RESERVOIR SIMULATION ON THE KIRISHIMA GEOTHERMAL FIELD

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ABSTRACT

The Kirishima geothermal field is located in the southwestern part of the Kirishima volcano in Kagoshima Prefecture.

Nippon Steel Corporation(NSC) and Nittetsu Mining Company(NMC) joined to explore the geothermal resources of the field in 1978.Before then,the Government and NMC carried out surface surveys in the fields of geology,gravity,resistivity and surface temperature and three shallow structural wells were drilled.After considering their results,twenty-one exploratory wells were drilled,and geological and geophysical loggings and well tests were carried out to obtain more detailed information on the geothermal reservoir in a 12 km² area of the field.The results suggested that the predominant reservoir existed in the Ginyu area.On the basis of the information obtained,a simulation of the natural state was computed repeatedly using the simulator developed by NSC,and a geothermal structural model for the Ginyu area was established.Pressure change computed by this model for three years of actual production/reinjection agreed with the observed data.We consider that the validity of this model is assured.The simulation of production indicated that steam production equivalent to 35 MW of electricity could be secured in the Ginyu area for more than 30 years.

SIMULATOR

NSC started to develop the reservoir simulator in 1979.This simulator can be used for a tridimensional,heterogeneous transient problem not only for single phase water but also for two-phase water-steam.The formulation of this simulator was reported at the Stanford Geothermal Reservoir Engineering Workshop by Tachimori in 1982.The simulator used to estimate the reservoir this time is a modified one.

RESERVOIR MODEL

(1)Area of simulation

As shown in Fig.1,the area of this simulation was 1.9 km from north to south and 3.5 km from east to west.Thirty-six exploratory wells were drilled by NSC,NMC and the Government in the area and in the neighbouring area.Many data were obtained on geological structure,permeability,porosity,temperature,pressure,etc.

(2)Block model

Fig.2 represents a tridimensional structural model of the Ginyu reservoir.The model is divided into 224 blocks (7 in the direction from north to south,8 from east to west, and 4 in the vertical direction) considering differences in the geological structure and permeability.Three faults (the Ginyu Fault,the Ginyu Sub Fault and the Sakkogawa Fault) lie from ENE to WSW in this area.The Ginyu Fault is a production zone.The Sakkogawa Fault and one block to the south of the fault are reinjection zones.The width of the Ginyu Fault was set at 100m and the length at 1,200m in consideration of the distribution of the productive points in the exploratory wells and of the fumaroles and the alteration zones.

(3)Boundary conditions

In regard to boundary conditions,a closed model is desirable,but there were insufficient data covering the range in the horizontal and vertical directions to achieve a closed model.So boundaries were set in constant pressure and temperature.Fluid could flow throuth the boundaries.To determine the distance in the horizontal direction from the edge blocks to the boundaries, computation was made under natural conditions in three cases (1,2 and 10 km),and as it was confirmed that there was little difference in the simulated results of these cases,a setting was made at 2 km.The lower boundary was set at 0.6 km below the bottom blocks because there is a boundary between the Kirishima welded tuffs and the Shimanto group.Conditions were set so that no flows occurred through the upper boundary because of the impermeable caprocks except at the Ginyu Fault.A certain condition of pressure and temperature was imposed on the upper boundary of the Ginyu Fault in order to cause a fluid flow equivalent to the natural discharge from the fumaroles.

FORMATION PROPERTIES

(1)Permeability

The permeability of the blocks was given,based on the permeability thickness product (kh) obtained by the well tests as follows;

The Ginyu Fault	center, east	600 md
	west	400 ~ 200 md
The Sakkogawa Fault		300 md
The Ginyu Sub Fault		30 md

The permeabilities of the matrix were classified into two levels according to the quantity of fracture and given as follows;

	quantity of fracture	
	many	few
The Makizono lava	7 md	4 md
The Ebino group, the Iino lava	10 md	3 md

The permeabilities of the caprock, the upper blocks of the model, except in the reinjection zone, and of the slightly fractured Kirishima welded tuffs, a component of the bottom boundary blocks, were given as 1 md.

