Proc. 10th New Zealand Geothermal Workshop 1988

POWER POTENTIAL OF INITIAL BORE DISCHARGE

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ABSTRACT

The electric power potential of a discharging geothermal well is determined from the product of three parameters; thermal efficiency, flowrate, and stagnation enthalpy. The first factor is sensitive to enthalpy and when a lip pressure tapping is used, so is the second factor.

For a dry steam discharge, the stagnation enthalpy can be taken as 2804 kJ/kg so that all parameters are calculable, hence permitting the power potential to be evaluated.

For wells fed from a hot water reservoir, the maximum discharging-pressure is used to determine enthalpy; hence for both types of wells, A quick result is achieved with minimum equipment and of adequate accuracy.

INTRODUCTION

A newly discharged geothermal well usually has minimum equipment installed and quite often the efflux of steam or steam-water is vented vertically. Naturally, there is considerable interest technically (and politically) to have an immediate estimate of the power potential of the first discharge. To accomplish this, it is of course possible to have complete separation and metering equipment erected at the wellhead by advanced planning; however this would be extremely expensive and worst still, the well may prove to be a dud and hence all the time, trouble and cost will have been to no avail.

A technique to overcome this problem was presented earlier (James, 1975) in which a lip pressure tapping was all that was required to be able to evaluate directly the power potential in megawatts of electricity of which the well was capable. Assumptions made at the time were that double-flash would be involved with a thermal efficiency of 0.10 for wells discharging steam-water mixtures. For the case of completely dry saturated steam discharges, enthalpy was taken as 2794 kJ/kg and a thermal efficiency of 0.15. It was recognised that for fields of enthalpy similar to that at Wairakei (1085 kJ/kg), a power station based on single-stage flash would have a thermal efficiency of about 0.075; however it was assumed that double-flash was likely to be the wave-of-the-future hence the higher value of thermal efficiency was considered appropriate. Today, this is not so sure because of the widespread insistence that reinjection should be employed and also because of the drilling of higher temperature reservoirs. These have an increasing tendency to mineral deposition from the separated hot pressurised water which has to be transported by pipeline overland and then disposed of in injection wells.

To avoid problems associated with chemical scaling within overland pipelines and downhole injection wells, together with the even worse problem of choking reservoirs, the simplest solution is to employ one-stage separation at a pressure high enough to give hot water temperatures exhibiting minimum scaling characteristics. An advantage of this approach is that the separated hot water usually now has a sufficient pressure to permit its transmission overland and down injection wells without the aid of pumps (James, 1979).

Two other aspects would be useful to obtain a quick and adequately accurate determination of power potential. The first is to establish a relationship between the enthalpy of the flowing fluid (steam-water) and the thermal efficiency, and the other is to establish the enthalpy value itself.

THERMAL EFFICIENCY RELATED TO ENTHALPY

Because of the reasons given above, it would be useful to obtain this relationship for single-stage flash; in other words for one separator interposed between the wellhead and the turbine. James and Meidav (1977) presented such a relationship for both single-stage flash and double-flash and for various values of condenser pressure. In order to conservatively predict the power potential, we shall here consider only single-stage flash with a condenser pressure of 0.135 bar (4 inches of mercury).

Taking η_t = thermal efficiency, and h_o = enthalpy, kJ/kg.

$$\eta_t = 0.1807 - \frac{112.6}{h_o} \quad \text{for } 700 < h_o < 2800 \qquad (1)$$

This estimate of thermal efficiency* is based on a separator pressure of 5.17 bar and a turbine inlet pressure of 4.48 bar with exhaust at 0.135 bar. Although many geothermal fields have production wellhead pressures which much exceed this separation pressure initially, under exploitation, pressure decline takes place so that a longer project-life is gained for a lower separation pressure. Of course, if too low a pressure (of separation) is decided, then capital costs will be excessive, hence the value taken here is a balance of cost and time of exploitation to give maximum financial returns over the life of the field.

It is clear from equation (1) above that thermal efficiency is sensitive to the enthalpy of the well discharge. This presents no difficulty when the discharge is self-evidently that of saturated steam as for this case the enthalpy may be taken as 2804 kJ/kg which is the maximum value and occurs at a saturation vapour pressure of 30 bar. Many steam reservoirs approximate to this pressure so little error will be obtained when this enthalpy is assumed.

However, in the case of pressurised hot water reservoirs, a wide range of enthalpies exists and so it is necessary to estimate the feed water enthalpy which the borehole taps in order to achieve a reasonably accurate value of thermal efficiency.

*_The equation given in James and Meidav (1977) for single-stage flash was incorrect and should have been η_t = 0.1807 - 48.4/h_n with h_n in Btu/lb. Condenser at 4 inches mercury (0.135 bar).

