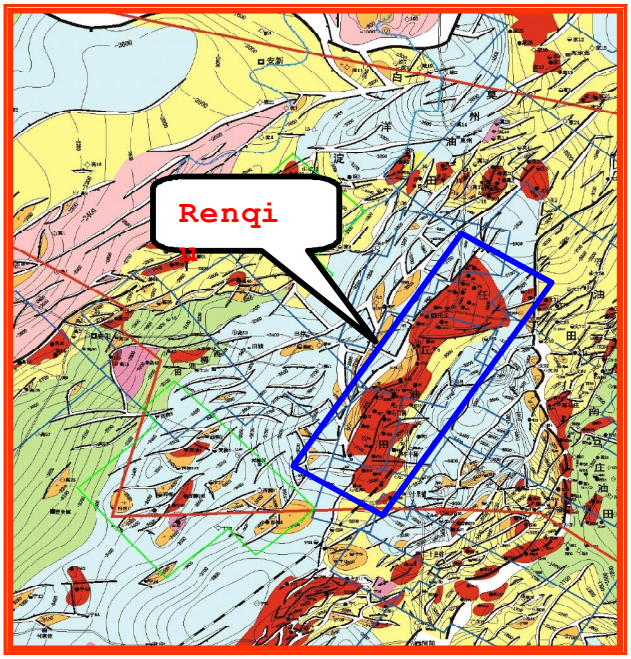

Figure 2. Location of Renqiu reservoir at Huabei oilfield.

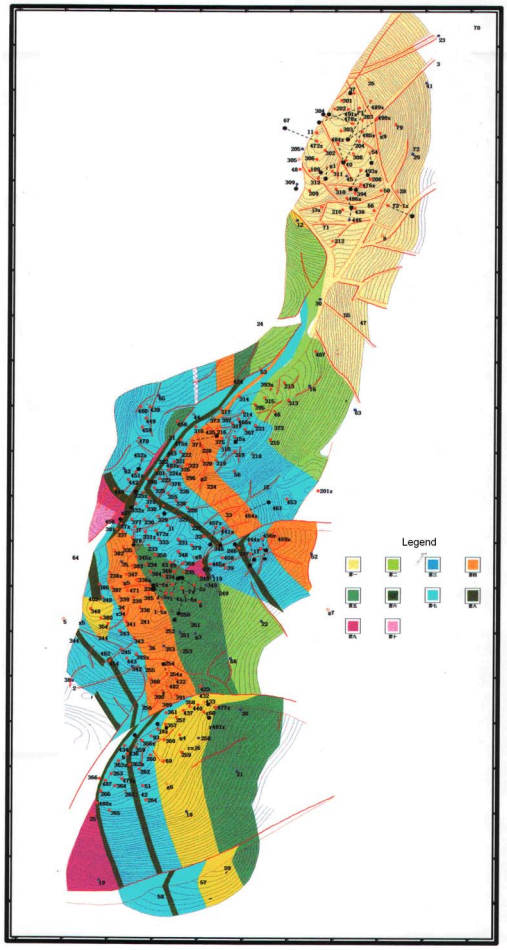

Figure 3. Areal map of faulted blocks in Renqiu reservoir.