Though the boundary blocks under the Ginyu Fault are composed of the Kirishima welded tuffs, the permeabilities were given as 600 md, as the Ginyu Fault was assumed to extend deeply into the Shimanto group. The depths of the hypocenter of many earthquakes along the Ginyu Fault were almost 3.5 km below sea level.

(2) Porosity

The porosity of each rock was obtained by measuring core samples of several core-drilled wells. The porosity of each block was given in proportion to component rocks of the block.

SIMULATION PROCEDURE

Preceding to the simulation to estimate the optimum production, simulations of the natural state were repeated to obtain the optimum values of parameters so that the initially set temperature and pressure would be stable at appropriate values. In succession, temperature and pressure changes were computed for three years of actual production/reinjection. An acceptable history match on pressure was obtained between the simulated results and the observed data.

(1) Simulation of the natural state

A. Initial conditions

a. Temperature

There are many temperature data from a comparatively wide area of the field. An initial temperature was assigned to each block, considering the isotherm map of each depth elaborated from the data of the temperature loggings and the homogenization temperature of the fluid inclusion. Fig.3 represents the isotherm contour map at 500 m below sea level. The high temperature zone extends along the Ginyu Fault from the hotter southeastern zone.

b. Pressure

The initial pressure distribution in the Ginyu Fault blocks was determined, based on the gradient of the measured reservoir pressure against the elevation at the Ginyu Fault (as shown in Fig.4). The pressure of the blocks in the fourth layer around the Ginyu Fault was assumed to be the same as that of the Ginyu Fault blocks. The pressure of the blocks in the other layers was calculated, based on a hydrostatic pressure gradient considering the initial temperature distribution.

B. Results of simulation

To establish the appropriate model, permeability and pressure were handled repeatedly so that the calculated temperature coincided with the initially set values, because there were more data on temperature than on pressure.

Fig.5 represents the simulated temperature behaviour of the Ginyu Fault blocks. The temperature of each block decreases a little for the first 3 or 4 years, but after that, it becomes stable. The pressure behaviour is almost the same as that for temperature. Fig.6 shows that the simulated temperature contour after 30 years matches the contour elaborated from the measured data. These results indicate that the formation properties were compiled successfully.

(2) Simulation for three years of actual production/reinjection

In the Ginyu area, the continuous production test of well KE1-7 was started in July 1984. Subsequently, two large and one medium diameter wells drilled in the Ginyu area were added to the continuous production test in 1986 and 1987. The maximum production rate of hot water and steam during the period was about 630 t/h. In December 1984, the continuous measurement of the wellbore pressure was started using capillary tubing type pressure units. Pressure change during this period was computed using the observed production/reinjection flow rate and an enthalpy as input data. Fig.7 shows a comparison between the calculated results for the producing block No.74 and the observed pressure data obtained at wells KE1-7 and KE1-13s. Although partial differences can be seen, the overall behaviour corresponds fairly well. Fig.8 shows a comparison with reinjection block No.45. The pressure behaviour is almost similar.

Tracer tests were carried out between the reinjection wells(KE1-14 and KE1-18) and the production wells(KE1-7,KE1-17,KE1-19s,and KE1-22) during this period.The ratio of tracer recovery obtained from the test at each production well was similar to that of reinjected water recovery calculated by the simulated mass flow balance.

