Proceedings Eighth Workshop Geothermal Reservoir Engineering
Stanford University, Stanford, California, December 1982
SGP-TR-60

DESCRIPTION OF GEOTHERMAL RESERVOIR SIMULATOR "NSCGREATS" AND A PRELIMINARY SIMULATION OF THE KIRISHIMA FIELD

Masaharu Tachimori

Process Technology R&D Laboratories,
Nippon Steel Corporation
Kitakyushu City, Japan 805

Abstract

Anumerical simulator for geothermal reservoirs (NSCGREATS) is presented, that includes sub-simulator for flow in geothermal wells. The flow in reservoir is expressed on the basis of mass and energy transport in porous media. The flow toward the well in the wellblock are treated as a steady horizontal radial flow. The vertical flow in geothermal wells is expressed by a new set of correlations. Its details are presented in another paper by the author in these proceedings.

NSCGREATS has been applied to a preliminary simulation of the Kirishima geothermal field. The simulation revealed several mechanisms at work in the transition of the reservoir. The important mechanisms are: (1) steam/water counterflow which forms a steam cap in shallow levels but remains liquid water at deep levels, and (2) recharging from outside of the reservoir which compensates for production to a considerable extent. It has been predicted by the simulation that an enthalpy of 1500 GJ/h may be produced by wells drilled at intervals of 200m in a main fault zone having a length of 1.2Km. However, further investigations into the deep levels in the field are necessary to make more accurate prediction, since production depends strongly on recharging from the fluid source deep below the reservoir.

Introduction

A computer simulator for geothermal reservoirs called NSCGREATS has been developed by the author. It is a three-dimensional and distributed parameter model, applicable to compressed water, superheated steam and two-phase steam-water reservoirs. Compaired to the other simulators that have been presented in previously published literature, the main distinctive feature of NSCGREATS is that it includes the simulation of flow in wells and makes it possible to perform simulations under the practical conditions prescribed at well heads. The numerical model for the flow in geothermal wells used in NSCGREATS has also been developed by the author and its details are reported in another paper presented at these proceedings.

NSCGREATS is now in practical use for preestimating the characteristics and the performance of the reservoirs and wells at the Kirishima geothermal field in Japan that is currently under development now. The results of a preliminary simulation of the Kirishima geothermal field is presented in this paper.

1. Description of simulator

Equations

Basic equations of fluid and energy transport in geothermal reservoirs, used in this simulator, are mass and energy conservation equations and Darcy's flow equation, using the assumptions given below.

Assumptions:
1) All rock properties are independent of temperature, pressure, and vapor saturation.
2) Liquid, vapor, and rock are in local thermodynamic equilibrium.
3) Capillary pressure is ignored.
4) Kinetic energy and potential energy are ignored.
5) Momentum balance is not considered.

Coupled equations for the conservation of mass and energy are solved in terms of fluid specific internal energy u and density ρ. Advantages of this formulation are that variables u and ρ are continuous and single-valued beyond phase changes, and that u and ρ are directly related to the conserved quantities of mass and energy.

The numerical method used for space discretization of equations of mass and energy is an integrated finite difference method. This method maintains conservative properties of the original differential equations in the numerical equations for the discretized system, so that abnormal phenomena caused by cumulative errors are eliminated. Besides that this method makes it easy to deal with boundary conditions. Time is discretized fully-implicitly as a first-order finite difference. The weighted upstream method is used to calculate the mass and energy fluxes between grid blocks. It uses the fluid properties of the upstream grid block. Nonlinear finite difference equations are solved using the Newton/Raphson method and the SSOR method.

The basic equations and the finite difference equations are similar to those used by Pruess et al. [1], [2], their descriptions are not presented here.

