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A MODIFIED GAS CORRECTION FOR THE LIP-PRESSURE METHOD

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ABSTRACT

The lip-pressure method is the most convenient means of measuring the flow of many geothermal wells. The technique used is empirical and is based upon measurements made on wells with low content of noncondensible gas or dissolved solids. A correction was suggested by James (1970) for gas content. Recent results from wells of high gas content show that this correction must be revised. A theoretical derivation from Fauske's critical flow model partly supports the revision.

INTRODUCTION

Geothermal reservoirs containing significant amounts of noncondensible gas or dissolved solids occur in many parts of the world. The most extensively used method of flow measurement is the lip-pressure method suggested by James (1962). A correction for gas content of discharge was suggested by James (1970):

$$P'_{lip} = P_{lip}(1-y/3.2) \qquad (1)$$

where y is the ratio of gas to steam by mass at the lip. This has apparently been satisfactory in practice although careful checks of its validity were never made.

From 1978 onwards wells have been drilled at Ngawha geothermal field, finding a reservoir of water at 220°-250°C and with gas content of 1-3% (wt) in deep fluid. Flow measurement by lip pressure and weir consistently gave discharge enthalpies up to 100 kJ/kg above liquid water enthalpy at feed-point temperature, although downhole profiles showed liquid water entering the wellbore. Careful checking of all instruments and apparatus left only the gas correction itself as the possible source of error.

We suggest a revised equation

$$P'_{lip} = P_{lip}(1-f_s) \qquad (2)$$

correcting by the mass fraction f_s of gas in the vapor phase at the lip.

For the purposes of computation, rather than actually correcting the lip pressure, it is more convenient to directly correct the enthalpy by ΔH_t:

$$\Delta H_t = H_2(H_t)\cdot f_s \qquad (3)$$

where H_2 is defined in the Appendix and shown in figure A1. Equation (3) is simply a reformulation of Eq.(2), and permits the evaluation of the gas correction in one step.

NOTE

To avoid confusion, we will use "vapor" to refer to the gaseous phase containing both steam and noncondensible gas, and "steamwater" to refer to the combined amount of steam and water, exclusive of noncondensible gas. The enthalpy as found by the corrected lip pressure method is the enthalpy of the steamwater flow, not the total flow of steam, water and gas.

NGAWHA RESULTS

Table 1 lists the results of flow measurements by lip-pressure and weir at some Ngawha wells, and compares the results with discharge enthalpy as measured by discharging profiles showing feedwater temperature. The measurements used are those at the time of the chemical sampling. The flowing profiles are measured at other times. Experience elsewhere indicates that wells feeding from liquid water are very stable in performance, and in particular in feedwater temperature. There are many more discharge measurements, at times when a chemical sample was not taken. These show considerable scatter in the (uncorrected) enthalpy, and this scatter is not removed by a gas correction if the gas content does not vary. This scatter is unusual and its source is not yet known. The uncorrected enthalpy of each well may vary over a range of 40 kJ/kg, so that only differences beyond this range are significant for testing the gas correction.

Of the Ngawha wells, NG18 gives the results of greatest significance, because it has the greatest gas content and hence correction. In all cases the new correction gives an enthalpy that lies within 40 kJ/kg of the correct value, and the old correction gives some values that differ by more than this; but the scatter is such that alternative forms

Well	Date	WHP	P_{lip}	W''_w	P_{sample}	x_s^{sample}	H_t kJ/kg			
		bar	bar	t/h	bar	mM/M	actual	uncorr.	old	revised
NG8	22.6.82*	10.1	2.30	205	3.9	28.3	900	914	902	884
	22.6.82	9.0	2.40	205	3.9	28.3	900	936	924	906
	29.6.82	18.7	1.97	89	4.7	49.5	900	982	957	925
NG2	12.8.82	18.8	1.42	55	3.8	35.2	1000	1080	1064	1043
NG9**	6.9.81	6.8	2.25	89	6.6	38	980	1057	1042	1022
NG18	24.8.82	6.8	2.5	102	6.1	113	940	1039	985	917
	24.8.82	6.8	2.5	102	5.4	113	940	1039	989	928

TABLE 1. Ngawha well measurements.

