Assessment of Thermal Resources in the Niutuozhen Geothermal Field, Gu'an County, North China Basin

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Resource assessment, geothermal field, North China Basin

ABSTRACT

In this paper, the geological characteristics of thermal resources in the Niutuozhen geothermal field, Gu'an County, North China basin, are studied. The preliminary assessment of the thermal resources in this area is given for future exploration and development. Total geothermal reserves in Gu'an county are 1003.86x10^{16} J, the thermal water reserve is 79.08x10^8 m^3, exploitable thermal water is 1110.63x10^4 m^3/a, and exploitable heat energy is 105.73 MW/a.

1. Introduction

Although petroleum is still a dominant source for energy, more attention and effort have been directed to develop new and sustainable energy sources, such as nuclear, solar or wind power generation. Geothermal energy has also emerged as another "green" and sustainable energy source with various advantages. It is a renewable resource and environmentally benign compared to hydro powder, nuclear energy or fossil fuels. It is there all the time and does not depend on the sun shining or the wind blowing. Because of this, enormous interest and effort have recently been directed to the research and development of geothermal resources in China. As a part of this effort, we have studied the geological characteristics of and provided a preliminary assessment of thermal resources of the Niutuozhen geothermal field in Gu'an County, China.

2. Geological Setting

Gu'an County covers 120 km^2 of Niutuozhen geothermal field in Jizhong depression, Northern China basin (Fig.1).

There is diverse sedimentary system in Niutuozhen geothermal field, including units from the Archean, middle-upper Proterozoic, Paleozoic, Mesozoic and Cenozoic Eras. Quaternary and Neogene sedimentary units of variable thickness are distributed over the whole field. Paleogene sedimentary units are very thick both in the Baxian depression and Langfang-gu'an depression, but do not appear in the Niutuozhen anticline. Basement is exposed between the Daxing and Niudong faults and its rocks are composed of Carboniferous, Permian, Ordovician, and Cambrian units of the Paelozoic, Qainbaikou, Jixian and Changcheng system units of the Proterozoic, and units from the Archean Era, all with a northeasterly strike and a dip towards the northwest. This sequence turns to a monoclinal structure from southeast to northwest (Figure 2, overleaf).

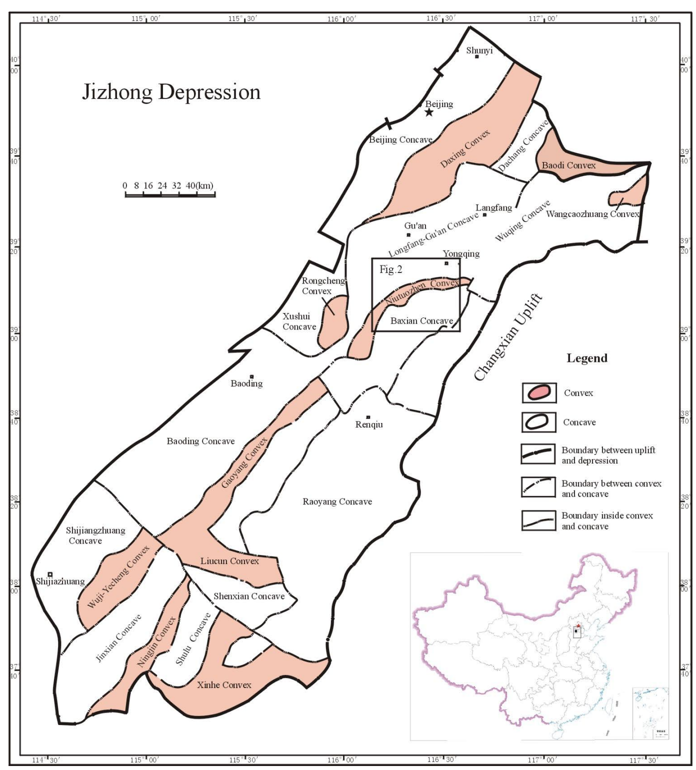

Figure 1. Geological background of Niutuozhen geothermal field in Jizhong depression.

