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Geothermal Resources Potential Assessment in Shandong Province, China

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ABSTRACT

Shandong is a province of eastern China bordered by the Gulf of Bohai and the Yellow Sea. The eastern part of the province forms the Shandong Peninsula. Jinan is the capital. Shandong Province is rich in low- medium temperature geothermal resources with temperatures ranging from 40 to 100 °C, which are characterized by largely distributed geothermal reservoirs, various categories, suitable depths, great reserves and high utilization value. Their development conditions are preferable.

According to the investigation by Shandong Provincial Bureau of Geology and Mineral Resources, the available geothermal resources within 3000 m are estimated to be 31.863×10^{19}J, which is equivalent to 10 billion tons of coal. The production potential has been estimated to be approximately 20×10^{8} tons per year, for the next 100 years. The geothermal resources can be directly used for space heating, industrial processing, bathing, balneology, fish farming, spa, sanatorium and greenhouse, etc..

1. INTRODUCTION

Shandong (Figure 1) is a province of eastern China bordered by the Gulf of Bohai and the Yellow Sea, covers an area of approximately 156,700 km^2. The eastern part of the province forms the Shandong Peninsula with a 3024 km long coastline, while the northeastern forms the Shandong Plain and the central-south forms Shandong mountainous-hilly land. Jinan is the capital.

Shandong Province comprises 17 municipalities/prefectures, 139 counties, with the population of about 90 million. It has a monsoon climate with distinct wet and dry seasons. The annual average precipitation is 671 mm, while heavy rainfalls often occur during the summer period—July to September.

2. GEOTHERMAL MANIFESTATION

There are 14 geothermal springs mainly distributed in Shandong Peninsula, with temperatures ranging from 44 to 90 °C, while more than 150 geothermal wells have been successfully drilled in Shandong Province, with temperatures between 40 and 100 °C.

3. CLASSIFICATION OF HYDROTHERMAL SYSTEMS

Based on geothermal reservoir categories, the hydrothermal systems in Shandong Province can be divided as 3 types: fractured geothermal reservoirs, sedimentary geothermal reservoirs and mixed geothermal reservoirs.

Figure 1: Location of Shandong Province and Jinan, Dezhou City

3.1 Fractured geothermal reservoirs

Fractured geothermal reservoirs are mainly distributed in Shandong Peninsula, which are controlled by neotectonisms and large- and deep faults, with convective heat flow. The reservoir aquifers are granite and metamorphic rocks. Geothermal springs are the main manifestations with temperatures ranging from 44 to 90 °C (Figure 2).

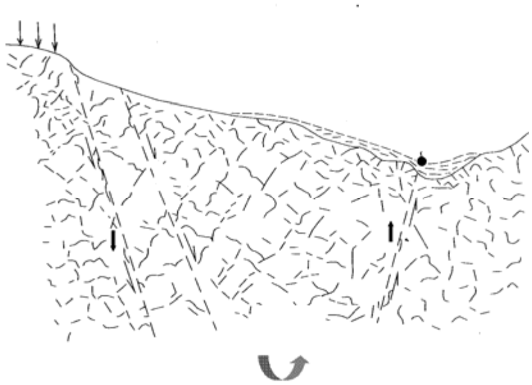

Figure 2: Conceptual model of fractured geothermal reservoir in Shandong Peninsula

3.2 Sedimentary Geothermal Reservoir

Sedimentary geothermal reservoirs, which are widely distributed in northwest Shandong Plain, are characterized by large areal extent, rather homogeneous aquifers, quite productive wells and great energy potential. Geothermal anomalies concentrate on horst areas in sedimentary basin, which are conduction-dominated reservoirs. The main aquifers are Neogene sandstone or Cambrian- and Ordovician limestone. Artesian geothermal wells are the main manifestation with temperatures varying from 40 to 98 °C (Figure 3, 4).

