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APPLICATION OF TRANSIENT WELLBORE SIMULATOR TO EVALUATE DELIVERABILITY CURVE ON HYPOTHETICAL WELL-X

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ABSTRACT

The transient wellbore simulator has been applied to evaluate the deliverability curve on a hypothetical Well-X. The aim of the study is to propose a new procedure in producing a deliverability curve of production well. The procedure of obtaining deliverability curve is carried out by giving the mass flow rate input at the wellhead into the software for the specified time length. The continuous calculated wellhead pressures then are plotted against the respective mass flow rates. In this study, the various permeability-thickness (*kh*) values are evaluated to study their effects on deliverability curves. The results showed that for lower *kh* values, the shape of deliverability curves tend to be flat and do not show the maximum values for flow rate. On the other hand, the higher *kh* values give larger mass flow rates for the same wellhead pressures and show maximum values for mass flow rates at the specific wellhead pressures.

INTRODUCTION

Practically, a deliverability curve of production well is obtained by plotting measured wellhead pressures against the respective mass flow rates. This is used as one of tools for evaluating well performances. In the course of geothermal development for power generation, understanding well performances and evaluating well deliverability are an important task for reservoir engineers. This is because that predicting steam discharge rate from wells and evaluating the effects of reservoir conditions provides valuable information for designing a size of power plant. The possible characteristics of the deliverability curve depend on factors, such as the reservoir permeability, reservoir pressure and temperature, gas content, and scaling both in reservoir and/or wellbore.

A typical deliverability curve is characterized by the existence of maximum discharge pressure. The experience in Wairakei showed that the wellhead pressures could only be raised to a certain maximum value by throttling discharge. Further raising it results in collapse of the flowing steam-water mixture and closure of the well corresponds to a maximum value of discharge pressure (James, 1980).

Nakamura *et al.* (1981) presented the deliverability curves of production wells at Takinoue, Japan. Most of the curves indicated the increase in flow rates as the wellhead pressures decrease. The measured flow rates of the steam were in the range of 10t/h and 130t/h.

Grant *et al.* (1982) discussed qualitatively on the collapse of the discharge by throttling from a large flow (well wide open). The similar explanation was given by Khasani *et al.* (2002). They analyzed numerically on the pressure drops for low mass flow rates. Their calculated results showed that at low flow rates the pressure drops in wellbore was dominated by potential pressure drop component then followed by frictional component and finally acceleration component. As the flow rate increased the potential pressure drop became smaller while the rest of two others tend to increase.

However, a deliverability curve for one well at Cerro Prieto, Mexico showed a unique characteristics (Freeston, 1992). The mass flow rate increases with increasing wellhead pressure until it reaches a maximum value then decreases with increasing wellhead pressure. This may happen also to other geothermal fields. For this situation, therefore, careful measurement of wellhead pressures and mass flow rates to obtain deliverability curve using conventional method must be prioritized. This is because, for example, if we just make repeated measurements for corresponding mass flow rate and wellhead pressure for several times from the well in fully open condition to the complete closure, we may have an unreliable deliverability curve. Due to the limited measured flow rate and wellhead pressure, we may not get the maximum flow rate. In order get more reliable results we need more points or number of measurements, which is time consuming.

This paper proposes a new technique of obtaining deliverability curve numerically using transient wellbore simulator developed initially by Miller (1980). A hypothetical Well-X is utilized for study case. The results of the calculated wellhead pressures need to be verified using continuous wellhead pressure and mass flow rate measurements. The confirmation between two techniques will allow us to carry out shorter measurement on wellhead pressures and mass flow rates, for example, just by closing the main valve from fully open condition continuously to the complete closure while measuring wellhead pressures and mass flow rates continuously at the same time. In addition, we can also evaluate the properties of the reservoir and the possible problems occurring both in the reservoir and wellbore.

The main concern on measurement of flow rate and well head pressure is how long it will take to reach stabilization with flow rates of steam and water after changing the degree of valve opening. If this elapsed time can be evaluated properly from numerical simulation, well characteristics measurement can be designed rationally. No reliable data can be obtained just by conducting continuous measurements of wellhead pressure and flow rates.

