A LOW TEMPERATURE GEOTHERMAL RESOURCE AND ITS DEVELOPMENT PROSPECT IN THE YELLOW RIVER DELTA, CHINA

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SUMMARY –The Yellow River is the second largest river in China. Its delta has an area of 9600 km^2. There are three kinds of low temperature reservoir; the upper Tertiary Guantao Formation, the lower Tertiary Dongying Formation and the Cambrian-Ordovician Formation. The temperature gradients of the reservoirs were evaluated and found to be between 50°C and 100°C, with the heat source originating from the continental heat flux. Assuming no recharge, and a development life of 100 years, the allowable extraction of geothermal water is 15,918 m^3/d and the usable heat energy is 110,984MW, being equal to 11.56MW/km^2, showing good potential for development of the geothermal resource.

1. INTRODUCTION

The Yellow River is the second largest river in China. It has a length of 5,464 kms, a catchment area of 750,000 km^2, an average runoff of 48,500 million m^3 each year and the highest known silt content, carrying 1,600 million tons of sediment each year to its lower reaches. This sediment forms the Yellow River alluvial plain and the Yellow River delta. The Yellow River delta is still growing by 12 km^2 per year and contains the Shengli Oil Field and many geothermal resources (Duan Yonghou., 1999).

2. GEOGRAPHY AND GEOLOGY

2.1 General Geography

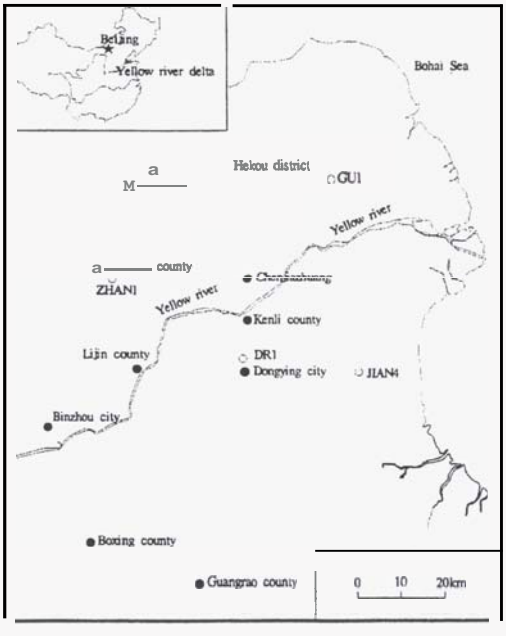

Figure 1 Location of the Yellow River delta geothermal area

The Yellow River delta is located in the coastal zone of East China. The study area comprises the main part of the delta, covering about **9,600** km^2, between longitudes 118°00′ and 119°10′, and latitudes 37°00′ and 38°10′ (see Figure 1). The climate of the area is northern temperate and is influenced by the monsoonal winds. The annual average temperature is 14.5°C with precipitation of 750 mm.

2.2 Stratigraphy and Geological Structure

Archean gneissic granite forms the basement rock of the area. It is overlain by a series by hard rocks from the Cambrian, Ordovican, Carboniferious, Permian, Jurassic, and Cretaceous Periods. The geological structures of the area were influenced by the Yanshan Movement and the Himalayas Movement after the Mesozoic Era. They controlled the distribution of 3 upthrown blocks and 2 downthrown blocks of the hard rocks. The Yihezhuang upthrown block is the most northerly, followed by the Zhanhua downthrown block, the Chenjiazhuang upthrown block, the Dongying downthrown block, and the Guangrao upthrown block as the most southerly. The area has been sinking slowly since the Tertiary, and a vast thickness of Cenozoic loose sediment has accumulated over the hard rocks. The total thickness of the sediments could reach 2000 to 4000 m (Zhang Zengqi et.al.,1996). The local geological conditions led to the development of a geothermal area and plentiful oil forming in the loose sediments.

3. GEOTHERMAL RESOURCES

3.1 Types of Geothermal Reservoir

According to the distribution of the strata, the type of rock, and the degree of porosity, three types of geothermal reservoir can be determined as follows:

(1) Guantao Formation: This formation occurs throughout the Yellow River delta. It has a lithology of interlayered sandstone and mudstone with a thickness varying from 400 to 600 m in the downthrown areas and 200 to 300 m in the upthrown areas. The reservoir lithology is sandstone and fine sandstone, having a semi-loose texture with a porosity of 25% to 35%. The conditions for storing water are very favourable. The single well yield is about 2000 m^3/d. The top layer of the reservoir in the Dongying downthrown area is at a depth of about 1000 to 1100 m and the supposed reservoir temperature about **54** to 57°C. The top layer of the reservoir in Zhanhua downthrown area is at a depth of about 1000 to **1450** m and the supposed reservoir temperature about 68 to 77°C.

