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Modelling of Chemical and Thermal Changes in Well PN-26. Palinpinon, Philippines

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ABSTRACT

Significant chloride changes in well PN-26 during its period of exploitation have been mainly attributed to reinjection fluid returns. Here fluid returns are modelled by a simple time-dependent production-reinjection lumped parameter model. Analytic solutions are derived for the cases of constant and variable production rates. The variable production rate model adequately described the chloride changes in well PN-26.

The early return of reinjection fluid has also resulted in a substantial decline in the measured temperature in the well. This change in temperature is modelled by coupling the mass balance model to a fracture flow model.The simple heat advection model satisfactorily represents the thermal decline observed in the well.

INTRODUCTION

Geochemical changes observed in production wells after more than three years of operation of the Palinpinon I power plant have been attributed to reinjection fluid returns. This return of reinjection (RI) fluid to the production area has been confirmed by changes in the production well chemistry, particularly the chloride concentration $[Cl]_p$, which has resulted in changes to the reinjection line chloride concentration $[Cl]_r$ (Fig. 1).

Harper and Jordan (1985) have reported that the properties of the production fluid depend on operating conditions, reinjection load, and the configuration of reinjection wells in service at any one time. Extensive chemical and radioactive tracer tests conducted in Palinpinon have further established the communication of individual RI wells with the production sector (Urbino et al, 1986). The most serious problem associated with an increase in the rate of RI fluid returning to the production were:

1) decline in the production temperature,
2) permeability reduction at the reinjection and production wells arising from mineral deposition,
3) silica breakthrough.

The term "silica breakthrough" is used to describe the situation when the silica concentrations in the produced fluid are no longer governed by quartz solubility (Harper 1986).

Production wells OK-7, PN-26, PN-28 and PN-29D have exhibited an increasing chloride concentration as shown in Figure 1. Well PN-26 in particular, was strongly affected by RI fluids after discharging a cumulative mass of 3.0 million tonnes from the production zone. Despite the large increase in production chloride concentrations, reservoir silica concentrations $[SiO_2]_{res}$ for well PN-26 remained constant for the first two years of exploitation. Silica breakthrough in PN-26 was only observed in the succeeding years.

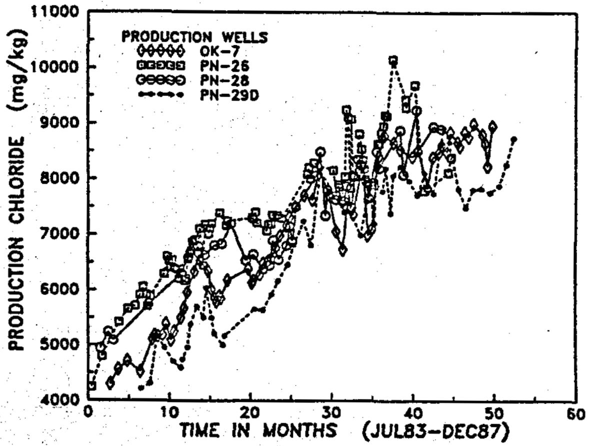

Fig. 1 Production Chloride Vs. Time.

Well PN-26 has also shown a substantial temperature decrease of approximately 38°C, measured at the main production zone (1600 m CHF) from its average baseline temperature of 280°C (Fig. 2) and has shown no sign of recovery to date. Amistoso and Torrejos (1986) have also reported that the thermal decline in PN-26 has been accompanied by a mass flow decline (see Fig. 3). It was postulated that this resulted from permeability damage due to mineral deposition in the immediate vicinity of the wellbore.

Reservoir sulphate concentration $[SO_4]_{res}$ for well PN-26 has also remained essentially constant during its production monitoring period (Harper and Jordan, 1985). These authors suggest that this results from the removal of sulphate bearing minerals from the mixed reservoir and reinjected fluid by deposition.

An estimate of the effects on the production sector of RI fluid returns have been previously made using chloride mass balance calculations (Menzies, 1985; Harper and Jordan, 1985; Brodie, 1986). These authors considered steady state models only. Here, a time-dependent model is derived to describe the chloride changes in well PN-26. Fluid returns are modelled by a simple production-reinjection lumped-parameter model which can be solved analytically for the cases of either a constant or a variable production rate.

