Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

A METHOD FOR ESTIMATING REINJECTED WATER RETURNS USING NATURAL TRACERS

Ryuichi Itoi, Kenjiro Yoshioka, Toshiaki Tanaka and Michihiro Fukuda
Department of Earth Resources Engineering, Graduate School of Engineering, Kyushu University,
6-10-1, Hakozaki, Higashi-ku, Fukuoka, JAPAN 812-8581

Key Words: lumped parameter model, chemical monitoring, reinjection.

ABSTRACT

A lumped parameter model for the masses of fluid and natural tracers (chloride (Cl) and nitrogen gas (N_2)) is developed for a reservoir system consisting of reinjection and production zones, and a shallow aquifer. Fractions of reinjected water as well as shallow aquifer water in produced fluids are estimated with this model. The method employs on-line analysis algorithm and estimates optimum values of the fractions at each moment when Cl and N_2 concentrations of produced fluids are measured. Field data for more than ten years from Nigorikawa, Japan, are analyzed with the present method. Estimated fractions for the reinjected fluid indicate a relatively constant of about 0.5 during the first 1500 days followed by a steady decrease until 3200 days. This decrease is probably due to reinjecting water outside of the reservoir system. Reservoir volumes of the reinjection zone and the production zone are also estimated to be 0.6×10^8 and 0.7×10^8 m^3, respectively.

1. INTRODUCTION

Reinjecting waste water back into the formation has been widely performed at many geothermal fields of the water dominated type. This operation has several advantages over discharging the separated water into nearby rivers or lakes. They are, for example: 1) moderating reservoir pressure decrease due to exploitation, 2) avoiding chemical and thermal impacts on surface water environment. On the other hand, return of heat depleted reinjected water to a production zone will eventually cool down the whole reservoir. Timing and degree of cooling depends on permeability of fractures between reinjection and production zones and the magnitude of return of reinjected water to the production zone. This results in a decrease in steam output of production wells. Thus, estimating a fraction of reinjected water in the produced fluids is an important task for reservoir management.

Detecting the mixing of reinjected water into produced fluids can be realized through tracer tests. Results obtained from the tests generally provide information to evaluate a degree of connectivity between reinjection and production wells. Alternative methods for detecting influences of mixing of reinjected water are chemical monitoring for both reinjection and production wells. Chemicals such as chloride remain in the water phase and are conservative elements, and thus enriched in the separated water to be reinejcted. For this reason, chloride is the most appropriate chemical element for natural tracer. Chemical monitoring has been conducted at various fields (Koga et al., 1988; Malate and O'Sullivan, 1991; Kennedy et al., 1999). The results of chemical monitoring allow quantitative and qualitative evaluation of reinjected water returns not only the case for well by well but also for field wide scale.

However, estimating the fraction of reinjected water in the produced fluids requires mathematical modeling of reservoir systems. Malate and O'Sullivan (1991) developed a model for evaluating a fraction of reinjected water in the produced fluids, using a simple lumped parameter model in terms of Cl mass. They analyzed the data from Palinpinon, Philippine, using an analytical solution, then estimated the fraction of reinjected water return by trial and error. Itoi et al. (1998) estimated the fractions with an online analysis method using the same data as Malate and O'Sullivan (1991). Sullera Ma and Horne (1999) also analyzed the data of Cl monitoring from Palinpinon with the method of multiple regression techniques and predicted Cl concentration of wells. Kennedy et al. (1999) conducted a quantitative analysis for estimating volume fractions of reinjected fluid in produced fluids using chemical monitoring data on Cl, stable isotopic component of water along with noble gases at Dixie Valley, USA.

We have developed a lumped parameter reservoir model that consists of reinjection and production zones, and a shallow aquifer. We applied an online analysis method using Kalman filtering (Brown, 1983) to this model for estimating fractions of reinjected water and shallow aquifer water in produced fluids. The data from the Mori geothermal field, Japan, was analyzed with this method. Estimated fractions vary with time, which correlate well with the measured concentration changes of Cl and N_2 over time. Reservoir volumes for each zone are also estimated.