GOVERNING EQUATIONS

The simulator that was developed by Miller (1980) utilized a set of governing equations both in wellbore and reservoir. Basic equations for fluid flow in the reservoir are derived under assumptions as follows;

1) reservoir is of radial symmetric and horizontal with a constant thickness,
2) fluid flow obeys Darcy's law,
3) heat exchange between fluid in the wellbore and rock formation is taken into account.

They consist of mass, momentum, and energy conservation equations in a vertical wellbore as follows:

Mass:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x}(\rho v)=0 \qquad (1)$$

where ρ is the total fluid density (kg/m^3), t is the time (s), x is the spatial distance (m) and v is the fluid velocity (m/s).

Momentum:

$$\frac{\partial}{\partial t}(\rho v)+\frac{\partial}{\partial x}\left[\alpha\rho_s v_s^2+(1-\alpha)\rho_w v_w^2\right]+\frac{\partial P}{\partial x}+\rho g+\frac{\lambda \rho v^2}{4r_w}=0 \qquad (2)$$

where α is the void fraction (-), ρ_s is the density of steam (kg/m^3), v_s is the velocity of steam, ρ_w is the density of water (kg/m^3), v_w is the velocity of water, P is the pressure (Pa), g is the gravitational acceleration (m/s^2), λ is the friction factor (-), and r_w is the well radius (m). The friction factor λ is evaluated using a two-phase multiplier and is independent of flow regime (Chisholm, 1973).

Energy:

$$\frac{\partial}{\partial t}(\rho e)+\frac{\partial}{\partial x}\left[\alpha\rho_s v_s e_s+(1-\alpha)\rho_w v_w e_w\right]=$$

$$-P\left\{\frac{\partial}{\partial x}\left[\alpha v_s+(1-\alpha)v_w\right]\right\}+\frac{H}{2r_w}(T-T_{rw}) \qquad (3)$$

where e is the specific internal energy of fluid (J/kg), e_s is the specific internal energy of steam (J/kg), e_w is the specific internal energy of water (J/kg), H is the heat transfer coefficient (W/m^2.^{o}C), T is the temperature of fluid (^{o}C), and T_{rw} is the temperature of the wellbore wall (^{o}C).

It is required an additional equation of state that correlates between density, pressure, and energy of fluids,

$$\Delta\rho=(\partial\rho/\partial P)\Delta P+(\partial\rho/\partial e)\Delta e \qquad (4)$$

The reservoir and the wellbore calculations are linked explicitly by using an assumption that the flow rate of mass entering the wellbore is equal to that leaving the reservoir.

Pressure changes in time and space in the reservoir is expressed by,

$$\frac{\partial P}{\partial t}=\frac{k}{\mu\varphi C}\left[\frac{\partial^2 P}{\partial r^2}+\frac{1}{r}\frac{\partial P}{\partial r}\right] \qquad (5)$$

where k is the permeability (m^2), μ is the dynamic viscosity (Pa.s), φ is the porosity (-), C is the compressibility (1/Pa) and r is the radial distance (m). Energy conservation in reservoir is assumed to be isenthalpic.

Equation (5) can be expressed further in terms of pressure after discretization as,

$$P_i^{t+1}=P_i^t+\frac{2\Delta t}{r_{i+1}-r_{i-1}}\frac{k}{\mu\varphi C}$$

$$\left[\frac{2}{(r_{i+1}-r_{i-1})}\left(P_{i+1}^{t}+P_{i-1}^{t}-2P_{i}^{t}\right)+\frac{1}{r_i}\frac{P_{i+1}^{t}-P_{i-1}^{t}}{2}\right] \quad (6)$$

where subscript t denotes the time step and subscript i indicates the nodal point in the radial distance from the wellbore.

PROCEDURE OF CALCULATIONS

Numerical simulations are carried out in the following steps,

1) Specify wellbore and reservoir parameters, such as depth of well, well bottom pressure, mass flow rate, and specific internal energy of fluid flowing into the wellbore from the reservoir. For a hypothetical Well-X, the specified parameters are summarized in Table 1. Furthermore, the properties of the reservoir such as permeability thickness (*kh*), horizontal extent, and storativity (*φCh*) are also to be given. Other additional parameters are the thermal conductivity of the rock and the thermal diffusivity. Other input data consist of grid sizing of the wellbore and reservoir and time specifying.
2) Having given all data, then the program is executed to obtain the output, such as pressure and temperature profiles in the wellbore at a specified time, wellhead and downhole pressures vs time, the pressure and temperature distributions in the reservoir.

