Rapid Estimation of Electric Power Potential of Discharging Geothermal Wells

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ABSTRACT

By means of a lip pressure tapping at the end of the pipe discharging geothermal fluid to the atmosphere under the usual conditions of critical flow (mixture at sonic velocity), it is shown that a fairly accurate estimate can be made of the amount of electric power of which the well is capable. This applies both to wells deriving their flows from a dry steam reservoir and to those based on a pressurized hot-water system.

INTRODUCTION

When a newly drilled well is first discharged vertically, it normally takes some hours before the flow and pressures are stabilized. After this point is reached, it may be weeks, or even months, before the necessary equipment is assembled to measure the flow and enthalpy so as to estimate the electrical energy which the well could contribute to a power project. However, an estimate of adequate accuracy can be made right from the start with the stabilized well discharging vertically. The method merely entails attaching a lip pressure gauge at the extreme end of the discharge pipe (whose internal diameter must be measured). This simple device is all that is required, and it has been described in an earlier paper (James, 1962). It is now in common use in many geothermal fields in conjunction with twin-tower silencers for measuring the flow and enthalpy of steam-water mixtures.

In order to use this method, the efflux jet must be cursorily examined to see whether the discharge is fairly dry steam or an obvious steam-water mixture: the former is fairly transparent, whereas the latter is opaque. Slightly wet steam usually becomes dry after a few days of discharge if the well penetrates one source of fluid, whereas a steam-water jet indicates that the flowing enthalpy is most likely in the range of 400 to 600 Btu/lb, based on experience of actual well discharges.

WELLHEAD PRESSURE

If a turbine inlet pressure of 50 psig is required (James, 1967) and if a pressure-drop of 25 psi is allowed between the turbine entrance and the wellheads of suppling boreholes, then obviously the least acceptable wellhead pressure must be 75 psig, to be realistic under test conditions. But because of the decline in reservoir pressures under exploitation which progressively lowers the wellhead pressure over the life of the field, it would appear prudent to throttle the flow initially and hence start with a wellhead pressure of not less than, say, 175 psig. This excess pressure at the wellhead of 100 psi "in hand" can be lowered with time by releasing the amount of throttling, in order to sustain the discharge. For instance, if the pressure declines at a rate of 10 psi/yr, then 10 years would pass before the wellhead pressure had dropped to a value of 75 psig. A further pressure fall would drop the turbine inlet pressure below its design pressure of 50 psig, and hence reduce electric energy output.

It was not found necessary to throttle the Wairakei wells because in the early days of the project the wellhead pressures were quite high. For example, Well 67 had a wellhead pressure of 156 psig when discharging wide-open vertically through an 8-in. diameter discharge pipe. When switched to horizontal discharge—also through an 8-in. pipe—the wellhead pressure rose to 220 psig while the lip pressure fell from the vertical value of 70 psig to the horizontal value of 46 psig. These values show the effect on the flow of passing through a 90° angle when discharging horizontally. The resulting discharge is reduced to 0.73 of the vertical (as flow is proportional to lip pressure in absolute terms at a constant enthalpy). Similarly, the absolute wellhead pressure rose in inverse proportion from 156 + 14.5 = 170.5 psia to $0.73^{-1} \times 170.5 = 233.5$ psia = 219 psig. Absolute pressure at Wairakei averages 14.5 psia (1400 ft above sea level).

PROCEDURE

With the well discharging vertically under stable conditions and with the flow throttled so that the wellhead pressure is 175 psig, the value of lip pressure, P_c, is noted. Figure 1 shows a typical wellhead arrangement—the horizontal by-pass is often extended into a silencer. Figure 2 indicates the geometry of the lip pressure hole, which is drilled into the discharge pipe near its end-face. A socket is welded externally at this location and connected to a pressure gauge.

If the discharging jet is a steam-water mixture, Equation (A) from the appendix is used with English units where P_c is in psia and d_c is in inches. The metric equivalent is Equation (B) where P_c is in bars (absolute) and d_c is in centimeters. Where the jet is obviously dry steam, Equation (C) is used or its metric equivalent, Equation (D).