1100 to 1400 m deep in the Chengjiazhuang upthrown block, and about 700 m deep in the Guangrao upthrown block. The porosity of the limestone is normally less than **3%.** The single well yield ranges from 1000 to 2000 m^3/d. The temperatures of the geothermal water at the top of the wells reach 70 to ***90°C.***

3.2 Anomalies of Geothermal Gradient

As described above, the area consists of several upthrown and downthrown blocks, especially in the hard rocks; these blocks affected and controlled the formation of the loose and semi-loose sediments. The Bouguer gravity anomalies of the area clearly show that in the upthrown areas the gravity value is greater than

0 mgal (the highest is 24 mgal) whereas in the

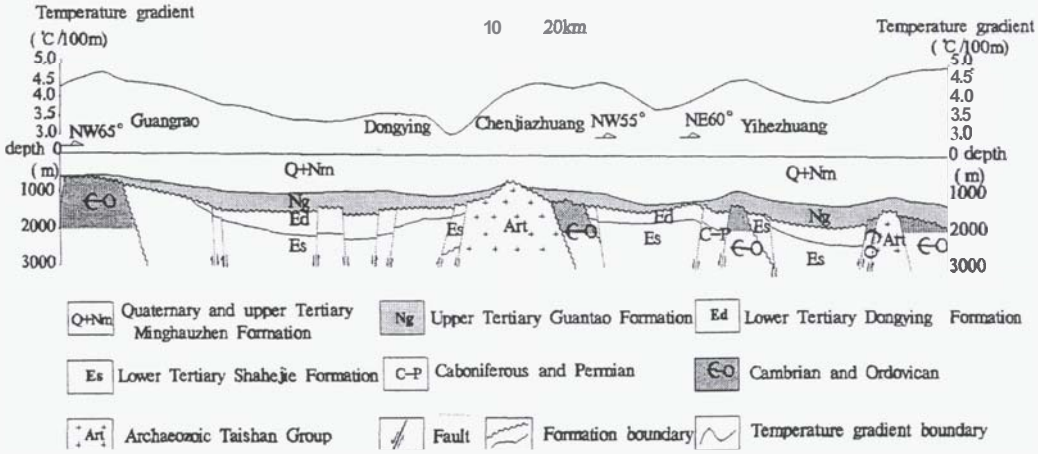

Figure 2 Profile of temperature gradients in the Yellow River delta geothermal area

(2) Dongying Formation: This formation develops only in the downthrown areas. The reservoir is composed of sandstone, conglomerate, and fine conglomerate having a semi-loose texture and poor sorting with an average porosity of about 30%. The reservoir thickness is usually between 150 and 200 m but occasionally may be less than 50 m or greater than 250 m. The single well yield is about 1500 m^3/d. The top layer of the reservoir, near Dongying City, is about 1400 to 1500 m deep and the supposed reservoir temperature about 64 to 74°C. The top layer of the reservoir in the north-eastem area is about 1500 to **2200** m deep and the supposed reservoir temperature round 77 to 100°C.

(3) Cambrian and Ordovician Formation: This formation, which is composed of limestone, lies below the loose and semi-loose sediments, occuring as a buried mountain, mainly in the upthrown area. The top layers of the formation range from ***950*** to **1400** m deep in the Yihezhuang upthrown block, 1600 to 1800m deep in the Gudao upthrown block,

downthrown areas the gravity value is less than 0 mgal, the lowest one -24 mgal (Zhang.,2001).

The measured data shows that the temperature gradient distributions for the loose sedimentary layers correlate very well with the Bouguer anomalies, **as** shown in Figure. ***2.*** In areas with **high** Bouguer anomalies the temperature gradients have high values ranging from 4 to **5°C/100m.** In the areas of low Bouguer anomalies the temperature gradients have values **of** less than **3.5°C/**100m.

3.3 Chemistry of the Geothermal Waters

The geothermal water is buried at depth, within a semi-closed environment, either moving very slowly, or not at all, with poor circulation. Therefore, the characteristics of the geothermal water show high TDS, and **a** high concentration of minor and trace elements (see Table **1).**

