A GAS CORRECTION FOR THE SEPARATOR METHOD USED IN GEOTHERMAL WELL TESTING

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SUMMARY - A geothermal well can be tested for its performance by using several methods, one of them is known as the separator method. This method uses a pressure separator to separate the vapour and liquid phases of the geothermal fluid, after which the flowrate of each phases are measured separately. The vapour phase of the geothermal fluid consists not only of steam but also of gases, The presence of these gases in steam, which may have concentrations ranging from 0.05 to 20 or 30% by weight, is usually ignored in the flowrate calculations. Later on this results could cause some problems in designing the power plant because the designing engineers need to have more precise data about the performance of the well. By using the gas data obtained from chemical analysis of gas samples taken during the period of well testing, it is now possible to make correction for the separator method used in geothermal well testing.

1. INTRODUCTION

After drilling a geothermal well is completed, several tests should be carried out in order to calculate the performance of the well. The first test is usually carried out by using the James' lips pressure method, which is simple and easy although the results are only approximate. this test would give approximate results about the mass flow rate and the discharge enthalpy of the well only at a particular condition. Following this, another test should be conducted which is known as the separator method and would give a much better result than the test mentioned earlier. This test usually needs several weeks to be completed and involves a number of different measurements simultaneously and continuously as well. Because of limited data, usually the gas content in steam is ignored during the calculations, since it is sometimes thought that the small amount of gas should give only very little error to the results.

However, the design engineers during the preparation of the conceptual design of the power plant would like to know precisely what kind of fluids and how the well behave upon different conditions they are dealing with. Very often the results from the mentioned separator method's tests do not fulfilled their requirement because the results do not show precisely the distributions of the components in that geothermal fluid. Sometimes they even requested to repeat the test or to redo the calculations from the test which are time and money consuming.

By using the gas data from specific samples taken during the test, it is possible to make corrections to the test results, which then give more accurate data to fulfill the requirements of the design engineers; preventing unnecessary time and money spending in the future.

2. THE SEPARATOR METHOD

A geothermal fluid consist of three phases; the liquid phase (major fraction) which is usually a solution of minerals (and gases) in water, the vapour phase which may have water vapour (steam) and gases as its components, and the solid phase (minor fraction) which consists of entrained particles from the reservoir. This fluid from the reservoir underneath is brought to the surface either naturally or by using some artificial method. During its way to the surface, various physical changes occur in relation to changes in physical condition it encounters; for example the liquid phase loses some of its water due to the flashing, and the vapour phase gained some more gases due to the exsolution process in the liquid phase.

At the surface this fluid is directed to a kind of pressure vessel, known as a separator, where separation of the phases is carried out under a controlled condition. The vapour phase is directed to flow inside a different pipe (the Steam-Line) where flow measurements are conducted. The liquid phase (and also the solid phase) is directed to another pipe (the Water-Line) then through another vessel which is known as the silencer. The silencer is actually an atmospheric separator where the high pressure liquid is introduced to an atmospheric pressure condition, letting part of the liquid to flash into vapour and giving an opportunity to measure the flow of the remaining liquid phase.

2.1 Vapour phase flow measurements

The flow rate of the vapour phase of the geothermal fluid is calculated by using the differential pressure method; that is to measure the pressure difference generated between the upstream and downstream sides of an orifice plate installed inside the steam line.

The basic equation for the vapour phase flow measurements is taken from British Standard 1042 (Part 1: 1961 p. 17) as follows :

$$W = C\ Z\ \epsilon\ B\ a\ (2\ g_c\ \rho\ \Delta P)^{0.5}$$ --- equation (1)

where : W = Mass flow rate, lb/s
C = Basic coefficient
Z = Correction factor, $Z_R * Z_D$
Z_R = Reynolds number correction factor
Z_D = Pipe size correction factor
ϵ = Expansibility factor
B = Velocity approach factor, $1/(1-m^2)^{0.5}$
m = Area ratio, (a/A) or $(d/D)^2$
a = Cross-sectional area (downstream), ft^2
A = Cross-sectional area (upstream), ft^2
g_c = Non dimensional factor, value equal to acceleration of gravity, 32.1710 ft/s^2
ρ = Fluid density at upstream condition, lb/ft^3
ΔP = Differential press., lbf/ft^2