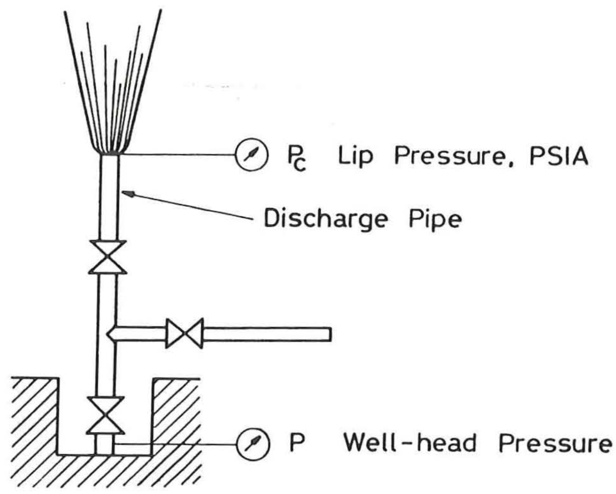

Figure 1. Geothermal well discharging to atmosphere.

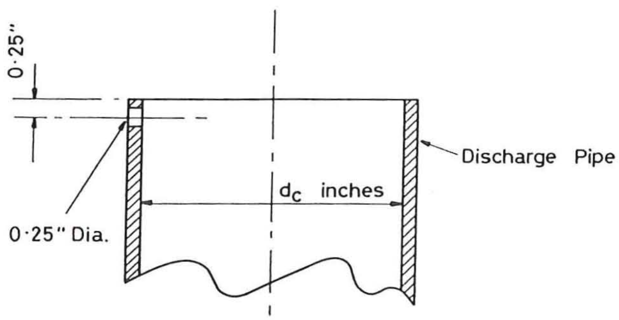

Figure 2. Lip pressure tapping dimensions in discharge pipe.

ILLUSTRATIVE EXAMPLE

The well shown in Figure 1 is discharging a steam-water mixture under stable flow with a lip pressure, P_c, of 45 psig. The internal diameter of the discharge pipe is 8 in., and atmospheric pressure is 14.7 psia. Calculate the electric power in megawatts which the well can produce

$$\text{electric power} = P_c^{0.96}\left(\frac{d_c}{16.94}\right)^2$$

$$= (45 + 14.7)^{0.96}\left(\frac{8}{16.94}\right)^2$$

$$= 11.31$$

If metric units are used, $P_c = (45 + 14.7)/14.5 = 4.12$ bar and $d_c = 8 \times 2.54 = 20.32$ cm. Using Equation (B)

$$\text{electric power} = P_c^{0.96}\left(\frac{d_c}{11.92}\right)^2$$

$$= 4.12^{0.96}\left(\frac{20.32}{11.92}\right)^2$$

$$= 11.31$$

For the same values but if the discharging jet is dry steam, Equation (C) is employed for English units as follows:

$$\text{electric power} = P_c^{0.96}\left(\frac{d_c}{14.48}\right)^2$$

$$= (45 + 14.7)^{0.96}\left(\frac{8}{14.48}\right)^2$$

$$= 15.47$$

Using metric units, Equation (D) is employed.

$$\text{electric power} = P_c^{0.96}\left(\frac{d_c}{10.19}\right)^2$$

$$= 4.12^{0.96}\left(\frac{20.32}{10.19}\right)^2$$

$$= 15.47$$

CONCLUSIONS

For discharges composed of steam-water mixtures within the enthalpy range 400 to 600 Btu/lb, it is probable that the electric power potential of a well can be estimated to within ±5%, assuming that the thermal efficiency of converting heat energy to electric energy is 0.10. It is likely that with careful design or a power project, this value of thermal efficiency can be somewhat exceeded when employing separation of the phases in two pressure stages; hence the estimated power will be slightly conservative.