Table 1. Reservoir and wellbore parameters.

Reservoir			Wellbore		
Horizontal extent	:	1500 (m)	Diameter	:	0.244 (m)
Permeability thickness	:	(1-3.5)x10^{-12} (m^3)	Length	:	2307 (m)
Storativity	:	5x10^{-7} (m/Pa)	Roughness	:	4.6x10^{-5} (m)
Thermal diffusivity	:	1x10^{-4} (m^2/s)			
Thermal conductivity	:	1.8 (W/m/^{o}C)			
Initial temperature in reservoir	:	330 (^{o}C)			

RESULTS AND DISCUSSION

Mass flow rate

Mass flow rate at wellhead vs time need to be given as boundary conditions as shown in Fig.1.

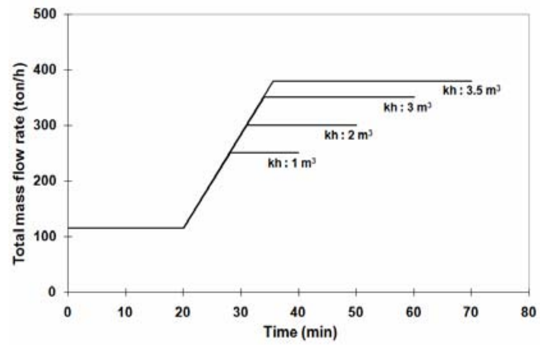

Figure. 1. Mass flow rates input data.

The mass flow rate increases with time in four modes such that it linearly increases, i.e. from 115 t/h to 250, 300, 350 and 380 t/h to adjust the various *kh* of 1, 2, 3, and 3.5 m^3, respectively. The various flow rates are determined as above values such that their values that represent discharged flow rates are enough to be produced for the respective *kh* (Khasani *et al.*, 2002). The modes of the flow rate increase are chosen to be similar to the increase in flow rates from measurement due to gradual valve opening.

Calculated deliverability curves

Figure 2 shows the calculated deliverability curves for different *kh*. Vertical axis represents total mass flow rate and horizontal axis indicates wellhead pressure. All deliverability curves are obtained by running the program using respective mass flow rate input data. For example, the deliverability curve for *kh* of 1 m^3 corresponds to the mass flow rate increase of 115 t/h to 250 t/h which is a function of time. Therefore, the deliverability curve that is obtained by plotting the mass flow rate against the respective calculated wellhead pressure is also the function of time.

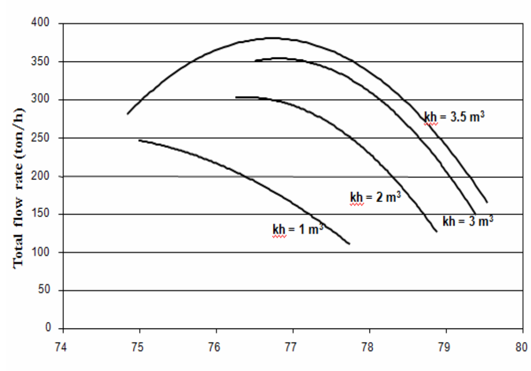

Figure. 2. Calculated deliverability curves.

It can be seen clearly that for a given wellhead pressure, the higher permeability thickness gives larger mass flow rate. There is an obvious difference between the deliverability curves for low and high *kh*.

For low *kh* value of 1 m^3, the increase in wellhead pressure is followed by the decrease in mass flow rate. This is the typical deliverability curve for most production wells as presented by Nakamura *et al.* (1981). In contrast, high *kh* value such as 3.5 m^3, show a maximum value of mass flow rate at a specific wellhead pressure. In the lower wellhead pressure range, the increase in wellhead pressure causes the mass flow rate increases. Reaching the maximum value for mass flow rate, further increase in wellhead pressure results in the decrease in mass flow rate.