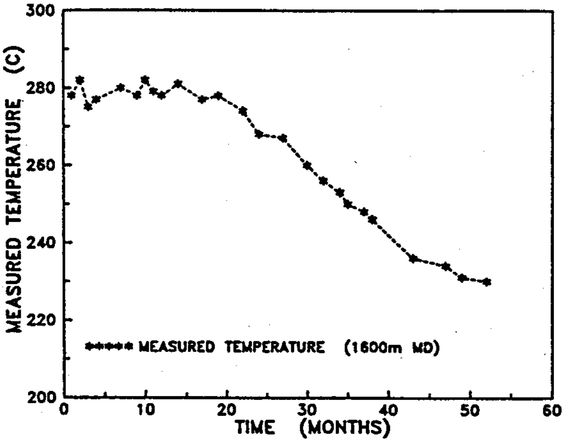

Fig. 2 Well PN-26 Measured Temperature Vs. Time.

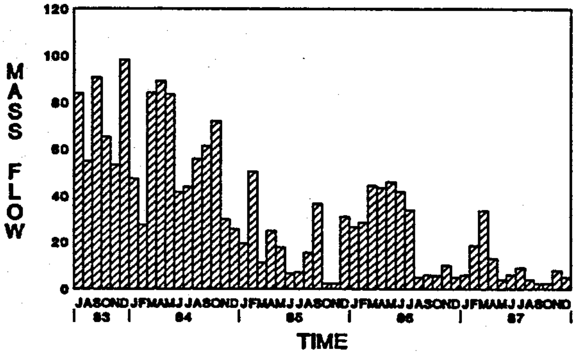

Fig. 3 Well PN-26 Discharge History (kg/s).

The temperature decline observed in PN-26 is also modelled by coupling the chloride mass balance model to a one-dimensional fracture flow model. Various models have been considered for the fractured zone connecting the reinjection and production wells. The simplest model presented here assumes that heat is transported primarily by advection along the fractured zone and that diffusion of heat from the fractured zone to the less permeable surrounding rock is small. Other more complex models allowing for lateral diffusion of heat have been studied but the results produced are not significantly better than those produced by the present simple model.

LUMPED PARAMETER MODEL OF CHLORIDE CONCENTRATION IN A PRODUCTION-REINJECTION SYSTEM

The simplified production-reinjection model is illustrated in Figure 4. This consists of a production sector, reinjection sector and a recharge sector. The basic assumptions used in the model are:

(i) There is no change in the mass of fluid stored in each of the production and reinjection sectors.

(ii) The chloride concentration $[Cl]_{rec}$ of the recharge flow RC is constant during the period of exploitation.

(iii) The production enthalpy remains constant.

(iv) The fraction of RI fluid returning to the production area is constant.

(v) The time delay of the chloride concentration returning $[Cl]_{ret}$ is assumed to be small.

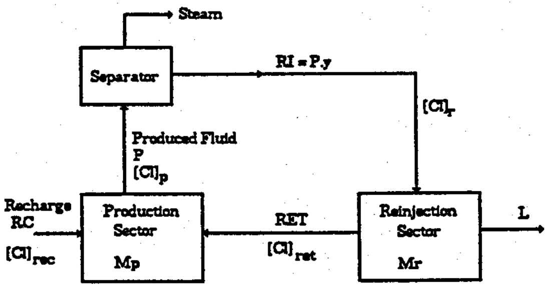

Fig. 4 Production-Reinjection Lumped Parameter Model.

These assumptions are valid for short term reservoir behaviour while the thermodynamic state of the reservoir is changing slowly. This is the case for Palinpinon as the pressure and temperature have both declined slowly so far. In fact the production enthalpy has declined but the corresponding change in the fraction of fluid reinjected is small and therefore the error introduced by (iii) is small. This assumption allows the model equations for the chloride concentration and temperature to be decoupled. The approximation (v) that the time delay in the returning fluid is negligible is reasonable as tracer returns occur within times ranging from a few days up to one or two months whereas temperature changes only occur after 20 months.

A chloride mass balance for the production sector gives

$$\frac{d}{dt} M_p [Cl]_p = RC\,[Cl]_{rec} + RET\,[Cl]_{ret} - P\,[Cl]_p \qquad (1)$$

where M_p is the mass of fluid in the production area, RC is the recharge flow to production, RET is the flow of RI fluid back to production and P is the flow of produced fluid.

The symbols $[Cl]_p$, $[Cl]_{rec}$ and $[Cl]_{ret}$ refer to the chloride concentration of the production, recharge and returning fluid respectively.

