TRANSMISSION OF PRESSURISED HOT WATER AT THE BOILING POINT

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INTRODUCTION

Most geothermal projects throughout the world appear to be roughly similar to Wairakei in that fluid flowing from wells is a steam-water mixture which has to be separated at the surface in order for steam alone to be transmitted to turbines to generate electric power. Cyclone separators used for this duty are extremely efficient and only about 0.03% of carryover bore water enters the steam pipelines. However, even this small quantity of water which contains dissolved minerals, has to be carefully removed by a series of extraction pots along the lines, which in turn, create a potential problem of steam condensate corrosion. This has taken place in some of the so-called High Pressure lines at Wairakei which operate at 125 psia; both extraction pot design and corrosion control have been described and solutions proposed, James (1975, 1979). At present, therefore, we may cautiourly state that the design of steam transmission line8 presents no major difficulties. But the transmission of the separated hot water is a seemingly intractable problem.

Visitors to Wairakei will observe that this difficulty has been completely avoided by the simple technique of discharging the fluid direct to the atmosphere from the separator water outlet. Of course, "flashing" of the hot water into a steam-water mixture takes place and a twin-tower atmospheric separator is aleo installed in order to control these fluids, so that the steam is vented to the atmosphere and the water - now at close to 100°C - is disposed of by means of open concrete channels overland to tho Waikato river, a distance of several kilometres, Haldane and Armstead (1962).

These open-air channels gradually choke with deposits of silica and other associated minerals and require a tedious and expensive cleaning programme but otherwise function well.

Nowadays, however, it is considered untenable to reject the separated wall water to a river, and throughout tho world the emphasis is mainly on reinjection of this fluid back into the subterranean reservoir or at least, somewhere underground In the periphery of the geothermal field. Arguments are still raging into exactly where and at what depth, etc., but acceptance is fairly widespread into its general inevitability.

The great difficulty on transmitting the hot water leaving the separators is that it is precisely at the boiling point for its pressure and hence any fall in pressure would result in a quantity of steam being generated which would increase the volume of fluid flowing and render extremely hazardous the whole design of the system. For example, at 85 psia, saturated hot water (water just at the boiling point for pressure), would produce 1% by weight of steam if its pressure falls to 75 psia and this would result in a volumetric expansion of more than three times its original volume of all-water. In other words - and more accurately - the steam would now consist of about 77% by volume of the fluid flowing. . Pressure-drop is, of course, inherent to the flow of fluids, and in the case of long pipelines would be almost wholly due to friction, as care would be taken to avoid intense restrictions such as orifice plates or choker, or even sharp bends and loops.

The term intractable was used specifically for the transmission of water which is at the boiling point. It is possible to expensively overcome the difficulty by pressurising the fluid by the use of pumps coupled with header tanks, and for added safety, the injection into the hot water line of slightly cooler water - the attemperation approach - in order to inhibit the chance of any boiling occurring. This method is the one which was used at Wairakei for the transmission of separated hot water along the 17 inch diameter 'H' line over a distance of about 2 km from a part-of the borefield to the power house, as described by Smith (1958).

In the came of saturated hot water being piped overland for reinjection purposes, however, there is a difference which proves significant in that the pipeline would not be insulated, and hence the water would decline in temperature <u>en route.</u> The pressure at which the water boils will therefore also decline along the pipeline. Frictional pressure-drop (an inevitable concomitant of flow) will also produce a fall in pressure along the line which if it does not exceed that due to heat loss will produce a condition in which no boiling will take place. If these two conditions are brought into'. state of quàsi-equality, the hot water can indeed by transmitted at very close to its boiling point and the pipeline designed for the condition of all-water.

Saturated Hot Water Transmission

The approach here is to first estimate the heat loss to the atmosphere along the pipeline, then to convert this to the temperature decline of the all-water flow. Then convert this temperature-drop to an equivalent reduction in the saturated vapour pressure of the water. This in turn is equated to the frictional pressure-drop along the line to determine conditions at which these factors are in balance and in which incipient ebullition is imminent.

Over the likely range at which boiling water will be transmitted for reinjection or other purposes, which is from 20 to 200 psia, we obtain from Lyle (1947), the heat loss for bare pipe:-

$$H_L = 102.75 \ P_s^{0.437} \quad \text{Btu/ft}^2\text{h}$$

where P_s is the saturated vapour pressure, psia.