2. MORI GEOTHERMAL FIELD

The water dominated Mori geothermal field is located at the Nigorikawa Basin in southern Hokkaido, Japan (Figure 1). A geothermal power station with an installed capacity of 50MWe has been operated by Hokkaido Electric Power Company since 1982 (Sakagawa et al., 1994). The Nigorikawa Basin is geologically characterized as a caldera structure 3 km in diameter. This caldera is filled mainly with vent fill and post caldera intrusions. Fractures are intensively developed along these intrusions, and form main conduit for geothermal fluid. The caldera is underlain by pre-Tertiary formation consisting of limestone, slate, chart, and tuff (Yoshida and Sato, 1995).

Chemical monitoring of produced fluids has been conducted more than ten years since the start of operation. Distinctive changes with time in concentrations of chloride and nitrogen gas were detected, and this implies a return of reinjected water enriched with chloride to a production zone (Aoyama, et al., 1994). Geochemical studies on helium isotopes also suggested that there might be a quick inflow of meteoric water into the geothermal reservoir (Sato et al., 1992). A notable reservoir pressure decline was monitored during the early period of exploitation, which might have induced an inflow of shallow aquifer water (Aoyama, et al., 1994).

3. MATHEMATICAL FORMULATION

A schematic of reservoir model is shown in Figure 2. The model consists of production and reinjection zones, and a shallow aquifer. There is a recharge of hot fluid from a deep zone to the production zone, and a leak of reinjected water from the reinjection zone to outside the reservoir system. There is also a fluid inflow from the shallow aquifer into the production zone. A mathematical model was thus developed using the following assumptions: 1) no change in the masses of fluid stored in each of the production and reinjection zones, 2) chloride and nitrogen concentrations of the recharge fluid and the inflow fluid are constant during the period of exploitation, 3) no nitrogen is contained in the reinjected fluid, 4) volume fractions of the reinjected fluid and the inflow fluid flowing into the production zone are constant, 5) the time delay of the chloride concentration in the returning fluid is assumed to be small. Then, chloride and nitrogen mass balances for both production and reinjection zones are introduced in combination with fluid mass balances and yield a set of ordinary differential equations.

$$\frac{d[Cl]_p}{dt} = \frac{P}{M_p}\left\{(1 - F_1 - F_2)[Cl]_{rec} + F_1[Cl]_{ret} + F_2[Cl]_{inf} - [Cl]_p\right\} \quad (1)$$

$$\frac{d[N_2]_p}{dt} = \frac{P}{M_p}\left\{(1 - F_1 - F_2)[N_2]_{rec} + F_2[N_2]_{inf} - [N_2]_p\right\} \quad (2)$$

$$\frac{d[Cl]_{ret}}{dt} = \frac{P}{M_r}\left\{[Cl]_p - y[Cl]_{ret}\right\} \quad (3)$$

where F_1 is the fraction of reinjected fluid in the produced fluid (=RET/P, -), F_2 is the fraction of shallow aquifer water in the produced fluid (=INF/P, -), [Cl] is the chloride concentration (mg/kg), $[N_2]$ is the nitrogen concentration (mg/kg), P is the flow rate of production (kg/s), RET and INF are the flow rate of fluid returning from the reinjection zone and of shallow aquifer water inflow to the production zone (kg/s), y is the water fraction from the separator (-), M_p is the mass of fluid in the production zone (kg), M_r is the mass of fluid in the reinjection zone (kg), t is the time (sec). Subscripts *p* , *r* represent the production and reinjection zones, *ret* , *rec*, *inf* the returning fluid from the reinjection zone, the recharge of deep fluid, and the inflow of shallow aquifer water to the production zone, respectively.

Equations (1) to (3) correspond to the system equation to form Kalman filtering for online analysis (Brown, 1983). They can be expressed in a vector form as

$$\frac{d\mathbf{x}}{dt} = g(\mathbf{x}) + \mathbf{v} \quad (4)$$

where **x** is the state vector and expressed as

$$\mathbf{x} = \left[x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}\right]^T$$

where superscript T denotes transposition.

Components of **x** are; $x_1=[Cl]_p$, $x_2=[N_2]_p$, $x_3=[Cl]_{ret}$, $x_4=[Cl]_{rec}$, $x_5=[N_2]_{rec}$, $x_6=M_p$, $x_7=M_r$, $x_8=F_1$, $x_9=F_2$, $x_{10}=[Cl]_{inf}$, $x_{11}=[N_2]_{inf}$.

