EFFECTS OF LOW TEMPERATURE WATER INFLOW INTO WELLBORE AT SHALLOW FEEDZONE OF PRODUCTION WELL ON STEAM-WATER TWO-PHASE FLOW IN WELL

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ABSTRACT

Geothermal wells completed with multi-feed zones may experience unstable production characteristics such as oscillations of wellhead pressure and discharge rate. Unsteady state steam-water two-phase flow in wellbore was numerically analyzed for examining the effects of low temperature water inflow probably due to quick return of reinjected water to production wells. Simulated results showed that depths of flashing point are affected by a degree of inflow of low temperature fluid from shallow feed zone.

1. INTRODUCTION

In a fractured geothermal reservoir, production wells penetrate fractured zone that play feed zones of geothermal fluids flowing into the wellbore. By completing the production well with multiple feed zones, the well could produce more fluid compared to a well with a single feed zone. Pressure and temperature differences between feed zones, however, may lead to instability of well performance such as oscillations of wellhead pressure and discharge rates. This instability results in unstable steam production, and consequently unstable electricity generation of the power plant.

Grant et al. (1979) examined instability of well performances for wells in New Zealand geothermal fields. They found out that multiple feed zones would cause instability of wells when a shallow feed zone is located in a vapor-dominated zone and a deep feed zone in a water-dominated zone. Relationship between well head pressure and feed zone pressures was discussed in detail how it caused instability of wells.

A similar situation was found in the well T052 at the Uenotai geothermal field in Japan (Iwata et al., 2002). They carried out a downhole survey for pressure, spinner and density under flowing condition. The results indicated that an inflow of liquid phase fluid from the deep feed zone into the wellbore causes oscillation of discharge rate and specific enthalpy of the produced fluid. Upon this result, the deep feed zone was plugged and they succeeded to eliminate cyclic behavior of the well. The well showed about 70 minutes for one cycle for both discharge rate and wellhead pressure.

In the Sumikawa geothermal field in Japan, a couple of production wells show an oscillation in wellhead pressure, and eventually cease to stop discharging (Itoi et al., 2013). However, the well could successfully restart discharging after allowing temperature recovery in the well. One of the wells has two feed zones wherein the shallow feed zone seems to have a cooling effect due to the return of the heat depleted reinjected water that flows through a fault zone. Thus, the effect of water flow into the well at the shallow feed zone needs to be evaluated for designing any countermeasure for suppressing instability of wellbore.

In order to understand the cyclic behavior of wells, a set of mathematical models of wellbore flow and reservoir flow need to be developed. Miller (1980) developed a wellbore flow model coupled with reservoir flow, which was used for analyzing pressure build-up of the well with a single feed zone. We have improved their model such that it can handle two feed zone under unsteady state, and carry out numerical simulations for evaluating the effects of temperature of water flowing into the wellbore at shallow feed zone.

2. INSTABILITY OF PRODUCTION WELLS AT SUMIKAWA

The Sumikawa geothermal field is located in Akita Prefecture, northern Japan. A 50 MW steam-turbine geothermal power plant started operating in 1995 with 7 production wells and 10 reinjection wells. All of the separated water and a portion of the condensed water from the cooling tower are injected back into the reservoir. Repeated tracer tests indicated a return of reinjected water to the production wells (Kumagai et al., 2004). A couple of production wells exhibited cyclic changes in wellhead pressure and eventually stopped discharging. This may have been caused by the return of low-temperature reinjected water into the production wells. Figure 1 shows a history of wellhead pressure in Well SA-6. This well was completed with two feed zones at different depths, and exhibits unstable behavior. The wellhead pressure, which starts oscillating soon after discharge, is initiated with a cycle period of about 100 minutes and amplitude of 0.12 MPa.
The well eventually stops discharging after about 10 days. But after a period of recovery, the well can be restarted again and tends to repeat this cycle of discharge followed by flow interruption.

