GEOTHERMAL WATER RESOURCES AND DISSOLVED GAS IN EASTERN JIYANG DEPRESSION

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ABSTRACT

Jiyang Depression is located in northeast of Shandong province. It belongd to a petroliferous basin in the hydrocarbone-bearing Bohai Bay. This is a rift type Meso-Cenozoic lake basin. It consists of four depressions of Dongying, Zhanhua, Chezhen and Huimin and a Chenjiazhuang uplift, covering an area of 8,640 km^2. It is a part of the Yellow River delta geographically.

1. GEOTHERMAL GEOLOGICAL CONDITION

1.1 Geological Structure Features

Stratigraphical sequences and their distribution

Seismic, drilling, logging and biostratigraphy have revealed and proved that the sequences in Jiyang Basin contains two groups, i.e. the base formations and the infill strata. The base refer to the Lower Triassic (T) or the more older formations, and the infill strata include the Jurassic (J_3) and newer formations, i.e. the Upper Jurassic (J_3), Cretaceous (K_1 and K_2), Paleogene (E), Neogene (N) and the Quaternary (Q) , among which the Paleogene strata are mainly lacustrine facies and those of the Neogene are mainly fluvial deposits.

1.1.1 Structural Evolution of the Basin

The analyses of stratigraphy, sedimentary, igneous rock and the stress field indicated that different tectonic layer has different geological, geophysical and geochemical characteristics (Table 1).

The structural evolution of the late Mesozoic and the Cenozoic mainly corresponded an episodic rifting and chasmic history, which could be divided into the following four stages:
(1) Triassic thrusting orogeny;
(2) Negative inversing from the Late Jurassic to Early Eocene;
(3) Right lateral transtension from the Miocene to Oligocene;
(4) Entire subsidence after rifting of the earth's crust from the Miocene to Holocene.

1.2 Basic Features of Geotemperature Filed

1.2.1 Horizontal Distribution of Geotempreture Field

The average isogeotemperature gradient map in east Jiyang basin, which is plotted using thermal logging and PVT temperature date from more than 1000 hydrocarbon exploratory wells and temperature data from 9 hot water wells, and the temperature contour map of 1500m depth obviously show that in the geotemperature field, high and low temperature alternates horizontally. The geotemperature gradient varies from 3.6 to 4.0 ^{o}C /100m generally, while that in area with base rock underlie could be more than 4.3 ^{o}C/100m. The temperature at 1500m is 60-76 ^{o}C. The regions of higher geotemperature gradient extend EW approximately, with alternating of high-low-high from the south to north. This variation is related closely to geological structure. In general, the uplifted area and the northern slope are always of higher geothermal gradients. The large rifting strike is almost coincident with higher geotemperature gradient. The subsidence areas are of lower geotemperature gradient, but not always the areas of lower geotemperature.

1.2.2 Vertical Distribution of Geotemperature Gradient

The relationship of depth versus temperature of the 3 geothermal fields in the studied areas (Fig. 1) indicated that the geotemperature increases as the buried depth increases.

1.3 Characteristics of Geothermal Reservoir

1.3.1 Distribution of Geothermal Reservoir

The areas studied include three types of geothermal reservoirs, i.e. the porous reservoir of Guangtao Formation of Upper Tertiary, the porous-fissure reservoir of Dongying Formation of Lower Tertiary, and Karst -fissure reservoir.

The cap rock is the shale of Lower Minghuazhen Formation of Upper Tertiary. The features of stratigraphy, structure, hydrocarbon distribution, and of water pools indicated that different areas have different geothermal reservoirs in Jiyang Depression. The mail geothermal reservoirs in Dongying Depression are those of Dongying Formation of Lower Tertiary, while in Zhanhua Depression, the main geothermal reservoirs are in Guangtiao Formation of Upper Tertiary. The geothermal reservoirs of Lower Paleozoic are determined as secondary pools due to their various buried depth.

