SIGNIFICANCE OF THE MAXIMUM DISCHARGING-PRESSURE OF GEOTHERMAL WELLS

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ABSTRACT

It would be impressive to raise the wellhead pressure of a hot-water geothermal borehole to the maximum sustainable by flow and from this deduce the supply water temperature, rate of discharge, dryness fraction and density of the wellhead fluid. All this data can, in fact, be obtained from the reading of the pressure gauge installed below the wellhead control valve so long as the flow condition is that given above. The tentative results can be valuable for untested wells drilled in isolated areas; and for monitoring production wells as it permits estimates to be made of changing subterranean conditions.

INTRODUCTION

From the early days at Wairakei, it was noted that wellhead pressures could only be raised to a certain maximum value when throttling discharge. Any attempt to raise it further resulted in collapse of the flowing steam-water mixture and closure of the well. From a wide-open vertical discharge of about 500 t/h, the most productive wells would reduce to about 110 t/h at a Maximum Discharging-Pressure (MDP) of 25.7 bars or thereabouts. This was for 0.2 m diameter boreholes drilled into the Wairakei reservoir, which approximated to Boiling Point with Depth (BPD) down to about 460 m at 250°C. A correlation between the essential factors was calculated by James (1970) as:-

$$C = 99.75 \; P_m^{0.283} \quad \text{for} \quad 8 < P_m < 80 \quad \text{(see Notation)} \qquad (1)$$

Borehole tests in a number of countries have shown this equation to be surprisingly accurate (confirmed by downhole Kuster measurements on flowing wells) in estimating supply water temperatures from values of MDP; this in spite of steam-water mixtures being considered as homogeneous. Also, frictional pressure-drop was ignored, as was kinetic energy increase in the flowing fluid and potential energy requirements to elevate fluid to the wellhead. These were found negligible compared with the hydrostatic head imposed by the column of ascending steam-water mixture.

Hence $$P_s - P_m = \frac{0.981 \; L}{10 \; V_{sw}} \qquad (2)$$

where V_{sw} is the homogeneous steam-water specific volume taken at the average pressure of $\frac{P_s + P_m}{2}$ over the flashing length L and at the enthalpy h of the supply water temperature C. The temperature with depth relationship in a reservoir which has a boiling mixture down to a level below which pressurised hot water exists is shown on Figure 1 and has the equation:-

$$C = 69.56 \; L^{0.2085} \quad \text{for} \quad 30 < L < 3\,000 \qquad (3)$$

Even if a well is drilled to below depth L and then discharged at MDP, boiling will first start within the casing at very close to depth L associated with temperature C in the above equation. This, no doubt, explains the accurate results obtained whether fluid is supplied from the BPD zone or from greater depth within the pressurised hot water underlying it.

Equations (2) and (3) are required to solve for P_m. The results are given in equation (1), which is independent of well diameter due to the dominance of the hydrostatic head over frictional and kinetic energy effects. Using the latter equation, for various values of P_m, the associated supply water temperatures and enthalpies are given in Table 1.

DRYNESS FRACTION AND SPECIFIC VOLUME AT THE WELLHEAD

When the wellhead pressure equals P_m, it is of interest to see how the dryness fraction and specific volume of the steam-water mixture varies. Values are calculated and given in Table 1 and it is seen that, over a range of P_m up to 70 bar, dryness fraction

$$q\% = \frac{P_m}{4} \qquad (4)$$

while V_{sw} is approximately constant at 6 $m^3/_t$.

In other words, whatever the water temperature (up to 332°C) supplying the well at MDP, the density of the steam-water mixture at the wellhead is fairly constant It appears likely that 'Bubble' flow takes place over the lower levels of the well with 'Churn' flow at higher levels, as described by Taitel et al. (1980). For these conditions, at MDP, both steam and water phases travel at approximately the same velocity, hence the concept of homogeneity adopted here is a realistic one.

FLOW-RATE AT MDP

MDP values of boreholes in New Zealand are recorded by the Ministry of Works and Development, and a study of flow-rates at different supply water enthalpies h and bore diameters d, gives the pragmatic rule

$$W = 2.5 \; h \; d^2 \qquad (5)$$

Values of flow-rate are given in Table 1 for a well of 0.2 m diameter.