The function g(**x**) can be also expressed as

$$g(\mathbf{x}) = \left[g_1, g_2, g_3, g_4, g_5, g_6, g_7, g_8, g_9, g_{10}, g_{11}\right]^T$$

From the assumptions, $[Cl]_{rec}$, $[Cl]_{inf}$, $[N_2]_{rec}$, $[N_2]_{inf}$, M_p, M_r, F_1, F_2 are time invariant. Thus, the components of g(**x**) are expressed using those of **x** as

$$g_1 = \frac{P}{x_6}\left\{(1 - x_8 - x_9)x_4 + x_3 x_8 + x_9 x_{10} - x_1\right\}$$

$$g_2 = \frac{P}{x_6}\left\{(1 - x_8 - x_9)x_5 + x_9 x_{11} - x_2\right\}$$

$$g_3 = \frac{P}{x_7}(x_1 - y x_3)$$

$$g_4 = g_5 = g_6 = g_7 = g_8 = g_9 = g_{10} = g_{11} = 0$$

Equation (4) can be expressed in terms of time step as;

$$\mathbf{x}_{k+1} = g(\mathbf{x}_k)\Delta t + \mathbf{x}_k + \mathbf{v}_k \Delta t \quad (5)$$

where Δt is the time increment, subscript *k* denotes the time step.

A measurement equation is linearly correlated to the state vector and is expressed as

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{x}_k + \mathbf{w}_k \quad (6)$$

where **y** is the measurement vector, **H** is the measurement matrix, **w** is the measurement noise vector of zero-mean independent gaussian noise with known covariance **R**. As the chloride and nitrogen concentrations of the produced fluid is the only measurement among components of the state vector, **y** and **H** are given as,

$$\mathbf{y} = [y_1, y_2]^T, \quad \mathbf{H} = \begin{bmatrix} 1,0,0,0,0,0,0,0,0,0,0 \\ 0,1,0,0,0,0,0,0,0,0,0 \end{bmatrix}$$

where $y_1=[Cl]_p$, $y_2=[N_2]_p$.

A function, g(**x**), in the state equation (Eq.(5)) is nonlinear with respect to the state vector. Thus, it is linearized using Taylor's expansion (Brown, 1983) and expressed as

$$\mathbf{x}_{k+1} = \phi_k \mathbf{x}_k + \mathbf{D}_k + \mathbf{v}_k \quad (7)$$

where

$$\phi_k = 1 + \mathbf{J}(\hat{\mathbf{x}}_{k/k})\Delta t$$

$$\mathbf{D}_k = \{ g(\hat{\mathbf{x}}_{k/k}) - \mathbf{J}(\hat{\mathbf{x}}_{k/k})\hat{\mathbf{x}}_{k/k} \} \Delta t$$

$$\mathbf{v}_k = \mathbf{v}_k \Delta t$$

$$\mathbf{J}(\hat{\mathbf{x}}_{k/k}) = \left. \frac{\partial g(\mathbf{x})}{\partial \mathbf{x}} \right|_{\hat{\mathbf{x}}_{k/k}}$$

The hat(^) denotes the estimate. ϕ_k is the state transition matrix and $\mathbf{v}_k\Delta t$ is written as $\mathbf{v}_k$ which is the system noise vector of zero-mean independent gaussian noise with known covariance **Q**. Equation (7) indicates that the state vector at new time step, t_{k+1}, is correlated with that at time, t_k. Then, the Kalman filtering algorithm, using Equations (6) and (7), provides estimate of **x** at the time t_k, using the following set of equations when a new measurement of chloride and nitrogen concentration is made.

