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NUMERICAL STUDIES OF THE DECREASE IN PERMEABILITY CAUSED BY DEPOSITION OF SILICA AROUND AN INJECTION WELL

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ABSTRACT

We present a mathematical model to estimate the injectivity decrease caused by silica deposition around a reinjection well for isothermal injection. It consists of two continuity equations of fluid mass and silica, and the rate equation of silica deposition. The rate equation deals with the rapid decrease in permeability at early stages, and the following slow decrease which were observed both in laboratory experiment and the actual reinjection. In this calculation, the Otake water(90°C and 500 ppm of SiO_2) is assumed to have been injected into the porous reservoir with a homogeneous thickness. The results indicate that the area where permeability decreased remarkably is restricted in the close vicinity of the reinjection well.

INTRODUCTION

In most water-dominated geothermal systems, reinjection of the waste hot water is widely employed instead of surface discharge. The main reasons for reinjecting waste water are;(1)to avoid the environmental contamination due to various chemicals in the water, (2)to ease the drawdown of reservoir pressure and the depletion of reservoir fluid.

The waste water separated from the produced geothermal fluid is usually super saturated with silica, which causes silica scale formation in the surface facilities, reinjection wells and also in the reservoir. In Otake and Hatchobaru, Japan, where full scale reinjection of the waste water is employed, reinjection wells lose their injectivity roughly by 30 % a year. The decrease in injectivity is probably caused by the silica scale formed in fractures. Therefore ,it is necesary to estimate properly the decrease rate of injectivity for the reinjection scheme.

We conducted experimental studies of silica deposition in a porous medium using the Otake geothermal water for isothermal flow1), and developed a mathematical model to describe the silica deposition in a linear system2). In this paper, we have extended our model further into the radial coordinate which can predict distributions of silica deposit and permeability around the well, and the decrese in injectivity of the well.

MODEL

In developing a mathematical model of silica deposition around a well, it is assumed that (1)The fluid is non-compressible, (2)The fluid flow is isothermal,(3)The gravity accereration is neglected, (4)The reservoir is porous and radially symetric type with a homogeneous thickness, (5)The effect of trace metals on the deposition is neglected, and (5)The waste water is reinjected at a constant flow rate from a well.

Continuity equation of fluid mass in radial coordinate is expressed as:

$$-\frac{1}{r}\frac{\partial(rv)}{\partial r} = 0 \qquad (1)$$

where velocity v is given by Darcy's law

$$v = -\frac{k}{\mu}\frac{\partial p}{\partial r} \qquad (2)$$

where p is the pressure, k is the permeability, μ is the fluid viscosity.

Conservation equation for silica is expressed as

$$\frac{\partial C}{\partial t} + \frac{v\partial C}{\varepsilon\partial r} = \frac{1}{r}\frac{\partial}{\partial r}\left(rD\frac{\partial C}{\partial r}\right) - \frac{(1-\varepsilon o)\rho m}{\varepsilon}\frac{\partial Qs}{\partial t} \qquad (3)$$

where C is the concentration of silica ,D is the diffusion coefficient, ε is the porosity(εo is initial value), ρ_m is the rock density, Qs is the specific deposit of silica defined by the ratio of the weight of silica scale to a unit weight of reservoir rock. When the silica scarcely deposits at the begining of reinjection, the diffusion term in Equation 3 seems to be effective. The time derivative in Equation 3 is not sensitive. Therefore, the diffusion and the time derivative terms can be neglected in the calculation.

The rate equation of silica deposition used in the former work2) explained well the experimental results when the aluminum beads were filled in the column. Other experiments using rock particles, however, showed rapid decrease in permeability of the column at early stages of the experiments, follwed by slow decrease. This fact can not be explained by the former model[2]. A similar phenomenon of injectivity decrease in reinjection wells at Hatchobaru was reported[3]. This characteristic caused by silica deposition should be considered in the rate equation which can be expressed as

$$\frac{\partial Qs}{\partial t} = \frac{\varepsilon}{(1-\varepsilon_o)\rho_m} \beta_1 AC(\beta_f - \beta_2 Qs)(1 + \beta_3 Qs) \quad (4)$$

$$\beta_f - \beta_2 Qs = 1 \qquad \text{if } \beta_f - \beta_2 Qs \leqq 1$$

where A is the surface area of the rock in contact with the fluid to a unit volume of the reservoir rock, β_1, β_2, β_3, β_f are the rate constants. The term $\beta_f - \beta_2 Qs$ is for the large rate of silica deposition at the begining of the injection. The values of $\beta_f - \beta_2 Qs$ will gradually decrease to a unit value as the silica deposit. Another term $1 + \beta_3 Qs$ explains the acceleration of the deposition rate as the silica deposits.

