Proc. 8th NZ Geothermal Workshop 1986

MODELLING OF LOW TEMPERATURE AQUIFERS IN THE TIANJIN AREA (P R CHINA)

Ouyang Juqin* M.J. O'Sullivan+ M.P. Hochstein*

Geothermal Institute* T.A.M. Dept., School of Engineering'
University of Auckland

ABSTRACT

The city of Tianjin and its surroundings is underlain by two Tertiary and two basement aquifers. At present, only the Tertiary aquifers are being exploited (20 Mt/yr) resulting in a pressure drop of 7 to 9 bars beneath the city; the useable energy produced is about 100MW th.

The two Tertiary aquifers can be approximated by simple computer models whose permeability and compressibility were obtained by optimization and matching of observed pressure drawdown histories. Future behaviour of both aquifers has been assessed using various abstraction and re-injection scenarios.

Introduction

The area around Tianjin, the third largest city in China P.R. (about 7.7 Mill), is underlain by a sequence of low temperature aquifers. These aquifers contain thermal water with temperatures in the range of 40 to 90°C (depth range of wells about 600 to 2000m). The anomalous temperatures are caused by a slightly higher than normal terrestrial heat flux over the uplifted flanks of a deep, NNE trending basement depression (BAI-TANG-KOU depression). Of particular importance for Tianjin is a heatflow anomaly associated with the W flank (Wanglan anomaly) covering some 600km^2 and which extends beneath the S part of the city (see Fig.1).

Overall, the setting of the Tianjin geothermal resource is similar to that of the Beijing geothermal prospect (about 120 km NW of Tianjin) which has been summarized by Hochstein et al., (1984). In Tianjin, there are two basement aquifers; one in Ordivician limestone and another one in dolomitic limestones. In addition, there are two aquifers in the overlying Tertiary section, an upper Tertiary aquifer (UTA) and a lower Tertiary aquifer (LTA) which are reached in the southern part of the city at depths between 600 to 1000m and which produce fluids with wellhead temperatures of typically 35 to 55°C. The basement aquifers are reached at depths of 1200 to 2000m and produce fluids with wellhead temperatures of 50 to 90°C.

The two Tertiary aquifer have been exploited on a large scale since about 1970; in 1981 about 650 kg/s of fluids were produced from the UTA (about 75MW) and about 150 kg/s from the LTA (about 20MW). The water has been mainly used by industry (Sun Kai Yao and Su Jialin, 1985). The LTA is also used for pilot scheme space heating (0.7MW within the city). Present production from the basement aquifers is insignificant.

The thermal fluids from the UTA and LTA have been produced since about 1970 without re-injection; pressures within the aquifer have dropped by up to 7 to 9 bar in 1982, the pressure drop can still be noticed in wells far away from the abstraction centre. The -50m piezometric level contour of both aquifers as observed in 1982 is shown in Fig. 1.

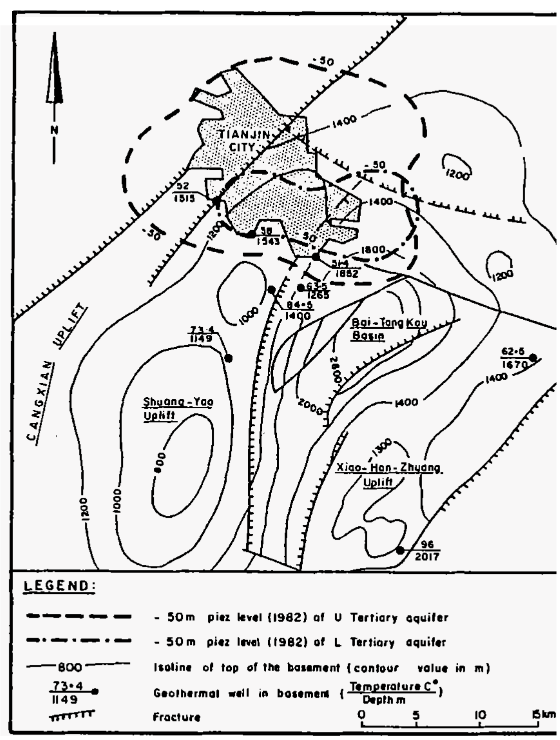

Fig.1 Basement structure of Tianjin geothermal field and extent of pressure drop in Tertiary aquifers in 1982.