Table 1 Brief summary of tectonic layers in Jiyang basin

tectonic layer	Stratigraphical sequence			Seismic marker	Absolute age	Deposition rate (mm/Ka)	Igneous rock feature of Mesozoic and Cenozoic	Fault and fold geometry
Top	K_Z	Q			2.0	225	(Mainly) alkali basalt, (locally) andesite	Weak faulting activities, developed draping anticlines
		N_2		T_o	5.1	335		
		N_1			24.6	45		
Upper		E_3		T_2	37	129	Mainly alkali basalt, secondary atlantite, tholeiite	Grow better toward fault, and fault rolling anticlines, syn-depositional drag fold and anticlines deveolped
		Es	E_3S_1					
			E_3S_2 U					
			E_2S_2 L	T_3	42	237		
			E_2S_3	T_6				
			E_2S_4	T_7	45			
Lower		E_k	E_2K_1	T_8	54.9	260	Mainly tholeiite, secondary alkali basalt	Mainly negative inverse fault of NW strike
			$E_{1-2}K_2$					
			E_1K_3	T_R	65			
	M_Z	K_2			100	0.0	Mainly alkali basalt, secondary tholeiite and alkali basalt, etc.	
		K_1			135	<30		
		J_3			149			
		J_{1-2}			190			Mainly negative inverse fault of NW strike, separated by left- lateral transtensional faults of SN (local ENE) strike (e.g reverse thrusts),
Basal strata		T				0.0	Neutral, acid intrusive rock	Faults and folds of NW strike
	P_Z	C-P		T_{g1}	350	<10		No large scale faulting and folding
		E-O		T_{g2}	570			
	Ar	Art					Basic, neutral, and acid intrusive rock	Reserve thrusts and folds of NW strike

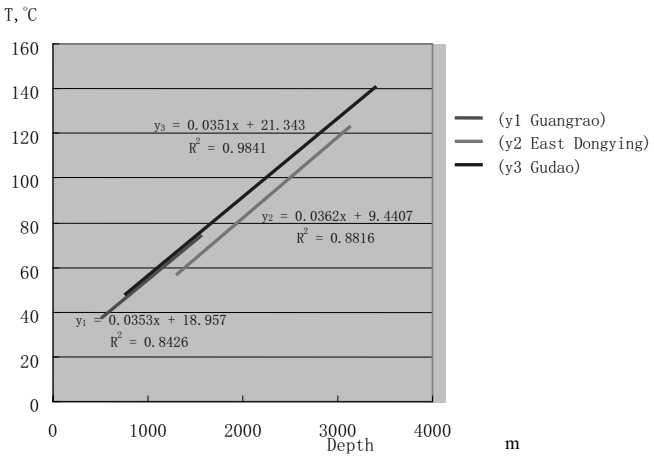

Figure 1 Depth versus temperature of the 3 geothermal fields

1.3.2 Features of Main Geothermal Reservoirs

The buried depth of the Dongying Formation geothermal reservoirs in Dongying depression varies from 800 to 1500m, and goes shallower from center to peripheral areas of the Sag. The bottom depth is from 1000 to 2300 m, and it turns smaller from depression center to the erosion area. The formation thickness of Dongying Formation is 100 to 700m, and the sand thickness is 20 to 200 m. The porosity interpreted is 26~32%, and the interpreted permeability is 1000 to 3000 $\times 10^{-3}$ μ m.

1.4 Geothermal Fluid Properties

Because of the discrepancy of analysis techniques and constrained by sampling conditions, the analyses of formation water from most of the regions only involve 6 ions in the water, which could only reveal the common properties of the geothermal fluids. The total salinity of formation water in Dongying Sag is relatively high, which is from 30 to 150 g/L, with the maximum of more than 300 g/L, and it owns the type of $CaCl_2$ (B.A. ЩУЛИН Classification, and the same below). The formation water's salinity in Zhanhua depression is lower, most are less than 10 g/L, and the water with salinity more than 20 g/L can only be found in the lowest part of the depression (Maximum 40 g/L), and the water type is $NaHCO_3$. In order to study the detailed composition of the geothermal water, samples from the geothermal wells were sent to the Central Laboratory of the Geology and Mining Bureau of Shandong Province. And the result shows that most of the water from Guantao Formation is of sub-acidity, brine, and very hard water, in which the ions of Bromine (Br), Iodine (I), Strontium (Sr), Manganese (Mn), metabotic acid (HBO_4), metasilicate acid (H_2SiO_3) and Radium (Ra) reached the concentration of mineral water concentration specification, and the Bromine, Strontium and Radium reached the mineral water nomenclature specification. All the heavy metal ion concentrations are less than the maximum drainage-permissive concentration of the National First and Second Pollutant, with the exception of Manganese (it reached the maximum drainage-permissive concentration of National Third Pollutant concentration).

The geothermal water in Dongying Formation is typical extremely hard water, in which Bromine (Br), Strontium (Sr), metasilicic acid (H_2SiO_3), metabotic acid (HBO_4) and Manganese (Mn) reached the concentration of mineral water concentration specification, and Strontium and metasilicic acid reached the mineral water nomenclature specification.

1.5 Calculation of Geothermal Resources

The calculation of geothermal resources in Jiyang Depression is carried out using geothermal volumetric method prescribed by the National Standard GB11615-89 (formulas omitted). Two calculating methods are adopted for the sake of more accurate result of geothermal resources. The first one is to determine the calculated area using sandstone thickness, and the parameters within the area are substituted into the formula. The second method is to determine sandstone thickness and other parameters using unit area (defined by the rectangular grid). The calculations are performed on the computer using the parameters determined. The results derived from these two methods differ slightly, as shown in the table 2 followed.