For the discharge of dry steam, the accuracy will be improved as the enthalpy is less prone to wide variation, according to data from existing steam fields.

Power-house auxiliaries (cooling-water pumps, gas extractors, and so on) usually impose a toll of up to 5% in geothermal stations; hence the electric power calculated by this method would have to be reduced by that amount to gain a first estimate of net power.

APPENDIX

The basic formula connecting flow rate, enthalpy, and lip pressure (James 1962) is:

$$\frac{G h_0^{1.102}}{P_c^{0.96}} = 11400$$

where G is in lb/ft²·sec, P_c = psia, h_0 = Btu/lb (enthalpy), and the specific heat flow is (Gh_0) in Btu/ft²·sec = $(11400\, P_c^{0.96}/h_0^{0.102}$. If the internal diameter of the discharge pipe is d_c (in.), then the heat flow in Btu/hr is

$$(Gh_0)\frac{\pi}{4}\left(\frac{d_c}{12}\right)^2 60^2 = (Gh_0)\, 19.6 d_c^2$$

$$= \frac{11400\, P_c^{0.96}\, 19.6\, d_c^2}{h_0^{0.102}}$$

Converting heat flow to megawatts of heat MW(H), where 3.412×10^6 Btu/hr = 1 MW(H)

$$\text{MW(H)} = \frac{11400 P_c^{0.96}\, d_c^2\, 19.6}{h_0^{0.102}\, 3.412 \times 10^6} = \frac{P_c^{0.96}\, d_c^2}{15.27\, h_0^{0.102}}$$

To convert heat energy, MW(H), to electric energy, MW(e), the thermal efficiency η_t is used; hence $MW(e) = \eta_t MW(H)$. In the case of dry-steam systems such as Larderello and The Geysers, the thermal efficiency $\eta_t = 0.15$. For systems discharging steam-water mixtures and which use steam separated in two pressure stages, $\eta_t = 0.10$. The difference is due to the large quantity of hot water rejected at the wellheads or from surface equipment when a hot-water system discharges mixtures from the wells. At Wairakei, where only one stage of separation was employed, the thermal efficiency was 0.075, whereas a study of the El Tatio geothermal field in Chile showed that a thermal efficiency of 0.1054 could be obtained when separation was in two pressure stages. As we are considering a field prior to a feasibility study, a thermal efficiency rounded to 0.10 was considered quite adequate for present estimates and is somewhat on the conservative side.

$$MW(e) = \frac{\eta_t P_c^{0.96} d_c^2}{15.27\, h_0^{0.102}}$$

For steam-water discharges within the enthalpy range 400 to 600 Btu/lb,

$$400^{0.102} = 1.843$$
$$600^{0.102} = 1.920$$
$$\text{average} = 1.881 \text{ accurate to } \pm 2\%$$

thermal efficiency, $\eta_t = 0.10$

$$MW(e) = \frac{P_c^{0.96} d_c^2}{287.08} = P_c^{0.96} \left(\frac{d_c}{16.94}\right)^2 \qquad \text{(A)}$$

Hence the only data required to obtain an estimate of the electric power potential of a geothermal well are the lip pressure and the internal diameter of the discharge pipe. For metric units where the lip pressure is in bars (absolute) and the internal diameter of the discharge pipe in centimeters, the formula is:

$$MW(e) = P_c^{0.96} \left(\frac{d_c}{11.92}\right)^2 \qquad \text{(B)}$$

For wells discharging dry steam, the enthalpy $h_0 \simeq 1200$ Btu/lb and $1200^{0.102} = 2.061$. Also thermal efficiency $\eta_t = 0.15$.

$$MW(e) = \frac{P_c^{0.96} d_c^2}{209.81} = P_c^{0.96} \left(\frac{d_c}{14.48}\right)^2 \qquad \text{(C)}$$

For metric units where P_c is in bars (absolute) and d_c is in centimeters

$$MW(e) = P_c^{0.96} \left(\frac{d_c}{10.19}\right)^2 \qquad \text{(D)}$$

REFERENCES CITED

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