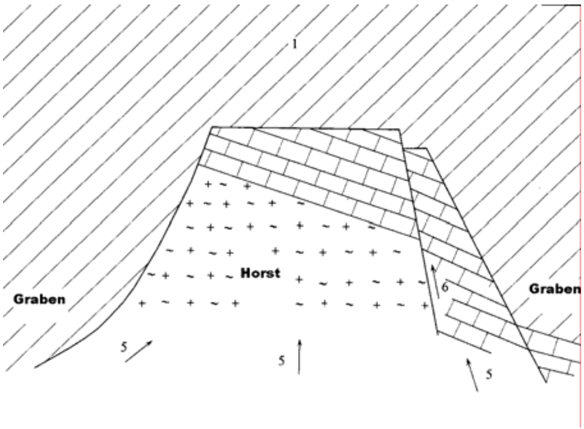

Figure 3: Conceptual model of sedimentary geothermal reservoir in northwest Shandong Plain

Figure 4: One of the artesian geothermal wells in the North of Jinan City

3.3 Mixed geothermal reservoirs

Mixed geothermal reservoirs are extensively distributed in central-south mountainous and hilly areas of Shandong, The geothermal fields concentrated on contact zones between graben and horst, which are dominated by both heat conduction and convection. The geothermal water are stored in magamatic and metamorphic rocks. Geothermal wells, along with some springs, are the manifestation with temperatures between 40 and 80 °C (Figure 5).

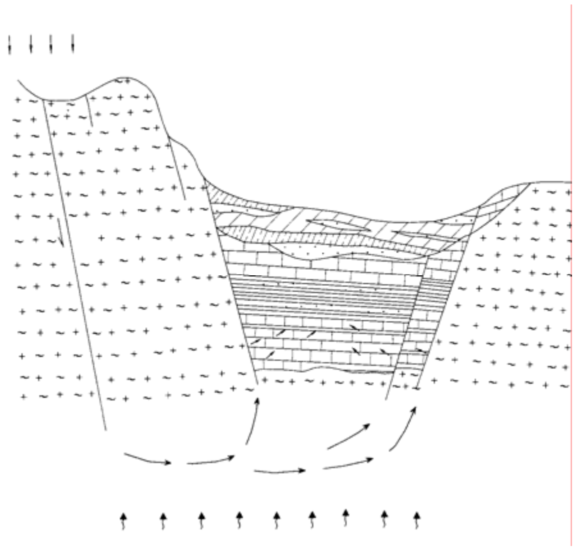

Figure 5: Conceptual model of mixed geothermal reservoir in central-south mountainous and hilly areas of Shandong

4. GEOTHERMAL POTENTIAL

According to the investigation by Shandong Provincial Bureau of Geology and Mineral Resources, the available geothermal resources within 3000 m are estimated to be 31.863×10^{19}J, by using the formula as follows:

$$E = E_r + E_w = VC_r\rho_r(1-\phi)(T_i - T_0) + VC_w\rho_w\phi(T_i - T_0)$$

where E =Total thermal energy in the rock and water [kJ];

V =Reservoir volume [m^3];

T_i =Initial reservoir temperature [^oC];

T_0 =Reference temperature [^oC];

C_r =Heat capacity of rock [kJ/kg ^oC];

C_w =Heat capacity of water [kJ/kg ^oC];

ρ_r =Density of rock [kg/m^3];

ρ_w =Density of water [kg/m^3];

ϕ =Porosity.

Moreover, based on the reserve, recharge of geothermal reservoirs, as well as rational maximum allowable drawdown of the production wells, the production potential has been estimated to be approximately 20×10^8 tons per year, for the next 100 years. The geothermal water can be directly used for space heating, industrial processing, bathing, balneology, fish farming, spa, sanatorium and greenhouse, etc..

5. CASE STUDY--DEZHOU GEOTHERMAL RESERVOIR (KANG FENGXIN, 2000)

The Dezhou geothermal reservoir is located in the northwest Shandong Plain, which is an alluvial plain dominated by the Yellow River (Figure 1). The Dezhou geothermal reservoir is a low-temperature sedimentary reservoir yielding water with a temperature between 46 and 58°C. The emphasis on geothermal development has been in the area of direct-utilization, such as for space heating, swimming pools and balneology.