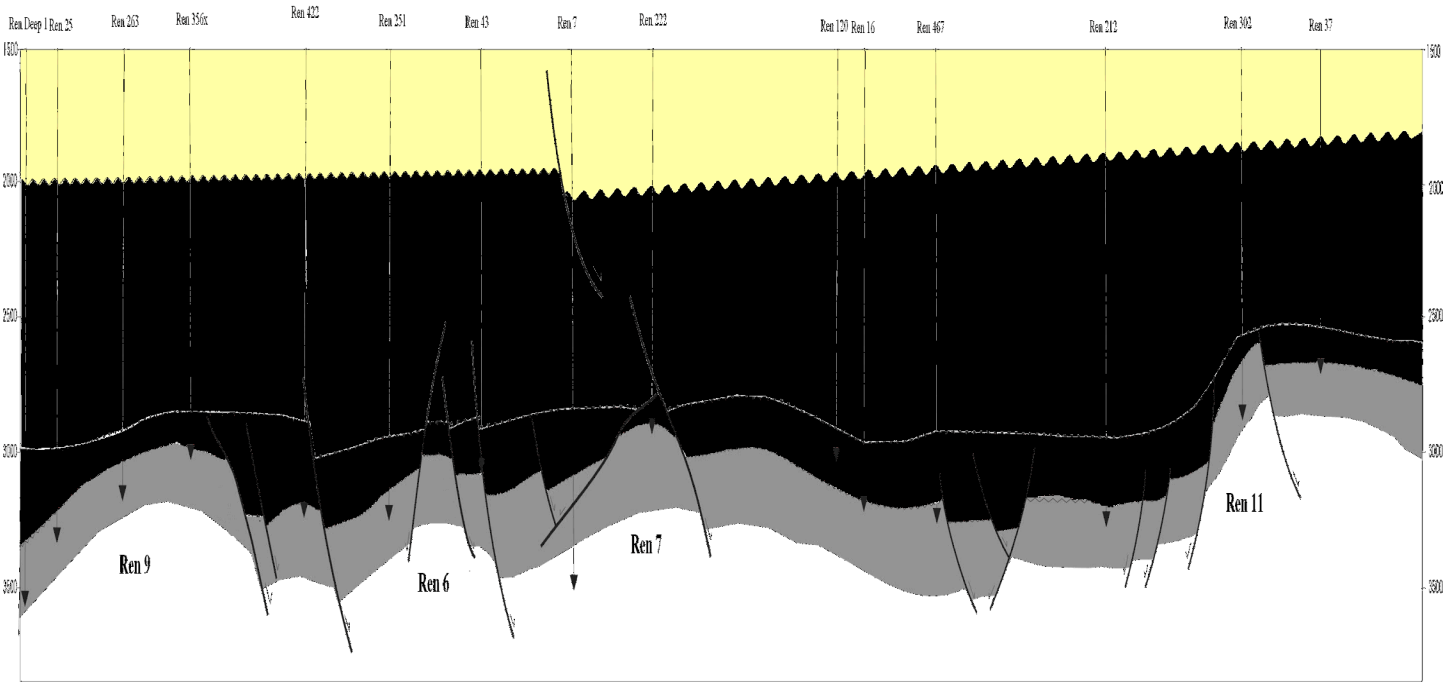

Figure 4. Structure of Renqiu reservoir.

The buried hill is mainly composed of Wumishan formation, Middle Proterozoic Jixian series (usually known as "Sinian"), most of which is overlapped by Tertiary formations. According to the depositional cycle exhibited in a profile, it is divided from top downward into ten oil bearing zones with an aggregate thickness of 2341 m. The lithology of Wumishan formation is a suit of cryptoalgal dolomite with siliceous dolomite and argillaceous dolomite intercalated in. The permeable storage space of the reservoir is composed mainly of pores, fractures and cavities formed by epigenesis with the primary pore texture as a basis (see Figure 5). It is highly heterogeneous and very complicated double porosity medium.

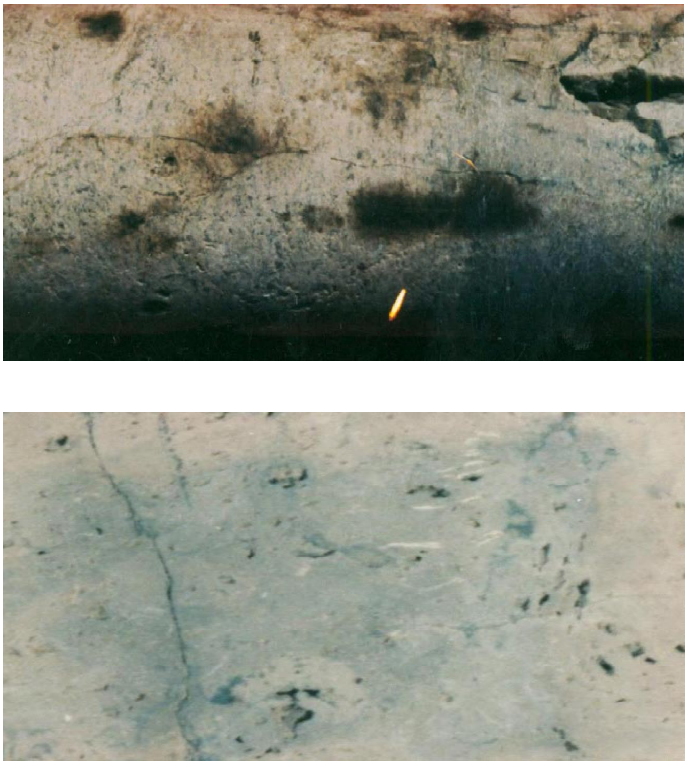

Figure 5. Rock sample from Renqiu reservoir.