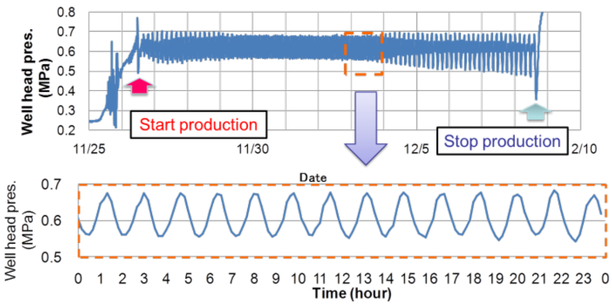

Figure 1: Wellhead pressure with time in Well SA-6 in Sumikawa

3. SIMULATION MODEL

A coupled model of wellbore flow and reservoir flow was used. The WELLBORE simulation code developed by Miller (1980) was modified for handling two feed zones as WELLBORE can handle only one feedzone (Itoi et al., 2013). These feed zones are connected to shallow and deep reservoirs that are expressed in the model as conventional porous reservoir in radial coordinate system. Thermodynamic properties of water were calculated using a software package for thermophysical properties of fluids called PROPATH (PROPATH group, 1999).

Figure 2 shows a conceptual model of the fluid flow in the wellbore and the reservoir. The well has two zones through which single-phase liquid water enters. Fluid from the deep reservoir enters the wellbore at the deep feed zone and flows upward. Then, this fluid mixes with the fluid from the shallow reservoir at the shallow feed zone. This mixed fluid flows further up the wellbore and then starts flashing

3.1 Reservoir model

A conventional constant-thickness horizontal radial-flow porous-medium reservoir model was used. Reservoir pressure in the radial coordinate system is governed by:

$$\frac{\partial P}{\partial t} = \frac{k}{\phi c \mu}\left(\frac{\partial^2 P}{\partial r^2} + \frac{1}{r}\frac{\partial P}{\partial r}\right) \tag{1}$$

where c is the fluid compressibility (1/Pa), k is the rock permeability (m^2), P is the pressure (Pa), r is the radial distance (m), t is the time (s), ϕ is the porosity, and μ is the coefficient of viscosity (Pa s).

In this study, the heat conduction equation in radial geometry is also used to calculate the heat transfer between the wellbore and the surrounding rock formation:

$$\rho_r c_r \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda\frac{\partial T}{\partial r}\right) \tag{2}$$

where c_r is the specific heat of the rock (J/kg K), T is the rock temperature (^oC), λ is the heat conductivity of rock (W/m ^oC) and ρ_r is the rock density (kg/m^3).

3.2 Wellbore model

Transient two-phase flow in the wellbore is described by the mass, momentum and energy conservation principles (Miller, 1980; Atomic Energy Society of Japan, 1993):

$$\frac{\partial \rho_m}{\partial t} + \frac{\partial}{\partial z}(G) = 0 \tag{3}$$

$$\frac{\partial G}{\partial t} + \frac{\partial}{\partial z}(Gv) = -\frac{\partial P}{\partial z} - \rho_m g \sin\theta - F_w \tag{4}$$

$$\frac{\partial}{\partial t}\left[\rho_m\left(E_m - P/\rho_m\right)\right] + \frac{\partial}{\partial z}(GE_m) = q \tag{5}$$

$$E_m = e + P/\rho_m \tag{6}$$

$$F_w = \frac{f\rho_m v^2}{4r_w} \tag{7}$$

$$G = \rho_m v \tag{8}$$

$$q = \frac{H\left(T_r - T_w\right)}{2r_w} \tag{9}$$

where e is the internal energy per unit mass (J/kg), E_m is the specific enthalpy or total energy per unit mass (J/kg), f is the coefficient of pipe friction, F_w is the frictional pressure loss per unit volume (Pa/m), g is the gravitational acceleration (m/s^2), G is the mass flow rate per unit area (kg/s-m^2), H is the coefficient of heat transfer (W/m^2 ^oC), q is the heat transfer per unit volume (W/m^3), r_w is the wellbore radius (m), T_r is the rock temperature surrounding the well (^oC), T_w is the fluid temperature in the wellbore (^oC), v is the average fluid velocity (m/s), θ is the inclination angle of the well (rad), and ρ_m is the average fluid density (kg/m^3).

