PROCEEDINGS, Thirteenth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 19-21, 1988
SGP-TR-113

THE DEPTH OF FEED WATER INFLUENCES MAXIMUM DISCHARGE-PRESSURE OF HOT WATER GEOTHERMAL WELLS

Russell James

Geothermal Research Centre, Wairakei,
D.S.I.R., Private Bag, Taupo, New Zealand

ABSTRACT

The maximum wellhead pressure at which hot water wells discharge is an important parameter for geothermal power and as it slowly declines with years of exploitation presents a moving target for project designers.

It can also decrease rapidly for newly closed-in wells (within days or even hours) to a point at which auto-discharge is impossible and tedious techniques have to be employed to restart flow.

The common cause of this phenomenon is reduction in the temperature of the hot water feeding the well; in the former case is the result of a general decline in the reservoir water enthalpy, and in the latter is due to cooler denser water from higher in the uncased part of the well percolating down and flooding the lower more permeable levels from which a discharging well mainly draws its fluids.

The inter-relationship of feed water temperature, depth and maximum discharging-pressure is determined in this study with illustrated examples demonstrating application.

INTRODUCTION

The highest well head pressure which can be attained by a hot water geothermal well is related to the feed water temperature and in the particular case where the subterranean reservoir is at Boiling Point with Depth (BPD), the relevant relationships have been deduced James (1980). These are as follows, with notation given later in metric units.

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

$$C = 69.56\, L_m^{0.2085} \quad \text{for } 30 < L_m < 3000 \qquad (2)$$

Although the BPD condition is common for hot water reservoirs, it is not unusual to find fields where displacement of this zone is downwards, or even upwards, by an amount which formerly could only be determined by careful downhole measurements under discharge. Such measurements have now been accomplished and indicate that the following equation is applicable:

$$P_m L_m^{0.574} = P_x L_x^{0.574} \qquad (3)$$

As an example of the use of this equation we can consider a well whose feed water temperature was measured at 247°C and from equations (1) and (2) with BPD prevailing, $P_m = 24.63$ and $L_m = 436$. The actual value of MDP was $P_x = 19.24$. When these values are substituted in equation (3), it is found that $L_x = 670.7$ which represents a displacement downwards of the BPD by 670.7 - 436 equaling 234.7 m.

Another well with feed water temperature of 320°C gave an actual MDP of $P_x = 67$ while from equations (1) and (2), $P_m = 61.5$ and $L_m = 1509.6$. Using these values in equation (3) gives $L_x = 1300$ which represents a displacement of the BPD upwards by 1300 -1509.6 equaling - 209.6 metres. Downhole measurements confirmed these figures.

It should be noted that the discharge at the highest operating wellhead pressure (MDP) is usually quite large being of the order of 100 t/h for a 0.2032 diameter well with a feed water temperature of 250°C. This condition is not the same where a well is discharging through a small "bleed" pipe of about 20 mm diameter as in this case flows are of the order of 1 t/h as studied previously, James (1987). The bleed condition is a long-term small discharge whose purpose is to retard corrosion in a well and to avoid differential expansion of the steel casing with possible rupture when full flow is required. Some wells if fully closed can also gradually increase in well head pressure due to the presence of non-condensible gas (mainly carbon dioxide) up to a point at which they exceed the safe working pressure of surface equipment; bleeding retards this gas pressure build-up to acceptable values and is mandatory where gas generation is suspected.

DECLINE IN MDP (SLOWLY)

Under production discharge, flow rate and MDP decline with time and in fact these parameters are roughly proportional to each other (so long as factors such as mineral deposition within the well does not intrude). The cause of this decline is sympathetic fall in the feed water temperature entering the well, and this is usually found to be precisely at the boiling point for the pressure.

For example, one of the most powerful of the Wairakei wells, WK30, originally derived its flow from a permeable horizon at a depth of 564. Flashing of the 254°C water took place at a depth of 499 giving a MDP of about 27.2. After 25 years of production, the MDP has fallen to 12.3 with flashing over the whole depth of 564 now taking place. To determine the associated feed temperature from these data in place of actual downhole measurements, which would require taking the well off production (not an attractive idea to the power station engineers) requires re-arranging the equations, as follows:

Substituting C for both P_m and L_m from equations (1) and (2) in (3), we have:

$$C = 85.1835\ P_x^{0.1591}\ L_x^{0.0913} \qquad (4)$$

Hence for $P_x = 12.3$ and $L_x = 564$, C = 226.4°C.

Downhole measurements made while bleeding the well in 1986 gave a Bottom Hole Temperature (BHT) of 226.5°C which is in good agreement with this result and for most other wells of that area for approximately the same depth.