Aim of study, input data, method, assumptions:

The aim of the study was to simulate the hydraulic characteristics of both Tertiary aquifers, their past behaviour, and to predict future behaviour for a few production and (partial) re-injection scenarios. In the following, the UTA will also be referred to as Group I aquifer, the LTA as Group II aquifer. The basement aquifers were not investigated.

Available for the study was a map of piezometric levels (up to 1982) for the whole area for both Tertiary aquifers which had been compiled by the Geological Bureau of Tianjin (for earlier data see Chen Jiafa and Gu Da Tong, 1981). Average hydraulic parameters had been obtained from pumping tests; for a selected number of wells lithostratigraphic sections and pressure decline history were also available which had been compiled by a UNDP project (CPR/81/011). The behaviour of both aquifers was modelled using a computer program which is widely used to study Fluid movements and energy transfer in geothermal systems (Pruess, 1983; O'Sullivan et al., 1983).

For the model of the Group I aquifer, which occurs at a depth of about 550 to 700m beneath the city, radial symmetry was assumed as indicated by the pattern of piezometric levels for this aquifer in 1982 (see Fig. 1). Ten rings were used up to r= 20km, the width of the rings was increased for r> 20km. Of the 146 wells which produced in 1982 from the Group I aquifer, about 60% are located in the inner zone defined by r=20km. The centre of the inner zone almost coincides with the city centre.

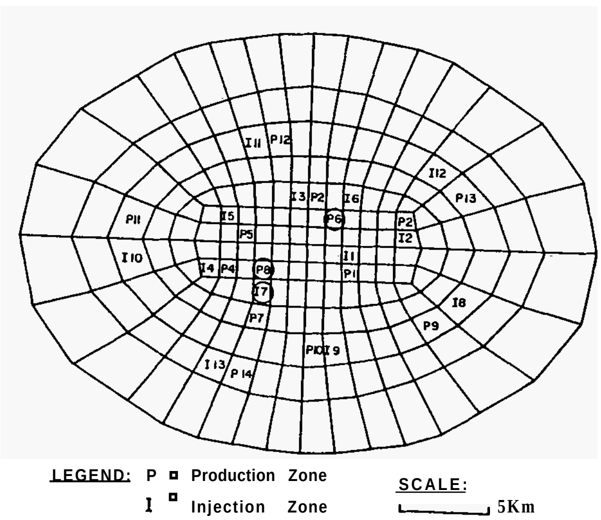

Fig. 2 Reservoir model for inner zone of lower Tertiary aquifer beneath Tianjin (P denotes existing production well; I denotes assumed re-injection well; encircled blocks are referred to in the text).

For the Group II aquifer (depth range: 750-1200m), which is presently tapped by 12 wells, an inner elliptical grid (see Fig 2) was used which was increased by elliptical rings to cover an outer zone (up to about 250km); the piezometric level of wells in the inner zone also showed an elliptical pattern in 1982 (see Fig. 1). The centre of the inner zone coincides with the long axis of the -50m contour in Fig. 1.

Pumping tests have shown that beneath the city both aquifers are separated by an impermeable layer; this layer is less perfect beneath the outer zone, but any regional hydraulic connection between the two aquifers was neglected. Also neglected were small changes in level and thickness of each aquifer as well as the fine structure within both aquifers which might consist of numerous smaller lensoidal but well connected sub-aquifers.

The pumping tests had shown that the transmissivity of both confined Tertiary aquifers lies within the range of 0.0009 and 0.002m^2/s with an average storage coefficient of S = 0.001. It was also assumed that:-

1. The flow in each aquifer is two dimensional and governed by D'Arcy's Law (each aquifer represents a geothermal reservoir).
2. Each reservoir is infinite, isotropic and homogeneous, and boundaries (beyond r = 250 km) do not affect the pressure gradient during the duration of any abstraction.
3. The flow is horizontal and uniform with depth in each reservoir.
4. Isothermal initial state. i.e. the temperature of the water was constant initially throughout each reservoir.
5. The storage coefficient for each reservoir is constant and the geothermal water is released instantaneously.
6. The thickness of each reservoir was assumed to be constant and each reservoir has the following physical properties:-

    porosity = 0.1; density = 2.5 x $10^3 kg/m^3$;
    specific heat = 950 J/kg K;
    thermal conductivity = 1.4-1.5 W/mK;
    compressibility lies between 20E-9 and 20E-10; permeability and compressibility were retained as parameter

Results (Group I aquifer):

An average initial temperature of 41°C and an average thickness of 50m was assumed for this aquifer. The Group I aquifer model was subjected to the historical time-variable abstraction rates which occurred between 1970 and 1982, allowing also for the geometry of abstraction (abstraction rates increased from about 3.5 Mt/yr in 1970 to about 20.7 Mt/yr in 1981). The computed pressure change as function of distance was then compared with the observed pressure changes and permeability and compressibility of the model were optimized until the observed pressure changes in 1982 (and between 1970 and 1982) agreed closely with the observed changes (see Fig. 3).