Table 1 Chemical composition of thermal water discharge at wells

Well number	DR1	JIAN4	GU1	ZHAN1
Reservoir type	Guantao Formation	Dongying Formation	Cambrian-Ordovian Formation	Guantao Formation
pH	6.89	7.19	7.00	6.97
TDS	18515.73	20630.80	3141.00	9903.80
Total hardness	3021.37	6726.68	1182	1345.55
Dissociated CO2	12.28	14.34	-	35.08
K^+	47.38	55.91	192.64	55.36
Na^+	6187.37	5218.22	5688.9	3216.67
Ca^{2+}	1025.01	1831.39	8.80	416.40
Mg^{2+}	112.18	518.03	111.37	77.24
Sr^{2+}	49.72	62.56	48.00	22.80
Pb^{2+}	<0.01	<0.019	<0.003	<0.001
Hg^{2+}	0.00027	0.0001	-	<0.0001
As^{5+}	<0.01	<0.01	-	<0.01
F^-	0.6	-	2.92	1.30
Cl^-	10900.01	12738.00	719.54	5774.50
SO_4^{2-}	93.42	4.44	-	117.41
HCO_3^-	84.87	103.35	338.30	163.68
$H_2SiO_3^-$	35.82	35.60	59.50	46.10
$H_2BO_3^-$	12.00	1.682	-	18.20
α(q/L)	0.46	1.72	3.92	1.18
β(q/L)	2.78	5.88	24.10	2.56
Ra(q/L)	0.70	0.96	5.53	0.36
Rn(q/L)	-	9.09	21.31	2.23
δD (‰)	-	-63.72	-65.68	-68.21
$\delta^{18}O$ (‰)	-	-8.14	-7.03	-8.51

The chemical compositions show two types of thermal water: Cl waters with high mineralization occuring in the semi-loose sediments, and Cl-SO_4 waters with relatively low mineralization occuring in the hard rocks. These results may imply that the geothermal water in the semi-loose sediment reservoir has undergone strong evaporation or mixture with sea water, whereas the hard rock reservoir water has not undergone such changes.

4. PROSPECT OF DEVELOPMENT OF THE GEOTHERMAL RESOURCES

3.4 Brief Calculation of Geothermal Resources

Exploration of the area is just starting. Therefore, the calculation of geothermal resources is rather rough. The following summary of the geothermal resources was evaluated using the volume method (Zhang.,2001). Table 2 shows that there are no more heat anomalies in the area because the temperature gradient anomalies are so small.

However, the total amount of the geothermal heat is large enough to use for local development because of its wide distribution. Even if the usable heat forms only a small part of the total heat stored in the reservoir, the potential for development and use is enormous.

Assuming no recharge, and a development life of 100 years, the allowable extraction rate of geothermal water is 15,918 m^3/d and the usable heat energy is 110,984MW, equating to 11.56MW/km^2.

Table 2 Summary of the geothermal resources in the Yellow River delta geothermal area

Reservoir	Thermal water ($10^{18}m^3$)	Total heat ($10^{18}J$)	Anomaly heat ($10^{18}J$)	Usable water (10^8m^3) *	Usable heat ($10^{18}J$)*
Guantao Formation	2730.86	140.43	23.90	3.34	0.17
Dongying Formation	1625.34	109.14	33.20	2.42	0.16
Cam.-Ord. Formation	240.69	116.06	27.80	0.05	0.02
Sum of Reservoirs	4596.89	365.63	84.90	5.81	0.35

3.5 Development of the Geothermal Resources

The geothermal resources of the area have several advantages that would favour their commercial development. These are:

- Even distribution of the geothermal resources in the Guantao Formation and the Dongying Formation, that allow the successful construction of exploitation wells and minimise investment risk.
- High quality of the geothermal water, and low mineralization, especially in the Cambrian-Ordovican reservoir, suitable for domestic heating, plant cultivation, fish breeding, medical treatments, recreation, etc.
- Vast geothermal resources in the reservoirs that allow long term, large scale developments.

3.6 Analyses of Environmental Problems for Geothermal Resource Development

According to the regional geology and geography, the main problems for the geothermal resource development may be the lowering of the thermal water table, subsidence, and thermal and chemical pollution, etc. Therefore, more detailed explorations should be done, the environmental impact should be assessed, and scientific management should be used before, and during, the development of the geothermal resource.

5. CONCLUSIONS

The Yellow River delta has a plentiful geothermal resource, with $4596.89m^3$ of geothermal water less than 2000m below the surface, usable thermal water of $5.81*10^8$ m^3 less than 200m below the surface, stored heat energy of $365.63*10^{18}J$ and usable heat energy of $0.35*10^{18}J$. The heat source is the continental heat flux, and the geothermal resource is spread across three reservoirs; the Guantao Formation, the Dongying Formation and the Cambrian-Ordovician Formation. The geothermal gradient ranges from 50 to 100°C in the low temperature reservoir. There are many factors favouring the development of the geothermal resource, but plans for detailed exploitation should include environmental assessment and protection measures to ensure the sustainable development of the geothermal resource.

6. REFERENCES

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