Another equation, which is called the working equation, was derived from the basic equation according to the types of orifice plate (square-edged) and pressure tappings (D and D/2) installed, and substituting values which are constant such as g_c, and also by using units of measurement which are more convenient to be applied in the field as follows :

$$W_v^{SL} = 39.59172\ C\ Z\ \epsilon\ B\ d^2\ (\Delta P\ /\ v_v)^{0.5}$$ --- equation (2)

where : W_v^{SL} : Vapour flow rate, kg/h
d : Orifice diameter, mm
D : Pipe diameter, mm
ΔP = Differential press., kgf/cm^2
P = Upstream press., kgf/cm^2 abs
v_v : Vapour phase specific volume, cm^3/g

The values for the basic coefficient (C), the pipe size correction factor (Z_D), the Reynolds number correction factor and the velocity approach factor (B) can be taken from the corresponding graphs.

2.2 Liquid floe measurements

The flow of the remaining liquid, after allowing it to flash into an atmospheric pressure condition at the silencer, is measured by using a triangular weir in an open channel. The result are then recalculated to the condition in the water line.

The volumetric flow rate of the liquid in the open channel is calculated according to the basic equation (Bean H.S., 1911, p 117) :

$$q = (8/15)\ C\ \{\tan\ (\theta/2)\}\ (2\ g_c\ h^5)^{0.5}$$ --- equation (3)

where : q : volumetric flow rate, m^3/s
C = flow coefficient
θ : angle of the weir, degrees
g_c : acceleration of gravity, 9,80665 m/s^2
h = height of liquid above weir, m

So the mass flow rate of the liquid in the weirbox (W_l^{WB}) is : $W = q\ /\ v_l$ or,

$$W_l^{WB} = 1.92\ C\ (2\ g_c\ H^5)^{0.5}\ /\ v_l\ \text{kg/hr}$$ --- equation (4)

where : v_l = specific volume of liquid, cm^3/g
θ = 90'
g_c : acceleration of gravity, 980.665 cm/s^2
H = height of liquid above weir, cm

To calculate the flow of liquid in the water line (W_l^{WL}), the steam fraction at the silencer is first calaulated by using this equation :

$$SF = (h_l^{WL} - h_l^{WB})\ /\ (h_v^{WB} - h_l^{WB})$$

where : h_l^{WL} = liquid enthalpy in the waterline
h_l^{WB} = liquid enthalpy in the weirbox
h_v^{WB} : vapour enthalpy in the weirbox

and the result is used in the following equation :

$$W_l^{WL} = W_l^{WB}\ /\ (1 - SF)$$ --- equation (5)

The uncorrected total flowrate of the well (W_t^{TOT}) is the sum of the vapour phase and the liquid phase flowrates :

$$W_t^{TOT} = W_v^{SL} + W_l^{WL}$$

And the uncorrected discharge enthalpy (DE_t) is calculated by using the results of those two flow measurements as follows :

$$DE_t = [(W_v^{SL}\ h_v) + (W_l^{WL}\ h_l)]\ /\ W_t^{TOT}$$ --- equation (6)

3. GAS CORRECTION

3.1 Methodology

As can' be seen from equations above, some values like the specific enthalpy (= h) and the specific volume (= v) of the vapour phase, are taken directly from a steam table using measured pressure or temperature data. Since there are two components in the vapour phase (steam and gas) so the total pressure in the steam line is the sum of partial pressures of the steam and the gas and this make the values taken from the steam tables would be incorrect.

