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Petroleum Enterprises Boost the Healthy Development of China's Geothermal Industry

Yan Jiahong, Hu Junwen, Ren Hengtai, Wang Kaihong and Wang Shejiao

PetroChina Research Institute of Petroleum Exploration and Development, 20 Xueyuan Road, Haidian District, Beijing,100083

yanjiahong@petrochina.com.cn

hjwen@petrochina.com.cn

renhengtai@petrochina.com.cn

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ABSTRACT

The direct utilization of geothermal energy in China has long been first in the world, which is closely related to China's population and the characteristics of geothermal resources. For a long time, hot springs and direct heat exchange has been the main geothermal development and utilization in China. In the past 5 years, shallow ground source heat pumps and water source heat pumps have developed rapidly, while the development and utilization of middle-deep geothermal resources is slow. Petroliferous basins are the most abundant with low-and-medium temperature geothermal resources in China; petroleum enterprises have inherent advantages in development and utilization. In 2006, Sinopec set up the Sinopec Star Co. Ltd and Green Energy Company to develop and utilize middle-deep geothermal resources. In 2018, China National Petroleum Corporation (CNPC) also set up Baoshihua Geothermal Energy Development Company to carry out projects in several areas of Henan and Hebei provinces in China. The re-injection in sandstone reservoirs has been successfully realized, the balance of mining and re-injection has been achieved, and the middle-deep geothermal resources have been scientifically and effectively utilized. After nearly 60 years of development, China's petroleum industry has accumulated a vast amount of data in geophysical prospecting, drilling, logging, and geochemistry, and mastered the layout information of underground geothermal resources. China also has industrial advantages in drilling, development, thermal water transportation, water quality treatment, ground facilities and land resources. The entry of petroleum enterprises into the geothermal field will boost the healthy development of geothermal industry in China.

1. INTRODUCTION

The geothermal resources in China are mainly medium-low temperature (Zhang and Xie, 1984; Li, 2011). Geothermal heating is important in development and utilization. The use of clean energy for heating in winter is highly valued by governments and enterprises at all levels. In the past 10 years, the direct utilization of hydro and geothermal energy in China has increased by 10%, by the end of 2017 it had surpassed 150 million square meters. Petroliferous basins in China are also rich in medium-low temperature geothermal resources, especially in the North China area in the eastern part of China (Wang, 1993).

CNPC in North China mainly covers the Huabei Oilfield, the Dagang Oilfield and the Eastern Hebei Oilfield, all of which are in Hebei Province, close to Beijing and Tianjin –the important economic development areas in China (Chen and Wang, 1994). The geothermal resource evaluation in the oil field area provides an important resource base for geothermal development (Wang et al., 2017). The main content of the study is the evaluation of geothermal resources in the upper tertiary system and the bedrock of the three oilfields.

Evaluation of geothermal resources involves the key parameters as following: thickness of geothermal reservoir, effective porosity, area of geothermal reservoir, temperature of geothermal reservoir, reference temperature, thermal capacity, density of rock, thermal capacity, density of oil and water, recovery factor, etc. (Yan and Yu, 2000). Thickness of the geothermal reservoir is the thickness of net pay which is calculated by well log data on the basis of studying the relationship between the lithology, properties, water bearing and electricity of geothermal reservoir. Effective porosities of geothermal reservoir are determined with core experiment and, well log data interpretation. Area of the geothermal reservoir is the total area of the sandstones in which the geothermal gradients are more than 3°C/100 m. The temperature of geothermal reservoir is calculated with the downhole temperature measurement or well log data and it is estimated with the geothermal gradient of the area where there is no well (Wang et al., 2014). Reference temperature, the temperature of strata of constant temperature, is approximately equal to the local annual average temperature of atmosphere in theory and its value is 15°C in this paper.