Importance of continuous measurement

As described in the previous section, it is sometime found from field measurements that the deliverability curve takes one as obtained from numerical simulation that shows maximum value for mass flow rate. From numerical simulation point of view, this phenomenon may be found for the reservoir having higher *kh* values. It must be pointed out here is that the calculated deliverability curves are obtained from transient numerical simulation. In this study, the time step for succeeding calculated parameters is 0.5s. It means, the corresponding calculated wellhead pressure and mass flow rate are calculated every 0.5s. Therefore, we can observe the behavior of both parameters from deliverability curve in detail.

Because the maximum flow rate is some time found from field measurement, in practical application point of view, observation of the phenomenon is necessary, especially for reservoir having high *kh*. The conventional measurement of wellhead pressure and mass flow rate that usually measures for several well head points for newly drilled well may not show the phenomenon. This is because, there may be some important points that give characteristic of maximum flow rate missed from the measurement. In order to make sure that the phenomenon can be observed, the continuous measurement needs to be carried out. The main idea of the continuous measurement is illustrated in Fig. 3.

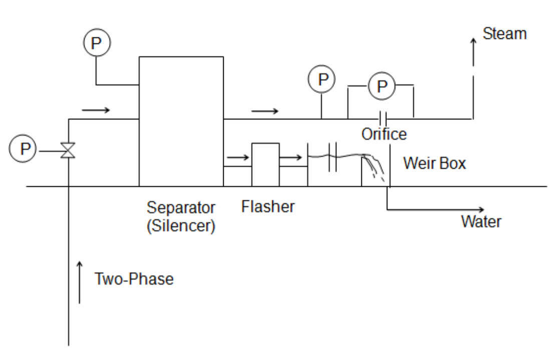

Figure. 3. Schematic diagram of continuous measurement.

The continuous measurement can be carried out by operating the main wellhead valve from fully open condition then throttle gradually into full closure. Then, the wellhead and mass flow rate are measured every second by the method as illustrated in Fig. 3. Symbol P represents pressure transducers for measuring pressure and pressure difference. The water level in the weir box is measured using electrodes. The measured pressures and water level are used to calculate steam and water flow rates. It must be underlined here that the measured wellhead and flow rate from continuous measurement are still in transient condition. So, the aim of the continuous measurement here is to get the idea about the "*transient deliverability curve*" to understand early information on well characteristic, especially the existence of maximum flow rate in short time. It should be verified by conventional measurement later when the fluids condition is already in stable condition where usually takes longer time.

CONCLUSIONS

1. Transient numerical simulation work can be applied to make preliminary investigation on the characteristics of deliverability curve of a production well.
2. The presence of maximum value of mass flow rate shown on a deliverability curve can be interpreted as the reservoir having high permeability-thickness.
3. Deliverability curve obtained from numerical simulation should be verified with both the continuous measurement and conventional measurement methods for wellhead and mass flow rate.

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REFERENCES

Chisolm, D. (1973), "Pressure Gradients Due to Friction during the Flow of Evaporating Two-Phase Mixtures in Smoother Tubes and Channels," *International Journal Heat Mass Transfer*, **16**, 347-358.

Freeston, D.H. (1992), "Geothermal Energy Systems," *Engineering Lecture notes*, *Geothermal Institute, The University of Auckland*, 54-55.

Grant, M. A., Donaldson, I. G. and Bixley, P. F. (1982), “Geothermal Reservoir Engineering,” *Academic Press*.

Khasani, Itoi, R., Tanaka, T. and Fukuda, M. (2002), “An Analysis of Pressure Drops in Wellbore under Low Flow Rate Conditions Shown on a Deliverability Curve,” In *Proceedings. The 24th New Zealand Geothermal Workshop2002*, 115-120.

Miller, C. W. (1980a), “Wellbore User’s Manual,” Lawrence Berkeley Laboratory, University of California, 48p.

Miller, C. W. (1980b), “Eliminating the Wellbore Response in Transient Well Test Analysis,” In *Proceedings. 6th Workshop Geothermal Reservoir Engineering, Stanford University.*

Nakamura, H. And Kiyoshi, S. (1981), “Exploration and Development at Takinoue, Japan,” In *Geothermal Systems: Principles and Case Histories.* Ed: L. Rybach and L.J.P. Muffler, John Wiley & Sons Ltd., 247-272.