In order to calculate the partial pressure of the gas, it is necessary to know the concentration of the gaaes in the vapour phase at a particular condition. So a sarpling hole was drilled into the steam line, a few meters upstream the orifice, where a Webre type sampling separator could be installed and gas sarplee could be collected using vacuum flasks containing caustic soda solution. Wet chemical analysis was carried out in the field laboratory as soon as sampling were completed,

3.2 Correction procedure

- First calculate the mole fraction (N_g) and the weight fraction (X_g) of the gas by using the chemical data from the field laboratory, Then calculate the partial pressure of steam (PP_s) which is equal to $P (1 - N_g)$, and find the values for the specific volume (v_s) and the specific enthalpy (h_s) for the steam at the measured temperature and the corresponding partial pressure of the steam from the steam table,
- Calculate the partial pressure of the gas (PP_g) which is equal to ($P - PP_s$) then find the specific enthalpy of the gas at the measured temperature and the corresponding partial pressure of the gas from the gas table, At this point, for practical purposes, an assumption that the gases in the vapour phase consists only of CO_2 had to be made, although the analysis itself shows the concentration of CO_2, H_2S and the residual gas. This is not absolutely true but previous experiences show that the major component (> 90%) of the gases in geothermal steam is CO_2.
- Calculate the specific volume of the vapour phase (mixture gas and steam, v_{sg}) for that particular condition.
- Recalculate the mass flow rate for the vapour phase (W_{sg}^{SL}) by substituting the new value of v_{sg} for v_v into equation (2) then recalculate the mass flow rate for each component as follows :

$W_s = W_{sg} (1 - X_g)$ and $W_g = W_v - W_s$

- Finally recalculate the total mass flowrate and the discharge enthalpy by using equations (5) and (6):

$W_c^{TOT} = [(W_s^{SL} + W_g^{SL} + W_v^{WL})]$ and

$DB_c = [(W_s^{SL}\ h_s) + (W_g^{SL}\ h_g) + (W_l^{WL}\ h_l)] / W_c^{TOT}$

3.3 Example of correction

This method for correcting mass flow rate and discharge enthalpy data had been applied to test results from well DNG09 in Dieng Field during a test period between April and August 1989 (Suwana, 1989, 1990). During this period, the well was discharged at various well head pressures, each pressure setting was held for a duration of 5 days, while the separation pressure was held constant at around 7.5 kg/cm² g. During each wellhead pressure setting, gas sampling were carried out every second and fifth day and at each sampling a minimum of two gas samples were collected which were analysed in the field laboratory as soon as sampling accomplished,

The following is an example of calculation for gas correction by using data no.3 :

- mole fraction (N_g) of the gas = 0,0115
- weight fraction (X_g) of the gas = 0.0270
- partial pressure of steam (PP_s) = 8.1158 kg/cm² a.
- specific volume of steam (v_s) = 244.14 cm³/g
- specific enthalpy of steam (h_s) = 2766.8 kJ/kg
- partial pressure of gas (PP_g) = 0,0371 kg/cm² a.
- specific enthalpy of gas (h_g) = 859.6 kJ/kg
- specific volume of steam+gas (v_{sg}) = 250,911, cm³/g
- corrected vapour phase flow rate (W_{sg}^{SL}) = 16334 kg/h
- steam flow rate (W_s^{SL}) = 15892 kg/h
- gas flow rate (W_g^{SL}) = 441 kg/h
- corrected total flow rate (W_c^{TOT}) = 26980 kg/h
- corrected discharge enthalpy (DB_c) = 1940 kJ/kg

Tables 1, 2 and 3 show some data selected from the results of testing well DNG09. Data about the physical condition of the well with the uncorrected results is presented in Table 1. The result of gas sampling and chemical analysis is presented in Table 2, table 3 show the results after gas correction had been applied.

Table 1 : Uncorrected test results

No.	P^{WH}	P^{SEP}	P^{SL}	P^{WL}	T^{SL}	W_v^{SL}	W_l^{WL}	W_u^{TOT}	DB_u
	(------ ksc	g.		----)	(°C)	(----	kg/h	-----)	kJ/kg
3	29.84	7.73	9.30	7.63	169.5	16661	10146	27096	1980
18	10.00	7.61	7.30	7.61	168.0	22597	10208	32805	2131
28	40.13	1.50	7.30	7.50	170.0	9360	13814	23204	1548
39	20.73	7.50	7.30	7.50	170.0	15986	15885	31851	1750

