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GEOTHERMAL ENERGY DEVELOPMENT IN TIANJIN, CHINA

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ABSTRACT

Tianjin is located in the northest of China. It is the first area in China where systematic geothermal exploration took place, starting in the 1970's. Nine geothermal anomalies have been delineated and two geothermal fields, Wanglanzhuang and Shanlingzhi, have been explored. Geothermal water was mainly used in industry in the 1970's and 1980's. The hot water was originally taken from reservoir formations of Tertiary age at a depth between 1000 and 2000 m and with temperatures of 40-70°C. Since 1990, the use of hot water has shifted towards space heating, and to a basement reservoir at a depth of 2000-4000 m. The 'Geothermal resource appraisement method', 'Geologic exploration standard of geothermal resource' and 'Tianjin geothermal management stipulation' provide the legal framework for geothermal development in Tianjin.

1. INTRODUCTION

Tianjin is situated in the northeast part of China, at a longitude of 117°E, and latitude 39°N. It has an area of 11305 km^2, and most of it is lowlands. The population of Tianjin is about 9,000,000, half of which lives in the city of Tianjin. The climate is of the tempered continental type. Precipitation varies with location from 400 to 800 mm/a. The average annual temperature in Tianjin is 13°C, with the monthly average ranging from -10°C in January to 25°C in July. Days with temperatures below -5°C are, on average, more than 30 a year. Space heating is required four months a year.

Due to Tianjin's location in the North China basin, the geothermal gradient is higher than average, i.e. 3.5-8.8°C/100 m. The region is covered with Quaternary and Tertiary sedimentary formations except for mountain regions. The thickness of the sediments varies from 100 to 9000 m. Ordovician, Cambrian and Precambrian formations underlie the Tertiary formations, comprising the main basement geothermal reservoirs.

Nine geothermally anomalous areas have been found and comprehensively researched in Tianjin. Two geothermal fields, Wanglanzhuang and Shanlingzhi, have been explored. All of the investigations have been made by Tianjin Geothermal Prospecting, Exploitation and Designing Institute. Several of the experts of the institute received training in Iceland.

2. GEOTHERMAL EXPLORATION

Geothermal exploration in Tianjin began in the 1970's. By the end of the decade the distribution, depth, type and total reserves of the Tertiary geothermal resource had been established. It had also been developed on a large scale.

The Tianjin region is covered with Cenozoic sediments except for the mountain areas. Their thickness is 100-400 m north of the Baodi fault, 1000-2000 m south of the fault and 8000-9000 m in the greatest depression (Figure 1). An immense amount of geothermal water is found in the sandstone formations of the Tertiary reservoir. These Tertiary formations cover an area of 9000 km². Nine geothermally anomalous areas of 2320 km² have been delineated in the area that have geothermal gradient greater than 3.5°C/100 m, which is the geologic exploration standard of a geothermal resource. Figure 1 shows the main tectonic features in the region and the nine anomalous areas. The highest geothermal gradient is 8.8°C/100m in the centre of the anomalous region. Table 1 shows the basic data of the these anomalous areas (Pan Jinglong, 1986).

Table 1: Basic data of the Tianjin geothermal anomalies

Place	Depth (m)	Areas (km²)	Gradient (°C/100m)	Resource (10^{18}J)
Wanglanzhuang	400-1500	640	8.0	20.88
Shanlingzhi	400-2500	315	8.3	10.07
Wanjiamatou	400-1500	235	8.8	5.42
Zhouliangzhuang	500-2700	180	5.5	4.66
Panzhuang	450-2800	610	6.9	23.8
Qiaogu	500-3000	110	5.5	5.99
Shajingzhi	470-2800	190	4.5	9.17
Wangqingtuo	470-3000	114	5.0	4.17
Tangguantun	500-1100	40	7.6	0.52
Total		**2320**		

The first geothermal well reaching into the basement was drilled in July 1979, the pioneer of basement geothermal development in China. The exploration of Wanglanzhuang geothermal field was carried out in 1982-1986 in cooperation with UNDP and the Italian government. Ms. Lu Run, who was in charge of the project, was trained in Iceland in 1983. The area of the geothermal field is approximately 1000 km². It is estimated that the allowable production from the basement reservoir is 6048×10^3 m³/a. Table 2 shows the estimated geothermal resources of the Wanglanzhuang geothermal field (Lu Run, 1986).

