A 400 kW Geothermal Power Generator Using Co-Produced Fluids From Huabei Oilfield

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Keywords

Geothermal power generator, co-production, oil reservoirs, low temperature, Huabei, China

ABSTRACT

Some important aspects of power generation using the co-produced hot oil and water from LB reservoir, Huabei oil field were studied. The temperatures of the formation and the produced liquids were about 120°C and 110°C respectively. One of the main differences between geothermal and oil wells is the production rate. Usually the production rate in oil wells is much less than that in geothermal wells. The possibility of significantly increasing the total liquid injection and production rates of the injectors and the oil wells in LB reservoir was investigated. Some pilot tests were conducted in the wells. A 400 kW power generator, which was a binary screw expander system, was installed and put into operation after the feasibility and field studies. Operation data over several months since April 2011 were measured and collected.

Introduction

Water cut in many mature oil and gas fields is very high, up to almost 98%. The traditional "oil" field has become a "water" field. 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 technologies. Electricity generation from the produced water may give new life to low yield oil and gas producers because of high water cut.

There is a huge amount of geothermal resource associated with oil and gas reservoirs for power generation and other purpose (Li, et al., 2007; Erdlac et al., 2007; Zhang, et al., 2009; Sun and Li, 2010; Johnson and Walker, 2010). For example, 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 over 7000 ft may yield large volumes of water at temperatures exceeding 250°F (121°C). Gross power potential at NPR-3 from 130 MBWPD at 220°F would be 76 MW. The initial power generation unit was installed at the Naval Petroleum Reserve No. 3 and was put into service in September 2008. The ORC power unit was designed to use 40,000 bpd of 170 °F produced water from the field's Tensleep formation to vaporize the working fluid, isopentane. This power unit has averaged about 180 kW net power output (Johnson and Simon, 2009; Johnson and Walker, 2010).

Bennett et al. (2011) analyzed the potential of geothermal power generation using coproduction for oilfields in the Los Angeles basin. Erdlac et al (2007) reported that 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).

Geothermal power generation in China has not been increased significantly in over thirty years. However more and more attention has been paid to the power generation by utilizing hot fluids co-produced from oil and gas reservoirs as well as other geothermal resources. In this study, we reported a pilot 400 kW power plant which used the hot fluids co-produced from LB oil reservoir. The power generator was a binary screw expander system. The pilot geothermal power plant has been in service for a couple of months since April 2011. This was the first low-temperature, geothermal power plant ever built in China using fluids co-produced from an oil field.

Geological Background of LB Oil Reservoir

LB oil reservoir is part of Huabei oilfield owned by PetroChina. Huabei oilfield (see Figure 1) is located 150 kilometers south of Beijing, China. LB oil reservoir has an area of 44.9 km^2 and is a buried hill oilfield in the east of Huabei. The peak surface morphology of LB buried hill is a nose structure along the direction of north east. The west side of LB buried hill is cut by the main fault, and the buried depth of high spot is 3216 m. The oil layer is located in Mesoproterozoic Jixian System Dolomite.