Based on the core analysis and other laboratory measurements, the reservoir has a porosity ranging from 3.0% to 6.0%. However the permeability varies in a very wide range from about 1 md to about 13000 md. The in-situ viscosity of the crude oil is about 8.21 cp, and the oil/water viscosity ratio 34.2. The saturation pressure is about 13.5 atm and the gas/oil ratio 4.4 m^3/ton.

Production at Renqiu Oil Reservoir

The commercial oil production began in the middle 1970s and was not fully developed until 1976. Featured as a typical carbonate reservoir, Renqiu oil reservoir experienced a brief period of high production of oil and gas and followed by a sharp decline in production. Water flooding has been started at the end of 1976 with an uneven triangular well pattern to maintain the reservoir pressure. Water was injected along the peripheral reservoir bottom with some infill wells drilled on the top and flank.

The water production increases as the oil production declines. Currently the average water cut in Renqiu oil reservoir is about 93.5%. The oil production is about 1300 m^3/day, and the water production is about 18,000 m^3/day, from 200 active wells. The production history of Renqiu oil reservoir is shown in Figure 6.

One can see from Figure 5 that the oil field has become a "water" field. Because of high crude oil price, the operation of

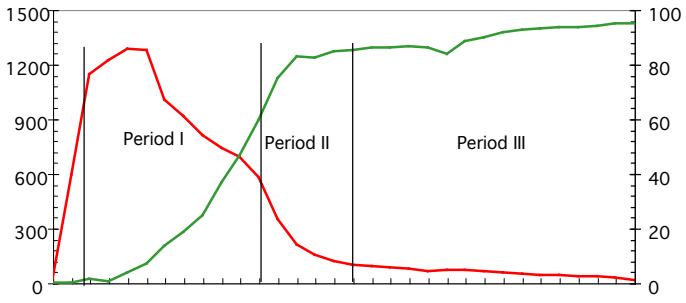

Figure 6. Production history of Renqiu reservoir.

Renqiu oil reservoir is still economical but the net profit value is greatly decreased due to the large amount of water and the re-injection into the reservoir. The water produced from Renqiu oil reservoir can not be disposed on the surface because of the relatively high salinity and the small amount of oil in water. The salinity of the produced water ranges from 3063 to about 5358 mg/L (see Table 1).

Table 1. Property of water produced from Renqiu oil reservoir.

Hill No.	Cl (mg/L)	Total Salinity (mg/L)	Type of Water
Ren 6	1395.9	3202.3	N_aHCO_3
Ren 7	1213.9	3063.1	N_aHCO_3
Ren 9	1604.8	3583.8	N_aHCO_3
Ren 11	2490.3	5358.3	N_aHCO_3

As mentioned previously, the temperature of the produced water is over 100°C, high enough to generate electricity. By doing so, it will improve the net profit value of operating the oil field significantly. There are also many advantages to generate electricity by using the waste water produced from oil reservoirs compared to constructing a new geothermal power plant:

- Geothermal power production can use the existing infrastructure, including reservoirs, wells, pumps, roads, power lines, etc. and so the costs are lower (a significant amount of costs for exploration and drilling are saved) than a new geothermal development, the estimated pay back time possible in 3 - 6 years;
- Power generation facilities are scaleable with moveable turbines (even truck-mounted) to meet the need for wide spreading of oil wells and to meet the changing needs of an oil/gas field;
- Electricity generated from the geothermal energy co-existed in oil reservoirs may cover pumping needs and the extra energy can be sold to local utilities. And the power is green, Renewable Energy Credits (RECs) are an additional commodity that the Petroleum Industry can use or sell.

Selection of Method of Power Generation

Many factors affect the power generation from geothermal resources. These include the temperature of the geothermal fluid, the flow rate or production of geothermal fluid, the exit temperature, the method of energy conversion, and the efficiency.

