AN ANALYSIS OF STEAM-WATER TWO-PHASE FLOW IN THE GEOTHERMAL WELL

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ABSTRACT

The objective of this study is to make it possible to numerically estimate the fluid pressure at well bottom/feed point during discharge; from wellhead data that may be comparatively easily obtained. For that purpose, initially, measured pressure profiles are analyzed to estimate an average pipe friction factor that seems to be available for geothermal wells. Secondly, using the estimated friction factor, pressure profiles are calculated to compare with the measured ones. Finally, pressures at a feed point in Otake well 0-7 are estimated.

1.0 INTRODUCTION

The fluid data (temperature and pressures) at well bottom/feed in a discharging geothermal well, and well diameter variations due to scaling or wall collapse, are the interests to resetvoir and production engineers. These data may be obtained precisely by well loggings. However, since a possibility for the logging usually exists during the power plant maintenance only, once a year or every two years or so, the obtained data may be considered 'spot data'. Another method to estimate pressures (and temperatures in some cases) at feed (s), will be to predict a pressure-depth profile using wellhead pressure, steam and water flow rates, and mixture enthalpy. It has the advantage of a possibility for obtaining denser data with short time intervals, though probably less accurate. Some literatures on this subject can be found, among which the authors take a particular interest in the report by Bjornsson et al [1987], in which complicated downhole models are dealt with and excellent results are obtained. Unfortunately, details of the simulator are not described.

In this study, apart from the above simulator, with some assumptions to simplify the calculations, an analysis of pressure profile shown in the report is tried, and the relative roughness of pipe is estimated. For the analysis and calculation of the pressure profile, the total pressure loss equation composed of potential loss term, acceleration loss term and friction loss term is used. The first two terms are evaluated by traditional methods, while a method essentially based on Chisholm's procedures (1973,19831 is applied for the evaluation of friction loss term, similarly to Bjornsson et al. Applying this method to Otake well 0-7, pressure profiles for variable wellhead conditions are predicted, and pressures at the feed point are estimated.

2.0 FLOW PATTERNS

The flow patterns of two-phase flow adopted in this study are the bubble, slug, transition and annular-mist from a flash inception level upward to the wellhead, as Orkiszewski [1967] categorized in relation to boundaries for these patterns to exist.

3.0 EQUATIONS USED FOR CALCULATIONS

3.1 Total Pressure Losses in Segment, ΔL

When a single-phase fluid flows up a vertical pipe, the fluid pressure drops due to the acceleration losses, ΔP_a potential losses, ΔP_h and friction losses, ΔP_f

$$\Delta P_t = \Delta P_a + \Delta P_h + \Delta P_f \tag{1}$$

where ΔP_t is the total pressure losses, and

$$\Delta P_a = G^2(\nu_1 - \nu_2) \tag{2}$$

$$\Delta P_h = \rho \cdot g \cdot \Delta L \tag{3}$$

$$\Delta P_f = \frac{\lambda}{2D}\frac{G^2}{\rho}\Delta L \tag{4}$$

6. calculate ΔP_a, ΔP_h, and ΔP_f (= ΔP_t-ΔP_a-ΔP_h)
7. substituting Eq. (12) into Eq. (10), and equating Eqs. (10) and (13), evaluate ε/D
8. repeat procedures 4 - 6 for all of ΔP_t

4.2 Calculations of Pressure Profiles

When ε/D is given, λ_{lo} and Φ_{lo}^2 are easily obtained. Then, from Eqs. (1), (2), (3), (8), (11) and (12), a flow length ΔL for ΔP_t can be calculated by

$$\Delta L = \frac{\Delta P_t - \Delta P_a}{\rho_m g + \frac{\lambda_{lo}}{2D}\frac{G^2}{\rho_l}} \qquad (26)$$

The pressure profile will be depicted by plotting P (= $\Sigma\Delta P$)~L (=$\Sigma\Delta L$).

5.0 RESULTS OF CALCULATIONS

Three profiles with different downhole conditions were selected from the report by Bjornsson et al: a two-phase condition (W-1 for convenience' sake) and a liquid single-phase condition (W-2) at the feed point with a constant well diameter, and a liquid single-phase condition (W-3) at the feed point with variations of well diameter. The data used for analysis are read from the figures by a scanner.

