OPTIMIZING INJECTION-PRODUCTION WELL PATTERN
IN HOT WATER DOMINATED GEOTHERMAL RESERVOIR

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ABSTRACT

This paper presents an approach to optimize the injection-production well pattern for hot water geothermal reservoir based on the quantitative investigation about the effects of reinjection water on production water. Also, this paper describes the tracer test analysis. The tracer test gives valuable information for grasping the reservoir characteristics distributions and water flow conditions between production-injection wells, which are required for application of this optimization approach to actual fields.

INTRODUCTION

From 1977 to 1984, as a part of the program named "Studies on Physicochemical Mechanism of Hot Water Injection" entrusted from Agency of Industrial Science and Technology[1] and New Energy Development Organization[2], evaluation study of Takinoue and Nigorikawa geothermal fields in Japan was carried out. The objectives of the study were to analyze hot water flow behavior in the reservoir by using numerical reservoir simulation model and to evaluate the effect of water injection on production water. As a result of the study, it became recognized that the study on optimizing injection-production well pattern on the basis of understanding of fundamental production-injection mechanism in hot water dominated reservoir is important.

In this paper, considering electric power plant generated by geothermal steam, the constraints of the minimum pressure and temperature in the production well are introduced, and the sensitivity of the distance between injection well and production well is analyzed by assuming a typical two-spot pattern. Reservoir characteristics are also changed in the course of the sensitivity analysis of this study.

The approach proposed in this paper is to optimize the distance between injection well and production well in order to delay the cooling effect of injection water on production water and simultaneously to achieve pressure maintenance purpose.

In this paper, the reservoir is treated to be porous media and the fluid flows through them. But many investigators point out such flow is controlled by fractures. We also confirm them on Takinoue and Nigorikawa fields by tracer test. The tracer test gives very useful information for us to know the reservoir characteristics distributions between the wells and reinjection water flow behavior. Also this test is very important for application of this proposed optimization approach to actual fields. The tracer test analysis and the results are discussed here briefly.

CASE SIMULATION

The studies on effects of reinjection water on pressure and temperature of production water were carried out by using numerical reservoir simulation model. The one-phase three-dimensional geothermal reservoir simulator was used. In this simulator, Darcy's law for fluid flow through porous media and Fourier's law for convective-conductive heat transfer are assumed to hold, and the flows of mass and heat through geothermal reservoirs are described by the equations of conservation of mass and conservation of energy, and the equations are solved by means of the finite difference method.

In the preparation of reservoir model, the domain and the reservoir characteristics are determined in reference to actual fields data.

Sensitivity study of reservoir characteristics such as porosity, permeability, thermal conductivity, rock specific heat and rock density, which are used within the range presented in Table 1, was made for a two-spot pattern. As a result, except the effect of permeability on the pressure of production water (Fig. 1)[2], other parameters were found not to affect the pressure and temperature very much.

Table 1. Reservoir Characteristics

Reservoir Characteristics	Investigation range of the values on the basis of the actual data obtained from Japanese production fields	Standard values employed in discussion on well locations
Porosity	10 ~ 30 %	20 %
Permeability	5 ~ 500 md	10 md
Thermal Conductivity	1 ~ 5 kcal/m/hr/ ℃	4 kcal/m/hr/ ℃
Specific heat of rock	0. 22~0. 26 kcal/kg/ ℃	0. 25 kcal/kg/ ℃
Density of rock	1. 500~3. 000kg/m³	2. 500kg/m³

In this study, the injected water was assumed to establish an instantaneous thermal equilibrium with reservoir rock in contact, and the resulted water temperature depended upon the rock heat capacity. In case of water flow through fractures, the volume of rock in contact with water is much less compared to the flow through porous media, and the rock heat capacity has to be so adjusted reflecting the fracture system. Actually in the process of history matching simulation studies on Takinoue and Nigorikawa fields, it was necessary to use fairly small values of rock heat capacity to simulate measured temperature change. Fig. 2 shows the effect of rock heat capacity on the pressure and temperature of production water. The temperature was affected significantly but the pressure did not change very much.

In the simulation study to optimize injection-production well pattern, reservoir characteristics were adopted of standard values in Table 1 based on above investigations, while reservoir fluid was assumed to have pure water properties. The initial reservoir pressure and temperature of 230°C and 100 KSCA were set in the model.

