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Geothermal Resources and Utilization in Oilfields

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ABSTRACT

China's oil companies have long attached importance to the development and utilization of geothermal energy in oilfields. In order to exploit and utilize geothermal energy effectively, it is very important to know about the potential and distribution of geothermal resources in oilfields. In this paper, the authors systematically evaluated the hydrothermal geothermal resources up to a depth of 4,000m in China's main oil-gas basins based on a large number of well drilling and rock thermo physical properties testing data. The results showed that the geothermal resources in China's oilfields are large, and medium-low temperature hydrothermal geothermal resources are equivalent to 1084.5 billion tons of standard coal, with an annual production capacity of 1.617 billion tons of standard coal. High-quality geothermal resources are mainly concentrated in Bohai Bay, Songliao and Subei basins in eastern China. Huabei, Dagang, Jidong and Liaohe oilfields in Bohai Bay basin, Daqing and Jilin oilfields in Songliao basin and Zhejiang oilfield in Subei basin enjoy the best economic efficiency of development and utilization with high geothermal gradient, abundant geothermal resources and shallow burial (mostly shallower than 3000 m). Oilfields in western China, such as Tarim, Xinjiang, Tuha and Southwest, have low degree of economy of exploitation and utilization due to their low geothermal gradient, although the amount of geothermal resources in oilfields is relatively large, but the abundance of resources is small, the burial depth is large (deeper than 3000 m). Direct utilization of geothermal resources runs firstly for oil -water separation, heavy oil production, oil -gas gathering and transportation, oil pipeline cleaning, building heating, hot spring bathing, agricultural breeding, etc. The second is geothermal power generation, geothermal water over 100 ^{o}C can be used for power generation for the production and life in oilfields. In the current period of China's vigorous development of clean low-carbon energy industry and the promotion of clean geothermal energy heating, the exploitation and utilization of geothermal resources in oilfields, especially the development of high-quality geothermal resources in oilfields in eastern China in line with the heat market, to meet the demand for clean heating in northern China, will promote the realization of energy conservation, emission reduction and clean energy development of oilfields, and accelerate the development of China's geothermal industry.

1. INTRODUCTION

In recent years, China has attached great importance to the development and utilization of geothermal energy, formulated the national "13th Five-Year Plan" for geothermal development, accelerating the development of geothermal industry, and it is hoped that geothermal energy will play an important role in promoting coal-burning reduction substitution, environmental governance and energy restructuring.

China is rich in geothermal resources at medium-low temperatures, which has kept the world's first in direct utilization. The study shows that the hydrothermal resources located in sedimentary basins are the main constitutions of medium-low temperature geothermal resources, especially the oil and gas-bearing basins in China are not only rich in oil and gas, but also in hydrothermal geothermal resources (Wang et al. 2016, 2017). However, it is not clear how large the geothermal resources are and where the high-quality resources are enriched in these basins. Some evaluations have been launched in some basins or oilfields, such as Huabei Oilfield, Dagang Oilfield, Jidong Oilfield, Liaohe Oilfield, Daqing Oilfield, Shengli Oilfield, etc, the results of which differ greatly. In order to find out the actual state of geothermal resources in oilfield, this paper systematically evaluates the geothermal resources in oilfields for the first time based on a large number of geological, geophysical, drilling, temperature measurement and experimental data obtained during oil exploration process for many years, and establishes the evaluation methods of geothermal resources such as random simulation method, unit volume method and analogy method, evaluating the amount of geothermal resources in different reservoirs in China's main oil-gas basins, analyzing the distribution characteristics and application prospects of geothermal resources, and providing resources guarantee for the large-scale development of geothermal resources in oilfields.