Table 2 : Gas data

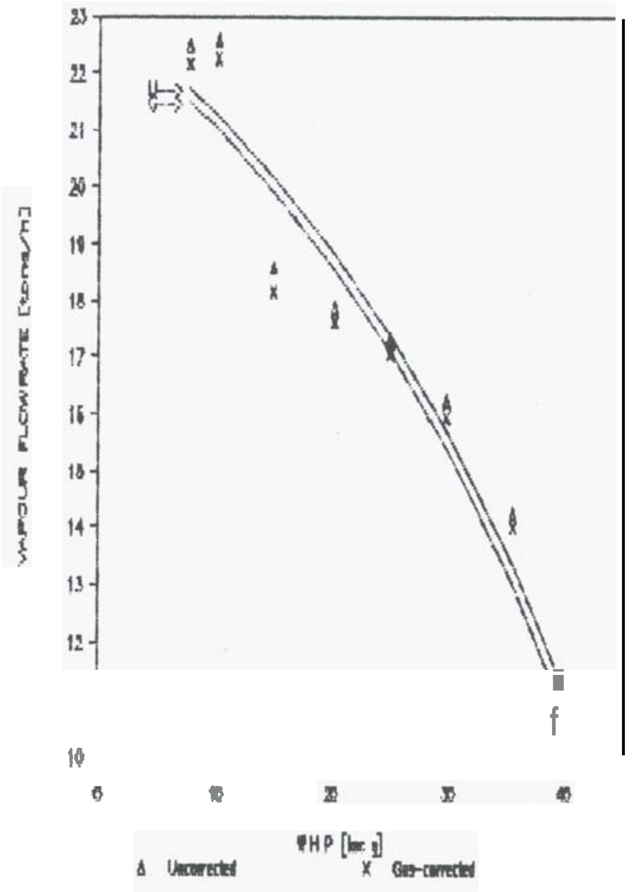
No.	P^{WSS}	RES	CO_2	H_2S	N_g	X_g
	ksc g	(mmol/100	mol	H2O)	(--- %	--)
3	7.30	56.2	1065	47.8	1.15	2.70
18	7.00	50.7	787	38.2	0.87	2.03
28	7.20	54.7	1178	68.0	1.28	3.00
39	7.30	41.0	845	50.5	0.93	2.18

Table 3 : Corrected results

No.	W_l^{WL}	W_s^{SL}	W_g^{SL}	W_c^{TOT}	DB_c
	(--------	kg/h		--------)	kJ/kg
3	10446	15892	441	26780	1940
18	10208	21822	452	32482	2099
28	13844	8887	275	23006	1515
39	15865	15399	342	31606	1721

4. DISCUSSION

It is found that the results of the gas-corrected vapour flow rate calculation are always smaller than the results from the original calculation. These made the gas-corrected total flow rate and the discharge enthalpy also smaller than before. Figures 1, 2 and 3 shows the difference of results from the two calculations. These data points (A and x) are the average values on each wellhead pressure setting while the continuous lines are drawn by using the Least Square Fit method.