Steam-water mixture density, $\rho_{m,}$ is calculated using a void fraction that is expressed by the Smith formula (Smith, 1969-1970). The pipe friction factor for single-phase water flow is calculated using the Karman-Nikuradse equation:

$$f = \frac{1}{(1.14 + 2\log D/\varepsilon)^2} \tag{10}$$

where ε is the surface roughness of the pipe (m) and D is the pipe diameter (m). For the steam-water two phase flow in the wellbore, the friction factor calculated with Eq.(11) was multiplied by 1.1. The heat transfer coefficient in Eq. (9) is calculated by (Holman, 1976):

$$H = 0.023\left(\frac{\rho v(2r_w)}{\mu}\right)^{0.8} \tag{11}$$

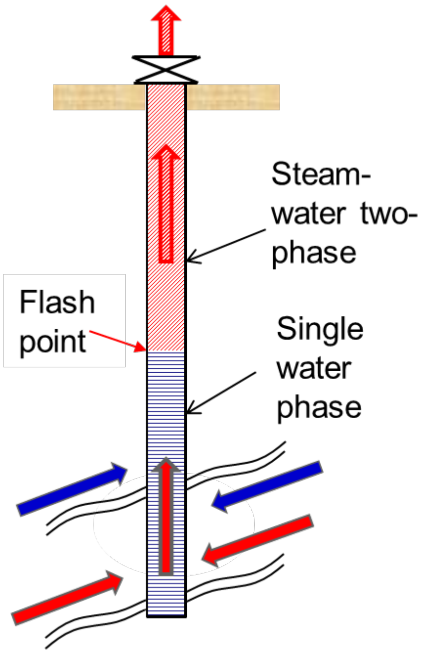

Figure 2: Conceptual model of fluid flow in wellbore and reservoir

4. NUMERICAL SIMULATION

The well was assumed to be vertical and uniform in diameter. Deep reservoir temperature was kept constant at 240^{o}C whereas temperature of shallow reservoir fluid was changed linearly with time from 220^{o}C to 180^{o}C in 40,000 seconds as shown in Fig.3. Specific enthalpy of the water flowing into the wellbore is the same as that of saturated water with respect to the temperature. Thus, the specific enthalpy of water flowing into the wellbore at the shallow feed zone decreases with time corresponding to the temperature indicated in Fig.3: from 944 kJ/kg at 220^{o}C to 763 kJ/kg at 180^{o}C.

Other conditions were given as follows. The well has a uniform diameter of 0.1m, and extends to as deep as 2000m with the shallow feed zone located at 1700m depth and the deep feed zone at 2000m depth. These depths correspond to those of shallow and deep reservoirs. The permeability-thickness product of both reservoirs was given as 3.0×10^{-12} m^3. Deep and shallow reservoir pressures were given as 122.6 and 92.0 bar, respectively, which were taken from the results of well logging data at respective depths conducted under static conditions.

Initial conditions for unsteady state simulation were given as follows. Firstly, steady state flows both in wellbore and reservoirs were to be formed. The steady state simulation in wellbore was carried out only with the deep feed zone that supplies 240^{o}C water into the wellbore. The feedpoint pressure at the deep reservoir was first specified, then the mass flow rate was calculated using the Darcy law whose pressure gradient at the well radius was calculated using a steady state pressure equation for a radial coordinate system in the reservoir. Then, the wellbore flow simulation under steady state was carried out to obtain the wellhead pressure. This process was repeated until the simulated wellhead pressure reaches a specified value: 7 bar in our simulation.

