SIMULATION AND FORECAST OF CHANGE DUE TO EXPLOITAION OF A GEOTHERMAL WATER REGIME

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SUMMARY - Change due to exploitation of geothermal water levels in the Beijing Urban Geothermal Field during a 5 years period was computed using a multivariant simulation of compound relation for factors of time sequence and production rate counted from two different acquires (lower and upper) for a certain range and period of time. The result shows a compound relation coefficient of 0.9405. The optimized simulation expression which had satisfactorily passed an analysis of computational checking using a set of actual monthly production rate data was used to forecast the monthly water level until the year 2000 for both the upper and lower reservoirs of the geothermal field. The extractable production rate of the field are also given.

INTRODUCTION

Beijing Urban Geothermal Field is a low temperature field presently exploited in China. Reconnaissance and detailed surveys (exploration stage) of the field had been successively completed. The field has been in the production stage since 1983. During this period, various studies of the field were conducted (Zheng, 1981; Zheng et al., 1982; Hochstein et al., 1984; Hochstein and Caldwell, 1985; Hochstein and Yang, 1988; Xiong and Gao, 1989). These studies discussed the origin of geothermal anomaly and the mathematical models of various aspects of the field. Although the viewpoints and conclusions the authors are not always consistent, it is obvious that their results have been useful for the general progress of the field. Some of the results from these studies are summarized in the following:

Beijing graben is oriented in the northeast direction. The basement is Sinian siliceous dolomites. Drillhole data show that the maximum thickness of the infill which constitutes mainly of Tertiary and Quaternary rocks is about 2500 m. The Tertiary rocks consist of consolidated sandstones and mudstones. Cretaceous and Jurassic rocks were partially distributed beside these Tertiary rocks. There are series of NE sub-faults in the graben which do not cut the Tertiary rocks except along the boundaries of the graben. The graben itself is asymmetric. A basement sub-uplift region with an area of less than 100 km^2 occurs on its gentle slope of the SE flank. The top of basement in the sub-uplift is only 500 m deep. The Beijing Urban Geothermal Field is located in this sub-uplift region.

The maximum geothermal gradient in the cap rocks of the Beijing Urban Geothermal Field is 6 °C/100 m which occurs in the central area. The thermal anomaly of the field is bounded by the gradient of 3°C/100 m. This thermal anomaly is mainly caused by a redistribution of heat flow associated with the tectonic framework of the area. The average heat flow of the sub-uplift region is 74.1 mW/m^2. The heat flow at the top of sub-uplift (80 90 mW/m^2) is two times higher than the lower flux (less than 45 mW/m^2) in the deeper part of the graben (Hochstein et al., 1984). The geothermal reservoir has been classified as the type of geothermal heated by geotemperature conduction (Xiong and Gao, 1989).

The field produces low temperature geothermal water of 37-70°C. The water chemistry is mainly of the Na-HCO_3-SO_4 type, and belongs to fluorine, radon, radium mineral water; it also bearing silica, boron and hydrogen sulphide. Its TDS is 0.47 - 0.69 g/l. Isotopic study shows that the thermal water are of meteoric origin (Zheng et al., 1982). Meteoric water seeps into the ground in the northwest mountain area and flowing down as cold ground water runoff which recharges into the thermal field. This cold recharge is heated by conduction. Some hot water also recharging into the reservoir, rising along the faults. Water/rock equilibrium computation indicates that deep hot water recharges through the fault system, first into the lower reservoir (the Wumishan Formation) and then into the upper reservoir (the Tieling Formation). These lower and upper reservoirs are separated by a shale layer with a thickness of about 100 m.

The results of studies described above represent an extensive and significant discussion of the field. However, present production stage of the field faces a real problem, i. e. how to assess the actual trend of water level change of the reservoir under a certain designed production rate. The assessment of such problem is the objective of this paper.