(Basic Discussions)

In the case of a two-spot setting, the effect of distance between the wells on the pressure and temperature of production water is discussed. Here, the production rate of 300 ton/hr, injection rate of 240 ton/hr (80% reinjection) or 150 ton/hr (50% reinjection) and injection water temperature of 150°C are employed. Fig. 3 shows one of the results[2]. As described before, the minimum pressure and temperature constraints of production water, or minimum bottom hole pressure and temperature, are decided for the operation of power generation. Therefore, it is very important to produce as long as possible until these pressure and temperature reach their minimum values. Fig. 3 shows that the period required for bottom hole pressure of production well to become less than a certain value is inversely proportional to the distance between the wells, conversely, the period required for bottom hole temperature of production well to reach a certain value is proportional to the distance. From this point of view, the results shown in Fig. 3 are rearranged as in Fig. 4 which shows the relation between the distance between the wells and the time elapsed[2]. Fig. 4 is one of the diagram determing the optimum well locations in the case of a two-spot setting. For example (See asterisks in Fig. 4), it is assumed that the required minimum bottom hole pressure and temperature of the production well for steam production are 80 KSCA and 228°C, respectively, and reinjection rate is 80% of production rate. When the distance between the wells is 500m, the pressure reaches that value in 1.2 year, and when the distance is 200m, the temperature reaches that value in 0.3 year. When the distance is set to be 360m, both of temperature and pressure reach their minimum values at the same time and the period of production is the longest. Accordingly, the distance of 360m is considered the best arrangement of the wells.

Fig. 4 is the diagram constructed only on the selected setting conditions, and the figures like Fig. 4 must be made for individual field based on its characteristics and production-injection scheme.

(Effect of Permeability Distributions)

The heterogeneous distributions of permeability are discussed here in consideration of fracture dominated zone or fault zone in the reservoir. Fig. 5a and Fig. 5b show examples of the results of some

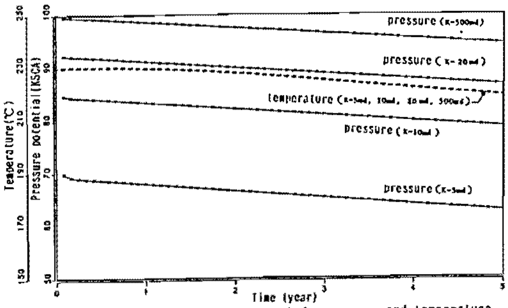

Fig.1 Effect of permeability on bottom hole pressure and temperature (distance between injector and producer is 225m)

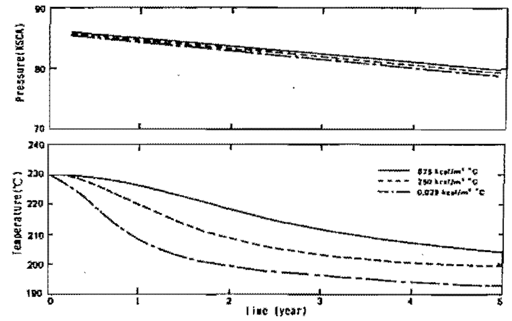

Fig.2 Effect of rock heat capacity on bottom hole pressure and temperature (distance between injector and producer is 150m,80% reinjection)

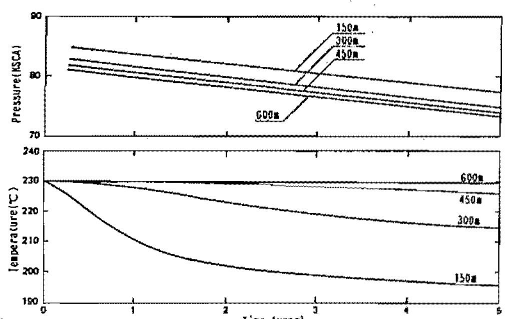

Fig.3 Effect of distance between injector and producer on bottom hole pressure and temperature (80% reinjection, rock heat capacity; 0.025kal/m³ / ℃)

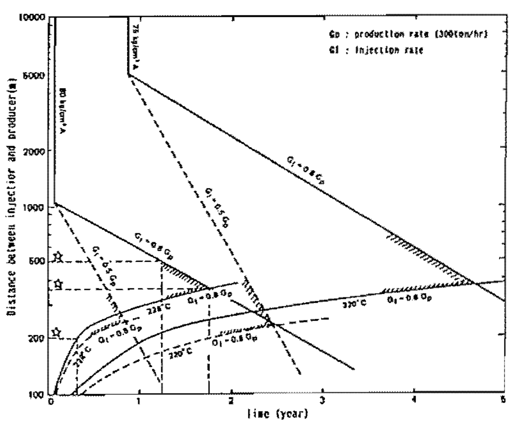

Fig.4 A diagram for determination of optimum distance between injector and producer(rock heat capacity : 0.025 kg/m³ / ℃)

