A COMPARISON OF TWO WELLBORE SIMULATORS USING FIELD MEASUREMENTS

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SUMMARY- Predictions are made of the pressure and temperature distributions in two flowing wells using two different wellbore simulators. The predictions are compared with the measurements. The predictions of a discharge characteristic are also compared with the measured characteristic. One of the simulators is based on flashing flow two-phase correlations and the other on correlations for heated flows. Homogenous flow equations are used to show that the heated flow correlations should not be expected to give good results, yet the simulator based on them sometimes shows better results than the other. The reasons are discussed.

1. INTRODUCTION

This paper is based on a 1998 Geothermal Institute Diploma project (Karaalioglu, 1998). The aim of the project was to compare two wellbore simulators, WELLSIM, a commercial package developed by GENZL (now PBPower) and Assoc Prof Derek Freeston of the Geothermal Institute (Gunn and Freeston, 1991), and a slightly older one Written by KRTA (Sinclair Knight Merz Ltd) and reported in 1987 (Brennand and Watson, 1987), referred to here as WELL. The comparison was carried out by collecting together some sets of two-phase flowing surveys, simulating them using both simulators and comparing the predictions with the measurements.

The problem of predicting the pressure distribution (pressure drop) in a flowing well and hence the discharge characteristics is scientifically challenging. The factors making it a difficult task are :

(a) the need to use correlations based on experimental data for two-phase flow pressure drop

(b) the slotted liner, which is a very complicated flow passage. Even with an open annulus behind the liner the flow characteristics of the combined hole and liner passage are complicated. In reality, the annulus may be blocked in parts and flow may enter from any part of the hole over the liner length. An empirical approach to the slotted liner is always required. The production casing does not present these problems.

(c) the presence of gas or dissolved solids in the fluid which changes the flashing characteristics.

To test a prediction method (wellbore simulator) simultaneous flowing temperature and pressure surveys are required together with accurate mass flow rate and discharge enthalpy measurements; not many flowing surveys are available, and discharge measurements are only accurate to about 10%. In addition, only the production casing is really suitable for testing because of the difficulties with the slotted liner and the uncertainty about production zone location, specific enthalpy and flow rates.

To develop a prediction method one might use available empirical correlations or carry out laboratory experiments on scaled down wellbore flows. For single phase flows there is no problem with prediction, as the scaling (or similarity) laws hold. For two-phase flows a theoretical approach is only partly possible. The scaling laws hold over an uncertain range of parameters and given the very large scale of a geothermal well it is difficult to be sure that laboratory scale two-phase experiments will produce data that can be applied to real wells. The length/diameter ratio for a 600m depth with 9 5/8" casing is 2500, so any reasonable laboratory model must be of small diameter tubing.

This is not the case for power station boilers or process plant, so laboratory experiments for these are less demanding of scaling laws. In addition these applications economically warrant research and development. The result is that perhaps **90%** of all two-phase literature is for heated rather than flashing flows.

2. DESCRIPTION OF THE TWO SIMULATORS

Both simulators assume that the flow is steady and one-dimensional, and that both phases are in thermodynamic equilibrium. WELL assumes pure water and uses the **1967 IFC** Formulation properties (Schmidt, **1982).** WELLSIM has the facility for fluids with dissolved solids and non-condensable gases, represented by an equivalent NaCl content and equivalent CO_2 content respectively (Gunn, C. and Freeston, D., **1991).**

The KRTA simulator was written before a commercial simulator was available and was based on the Engineering Science Data Unit (ESDU) reports on the calculation of pressure drop in two-phase flows, which are for heated flows. WELLSIM on the other hand used correlations based on oil and gas industry flashing flows with some air-water (isothermal) flows; the correlations were reviewed by Probst et al. **(1992).**

Both simulators follow the same calculation procedure, stepping up or down the well in discrete steps of pressure or distance and calculating the pressure reduction at each new location based on the value of pressure, temperature and specific enthalpy at the previous one. The calculation must start either with known wellhead conditions or known conditions at the production zone(s). WELL has no facility for multiple production zones whereas WELLSIM has.

3. COMPARISON OF PREDICTIONS WITH SURVEY MEASUREMENTS

For the study (Karaalioglu, **1998),** the flowing data from two vertical PNOC wells in the Philippines were used, referred to **as A** and B, and the measurement method was **by** Kuster gauges. The comparison covers both production casing and slotted liner. The depth of feed zones and their mass flow rates were not available, hence it is assumed that there is **only** one production zone at the bottom of each well. Wellbore heat loss is assumed to be zero.