$$\hat{\mathbf{x}}_{k/k} = \hat{\mathbf{x}}_{k/k-1} + \mathbf{K}_k(\mathbf{y}_k - \mathbf{H}_k\hat{\mathbf{x}}_{k/k-1})$$

$$\hat{\mathbf{x}}_{k+1/k} = \phi_k \hat{\mathbf{x}}_{k/k}$$

$$\mathbf{K}_k = \mathbf{P}_{k/k-1}\mathbf{H}_k^{\mathrm{T}}[\mathbf{H}_k\mathbf{P}_{k/k-1}\mathbf{H}_k^{\mathrm{T}} + \mathbf{R}_k]^{-1}$$

$$\mathbf{P}_{k/k} = \mathbf{P}_{k/k-1} - \mathbf{K}_k\mathbf{H}_k\mathbf{P}_{k/k-1}$$

$$\mathbf{P}_{k+1/k} = \phi_k\mathbf{P}_{k/k}\phi_k^{\mathrm{T}} + \mathbf{Q}_k$$

where **K** is the Kalman gain matrix, **P** is the error covariance matrix of estimated state vector. Superscript -1 denotes inverse.

4. RESULTS AND DISCUSSIONS

The field data from the Nigorikawa geothermal field were analyzed for fractions of reinjected water return and shallow aquifer water inflow to the produced fluid. Flow rate history for both production and reinjection are shown in Figure 3. The flow rate of produced fluids first increased with time, but it turned to decrease after about 1000 days of production. Continuous decrease stopped and the flow rate jumped from 1000 t/h to 1500 t/h at about 2800 days. Then, it remained relatively constant. Reinjected water flow rate also varied with time, but it showed similar behavior to the production rate. This indicates that water fraction to the total flow rate were kept relatively constant at about 0.8 throughout the monitoring period. Flow rates are averaged during the period of concentration measurement, which conducted more frequently than flow rate measurement. Sharp drops in both flow rates correspond to the period when both production and reinjection stopped.

Figure 4 shows concentration changes with time for chloride (Cl) and nitrogen gas (N_2). Water fraction of produced fluid (y) is directly calculated using both flow rates at each time of flow measurement. Values of initial estimates for the components of the state vector other than those specified later were given as,

$x_1=[\mathrm{Cl}]_p=5500$ mg/kg, $x_2=[N_2]_p=100$ mg/kg, $x_3=[\mathrm{Cl}]_{ret}=7500$ mg/kg, $x_4=[\mathrm{Cl}]_{rec}=5500$ mg/kg, $x_5=[N_2]_p=100$ mg/kg, $x_6=M_p=5\mathrm{x}10^9$ kg, $x_7=M_r=6\mathrm{x}10^9$ kg, $x_{10}=[\mathrm{Cl}]_{inf}=600$ mg/kg, $x_{11}=[N_2]_{inf}=4.0$ mg/kg.

In the above data, initial concentrations of Cl and N_2 for recharge fluids are given as those for the produced fluids at the beginning of production. This is because initially produced fluids may have concentrations approximately equal to the deep recharge fluid. Those for shallow aquifer water are taken from the paper by Aoyama et al. (1994).

Initial estimates for F_1 and F_2 requires a priori information. These values could be in a range $0 \le F_1, F_2 \le 1.0$. However, a large value of F_2 cause a serious temperature drop in the production zone and thus impractical. Concentration of Cl in produced fluids with time increased in the early period as shown in Figure 3. This implies a return of reinjected water enriched with Cl to the production zone. Thus, relatively a large value for F_1 and a small value for F_2 are given as the initial estimates. Two cases were first analyzed as a base case by giving a different set for initial values of F_1 and F_2 . They are 1)$F_1=0.5$ and $F_2=0.2$, and 2)$F_1=0.7$ and $F_2=0.3$. During the analysis, values of other components, M_p, M_r, $[\mathrm{Cl}]_{rec}$, $[N_2]_{rec}$, $[\mathrm{Cl}]_{inf}$, $[N_2]_{inf}$ were assumed to be constant. No *a priori* information on the initial values of error covariance matrix, **P**, is available, but rather large values are given for the component of P_{nn} as they continuously decrease. The initial values of error covariance matrix P_{nn} (n=11) were given as $P_{11}=2.5\mathrm{x}10^4$, $P_{22}=100$, $P_{33}=2.5\mathrm{x}10^4$, $P_{88}=0.1$ and $P_{99}=0.05$. All other components were given to be 0. As for the matrix element of covariance, **Q**, roughly 5 % of the initial values of **x** are squared and set to be in time invariant as $Q_{11}=6.25\mathrm{x}10^4$, $Q_{22}=25$, $Q_{33}=6.25\mathrm{x}10^4$, $Q_{88}=9.0\mathrm{x}10^{-4}$, $Q_{99}=1.0\mathrm{x}10^{-4}$ with other components being equal to 0. Those of **R** were also given to be time invariant as $R_{11}=450$ and $R_{22}=10$ with all other components being equal to 0.