The specific heat of boiling water over the pressure range above is roughly given by:-

$$S = \frac{P_s^{0.031}}{1.107}$$

The ratio of pressure change to temperature change at the boiling point is given by:-

$$R = \left(\frac{P_s}{66.6}\right)^{0.7784} \quad \text{psi/deg ?}$$

If we take the pipe diameter as d inches and the water flowrate as

W lb/h, then the pressure-drop over 1 ft length of pipeline is calculated as follows:-

ΔP_t is the pressure-drop due to thermal loss, psi/ft

$$\Delta P_t = \frac{R \; H_L \left(\frac{\pi \cdot d}{12}\right) 1.0}{W \; S}$$

$$W = G\left(\frac{\pi}{4}\right)\left(\frac{d}{12}\right)^2 3600 = \left(\frac{u_w}{V_w}\right)\left(\frac{\pi}{4}\right)\left(\frac{d}{12}\right)^2 3600 \qquad \text{lb/h}$$

where G = flow in lb/ft^2s

u_W = water velocity in ft/s

V_w = water specific volume in ft^3/lb = 0.018 ft^3/lb

Substituting these various factors in the pressure-drop equation:-

$$\Delta P_t = \frac{P_s^{1.1844}}{960.57 \; d \; u_w} \qquad \text{(i)}$$

The frictional pressure-drop ΔP_f psi/ft is calculated as follows:-

$$\Delta P_f = \frac{u_w^2 \; f}{V_w \; (13.92)^2 \; d}$$ psi/ft, where f is the Fanning friction factor.

For commercial steel pipe, f is calculated from the Reynolds Number R_e as follows:-

$$f = \frac{0.0344}{R_e^{0.1505}}$$

where $$R_e = \frac{124 \; G \; d}{\mu_w} = \frac{124 \; u_w \; d}{\mu_W \; V_w}$$

We assume an average value of the water viscosity μ_w = 0.17 c'poise as valid over the range of pressures *20 -200* psia and water velocity as 6 ft/s. Reinjection pipelines will be about 12 inches diameter.

$$R_e = \frac{124 \quad 6 \quad 12}{0.17 \quad 0.018} = 2.92 \; (10)^6$$

$$f = \frac{0.0344}{\left[2.92 \; (10)^6\right]^{0.1505}} = 0.00366$$

$$\Delta P_f = \frac{u_w^2 \; 0.00366}{0.018 \; (13.92)^2 \; d}$$

$$\Delta P_f = \frac{w^2}{452.95 \; d} \qquad \text{(ii)}$$

Equating (i) and (ii), $\Delta P_t = \Delta P_f$

$$\frac{P_s^{1.1844}}{960.57 \, d \, u_w} = \frac{u_w^{2}}{952.95 \, d}$$

$$u_w = \frac{P_s^{0.3940}}{1.00266}$$

Taking into account the various slight inaccuracies inherent to this approach, we can take the maximum velocity acceptable for design purposes as:-

$$u_w = P_s^{0.4} \quad \text{ft/s} \qquad \text{(iii)}$$

The velocities calculated froa this equation are not very different from 'normal' velocity of cold water flow in pipelines which is often taken as about 6 ft/s for moderate pressure-drop and pump power requirements. Prom the above equation (iii), boiling water velocities at say 65 psia and 165 psia are 5.3 and 7.7 ft/s respectively and should not be exceeded for horizontal pipes.

Mention should be made that the heat loss equation is based on factory conditions where the ambient temperature is 70°F (18.5°C) with no wind. For overland pipelines where wind and lower temperatures - as well as occasional rain - prevail, higher water velocities should be permissible before boiling can occur, hence for horizontal pipes, the veloaity derived from equation (iii) should not be reduced to be on the safe side, as an inherent safety margin is already contained in it.

As completely flat ground is unlikely to be found in practice, the best arrangement would be to select the sites for separators as somewhat uphill from that of injection wells. This will insure that further safety is built-in and even higher hot water velocities could be allowed.

CONCLUSIONS

As all equations used in this study are empiracally based, there is little reason to doubt the general correctness of the approach, Equation (iii) can be used with confidence to calculate the boiling water velocity in overland pipelines because the heat loss in practice will exceed that used in this study which were based on in-door conditions. Also horizontal ground is unlikely to be found in a geothermal field and hence separators will be located uphill from injection wells, which would permit higher water velocities to be used with impunity.

This rather deceptively simple approach will provide considerable economic and maintenance advantages in that pumps and various ancillary equipment will not be necessary. Because of the importance Of not discharging bore water into a river or on the land surface, electrically-operated centrifugal pumps would no doubt also require Diesel-driven standby pumps in case of electrical failure, thus adding to the cost.

Because of limitations on the length of papers for this conference, a more expanded version of this paper is to be published elsewhere.

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