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A STUDY ON GEOTHERMAL RESERVOIR ENGINEERING APPROACH COMBINED WITH GEOLOGICAL INFORMATIONS

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ABSTRACT

This paper presents the combined approaches of reservoir geology and engineering to a geothermal field where geological characteristics are highly complex and heterogeneous.Especially,the concrete approaches are discussed for the case of geothermal reservoir performance studies with a developed numerical model,by showing example cases accompanied with reinjection of produced disposal hot water into underground in an object geothermal reservoir.This combined approach will be a great help in solving complicated problems encountered during the development of a geothermal field.

INTRODUCTION

The efficiency of the combined approach of reservoir geology and engineering to an oil field development has been recognized.In Japan,Sarukawa waterflooding is in operation with success. One of the authors studied the problems on the determination of subsurface geologic structure in case of the Northern Reservoir of Sarukawa oil field[1,2].At the planning stage, the exact maps showing subsurface geologic structure and geologic section were obtained by means of the application of oil reservoir engineering data in addition to the usual geological and geophysical informations. Further research from the standpoint of planning on Sarukawa waterflood projects was published in a paper[2].It was significant to use many engineering data as the background on interpretation of subsurface geology,Dr.S.Hirakawa divided this reservoir temporarily into some blocks and concluded that A and B blocks should be given the priority of waterflooding projects.

In dealing with complicated problems in geothermal fields,where geological characteristics are highly complex and heterogeneous for many cases,the combined approach will also be required. This paper describes the combined study of reservoir geology and engineering especially in the case of geothermal reservoir by showing the example cases in an object geothermal area.

GEOTHERMAL RESERVOIR GEOLOGY AND ENGINEERING

It should be emphasized that the reservoir engineering studies on geothermal reservoirs must depend on the geological informations such as geology,stratigraphy,lithology and geological structure obtained by the detailed geological researches for the complexity and heterogeneity of geothermal reservoir structures. The combined study of reservoir geology and engineering is required for accurate analyses of a geothermal reservoir. Especially,in the case of investigations on fluid flow and heat transfer systems,pressure and temperature performances, and production history prediction with a numerical model,which are commonly required through the development of a geothermal reservoir,geological informations should be mainly utilized for the decision of a reservoir zone, reservoir modelling, specification of boundary conditions and the interpretation of results obtained through numerical calculations. The following will describe more about the above items with some examples which will be utilized for the later reservoir engineering approach in this paper.

The work to decide a reservoir zane in a geothermal area for the numerical study is a rather difficult one due to the complexity of geothermal structures in a geothermal area. And therefore, the detailed geolqgical researches play an important role for W e decision. Adding to the survey of geology,stratigraphy and lithology,the survey of fracture orientation and continuity is important in a geothermal area,because geothermal fluid is often considered to be supplied through fractures. The accompanying papers[3,4,5] summarize the results of reservoir geological survey in an object geothermal area for the later reservoir engineering approach. The area for example studies is 750m x750m areally,and 1200m thick (150--1350m),which contains 8 productioh and reinjection wells.

In the modelling of a geothermal teservoir zone for a numerical model, the first problem encountered is the dimension of the model, whether two or three dimension,which fixes the available numerical models such as two-dimensional, two-dimensional with pseudo functions,quasi-three-dimensional,or full three-dhmensional model. At this decision,the degree of geological researches is an important factor, combined