Figure 5 shows changes in estimated fraction of F_1 with time for the two cases above given different initial values for F_1 and F_2. There are apparent differences between two kinds of estimates (F_1) during the very early period up to about 300 days. Then, these estimates seem to be identical throughout the rest of the period. Estimated F_1 remains about 0.5 until 1500 days from the start of measurement. A rapid decrease, then, occurs and it continuously decreases down to 0.1 during the latter times. This rapid decreasing behavior indicates that a return of the reinjected water to the production zone is gradually moderated, probably due to a relocation of reinjection wells at relatively great distances from the production wells.

Figure 6 presents the estimated behavior of F_2 for the two cases above. Discrepancies between two kinds of estimates are also recognized during the very early period. Then, these estimates show decreasing behavior till reaching down to almost 0 at about 1200 days. They, in turn, steadily increase with time up to 0.1 and remain constant in the latter times. Estimated values of F_2 rarely exceed 0.1. A relatively sharp drop in reservoir pressure was measured at about 1500 days (Aoyama et al., 1994). This pressure drop is possibly due to a decrease of reinjected water return to the production zone, and subsequent increase in the rate of inflow from the shallow aquifer to the production zone. This can be a reason for an increase in F_2 during the period later than 1200 days in Figure 6.

Initial values of F_1 are given in a range of 0.2 to 0.8 while that of F_2 given to be constant at 0.2. Other conditions are same as those of the base case. Estimated values of F_1 with time show the same trend as in Figure 5. Discrepancies among estimated values of F_1 are only found during the early period. Then, estimated values show almost identical ones for the rest of the measurement period. This suggests that the effects of initial values of F_1 on estimating behavior of F_1 will be small as the number of concentration measurement increases.

Figures 7 and 8 show comparisons of measured concentrations of Cl and N_2 with predicted concentrations for the next measurement of these concentrations. A very good fit between two kinds of Cl concentrations is observed in Figure 7. Thus, estimated values of F_1 are good enough for predicting Cl concentration of the next measurement on time series. On the other hand, matches between those of N_2 are not as good as those of Cl (Figure 8). Relative differences between these two kinds of N_2 concentrations are 2.1 % on average whereas those of Cl are below 0.1%. Variation in the estimated fraction of F_1 does not affect on estimating F_2. This is because reinjected water does not contain any N_2 gas. Moreover an estimated fraction for F_1 is roughly five times larger than that for F_2 throughout the measurement period except the latter times. Thus, these may cause marked differences between the two kinds of N_2 concentrations shown in Figure 8.

Next, we examine the effects of the size of each zone on estimated fractions by giving different masses for reinjection and production zones. Three cases of M_p and M_r are given; 1)M_p=7.5x10^{10} kg and M_r=9.0x10^{10} kg, 2)M_p=1.5x10^{10} kg and M_r=1.8x10^{10} kg, 3)M_p=0.5x10^{10} kg and M_r=0.6x10^{10} kg. Other parameters are given as the same as those of the base case. Figure 9 shows the estimated values of F_1 for different masses of each zones. Parameters of M_L, M_M, and M_S correspond to the cases of 1, 2, and 3, respectively. Estimated values of F_1 for large reservoir masses show a continuous decrease with time for a whole period of measurement except the early period. They also exceed a value of 0.7 during the early period. On the other hand, the case 3 shows stable estimates up until 1500 days as explained above. Error covariances for estimated F_1 are compared in Figure 10. It is apparent that covariance for the case 3 shows the smallest values over the total period of measurement. Thus, fluid masses in the two zones for the case 3 seems to be most probable. Reservoir volumes are also calculated for these fluid masses by assuming the porosity to be 0.1 and the fluid density 813.7 kg/m^3 (for saturated water at 240 °C). The results are 0.6x10^8 m^3 and 0.7x10^8 m^3 for the production zone and reinjection zone, respectively.