3.1 WELL-A

Production casing is **9 5/8"** to **920m,** with **7 5/8"** slotted liner **to** a total depth of 2360m. The roughness of the casing string is taken as **0.000046m.** WELLSIM uses a slotted liner with zero roughness, while the same roughness as the production liner was used for WELL, both approaches being empirical.

In using the simulators, consistent values of saturation temperature and pressure are required so the measured wellhead values have to be adjusted for measurement errors or the presence of gas by intelligent guessing.

Figure **3.1** shows temperature measurements called **KT13;** there were no pressure measurements.

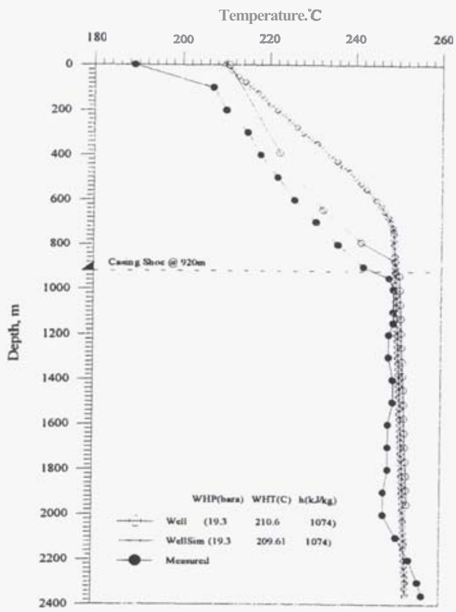

Fig 3.1 KT-13 Temperature Profiles for Well-A

The mass flow rate was **20.3kg/s.** At the measured **19.3** bar abs wellhead pressure, the saturation temperature is **209.8°C.** This value was used, assuming that the wellhead temperature of **189°C** is in error, together with the measured specific enthalpy of discharge of **1074kJ/kg.** Since the location and type of the production zones were not known, **only** the flow in the production casing should be compared, and Figure **3.1** shows the shape predicted by WELL **to** be the better match to the measurements. No pressure measurements were available but the pressure predictions are quite different. Karaalioglu (1998) provides more detail.

Figures 3.2 and 3.3 show a tandem pair of measurements referred to as KT14 and KP12. The mass flow rate was 13.8 kg/s and the discharge specific enthalpy was 1093 kJ/kg.

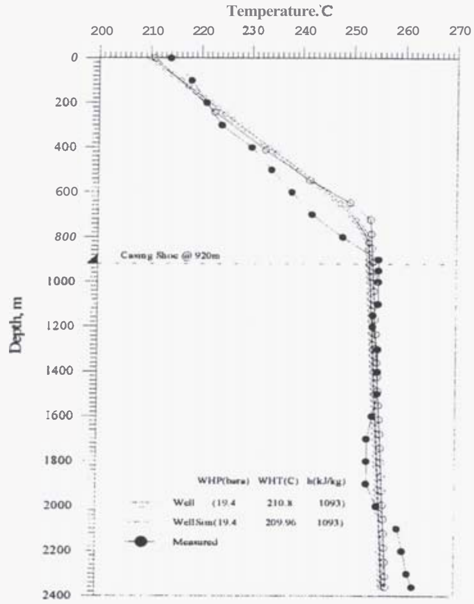

Fig 3.2 KT-14 temperature profiles for Well A

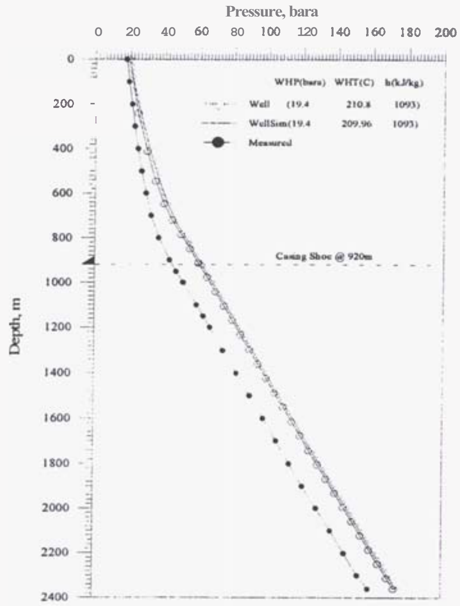

Fig 3.3 KP-12 pressure profiles for Well A

The saturation temperature for pure water at the measured wellhead pressure is 210.8°C, different from the measured wellhead temperature of 214°C, so the saturation temperature was used. The results of the WELLSIM and WELL closely match the measured temperature data in the interval between casing shoe depth and the bottom of the well (Figure3.2). Since the location of the production zone is not known, the comparison can not be examined any further. Figure 3.3 shows the measured flash point at about 880m depth, that predicted by WELL as 700m and by WELLSIM 780m depth, a better result for WELLSIM.