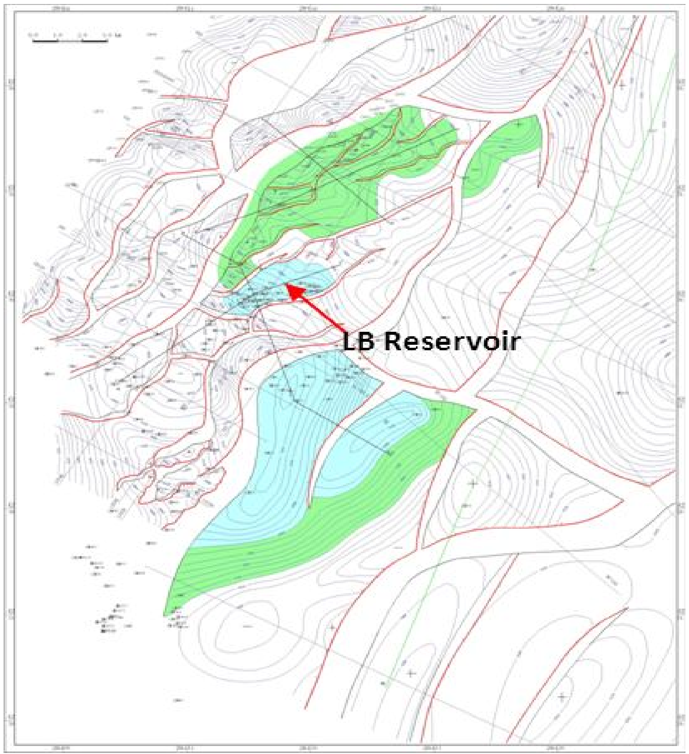

Figure 1. Location of LB reservoir in Huabei oilfield.

The reservoir characteristics of LB buried hill are as follows. The rock is a dual porosity porous media with a porosity of about 6.0% and a permeability of around 158 md. The density of micro fractures is great, about 1~2 fractures/cm2. However the fracture aperture is small. The rock is dominated by small vuggs, and the fractures are the main channel for fluid flow. The structural fractures are characteristic of high-angle, whose dip angle ranging from 70º to 90º. These high-angle fractures accounted for 87.8%. The fracture aperture ranged from 0.1 to 5 mm; those with aperture between 0.1 and 0.2 mm accounted for 74.5%.

The temperatures of the produced water from many wells in LB reservoir were over 100°C. In some of the wells, the produced water even had a temperature of about 120°C. The geothermal gradient was about 3.5°C/100 m and the average formation temperature was around 120 °C.

History of Oil Production

The commercial oil production in LB reservoir was begun in June 1978, and water injection started about four months later. The liquid production rate per well decreased significantly because of the characteristics of naturally fractured carbonate reservoirs, from about 700m^3/day at the early production period to about 150m^3/day at the late stage.

The reservoir had a total of 27 wells at the end of October 2009. Currently, there were only 6 production wells. Water cut of the entire reservoir was very high, about 97.8%.

Pilot Test of Increasing Liquid Production and Reinjection

In order to increase the output of electricity generated from the coproduction, it is necessary to enhance the total liquid production. Several questions may arise from the enhancement. For example, can the total liquid production rate be improved significantly? Is there any significant temperature decline in oil reservoirs? What are the effect on oil production and water cut? To answer these questions, we have investigated these problems using a numerical simulation technique (Gong, et al., 2011). In this study, we have conducted the pilot field test because of the positive results from numerical simulation. To do so, 3 producers (Wells 1, 2, and 3) and 1 reinjection well in LB buried hill reservoir have been chosen. The pilot field test was also designed for the possibility to increase the water reinjection rates.

Effect on Well Head Temperature

The pilot field test results are described briefly as follows (see Table 1 too). The liquid production rate of Well 1 increased from 54.2 to 727 t/d, and the well head temperature increased from 54 to 115°C. Well 2 was a well put in production again after being abandoned. The average production rate was about 1385.2t/d in October 2008, and the average temperature of well head was about 114°C. The liquid production rate of Well 3 increased from 49 to 821.6 t/d, and the well head temperature increased from 77 to 110°C. In addition, Well 4 was producing with a 300 m^3 ESP (Electric submersible pump) since September 2003. The liquid production rate stayed at 350~450t/d, and the well head temperature was around 112°C.

Table 1. Temperature variation before and after the enhancement of production rate in LB reservoir.

Well No.	Date	Before		After	
		q_l (t/d)	T (°C)	q_l (t/d)	T (°C)
Well 1	2006.9	54.2	54	727	115
Well 2	2008.9	Abandoned well*		1385	114
Well 3	2008.11	49.1	77	821.6	110
Average		**51.7**	**65.5**	**977.9**	**113.0**

*Production ceased in November 2008 because of pump problems, data taken in October 2008.