CHANGES DUE TO EXPLOITATION OF THE BEIJING GEOTHERMAL FIELD

Geothermal water in the Beijing Urban Geothermal Field has been exploited and used since 1971, when the fust well was completed. Its production rate has been increasing yearly. Previous utilization of the field was extensive and mainly for industrial processes, space heating, medical treatment and bath, agricultural use etc. Since early 1980's, the thermal water is mostly used for bathing (all year around) and space heating (only in winter).

There are a total of 53 geothermal wells in the field. Most of them are production wells, except about 1/4 which are used as observation wells. The production consists of a

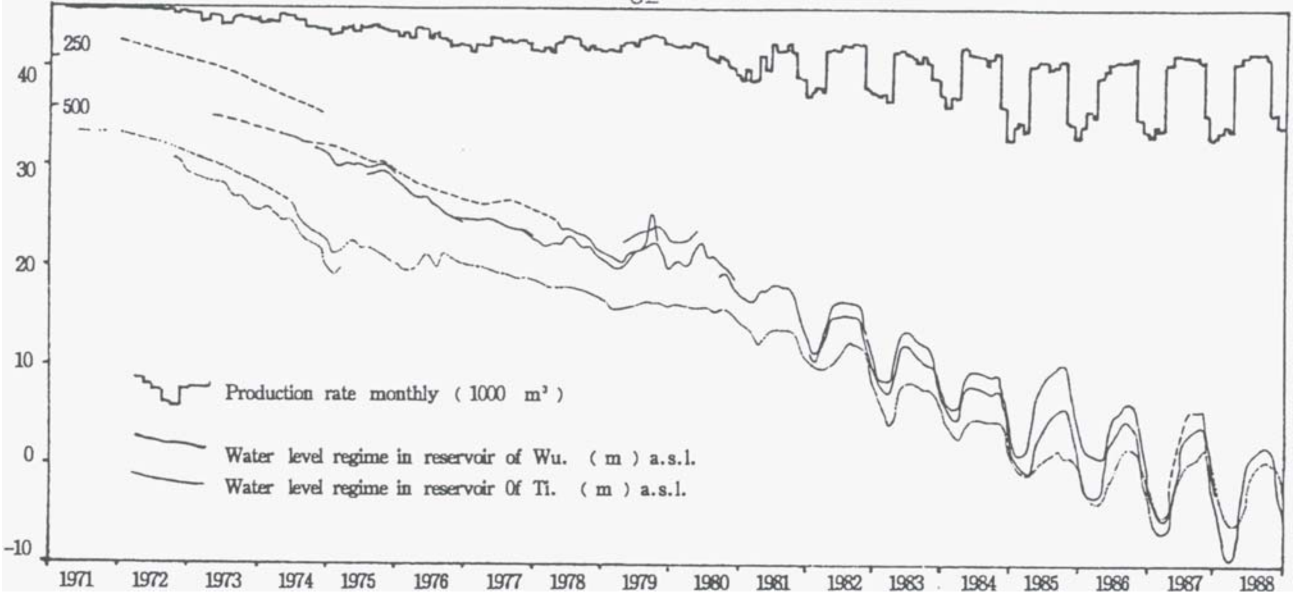

Fig. 1. The changes in the water level of, and production rate from, the Beijing geothermal field.

base load for bathing and a seasonal load of heating.

There was no apparent decrease in temperature during the exploitation period of 20 years. However, the water level showed an obvious trend of decrease (Fig. 1). The water level of the reservoir has dropped 37.41 m from the original level of 32.01 m a.s.l..in the Tieling Fm. 53. 56 m from the original level of 44.56 m a.s.l. in the Wumishan Fm. The water level decrease was non-uniform. In general, the decreasing rate corresponds directly to the increasing of well number and the meantime production rate. When there was no apparent increase of production rate, the water level decrease was quick at the beginning and slowing down at the later period, i.e. looks like a reverse parabola. This trend can still be seen in Fig. 1, although the effect of increasing production rate has been repeatedly added. It is also clear that water level slowly decreases during the recent years. Even when the production rate is basically stable, the water level has not shown a stability as described by Hochstein and Yang (1988). The rate of decrease of the annual highest water level is slower (0.21 - 0.48 m/a) than that of the annual lowest water level (over 1 m/a).