cases in which the permeability inside the injection-production area is different from that of its surroundings. If the permeability inside the area is higher, inflow rate of injection water into the production well is high (Fig. 5b), conversely if the permeability is lower, inflow rate of injection water into the production well is depressed and inflow rate of connate water existing around the production well is high correlatively. Therefore the energy recovery within a given period is different between them. In the case of Fig. 5a and Fig. 5b, and in use of same conditions as described before, the cumulative energy productions after 5 years are compared to the homogeneous distribution case of permeability of 10md as follows; 2% up in the case of the permeability of 5md inside the injection-production area (Fig. 5a), and 6% down in the case of 50md (Fig. 5b). As discussed here, the permeability distribution has big effects on determination of production-injection well locations. Therefore they must be grasped as correctly as possible.

(Discussion on Multi-Well Pattern)

The evaluation on multi-well pattern was carried out in case studies. The results show that production wells should be arranged not to be encircled by low temperature zones which are formed by injection water.

In Takinoue field, many above discussions were carried out synthetically and organically, and noteworthy fruits were obtained. Especially rearrangement of production-injection rates, and change of production-injection conditions including new wells, which were implemented from middle of 1980, accomplished a remarkable improvement on effect of reinjection water on production water[1].

TRACER TEST ANALYSIS AND ITS APPLICATION

As was discussed above, the permeability distributions and/or fracture distributions mainly control the degree of effect of reinjection water on bottom hole pressure and temperature of the production well.

Therefore it is very important to know these distributions in consideration of optimum injection system. Tracer test is one of the useful methods to investigate them especially after the start of the operation. In Takinoue and Nigorikawa fields, the tracer tests have been carried out periodically and their quantitative analysis results have improved injection operation.

The purpose of the tracer test is to know Reproduction ratio and Mixing ratio by measuring the concentration of the tracer reagent in the production water with time. Reproduction ratio is defined as the ratio of produced quantity of the injected water to total quantity of injected water. Mixing ratio is defined as the ratio of produced quantity of the injected water to total quantity of produced water.

The purpose of the tracer test analysis is furthermore to know the length of the path in which the injected water flows to the production well with the shortest time (which is named "Shortest Path") and average velocity of this water flow by the matching of tracer reagent concentration change

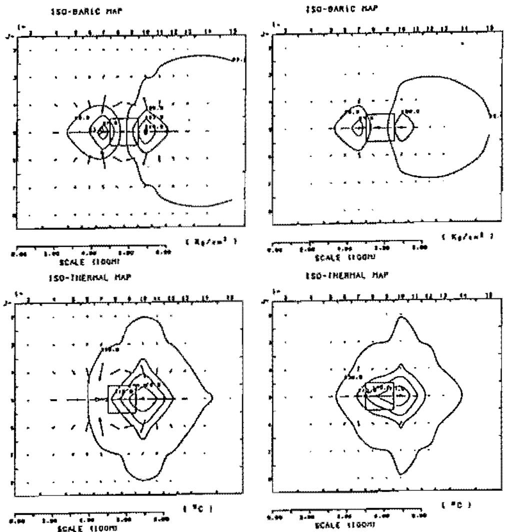

Fig.5a Fig.5b

Fig.5 Iso-baric and iso-thermal maps
(permeability inside the injection-production area; 5md(Fig.5a)and50md(Fig.5b),Other area;10md, after 5years)