The porosity which decreases in the reservoir as the silica deposits is given by

$$\varepsilon = \varepsilon_o - \frac{(1-\varepsilon_o)\rho_m Qs}{(1-f_\sigma)\rho_s} \quad (5)$$

where ρ_s is the density of silica scale, f_σ is the secondary porosity of silica scale which represents the pore volume formed in the scale.

Kozeny-Stein equation is used to correlate the permeability and the amount of silica scale[2].

Equations (1),(3) and (4) are numerically solved with equations (2),(5), and Kozeny-Stein equation under the initial and the boundary conditions:

Table 1. Parameters used for the calculation.

Well radius	r_w=0.1 m
Effective radius	r_e=100 m
Injection flow rate	Q=60 m^3/hr
Temperature of injected fluid	T=90°C
Silica concentration	Co=1 ppm
Reservoir depth	H=500 m
Reservoir thikness	h=10 m
Initial permeability	ko=2 darcy
Initial porosity	εo=0.005
Initial pressure	p_o=2 MPa
Density of rock	ρm=2720 kg/m3
Density of silica scale	ρs=2040 kg/m3
Rate constants	$\beta_1=1.26\times10^{-3}$ m/hr $\beta_2=5\times10^3$ $\beta_3=1.5\times10^3$ $\beta_f=1\times10^1$

initial conditions:

$t=0 \qquad p=p_o$
$\qquad\qquad C=0$

boundary conditions:

$t>0 \qquad r=r_w \qquad Q=\text{constant}$
$\qquad\qquad\qquad\qquad C=Co$
$\qquad\qquad r=r_e \qquad p=p_o$

where r_w is the well radius, r_e is the effective radius, Q is the volumetric flow rate, Co is the silica concentration in injected water, and p_o is the initial pressure of the reservoir.

CALCULATIONS

As an example, we calculate the case of injecting the Otake water at 90 C and at pH=8. The dissolved silica in the water is monomer type with a concentration of about 500 ppm which is super saturated by 180 ppm as amorphous silica, when calculating using a geothermometer . The amount of silica which can deposit in the reservoir was very small as compared with the degree of super saturation . Accordingly, the silica concentration Co in the calculation is given as low as 1 ppm.

We use the rate constants β_1, β_2, β_3, β_f determined by the experiments in which the Otake water supplied to the porous column consisting of the rock particles. Parameters used for the calculation are summarized in Table 1.

RESULTS AND DISCUSSION

Figure 1 shows the pressure distributions around a well from t= 100 to 380 days. The radial distance is represented in a dimensionless form r/rw on log axis. Pressure increases appreciably with time in the close vicinity of the well; within a radius of 50r_w(5 m). On the other hand,

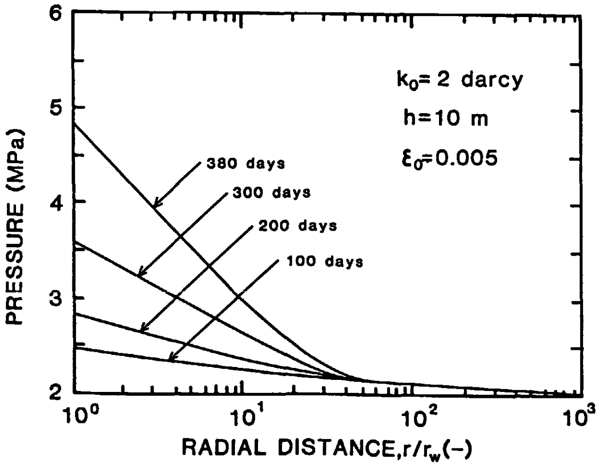

Figure 1. Pressure distributions around a well with time.

pressure gradients are almost unchanged at the distant places. Water level in the well reaches the wellhead after 380 days since the injection started.