Table 2: Geothermal resources of the Wanglanzhuang geothermal field

	Area /depth	Geothermal resource			Hot water resource		
		(10^{18}J)	(10^{14}kcal)	(10^{10}kWh)	Total (10^8 m³)	Drawdown -110 m (10^6 m³)	Drawdown -150 m (10^6 m³)
Tertiary	1002 km²	20.88	49.89	580.14	503.15	643.16	979.95
	640 km²	13.81	32.99	383.60	236.25	325.82	535.75
Basement	2000 m	18.92	45.19	525.54	35.07		
	3000 m	45.79	109.36	1271.86	46.19		

The exploration of the Shanlingzhi geothermal field was conducted in 1986-1991. Ms. Chen Zhenxia, who was in charge of the project, was trained in Iceland in 1986. Shanlingzhi geothermal field is located in the eastern part of Tianjin and has an area of 840 km². It is estimated that the geothermal

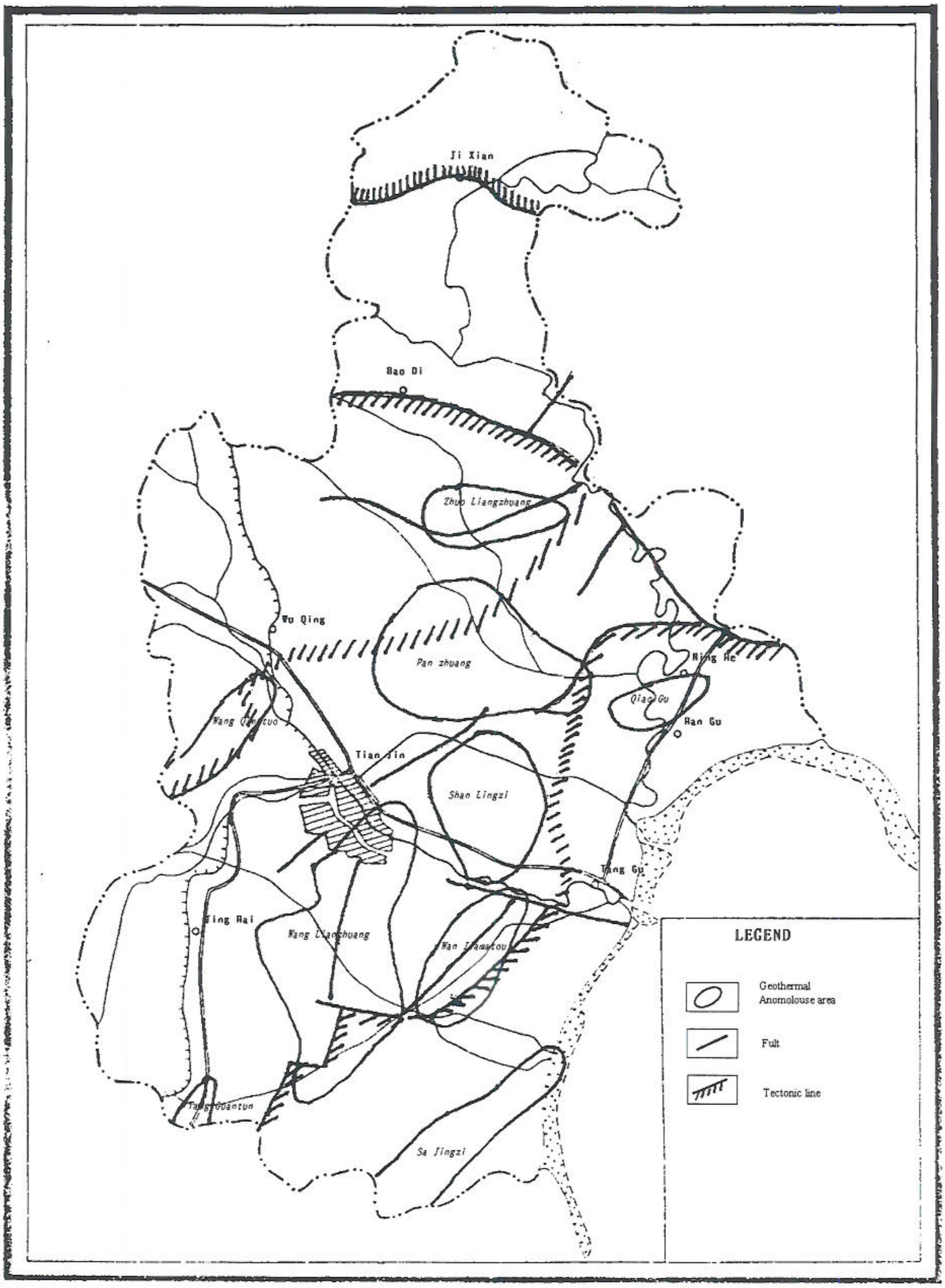

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Figure 1: Main tectonics and the nine geothermally anomalous areas of Tianjin

resource amounts to 155 × 10^{18} J. The allowable hot water production is estimated to be 39 × 10^6 m^3/a from the basement reservoir and 20 × 10^6 m^3/a from the Tertiary reservoir. Table 3 shows the assessment of the geothermal resources of Shanlingzhi geothermal field (Chen Zhenxia, 1991).

Table 3: The geothermal resources of the Shanlingzhi geothermal field

		Geothermal resource			Hot water resource
		(10^{18}J)	(10^{14} kcal)	(10^{10} kWh)	Drawdown - 100 m (10^6 m^3)
Tertiary		34.50	82.40	958	601.10
Basement	2000 (m)	48.98	117.00	1361	266.00
	3000 (m)	106.14	253.50	2948	912.13

The exploration of the deeper geothermal reservoirs, down to approximately 4000 m, was started in 1996, expecting to be continued to year 2000 . The area is about 1000 km^2. Lumped and distributed parameter models are going to be used to estimate the geothermal resources of these reservoirs.

The exploration of the Wuqing geothermal field is being conducted in the years 1997-1999. Ms. Wang Kun was trained in Iceland, and her project was on the Wuqing geothermal field.

3. MONITORING

Monitoring of the effects of hot water production on the geothermal reservoirs is a very important part of geothermal exploration and management. The monitoring of the Tertiary reservoir and basement reservoir is carried out during exploration and exploitation. The monitoring parameters that are collected are