The main methods to generate geothermal energy to electricity are: 1) flash steam; 2) binary cycle; 3) screw expander; 4) integrated system. Flash steam method is usually suitable for a temperature over 150°C. So flash mode is not suitable for Renqiu oil reservoir. The number of geothermal power plant using screw-type expander is very limited now. Considering the oil in water, binary cycle may be suitable for Renqiu oil reservoir. By choosing binary cycle method, it is not necessary to separate oil from water before electricity generation when the temperature of liquid is high. Oil separation from water can be done at low temperature after the electricity is generated. All of the following calculations were based on binary cycle method.

Geothermal Resources at Renqiu Oil Reservoir

As mentioned previously, the current daily water production at Renqiu oil reservoir is about 18000 m^3/day and the temperature of the produced water is about 110°C. The potential power was estimated based on this value of daily water production and the results at different exit temperature are listed in Table 2 as follows.

Table 2. Power potential at Renqiu reservoir at a temperature of 110°C of produced water (for water production of 18000 m^3/day).

Exit Temp. (°C)	25	30	35	40	45	50
Power (MW)	4.671	4.397	4.122	3.847	3.572	3.297
Annual income (10^4 yuan)	2046.1	1925.7	1805.4	1685.0	1564.6	1444.3
Cost (10^4 yuan)	6306.4	5935.4	5564.5	5193.5	4822.5	4451.6

One can see from Table 2 that the effect of exit temperature on the power generation is significant. The possible exit temperature may be chosen between 35 and 40°C. Based on this, the feasible power that may be designed is around 4 MW if the water currently produced from Renqiu oil reservoir is used.

The local price of electricity at Renqiu oil reservoir is about 0.5 yuan/kw.h. According to this sale price, the pay back time is about 3 years. Note that the cost of the existing facility such as water pumps, wells, drilling cost was not included.

Increasing liquid (oil and water) production is a frequently used measure to increase the oil production to maximize the net profit value during the period of high water cut. Power generation can also benefit from the increase in liquid production. According to the reservoir engineering study on Renqiu oil reservoir, the water production of single well could be raised to 5000 m^3/day. The total water production would be 500000 m^3/day at Renqiu oil reservoir if 100 wells were used. In this case, the potential power was estimated and the results at different exit temperature are listed in Table 3 as follows.

The power potential is about 110 MW in the case in which the water production is increased to 500000 m^3/day for the exit temperature chosen between 35 and 40°C. One can see from Table 3 that increase in water production can enhance the power potential significantly.

Because of the great power potential, a project on building a pilot power plant with a design power of 300 KW was

Table 3. Power potential at Renqiu reservoir at a temperature of 110°C of produced water (for water production of 500000 m^3/day).

Exit Temp. (°C)	25	30	35	40	45	50
Power (MW)	130	122	115	107	100	92
Annual income (10^4 yuan)	56835.5	53492.2	50148.9	46805.7	43462.4	40119.2
Cost (10^4 yuan)	175177.8	164873.2	154568.7	144264.1	133959.5	123654.9

proposed. This was based on the water production of 2000 m^3/day from a single well. the potential power was estimated and the results at different exit temperature are listed in Table 3 as follows.

Table 4. Power potential at Renqiu reservoir at a temperature of 110°C of produced water (for water production of 2000 m^3/day).

Exit Temp. (°C)	25	30	35	40	45	50
Power (KW)	519	489	458	427	397	366
Annual income (10^4 yuan)	227.3	214.0	200.6	187.2	173.8	160.5
Cost (10^4 yuan)	988.5	940.0	890.6	840.5	789.4	737.4

According to Table 4, the power estimated at an exit temperature of 50°C is about 366 KW. So the designed power of 300 KW may be conservative. The pay back time was estimated about 4.5 years. Currently this project has been embarked.

Conclusions

Based on the present study, the following conclusions may be drawn:

1. Binary cycle method may be the best choice for power generation from geothermal energy coexisted in Renqiu oil reservoir.
2. The power potential is around 4 MW if the water currently produced from Renqiu oil reservoir is used. However the water production from Renqiu oil reservoir may be increased significantly, up to 500000 m^3/day. The power potential is about 110 MW in the case.
3. Because of the great power potential, a project on building a pilot power plant with a design power of 300 KW was proposed.

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