In these wells, as the enthalpy at the wellhead is a little lower (1 ~ 3 %) than that at the feed point, an average enthalpy was adopted for H_t.

5.1 Estimation of ε/D for Geothermal Well

If D and ε of tube are constant, the value of ε/D should also be constant. However, as obtained values for segments scattered, an average value was taken. Figure 1 shows an example of the scatter for W-1, where values for the slug flow pattern alone were adopted because the slug flow pattern was predicted for most part of two-phase flow in the well. From the figure, an average value for W-1 can be estimated as 0.004, and similarly 0.003 for W-2, which correspond λ_{lo}=0.028 and 0.026 respectively.

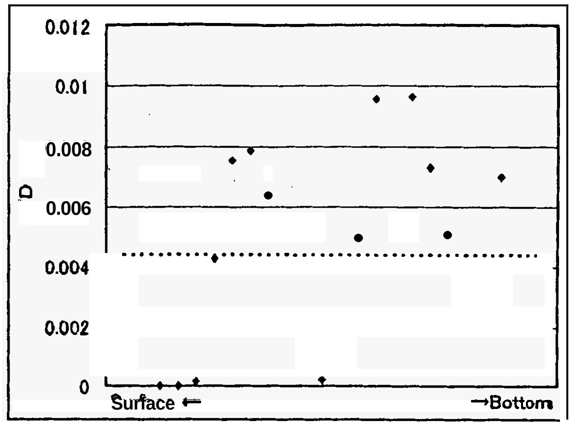

Figure 1. Scatter of ε/D in slug flow pattern

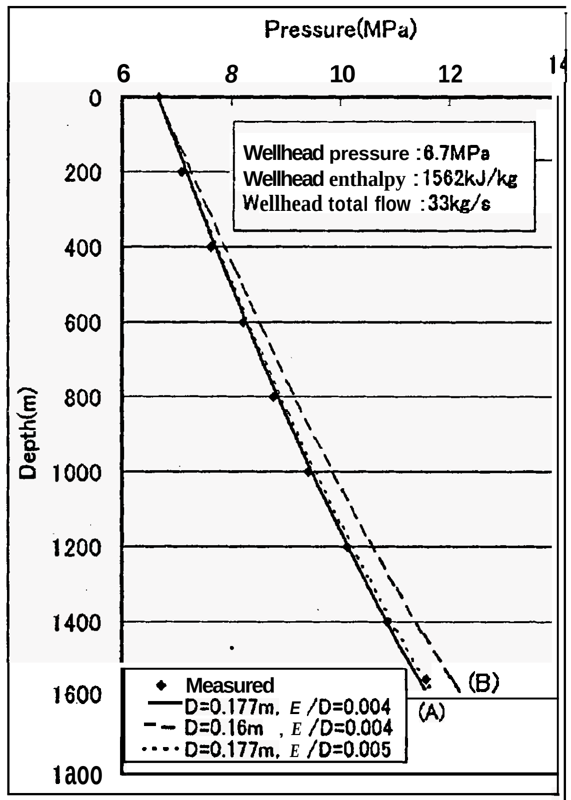

Figure 2. Comparison of measured and calculated pressure profiles for W-1 (data are based on a report by Bjornsson et al.)

5.2 Pressure Profile

The pressure profile was calculated downward from the surface to the bottom. Figure 2 shows the measured and calculated profiles for W-1, by giving 0.004 to ε/D in the calculation. Fairly good agreement results. Together with these, a comparison of calculated pressure profiles for cases of 25 % increase in ε/D (A) and 10 % decrease in D (B) are