(3)Simulation to estimate the optimum production

To predict future development,we divided this problem into four stages.At the first stage,to make a rough estimate of power generation from the Ginyu area,we repeatedly simulated and checked the pressure,temperature and specific enthalpy changes in the producting blocks,while varying the production rates.At the second stage, we made an annual production scheme for 30 years in each producing block,and simulated the behaviour of pressure,temperature,specific enthalpy,and fluid quality under this production scheme. At the third stage,we simulated the wellhead conditions for each producing block,using the simulator for vertical flow in the well under the bottomhole conditions obtained in the second stage.At the fourth stage,the wellhead conditions were checked for accuracy.If the wellhead pressure did not exeed 5 ata,the annual scheme must be corrected.Because of the previous production,the pressure and temperature of each producing block decreased gradually.Therefore,if some blocks did not maintain their abilitys to produce the planned steam rate,the production scheme must be corrected.If so,the production rate of the deteriorated block was reduced and that of the blocks which had enough ability was increased to satisfy the required amount of steam.And then,simulation of the second and third stage was repeated until the optimum scheme was obtained.It was predicted by this procedure that steam production equivalent to 35 MW of electricity could be secured for more than 30 years in the Ginyu area.Fig.9 and Fig.10 show the predicted pressure or temperature history for each producing block under the finally designed annual scheme for 30 years.Though the pressure of each producing block declines by 7 or 8 bars in the first year,the pressure drop subsequently becomes small.Temperatures of the central and western blocks in the second layer decline by $4\sim7$ ℃ in the first year,and after 10 or 12 years they can produce only $14\sim15$ t/h of steam.Then both blocks are shut in at that time.The large temperature decrease of the blocks is caused by the effect of the circulation of reinjected water.Also,the western block of the Ginyu Fault in the third layer has a tendency to decline in temperature,but as a result of reducing the production rate gradually,the temperature drop remained within 10 ℃ for 30 years of production.The temperature of the central and eastern blocks of the Ginyu Fault in the third layer tends to rise gradually for the first 5 years,and then to decline,but the drop is slight.So the shortage in production at the blocks in which temperature or pressure declined was covered by the increase to these blocks.

CONCLUSIONS

(1)We carried out an estimation of the reservoir in the Ginyu area,using the simulator developmed by NSC.As a result of repeated simulations in the natural state,using the measured data as initial conditions,we achieved the appropriate reservoir model.Using this model,temperature and pressure became stable at the early stages of calculation.

(2)As the results of the simulation for three years of actual production/reinjection by this reservoir model showed good agreement with the observed data,the validity of this model was proved.

(3)Simulation to estimate the optimum production using this model suggested that steam production equivalent to 35 MW of electricity could be secured for more than 30 years in the Ginyu area.

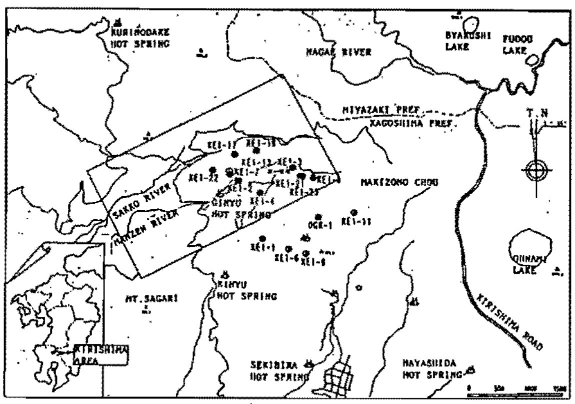

Fig.1 Extended field area used for the simulation

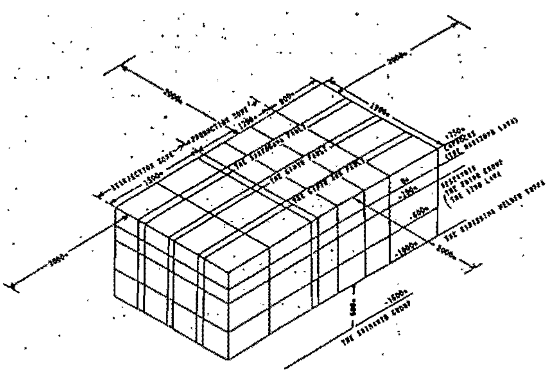
Fig.2 Tridimensional representation of the Ginyu reservoir model