The annual periodicity of change of the geothermal water level which caused by annual winter heating over 4 months from November to March (following year), became more clear in the recent years. Its annual amplitude reached a maximum of 12.93 m.

SIMULATION OF REGULARITY OF WATER LEVEL REGIME

There are no unified planning and centralized development for the Beijing field. The development combines exploration with exploitation, and production disperses. Even though the field covers an area of over 100 km^2, the exploitation area is only concentrated in less than one third of the total field area. If an advanced numerical model such as the finite element method is applied, a number of interpolated parameters would tend to increase the error of the general assessment. So, in this study mathematical simulation by the "Grey system method" is adopted. It is based on actual data monitored by reservoir engineering technique, using an objective reflected among various combination of measured data to simulate their mathematical relationship.

Concretely speaking, multivariant simulation of compound relation method was applied here. For each of the reservoirs, monthly production rate was counted for a certain range with a certain shape around every centre of observation wells, respectively. The selected shapes included circles and ellipses. The major axis of these ellipses were set along the NEE trending following the main tectonic line. Their minor axis was taken as a half of the corresponding major axis. The radius of circles or the major axis of ellipses were taken to be 3 km, 4 km and 5 km (*Fig. 2*). In this method, water level in the observation well was taken as the function of multivariant. The multivariant values were considered for 4, 5, 6 and 7 variables respectively. The first variable is the factor of time sequence. The rest of the variables are the monthly production rates starting from the current month and going backward to the successive previous months.

A total of 76 groups of multivariant simulations of compound relation were carried out for a set of 5 years observation data (1983 to 1937) from 3 observation wells (2 in the Wumishan Fm. and 1 in the Tieling Fm.). Optimized simulation expressions were selected by a comprehensive comparison of the highest value of the compound relation coefficient and the lowest value of the sum of deviation square. These "good" and "bad" mathematical relationships indicate internal relations with geological and hydrogeological conditions to a certain extent. As an example, the expression of optimized simulation for 6 variables for the factor of time sequence and the production rates in a range of ellipse with a major axis of 4 km around the observation well No. 7 is shown in equation (1).

$$H_w = 6.4139 - 0.1877362\,T - 1.706538' \,10^{-5}\,Q_1 - 1.31654*10^{-6}\,Q_2 - 6.819941*10^{-8}\,Q_3 - 3.621831*10^{-8}\,Q_4 - 2.096405*10^{-8}\,Q_5 \qquad (1)$$