1. Production of each well;
2. Water level and temperature of observation and production wells;
3. Chemical content of the fluid produced.

Generally, the production data is collected monthly by a flowmeter, and water level and temperature observed twice a month. The chemical content is measured twice a year. A geothermal observation report is published every year (e.g. Chai Guanying, 1994)

4. INJECTION EXPERIMENTS

Four injection experiments have been carried out in Tianjin. Table 4 gives the basic information on the experiments. The first injection experiment was carried out in 1982-1986, in the Tertiary reservoir of Wanglanzhuang geothermal field in Tianjin. Two injection experiments were carried out in the Tertiary reservoir of the Dagang district in 1987-1990: a) With wells 2 and 5 as production wells, located about 100-150 m from the injection wells R2 and R12. The injected water came from 700 m depth (37°C) and 1370 m depth (55°C); b) With waste water from the heating system being used. Production well R2 is located about 1820 m from injection well R12. Table 5 gives the basic information on the two injection experiments.

Table 4: Basic information on the four injection experiments in Tianjin

Time	Place	Reservoir	Depth (m)
1982-1986	Wanglanzguang	Tertiary system	500-700
1987-1990	Dagang	Tertiary system	1700-2000
1992-1996	Tanggu	Tertiary system	1700-2000
1996-2000	Wanglanzhuang	Precambrian system	1700-2000

Table 5: Basic information on the injection experiments in Dagang (Oyang Juqin, 1990)

Date	Time (day)	Injection well	Amount of injection (m^3)	Temp. of injection (°C)	Production well	Distance (m)
1987.7.23-9.15	54	R2	23000	55	5	150
1987.11.11-11.27	16	R12	8889	38	R2	1820
1988.5.14-7.21	68	R12	23819	37	2	100
1988.8.9-9.9	31	R12	9867	37	2	100
1989.8.31-9.5	6	R12	2465	37	R2	1820
1989.9.10-9.25	15	R12	12503	37	R2	1820
1989.10.6-10.12	7	R12	7400	32.5	R2	1820

The injection experiment in Tanggu was carried out between 1992 and 1996. During the experiment, hot water from the Tertiary reservoir was used for space heating and the waste water from the heating system was used for injection. Production well TR5 is located 650 m from injection well TRI9. Table 6 gives the basic information on the injection experiment.