2. STATUS QUO OF GEOTHERMAL DEVELOPMENT IN OILFIELD

2.1 Status quo of geothermal development and utilization in oilfield

Oilfield geothermal development and utilization mainly concentrated in two oil companies, PetroChina (CNPC) and Sinopec. PetroChina started to develop and utilize geothermal energy in oilfields earlier. In the 1970s and 1980s it began to use geothermal energy, mainly for heating and planting, and later for oil pipeline heating, cleaning, housing heating, geothermal power generation in medium-low temperature. PetroChina's geothermal development and utilization of oilfields are mainly concentrated in Huabei, Liaohe, Jidong and Daqing oilfields in Songliao Basin, Bohai Bay Basin. More than 30 geothermal projects have been carried out, mainly utilizing the associated water waste heat resources or abandoned wells in the process of oil and gas development to transform them into geothermal wells (Templeton et al.2014; Li et al. 2011; Weight et al.2015). Heat pump technology or direct heat transfer technology is adopted for heat energy extraction for oilfield production and residential heating, saving the fuel, gas, coal, in an annual replacement amount of thermal energy equivalent to more than 150,000 tons of standard coal; Sinopec's geothermal utilization of oilfields is mainly concentrated in Shengli and Zhongyuan oilfields in Bohai Bay Basin, and is also mainly used for oil transportation and heating. Sinopec's geothermal development goes fast, the speed has almost doubled year by year since 2006, it has become the largest enterprise in the development of medium deep geothermal resources in China. The geothermal heating capacity reaches 50 × 10^6 m^2, accounting for 30% of the China's medium deep geothermal heating, replacing 1.42 × 10^6 tons of standard coal annually and reducing 3.70 × 10^6 tons of carbon dioxide. The "Xiong County Model" of the development and utilization of geothermal energy made by Sinopec has become a model project for the development and utilization of medium deep geothermal energy in China.

2.2 Status Quo of Evaluation of Geothermal Resource in Oilfield

In the early period, Chen Moxiang (1994) and others estimated the geothermal resources of the main sedimentary basins in eastern and central part of China, it is believed in their evaluation that China's hydrothermal geothermal resources have a certain rather than rich potential for development. Li Kewen (2012) has calculated the total geothermal resources in China's main oil field within 5000 m of depth, which is 600×10^9 tons of standard coal. Yan Dunshi(2000) and others have evaluated the buried hill reservoirs in Neogene system reservoirs shallower than 3000m in Huabei, Dagang and Jidong oilfields of Bohai Bay Basin, total resources were evaluated as 62.89×10^9 tons of standard coal. Wang Shejiao (2014) and others have evaluated the ancient buried hill reservoirs in Neogene system in Huabei and Liaohe Oilfields, and Cretaceous reservoirs of Daqing Oilfield, where 4000m shallower in depth, the total amount of geothermal resources is evaluated as 373.07×10^9 tons of standard coal. It can be seen from the evaluation result, even the same layer system in the same basin, the results are quite different, which is due to the difference in data mastery, geological recognition degree and calculation depth. However, the comprehensive evaluation shows that the oil fields in Bohai Bay and Songliao Basin in eastern China have not only good geothermal formation conditions, but also the large amount of resources, especially in Huabei Oilfield in Bohai Bay Basin, the high temperature storage in buried hills and good water quality push it as the oilfield with richest resources and greatest development potential.

3 EVALUATION METHOD FOR GEOTHERMAL RESOURCE

The evaluation methods of stochastic simulation, unit volume and analogy are newly established to evaluate the geothermal resources of oilfields in this paper.

3.1 Stochastic simulation method

Stochastic simulation, also known as Monte Carlo method, is suitable for areas with relatively few data and uncertain evaluation parameters (Limberger et al.2018). The results are usually expressed in the form of probability. The formula used is the thermal reservoir method (formula 1, formula 2), characterized by the rapid estimation of geothermal resources using relatively few parameters and data. The formulas are as follows:

$$\mathrm{Q}_r = \mathrm{CAd}(t_r - t_0) \tag{1}$$

$$\mathrm{C} = \rho_r C_r (1 - \varphi) + \rho_w C_w \varphi \tag{2}$$

where Qr is the heat stored in thermal reservoir, J; A is the calculated area, m^2; d is the thermal reservoir thickness, m; t_r is the average temperature of thermal reservoir, ºC; t_0 is the local average annual temperature, ºC; C is the mean specific heat capacity of thermal stored rock and water, J/ m^3.ºC; ρ_r is the thermal stored rock density, kg/ m^3; C_r is the specific heat of thermal stored rock, J/ kg.ºC; ρ_w is the geothermal water density, t/ m^3; C_w is the specific heat of water, J/ kg.ºC; Φ is the porosity of thermal stored rock, dimensionless.