5. RESULTS AND DISCUSSION

Figure 5 shows the simulated result of production rate with time. The production rate shows a fluctuation in early times such that there is more than 10 kg/s drop in production rate within 800sec from the initial flow rate of 31.3 kg/s under steady state. The magnitude of fluctuation reduces with time, then the production rate stabilizes as it gradually decreases. The production rate, then, restarts fluctuation at around 20,000 sec and its magnitude grows larger with time. The simulation was stopped when the fluid from the shallow reservoir changed its flow direction into the reservoir.

Figure 6 shows the flow rates of fluid from the shallow and the deep reservoirs into the wellbore with time. The fluid inflow from the deep reservoir into the wellbore dominates the flow in the wellbore whereas that from the shallow reservoir is less than 5 kg/s throughout the simulation period. Both flow rates show continuous decrease with time and in particular, the flow rate from the shallow reservoir reaches to 0 when the simulation stopped.

Figure 7 presents the history of specific enthalpy of produced fluid at wellhead. The specific enthalpy shows 1,030 kJ/kg during the very early period of the history. Then, quick drop of the enthalpy as well as its fluctuation ccurs in the early period. This is because low temperature water starts flowing into the wellbore from the shallow reservoir. Then, the specific enthalpy continuously decreases with time up to around 20,000sec. It then starts

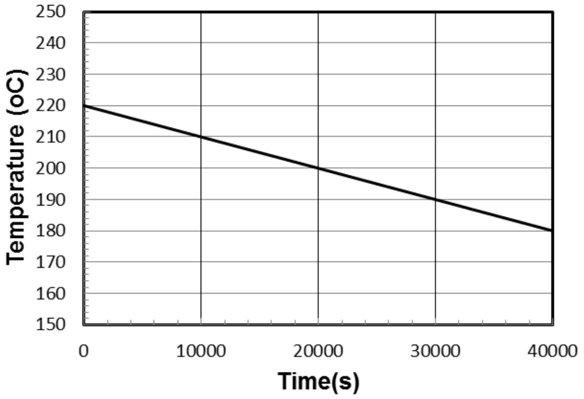

Figure 3: Temperature change of fluid flowing into wellbore at the shallow feedzone.