The Dezhou geothermal reservoir is situated within the Dezhou depression. It is bounded by the Bianlinzhen fault on the east, the Cangdong fault on the west, the Xiaoyuzhuang fault on the south, and the Xisongmen fault on the north. All of these faults appear to act as permeable boundaries. Some other faults, such as the Jianhe fault, intersect the Dezhou reservoir, and then result in anisotropic permeabilities of the reservoir.

It is believed that the reservoir exists because of the occurrence of highly permeable sedimentary layers at great depth, and an above average geothermal gradient; as well as because of the faults and fractures. The cap rock is upper Minghuazhen formation of Neogene age. The upper Minghuazhen formation, with a thickness of 900 m, is composed of argillite and sandy argillite with interbedded sandstone.

The Dezhou geothermal reservoir is located within the Guantao formation of Neogene age, with a depth ranging from 1350 to 1650 m and a thickness of 300-480 m (Figure 6). The main production aquifer of the reservoir is comprised of sandstone and conglomerate, covers an area of 169 km^2 and has a thickness of 160-180 m.

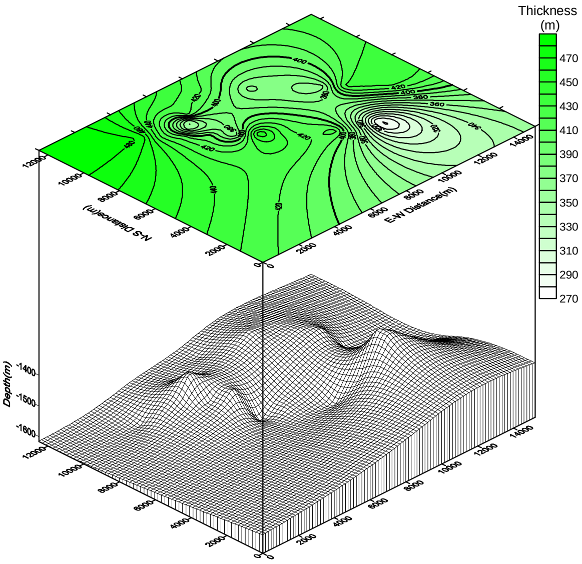

Figure 6: Contour diagram of the thickness of the Guantao formation in meters (top) and a three-dimensional surface map of its bottom (bottom)

5.1 Reservoir modelling for the Dezhou geothermal system

5.1.1 Conceptual model

Conceptual model is the fundamental element of reservoir modelling. The conceptual model of the Dezhou geothermal reservoir may be briefly delineated as follows:

(1) Reservoir type: low-temperature sedimentary sandstone reservoir, conduction-dominated;
(2) Boundary: permeable faults boundaries;
(3) Production aquifer: confined Neogene Guantao Formation, with a thickness from 160 to 180 m at a depth between 1350 and 1650m, and covering an area of 169 km^2;
(4) Cap rock: upper Minghuazhen formation of Neogene period, composed of argillite and sandy mudstone;
(5) Underlying rock: Eogene Dongying Formation, composed of argillite, fine sandstone, and siltstone;
(6) Recharge: meteoric origin.

5.1.2 Analytical distributed parameter modelling

On the basis of its conceptual model, the Dezhou geothermal reservoir can be outlined as horizontal and homogeneous, with a constant thickness and an infinite areal extent. This kind of reservoir is in good agreement with the prerequisites of a simple analytical distributed parameter model. In the distributed parameter model, locations, productions, injections, and observations of each individual wells are taken into account. In other words, the behaviour of individual wells and the interferences among different wells can be simulated by the distributed model.

The distributed parameter computer code is based on the Theis model as follows:

$$\Delta p(t) = \frac{\mu}{4\pi kh} \int_{\tau_n}^{\tau_{n+1}} \frac{q(\tau)}{t-\tau} \exp\left[\frac{-r^2}{4\eta(t-\tau)}\right] d\tau$$

The computer code calculates pressure changes in response to water production/injection from/into an idealized reservoir system. Based on the actual conditions of the Dezhou reservoir, anisotropic permeabilities are chosen, and the initial state of reservoir pressures prior to productions is assumed as constant. The parameters (transmissivity and storage coefficient) are varied until a satisfactory match was obtained. Figure 7 represents the match between the observed and simulated pressure in well DR1 by using the data of short-term well test during Mar. 28—Apr. 4, 1997. It is obvious that the match is quite good.