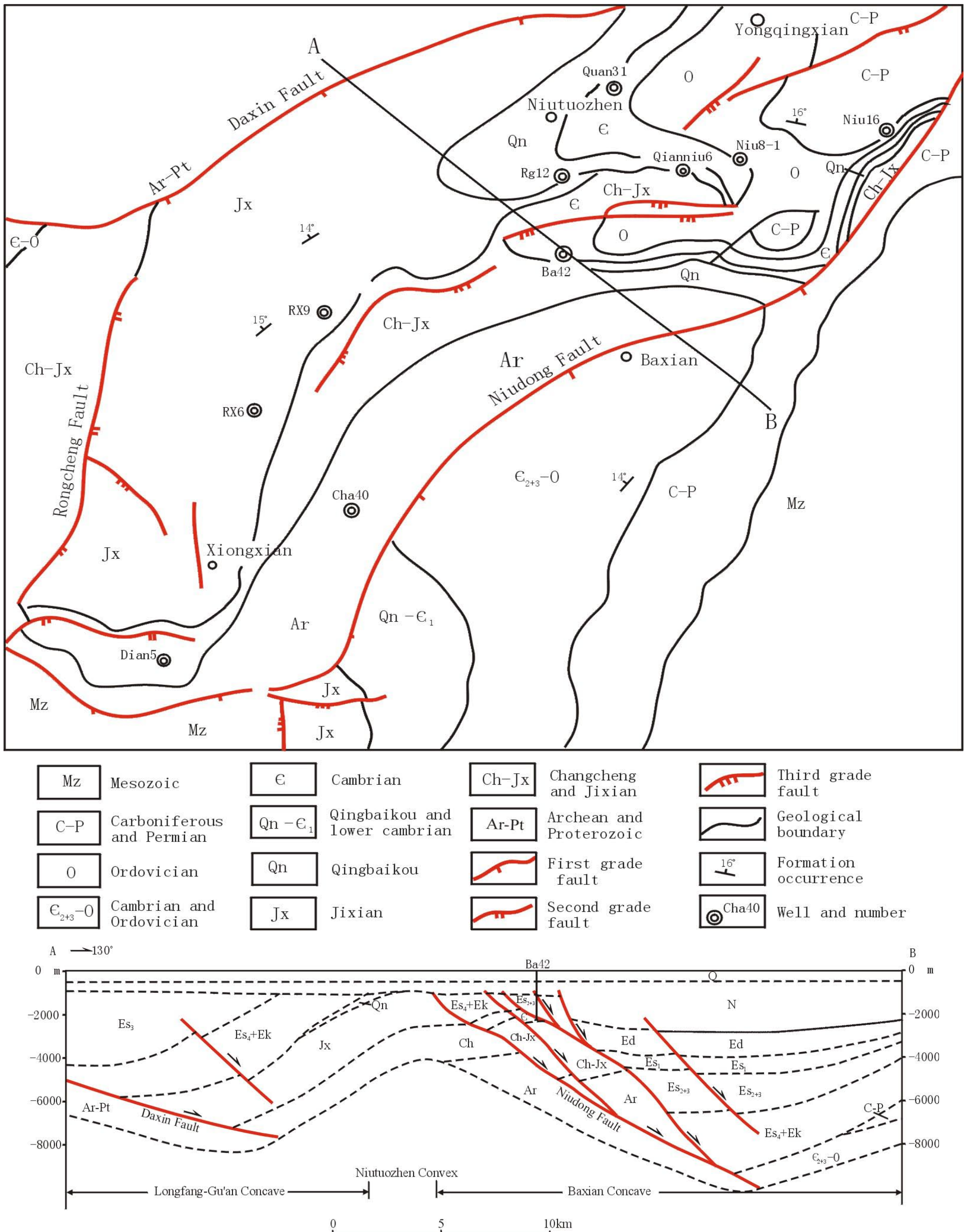

Figure 2. Geological map of basement rock in Niutuozhen geothermal field.

Niutuozhen geothermal field is located in the northern part of the Jizhong depression, North China basin. Delineated by an average depth of 2000 m to the basement, the area of the field is 487 km^2. There are three sets of faults in the area, trending northeast/north-northeast, east-west and northeast, respectively. Most of the faults are normal (Zhang et al., 2001).

3. Geology of Geothermal Field

The fine cap rocks of the geothermal field are Quaternary fluvial and lake deposits. The thermal conductivity of the formation is low due to superimposed clay, silty clay, silty sand and sand layers. Calcification in the lower Quaternary resulted in a significant clay increase, with the proportion of clay comprising up to 65% of the formation thickness. The thickness of single layer, which can form a regional aquifer, might be 5 to 15m.

Under the Quaternary deposits, the Neogene reservoir directly covers the basement rocks within the Niutuozhen anticline and the Paleogene system within the Baxian and Langfang-gu'an depression. There is a 50m-thick clay layer at the bottom and the average thickness fraction of clay is about 80%. It is a fine aquifer. The Neogene reservoir is composed of sandstones and conglomerates of Minghuazhen formation and of grey sandstones of Guantao formation. The area delineated by a geothermal gradient of 3.0 °C/100 m is 615.6 km^2 with a change in thickness of the reservoir from 150 m in the central part to 400 m along the boundary of the Niutuozheng anticline. The main parameters of the reservoir are given in Table 1.

Lithostratigraphic units of the fissured and karst basement reservoir include Paleozoic Ordovician and Cambrian as well as Paleozoic units of the Qainbaikou and Jixian systems. The reservoir mainly consists of limestones, dolomitic limestones and calcite dolomites. Clays and thick shale are intercalated between different reservoirs which developed into significant interlayer hydraulic relationships as a result of karst formation and structural movement over geologic time. Permeable connections between layers developed only in weathered leaching zones and local fracture zones. The area of the reservoir as delineated by an average depth of 2000 m to the basement is 406.7 km^2. The main parameters of the reservoir are also given in Table 1.

Table 1. The main parameters of the reservoirs in Gu'an county.