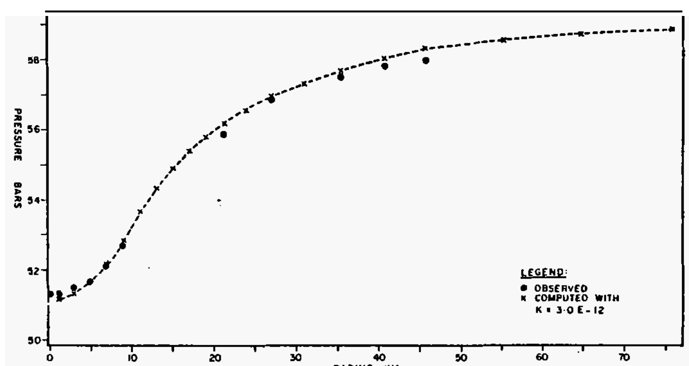

Fig.3 Observed and computed pressures for different permeabilities in upper Tertiary aquifer for 1982 (12 yr production history) as a function of radial distance from centre of model.

For the optimized model of the Group I aquifer it was found that:

    permeability k = 3.0 E-12(m^2), and
    compressibility c = 20E-09

gave the best fits. The values correspond to:

    transmissivity T = 2.24E-3(m^2/s) and
    storage coefficient S = 9.7E-3;

both values lie at the upper range of the values inferred from pumping tests. The response of this model was then tested using a worst (no re-injection) and an average (partial reinjection) scenario. For the worst scenario (abstraction of 20.7 Mt/yr remaining constant until 2000) it was found that the piezometric level will continue to drop at a rate of 1.3–1.5 m/yr for the whole inner zone (r=20km). For partial re-injection (5 Mt/yr at T = 17°), the pressure drop could be reduced to 0.7 to 1 m/yr for the inner zone. In the worst case the piezometric level will drop to about 80 to 94m for the innermost zone (r = 10km) for partial re-injection it might drop to about 63 to 73m (within r = 10km). Since with the presently installed shaft pumps in wells, where the level is lower than 70m, production is already a problem, these figures indicate that production of fluids from the Group I aquifer might require new production techniques. Changes in enthalpy of fluids were also analysed for the Group I aquifer; for both scenarios these changes arc small (less than 2kJ/kg up to the year 2000 for an average enthalpy of 171.5 kJ/kg in 1982).

Results (Group II aquifer):

For the Group II aquifer an average temperature of 45" was used which lies within the range of 35 to 56°C observed in wells which penetrate' this aquifer; its thickness was reduced to 30m. Matching of the observed pressure drops showed that the permeability of this aquifer varies laterally; a best fit value of k = 7.5 E-13(m^2) is indicated for the inner zone beneath Tianjin City whereas elsewhere k = 3E-12(m^2). The predicted and observed pressure change was then computed for 5 wells in the inner zone (see part of Fig.4 up to 1982). For testing of the model it was assumed that production remains constant until 1990 (annual rate 5.8 Mt/yr) and that from 1990 onwards production increases to 11.3 Mt/yr of which 5 Mt/yr are re-injected (T = 17°C) in "doublet schemes"; for Location of re-injection wells see Fig. 2. The resulting pressure behaviour is shown in Fig.4 (part of curve between years 1982 and 2000). Since in the innermost zone of the reservoir, as shown in Fig. 2, production and reinjection wells are only about lkm apart, some minor cooling of the reservoir can be noticed at the production wells (about 1°C between 1990 and 2000) whereas the temperature in the injection well drops significantly by about 10°C (see Fig. 5).

Implication of model studies

The model studies (Ouyang JuQin 1985) have shown that the two Tertiary aquifers beneath Tianjin City, which are presently exploited, can be approximated by rather simple models; the permeability structure of the two aquifers can be obtained by optimization of permeability and compressibility, i.e. matching of observed pressure drawdown data. The permeability of the Upper Tertiary aquifer (Group I aquifer) is approximately constant, while that of the Lower Tertiary aquifer (Group II aquifer) varies laterally.