5. CONCLUSIONS

Chemical monitoring data for chloride (Cl) and nitrogen gas (N_2) from the Mori geothermal field were analyzed for fractions of reinjected water return and shallow aquifer cool water inflow to the produced fluid. A lumped parameter model consisting of production zone, reinjection zone and a shallow aquifer was developed and used for analysis by incorporating an online analysis algorithm using Kalman filtering. Estimated fractions for the reinjected fluid indicate a relatively constant value of about 0.5 during the first 1500 days followed by a steady decrease until 3200 days. A rapid decline of estimated fraction for reinjected water return occurred when a sharp reservoir pressure drop was monitored. This may be because of the relocation of reinjection wells to moderate cooling due to excessive return of reinjected water to the production zone. On the other hand, fractions of shallow aquifer water were estimated below 0.1 throughout the measurement period. Reservoir volumes were estimated to be 0.6x10^8 and 0.7x10^8 m^3 for production zone and reinjection zone, respectively.

ACKNOWLEDGMENTS

Authors thank Dohnan Geothermal Energy Co. Ltd. and Japan Metals and Chemicals Co. Ltd. for their permission to use the data in this study.

REFERENCES

Aoyama, K., Tanaka, T., Kato, M. and Tominaga, T. (1994). A development of the lumped parameter model, designed in consideration of production fluid chemistry changes, *Abstr. of Annual Meeting Geothermal Research Society of Japan*, C22(in Japanese).

Brown, R.G. (1983). *Introduction to Random Signal Analysis and Kalman Filtering*, John Wiley & Sons, New York, 348pp.

Itoi, R., Imura, K., Tanaka, T. and Fukuda, M. (1998). An Estimating method of fraction of reinjected water to produced fluid on the basis of a lumped parameter model., *Proc. of the 19th Annual PNOC EDC Geothermal Conference*, pp.121-125.

Kennedy, B.M., Janik, C., Benoit, D. and Shuster, D.L. (1999). Natural geochemical tracers for injectate fluids at the Dixie Valley, *Proc. of 24th Workshop on Geothermal Reservoir Engineering*, *Stanford University*, pp.108-115

Koga, A., Umehara, S. and Hirowatari, K. (1988). Geochemical monitoring system of production well in Hatchobaru geothermal area., *International Symposium on Geothermal Energy, 1988, Kumamoto and Beppu*, pp.55-58.

Malate, R.C.M. and O'Sullivan, M.J. (1991). Modeling of chemical and thermal changes in Well PN-26 Palinpinon geothermal field, Philippines., *Geothermics*, Vol.20, No. 5/6, pp.291-318.

Sakagawa, Y., Takahashi, M., Hanano, M., Ishido, T. and Demboya, N. (1994). Numerical simulation of the Mori geothermal field, Japan, *Proc. Of 19th Workshop on Geothermal Reservoir Engineering, Stanford University*, pp.171-178.

Sato, K., Kasai, K. and Demboya, N. (1992). Isotopic geochemistry in the Mori geothermal field., *Abstr. of Annual Meeting Geothermal Research Society of Japan*, B7(in Japanese).

Sullera, Ma. M. and Horne, R.H. (1999). Inferring injection

Sullera, Ma. M. and Horne, R.H. (1999). Inferring injection returns from chloride monitoring data, *Proc. of 24th Workshop on Geothermal Reservoir Engineering, Stanford University*, pp.40-52.

Yoshida, Y. and Sato., K (1995). Isotopic composition of sulfate in the Nigorikawa geothermal system, southwest Hokkaido, Japan., *Proc.8th International Symp. on Water-Rock Interaction*, pp.227-230.

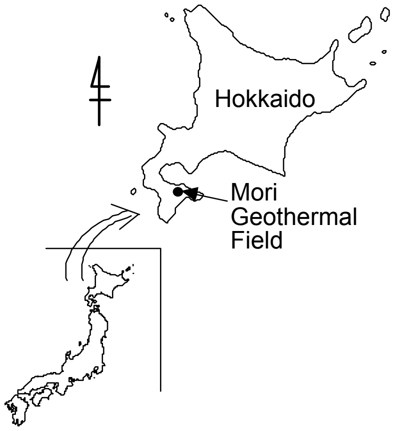

Figure 1. Location map of the Mori geothermal field.