Table 6: Basic information on the Tanggu injection experiment (Jin Jianxin, 1996)

Date	Time (days)	Amount of injection (m^3)	Injection rate (m^3/h)	Pressure (MPa)
1995.12.18 -1996.3.6	79	12332	46.90	0.50
1996.2.5-2.12	7	7931	45.26	0.50
1996.3.1-3.2	1	927	84.00	0.78

Injection experiments in the Wanglanzhuang geothermal field started in 1996 and are planned to continue through 2000. During the experiment, 70°C waste water from the heating system is injected into the injection well, which is 1600 m deep. At first the injection rate was 100 m^3/h; later the injection rate was 70-80 m^3/h. The total amount injected is 270,000 m^3 for the last 5 months. Concurrently, the water level in nearby wells is monitored carefully. Chemical tracer tests will be employed during the winter of 1998/99.

5. UTILIZATION

The earliest geothermal well was drilled in 1936. By 1985, 231 wells (Tertiary system reservoir) had been drilled in Tianjin. The annual fluid production reached 20 million m^3. The growth of production over a period of 50 years is shown in Figure 2. The geothermal water from the Tertiary reservoir has a temperature of 40-50°C. It is commonly of the chemical type HCO_3-Na, with total dissolved solids 800-1300 ppm and hardness 1-2H^0. It is widely used in industries (textile, wood processing 73%), for bathing (26%) and in agriculture (1%) (Figure 3). The economic benefit