Assumption (i) means that M_p is approximately constant and a total mass balance for the production sector gives

$$RC + RET - P = 0 \quad .$$

Then (1) reduces to

$$\frac{d[Cl]_p}{dt} = \frac{P}{M_p}\left\{ (1-F)\,[Cl]_{rec} + F[Cl]_{ret} - [Cl]_p \right\} \qquad (2)$$

where

$$F = RET / P$$

is the fraction of the RI fluid in the produced fluid. Similarly, a chloride mass balance for the reinjection sector gives

$$\frac{d}{dt} M_r\,[Cl]_{ret} = y\,P\,[Cl]_r - L\,[Cl]_{ret} - RET\,[Cl]_{ret} \qquad (3)$$

where y is the water fraction from the separator, M_r is the mass of fluid in the reinjection area, $[Cl]_r$ is the reinjection line chloride concentration and L is the flow of RI fluid leaving the reinjection sector. But mass conservation gives $y\,P = RET + L$, therefore equation (3) becomes

$$\frac{d[Cl]_{ret}}{dt} = \frac{P}{M_r}\left\{[Cl]_p - y\,P\,[Cl]_{ret}\right\} . \tag{4}$$

ANALYTIC SOLUTION FOR A CONSTANT PRODUCTION RATE

The two unknowns in (2) and (4) are $X = [Cl]_p$ the production chloride concentration and $Z = [Cl]_{ret}$ the chloride concentration returning from the reinjection sector to the production sector. For a constant production rate P, (2) becomes

$$\frac{dX}{dt} = \frac{P}{M_p}\,[A + FZ - X] , \tag{5}$$

where $A = (1 - F)\,[Cl]_{rec}$ and (4) becomes

$$\frac{dZ}{dt} = \frac{P}{M_r}\,[X - yZ] . \tag{6}$$

In these equations the production rate P is known, the water fraction y from the separator is known but the other parameters M_p, M_r, $[Cl]_{rec}$ and F are not known and must be selected by calibrating the model with field data.

These two coupled linear ordinary differential equations can easily be solved using standard techniques to obtain

$$X(t) = C_1\exp(\lambda_1 t) + C_2\exp(\lambda_2 t) + X_\infty \tag{7}$$

and

$$Z(t) = b_1C_1\exp(\lambda_1 t) + b_2C_2\exp(\lambda_2 t) + Z_\infty \tag{8}$$

where X_∞ and Z_∞ are the steady state solutions reached after a long time and are given by

$$X_\infty = \frac{yA}{y - F} , \quad Z_\infty = \frac{A}{y - F} .$$

The coefficients b_1 and b_2 are given by

$$b_j = \frac{1}{F}\left[\frac{M_p\lambda_j}{P} + 1\right] , \; j = 1,2 .$$

Here λ_1 and λ_2 are the two roots of the quadratic equation

$$M_pM_r\lambda^2 + (M_p\,y + M_r)\,P\,\lambda + (y - F)\,P^2 = 0 . \tag{9}$$

The constants C_1 and C_2 are evaluated from the initial conditions given

$$X(0) = X_0$$
$$Z(0) = Z_0.$$

Therefore, it follows that

$$C_1 = \frac{1}{\lambda_1 - \lambda_2}\left[a\,(FZ_0 - X_0 + A) - \lambda_2(X_0 - X_\infty)\right] \tag{10}$$

and

$$C_2 = \frac{1}{\lambda_2 - \lambda_1}\left[a\,(FZ_0 - X_0 + A) - \lambda_1(X_0 - X_\infty)\right] . \tag{11}$$

The coefficient a is defined by $a = P / M_p$.

The steady state solution for equation (5) gives the long term production chloride concentration. This can be obtained by rearrangement as

$$X_\infty = \frac{(1 - F)\,[Cl]_{rec}}{(1 - f)} . \tag{12}$$

Here $f = RET / RI$ = fraction of the RI fluid returning. Also since $RI = y\,P$ and $F = RET / P$, then

$$f = F / y . \tag{13}$$

VARIABLE FLOW RATE

Here a variable production rate is approximated by a piecewise constant function and then the analytic solution derived above can be used in each of the intervals (t_i, t_{i+1}) as shown in Figure 5 below.