Production condition

This simulator is available for the production conditions that prescribe the pressure or discharge rate at well heads, as well as that prescribe sinks/sources at wellblocks, because it is provided with the sub-simulator for the flow in geothermal wells. At the beginning of each time step, the production rates and the pressure drops in the well and in the formation around the well are calculated on the basis of the last calculated state of the wellblocks. The calculated production rates are assigned to the blocks as explicit sink/source terms for the calculation of mass and energy transport between blocks in the new time step. The correlation of wellbore pressure P_W and block pressure P_B is expressed as follows using the assumptions below.

$$P_W - P_B = \frac{W \ln (r_w/r_e)}{2\pi k H \left(\frac{K_g}{\nu_g} + \frac{K_\ell}{\nu_\ell}\right)} \qquad (1)$$

$$r_e = \gamma(\Delta x \ \Delta y)^{\frac{1}{2}} \qquad (2)$$

where W is mass flow rate, H open interval in a well, r_W wellbore radius, Δx, Δy well block spacing.

Assumptions:

1) Flow toward the wellbore in the wellblock is steady, horizontal radial flow.
2) Steam and water flow rates are proportional to the ratios of the relative permeability k_g, k_ℓ and the kinematic viscosity ν_g, ν_ℓ of each phase [3].
3) Relative permeabilities are uniform along the radial direction and take the values calculated from the state of the wellblock.
4) The absolute permeability k in Eq.2 is evaluated as the arithmetic average of its directional components.

Factor γ of effective radius r_e takes the value proposed by van poollen [4] in most cases and those by Pritchett [5] in special cases of two dimensional simulations.

Boundary condition

The following boundary conditions, allowing any overlaps, satisfy various boundary conditions encountered in reservoir simulations.

1) Prescribed mass or energy fluxes through the boundary.
2) Prescribed fluid and rock properties at prescribed distances outside the boundary.

2. Preliminary simulation

Outline of the Kirishima field

The Kirishima geothermal field that Nippon Steel Corporation and Nittetsu Mining Company have been developing is located 2km west of the Kirishima group of volcanoes in the southern part of Kyushu island, Japan. The area of our field is about 15km². Geological, geophysical, and geochemical surveys have been carried out to locate wide regions of hydrothermal alteration, low electric resistivity, and several faults. The prominent faults run from SW to NE and along them on the surface are found hydrothermal alteration zones, hot springs and fumaroles. They could be considered to penatrate into the basement. To date, three test wells have been drilled by NSC and NMC in the northern quarter of the area. These have been tested to examine subsurface structures and reservoirs. Figure 1 shows a cross section of the area, including some speculations on deep layers. The area is one of andesitic volcanism, and lavas are in layers with a thin layer of tuff breccias and sediments between them. Underlying the lavas are the Kirishima welded tuffs, which are of very poor permeability, and the Shimanto Group of sediments, which is considered the basement. The hydrothermal alteration of andesites has several zones with increasing depth. At shallow levels the alteration mineral assemblage is Montmorillonite-Crystobalite-Tridymite-Pyrite. Below a depth of about 400m it is Chlorite-Quartz-Calcite-Sericite-Wairakite-Laumontite-Epidote. Table 1 shows the results of well test analysis. The major permeable formations are associated with faults and the second permeable formations are tuff breccias and sediments. The andesitic lavas have some fractures in them, but they are generally of poor permeability. The pressures and temperatures at the main feed zones and the fluid enthalpies indicates that fluids in the prominent fault are saturated water or steam-water mixtures and in other formations are compressed water. It is estimated that permeable formations of faults, tuff breccias, and sediments from a depth about 400m to the top of the welded tuffs form reservoirs in this area, and that promi-

