Geothermics 51 (2014) 388–396

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

A novel geothermal system combined power generation, gathering heat tracing, heating/domestic hot water and oil recovery in an oilfield

Tailu Li[b], Jialing Zhu[a], Shouliang Xin[c], Wei Zhang[a,*]

[a] Key Laboratory of Efficient Utilization of Low and Medium Grade Energy, MOE, Tianjin University, Tianjin 300072, PR China
[b] School of Energy and Safety Engineering, Tianjin Chengjian University, Tianjin 300384, PR China
[c] Exploration & Development Research Institute, PetroChina Huabei Oilfield Company, Cangzhou 062552, PR China

ARTICLE INFO

Article history:
Received 30 October 2011
Accepted 9 March 2014
Available online 28 March 2014

Keywords:
Geothermal water
Organic Rankine cycle
Energetic and exergetic analyses
High water cut
Heat tracing
Oilfield

ABSTRACT

Oil wells in the high water-cut period become geothermal wells, thereby increasing the recoverable reserve. A novel geothermal system involving organic Rankine cycle (ORC), absorption refrigeration, gathering heat tracing, direct and indirect heating, and oil recovery was presented. The objective is to improve the system efficiency. The results show that R601a has the highest cycle performance and auxiliary cold sources do increase the power output. Replacing oil boilers with geothermal water as the heat source of gathering heat tracing (GHT) can save about 8163 tons of oil a year. About 34,600 tons of oil can be recovered each year. Moreover, the system can also provide heating for sixty 5000-square-meter residential buildings and domestic hot water for over 8000 people.

1. Introduction

Petroleum is the most significant mainstay industry for many countries. Most of onshore oilfields in China adopting water flooding have already entered the high water cut period with an average water cut of 81.4%, and the corresponding recovery ratio is relatively low, only 21.7% (Han, 2008). The ever-higher water–oil ratio decreases the production and increases the cost year by year. Many countries have always been seeking new methods and technologies to increase the recoverable reserves and simultaneously to enhance the recovery factor, which is long-term and arduous. Moreover, the petroleum industry needs lots of energy during production. GHT consumes a great deal of thermal energy usually provided by oil boiler. The boiler efficiency is relatively low due to equipments aging, incomplete combustion, corrosion, scaling, and so on. The issue that the boiler brings subsequently is seriously environmental pollution, which has become a bottleneck for energy conservation and environmental protection in oilfield (Tian, 2009). The running maintenance cost is proportional to the oil price.

Once the water cut reaches 98%, oil wells are no longer suitable for further exploitation in economy, with large quantities of oil unrecovered. Generally, oil and gas fields are simultaneously geothermal fields, and oil wells in the high water cut period can turn into geothermal wells. The economically mineable thermal reservoirs locating within 2000 m include Minghuazhen Formation and Guantao Formation of Neogene, and carbonate rocks of the lower Paleozoic. The associated geothermal water is about 110 °C in an oilfield in China. If it is only used as the heat source of the GHT system, the tail water temperature will be high, thereby causing energy dissipation and diseconomy. Cogeneration should be used to make the best of geothermal resources.

Cogeneration produces both electricity and usable thermal energy efficiently, leading to ameliorate environmental issues. Compared with other technologies, cogeneration is more competitive. Sun (2008) proposed a cogeneration system driven by gas engine, providing electricity and cooling/heating for buildings. Havelsky (1999) found that cogeneration systems showed a large potential for energy saving. Maidment and Tozer (2002) did a theoretical analysis of combined cooling heat and power schemes applied to a supermarket. Zaporowski and Szczerbowski (2003) researched a natural gas fired combined heat and power plants with high efficiencies. Wang et al. (2009) carried out an exergetic analysis for different cogeneration power plants in cement industry. They found that the Kalina cycle achieves the best performance. Matelli et al. (2011) developed a case-based reasoning prototype for cogeneration plant design. Rosen et al. (2005) investigated

* Corresponding author. Tel.: +86 22 27401830; fax: +86 22 27401830.
E-mail address: zhangweitju@163.com (W. Zhang).