3.2 Unit volume method

The unit volume method is suitable for calculating geothermal resources with abundant data. This method is an amelioration from thermal reservoir method, which divides the evaluation area into several small units, then calculates the geothermal resources in each small unit by using thermal reservoir method, and finally sums up the resources in the whole evaluation area. The characteristic of this method is that the result of resource evaluation can be shown directly on graph, which is very helpful for optimizing geothermal anomaly area or favorable areas. The calculation steps include:

Firstly, dividing the evaluation area into small meshes usually in rectangular net, or the grid type can be determined according to the data source of thermal reservoir parameters in the evaluation area to be in rectangular, PEBI, triangular or variable area meshes. Then calculating the parameters such as reservoir thickness, rock porosity, reservoir temperature and specific heat of rock. If there are data points in the evaluation units, the attribute parameters take the average value of the data point. If there are no data points, grid interpolation is used to find the evaluation parameters. Finally, the geothermal resources in each unit are calculated by thermal reservoir method, and the total resources in the evaluation area are summarized aggregated.

3.3 Analogy Method

The analogy method is mainly used to calculate and analogy the abundance of geothermal resources. The steps of which include: establishing the standard of analogy evaluation firstly. Analogical evaluation standard mainly considers the characteristics of thermal reservoir, the nature of geothermal water and preservation conditions. Emphasis is placed on evaluation parameters of thermal reservoir, including pore type, thickness, area, porosity, permeability, burial depth, temperature and so on. Table 1 is an analogy for establishing evaluation criteria for parameters and assignment ranges. Then the similarity coefficients are obtained by comparing parameters in the evaluation area with the known area with similar geological characteristics (the known area refers to the well-known geothermal geological knowledge, the well-distributed resources and the geological units that have already been developed), so as to calculate the amount of geothermal resources in the evaluation area. The key point of analogy evaluation is to obtain the evaluation parameters of thermal reservoir. Because the thermal reservoir in different basins, regions and strata are quite different, when using the analogy method to calculate geothermal resources, the areas with similar geothermal geological conditions should be selected so as to reduce the calculation error. The calculation formula is:

$$\mathrm{Q}_r = \sum_{i=1}^{n} (A \times Zi \times ai)/n \tag{3}$$

$$\mathrm{a} = \mathrm{R}_a / \mathrm{R}_k \tag{4}$$

Where Q_r is the quantity of geothermal resources, J; A is the evaluation area, m^2; Z_i is the abundance of geothermal resources in the first known region (J/ m^2); a_i is the analogical similarity coefficient between evaluation area and the i-known area; n is the number of known regions; a is the analogical similarity coefficient between the evaluation area and the known area; R_a is the geology evaluation result of geothermal resources in evaluation area; R_k is the geology evaluation results of geothermal resources in known areas.

At present, the degree of exploitation and utilization of geothermal resources in oil fields is rather low, and there are few analogous evaluation objects for geothermal resources evaluation, which can be used in the part of geothermal fields in Huabei and Liaohe Oilfields for a long time. The evaluation of geothermal resources in this paper mainly uses stochastic simulation method and unit volume method to calculate geothermal resources.

Table 1: Parameters of analogy-based geothermal resources assessment

Conditions	Parameter name	Fractional value			
		1-0.75	0.75-0.5	0.5-0.25	0.25-0
Thermal reservoir	Pore type	Karstic	Pore	Pore-crack	Crack
	Thickness (m)	> 100	100-50	50-10	10-5
	Area (km^2)	> 100	100-50	50-10	<10
	Porosity (%)	> 30	30-15	15-5	<5
	Permeability (mD)	> 500	500-100	100-10	<10
	Burial depth (m)	<1000	1000-2000	2000-3000	3000-4000
	Temperature (℃)	150-90	90-60	60-40	40-25
Geothermal water	Water quantity (m ^{3}/ d)	> 1000	500-1000	100-500	<100
	Total salinity of water (g/ L)	<1	1-3	3-10	> 10
Preserve	Cover layer (m)	> 50	30-50	10 - 30	<10

4 EVALUATION PARAMETERS OF GEOTHERMAL RESOURCE

Geothermal resource evaluation parameters include various kinds of parameters using different evaluation methods, as well as geological evaluation parameters used in analogy evaluation. Because the objective evaluation of geothermal resources in this paper is hydrothermal geothermal resources in sedimentary basins, on consideration of the geothermal geological conditions in the basin, the evaluation parameters of geothermal resources mainly include reservoir area, thickness, temperature, thermal conductivity of rock, specific heat, porosity, abundance of resources and recoverable coefficient.