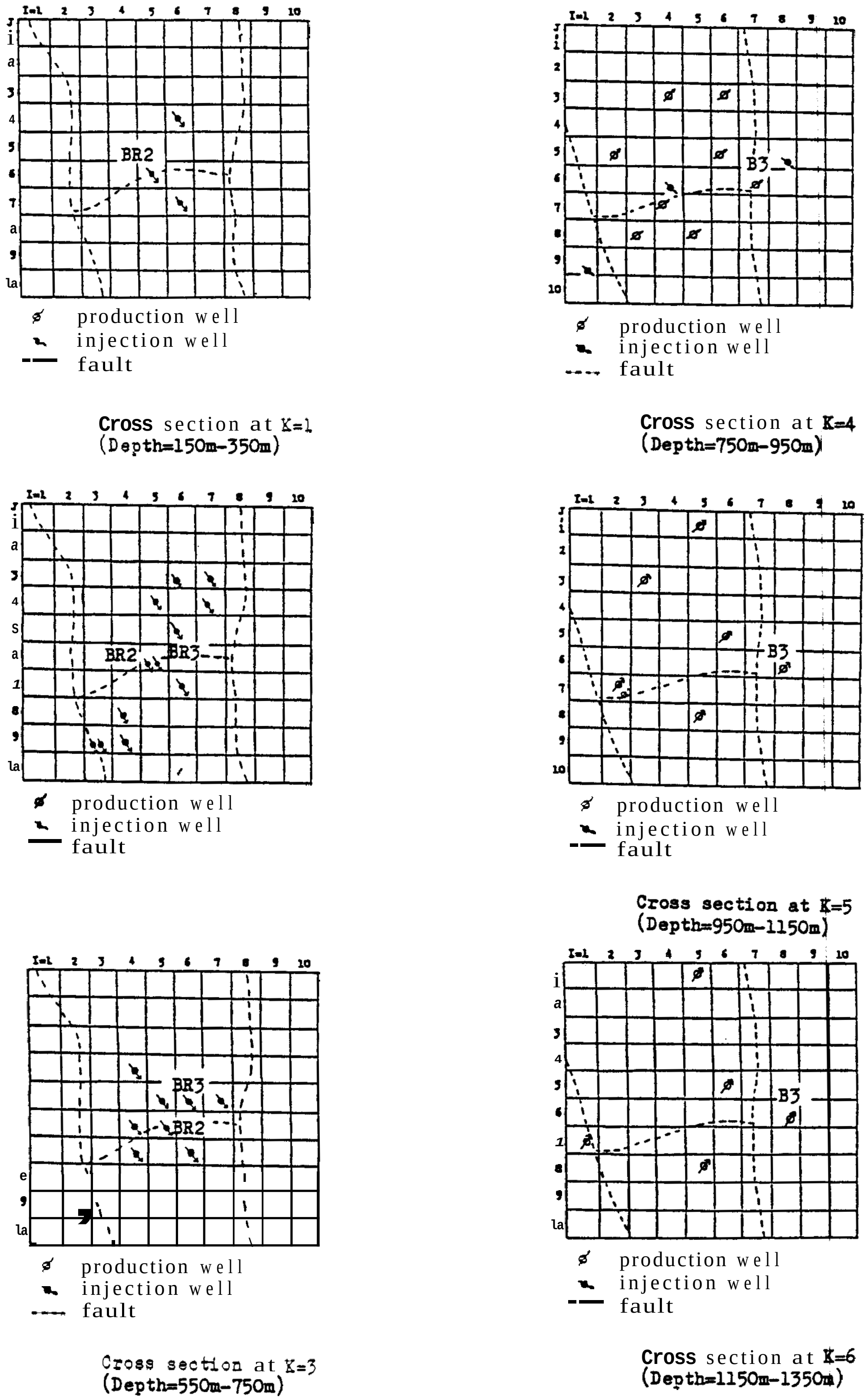


Fig. 1 Horizontal **cross** section of the reservoir **model**

with reservoir engineering factors such as sampling points of available input data,available computing time and expense. For most geothermal areas, geological structures are complex and therefore three-dimensional treatment is suggested if possible. For the example studies,three-dimensional modelling is performed to deal with fracture systems characterizing the geological structures in the studied geothermal area. The next problem is the decision of the grid frameworks covering the modelled reservoir zone for numerical approximate calculations. At this decision, major governing factors are also the combination of geological factors such as the degree of geological heterogeneity (variation of lithostratigraphic units,the continuity and orientation of faults, etc)and reservoir engineering factors such as well locations,available input data points, computing time,computing expense,and computer's storage capacity.