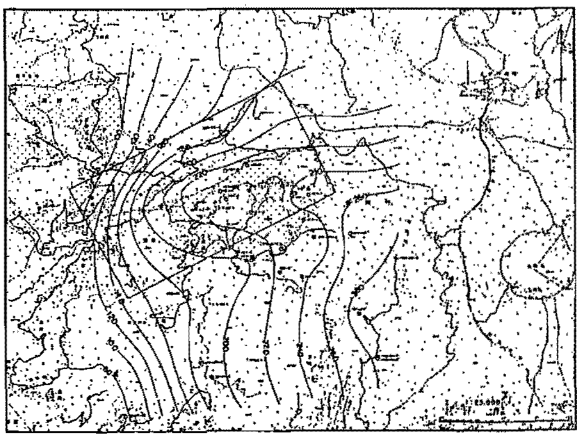

Fig.3 Isotherm contour map at 500m below sea level

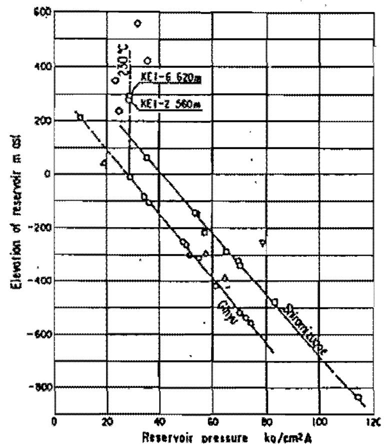

Fig.4 Measured reservoir pressure against the elevation at the Ginyu Fault

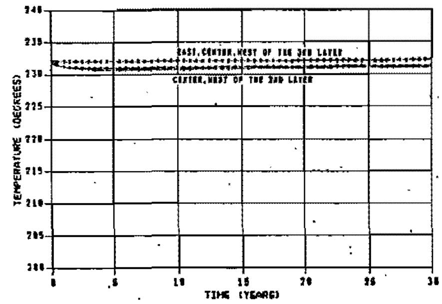

Fig.5 Simulated temperature behaviour of the Ginyu Fault blocks under natural conditions

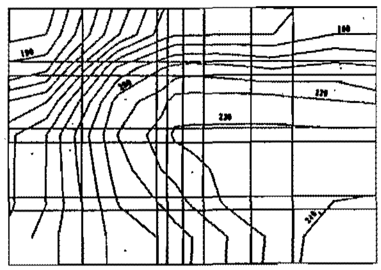

Fig.6 Simulated temperature contour after 30 years under natural conditions

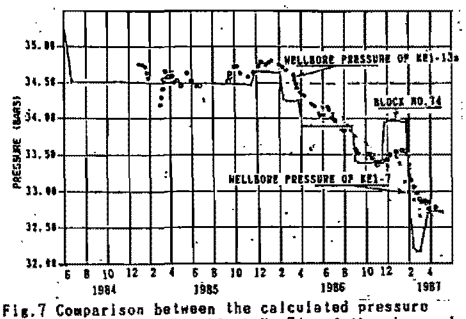

Fig.7 Comparison between the calculated pressure of the producing block No.74 and the observed data at KEI-7, KEI-13a

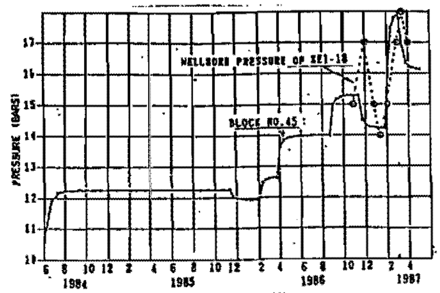

Fig.8 Comparison between the calculated pressure of the reinjection block No.45 and the observed data at KEI-18

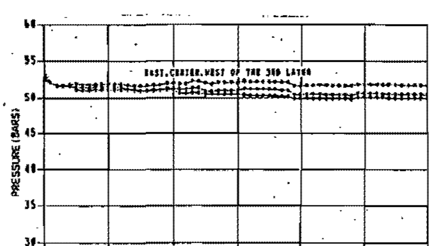

Fig.9 Predicted pressure change of the producing blocks

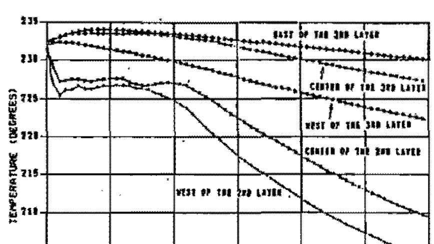

Fig.10 Predicted temperature change of the producing blocks