ENTHALPY OF DISCHARGE OF HOT WATER WELL

As flows of steam-water mixtures discharging to the atmosphere at the speed of sound commonly attain 100 kg/s, it has proved difficult to estimate the enthalpy quickly and cheaply. Various workers have, however, attempted this feat such as Banwell (1957), Belin and Bainbridge (1957), James (1966), James et al. (1982) and James (1987). None of these techniques have proved popular and none are in current use on newly discharged wells as far as is known. However, there is one method which has proved easy, fast and often surprisingly accurate especially where the subterranean pressure approximates to the hydrostatic for hot water with depth measured from the ground surface. This approach depends on a relationship between the temperature of the hot water feeding the well and the maximum discharging-pressure at the wellhead, i.e. the highest operating pressure that the wellhead will sustain under commercial flow. The relationship was established between C the hot water temperature in degrees Celcius and P the maximum discharging-pressure (MDP) in bar by James (1980) as follows:

$$C = 99.75\, P_m^{0.283} \quad \text{for } 8 < P_m < 80 \qquad (2)$$

Once the temperature of the hot water is obtained from this equation, its enthalpy h_o may be derived from steam tables (Keenan et al, 1969), or less accurately from the following approximation:

$$h_o = 1.475\, C^{1.107} \quad \text{for } 210° < C < 350° \qquad (3)$$

DISCHARGE OF STEAM-WATER MIXTURES AT SONIC VELOCITY

The relationship between lip pressure P_c bar and flowrate w kg/s is given in James (1975) and the metric equivalent is as follows:

$$w = 1.444\,(10)^6 \frac{P_c^{0.96}\, d_c^2}{h_o^{1.102}} \qquad (4)$$

where d_c is the inside diameter of the discharge pipe in metres.

This relationship is independant of pipe orientation and the discharge may be horizontal or vertical, although the latter is common for first discharge as this requires the very minimum of wellhead equipment. To avoid damage to agricultural lands, atmospheric discharge is often undertaken when raining or when winds carry the efflux plume in a preferred direction.

POWER POTENTIAL OF DISCHARGE IN MEGAWATTS (ELECTRICAL)

The thermal efficiency is the fraction of the heat flux which is convertible into electric power at the turbo-generator, where heat flux ($w\,h_o$) is in units of kW of heat flowing. Convenient units for geothermal power are MWe, megawatts of electricity,

where
$$MWe = \frac{w\, h_o\, \eta_t}{1000} \qquad (5)$$

Hence employing equations (1) and (4) in (5), we have;

$$MWe = 1.444\,(10)^3 \frac{P_c^{0.96}}{h_o^{1.102}} \cdot \frac{h_o}{1000}\left(0.1807 - \frac{112.6}{h_o}\right)$$

$$MWe = 1444\, \frac{P_c^{0.96}\, d_c^2}{h_o^{0.102}} \left(0.1807 - \frac{112.6}{h_o}\right) \qquad (6)$$

PROCEDURE FOR FIRST DISCHARGE (Figure 1)

A well is usually discharged wide-open vertically for a few hours, or until a stable

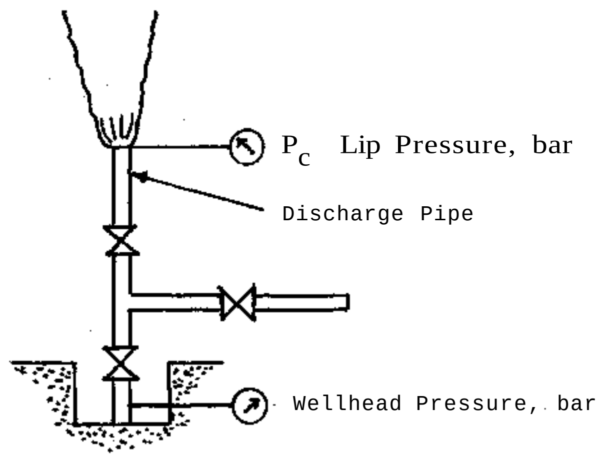

Figure 1 Geothermal Veil discharging to Atmosphere

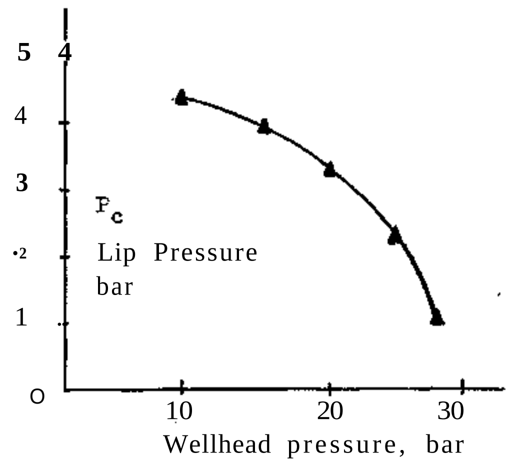

Figure 2. Plot of Li? Pressure versus Wellhead Pressure

condition is acquired, at which point the highest value of lip pressure is achieved (under steady flow conditions) and lowest wellhead pressure. The well is then slowly closed-in over a period of an hour or two, depending on the time to attain a stable flowrate which is reflected in a similarly steady wellhead pressure. During this closure-time values of lip pressure and wellhead pressure are noted and plotted on Figure 2 where typical coordinate points are shown through which a characteristic wellhead curve is drawn. Here it should be noted that the greatest lip pressure is 4.3 bar with the wellhead valve (or valves) wide-open; under severe throttling the wellhead pressure attains 28 bar which therefore is taken as the maximum discharge-pressure, P_m.