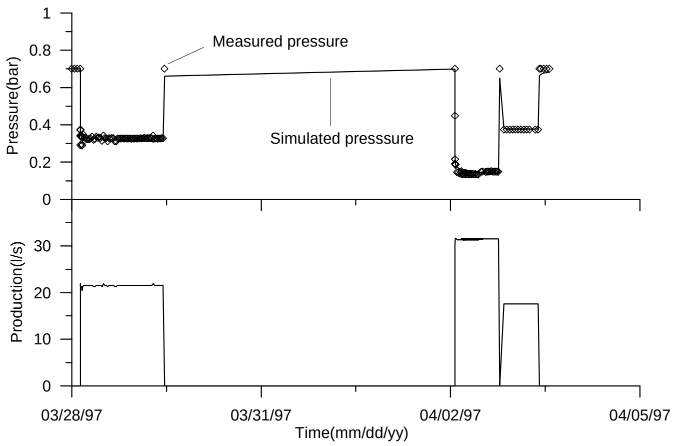

Figure 7: Comparison between observed and simulated pressure changes combined with production during testing of well DR1 in 1997

The pressure distribution in the reservoir can also be calculated by the distributed parameter model, and then the water level contour maps at any times can be plotted.

5.1.3 Production potential

The prerequisite of calculating production potential is to determine a rational maximum allowable drawdown of the production wells in the reservoir, since it determines the economic production potential directly. In other words, the production potential is restrained by the maximum allowable drawdown of the reservoir.

Considering constraints in the Dezhou geothermal reservoir, including the setting depths of well pumps, design of the production wells, risk of colder water inflow, and especially the land subsidence in the area, the maximum allowable drawdown is defined as 100 m.

On the basis of the maximum allowable drawdown and the established distributed parameter model, the water level predictions were calculated for two different production scenarios:

(1) Scenario I: the production during pumping test for wells DR1 and DR2 is maintained for the next ten years, i.e.:

Annual average production: 62 l/s;
Production in heating season (Nov.—Mar.): 120 l/s;
Production in non-heating season: 10 l/s.

The water level predictions, calculated by the distributed parameter model, are presented in Figure 8, which shows the calculated water level changes in well DR1 for the next ten years. Well DR1 is located in the centre of the depression cone of the water level (Figure 9). Figure 9 represents the water level contours at the end of the prediction period on March 31, 2010, calculated by the distributed model. The water level drawdown distribution can also be seen from Figure 9.

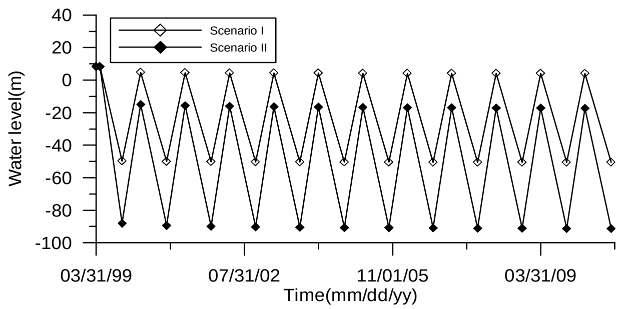

Figure 8: Predictions of water level trends up to the year 2010 in well DR1 for production scenario I and II

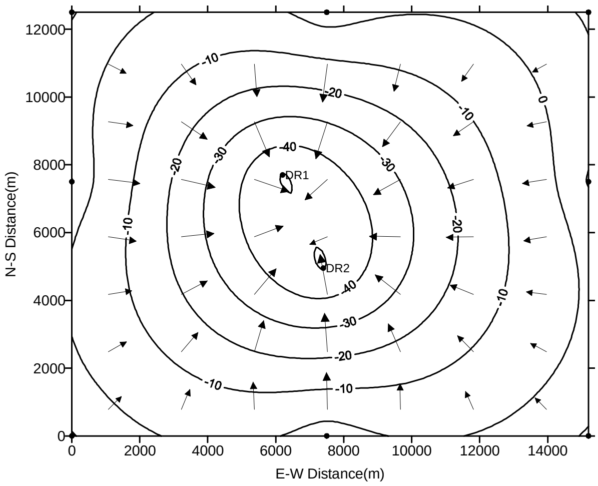

Figure 9: Predicted water level contours (m) on Mar. 31, 2010 for production scenario I

(2) Scenario II: besides the wells DR1 and DR2, four additional production wells are included according to geological conditions and the requirements of the Dezhou municipality. The production is increased to:

Annual average production: 220 l/s;

Production in heating season: 360 l/s;

Production in non-heating season: 120 l/s.