			Tertiary	Basement
			Neogene	Jixian system
Lithology			Sandstone and conglomerate	Dolomite and limestone
Thickness (m)			225	180.7
Depth (m)			380-470	987.6
Characteristic of reservoir	Temperature (°C)	portal	54	62-85
		reservoir	46.7	83
	Pressure (kgf/cm^2)			0.2-2.0
	porosity (%)		32.8	1.24
	Thermal conductivity (W/(m·°C))		0.542	5.782
	Water yield of a well (m^3/h)		20-50	20-100
	Water chemical type		HCO_3-Na HCO_3-Cl-Na	Cl-Na
	TDS (g/L)		0.5-1.5	2.8-3
	pH		7.2-8.4	6.5-7.0

4. Assessment of Gu'an Geothermal Resources

The geothermal reserves of Niutuozhen geothermal field were estimated using reservoir assessment and simple digital modeling. The thermal reserves (J) were calculated according to the formula:

$$Q_R = \overline{C}Ad(tr - tj) \quad (1)$$

where A is the area of the thermal reservoir, d is the thickness of thermal reservoir, tr is temperature of thermal reservoir (°C), and tj is the baseline temperature of the local reservoir formations at 14.5 °C, $\overline{C}$ is the average specific heat of the reserve water and rocks (J/m^3 • °C). The value of $\overline{C}$ is calculated using the following formula:

$$\overline{C} = \rho_c C_c(1-\Phi) + \rho_w C_w \Phi \quad (2)$$

where ρ_c and ρ_w are the densities (kg/m^3) of rocks and water, respectively, C_c and C_w are specific heats (J/kg • °C) of rocks and water, respectively, and Φ is the porosity (%) of the reservoir rocks.

The area of the Tertiary thermal reservoirs was determined based on contours of the geothermal gradient equal or greater than 3.0 °C/100 m, while the area of the basement reservoirs was determined by the 2000 m and 3000 m contours of their top burial depths. The thicknesses of the thermal reservoirs were determined based on the thickness of sand layers for the Tertiary reservoirs and on the thickness of fissuring and karst rock formations for the basement reservoirs, which were obtained from drilling data.

The temperature of the Tertiary thermal reservoirs was calculated using this formula:

$$t = \frac{d-30}{100} \times \Delta_t + 14.5 \quad (3)$$

where d is the burial depth of the middle reservoirs, and Δ_t is the geo-thermal gradient (°C /100 m):

$$\Delta_t = \frac{t - t_o}{H - h_o} \times 100 \quad (4)$$

in which *t* is the measured temperature (°C) of geophysical wells at the burial depth H (m), while t_0 is the temperature (14.5 °C) of constant-temperature layers at the depth of 30 m.

Similarly, the temperature of the basement reservoirs was calculated using this following formula:

$$t = \Delta t \frac{d-30}{100} + 14.5 + \overline{\Delta tj}\frac{\Delta d}{100} \quad (5)$$

where Δd is the thickness (m) from the middle basement reservoir to the top of basement, Δtj is the geo-thermal gradient (°C/100 m) of the basement reservoir. This is expressed as:

$$\Delta_{tj} = \frac{t_2 - t_1}{\Delta H} \times 100 \quad (6)$$

where t_2 and t_1 are the temperatures (°C) of the basement rocks at the different depths of drilling for the measurement of the temperatures, and ΔH is the interval thickness (m) of the reservoir at the depths of measurements t_2 and t_1. In addition, the porosities of the Tertiary and basement rocks were measured experimentally or based on petroleum acoustic well logs.

Table 2. Assessment of thermal reserves in Niutuozhen geothermal field.

	Tertiary	Basement rock <1200 m	Basement rock <2000 m	2000-3000 m
Thermal reserves (×10^{16}J)	1955.89	272.64	1729.09	4043.40
Exploitable reserves (×10^{16}J)	489.02	40.90	259.35	

The results obtained accordingly are given in Table 2 for the Tertiary reservoir and the Jixian reservoir at <1200 m, <2000 m, 2000-3000 m, respectively (3rd Hydrogeology and Engineering Geology Company, 1990).

More specifically, the evaluated area of Tertiary reservoir in Gu'an County is about 120 km^2 with an average geothermal gradient of 3.0 °C/100 m, and its depth is 2000 m. The basement reservoir with an area of 93.6 km^2 was evaluated for the depth of <2000 m and 2000-3000 m, respectively (Table 3) by the same reservoir assessment method.

The exploitable reserve of the Tertiary reservoir is calculated according to a production rate of 0.1%-0.2% per year and including re-injection. The exploitable reserves of the basement reservoir are evaluated according to the exploited yield with a decreasing level of less than 2 m (Liu et al., 2005; Zhang et al., 2001). The Tertiary and Jixian reservoirs at <2000 m were well evaluated by drilling and considered as areas of high exploration potential, but the other reservoirs without drilling information are considered as areas of low exploration potential.

Table 3. Assessment of geothermal resources in Gu'an County.

	Thermal reserves (10^{16}J)	Thermal water reserves (10^8 m^3)	Exploitable reserves	
			Thermal water (10^4 m^3/a)	Heat energy (MW)
Tertiary	527.19	65.93	988.95	85.18
Basement rock	476.67	13.15	121.68	20.55
Total	1003.86	75.98	1110.63	105.73

References

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