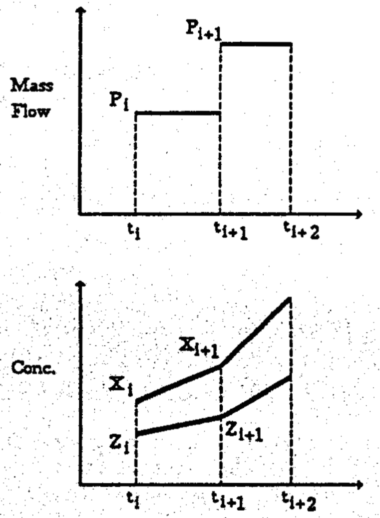

Fig. 5 Step Function Increase in Mass Flow.

For t in the interval $t_i < t < t_{i+1}$ the solutions can be written as

$$X(t) = C_{1i}\exp\lambda_{1i}(t - t_i) + C_2\exp\lambda_{2i}(t - t_i) + X_\infty \tag{14}$$

and

$$Z(t) = b_{1i}C_{1i}\exp\lambda_{1i}(t - t_i) + b_{2i}C_{2i}\exp\lambda_{2i}(t - t_i) + Z_\infty . \tag{15}$$

Here b_{1i} and b_{2i} are defined by

$$b_{ji} = \frac{1}{F}\left[\frac{M_p\lambda_{ji}}{P_i} + 1\right], j = 1,2.$$

When $t = t_i$, equations (14) and (15) reduce to

$$X_i = C_{1i} + C_{2i} + X_\infty \qquad (16)$$

and

$$Z_i = b_{1i}C_{1i} + b_{2i}C_{2i} + Z_\infty. \qquad (17)$$

Solving for the constants in equations (16) and (17) gives

$$C_{1i} = \frac{1}{\lambda_{1i} - \lambda_{2i}}\,[G_i - \lambda_{2i}(X_i - X_\infty)] \qquad (18)$$

and

$$C_{2i} = \frac{1}{\lambda_{2i} - \lambda_{1i}}\,[G_i - \lambda_{1i}(X_i - X_\infty)] \qquad (19)$$

where $G_i = a_i(FZ_i - X_i + A)$

and λ_{1i} and λ_{2i} are evaluated from the corresponding version of equation (9) and $a_i = P_i / M_p$.

Therefore when $t = t_{i+1}$

$$X_{i+1} = C_{1i}\exp \lambda_{1i}\,\Delta t_i + C_{2i}\exp \lambda_{2i}\,\Delta t_i + X_\infty \qquad (20)$$

where $\Delta t_i = t_{i+1} - t_i$, and

$$Z_{i+1} = b_{1i}C_{1i}\exp \lambda_{1i}\,\Delta t_i + b_{2i}C_{2i}\exp \lambda_{2i}\,\Delta t_i + Z_\infty. \qquad (21)$$

Then (18) – (21) provide a recurrence relationship between X_i, Z_i and X_{i+1}, Z_{i+1} which can be used to solve the problem beginning with known initial values for X_0, Z_0.

CHLORIDE MODELLING RESULTS

The analytic solutions for the two cases of firstly a constant and secondly a variable production rate derived above were used to match the observed changes in chloride concentration in well PN - 26. The average enthalpy of the produced fluid has remained essentially constant and a water fraction y of 0.65 was assumed which approximates the Palinpinon plant operating conditions. The model parameters used are listed in Table 1.

Table 1. Model Data used to Match PN-26 Production

Baseline Chloride Recharge, $[\mathrm{Cl}]_{rec}$ = 4000 – 4500 mg/kg

Initial Production Chloride, X_0 = 4000 mg/kg

Initial RI Chloride Returning, Z_0 = 6000 mg/kg

The recharge chloride was obtained from pre-exploitation chemistry data of the production area reported by Jordan (1982). An initial production chloride concentration of 4000 mg/kg was assumed which approximates the chloride concentration in PN-26 at the start of exploitation. The initial RI chloride concentration returning was then evaluated from the amount of water separated at the well head and the initial production chloride concentration.

For the constant production rate model, an average mass flow of 50 kg/s was used. The parameters M_p and M_r have been lumped into a single parameter τ (i.e. $\tau = M_p / M_r$). As an initial approximation, it was also assumed that M_p is equal to M_r ($\tau = 1.0$).

The two parameters M_p and fraction f were then adjusted to match the observed data given the initial model data from Table 1. After several trials, M_p = 4.0E08 kg was found to give results approximating the observed trend of increasing chloride concentration. The results of the model for different values of f are presented in Figure 6. The model results did not give a good fit to the observed chloride changes. However the results show that a value of f greater than 0.80 is required to match the data.