The water level predictions, calculated by the distributed parameter model, are presented in Figure 10, which shows the water level changes in well DR1 for the next ten years. The well DR1 is still located in the centre of the depression cone of the water level (Figure 10). Figure 10 illustrates the water level contours at the end of the prediction period on Mar. 31, 2010, calculated by the distributed model, combined with a three-dimensional presentation of the water level surface. The water level drawdown distribution may also be seen from Figure 9. Comparing Figures 9 and 10, it is obvious that the water level drawdown for scenario II will be much greater and more extensive over the whole reservoir at the end of the prediction period.

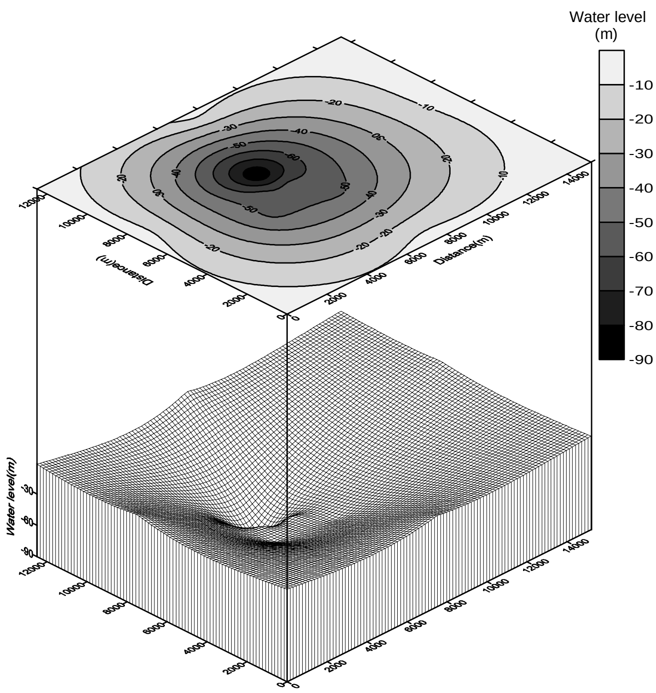

Figure 10: Predicted water level contours (m) (top) and 3D water level surface (bottom) in Dezhou on Mar. 31, 2010 for production scenario II

Figures 8—10 show that the greatest anticipated water level drawdown for scenario I is 58m, whereas for scenario II it is 99 m. In light of these results, and considering the maximum allowable drawdown of 100m, the production potential of the Dezhou geothermal reservoir is evaluated to be 220 l/s on the average for the next ten years, or 6.9 million tons per year. The allowable maximum production in heating seasons is 360 l/s.

As there are only a few geothermal production wells and limited field observation data is available at this time, the modelling is just based on a seven-day well test. It should be pointed out that the model has to be updated and refined as new production and response data becomes available.

Monitoring is essential for the model updating and refining, and also one of the most important parts of geothermal management. Hence, it is recommended that with the exploitation of the geothermal reservoir, a comprehensive observation system be established, not only including water level, flow rate, water temperature, but also water chemistry, corrosion, scaling and land subsidence.

6. CONCLUSIONS

Shandong Province is rich in low- medium temperature geothermal resources with temperatures ranging from 40 to 100 ^{o}C.

The available geothermal resources within 3000 m are estimated to be 31.863×10^{19}J. The production potential has been estimated to be approximately 20×10^{8} tons per year, for the next 100 years.

By taking Dezhou geothermal reservoir as the example, it is proven that the analytical distribution model is able to calculate and evaluate reservoir potentials, with acceptable accuracy.

REFERENCES

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