Study of Geothermal Resources Assessment and Numerical Simulation in the Tuanbo Region

Zhu Jialing[1] and Wang Kun[2]

[1]Tianjin Geothermal Research & Training Center?Tianjin University, Tianjin, 300072, China
[2]Tianjin Geothermal Exploration & Development Design Institute, Tianjin, 300072, China

Keywords

Assessment of geothermal resources, mass and energy balance, lumped-parameter model, distributed-parameter model

ABSTRACT

This paper deals mainly with the heat and mass transfer and mass and energy balance of a reservoir in geothermal field. The general characteristics of the reservoir are summarized. The paper emphasizes the mathematical descriptions transport and convection by two methods by geothermal, the lumped parameter model and distributed parameter model. It is effective to use these models in simulating response of heterogeneous and anisotropic fractured reservoir for the design lifetime of 15 years.

Introduction

A large geothermal utilization scheme in the Tuanbo region is located at the center of the Wanglanzhuang geothermal field. In the conduction-dominated system, upward circulation of fluid is less important than the existence of high vertical temperature gradients in rocks that include aquifers of significant lateral extent. The total area of the Wanglanzhuang geothermal field covers about 8700ha, where 6000ha of them is the Tuanbo reservoir.

In 1984, the first well was drilled outside of the Tuanbo and the exploitation zone sits at 988.24m depth. For ten years, the temperature remained almost constant with reasonable exploitation (below 54t/h). The demonstration engineering of the geothermal system has provided a wealth of experience. A geological and geophysical are the stratigraphic correlation of the geothermal field. A survey sample model was made to forecast the stored heat of the reservoir.

In the exploration stage geothermal surveys and geochemical sampling from surrounding springs, can give indications of the areas extent and possible downhole temperature of the resource. So, one of the most important tasks in geothermal reservoir engineering is to predict the useful lifetime of the resources for a given exploitation scheme. In order to make these predictions, reliable estimates must be available for the amount of hot water in place, the rate at which it can be extracted, and the rate and extent of hot-water recharge into the system.

Geological Model

The Tuanbo region, is located at the center of the Wanglanzhuang gothermal field. This is a typical sedimentary basin low-temperature system, which are common in eastern and northeastern China. The investigation area is located at the Cangxian uplift, which is mainly on the Shuangyao uplift. On the whole, the center part is raised with the low-lying part in east and west part. The anticline structure is the main regional trend. The main fractures are Tianjin Fracture in the west, and the Cangdong fracture and West Baitangkou fracture in the east. Several sub-fracture are associated with these factures[1].

Along the West Bai-Tang-Kou fault, the temperature logging data indicate that the reservoir temperature is higher than other areas. The deep circulation of hot water along the fault zone probably caused this effect.

The geothermal water is mainly located in the Cangxian uplift. Fractured geothermal reservoir exist in medium Jixiannian Wumishan (Pt_2W), lower Paleozoic Cambrian (PzH) and Ordovician (PzO) reservoir; indicates porous reservoirs existing in Tertiary and Quaternary. The isotope analysis, geothermal water comes from the precipitation seepage. It is a closed deep circulation system. The deep hot waters can flow through faults and pores in the reservoir. The continuous upward heat flow is obstructed by the huge thick Quaternary stratum and water mass. The seal favors the heated geothermal water. Although the sealed water moves slowly, it has high velocity in the decompression zone.

The well testing and assessment of geothermal resources indicate that $6.36x10^{18}$J of thermal energy is stored within the medium Jixiannian Wumishan (Pt_2W) group, of 600m thick-ness. The production rate is 80t/h of 82° water. The flow rate of the single well will be variable due to alternative porosity of the reservoir.

Choice of Assessment Methods

Reservoir assessment is a continuous process from the time a geothermal prospect is discovered to the time the project is completed. When several wells have been drilled in a geothermal field, there should have been some pressure transient tests carried out and the results should give estimates of the reservoir KH (transmissivity) product. At this time, a simple lumped-parameter model should be constructed. If computing facilities are available, it will be less time consuming and less costly to use an existing distributed-parameter code to perform the calculations. Finally, when considerable production history is available, the most reliable assessment tool is the distributed-parameter model.

However, the use of lumped-parameter model to estimate the generating potential of a low permeability reservoir will probably lead to reasonable results, and also the model runs very fast. Choice of a assessment depends on understanding of the response to exploitation, purpose of simulation and requirements.

Numerical Modeling

A new numerical simulator, capable of solving 2-D mass and heat transport in heterogeneous porous and /or fractured rocks, is described. The simulator is very general as it allows for temperature and/or pressure-dependent rock and fluid properties.

The equations that arise for each grid block must be linearized and then solved. The nonlinearities in the equations are generally handled by using New-Raphson iterations. The linear equations can be solved either by direct or iterative methods.