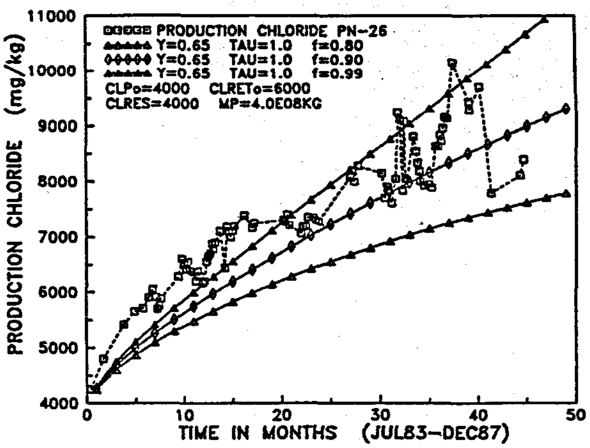

Fig. 6 Production Chloride Vs. Time.

For a range of f (0.80 – 0.95) the initial production chloride concentration and the corresponding RI chloride concentration returning were then slightly increased in an attempt to improve the match to the early data. The simulated results for a range of f are shown in Figure 7. The fit obtained to the early part of the observed data was slightly improved but it was no better at later times.

To fit the late time data, the effect of changing τ (hence M_p) was also tested for an f value of 0.80. The model results are given in Figure 8. Once again, there is not very good agreement between the observed and model results. Further experimentation showed that decreasing the value of τ improves the fit at later times but not at early times.

Since the match to the observed data was not quite satisfactory for the constant production rate model, the variable production rate was also applied. The results of the model for the approximate production history of PN-26 (Figure 3) using the initial model parameters in Table 1 and M_p = 4.0 E08 kg are presented in Figure 9. The model using an f value of 0.90 gave a good fit to the observed data.

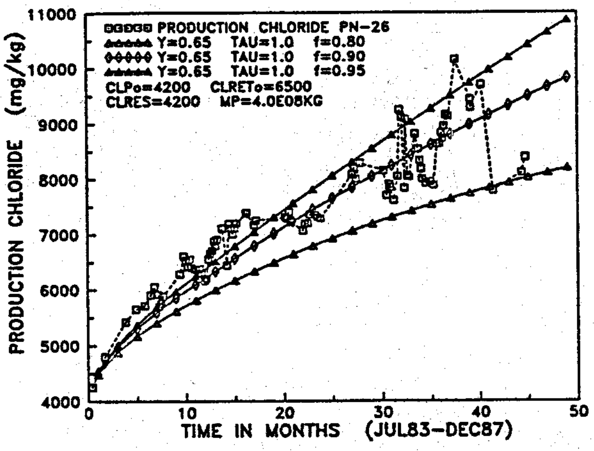

Fig. 7 Production Chloride Vs. Time.

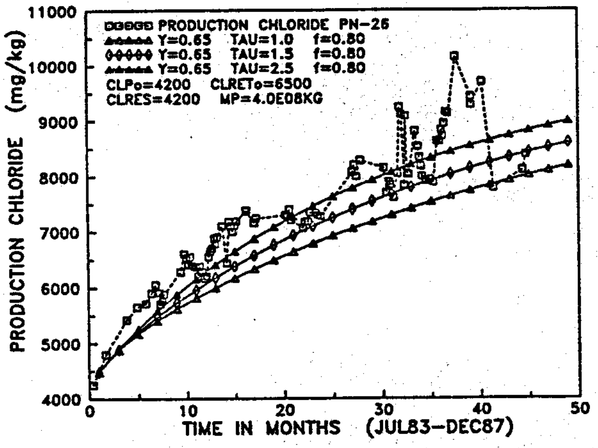

Fig. 8 Production Chloride Vs. Time.

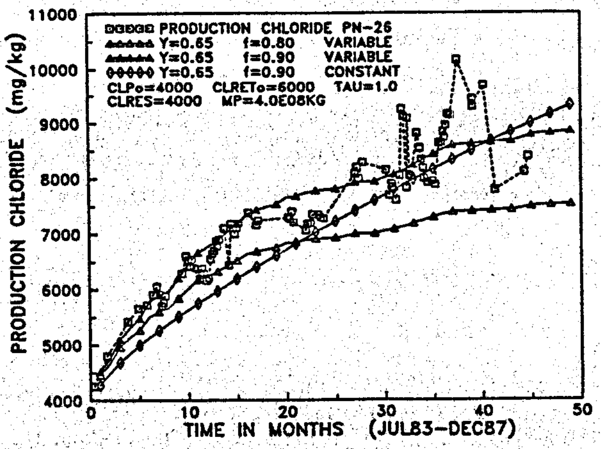

Fig. 9 Production Chloride Vs. Time.