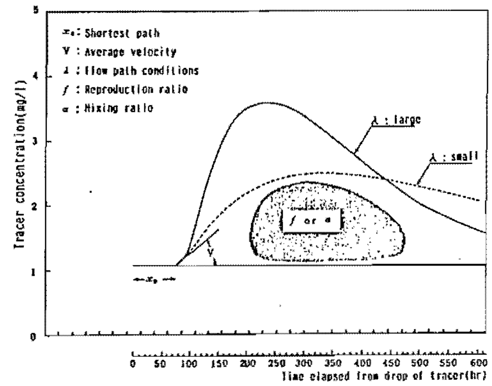

Fig.6 Schematic diagram of tracer response curve

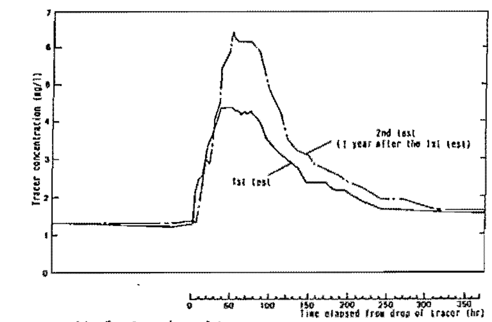

Fig.7 Comparison of tracer response curve

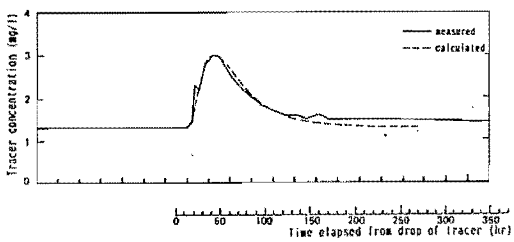

Fig.8 Matching of tracer response curve

observed in the produced water. Tracer test analysis also evaluates flow path conditions between the production-injection wells quantitatively. These parameters are related each other and not determined independently. But the response curve of the reagent concentration change gives us some information about these parameters. Fig. 6[3] shows which part of the response curve mainly represents one of these parameters. For example, flow path conditions are related to response curve pattern. This curve pattern is considered to be influenced by several factors such as reagent adsorption by the reservoir rock, reagent diffusion into the rock, heat transfer and fracture conditions. In Takinoue and Nigorikawa fields, potassium iodide (I^- ion) or potassium bromide (Br^- ion) is employed as a tracer reagent. Fig. 7[2] shows the comparison of the test results carried out periodically in the same production-injection wells. Reinjection rates and Mixing rates are different in each case because of the change of production-injection rates, but the curve patterns are the same. This phenomenon was observed in all tracer tests implemented in other production-injection wells. Therefore the curve patterns and flow path conditions are considered to be mainly related to the fracture conditions. The matching of tracer reagent response curve at a production well is demonstrated in Fig. 8[2].

As discussed here, tracer test is very useful. Furthermore the combination of tracer test analysis and the numerical simulation model can present us the information on the three-dimensional conditions of reinjection water flow and the heterogeneity of permeability distributions.

In the course of the study of Takinoue and Nigorikawa fields, it was recognized that injected water bypassed nearby production wells and affected a production well at a certain distance in the early stage of injection operation. This phenomenon was attributed to heterogeneous permeability distribution in the reservoir, and the reservoir model was modified through trial and error process based on the tracer test analysis. Fig. 9 presents the flow-chart of numerical simulation including tracer test analysis for water flow behavior analysis.

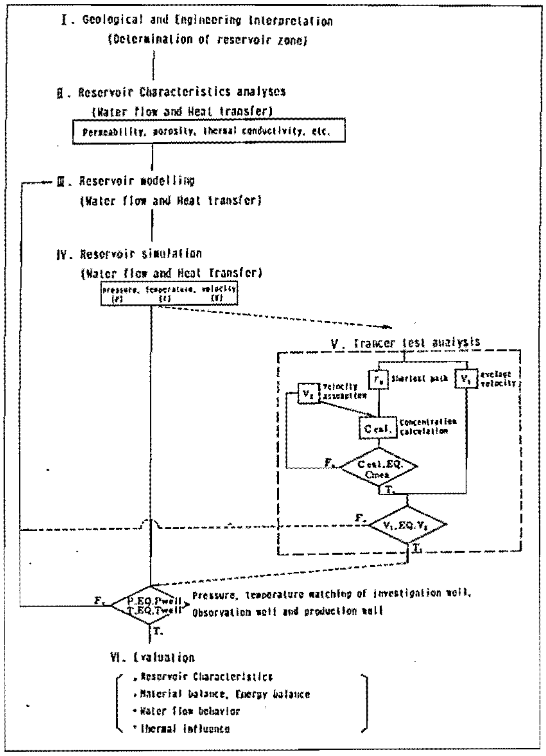

Fig.9 Flow chart for water flow behavior analysis

CONCLUSIONS

The pressure response induced by water production or injection is transmitted into the hot water reservoir relatively rapidly and widely. Therefore, the pressure maintenance effect of water injection influences rapidly every production well located widely in the field.

Temperature change induced by water injection is not transmitted as rapidly as the pressure response. Injected water replaces hot reservoir water around the injection well, and the cooling of the reservoir occurs gradually with the advance of the injected water front. Therefore, to design the optimum reinjection system it is most important to control the water replacement front and its velocity and to minimize the temperature effect of reinjection water on the production water.

Combined utilization of tracer test and numerical reservoir simulation is proved to be very helpful in evaluating reservoir heterogeneity and in optimizing injection-production pattern for the operation of hot water dominated geothermal field through the study of Takinoue and Nigorikawa fields in Japan.

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