The mass conservation equation for this system can be written as follows:

$$\frac{\partial \phi \rho}{\partial t} = \frac{-\partial \phi S \rho_v}{\partial t} + \frac{\partial \phi (1-S)\rho_l}{\partial t} = -\nabla F + q_\rho \quad (1)$$

Here:

- l: liquid phase;
- v: vapor phase;
- F: vector of mass matrix;
- q_ρ mass sink source
- ρ: density;
- ϕ: porosity;
- S: vapor saturation.

The energy conservation equation for this system is given below. It includes both conductive and convective heat flux.

$$\frac{\partial (\frac{Q}{V})}{\partial t} = \frac{\partial (u\rho\phi + u_s \rho_s (1-\phi))}{\partial t} = \quad (2)$$

$$-\nabla G + (\frac{F_v}{\rho_v} + \frac{F_l}{\rho_l})\nabla P + Q_u$$

Here:

- s: solid phase;
- u: internal energy;
- G: energy matrix;
- Q: energy;
- V: volume of reservoir
- Q_u: energy source on sink
- A_n or A_{nm} is the area of the relevant block.

Set of equations (1) and (2) is related to one or two phase filtration in a porous or fracture medium where rock matrix and fluid are considered to be in local thermal equilibrium. For a block of volume V_n of the field, the transfer of mass and energy (5) is given equations (3) and (4)[3][4].

$$\frac{\partial \phi \rho}{\partial t} = \sum_{m=1}^{N} \frac{F_m A_m}{\tau} + q \quad (3)$$

$$\frac{\partial u_s}{\partial t} = (\frac{\partial u_s}{\partial t})_\rho \frac{\partial u}{\partial t} + (\frac{\partial u_s}{\partial \rho})_u \frac{\partial \rho}{\partial t} \quad (4)$$

$$\Delta U_n = \Delta t \frac{\frac{1}{V_n}\sum_{m=1}^{N} A_{nm}(G_{nm} - u_n F_{nm}) + (Q_n - Q_n^{'})}{\phi\rho + (1-\phi)\rho_s\{(\frac{\partial u_s}{\partial u})_\rho + (\frac{\partial u_s}{\partial \rho})_u \frac{\alpha\rho / \partial t}{\partial u / \partial t}\}} \quad (5)$$

Performance Prediction

Properties of the Rock in the Reservoir

The aquifer properties of the medium Pro-terozoic Jixiannian Wumishan (Pt_2W) are listed in Table 1.

Several simulations were then carried out testing various choices for permeability and compressibility. The "best fit" values were permeability 3.0×10^{-12} and compressibility $20.0\times10^{-9}Pa^{-1}$. The transmissivity coefficient T and the storability S calculated from these parameters are:

$T=2.24\times10^{-3}\ m^2/s$
$S=9.7\times10^{-3}$

Table 1. Rock properties of medium Pro-terozoic Jixiannian Wumishan (Pt_2W).

Term	Density (kg/m³)	Specific Heat (J/kg°C)	Average porosity (%)	Permeability in X (m²) direction	Permeability in Y (m²) Direction
Pt_2W I	2500	800	0.5	2.0×10^{-15}	1.5×10^{-15}
Pt_2W II	2600	950	1.0	2.0×10^{-13}	1.8×10^{-13}

The Simulation of Single Well Exploitation

The results from the Tuanbo region simulations show how numerical simulators can help in determining the power potential of a geothermal field. A history matching is completed through different exploration plans with lump-ed model

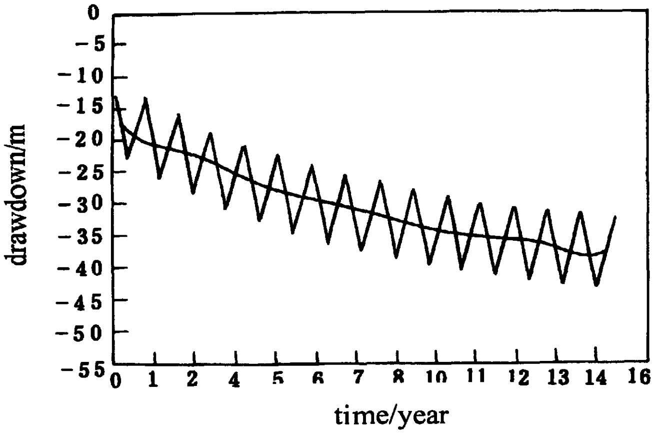

Figure 1. The drawdown of single well.

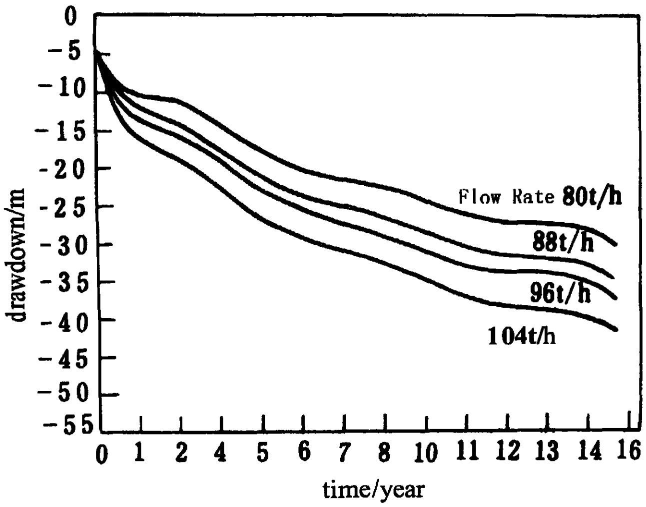

Figure 2. The drawdown of WR8 for different production rates.