In Figure 2, the relation between the specific deposit of silica and the distance from the well is shown. The amount of silica is almost constant within a radius of $10r_w$(1 m) from the well, and decreases rapidly with distasnce on the semi-log plot. As time passed, the deposition rate decreses because the effect of $\beta_f-\beta_2 Q_s$ is still larger in the rate equation than that of $1+\beta_3 Q_s$.

As is expected from the distributions of silica deposition in Figure 2, the dimensionless permeability, k/ko, at places near the well decreases quickly in early stages of the injection, followed by smaller decrease rates(Figure 3). A pronounced decrease in k/ko is observed in an area within a radius of $10r_w$, where k/ko reduces to 5 % of the initial value at t=380 days. The places beyond a radius 150rw retain the initial value of k/ko during the injection; the area where permeability decreased significantly due to the silica deposition is restricted only in the close vicinity of the reinjection well.

Figure 4 also illustrates the distributions of k/ko similar to Figure 3 except the initial porosity εo=0.05. A drastic reduction of k/ko can be seen in a very short period. The water level in a well reaches the wellhead at t=26 days which is very short compared with t=380 days in Figure 3. The lowest k/ko at t=26 days shows only 2 % of the initial value, but the places where k/ko reduced considerably are within a radius of 10rw(1 m). This is because that fluid velosity in the pore space decreases with an increase of the porosity.

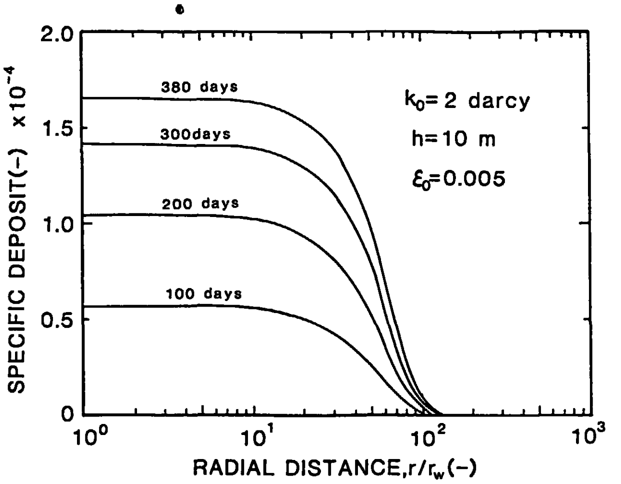

Figure 2. Distributions of specific deposit of silica around a well with time.

Consequently, the silica is transported a less distance resulting in a smaller range of silica deposition.

Figure 5 shows the decrease in the average permeability-thickness product kh of the well for four combinations of k_o and h, while the initial values $k_o h$ are given constant, 20 darcy-m. The decrease rate of kh with time reduces with an increase of the permeability. The calculations were stopped when the water level reached the well head for each case. The period varies from 0.5 year to 1.5 year for k_o=1 to 10 darcy. A larger k value under a constant porosity implies that the

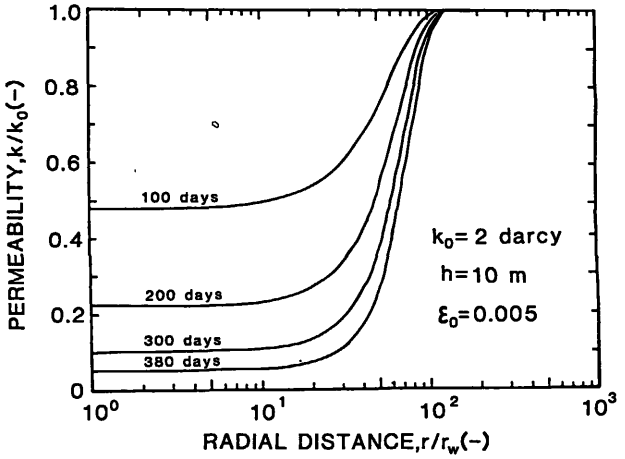

Figure 3. Decrease in permeability caused by silica deposition with time for εo= 0.005 .