Thermal reservoir area (km^2). Accurate delineation of reservoir area is of importance to calculate geothermal resources, and its accuracy has a decisive impact on the reliability of geothermal water resources evaluation using volumetric method. The minimum thickness is defined as the boundary condition to delineate the area of aquifer usually based on log interpretation.

Thermal reservoir thickness (m). Thermal reservoir thickness refers to the thickness of effective water reservoir which is defined on the basis of the study of the relationship among the lithology, physical properties, water-bearing capacity and electrical properties of the water reservoir, which is generally obtained by well logging.

Thermal reservoir temperature (^{o}C). It means the measured or predicted temperature of thermal reservoir which is usually obtained from continuously measured temperature data of a single well. When the reservoir temperature in the evaluation area cannot be actually measured, the geothermal gradient in the area or adjacent area can be used to calculate the reservoir temperature.

Geothermal gradient (^{o}C/ km). The rate at which ground temperature varies with depth. It can be calculated by continuously measured temperature, or by ground temperature data obtained by well logging or oil testing.

Thermal reservoir porosity (%). The porosity is an important parameter to evaluate geothermal resources, and the effective porosity is usually used to calculate geothermal water resources. Effective porosity refers to the ratio of the interconnected pore volume to the total volume of the rock. This parameter can be obtained according to the measured value of the sample or log interpretation.

Thermal conductivity of rock (W/ m. K). The thermal conductivity of rock is the key parameter to study the thermal properties of rock. This parameter is a measure of the thermal conductivity of a rock, i. e. the heat passing through a unit area in a time when the temperature of the unit length in the direction of heat transfer decreases by 1 ^{o}C.

The specific heat capacity (J/ kg. ^{o}C). It is the heat capacity of a unit mass material, that is, the heat absorbed or released in a certain mass of a rock, when its temperature rises or falls by 1^{o}C. Compared with the thermal conductivity of rock, the specific heat capacity of rock is the ability to absorb and release heat.

Terrestrial heat flux (mW/ m^2). The heat transmitted from the earth's interior to the earth's surface per unit area and time, and then released into the atmosphere, is numerically equal to the product of the thermal conductivity of rock and the vertical geotemperature gradient. It is the key parameter for calculating geothermal resources by terrestrial heat flow method.

Water saturation (%). Water saturation is the ratio of water volume ineffective pore to rock volume ineffective pore volume, that is, Sw = Vw/ Vp × 100%, in which Sw is the water saturation, %, Vw is water volume in effective pore, Vp is effective pore volume.

Resource abundance (J/ km^2). It refers to the amount of geothermal resources per unit area, and commonly used in analogy method. Analogous evaluation is usually established in areas with higher degree of exploration to obtain the resource abundance, the similarity coefficient is determined by analogy in evaluation area, and then the geothermal resource is calculated.

The recoverable coefficient (%). This parameter refers to the ratio of the allowable quantity of heat and geothermal fluid to the total geothermal resource on basis of sustainable development of geothermal field. This parameter is influenced by many factors, such as type of thermal reservoir, burial depth, reservoir pressure, reservoir lithology, and even development technology, and the value varies.

The recoverable coefficient should be determined according to the different geothermal geological conditions, different purposes of exploitation and utilization, the technical level of exploitation and utilization, the environmental geological problems and the disaster geological problems which may bring after mining. What especially important are the maximum allowable drop of geothermal water level and the maximum amount of recharge realized by the recharge project, which are the main bases for determining the recoverable coefficient.