2. CALCULATION OF GEOTHERMAL RESOURCES IN UPPER TERTIARY

2.1 The Calculation Formula of Thermal Storage Volume Method is as Follows:

$$Q_r = CAd\,(T_r - T_0) \qquad (1)$$

$$C = \rho_r C_r (1 - \varphi) + \rho_\omega C_\omega \varphi \qquad (2)$$

Q_r-Heat stored in geothermal reservoir, J

C- Average specific heat capacity of thermal stored rock and water, J/ m^3· ℃

A- Calculated area, m^2

ρ_r- Thermal stored rock density, kg/ m^3

d- Geothermal reservoir thickness, m

C_r-Specific heat of thermal stored rock, J/ kg · ℃

T_r- Average temperature of geothermal reservoir, ℃

ρ_ω- Geothermal water density, t/m^3

T_0- Local annual average temperature, ℃

C_ω- Specific heat of water, J/ kg· ℃

φ- Porosity of thermal stored rock, non-dimensionality

2.2 Calculation Parameters

The geothermal temperature gradient is 3°C/100 m which determines the geothermal reservoir area, and the determination of the thickness of the geothermal reservoir is to evenly select the oil drilling hole in the calculation area.

$$H = 100(40℃ - T)/G + \hbar \quad (3)$$

H is the depth of the top boundary. T is the temperature of the normal temperature layer set as 15 °C, and G is the average geothermal gradient (°C /100 m) of the tertiary system for well drilling. $\hbar$ is the thickness of normal temperature layer, which is at 20 m. The temperature value of the geothermal reservoir is calculated according to the average of burial depth and geothermal temperature gradient of geothermal reservoir. The porosity of geothermal reservoir is determined according to the porosity - depth correlation curve of upper tertiary sandstone in North China area (see Figure 1). For geothermal fields with higher exploration degree, the water density is corrected by temperature and pressure. Density and specific heat capacity of other hot fields are taken as 1 (Li 2011). The specific heat capacity and density of rock are based on the measured data of 15 upper tertiary sandstone samples, and the average values are 0.857J/g· ℃ and 1.965g/cm^3 respectively.

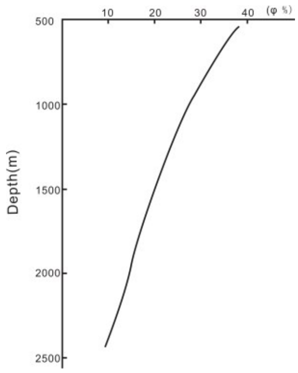

Figure 1: Porosity and depth graph of upper Tertiary sand in North China

2.3 Calculation Results and Evaluation

The total area of North China exploratory area is 26822 km^2, the Dagang exploratory area is 8647 km^2, and the Eastern Hebei exploratory area is 1421 km^2 (Liu et al. 2015). In the North China exploratory area in Hebei province, the total amount of upper tertiary geothermal resources is 748.9×10^{18} J, and the amount of thermal water resources is 20768.5×10^8 m^3. The calculation data of the three regions selected: Niutuo town-Rongcheng, Gaoyang-Wuji and Ningjin-Shulu are shown in Table 1:

Table1. Geothermal Resources of Upper Tertiary in Huabei Oilfield

Geographical or tectonic position	Area (km^2)	Formation	Sand thickness (m)	Average porosity (%)	Average temperature (℃)	Geothermal resources storage (10^{18}J)	Thermal water (10^{8}m^3)
Niutuo Town-Rong Cheng	1208	N_m	123	34	49.0	12.75	505.2
		N_g					
Gaoyang-Wuji	3487	N_m	196	30	48.7	55.91	2050.4
		N_g	211	22	64.8	81.60	1618.7
Ningjin-Shulu	1884	N_m	146	31	45.2	20.37	852.7
		N_g	187	25	57.1	34.14	880.8
Qianmodou	418	N_m	40	35	41.7	1.14	58.5
		N_g	210	29	52.1	7.82	254.6
SunHu	789	N_m	216	29	49.7	14.21	494.2
		N_g	156	23	64	13.58	283.1

The Minghua Town formation located in Dagang exploratory area of Tianjin city is the main petroleum interval. The calculation of geothermal resource is carried out in Guantao formation. The total area of geothermal resources is 8647 km^2, with 331.5×10^{18} J geothermal resources and 5740×10^8 m^3 thermal water resources. Data of the Tanggu-Beitang area, North Dagang and South Dagang are shown in Table 2.