In the example numerical studies,the three-dimensional reservoir model is covered with 10 x 10 x 6 block-centered grid frameworks, attached I,J,K in x,y,z directions respectively. Each block is 75 m in x and y directions and 200 m in z direction. For giving the three dimensional image of this reservoir model covered with grid frameworks,Fig.1 is presented. Fig.1 show horizontal grid frameworks,well locations,and fault systems (dashed lines)for each horizontal cross section of the reservoir model. Fig.2 is the vertical cross section at J=6,showing vertical grid frameworks. As shown in these figures,the N-S trending fault communicating with E-W transverse faults is carefully incorporated into the reservoir model based on the geological researches. These grid frameworks may not be the most favorable one and may seem rather rough. These frameworks, however, are adopted under the restrictive conditions on available input data points, computing time, and computing expense.

Boundary conditions on both heat and fluid flow for numerical models must also be specified based on the combined study of geological and reservoir engineering researches.Fluid and heat inflow from surrounding formations may be observed by observation wells. Geological informations may be a great help in deciding whether constant or unsteady inflow,or no flow boundary conditions. The estimation of heat or fluid inflow quantity,however,is a difficult work and sometimes these values are approximated through history matching calculations, supposing some boundary conditions. For the example numerical study,heat inflow from the bottom of the reservoir zone. and unsteady hot water encroachment from both sides of the reservoir zone are supposed based on geological informations and the quantity are approximated through history matching studies.

The interpretation of calculated results obtained through numerical calculations must also depend on geological informations. For example, geothermal reservoir properties such as permeability distribution,fault characteristics, and degree of fracturing, which are obtained through history matching studies, need to be checked up with geology, lithology,and geological structures obtained through geological surveys for Che corresponding geothermal area.

RESERVOIR ENGINEERING STUDY

As a concrete example of reservair engineering studies combined with reservoir geological researches,the reinjection problem in an object geothermal area is mainly tackled.

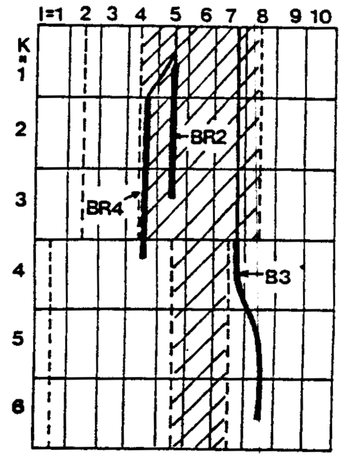
The object geothermal field is water dominated type,which produces hot water five or six times as much as steam. The field is located near the national park where environmental regulations prescribed by the gavernment are very strict. Therefore,reinjection of produced hot water into the underground is an inevitable operation to keep natural environmental conditions in the object geothermal area.Based on the above standpoint, the following example studies mainly investigate the effect of reinjected produced water on the pressure and temperature performances by use of the three-dimensional numerical model.

Acceptable matches on the pressure-time, temperature-time, and temperature-depth relations were established on the three-dimensional numerical model, using the reservoir data in Table *1* and initial temperature and pressure vertical profiles. Figs. 3 and 4 show the flow of geothermal fluids for that history matched case. Figs. 5 and 6 are vertical and horizontal temperature distributions respectively. These figures indicate that injected hot water flowed down the reservoir through vertical faults near injection wells affecting the temperature of production wells. And therefore, more detailed studies must be performed on the effect of produced hot water, which is required compulsory but may reduce the temperature of production wells.