In the evaluation of geothermal resources, it is better to use experimental data to reduce the calculation error. In the absence of experimental data, the parameters with similar conditions can be analogized. Table 2 is the key parameters involved in this evaluation of geothermal resources in oil-gas basin. The recoverable coefficient is influenced by many factors, such as thermal reservoir temperature, permeability and development technology, and the value varies greatly (Williams, 2007). With the gradually mature development of heat pump and irrigation technology, setting a lower drop limit of thermal reservoir temperature will be the key factor affecting the recovery coefficient. The recoverable coefficient in this evaluation is determined on an average of 15% of 100-year-development of hydrothermal geothermal fields(Geothermal Resource Evaluation Method, 1985; Geothermal Resources Geological Exploration Code, 2011; Wang et al.2017).The value of thermal reservoir thickness mainly counts water layers with more than 5m in a single layer, but in some areas such as Songliao basin where the reservoir thickness is much thinner, the minimum thickness is valued at 1m. The ground surface reference temperature is uniformly valued at 15°C.

Table 2: Key parameters of geothermal reservoirs in major petroliferous basins, China

Basin	Oilfield	Stratigraphy		Lithology	Area (km^2)	Thickness (m)	Porosity (%)	Temperature (°C)
		Geologic Time	Formation					
Bohai Bay	Huabei	Neogene, Paleogene, and Proterozoic Erathem	MingHuaZhen, Guantao, Dongying, Shahejie, Kongdian and Wumishan Fm.	Sandstone and carbonate rocks	22,000	2,349	6-35	41-182
	Dagang	Neogene, Paleogene	MingHuaZhen, Guantao, Dongying, Shahejie, and Kongdian Fm.	Sandstone	15,000	359	10-32	36-140
	Jidong	Neogene, Paleogene, and Paleozoic Erathem	MingHuaZhen, Guantao, and Dongying Fm., Ordovician and Cambrian	Sandstone and carbonate rocks	5,000	722.5	6-35	25-105
	Liaohe	Neogene, Paleogene, and bedrock	Guantao, Dongying, and Shahejie Fm., and bedrock	Sandstone, sandy conglomerate, granite, and basalt	6,500	1,451	6-28	38-145
Songliao	Daqing	Cretaceous	Yaojia Fm, Qing2 and Qing3 Members, and Quan3 and Quan4 Members	Sandstone	110,000	114	19.2-23.1	49.6-62.4
	Jilin	Cretaceous	Yaojia, Qingshankou, and Quantou Fm.	Sandstone	63,000	402	13-25	48-88
Ordos	Changqing	Paleozoic Erathem	Cretaceous, Zhiluo, Yan'an, and Yanchang Fm.	Sandstone	120,000	613	13.2-23.1	34.3-46.5
Subei	Zhejiang	Cenozoic Era	Yancheng, Sanduo, and Dainan Fm.	Sandstone	2,600	757	17-29	48-75
Qaidam	Qinghai	Neogene, Paleogene, Jurassic, and bedrock	Neogene, Paleogene, Jurassic, buried hill	Sandstone and volcanic rocks	31,000	141	7-20	74-110
Fushan sag in the Beibuwan Basin	Nanfang	Paleogene	Weizhou and Liushagang Fm.	Sandstone	2,500	959	14-25	80-150
Sichuan	Xi'nan	Mesozoic and Paleozoic	Jurassic, Triassic, Permian, and Carboniferous Systems	Sandstone and limestone	100,000	413	5.21-8.4	56.4-105
Tuha	Tuha	Paleogene System and Mesozoic Erathem	Shanshan and Tugulu groups, Jurassic, and Karamay Fm.	Sandstone	38,100	460	6-20	25-91
Junggar	Xinjiang	Neogene, Paleogene, Mesozoic, and Paleozoic	Neogene, Paleogene, Cretaceous, Jurassic, Triassic, and Permian	Sandstone and volcanic rocks	70,000	570	7-20	51-85.4
Tarim	Tarim	Neogene, Paleogene, and Mesozoic	Neogene, Paleogene, Cretaceous, Jurassic, and Triassic	Sandstone	390,000	141	9.5-14.8	51-79
Jiuquan	Yumen	Paleogene in the Jiuxi depression and Cretaceous in the Ying'er sag	Baiyanghe Fm. in Jiuxi depression, and Xiagou Fm. in the Ying'er sag	Sandstone	646	57.6	4.2-33	25-143

5 EVALUATION OF GEOTHERMAL RESOURCES IN OILFIELD

5.1 Evaluation of Geothermal Resources in Oilfield

In addition to the total and recoverable thermal energy resources in the thermal reservoir, the geothermal water resources and geothermal energy in the thermal reservoir are also calculated in this evaluation.