Table 2. Calculation of Geothermal Resources and Thermal Water Storage in Dagang Oilfield

Calculation spot	Area (km²)	Reservoir thickness (m)	Reservoir temperature (℃)	Geothermal resource storage (10^{18}J)	Thermal water storage (10^{8}m³)
Tanggu _ Beitang Area	1010	328	63	49.7	692
North Dagang (Qibei)	999	221	73	56.9	663
South Dagang (Qinan)	693	243	72	42.1	506

Total area of Eastern Hebei exploratory area in Tangshan City, Hebei Province is 1421 km^2. The upper tertiary geothermal resources were 49.32×10^{18} J, including 26.35×10^{18} J in the Minghua formation and 22.97×10^{18} J in the Guantao formation. The reserves of thermal water are 1884.9×10^8 m^3, including 985.3×10^{8}m^3 in Minghua formation and 899.6×10^8 m^3 in Guantao formation. Data from Matouying uplift, Xi'nanZhuang- Laowangzhuang uplift and Nanbao uplift with higher reservoir temperature are shown in Table 3:

Table 3. Calculation of Geothermal Resource in Upper Tertiary in Jidong Oilfield

Area	Area (km^2)	Formation	Reservoir thickness (m)	Porosity (%)	Thermal reservoir temperature(℃)	Geothermal resource storage (10^{18}J)	Thermal water resources(10^{8}m³)
Matouying Bulge	360	N_m	131	26	84.7	8.17	207.2
		N_g	131.8	28	91.3	9.22	264.4
Xi'nan Zhuang-Laowangzhuang Bulge	411	N_m	120	30	60.2	5.95	244.4
		N_g	92	30	64.4	4.98	222.1
Nanpu sag	158	N_m	00	25	74.4	6.93	226.2
		N_g	72	30	86.2	2.13	88.2

The upper tertiary reservoir is characterized by large thickness, good water permeability, developed pores, shallow burial depth and large water yield. The water yield of a single well can generally reach 1000 m^3/d, and some wells can reach 2500^3/d. When the burial depth of aquifer is between 500-1000 m, the water temperature is 35-45℃. When the burial depth is between 1500-2000 m, the water temperature reaches 70-78℃, with good upper tertiary water quality and low salinity, which is an economic geothermal resource. It can be seen from Figure 2 that the area with higher temperature gradient is the center of subsidence, which has great abundance of geothermal resources. In Beijing, Tianjin, and Hebei, the central uplift zone is constructed with Nituozhen, Gaoyang and Ningjin saddle - backing, it belongs to abnormal high temperature area of geothermal, in which gradient of temperature of reservoir ranges generally from 3.2^{o}C/100 m to 6.0^{o}C/100 m. The maximum gradient of temperature is more than 10^{o}C/100m in Niutuo saddle-backing.

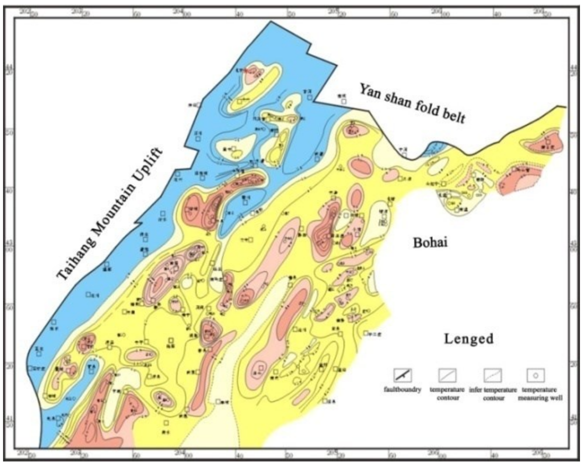

Figure 2: Isogram of Geothermal Gradient in Beijing-Tianjin-Hebei Region (within 3000 m in burial depth)

3.CALCULATION OF GEOTHERMAL RESOURCES IN BEDROCK

3.1 The Calculation Method Still Adopts Thermal Storage Volume Method, and the Concept of Reservoir Coefficient is Added

$$Q_r = CAd\,(T_r - T_0) \qquad (4)$$

$$d = De_v \qquad (5)$$

D indicates bedrock thickness (m), e_v represents the reservoir coefficient, that is, the percentage of thermal water reservoir with total formation thickness.