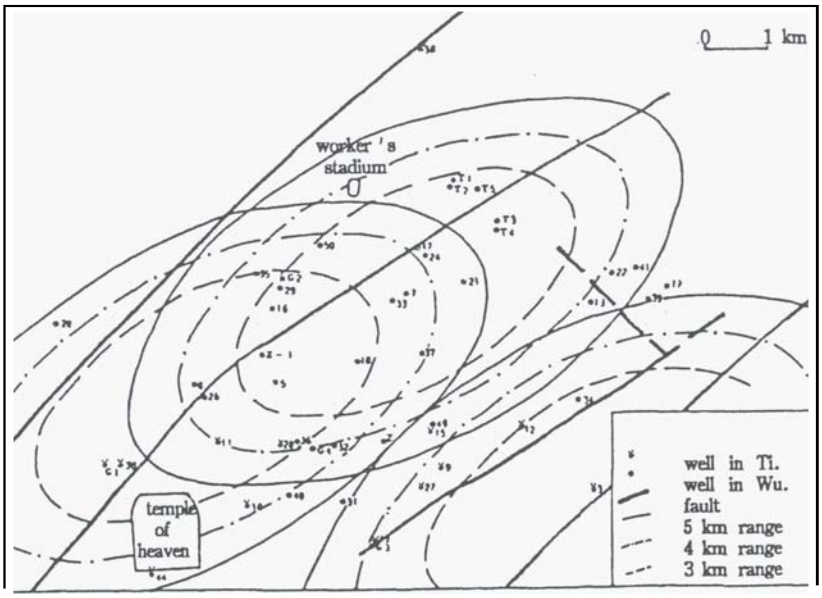

Fig. 2. Map of production decline in the Beijing geothermal field.

In equation (1) H_W is the average monthly water level for the observation well; T is the factor of monthly time sequence which is successively taken from 1 to 60 for a 5 years simulation and Q_1 to Q_5 are monthly production rates for the same month back to the fourth previous month.

CHECKING AND FORECASTING THE SIMULATION

A computational checking was carried out using the optimized simulation expression and the actual monthly production rate of the 1988-1990 period. The result of computation was compared with measured water level. This comparison showed that the general trend of the computed water level corresponds to the measured water level. Although certain errors appeared around the period of lowest level between February and March and around the period of highest level between September and October, the error in the end of the year (December) is less than 1 m. Therefore, for checking of water level in the following year, the error is acceptable. For example, the error for December 1988 is only 0.25 m. The optimized simulation was therefore successful and this method can be used for forecasting the water level. For a more accurate forecast for the water level in 1991, we would have to use a more reliable simulation expression determined using measured data from the 1983-1990 period.

As a trending forecast for medium to long periods, the above expression can be applied directly. Using the relationship of production rate between optimized simulated area and the whole field, the monthly distribution of production rates throughout the year, and the ratio of production rates between both reservoirs, the monthly water level forecasting for the Beijing field was solved until the year 2000; only the result up to year 1994 is shown in Fig. 3 due to limitation of the computer screen display used for this study.

The forecast results indicate that if the production rate is kept stable, the periodic rising-dropping water level will follow the effect of seasonal exploitation, with a gentle overall decreasing trend The lowest water level will occur in December 2000 when the water level for the reservoir of Wumishan Fm. will be -35.55 m (about 30 m lower than the present level)

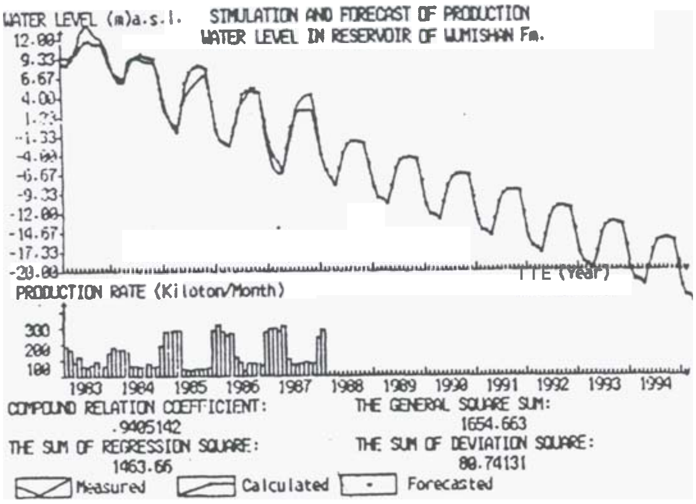

Fig. 3. Simulation of water level in Wumishan reservoir.

Its static water level will lie about 80 m under ground. Even if the drop when pumping is 30 m (a conservative assumption of the field), it will cause no problem for most of the well construction and the presently functioning underwater pump; i.e. present equipments can run safely until the year 2000. Within this condition, total production rate for the whole field can reach up to $898*10^4$ m^3/a. However, it is important to follow that any increasing of production rate has to be distributed around the periphery.

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