The simulated results for both the variable and constant production rate models for f = 0.90 are also shown in Figure 9. The results in the figure show that the variable production rate model accurately describes the observed changes in PN-26. The average fraction F of the RI fluid contibuting to the produced fluid is calculated as 0.58 and the maximum production chloride predicted is approximately 1300 mg/kg.

A SIMPLE MODEL OF THERMAL DECLINE

The temperature decline observed in well PN-26 was modelled by coupling the mass balance model to a one dimensional fractured zone model. An energy balance around the production block (see Figure 4) gives

$$V_p\,[(1-\phi)\rho_r\,C_r + \phi\rho_p\,C_p]\,\frac{dT_p}{dt} = -P\,C_pT_p + \mathrm{REC}\,C_{rec}\,T_{rec} + \mathrm{RET}\;C_{ret}\;T_{ret}\,(t) \qquad (22)$$

where T_p, T_{rec}, T_{ret} are the temperatures of the production, recharge and returning fluid respectively,

V_p is the total volume of the production sector,

ϕ is the porosity and

ρ_r and C_r are the density and specific heat of the rock matrix in the production sector.

Also C_p, C_{rec}, and C_{ret} are the heat capacities of the production, recharge and returning fluids respectively. These are assumed constant and correspond to the initial reservoir temperature of 280°C. The recharge temperature T_{rec} is also assumed constant. The temperature of the returning fluid T_{ret} is a function of time determined by the mathematical model of the fractured zone connecting the reinjection and production sectors.

The given initial conditions are

$$T_p\,(0) = T_0$$

and

$$T_{rec}(0) = T_0$$

where T_0 is the initial reservoir temperature. It is convenient to use T_0 as a base temperature and define

$$\theta_p = T_p - T_0$$

and

$$\theta_{ret} = T_{ret} - T_0.$$

Then (22) becomes

$$M_p\,(1+\beta)\,\frac{d\theta_p}{dt} = -P\,\theta_p + \mathrm{RET}\,\theta_{ret}\,(t) \qquad (23)$$

and the transformed initial condition is

$$\theta_p(0) = 0\ .$$

Here the relationships

$$M_p = V_p\,\phi\,\rho_p$$

and

$$P = \mathrm{REC} + \mathrm{RET}.$$

have been used and

$$\beta = \frac{(1-\phi)\rho_rC_r}{\phi\rho_pC_p}. \qquad (24)$$

Rearranging terms and simplifying gives

$$\frac{d\theta_p}{dt} + \alpha\theta_p = \gamma\, \theta_{ret}\,(t) \tag{25}$$

where

$$\alpha = \frac{P}{[M_p\,(1+\beta)]}$$

and

$$\gamma \;=\; \frac{RET}{[M_p\,(1+\beta)]} \;=\; F\,\alpha \;= f\,y.$$

Since permeability in Palinpinon is primarily controlled by structures and well siting was based on structures, the main path for the return of RI fluid to the production area is provided by faults. Here, a one-dimensional fractured zone model is assumed.

A range of models of the fractured zone have been considered by the authors. The simple model described here envisages the zone as a highly fractured region containing many flow paths which allow the water to be in good thermal contact with the fractured rock. Single fracture models were also considered, some allowing for lateral diffusion of heat into the surrounding rock. The single fracture models all predict a first arrival of some thermal effects with the first arrival of reinjected water. The observed time lag where chemicals arrive in 1 to 2 months and thermal effects take 18 - 20 months can only be explained by a fractured zone which acts like a porous medium.

Then for one-dimensional steady flow, the equation for conservation of energy is

$$\left[(1-\phi_f)\,\rho_r\,C_r + \phi_f\,\rho_\ell C_\ell\right]\frac{\partial T_f}{\partial t} \;+$$

$$\rho_\ell\, C_\ell\, V\frac{\partial T_f}{\partial x} \;=\; K\frac{\partial^2 T_f}{\partial x^2} \tag{26}$$

where T_f is the temperature in the fractured zone, V is the Darcy velocity, ϕ_f is the porosity of the fractured zone and K is the thermal conductivity of the rock matrix. Both ρ_ℓ the density and C_ℓ the specific heat of the fluid moving in the fracture are as approximated as being independent of temperature.