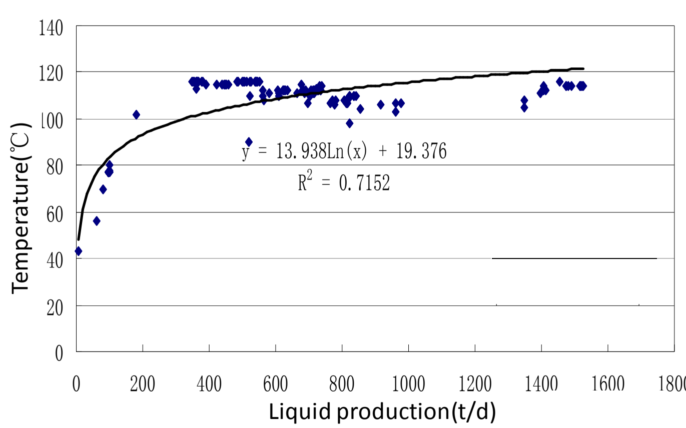

Figure 2. The relationship between temperature and liquid production of LB buried hill.

One can see from Table 1 that the well head temperature increased greatly after the enhancement of production rate in LB reservoir.

All of the pilot test results at different production rates are demonstrated in Figure 2. The well head temperature increased with the liquid production rate. When the production rate is lower, the well head temperature increased faster. The temperature increased slower while the production rate became higher. The well head temperature could be kept around 110°C at high production rates. Note that the well head temperature did not change significantly after the production rate is greater than about 400 t/d.

Effect on Oil Production Rates

The enhanced oil production because of the increase in total liquid production is described briefly as follows (see Table 2 too).

The oil production of Well 1 increased from 1.4 to 16.5 t/d. The water cut did not increase very much. Well 2 had an oil production rate around 12.2 t/d and a water cut of 98.7% after being reactivated from abandonment. The oil production rate of Well 3 also increased significantly, from 1.6 to15.1 t/d.

Table 2. Oil production before and after the enhancement of production rate.

Well No.	Date	Before			After			Enhancement
		q_l	q_o	f_w	q_l	q_o	f_w	
Well 1	2006.9	54.2	1.4	97.4	727	16.5	97.7	15.1
Well 2	2008.9	Abandoned well			1385	12.2	98.7	12.2
Well 3	2008.11	49.1	1.6	96.8	821.6	15.1	98.2	13.5
Average		**51.7**	**1.5**	**97.1**	**977.9**	**14.6**	**98.2**	**13.6**

One can see from Table 2 that the average incremental oil production rate of the tested three wells was about 13.6t/d because of the enhanced total liquid production.

Effect on Formation Energy

The test data of Well 1 illustrated that the liquid level in the well bore descended to 498 m away from the well head after the enhancement of production rates. However, oil gushed out from the wellhead after an hour of shut-in. Since oil production decreased in December 2007, liquid level increased slowly. The data of Well 3 showed that its liquid level stayed unchanged at the well head since the production enhancement in November 2008. It can be seen that the energy of LB buried hill reservoir was kept well and the liquid supply was sufficient during the pilot test.

Effect on Reinjection

The reinjection amount of formation water into Well 5, which is 2000 m away from Well 6, increased from 100 to 2319 m^3 since July 2008. Formation pressure of Well 7 increased quickly from 8.795 to 9.688 MPa in July 2009. The liquid level in Well 1 began to pick up, and it reached the well head in May 2009. The liquid level of Well 3 stayed around the well head during the test. It can be seen from these data and the observation that the connectivity between wells in LB buried hill reservoir was good and the reinjection capacity was great. The enormous enhancement in total liquid production from Wells 1, 2 and 3 might result in the decline in the formation energy but the effect was not very significant. The test data showed that the formation energy could be compensated properly by the reinjection and the total liquid production could be kept at high values for a long time.