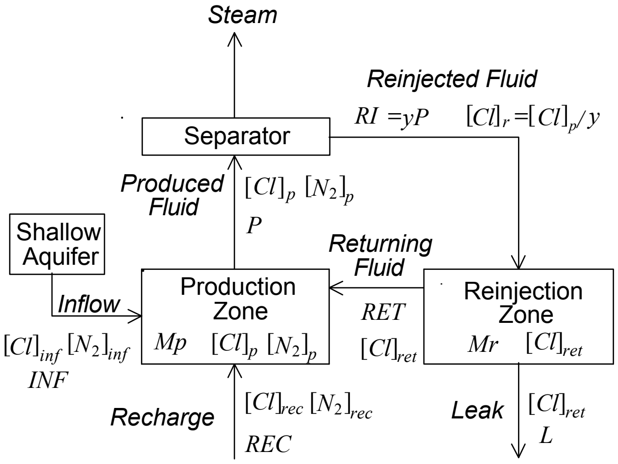

Figure 2. Lumped parameter model for a reservoir consisting production and reinjection zones, and shallow aquifer.

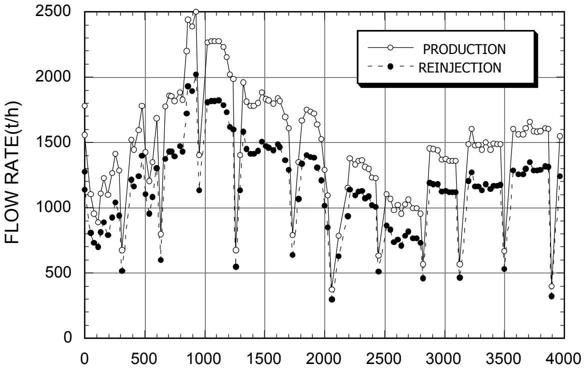

Figure 3. Flow rate history for production and reinjection at the Mori geothermal field.

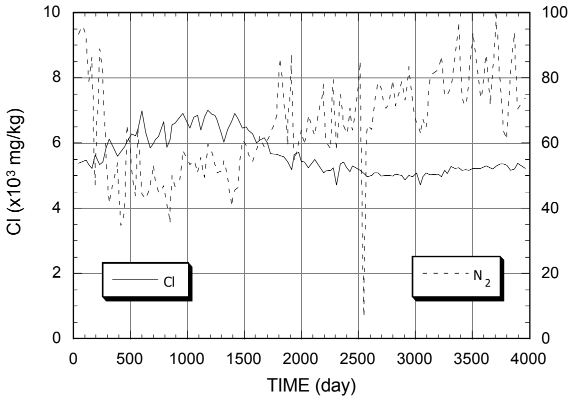

Figure 4. Measured concentrations of chloride(Cl) and nitrogen(N_2) of produced fluid.

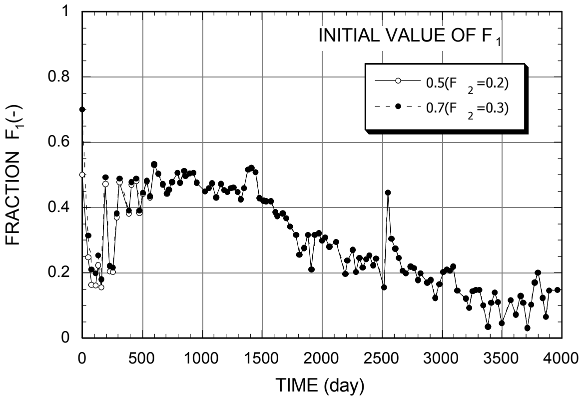

Figure 5. Comparison of estimated fraction, F_1, for a two combination of different initial values of F_1 and F_2.