There is very close agreement in the predicted shapes of the distributions but neither simulator gives good agreement with the measured data.

3.2 WELL-B

Production casing is 9 5/8” to 600m, with 7” slotted liner to a total depth of 2100m. The roughness of the production casing was again taken as 0.000046m for both WELL and WELLSIM with liner roughness as 0.000046m and zero respectively.

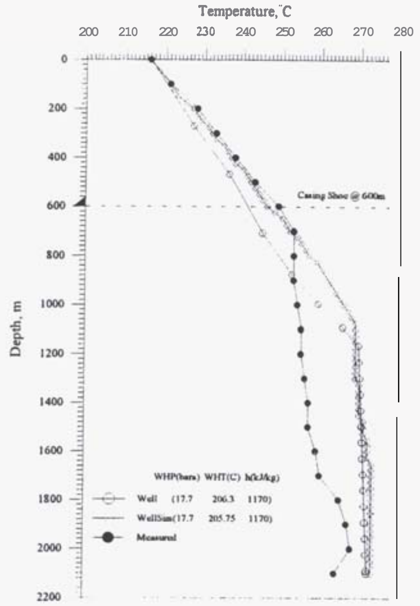

Fig 3.4 KT-21 temperature profiles for Well B

Figure 3.4 shows the results for the temperature measurements referred to as KT21, there being no pressure data. The mass flow rate was 13.8kg/s and the discharge specific enthalpy was 1170 kJ/kg. Pure water was again assumed because the wellhead measurements suggested this. The flash points predicted are almost the same, but the measured value is very different. Above the measured flash point, in the production casing, the WELLSIM prediction is much better than that of WELL. The success is suspicious in view of the flash point locations, as the void fractions at every depth would be very different.

Figure 3.5 shows the results of a pressure survey in Well B, KP-13, for which the mass flow rate was again 13.8kg/s and discharge specific enthalpy 1170 kJ/kg. Neither simulator gives good predictions; WELLSIM is closer than WELL.

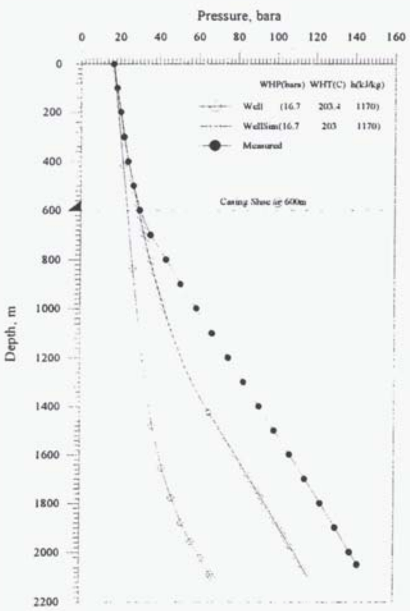

Fig 3.5 KP-13 pressure profiles for Well B

4. COMPARISON OF THE PREDICTIONS OF A DISCHARGE CHARACTERISTIC

The Rotorua well 703 was used because it has a long production casing. The production casing is 4½" diameter to 123m, below which is open hole of 5 ½" with no slotted liner, to a total depth of 206m. The roughness of the casing and open hole were taken as 0.000046m. Pure water was assumed.

To make the comparison using WELLSIM a mass flow rate of 8 kg/s was used, with a WHP of 8.5 bar abs and specific enthalpy of discharge of 900 kJ/kg. The predicted bottomhole temperature and pressure were 172.06°C and 13.78 bar abs respectively. The specific enthalpy of saturated water at this condition is 830 kJ/kg, indicating a slightly two-phase feed. With this reservoir pressure the discharge characteristic was calculated with the result shown in Figure 3.6. The production was assumed to come entirely fiom the bottom of the well.

An identical approach with WELL gave predicted reservoir conditions of 13.86 bar abs, 194.56°C and 902.0 kJ/kg for the same 8 kg/s mass flow rate, very close to the WELLSIM values. The discharge characteristic was then predicted assuming the same reservoir conditions as for WELLSIM. Figure 3.6 shows that WELL predictions are significantly better than those of WELLSIM.