Assuming the effect of heat conduction is negligible, (26) can be written in terms of $\theta_f = T_f - T_0$ as a simple advection model:

$$\frac{\partial\theta_f}{\partial t} + U\frac{\partial\theta_f}{\partial x} = 0\ . \tag{27}$$

Then the transformed initial and boundary conditions are

$$\theta_f(x,0) = 0$$

and

$$\theta_f\,(0,t) = \theta_1 = T_1 - T_0$$

where T_1 is the injection temperature. Here, U is the thermal front velocity given by

$$U = \rho_\ell\, C_\ell / [\,\phi_f \rho_\ell\, C_\ell + (1-\phi_f)\,\rho_r\, C_r\,]\ . \tag{28}$$

Then in equation (25)

$$\theta_{ret}\,(t) = \theta_f(L,t)$$

where L is the distance between the production and reinjection areas. The solutions for the production and returning fluid temperatures (Equations (25) and (27)) can be derived using Laplace Transforms.

In the Laplace transform domain, the temperature of the returning fluid can be expressed as

$$\bar{\theta}_{\;ret} = \frac{\theta_1}{s}\, e^{-sL/U} \tag{29}$$

where s is the transform parameter.

This gives a solution in the form of a step change in temperature and therefore the model will be called the step function model.

Similarly, from equation (25)

$$s\bar{\theta}_p + \alpha\bar{\theta}_p = \gamma\,\bar{\theta}_{ret}\ . \tag{30}$$

Substituting equation (29), the above equation reduces to

$$\bar{\theta}_p = \frac{\gamma\theta_1}{\alpha}\left[\frac{1}{s} - \frac{1}{s+\alpha}\right] e^{-\frac{s}{U}L} \tag{31}$$

Inverting (31), the solution becomes

$$T_p = T_0 \qquad\qquad \text{for } t < L\,/\,U \tag{32}$$

and

$$T_p \;=\; T_0 \;+\; \frac{\gamma}{\alpha}(T_1 - T_0)\left\{1 - \exp\left[-\alpha\,(t - \frac{L}{U})\right]\right\}$$

$$\text{for } t > L\,/\,U\,. \tag{33}$$

RESULTS FOR THE THERMAL DECLINE

From Figure 2, it can be seen that a fairly well defined thermal decline in PN-26 occurred after about 18 months. The distance between the production and reinjection areas is approximately 1km. Hence the thermal front velocity U can be easily evaluated as 56m/month. Since the chemical (chloride) front has been observed to have occurred in one or two months after production, the effective porosity ϕ_f for the fractured zone can be determined using

$$U\,/\,V = \phi_f\,\rho_\ell\,C_\ell\,/\,[\,\phi_f\,\rho_\ell\,C_\ell + (1-\phi_f)\,\rho_r\,C_r\,] \tag{34}$$

Assuming $\rho_r = 2500\ kg/m^3$, $C_r = 1.0\ kJ/kg\ .\ {}^\circ K$, $\rho_\ell = 751\ kg/m^3$ and $C_\ell = 5{,}26\ kJ/kg\ .\ {}^\circ K$ then from (34), the effective porosity is found to be 7.0%.

The parameters used in matching the temperature decline in PN-26 are listed in Table 2. An initial M_p of 4.0E08 kg and fraction of 0.90 were used, based on the chloride modelling results. A constant injection temperature of 165°C was also assumed.

Using the solution (equations 32 and 33) derived for the production temperature, the parameter β was then varied to match the temperature decline. The model results for different values of β are presented in Figure 10. The results obtained showed that β of 8.5 gave a good fit to the observed data.

Table 2. Model Data Used to Match the Thermal Decline in PN-26.

Thermal front velocity U = 56 m/month
Fraction f = 0.90
Reservoir temperature T_0 = 280°C
Injection temperature T_1 = 165°C
Production rate P = 50 kg/s
Factor β = 8.50

The effective porosity ϕ of the production block can then be calculated using the equation (24). This was found to be 7.0%, similar to the fracture porosity previously obtained.