DECLINE IN MDP (RAPIDLY)

Compared with the slow decline of MDP under production, some wells when fully closed or even when bleeding, decrease in wellhead pressure to a point at which they are difficult or impossible to start, without employing pressurising techniques or other means of starting discharge. When this is likely, engineers are hesitant about closing such wells - even for important measurements -because of the chance of losing flow completely. The cause of such relatively rapid decline in MDP (a matter of weeks rather than the years of production) is almost certainly due to fall in the water temperature within the well. And this is likely to be due to "cooler" water percolating down from minute fissures higher up the well in the uncased region. These fissures make a negligible contribution to flow when commercial discharges are taking place but when the well is closed (or bleeding) even a relatively small seepage of 1 litre/sec at say 150°C would flood the well bottom with over 600 m^3 of water in a week. It appears probable that flows much less than 1 litre/sec would also exert a considerable effect on the MDP and thus the ability of a well to autodischarge.

For closed wells which have long lengths of casing, it is possible that heat loss to cooler zones of the reservoir will result in cooling of internal fluids with the same overall effect but this is not so certain as for an uncased length.

For autodischarge to be possible, it would appear reasonable that the value of MDP should always exceed atmospheric pressure which we can assume at roughly 1 bar. If, for example, we take this figure together with a depth of L_x = 564 as for well WK30 at Wairakei, then equation (4) gives a water temperature of 152°C. For water of this temperature percolating downwards in the well, the MDP would not exceed atmospheric pressure and hence the well should not be capable of spontaneous discharge when the wellhead valve is open.

Although the accuracy of equation (1) is reduced where P_m is less than 8 ba and hence equation (4) cannot be accepted as exact, the relationship is considered reasonably correct. This is somewhat confirmed by results on Wairakei well WK107 which declined in output until it could not be discharged when the wellhead pressure had fallen to near atmospheric. Downhole measurements with the "Spinner" showed the existance of a downflow of cooler water at 140°C at 300 metres depth within the uncased portion of the well. When this horizon was sealed off, the well head pressure increased, and it was resurrected as a production well again.

Boiling point temperatures which are insufficient to give a wellhead pressure exceeding atmospheric (at 1 bar) are tabled below at various depths and have been calculated from equation (4).

TABLE 1: Boiling water temperatures at depth whose vertical flow develops a well head pressure of 1.0 bar abs.

Depth	230	500	1000	1500	2000	2500	3000
Temp	140	150	160	166	171	174	177

Illustrated Example 1

The Maximum Discharge Pressure (MDP) is 31 bar for a well which boiling water enters at a depth of 1500 m. Estimate the water temperature and likely displacement of the BPD zone. From equation (4),

$$C = 85.1835\ 31^{0.1591}\ 1500^{0.0913}$$
$$= 286.8°C \text{ water temperature}$$

From equation (2),

$$286.8°C = 69.56\ L_m^{0.2085}, \text{ hence } L_m = 893$$

Displacement of the BPD downwards = 1500 - 893 = 607 metres.

Illustrated Example 2

At Wairakei, production wellhead pressures are about 7 bar. What temperature of boiling water entering wells at 564 metres will give Maximum Discharging Pressures of 10, 9, 8, and 7 bar? From equation (4), for L_x = 564.

$$C = 85.1835\ P_x^{0.1591}\ 564^{0.0913}$$
$$= 151.9\ P_x^{0.1591}$$

For values of P_x = 10, 9, 8, and 7, boiling water feed temperatures are respectively 219.1°C, 215.5°C, 211.5°C and 207°C.

These temperatures may be close to the minimum which is acceptable to give reasonably stable flows when MDP approaches the production well-head pressure.

CONCLUSIONS

Geothermal wells which derive their flow from subterranean hot water have hitherto been considered as more complex than wells which discharge only dry steam. The use of the MDP can however give vital data on downhole conditions in the former and bring it more in line with the simplicities of the latter.

Its plot versus time for power production wells may be a useful aid in predicting the terminal condition where MDP approaches or coincides with the production well-head pressure.

NOTATION

C boiling water temperature, degree celcius

P maximum discharging pressure (MDP), bar

L depth in well from ground surface, metre

Suffixes

m for reservoir at boiling point with depth (BPD) where top is 100°C at ground surface

x condition which may diverge from ideal BPD

REFERENCES

James, R. (1980): Significance of the Maximum Discharging Pressure ofGeothermal Wells. Proc. 6th Workshop, Geothermal Reservoir Engineering, Stanford University, Stanford, California, U.S.A.

James, R. (1987): Bleeding Characteristics of Geothermal Wells. Proc. 12th Workshop, Geothermal Reservoir Engineering, Stanford University, Stanford, California, U.S.A.