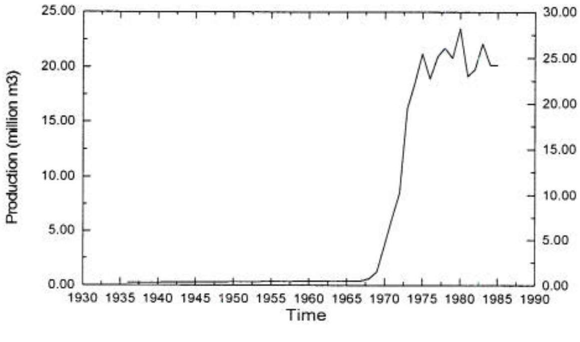

Figure 2: Geothermal production from the Tertiary reservoir

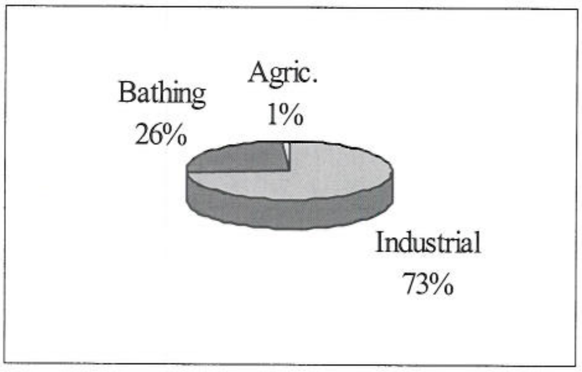

Figure 3: Use of hot water from the Tertiary reservoir

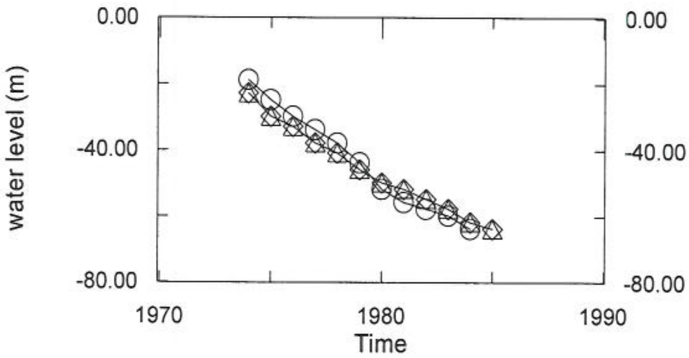

Figure 4: Water level draw down in the Tertiary reserovir

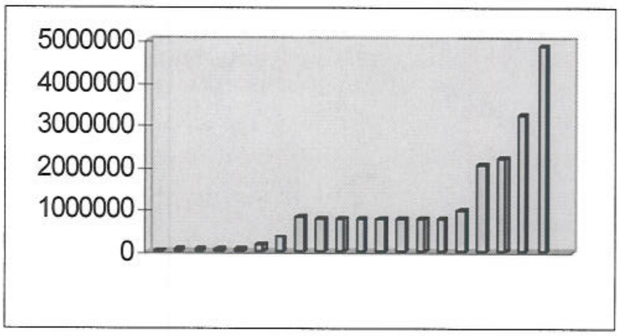

Figure 5: Production from basement reservoir

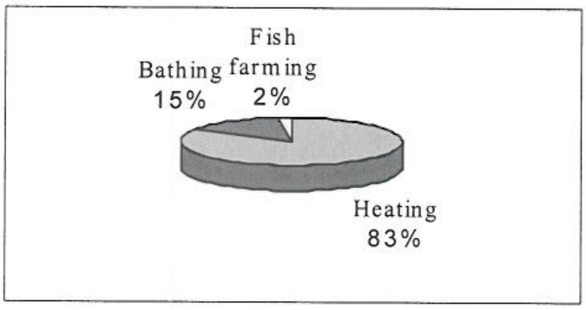

Figure 6: Use of hot water from basement reservoir

in industry is especially remarkable. Water level and production have been observed from the beginning of the geothermal development. The response to production of declining pressure (water-level draw down) indicates that the recharge to the reservoir is limited and the water level declined every year. By the end of the 1980's, the greatest draw down was about 90 m, and the area where the depth was more than 50 m was 404 km^2 (Figure 4). The rate of the water level draw down was 4.11m/a. This may cause an environmental problem such as land subsidence. All these wells are no longer in use because of the government of Tianjin's first plan to control land subsidence.

In the 1990's, the purpose of geothermal development changed from industry to heating and bathing as the living standard became higher. The temperature of the water is very important. The number of basement wells increases every year. Hot water comes mostly from the basement reservoir. The Ordovician system aquifer temperature is 70-100°C, the water has total dissolved solids of 4000-5000 ppm and is of the chemical type Cl-SO_4-Na with the hardness 80-90 H^0. Precambrian system reservoir has total dissolved solids of 2000 ppm, is of chemical type Cl-SO_4-Na and has the hardness 6-7 H^0. The area of geothermal heating is now 4,500,000 m^2. Production of hot water is 4,870,000 m^3, heating 83%, bathing 15%, and fish farming 2% (Figures 5 and 6). The economic benefits of geothermal heating are higher than of coal and oil heating systems. The cost of drilling is about UD$ 50,000 per well (depth 2500 m, 200 US$/m), which can provide heating for 100,000-150,000 m^2. The fee for this heating resource is 5 US$/m^2 which users pay to the heating service.

6. THE LEGAL FRAMEWORK OF GEOTHERMAL DEVELOPMENT

As geothermal research developed, the Geology Ministry of China issued the 'Geothermal resource appraisal method' in 1985, formulating the method of geothermal resource appraisal and calculation. The Mineral Reserves Committee formulated the 'Geologic exploration standard of geothermal resources' in 1989 which provided the requirements of geothermal field exploration and research, divided the types of geothermal fields, standardized the system of project control, technology and quality demand and reservoir appraisal and simulation. To rationalize geothermal development, and to more effectively protect the resource, Tianjin Geothermal Management Office was established in 1994, a governmental agency of Tianjin. It issued the 'Tianjin geothermal management stipulation' on geothermal exploitation license system. First, the user, company or person, applies for drilling license; secondly, the consultant company or institute writes a feasibility report; and thirdly, experts appraise the feasibility report and recommend or not the drilling of a well to the Geothermal Management Office.

Geothermal resources are owned by the state. Every user of geothermal exploitation must pay a resource tax. The standard of the tax is different depending on the temperature of the water as shown in Table 7. Each well must have a flowmeter to collect the data. The tax is used for geothermal exploration, management, research and observation.

Table 7: Standard of the resource tax

Temperature (°C)	Resource tax
40-50	0.2
50-60	0.3
60-70	0.4
70-80	0.5
>80	0.6

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