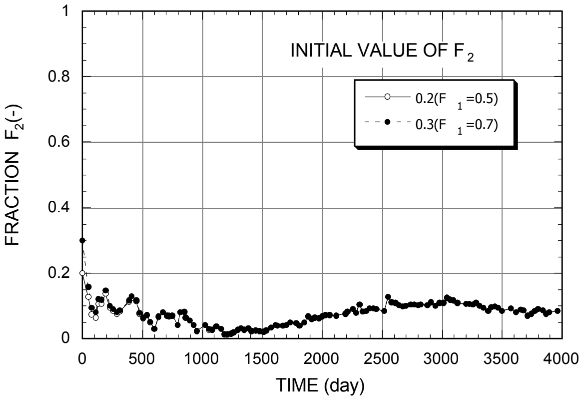

Figure 6. Comparison of estimated fraction, F_2, for a two combinations of initial values of F_1 and F_2.

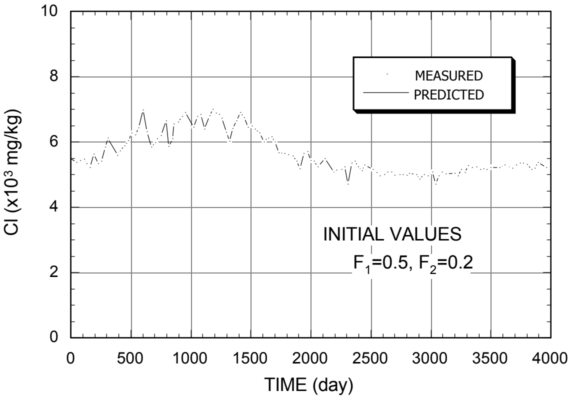

Figure 7. Comparison of measured and predicted Cl concentrations.

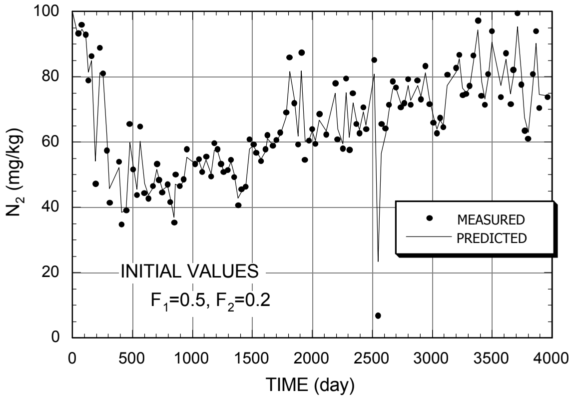

Figure 8. Comparison of measured and predicted N_2 concentrations.

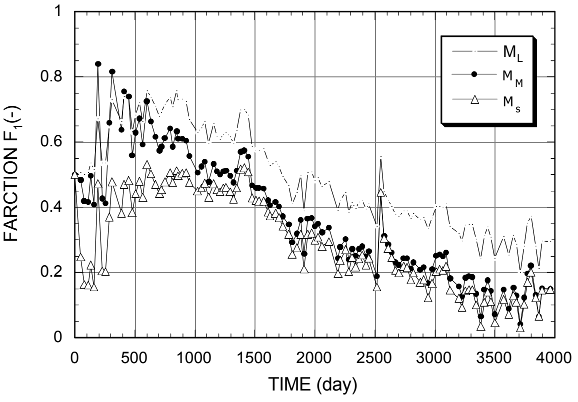

Figure 9. Effects of masses for production and reinjection zones on estimating behavior of fraction(F_1).

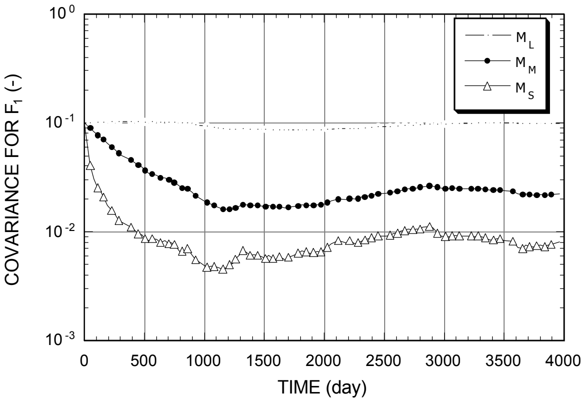

Figure 10. Covariances with respect to fraction(F_1) for three different combinations of masses for production and reinjection zones.