These values are, of course, merely displayed as examples; typically lip pressures are within the range 1 to 10 bar and maximum discharging-pressures within the range 10 to 100 bar, for the usual diameters of boreholes (0.15 to 0.30 metres).

ILLUSTRATED EXAMPLE 1

Taking Figures 1 and 2 as appropriate with the discharge a steam-water mixture assumed derived from an all-water source, we may accept equations (2), (3) and (6) as valid.

P_c = 4.3 bar, P_m = 23 bar and d_c = 0.20 metres

From equation (2), $99.75\ (28)^{0*283} = 256.13$°Celcius

From equation (3), $1.475\ (256.13)^{1{,}197}$
$= 1126.5$ kJ/kg $= h_Q$

At 256.13°C;from steam tables, h_o = 1115 kJ/kg which gives a slightly more accurate value.

From equation (6)

$$MWe = 1444\ \frac{(4.3)^{0{,}96}\ (0.20)^2}{1115 P\wedge}\ \ t\ \left(0.1807 - \frac{112.6}{1115}\right)$$

= 9.13 megawatts (electrical)

ILLUSTRATED EXAMPLE 2

For the same conditions of Figures 1 and 2 but where the efflux is obviously that of dry steam (or only very slightly wet) we may assume an enthalpy of 2804 kJ/kg, thus we dispense with equations (2) and (3) and only employ equation (6) as follows. Assume d_c = 0.20 metres as before.

$$MWe = 1444\ \frac{(4.3)^{0{,}96}\ (0.20)^2}{2804 U7L02}\ !\ \left(0.1807 - \frac{112.6}{2804}\right)$$

= 14.65 megawatts (electrical)

In both the above examples, the power potential can be calculated for all other values of lip pressures so that a curve similar to that of Figure 2 can be drawn which coordinates wellhead pressure and megawatts (electrical).

It should be noted that all other factors being equal, the greater the enthalpy, the greater the power potential. Occasionally, reservoirs are tapped having pressures less than hydrostatic and in this case the temperature (and hence enthalpy) is greater than that estimated from equation (2). This results in a power potential greater than that calculated from equation (6) with therefore gives a conservative result (this can later be rectified upwards when full — sized metering equipment is introduced).

If the reservoir has a degree of underpressure (compared with hyrostatic) which is known, then equation (2) can be corrected to give the higher and truer water temperature, as described by James (1988). This complication will not be pursued here as it is more applicable to an exploited field where drilled wells generally have atmospheric separator-silencers with integral lip-pressure and wei r-water meters.

When a well is first discharged, it is usually sampled to determine the gas concentration in the steam phase, and dissolved mineral concentration in the liquid phase of a steam-water well, Klyen (1982). High concentration of constituents in the phases can reduce the power potential of the discharge and has been described by Dipippo (1987) who presents correction factors.

CONCLUSIONS

Utilizing the very minimum of wellhead plant (see Figure 1), it is possible to gain an estimate of the electric power potential of a discharging well whether its fluid is dry steam or a steam-water mixture of unknown enthalpy. The latter can be determined for wells tapping a source of pressurised hot water by employing the maximum discharging-pressure and gives a conservative result for power which may be exceeded in practice.

Some steam-water wells have steam fractions which are boosted by extra primary steam entering at the inflow permeable horizon; such wells often have enthalpies intermediate between those supplied from a hot water reservoir and those tapping a supply of dry steam. These high enthalpy wells will have proportionately higher power potential compared with those drawing hot water alone. There is still a need therefore, for a simple, cheap and rapid means of identifying the unknown enthalpy of discharging steam-water mixtures.

This is not an easy task as significant gas may supplement the steam phase, and the water phase may contain very high concentrations of dissolved chemicals ranging up to 300,000 ppm; hence the number of variables may prove too great to permit the success of a technique which evaluates the enthalpy of all types of geothermal fluids (multi-phase and multi-component).

NOTATION

C Boiling water temperature, degrees Celcius
d_c Inside diameter of discharge pipe, metres
h_o Fluid enthalpy, kJ/kg
MWe Power, megawatts of electricity
P_c Lip pressure, bar
P_m Maximum discharging-pressure, bar
w Rate of discharge, kg/s
η_t Thermal efficiency

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