http://dx.doi.org/10.1016/j.geothermics.2014.03.009
0375-6505/

Nomenclature

ALT	atmosphere life time (year)
Expr	expansion ratio in turbine
F	total heat exchange area (m^2)
GWP	global warming potential
h	specific enthalpy (kJ/kg)
I	irreversibility rate (kW)
IHE	inner heat exchanger
m	mass flow rate (kg/s)
M	molecular mass (g/mol)
ODP	ozone deletion potential
P	pressure (MPa)
Q	heat transfer rate (kW)
s	specific entropy (kJ/kg K)
T	temperature (K)
V	volume flow rate (m^3/s)
W	power (kW)

Greek letters

γ	bypass valve opening
η	efficiency

Subscripts

b	boiling
c	condenser
cri	critical
e	evaporator
ex	exergetic
g	generator
H	high temperature reservoir
HE	heat exchanger
i	inlet
in	input
L	low temperature reservoir
net	net
o	outlet
out	output
p	pump
s	isentropic
se	screw expander
th	thermal
tot	total
0	environment
1,2,3,4	state points

a cogeneration-based district energy system with exergetic efficiency from 28 to 29%. Guo et al. (2011) investigated a novel cogeneration system by low temperature geothermal sources. Systematic performances under disturbance conditions had also been studied.

The total installed capacity from worldwide geo-plants was about 8930 MW in 2005 (Bertani, 2005a). An increment of about 1.8 GW in the period of 2005–2010 had been achieved, about 350 MW/year, with an obvious increase compared to about 200 MW/year in the period of 2000–2005 (Bertani, 2005a, 2005b, 2006, 2007). With the progress of the technology, binary cycle power plants enlarge the temperature range of geothermal resources to generate electricity. Organic fluids used as working fluids for low temperature geothermal resources result in a higher efficiency and do not need overheating. The feasibility of ORC in low temperature heat utilization has already been proven (Badr et al., 1990; Hung, 2001; Tamamoto et al., 2001; Barbier, 2002; Liu et al., 2002). However, there are still some key problems as follows:

(1) Low thermal efficiency

Due to the low temperature of the heat source, the temperature difference between the heat source and the environment is small resulting in a lower Carnot efficiency, so the practical thermal efficiency is also low. The condensing temperature is subject to the ambient temperature. A rise in condensing temperature lowers the expansion ratio of the screw expander and then decreases the net power output, so the thermal efficiency decreases with the increase of the ambient temperature. The ambient temperature in summer is higher than that in winter. So how to increase the thermal efficiency when the ambient temperature is high, especially in summer, is a key problem.

(2) Transient running status

The temperature difference between day and night can be more than 15 °C, and it is even higher between winter and summer. As the ambient temperature changes all the time, the operating state is exacerbated and the service life is shortened accordingly, which is extremely disadvantageous to the plant. Therefore, the improvement of running status of the plant is essential.

(3) Low economical efficiency

For a geo-plant, the drilling cost accounts for more than 50% (Barbier, 2002), thereby decreasing the overall economic efficiency and becoming a constraint for the development of the low and medium temperature geo-plants. So the increment of the economic efficiency is urgent.

As mentioned above, the economic efficiency for oilfields in high water cut period is low, especially in extra-high water cut period. Traditional geo-plant is also less economical due to the high drilling cost. Transforming oil wells in high water cut period into geothermal wells can overcome their respective disadvantages and complement with each other. For oilfields in the high water period, the heat utilization is given priority to oil extraction. Geo-plants driven by the associated water from oilfields in high water cut period are much more competitive compared with the traditional geo-plants, and the payback period is only about 3–5 years (Li et al., 2007). Another advantage is that the reinjection system is already operated successfully. Besides power output, GHT, large quantities of crude oil can be recovered.

In this paper, a novel geothermal system combined power generation, gathering heat tracing, heating/domestic hot water and oil recovery is put forward, based on the large heat demand for the residential buildings around the oilfield. To further decrease the condensing temperature, tail water is used as the auxiliary cold source in winter and the chilled water in summer. At first, the net power output of the ORC subsystem is calculated numerically with and without the plate heat exchanger through the energetic and exergetic analyses. The working fluids considered are R601a, R601, R123, R141b, R245fa, and R600. Then the exergetic efficiencies of the subsystems are calculated. Finally, the overall efficiencies of the system in winter and in other seasons are also calculated.

2. System modeling

2.1. System description

The system includes an ORC plant for electricity generation, an absorption refrigeration subsystem for the chilled water as the auxiliary cold source in summer, a heat exchange station for GHT, a direct heating subsystem for heating in winter and hot water in summer, an indirect heating subsystem for heating in winter,