3.2 Determination of Calculation Parameters

The area of the thermal reservoir is directly measured from the tectonic map of the geothermal field. Determination of thickness of the thermal reservoir is based on actual drilling data and seismic interpretation data; whose average value is taken as the average thickness of bedrock stratum. The product of average thickness of bedrock stratum with the reservoir coefficient, is the thickness of thermal reservoir. The calculated thermal reservoirs of bedrock are the Wumishan formation and Ordovician formation in Jixian County, their average reservoir coefficients and porosity are 64.2, 15, 6.44, and 5%, respectively. When Wumishan formation is the main factor in range of calculated depth and there is a few other strata at the deep level, the reservoir coefficients and porosity are taken as 50% and 6%, respectively. If the multi-layer reservoir is considered as one thermal reservoir and the thickness cannot be easily divided, the reservoir coefficient and porosity are taken as 30% and 5%. In addition, for a multi-cap geothermal field with poor leaching degree, the porosity is taken as 2-3%. For a geothermal field with a high exploration degree, the porosity value is directly derived from the physical parameters interpreted by electrical measurement. The geothermal reservoir temperature is calculated according to the average buried depth of the geothermal reservoir and the geothermal gradient. For a geothermal field with high exploration degree, water density is corrected by temperature, pressure and the specific heat capacity of water, which is 4.19 J/ g· ℃. The specific heat capacity and density of carbonate rock are calculated based on actual measured data of 14 samples, respectively 0.898 J/g· ℃ and 2.70g/cm^3. The measured average values of schist and granitic gneiss were respectively 0.874 J/g· ℃ and 2.79 g/ cm^3.

3.3 Calculation Results and Evaluation

According to the above methods, the total geothermal resources of bedrock (Qianshan County) geothermal field in the exploratory area of North China area, Dagang and Eastern Hebei oilfields in the study area was evaluated as 1017.92 × 10^{18}J, and the total thermal water storage was 2824.51 × 10^{8}m^3. The estimated results of the geothermal fields in Niutuo town, Rongcheng and Gaoyang in Xiong'an New Area of Hebei Province, and geothermal fields in Yanling, Renqiu and Xian County in North China Oilfield Mining Area are shown in Table 4:

Table 4. Estimated Results of Geothermal Resources in Sagged Thermal Bedrock in Jizhong Oilfield

Name of geothermal field	Depth	Area (Km^2)	Average reservoir thickness (m)	Porosity (%)	Average reservoir temperature (℃)	Geothermal resource (10^{18}J)	Thermal water resource volume (10^{8}m^3)
NiuTuozhen	<2000 m	395			60 ~ 95	51.68	185.75
	2000—3000 m	639			95 ~ 115	104.01	278.79
RongCheng	<2000 m	241			60	21.07	95.65
	2000—3000 m	254			95	35	90.77
Gao Yang	<2000 m						
	2000—3000 m	746.4	112	6	135.7	25.7	50.2
Yan Ling	<2000 m	8.3			118 ~ 125	0.11	0.21
	2000—3000 m	114.5	48 ~ 612	6	124 ~ 130	15.34	34.06
Ren Qiu	<2000 m	59.13			126 ~ 146	2.44	3.25
	2000—3000 m	168.3	28 ~ 833	6	146 ~ 159	43.71	91.48
Xian County	<2000 m	1000	143.4	5	70.1	19.98	71.7
	2000—3000 m	1000	300	5	98	63.39	150.0

In principle, the main parameters are measured or calculated by using thermal storage method. The area and reservoir thickness of the geothermal fields are calculated according to seismic, gravity and actual drilling data. The porosity of carbonate reservoirs in North China oilfield has been studied for decades. The temperature is measured according to the actual temperature data of oil drilling or geothermal drilling. The specific heat and density of geothermal reservoir rock are obtained by experiments. These parameters are rather practical under the current exploration level, so the data of the geothermal resources calculated here has high credibility.

4.SIGNIFICANCE OF GEOTHERMAL RESOURCE EVALUATION IN OIL FIELD

According to the abundant data in the process of oil exploration, it is of great significance to carry out geothermal resource evaluation in order to provide clean energy for the heating demand, for oilfield production, and daily life. It is also important to provide reliable resource data for the development and utilization of geothermal energy for the local government around the oil field area and to carry out geothermal heating projects. In the above geothermal resource research and evaluation area, Xiong County, Hebei Province, located in the exploratory area of North China oilfield, has become a smoke-free city that uses geothermal energy for heating. The geothermal heating area of the whole county has reached 3.85 million square meters, and the geothermal heating covers over 95% of the urban area, benefiting nearly 89,000 people. It is clean, economical, and has been widely recognized. Caofeidian area, located in East Hebei oilfield exploratory area, Tangshan city, Hebei province, has achieved a geothermal heating area of 2.3 million square meters in the winter of 2018 and completely replaced coal-fired boiler heating. The large-scale middle-deep geothermal heating projects in these two regions have successfully realized geothermal water re-injection and ensured the sustainable development and utilization of geothermal resources, which are completed by oil companies such as SINOPEC and CNPC. It is expected that oil companies in China will greatly boost the healthy development of China's geothermal resources.

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