The thermal water in both aquifers has a significant economic value, it is a soft water with low mineralization (total solids less than 1g/kg; hardness less than 1 G.D.). Data in Chen Jiafa and Gu Da Tong (1981) indicate that the replacement value of an artificially produced equivalent soft water with the same enthalpy is at least 1.5 Chinese yuan per tonne, which explains why the upper aquifer is heavily exploited at present.

However, without stabilization of the pressure in the aquifer by partial re-injection, production of fluids will become more and more difficult in the future. Since the waste fluids from industrial processing (mainly textile industry) are heavily polluted, these wastes cannot be reinjected without costly treatment - re-injection of surface waters might be an alternative.

Fluids from the lower Tertiary aquifer are well suited for space heating since they are almost corrosion free; their energy content is, however, rather low and boosting of temperature by boiler plants is required to obtain suitable inlet temperatures (i.e. greater than 60°C for district heating schemes.) However, exploitation of this resource by using doublet schemes is feasible.

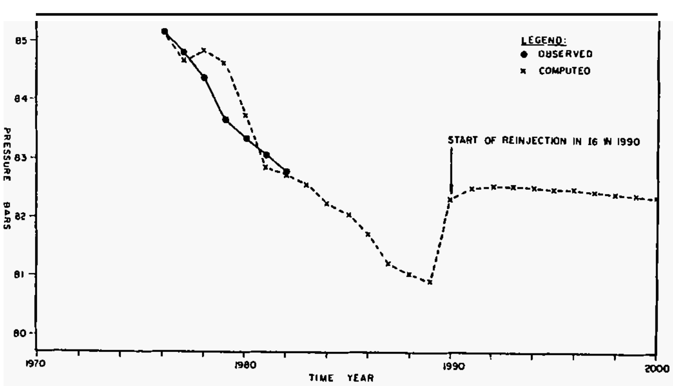

Fig.4 Observed and computed pressure in inner zone (block P6) of lower Tertiary aquifer (for location of P6 see Fig. 2). Production rate = 15.8 kg /s; reinjection into I6 from 1990 at 15 kg/s).

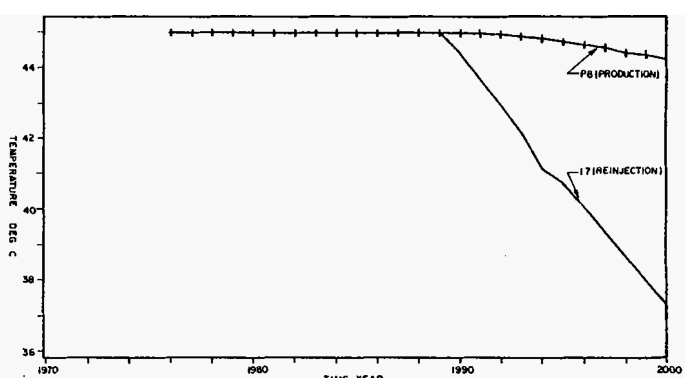

Fig.5 Temperature of lower Tertiary aquifer near re-injection and production well in inner zone (production rate at P8 = 25kg/s, reinjection rate at I7 = 15kg/s; production and reinjection starting in 1990).

REFERENCES

CHEN JIA FA; GU DA TONG (1981): Prospecting and utilization of geothermal resources of Tianjin. Report by Tianjin Geological Bureau, 33pp.

HOCHSTEIN, M.P.; McKIBBIN, R.; YANG YUTANG (1984): Assessment of the Beijing Geothermal Prospect (P R China). Proceedings of 6th NZ Geothermal Workshop 1984, 91–95 (University of Auckland).

O'SULLIVAN, M.J.; ZYVOLOSKI, G.: BLAKELEY, M.R. (1983): Computer modelling of geothermal reservoirs. School of Engineering Report 318, University of Auckland.

OUYANG YU QIN (1985): Computer modelling of the Tianjin geothermal reservoir system (China P.R.) Geothermal Institute Report GIR 015, 85pp, University of Auckland.

PREUSS, K. (1983): Development of the general purpose simulator MULKOM. Report LBL–15500, Earth Sctences Division, Lawrence Berkeley Laboratory, California.

SUN KAI YAO; SU TIALIN (1985): The latest development in geothermal utilization in Tianjin, China. 1985 Symposium on Geothermal Energy, Int. Volume, Geothermal Resources Council, Davis, USA, 373–377.