Table 2 Geothermal resource calculation of Jiyang Basin (east)

Tectonic unit	Geothermal formation	Calculation area (km^2)	Geothermal equivalent (10^{18}J)	Total hot water reserves (10^9m^3)	Recoverable hot water (10^9m^3)
Dongying depression	Guantao	5,700	75.82	180.97	1.81
	Dongying	4,304	85.8	146.6	1.47
	Subtotal	10,004	161.62	327.57	3.276
Zhanhua depression	Guantao	3,480	177.5	284.208	2.842
	Dongying	2,440	56.24	62.5	0.625
	Subtotal	5,920	233.74	346.708	3.467
	Total	15,924	395.36	674.278	6.743

*Equivalent to heat of 13.6$\times 10^9$T standard coal

The total geothermal resources of the two formations in Jiyang Depression (east) is 395.36$\times 10^{18}$J, which is equivalent to heat of 13.6$\times 10^9$T standard coal. The reserves of hot water (volumetric + compaction) is 674.278$\times 10^9m^3$, and the recoverable hot water will be 6.743$\times 10^9m^3$.

2. DISSOLVED GAS

2.1 Distribution

Water with soluble gas refers to the combustible gas dissolved in water, and it is associate with geothermal water, i.e. the byproduct of the water. It will be released when the pressure and temperature decrease as the exploitation of the hot water. At present, more than 30 geothermal wells have been drilled in Jiyang basin (east). As a principle, the exploitation of geothermal resources could not affect the exploitation of oil and gas. Therefore, the drilling of geothermal wells should avoid or be kept away from the recovered hydrocarbon formations. Nevertheless, there is still natural gas being produced as the production of hot water, which will burn when meet open fire. The geothermal wells encountered natural gas has a relatively extensive distribution.

2.2 Gas Composition

Well head gas samples were obtained from some wells and were analyzed by the Geochemical Laboratory of Geological Science Research Institute of Shengli Oil Field to get the gas composition, and the gas isotopic analysis was also carried out (Table 3).

Table 3 Composition and isotopes of dissolved gas

Well name	Formation	Sampling interval	Gas Composition						SP to air	Carbo isotop	GWR
			CH_4	C_2H_6	C_3H_8	N_2	CO_2	Sample with air			
Bo-3-20-8	Ng	1650-1820	52.44	1.17	0.01	42.96	3.39	5.31	0.77		
Dong-Re-11	Ed_3	1580-1720	94.22	0.14		4.64	0.99	29.58	0.58	-44.4	0.52:1
Bo-Re-1	Ng	1130-1450	95.21	0.21		2.94	1.72	13.07	0.58	-60.6	0.2:1
He-Re-2	Ng	1690-1720	92.96	0.42		4.63	1.97	4.26	0.59	-48.4	0.2:1
Gu-Re-3	O_2	1543-1800	70.03	3.23	1.12	5.82	19.44	31.64	0.79		
Gu-Re-Ce-3	Ng-L	1482-1542	64.27	1.53	0.44	5.02	28.54	66.09	0.86	-42.8	1.84:1
Xian-Re-1	Ng-L	1890-1980	45.14	0.86		47.96	6.01	10.47	0.81		

* Gas from well Gu-Re-3 contains 0.07 of isobutane, 0.2 of normal butane, 0.03 of isopentane and 0.03 of normal pentane.

** Gas from well Gu-Re-Ce-3 contains 0.03 of isobutane, 0.1 of normal butane, 0.02 of isopentane and 0.02 of normal pentane.

Table 3 shows that methane takes most of the components. Some wells have lower methane content due to conditions of sampling (e.g. high temperature of hot water, high gas content and harsh onsite sampling conditions). The gas will burn when meet open fire.

2.3 Exploitation and Use of Dissolved Gas

The 25 and 30 Articles of "Law of Mineral Resources of the People's Republic of China" stated that water solution gas that is associated with geothermal water is the byproduct of hot water production, and comprehensive investigation and evaluation to water solution gas should be performed when encountered by geothermal wells. Therefore, besides composition and isotopes and their origin, what is more important is to obtain the content of gas in the water, i.e. gas water ratio (GWR).

The most accurate technique to obtain GWR is the down-hole PVT sampling tool. The tool is tripped into the hole to a location high than the main water producing layer, and opened before pumping water. The sampler will be pulled out after water pumping and sent to the laboratory to be opened under special conditions, and the GWR can be determined. The water pumping data are recorded into the computer. When the GWR is obtained, the water/gas separator will be installed to collect the gas produced with hot water. It is reported that the natural gas produced from well Li 3, which is located in Lindian County of Daqing City, is used to heat the produced hot water effectively. Gudao Community of Shengli Oilfield has employed the associate gas from well Gu 3 to heat the boiler. The gas from this well can support one boiler of 10 tons capacity, and the last winter experienced a very good test run. And the geothermal wells in Hekou and Dongying will follow this usage.