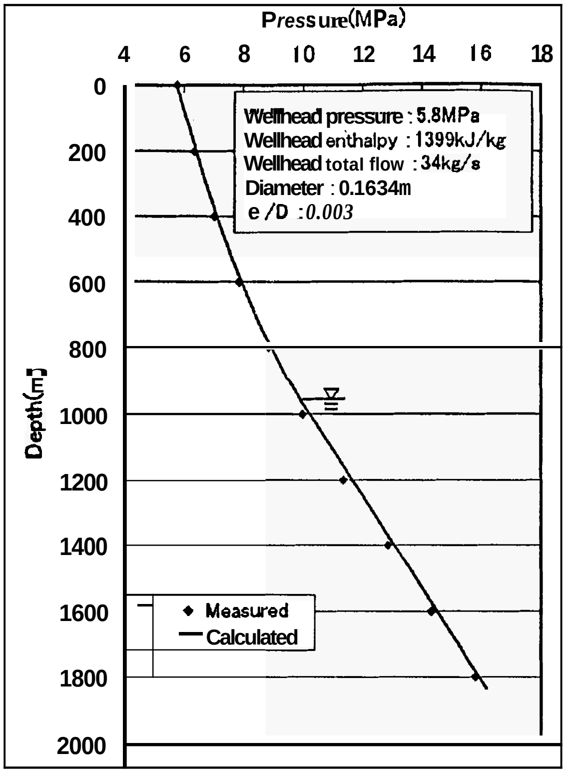

Figure 3. Comparison of measured and calculated pressure profiles for W-2 (data are based on a report by Bjornsson et al)

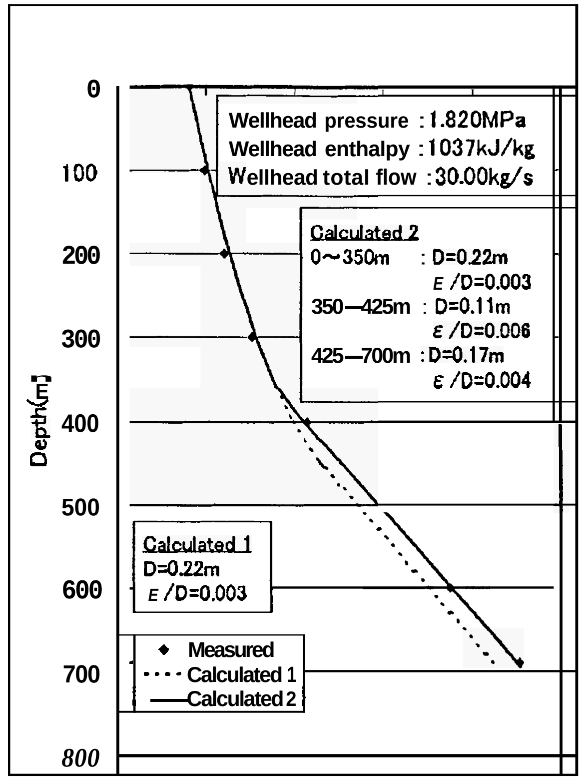

Figure 4. Comparison of measured and calculated pressure profiles for W-3 (data are based on a report by Bjornsson et al)

respectively shown, which indicates that the effect of well diameter is rather bigger than that of the relative roughness. Figure 3 shows the results for **W-2.** Both satisfactorily agree down to the flash inception level (around 945 m), below which the calculated profile shows slightly higher pressures. Figure 4 shows the results for W-3 by giving 0.003 to ε/D. In this case, when a constant D of wellhead (0.22 m) is given, both satisfactorily agree down to 350 m, below which the calculated pressures are a little lower. When variations in D and ε/D along the well are given, such as D=0.11 m and ε/D=0.006 between **350m-425m,** and 0.17 m and 0.004 below the level to the bottom respectively, a satisfactory agreement can be obtained as seen in the figure. Consequently, the variation of D becomes similar to that by Bjornsson et al.

5.3 Estimation of pressures at the feed point in O-7

Figure **5** illustrates flow characteristics of 0-7 (drilled depth: 350m, depth of feed: 335m). Fluid enthalpies calculated for various wellhead conditions are nearly constant (Ht=1190 kJ/kg) regardless of wellhead pressure. Using the flow characteristics and giving 0.003 to ε/D, pressure profiles were calculated, and the results are shown in Figure 6. The mist flow at the surface and the slug flow at the feed point were predicted. From the Figure 6, it is indicated that the pressure at the feed point in 0-7 decreases with increase in the wellhead pressure.