The Lifting Ability of ESP

Three new kinds of ESPs (600 m^3-600 m, 800 m^3-800 m, 1000 m^3-1000 m) have been tested respectively in LB buried hill reservoirs. The pump of 600 m^3-600 m was tested in three wells. The average liquid production rates reached 727, 755, and 837 t/d in Wells 1, 2, and 3 respectively. The pump of 800 m^3-800 m was tested in one well. Its average liquid production reached about 1100 t/d. The pump of 1000 m^3-1000 m was also tested in one well, and its average liquid production reached about 1176 t/d. The lifting capacity of these new ESPs was good. Table 3 lists the test data of the three kinds of ESPs (new) and the old pumps.

Table 3. The capacity of the ESPs.

Pump Rate m3/d	Average Liquid Production m^3/d		Average Enhancement m^3/d	Pump Inspection Cycle, d
	old	new		
600	55	773	718	200
800	55	1100	1045	-
1000	55	1176	1121	30

Results and Discussion

One set of 400 kW screw expander manufactured by Jiujiang Power was chosen for power generation. In early April of 2011, the geothermal power plant was put into operation. The temperature of the initial stage of hot water was 110 °C. The water flow rate was 2880 m^3/d. The entering pressure in the screw pump expander was 0.38 MPa. The inlet temperature of circulating cooling water was 21.1°C and the outlet temperature was 35.8°C. Note that the outlet temperature from ORC at Chena power plant is as low as 17.2 °C (Holdmann, 2007).

The design of the unit was based on the relatively low produced water temperature of 110°C and the total liquid production rate in LB reservoir. At the design conditions, the nominal 400 kW unit would produce a gross power of 360 kW and the net power of 310 kW. By the end of 2011, the effective power generation time was 2880 hour, the cumulative energy generated was about 31×104 kWh. The electricity was all successfully transmitted

Table 4. Operation data.

Water flow rate (m^3/d)	2880
Inlet water temperature (°C)	110
Outlet water temperature (°C)	85-90
Working fluid	R123
Installed power (kW)	400
Output power (kW)	360
Net power (kW)	310
Total energy generated (kWh)	31×10^4

into the local power grid with the permission obtained prior to the power generation. The operation data and parameters are listed in Table 4.

Figure 3 shows the oil-water tank and cooling tower and Figure 4 is the picture of the heat exchanger and geothermal power generation plant. Figure 5 demonstrates the binary expander for power generation.

Figure 3. Oil-water tank and cooling tower.

Figure 4. Heat exchanger and geothermal power generation plant.

Figure 5. Geothermal power generation system: binary expander.

This geothermal power plant was run by using the oil and water produced from 8 oil wells in LB reservoir. When fully operated, this power plant can generate electricity of 2,700,000 kWh per year. Moreover, it can increase oil production by 12,000 tons and save 4,100 tons of fuel annually, which indicates significant benefits of "oil-heat-electricity" co-production. In the past six months, an incremental increase in 2,902 tons of crude oil production has been obtained from 8 oil wells. The hot water after power generation was used to heat the crude oil for transportation, mitigating the need for 10 oil-burning furnaces. 2,000 tons of fuel were saved and about 6,000 tons of carbon dioxide emission were reduced because of the new co-production geothermal power plant.

Future Plans

- Different types of power generators will be tested.
- Optimize the entire geothermal power generation system to reach maximum efficiency.
- Power generators with a greater capacity will be installed.

Conclusions

A 400 kW power generator was installed and started to generate electricity after the feasibility and field studies in LB oil reservoir. This was the first low-temperature, geothermal power plant ever built in China using fluids co-produced from an oil field. The power generator was a binary screw expander system. The oil and water co-produced from LB oil reservoir, with a temperature of about 110C, were used for the geothermal fluids to generate electricity. It has been put in operation for several months since April 2011. By the end of 2011, the cumulative energy generated was about 31×10^4 kWh.

Nomenclature

q_l = total daily liquid production, t/d

q_o = daily oil production, t/d

f_w = water cut, %

T = temperature, °C

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