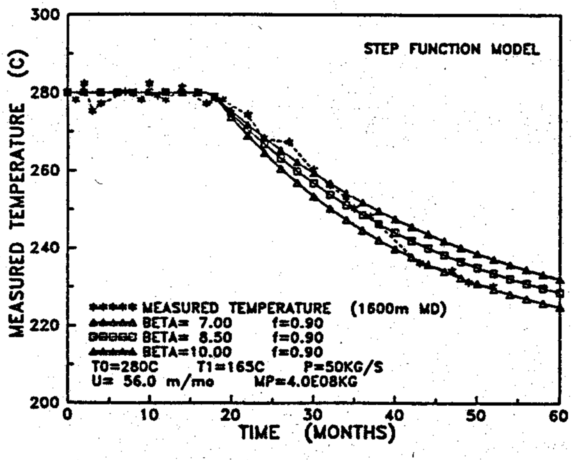

Fig. 10 Measured Temperature Vs. Time.

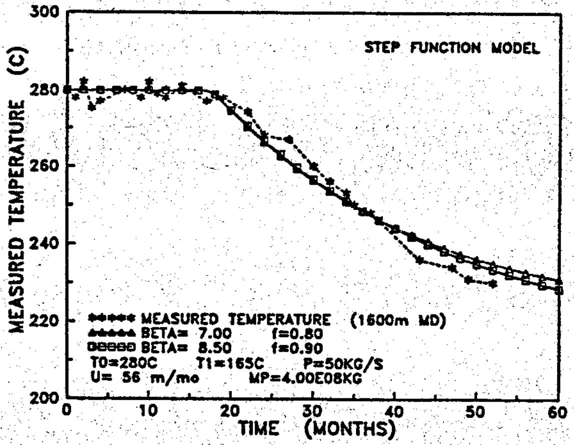

Fig. 11 Measured Temperature Vs. Time.

A value for f, the fraction of RI fluid returning, of 0.80 was also tested using the other model data from Table 2.

The results obtained did not give a better fit. The factor β was then decreased to improve the match and the results are shown in Figure 11. A fairly good fit was also obtained with β of 7.0 and f of 0.80. A further reduction in the factor f to 0.70 did not warrant extensive testing since the profile obtained was a significantly worse fit to the data than f = 0.80. Therefore, a minimum value of f = 0.80 was again derived which support the results obtained from chloride modelling. From the range of factor β (7.0 - 8.50) an effective porosity of 7.0 - 8.0% for the production sector can be calculated.

The sensitivity of changing M_p from the initial model value in Table 2, was also tested and the results are presented in Figure 12. Significant variation from the previously best fit was obtained.

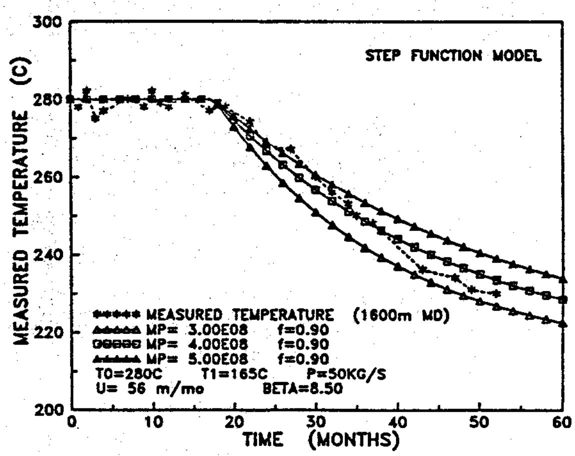

Fig. 12 Measured Temperature Vs. Time.

The simple heat advection model (27) gave a good approximation to the measured data with the assumption of negligible heat transport by conduction.

A detailed investigation of the significance of lateral conduction was made by allowing some diffusion of heat from the fractured zone into the adjacent rock matrix. The results from the fracture flow model derived did not improve the good match obtained from the simple heat advection model. The match for the more complex model gave very small values of heat lost to the country rock.

The small conductive heat effect can also be attributed to the preferential permeability (anisotropy) in a single direction observed in Palinpinon. This means that there is high permeability along the major axis of mapped faults and much less permeability perpendicular to it.

CONCLUSIONS

Production chloride changes observed in well PN-26 were modelled by a simple time-dependent production -reinjection lumped parameter model. The variable production rate model describes the increase in chloride concentration in PN-26 very well compared with the constant production rate model. The model shows a very strong return of reinjected fluid to the production sector. The fraction F of reinjection fluid in the produced fluid obtained from the model is approximately 50% and a maximum production chloride concentration of approximately 1300mg/kg is predicted.

A fairly well defined thermal decline has occured in well PN-26 after more than three years of utilisation. This decline was modelled by coupling the chloride mass balance model to a simple fractured zone model. The temperature decline was satisfactorily represented by the simple heat advection model which gave an effective porosity for the production block and the fractured zone of 7.0 - 8.0%.

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