Then the numerical model, on which acceptable history matches were established, was used to study the following two cases of performance prediction on pressure and temperature profiles. One is the case where produced hot water is reinjected into the underground from reinjection wells near production wells, which means both reinjection wells and production wells are in the same production station. Second is the case where produced hot water is reinjected into the underground from reinjection wells which are so separate from production wells in the same production station that reinjected hot water do not affect the production wells. For the prediction calculations, average production rate of about three years was assumed to

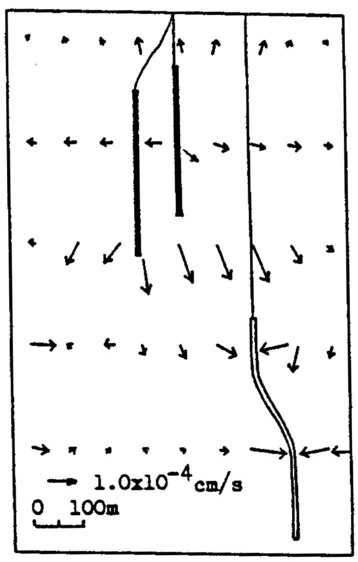
Table 1. Data of reservoir properties

Initial Temperature	= 232°C
Initial Temp. Gradient	= 2.4×10^{-4} °C/cm
Initial Pressure	= 70.7 atm
Matrix Permeability	= 1.0×10^{-4} darcy
Porosity	= 0.12
Initial Water Saturation	= 1.0
Water Compressibility	= 8.5×10^{-5} atm^{-1}
Formation Compressibility	= 4.4×10^{-5} atm^{-1}
Thermal Conductivity	= 1.53×10^{-3} cal/cm·°C·sec
Specific Heat of Rock	= 0.23 cal/g·°C



---- Fault
///// &It in x direction

Fig.2. Vertical cross section at J=6



injection well
production well

Fig. 3. Vertical velocity vector distribution at J=6 for a history matched case

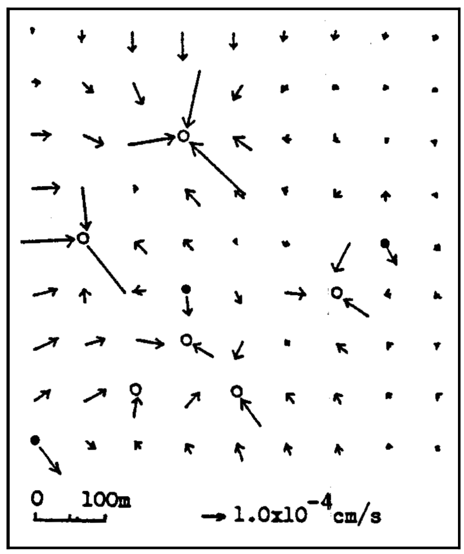
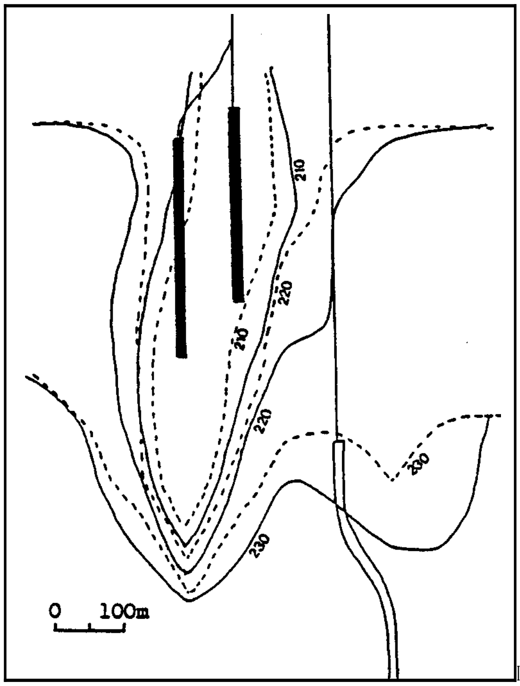
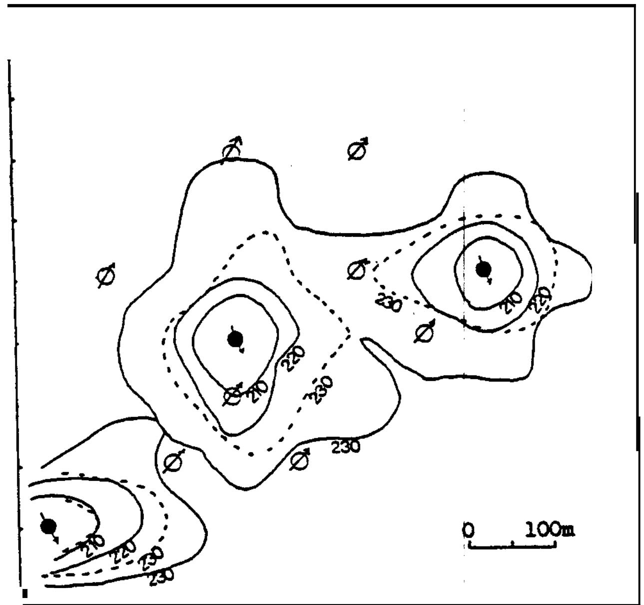