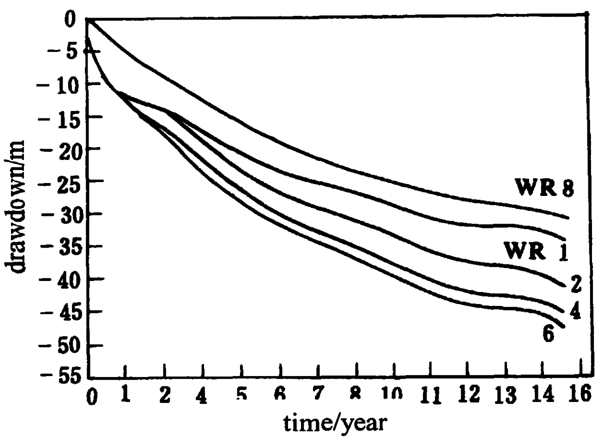

Figure 3. The drawdown of several wells.

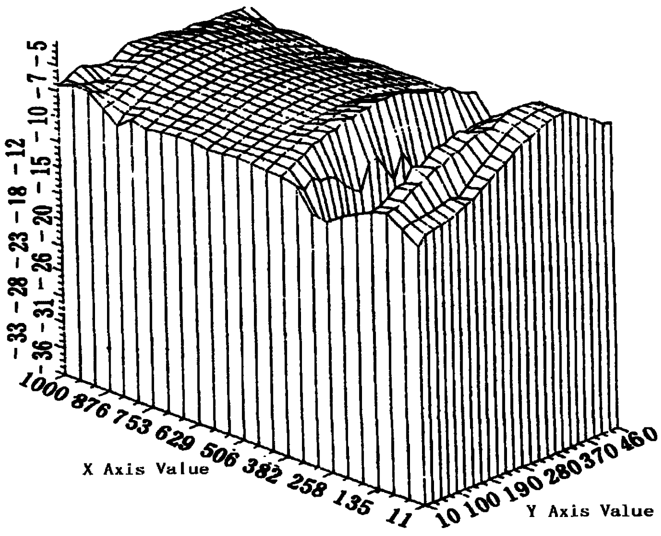

Figure 4. The contours of the drawdown/ production in geothermal field.

(Figure 1) and distributed-parameter model (Figures 2, 3, and 4). And the models also be applied to predict future field performance for various exploitation scenarios.

However, in most cases predictions for longer periods are made in order to obtain estimates of long term behavior. For example let us consider the decline rate predictions for well WR8, which is located at the outside of the Tuanbo region. From 1984 to 1999, athe water level dropped about 2.3m per year without any reinjection. There are four different cases considered. When the production increases from 80t/h to 104t/h, water level drawdown goes up rapidly in the reservoir (Figure 2).

The Simulation of Several Wells Exploitation

From such calculation for all wells (Figure 3), we can readily determine what flow rate will give the most economical returns through distributed-parameter model. We found that at the total present flow rate of 300t/h, the water level rate drop tends to stabilize with time. The average water level in the field declines approximately 2.5-3m per year. When the winter time is over, the flow rate is either reduced to supply tap water only, or the wells are shut in to recovers water level until next winter. However, in the most cases above, reinjection has not been considered. Figure 4 shows the contours map of the average water level drawdown for the whole Tuanbo geothermal field. In general, the data of average water level data can not be used resource evaluation. The lowest water level during the production period is more reasonable for future predictions.

Conclusions

1. The permeability, thick- ness of aquifer and flow rate have a great influence upon pressure change. However, temperature remains essentially constant.

2. The lumped-parameter model can not be used in low-permeability geothermal reservoirs. It leads to a gross overestimate of the potential heat capacity of the reservoir.
3. A 2-D distributed-parameter model, that considers non-homogeneous porous or fractured geothermal field can predict lifetime of the reservoir.
4. The temperature changed is less than pressure, and density of hot water remains uniform.
5. Reinjection should be considered. Simulation is very important for predicting the future response of the Tuanbo region.

References

Lu Run, " Exploitation Report of Wanglanzhuang in Tianjin" Report of project for Tianjin Geothermal Resources, 1987, 10.

Bodvarsson G.S, "Reservoir Development Strategy for Hot Water Reservoirs with Emphasis on Reservoir Modeling", Geothermal Resources Council Bulletin, 1989.4,Vol.17, No.4.

Bodvarsson G. S., "Mathematical Modeling of the Behavior of Geothermal Systems under Exploitation", Ph.D Thesis, 1 982.

Hochstein M P. Assessment and Modelling of Geothermal Reservoirs, Geothermics, 1988, 17(1): 15-49.