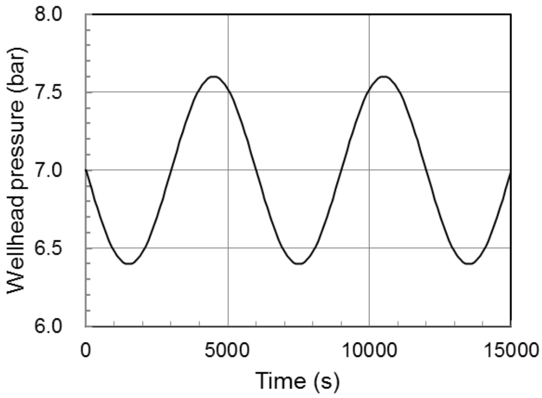

Figure 4: Boundary condition on wellhead pressure

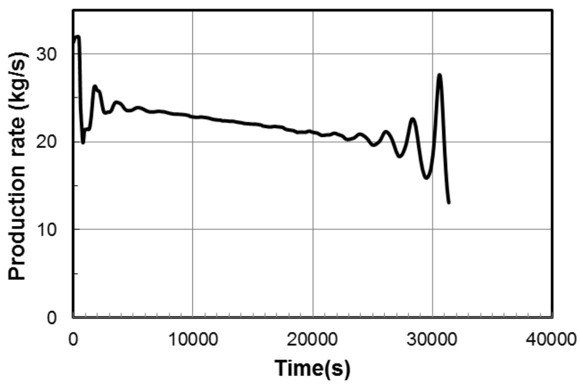

Figure 5: Simulated production rate

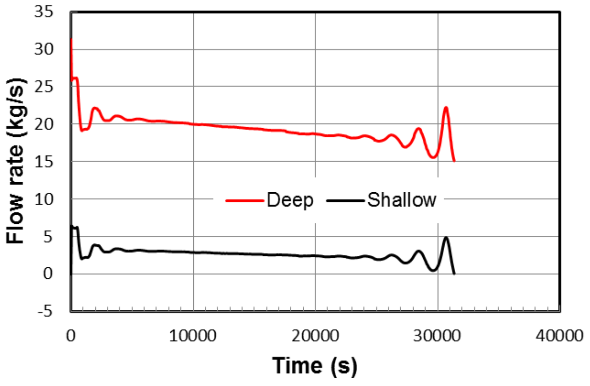

Figure 6: Simulated flowrates at deep and shallow feed zones.

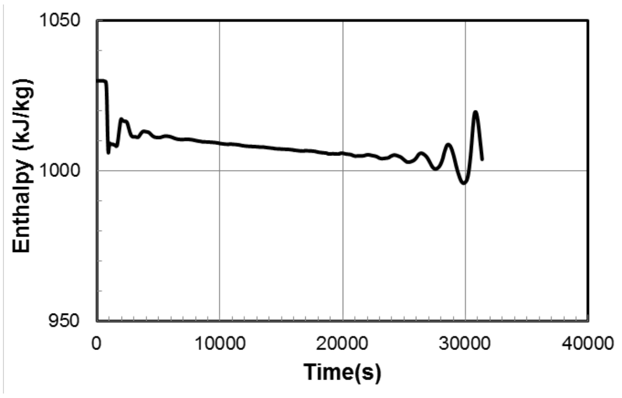

Figure 7: Specific enthalpy of produced fluid

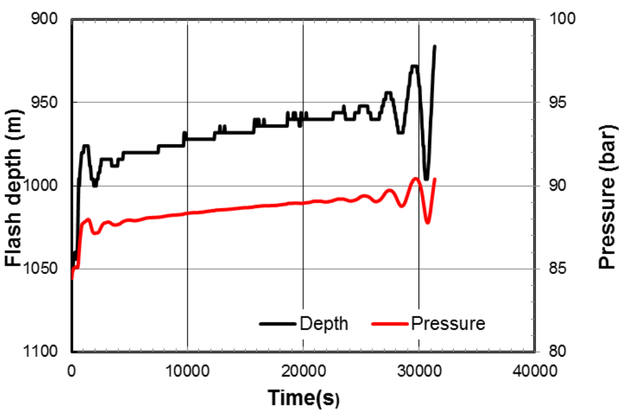

Figure 8: Depth of flashing point and pressure at the shallow feed zone.

oscillating in a similar manner to the discharge history as shown in Fig. 5; oscillation magnitude grows with time. This oscillation is caused by mixing of lower temperature water flowing into the wellbore at the shallow feed zone.

Figure 8 presents the depth of flashing point in the wellbore with time. The flashing point is at first around 1050m depth from the surface in the wellbore, and then it quickly moves to shallow depth at about 980m. Flashing starts when the fluid pressure in wellbore reaches to the saturation pressure of the water with respect to its temperature. As the high temperature water from the deep reservoir mixes with the low temperature water from the shallow reservoir, the specific enthalpy of the water in the wellbore decreases, accordingly the saturation pressure decreases. This results in a shift of flashing point to shallow depth. When the flashing point moves to the shallow level in the wellbore, the length of single water phase column in the wellbore increases. This resulted in a higher pressure at both feed zones of the reservoirs, then a decrease in the fluid flow rates from respective reservoirs, and an opposite direction in the flow of fluid from the wellbore into the shallow reservoir.

CONCLUSION

Numerical simulations of wellbore flow under unsteady state were carried out for the well which has two feed zones of different depths. Temperature of water flowing into the wellbore at the shallow feed zone linearly decreases with time whereas that at the deep feed zone is kept constant. The results indicate that both production rate and specific enthalpy decrease with time, and that the flashing depth in wellbore moves to shallow depth with time.

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