MIXTURE VELOCITY AT THE WELLHEAD

To determine the velocity of the steam-water mixture at the wellhead, upstream of the control valve.

$$\text{At MDP,} \quad u_{sw} = \frac{W \quad V_{sw}}{\frac{\pi}{4} \; d^2 \quad 3600}$$

Substituting W of equation (5), and taking the value of $V_{sw} = 6$ as constant over the range of interest where $P_m \leq 70$ bars.

$$u_{sw} = \frac{h}{188.5} \qquad (6)$$

As expected, mixture velocity is independent of borehole diameter and increases with supply water temperature and P_m as shown in Table 1.

TABLE 1 Physical Factors related to P_m for a Geothermal Well flowing at Maximum Discharge Pressure. W values for d = 0.2 m.

P_m	C	h	q%	V_{sw}	W	U_{sw}
10	191.4	814	2.54	6.03	81.4	4.32
20	232.9	1002	4.93	6.03	100.2	5.32
30	261.2	1140.6	7.36	6.03	114.0	6.05
40	283.3	1254	9.73	5.97	125.4	6.65
50	301.8	1354.1	12.19	5.94	135.4	7.18
60	317.8	1445	15.27	6.07	144.5	7.67
70	332	1535	17.81	5.99	153.5	8.14
80	344.7	1627	21.53	6.15	162.7	8.63
90	356.4	1724.7	26.21	6.41	172.5	9.15
100	367.2	1848	33.4	6.99	184.8	9.8

CONCLUSIONS

From a simple test on a hot-water geothermal well, the Maximum Discharging-Pressure gives a lot of information, and it is hoped it will gain world-wide use. Production wells can be occasionally checked for fall in P_m due to decline in the supply water temperature at depth, as a change as small as 1 degree C will be reflected in a measurable variation in the wellhead pressure gauge as determined by equation (1).

The concept of homogeneity, although not popular in the literature of two-phase flow, appears to apply to the ascent of geothermal steam-water mixtures over large distances and within the enthalpy range of hot-water reservoirs.

NOTATION

C	boiling water temperature at depth L, ^{o} Celcius
d	wellbore diameter, metres
h	boiling water enthalpy associated with C, kj/kg
L	depth, metres
P_m	Maximum Discharging-Pressure (MDP) at wellhead, bars
p_s	boiling water pressure associated with C, bars
q	dryness fraction of steam-water mixture at wellhead
u_{sw}	velocity of steam-water mixture at wellhead, m/s
v_{sw}	specific volume of steam-water mixture at wellhead, m^3/t
W	flow-rate at Maximum Discharging-Pressure, t/h

ILLUSTRATIVE EXAMPLE

Under discharging conditions, the wellhead pressure of a previously untested borehole is throttled to a maximum value of 37 bars gauge. What provisional deductions can be made, assuming a borehole diameter of 0.2 m, and atmospheric pressure of 1 bar?

Maximum Discharging-Pressure $P_m = 37 + 1 = 38$ bars

From Figure 1 or equation (1), $C = 99.75\ (38)^{0.283} = 279.25^{o}C$
This is the temperature of the water supplied to the well at depth, and from Steam Tables has an enthalpy $h = 1235$ kj/kg
From equation (5), $W = 2.5\ (1235)\ (0.2)^2 = 123.5$ t/h which is the flow at a wellhead pressure of 38 bars.
Conditions at the wellhead are as follows:-
From equation (4)
Dryness fraction as a percent $q\% = \frac{P_m}{4} = \frac{38}{4} = 9.5\%$

As the value of P_m is less than 70 bars, the specific volume of the steam-water mixture is constant at 6 m^3/t and density is the reciprocal 0.167 t/m^3. Wellhead mixture velocity (homogeneous) from equation (6),

$$u_{sw} = \frac{1235}{188.5} = 6.55 \text{ m/s}$$

Note This is not just an academic exercise as the above example is taken from the new Kawerau well KA 30 which was afterwards tested over a range of wellhead pressures. At the MDP of $P_m = 38$ bars, enthalpy was measured as 1235 kj/kg and flow W as 121 t/h, which is close confirmation of the above estimates.

REFERENCES

James, Russell (1970): Factors Controlling Borehole Performance. Geothermics-special issue, 2, 2, pt 2, p. 1502.

Taitel, Y., D. Bornea and A.E. Dukler (1980): Modelling Flow Pattern Transitions for Steady Upward Gas-Liquid Flow in Vertical Tubes AIChE J., 26, 3, p. 345.

Figure 1 Temperature versus depth and Maximum Discharge Pressure P_m for boiling throughout Reservoir, with 100° at Surface.