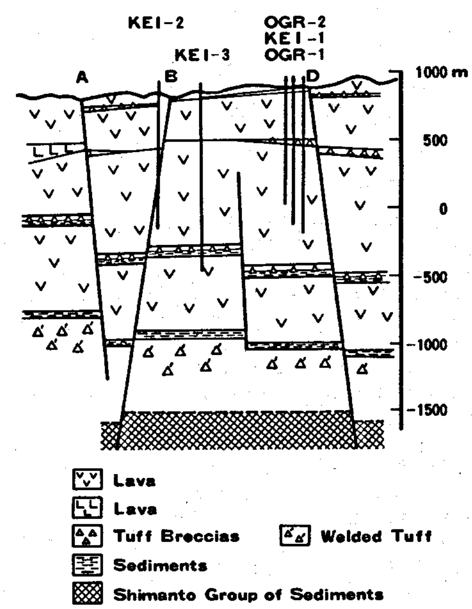

Figure 1. Cross section of the northern part in the Kirishima field, showing the positions of wells. OGR-1, 2 are the MITI's wells.

Table 1. Results of Well Test Analysys

MAIN FEED ZONE

WELL	FORMATION	DEPTH m	TEMPERATURE °C	PRESSURE MPa	FLOW-CAPACITY Darcy.m	FLUID ENTHALPY kJ/kg
KE1-1	LAVA	820	190	3.5-3.8	0.07	170
KE1-2	FAULT	560	225	2.8	5-10	440
KE1-3	T.B.S.*	1170	230	5.0	0.5	220

• T.B.S. is indicates formations of tuff breccias and sediments.

Table 2. Rock Properties for Simulation

FORMATION	PERMEABILITY md	POROSITY	DENSITY kg/m³	SPECIFIC HEAT kJ/kg	THERMAL CONDUCTIVITY J/sm°C
FAULT	100	.20	2200	1.	1.75
T.B.S	10	.15	2200	1.	1.75
LAVA	1	.10	2200	1.	1.75

nent faults form the main passages for geothermal fluids rising from deep sources.

Before going to the next stage of development, a preliminary simulation was performed in order to evaluate energy production rate tapped by a well located at a prominent fault (indicated as 'B' in the Figure 1), and to study transition of the reservoir.

Reservoir modeling and rock properties

A vertical cross section of the reservoir was chosen which extends from SE to NW across the main fault. Figure 2 shows the finite-difference grids and the simplified subsurface structure. The region has a width of 200m, a length of 1100m, and a height of 1400m (i.e. from 400 to 1800m in depth). The structure is assumed to be symmetrical on both sides of the main fault. Table 2 presents the rock properties of the formations, which were obtained from well tests and drilled-core investigations.

Initial state

Since the temperature and pressure data from test wells were not enouth to cover the distribution of temperature and pressure of the whole area concerned, several simulations were tried to reproduce the pressures and temperatures observed in the test wells and the natural leakage of fluid and enthalpy on the ground surface. This procedure is similar to that used by Mercer et al. [6]. To maintain the ground surface leakage in the steady state, a fluid and energy source had to be considered to supply geothermal fluids to the reservoir through the bottom boundary of the main fault. The initial pressure distribution is shown in Figure 3, and the initial temperature distribution in Figure 4. Slow circulation of flow is characteristic of the natural steady state. Fluids flow upward along the main fault, and downward along the subfaults.

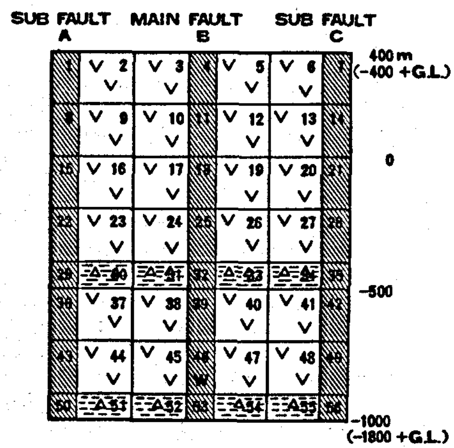

Figure 2. Simplified geological structure and finite difference grids used in the simulation. W indicates well position, and numbers in grids are sequential block numbers.