According to the calculation results, Bohai Bay Basin has the largest amount of geothermal resources , which is 297.4×10^9 tons of standard coal, 446×10^6 tons of standard coal per year of recoverable geothermal resources, followed by Sichuan, Tarim, Ordos, Songliao, Qaidam Basins with geothermal resources of 152.5×10^6, 144.7×10^6, 126.6×10^6, 117.8×10^6 and 72.3×10^6 tons of standard coal respectively, among which the average recoverable geothermal resources all exceed 100×10^6 tons of standard coal per year. Several other basins, such as Tuha, Subei, Beibuwan and Jiuquan basins, have little geothermal resources because of their small area. In terms of geothermal resource abundance, Bohai Bay Basin has the largest one with an average of 6131×10^3 tons of standard coal/ km^2, while Tarim Basin has the lowest abundance of geothermal resource of 114.8×10^3 tons of standard coal/ km^2 only, despite its third-largest amount of geothermal resource. Although the amount of geothermal resources in Beibuwan and Subei Basins is small, the abundance of geothermal resources areas high as averagely 2937.2×10^3 tons of standard coal/ km^2 and 2094.4×10^3 tons of standard coal/ km^2 respectively, which shows that the two basins have good geothermal resources and are more abundant.

For geothermal resources in hydrothermal type, the geothermal resources formed in different geothermal temperature fields are quite different. The geothermal resources formed in high geothermal temperature fields at the same depth will be better than those formed in low geothermal temperature fields, and the economy degree of exploitation and utilization will be obviously higher than that of low geothermal temperature fields. Therefore, in order to develop the geothermal resources effectively, it is necessary to classify the geothermal resources in different geothermal temperature fields.

In order to classify and evaluate the geothermal resources in oilfields, the evaluation indexes and standards should be established firstly. The comprehensive evaluation mainly takes into account index elements such as geothermal resource quantity, geothermal resource abundance, burial depth, geothermal gradient, market demand, policy support, development planning and development basis. From the viewpoint of geothermal exploitation and utilization, geothermal resources abundance is as much essential as the foundation of geothermal exploitation and utilization. However, it is not enough to consider only the quantity of resources, the degree of enrichment of resources also needs to be considered the more enriched resources, the higher the abundance of resources, the better the efficiency and effect of exploitation and utilization; Secondly, the depth of buried resources and the temperature gradient (or geothermal gradient) of the reservoir. The shallower the burial depth of resources, the higher the reservoir temperature, the better the economy of geothermal development. Thirdly, consideration should be given to the market demand, no matter from oilfield enterprises or local residents, the larger the demand market, the better the market prospect of geothermal development and utilization of oilfields; Fourthly, the policy support for geothermal exploitation and utilization. Where there is local policy support, it is will beneficial to promote the exploitation and utilization of geothermal resources in oilfields and to promote the development of geothermal industry. Fifthly, whether there are geothermal development plans from oilfields enterprises or local government, if so, it will facilitate the effective management and implementation of geothermal projects; Sixthly, whether there is a basis for development. A region with experience in development and utilization, will start quickly and be conducive to accelerating development. Considering that resources are the basis, while economy is the guarantee, the comprehensive weight of resources (resource quantity + resource abundance) and economy (burial depth + ground temperature gradient) are 0.25 and 0.3 respectively. The weight distribution of other evaluation indexes is shown in table 3.