2.4 Genesis Conditions of Dissolved Gas

The published literatures tell that the geneses of water with soluble gas vary in different counties of the world. They include organic, biogenic and volcanic origins. Industrial exploitation of water solution gas occurred in the Great

Table 4 Methane isotope comparison of well Gu-Re-3 to genesis known oil-type gas in Jiyang Basin

Name of Oilfield	Formation	Wells	Interval(m)	Methane isotope	Possible genesis
Gunan	C-P	3	2850-2854.8	-44.4—-56.4	Hydrocarbon type
Gudong	Nm	2	923.6-1129	-42.6---43.6	Hydrocarbon type
	Ng	17	1245.1-1413.9	-38.5---44.5	Hydrocarbon type
Gudao	Nm	1	999.2-1004.8	-42	Hydrocarbon type
	Ng	5	1140-1402.4	-41.4---42.4	Hydrocarbon type
Jinjia	Ng	4	804-1142	-43.8---46.2	Hydrocarbon type
Gu-Re-3	Ng	1	1465-1524	-42.8	Hydrocarbon type

British, Ukraine, Japan, Russia, Hasakstan, etc, and countries such as the Philippines, Nepal and Iran take it as civil use. The characteristics of the water solution gas reservoirs are briefly summarized in the following table (Table 4):
The genesis comparing to some ether country and combing the geothermal geology and analysis of methane isotopes from known gas reservoirs, the water solution gas from the following two areas are analyzed.

2.4.1 Gudao Area

The well Gu Re 3 is taken as a representative. The carbon isotope of this well is -42.8‰. This well has the depth of 1800m, and is close to Gu'nan Fault. It entered the Ordovician at 1578m, and pierced it through 222 m. The methane and CO_2 escaped upward into the formation water. In Gudao oilfield, the methane isotope content in the oil associate natural gas is -41.4~-42.4‰ and -42‰ for Guangtao and Minghuazhen Formation, respectively, which is similar to that of well Gu-Re-3 (-42.8‰). From this we concluded that the gas dissolved in the water of Guangtao Formation in Gudao area is the oil-type gas from the Tertiary source rocks by migration, diffusion and percolation along faults. The methane isotope in well He-Re-2 (in Zhanhua depression) and well Dong-Re-11 (in Dongying depression) is -48.4‰ and 44.4‰, respectively, which support the conclusion that the gas is oil type (Table 4).

2.4.2 Boxing Area

Well Bo-Re-1 is located in the northwest of Boxing county. The Boxing Fault has being kept in active. The gas from well Bo-Re-1 is dry gas, with the 95.12% of methane, 0.21% of ethane, 2.22% of CO_2, 0.15% of propane. The methane isotope is -64.7‰, which is close to that of the gas from the Quaternary of Caidam Basin and gas from Minghuazhen Formation of Fuyang. Therefore, it is concluded that the genesis of the gas here is biodegradation (Table 5).

Table 5 Methane carbon isotope comparison of biodegradation gas in Jiyang Depression

Area	Well name	Formation	Interval	Methane isotope	Genesis
Bohai Bay	Liang 4	Nm	855.8-864.1	-53.15	biodegradation
	Fucai 2	Nm	972.5-842.7	-57.78	biodegradation
Caidam Basin	Yishen 1	N	1,319-1,322.5	-67.3	biodegradation
	Caishen 1	Q	1,132.2-1,135.6	-67	biodegradation
Jiyang Depression	Bo-Re-1	Ng	1,167-1,564	-60.7	biodegradation

3. CONCLUSIONS

(1) The geotemperature gradient of the east of Jiyang Depression is 3.5-4.5°C/100m. The regions of higher geothermal gradient extend W-E approximately, with an alternation of high-low-high from the south to north. The temperature at 1500m is 60-76 °C, which is favorable area for hot water supply.

(2) This area exist three geothermal reservoirs as Guantao Formation of Neogene, Dongying Formation of Paleogene and the Ordovician of Lower Paleozoic. The geothermal reservoir usually has high production rate, and there are rich microelements in the water.

(3) The geothermal resources in Jiyang Depression (east) have been calculated. The total geothermal energy is estimated as 395.36×10^{18}J, and the volume of hot water is $674.278\times10^{9}m^{3}$ with $6.743\times10^{9}m^{3}$ of recoverable.

(4) Water soluble gas is found in lot of the geothermal wells, and methane takes most of the composition. The maximum gas water ratio is 1.84.

(5) Carbon isotope in methane has been analyzed for the four areas and compared to the results of other areas. It is concluded that the gas in Gudao area is oil type and the gas in Boxing area is from biodegradation.