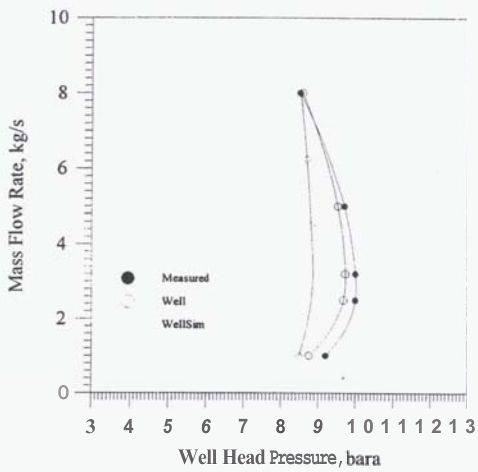

Fig 3.6 Discharge characteristic for Rotorua well 703

5. THE APPLICABILITY OF THE TWO-PHASE FLOW CORRELATIONS USED

There are two fundamental differences between a heated and a flashing flow. Firstly, the shape of a plot of void fraction (or dryness fraction) versus depth is different. For a flashing flow the bubbles appear at the flash depth and then grow because of the vertical pressure gradient. As the pressure reduces upwards, the specific volume of the fluid increases and also some additional fluid evaporates to maintain saturation conditions. In contrast, for a heated flow the void fraction grows because of the above processes but also because of the specific enthalpy of the fluid is being increased by the heating. The plots of void fiaction versus depth are more like a step change followed by a slight linear increase in a flashing flow, and a step change followed by a much more significant linear increase in a heated flow.

Secondly, in the flow over a wet heated wall the bubbles nucleate on the wall and move into the main flow. When the wall is dry, in annular flow for example, the water moves as droplets which evaporate in the steep temperature gradient near the wall. The dryness fiaction changes with axial distance according to the heat flux applied at the wall. In a geothermal well the flow flashes due to the pressure reduction up the well; the heat flux at the wall is small and negative, being a loss to the surroundings. Bubble nucleation will take place on the wall, as with boiling, but also on particles in the flow because the radial temperature variation will be negligible. The bubble growth rate and shape are likely to be very different, and the two-phase flow distribution may also. Droplets will still evaporate, but at a much slower rate.

Wallis (1969) provides an analysis of homogenous one dimensional flow that is satisfactory for examining the first of these differences. For a constant diameter vertical pipe he obtained the continuity, momentum and energy equations in the form :

$$-\frac{dp}{dz} = [2C_f G^2(v_l + xv_{lg}) + G^2 v_{lg}.\frac{dx}{dz} + g/(v_l + x.v_{lg})]/[1 + G^2(x.\frac{dv_g}{dp} + (1-x).\frac{dv_f}{dp}]$$

where G is mass velocity, v is specific volume, x dryness fiaction, p pressure, h specific enthalpy, D diameter and z the vertical dimension (depth). C_f is a friction factor. The suffixes l and g refer to liquid and vapour respectively and lg is the difference on change of phase.

This equation is the basis for the assumption that the pressure drop is made up of three independent parts due to friction, momentum (or acceleration) and gravity, corresponding to the three terms in the numerator respectively. The three terms are truly independent only for the one dimensional case, and any radial variations must be taken care of by the use of correlations.

The term $G^2 v_{fg}$ dx/dz is the acceleration term, in which dx/dz may be expanded to :-

$$\frac{dx}{dz} = (\frac{\partial x}{\partial h})_p.(\frac{dh}{dz}) + (\frac{\partial x}{\partial p})_h.(\frac{dp}{dz})$$

$$= \frac{4q}{GDh_{lg}} + (\frac{\partial x}{\partial p})_h.(\frac{dp}{dz})$$

where q is the heat flux. These are the heating and flashing components of the acceleration pressure drop respectively. $(dx/dp)_h$ is simply a property of water. For pressure gradients of the magnitude shown in the figures of this paper, the flashing term in eqn **2** is of order 5.0 x 10-5/m.

Taking a boiler tube of 50mm diameter with a high heat flux of 0.1MW/m^2 and mass velocity G of 1000kg/sm^2, typical of the parameters on which the ESDU correlation set is based, the heating term is of order **4.0** x 10^{-3}/m. In other words the acceleration term is two orders of magnitude greater for the data from which the ESDU correlations were formed than it is in a geothermal well. In physical terms, the entire flow regime should therefore be different, and the use of the correlations should not be expected to be reliable for use with wellbore flows.

It is impossible to be certain but whilst WELLSIM is based on the correct type of correlation, it appears that the available data to form these are so limited that they are not always accurate. On the other hand, WELL is based on an extensively researched set of correlations but of the wrong type - heated not flashing flows. Given that the measured wellhead discharge rate and specific enthalpy are not very accurate, perhaps to **10%**, the result of comparing the simulators with measurements is spasmodic agreement.

6. CONCLUSIONS

For the very limited range of comparisons made, neither simulator always gives good agreement with the measurements but both showed some instances of good agreement.

The use of heated two-phase flow correlations should not, in principle, be used to predict wellbore (flashing) flows as in WELL, but because of limitations in measurement accuracy their use may be acceptable.

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