Table 3: Comprehensive Evaluation Weight Table of Geothermal Development and Utilization in Oilfields

Range	1-0.75	0.75-0.5	0.5-0.25	0.25-0	Weight
Quantity of resources (10^8 tons of standard coal)	> 1000	1000-500	500-300	<300	0.1
Geothermal resource abundance (10^4ton/ km^2)	> 200	200-100	100-50	<50	0.15
Burial depth (m)	<1500	1500-2000	2000-3000	3000-4000	0.2
Geothermal gradient (℃/ 100m)	> 3.0	3.0-2.5	2.5-2.0	<2.0	0.1
Market demand	Very large	Large	Normal	small	0.15
Policy support	have	paucity	None	None	0.1
Development planning	Been worked out	Is working	None	None	0.1
Basis of development	Fine	Normal	None	None	0.1

Table 4 is the comprehensive scoring result and classification of each oilfield based on the comprehensive evaluation standard of geothermal development and utilization. According to the conditions of geothermal resources, market demand and development and utilization policy, the geothermal resources in oilfields are divided into four classifications, first one of which is the oilfields in best resource conditions, having the large market demand and the support of local policies and the basis of development and utilization. The second classification is those with better resource conditions, market demand, while uncertain policy; The third classification is these oilfields in normal condition with a certain market demand while uncertain policy; The fourth classification is those ones that the resource condition is not good, having certain market demand but no relevant policy. The evaluation results show that the first classification of resources is mainly distributed in Huabei, Liaohe, Jidong and Dagang Oilfields. The second one of resources is mainly distributed in Jilin, Daqing and Zhejiang Oilfields. The third one of resources is mainly distributed in Changqing, Nanfang, Qinghai and Xi'nan Oilfields. The fourth classification of resources is distributed in Xinjiang, Tuha, Tarim and Yumen oilfields.

Table 4: Results of Classification and Evaluation of Geothermal Resources in Oilfield

Sorting	Oilfield name	Fractional value	Characteristics of classification	Classification
1	Huabei	0.92	best resource conditions, large market demand, support of local policies, good basis for development and utilization	First class
2	Liaohe	0.91		
3	Jidong	0.90		
4	Dagang	0.83		
5	Jilin	0.78	better resource conditions, normal market demand, and the basis for development and utilization, uncertain the policy support	Second class
6	Daqing	0.77		
7	Zhejiang	0.71		
8	Changqing	0.67	Resources conditions are normal, there is a certain market demand but uncertain policy support	Third class
9	Nanfang	0.45		
10	Qinghai	0.52		
11	Xi'nan	0.38		
12	Xinjiang	0.36	Bad resource conditions, a certain market demand, no relevant policies	four classes
13	Tuha	0.30		
14	Tarim	0.29		
15	Yumen	0.26		

5.2 Potential in Exploitation and Utilization of Geothermal Resources in Oilfield

At present, a number of oilfield geothermal projects have been carried out in eastern China, including oil pipeline heating, oil pipe cleaning, oil-water separation, house heating, greenhouse, and medium-low temperature geothermal power generation. The main ways of exploitation and utilization of geothermal energy are to transform hot water, oil wells or abandoned wells produced from oil production process into geothermal wells and drilling geothermal wells, etc. The technologies adopted include direct exchange of ground heat, direct transfer of underground heat, heat pump and medium-low temperature geothermal power generation etc. (Liu et al.2015). Amount of utilization of geothermal energy per year from all geothermal projects that have been implemented is as great as more than 1.6×10^6 tons of standard coal, these projects concentrated in Huabei, Shengli, Zhongyuan, Liaohe and Jidong Oilfields in Bohai Bay and Daqing Oilfields in Songliao Basin.

By comparing the projects of geothermal development and utilization in oilfields, it can be seen that the economic efficiency of the project of direct heat transfer in oilfield in shallow burial depth and high temperature is obviously better than that of the geothermal project in oilfields in low temperature and with heat pump technology (Paul, 2015). The economy efficiency of exploitation and utilization of geothermal resources in different basins varies greatly because of the difference of fluid quality. Because of the low geothermal gradient in the mid-west oil fields, only the deep-buried areas can get higher temperature. Most of geothermal resources projects must be implemented by using heat pump technology which increases the development costs, so the economy efficiency is lower than that of eastern oilfields.