Notes. *taken 20 minutes after opening, enthalpy probably depressed by drilling fluid. **deep zone of dual completion. All pressures absolute. All gas measurements by courtesy of D. Sheppard, DSIR. Lip pressure pipe 154mm dia except for NG9 (204mm).

might be suggested instead.

The Ngawha results are limited in that they cover only a small range of discharge enthalpies, and so do not test for any systematic variation with enthalpy.

DNG-2 RESULT

An example at very different enthalpy is provided by DNG-2. This is the second well at Dieng, a high-temperature field in Indonesia. James (1980) describes the measurement of this well. At a wellhead pressure of 11.2 bar the flow was measured by separator and orifice meters as 24.4 t/h of steam, 20.0 t/h of water and 8.6 t/h of gas, giving for the steamwater flow a mass of 44.4 t/h and an enthalpy of 1880 kJ/kg.

At the same wellhead pressure, the lip pressure was 2.2 bar. The flow of water at atmospheric pressure can be computed from the separator results as 16.8 t/h. With no gas correction the enthalpy would be estimated as 2055 kJ/kg. At the lip pressure, the steam contains 24% (wt) of gas. The old correction gives an enthalpy of 2000 kJ/kg and the new 1920 kJ/kg.

Alternatively, we can compute that the steamwater flow alone would give a lip pressure of 1.53 bar, or 70% of the actual 2.2 bar. A correction of 30% is required, and Eq.(2) gives a 24% value.

CONCLUSION

The lip pressure correction suggested by James (1970) does not allow for the full effect of gas. A revised correction is suggested that is supported by a small amount of data. This interim revision will be checked against better data in the near future.

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NOTATION

This follows Grant et al. (1982). Symbols defined in text are not repeated.

C	specific heat
f	mass fraction of gas or solid
H	specific enthalpy, kJ/kg
P	pressure
T	temperature
v	specific volume
W''_w	weir water flow
x	mole fraction of gas
X	$= (H_t - H_w)/H_{sw}$ dryness

Subscripts

g	gas
s	steam
t	total flow
w	water

APPENDIX 1. CALCULATING A GAS CORRECTION

Given the lip pressure P_{lip} and weir water flow W''_w, the discharge enthalpy H_t is given by (James 1970, Grant et al. 1982)

$$H_t = f(Y, P_{atm}) \qquad \text{(A1.1)}$$

$$Y = W''_w/(AP_{lip}^{0.96}) \qquad \text{(A1.2)}$$

A correction to lip pressure results in a correction to the enthalpy. Let F be the fractional correction in Y (ie $\Delta Y/Y$).

Then

$$\Delta H_t = - H_1 \cdot F \qquad \text{(A1.3)}$$

where $$H_1 = -Y \frac{\partial H_t}{\partial Y} \qquad \text{(A1.4)}$$

The relation between H_t and Y is

$$W''_w/(AP_{lip}^{0.96}) = Y = C(H''_s - H_t)/H_t^{1.102} \qquad \text{(A1.5)}$$

where H''_s is steam enthalpy at atmospheric separation pressure. Then

$$H_1 = H_t(H''_s - H_t)/(1.102H''_s - 0.102H_t) \qquad \text{(A1.6)}$$

It incurs little error to take steam enthalpy as the sea level value, 2675 kJ/kg, for any elevation. Then if the lip pressure is corrected by Eq.(2), $F = 0.96f_s$, and eq.(3) is found, with $H_2 = 0.96H_1$, or

$$H_2 = H_t(2675 - H_t)/(3070 - 0.11H_t) \qquad \text{(A1.7)}$$

The function H_2 is shown in figure A1.