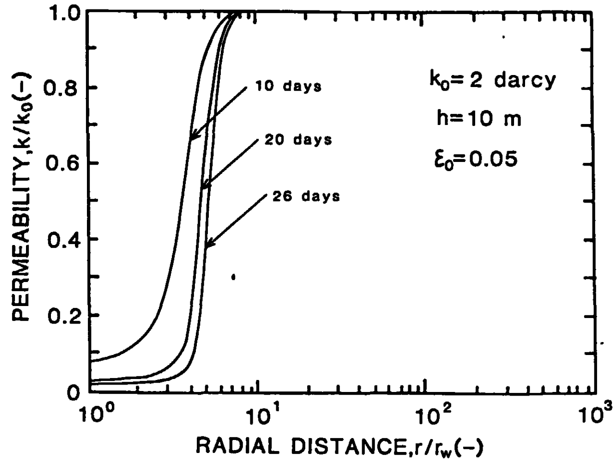

Figure 4. Decrease in permeability caused by silica deposition with time forεo= 0.05.

surface area of reservoir rock in contact with the water is smaller and that the flow path is more smooth. This results in the larger area of deposition and the smaller decrease rate of permeability. The well capacity has been commonly evaluated by permeability-thickness product from the analysis of well test data such as fall-off or build-up. However, the results in Figure 6 indicate the necessity to separate k and h for estimation of the injectivity decrease due to silica deposition.

CONCLUSIONS

1. A mathematical model is developed to estimate the reduction of injectivity of a reinjection well caused by the deposition of silica around the well for isothermal flow.
2. The rate equation of silica deposition involves the effect to express the rapid decrease in permeability during early stages of the injection followed by the small decrease rate.
3. The area where permeability reduced markedly due to silica deposition is restricted in a small range from the well.
4. Permeability and reservoir thickness should be separately evaluated to estimate the injectivity decrease with time and to predict the extent of the damaged area in permeability.

REFERENCES

1)Itoi,R.,Maekawa,H.,Fukuda,M.,Jinno,K.,Hatanaka,K.,Yokoyama,T.and Shimizu,S.,1984, Experimental Study on the SilicaDeposition in a Porous Medium, Geothermal Resources Council Transactions, vol.8,p 301- 304

2)Itoi,R.,Maekawa,H.,Tatsuta,K.,Fukuda,M.,Jinno,K.,Hatanaka,K.,Nozaki,S.,Yokoyama,T. and Shimizu,S.,1985, A Mathematical Model of Silica Deposition in a Porous Medium, Geothermal Resources Council Transactions, vol.9, p 337-340

3)Shimada,K.,Fujino,T.,Koga,A. and Horowatari,K.-,1985,Acid Hot Water Discharging from Geothermal Wells in the Hatchobaru Geothermal Fields, Chinetu, vol 22, no 4, p 276-292(in Japanese with English abstract)

4)Fournier,R.,1981,Application of Water Geochemistry to Geothermal Exploration and reservoir Engineering, Geothermal Systems, John Wiley & Sons

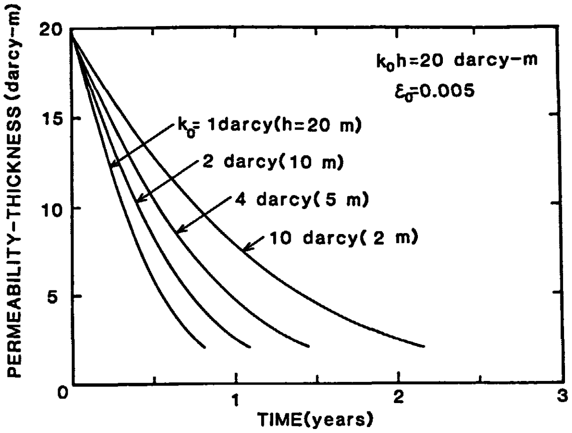

Figure 5. Decrease in average permeability-thickness products for a four combinations of permeability and formation thickness.