Researches show that the development and utilization of geothermal energy in oilfields can serve the production and life in oilfields, such as oil pipeline gathering and transportation, oil-water separation, improving oil recovery, heating in winter and agricultural breeding, which have great potential and remarkable advantages. Firstly, there is a large amount of geothermal resources in oilfield, which can meet the demand of production and residential heat in oilfield, for example, the heating consumption of CNPC oilfield is about 1890×10^3 tons of standard coal every year. Secondly, the oilfields have been development for many years, there are mature pipe network system and ground facilities, which can be reused with a little modification; Thirdly, after many years of oil exploration, a large number of geological, geophysical, drilling and other basic data have been gathered and clearly mastered, reducing the investment cost in geothermal exploration in early stage; Fourthly, there are a large number of abandoned wells in oilfield which can be transformed into geothermal wells for direct utilization. Based on comprehensive analysis of regional geothermal temperature field, reservoir distribution, formation and abundance of geothermal resources, considering the thermal demand in oilfield, it is necessary to give priority to the exploitation and utilization of geothermal fields in the eastern petroliferous basins with high temperature field and the most abundant resources, such as the Huabei Oilfield in Bohai Bay Basin, where there are the most abundant geothermal resources and the best economic efficiency in development, and where the "Xiong County model" built up in buried hill geothermal field in Niutuo Town has become a replicable model project for the exploitation and utilization of hydrothermal resources. The geothermal reservoir is featured in carbonate rock with a burial depth of 1500-2000m, a temperature of 60-80 ^oC, and a single well output of 50-70m^3/ h, the original coal-fired boiler is replaced by geothermal heating, with a heating area of 4.5×10^6 m^2, basically realizing the geothermal heating in the whole county. The Xiong'an New Area under construction in China is located in Huabei Oilfield. The underground geothermal resources can meet the heating demand of the whole Xiong'an New Area. Therefore, development and utilization of geothermal energy in oilfields is of great significance to promote the coal-fired reduction project of "coal to gas", "coal to electricity", to reduce the air pollution in northern China and improve the environmental quality. Following is Ordos, Qaidam and Sichuan Basins in central part of China. Although the resources in Tarim, Junggar and Tuha Basins in western China are large, the geothermal gradient and abundance of resources are low, and the economy efficiency of exploitation and utilization is lower than that of in eastern China.

6. CONCLUSION

(1). China attaches great importance to the exploitation and utilization of geothermal energy and is entering a stage of rapid development. The geothermal energy development index accounts for 30% of non-fossil energy sources in the geothermal development plan in national "13th Five-Year Plan". It is expected that geothermal energy will play an important role in reducing coal consumption, reducing northern air pollution and improving environmental quality.

(2). The evaluation methods and parameters of geothermal resources are optimized, and the evaluation methods of stochastic simulation, unit volume and analogy are established. Hydrothermal geothermal resources in 11 basins or blocks with a depth of less than 4000 m are systematically evaluated in stochastic simulation and unit volume method, the amount of geothermal resources and annual recoverable amount of geothermal resources, as well as geothermal and thermal resources in heat storage are calculated. The geothermal resources in 11 oil- gas-bearing basins or blocks in China is 1084.5×10^9 tons of standard coal, annual recoverable is 1627×10^6 tons of standard coal, $37508.5 \times 10^9 m^3$ of geothermal water resources and geothermal energy in the thermal reservoir is 250.4×10^9 tons of standard coal.

(3). The classification and evaluation scheme of geothermal resources in oilfield is established, and the geothermal resources in oilfield are evaluated by classification. The first class of resources are mainly distributed in Huabei, Liaohe, Jidong and Dagang Oilfields; The second class of resources are mainly distributed in Jilin, Daqing and Zhejiang Oilfields; The third class of resources are mainly distributed in Changqing, Nanfang, Qinghai and Xi'nan Oilfields; The fourth class of resources are distributed in Xinjiang, Tuha, Tarim and Yumen oilfields.

(4). The research shows that there is a great potential in geothermal development and utilization in oilfields which can be used in oil transportation and heat supply, heating, hot washing tubing, geothermal aquaculture, geothermal agriculture, medium-low temperature geothermal power generation by means of reforming oil wells or abandoned wells, utilizing waste heat from produced water, drilling geothermal well and so on. Based on the characteristics of geothermal resources abundance and heat demand, priority should be given to the development of geothermal resources in eastern oilfields with high temperature, high degree of resources abundance and high demand for heat, and then to the development of central and western oilfields.

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