6.0 SUMMARY AND DISCUSSION

It was proved that, when variations of well diameter D and pipe roughness ε along a well are given, satisfactory fluid pressure at the feed point in a discharging well can be estimated by the prediction of pressure profile using wellhead measurements. The well diameter variations can be directly measured with a caliper or by analyzing measured pressure profile, while the pipe roughness is estimated by analyzing the pressure profile only. From the calculated profiles **A** and B in Figure **2,** it can be said that the variation of well diameter affects to the calculation much more than that of the relative roughness. Therefore, the caliper logging

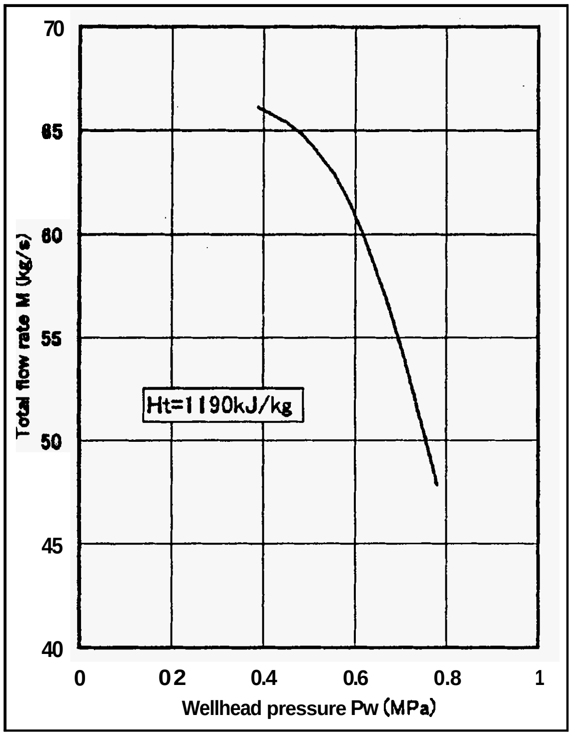

Figure 5. Flow characteristiccs of Otake well 0-7

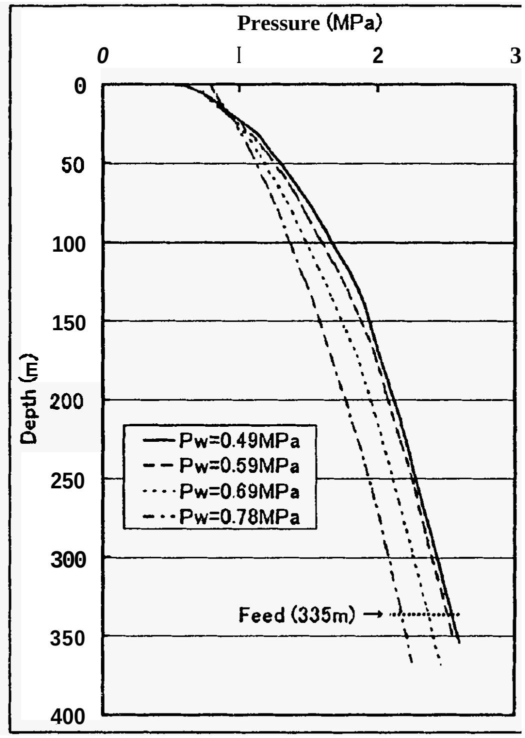

Figure 6. Calculated pressure profiles for 0-7

should be carried out at the same time with the pressure/temperature logging. Thus, the prediction would be a supplemental method to estimate downhole conditions during data-less terms. The values of ε / D=0.004 (λ_{lo}=0.02) and 0.003 (0.026) were estimated from W-1 and W-2 respectively. Applying these values to geothermal wells would not bring about big error when D is precisely estimated.

REFERENCES

Bjornsson, G. and Bodvarsson, G. (1987). A multi-feedzone simulator, GRC Trans., vol.11, pp. 503-507.

Chisholm, D. (1973). Pressure gradients due to friction during the flow of evaporating two-phase, mixtures in smooth tubes and channels. Inst. J. Heat Mass Transfer. vol. 16, pp.347-358.

Chisholm, D. (1983). Two-phase flow in pipelines and heat exchangers. George Godwin, London and New York.

Orkiszewski, J. (1967). Predicting two-phase pressure drop in vertical pipe. Journal of Petroleum Technology, pp.829-838.

NOTATION

D	:	well diameter
G	:	mass velocity
g	:	gravitational acceleration
H	:	enthalpy
J	:	superficial velocity
K	:	slip ratio
L	:	depth
P	:	pressure
Re	:	Reynolds' number
u	:	velocity
v	:	specific volume
x	:	dryness fraction
α	:	void ratio
ε	:	roughness
λ	:	pipe friction factor
ρ	:	density

Subscript

l		liquid
s		steam
m	:	mixture
t		total