Fig. 4. Horizontal velocity vector distribution at K=4 for a history matched case



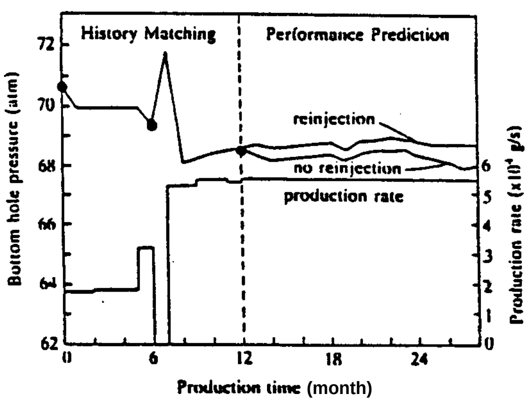
after 1/2 year production
after 1 *year* production
injection well
production well

Fig. 5. Vertical temperature distribution (°C) at J=6 for a history matched case



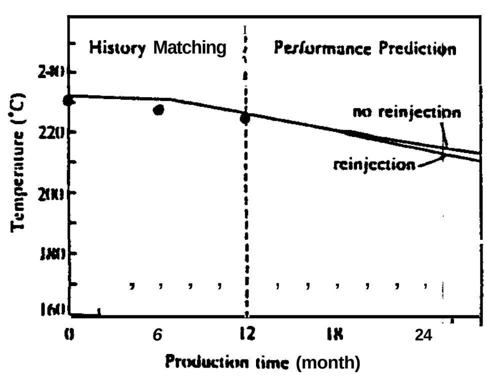
after 1/2 gear production
after 1 year production
injection well
production well

Fig. 6. **Horizontal** temperature distribution (°C) at K=4 for a history matched case



measured
calculated

Fig.7.
Prediction of pressure performance of B3 at the depth of 850m at constant production rate



measured
calculated

Fig.8.
Prediction of temperature performance of B3 at the depth of 850m at constant production rate

continue during the prediction period. Figs. 7 and 8 show predicted pressure and temperature performances of history matched production well, B3 for these two cases. These figures suggest that hot water reinjected from the reinjection wells near the production well maintain the reservoir pressure, consequently improving resource recovery but it reduces the temperature of the production well, resulting the reduction of reservoir energy. This is a controversial problem, which is often encountered in the reinjection processes of produced water. These example studies just show the problem and more detailed researches would be required to answer it in this area. The reservoir engineering studies combined with geological surveys shown in this paper, however, will be a great help in solving the problem.

CONCLUSION

It should be emphasized that the reservoir engineering studies on geothermal reservoirs must depend on the geological informations due to the complexity and heterogeneity of geothermal reservoir structures. Especially in the case of geothermal reservoir studies with a numerical model, the combined reservoir geology and engineering approach should be performed in the decision of a reservoir zone, reservoir modelling, specification of a boundary conditions, and the interpretation of results obtained through numerical calculations. The combined study will be a great help in solving complicated problems encountered during the development of a geothermal field such as reinjection of produced disposal water with minimum reservoir energy and pressure loss.

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