For example, consider NG2 in table 1. The uncorrected enthalpy is 1080, so $H_2 = 584$. Assuming $T_{lip} = T_s(P_{lip})$, the gas sample gives $f_s = 7\%$, using the uncorrected enthalpy to calculate the additional flashed steam between the sample and lip pressures. Then

$$\Delta H_t = 585 \times 0.07 = 40 \text{ kJ/kg.}$$

APPENDIX 2. THEORETICAL DERIVATION

Karamarakar and Cheng (1980) use three models of critical flow to make estimates of lip-pressure conditions and the critical mass flux density G_M. The simplest of these is Fauske's model. Under practical conditions, where

$$k_M = (v_s/v_w)^{0.5} >> 1$$

and $$k_M X >> 1$$

their expression can be greatly simplified to

$$G_M^{-2} = - \frac{d}{dP}(X^2 v_s) \qquad \text{(A2.1)}$$

$$= \frac{X^2 v_s}{P}(1 + 2R) \qquad \text{(A2.2)}$$

where $$R = \frac{H_s - H_t}{H_t - H_w} \frac{C_w}{H_{sw}} P \frac{dT}{dP} \qquad \text{(A2.3)}$$

The derivation of G_M is not specific to water substance. The results for a gassy fluid can be obtained by substituting the thermodynamics of a water-carbon dioxide mixture. We now redefine G_M and X as the flux density and dryness of the steamwater flow. Then the enthalpies of water and steam, and the dryness, remain unchanged as functions of temperature or saturation pressure, ignoring the heat of solution of CO_2. Then with f_t the mass fraction of gas in the total flow, and assuming sufficient flashing that all gas is in the vapor phase at the lip, the dryness of the total flow is $X + f_t$, and the total mass flux density is $G_M/(1-f_t)$.

$$P_g = 18f_t P_s/(44X) \qquad \text{(A2.4)}$$

which gives $$\frac{dP}{dT} = \frac{dP_s}{dT}\left(1 + \frac{18Rf_t}{44X}\right) \qquad \text{(A2.5)}$$

Then $$G_M = \sqrt{\frac{PX^2}{v_s(1+2R)}}\,(1 - R_1 f_t) \qquad \text{(A2.6)}$$

$$R_1 = 1 + \frac{1+R}{X(1+2R)} - \frac{9R}{44X} \qquad \text{(A2.7)}$$

The fractional correction F to mass flow is $R_1 f_t$, or a correction of $R_1 f_t/0.96$ to the lip pressure. This lies between the old correction and the new correction in most cases, and is closer to the new correction.

A dissolved solid has negligible effect on the P-T relation, but does affect dryness and mass flux, as the liquid phase contains more mass. With f_t as the fraction of dissolved solid in the total flow, and it is not neccessarily true that this fraction is negigibly small,

$$(1-f_t)^2 G_M^{-2} = - \frac{d}{dP}(v_s(1-f_t)^2 X^2) \qquad \text{(A2.8)}$$

since $1-f_t$ is the fraction of water substance in the total flow and $X(1-f_t)$ is the dryness. Eq.(A2.8) indicates that the lip pressure is unaffected by dissolved solid, provided that the lip pressure is regarded as measuring the flow of water substance, and the dissolved solid is just an inert contaminant. We have no experimental data to check this conclusion.

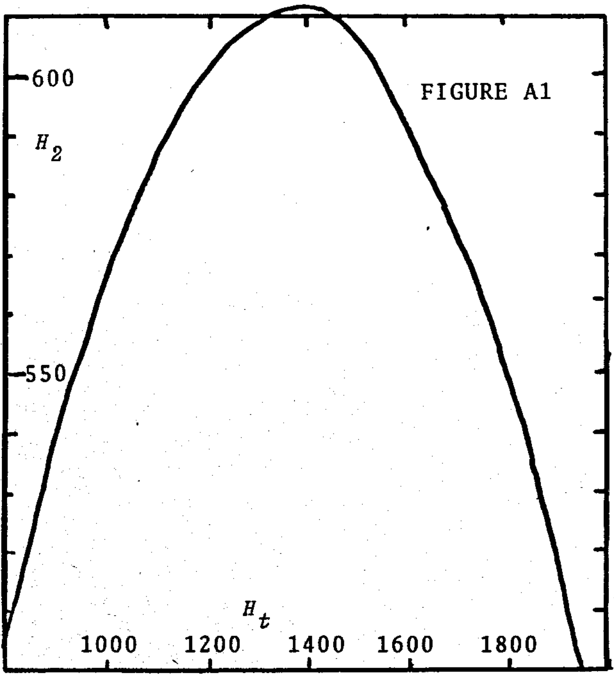

FIGURE A1