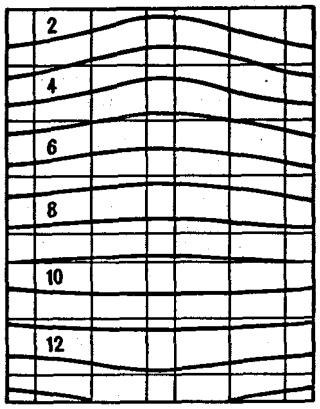

Figure 3. Initial pressure (MPa) distribution.

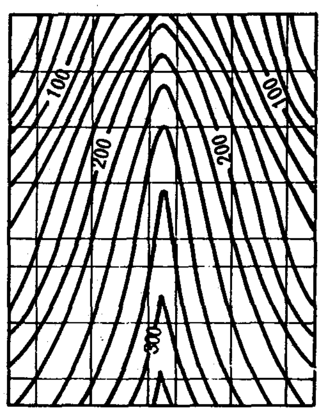

Figure 4. Initial temperature (°C) distribution.

Boundary condition

All boundaries of lava layers are assumed to be in the no-flow condition. Leakage only through the bounderies of permeable formations are considered. At 75m above the top boundaries of the faults the ground-water surface is prescribed, which is balanced against the initial pressure at the top blocks in the subfaults. At 1500m below the bottom boundary of the main fault a geothermal source almost in the critical state is prescribed. At 1000m outside the side boundaries of the tuff breccia formations, pressures, temperatures and vapor saturations are prescribed to keep constant values equal to the initial values at the blocks just inside the boundaries.

Production condition

One well is located in the main fault zone at a depth of 1600m, that is, in the No.46 block. The inner diameter of the well is chosen at 240mm. The well-head pressure is prescribed to keep a constant value of 1 MPa.

Results and discussion

The transitions of the total fluid (i.e. steam + water) and steam production rates are shown in Figure 5, that of the enthalpy produced in Figure 6. Production is large at first, but decreases rapidly and becomes steady because of pressure drops. In steady state an enthalpy of 250 GJ/h is produced. Since the main fault is known to extend for 1.2Km, an enthalpy of 1500 GJ/h may be expected in the whole fault. The recharge increases with time, and compensates for production to a considerable extent. About 70% of the recharge comes in through the bottom boundary of the main fault.

The pressure transitions in the main fault are shown in Figure 7. As a consequence of production, pressure drops in the wellblock, so that flow toward the well is initiated. The pressure decline spreads rapidly through the whole reservoir region. In shallow blocks pressure drops continue for a long term because of boiling. As shown in Figure 10, pressure drops are large in the main fault, which is the production zone.

Temperature behaviors in the main fault are similar to that of pressure, as seen in Figure 8. The temperature in the well field is maintained by hot fluid recharge through the botom boundary of the main fault. As shown in Figure 11, temperature drops are prominent in the main fault above the wellblock, in the subfaults, and in the holizontal permearble formations. They are cooled by the cool water initially stored in the shallow region, and by recharge of cold water through the top boundaries of the faults.

Figure 9 shows the transition in vapor saturation in the main fault. Pressure drop causes phase transitions to two-phase conditions and subsequent steam/water counterflow in the main fault zone. Steam rises along the fault and temporally accumulates in the top region of the main fault, whereas water flows downward toward the well field. Continual downflow promotes pressure drops, boiling, and increase of vapor saturation in shallow two-phase regoins that spread consequently to horizontally adjacent blocks, as seen in Figure 12.

The results indicate that the significant changes in the reservoir conditions progresses downward from the top zone, and that the recharge of fluids and energy, especially those supplied through the bottom boundary of the main fault, are very important in maintaining the productive potential of the reservoir. Deeper production wells are less affected by the reservoir transition and recharge themselves readily from the source, thus extending the life of the reservoir.

Conclusion

NSCGREATS made it possible to simulate the coupled systems of the geothermal reservoir and well. The method used in NSCGREATS, which assumes steady horizontal flow around wells, is a practical method. A preliminary simula-