. Figure 1 : Vapour flow rate vs Wellhead Pressure

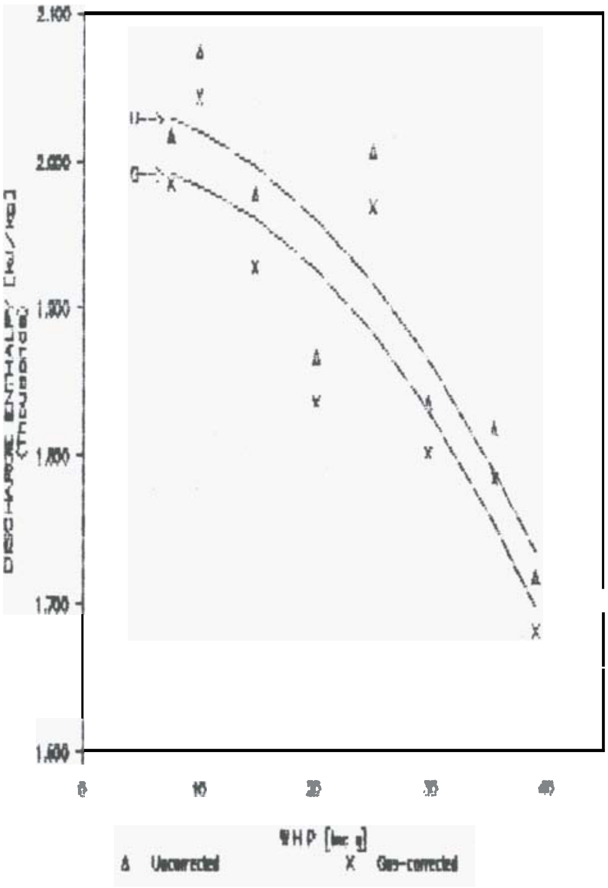


Figure 3 : Discharge Enthalpy vs Wellhead pressure

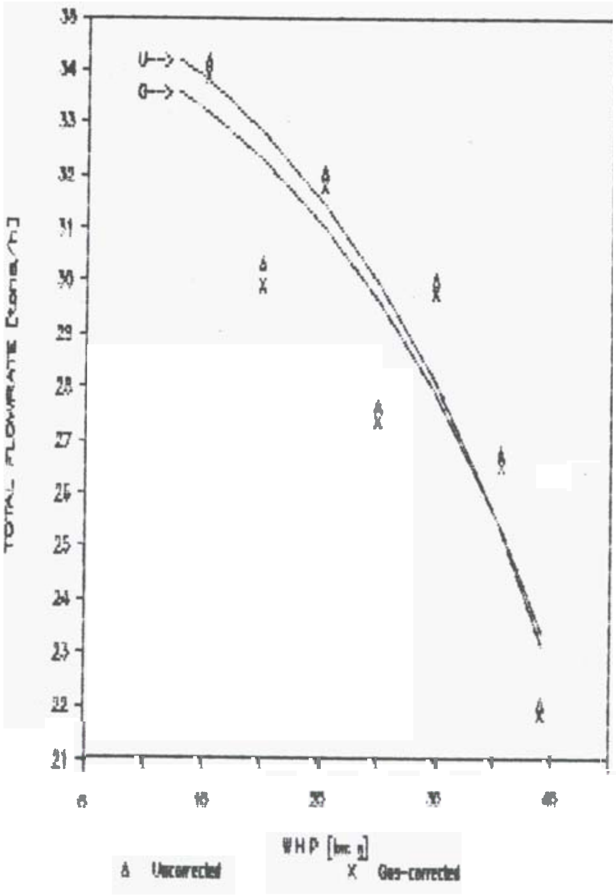


Figure 2 : Total flow rate vs Wellhead pressure

Table 1 shows the differences between the two calculations. It shows that the amount of gas in the vapour phase may have a rather direct influence to the difference of the results from the two calculations.

Table 4 : Difference of results

No.	Xi %	W_v^{SL}	W_{vg}^{SL}		Differ. %	DE_u	DE_c		Differ. %
		(--- kg/h	---)			(- kJ/kg	--)		
3	1.97	16651	16334	317	1.90	1980	1940	40	2.02
18	2.03	22597	22274	323	1.13	2131	2099	32	1.50
28	3.00	9360	9162	198	2.11	1548	1515	33	2.13
39	2.18	15986	15741	215	1.53	1750	1721	29	1.66

To evaluate the influence of the gas content in the vapour phase, a statistical test known as the regression line method had been carried out. Values of weight fraction of gas in vapour (= X_f) were used as independent variables and the difference between the two values of the specific volume of the vapour phase, of the mass flow rate calculations and of the discharge enthalpy calculations were used as dependent variables. The regression output for the correlation between the amount of gas in vapour (X's) and the differences between the three dependent variables (Y's), both in percent (%), are as follows :

	X_g >< v_v	X_g >< W_{TOT}	X_g >< DB
Constant	0.1127	0,2515	0. moo
Btd Brr of Y	0.0079	0.1169	0.0533
R Squared	0.9998	0.4901	0.9663
No. of Obsv.	42	42	42
Deg. of Freedom	10	40	40
X Coefficient	-1.4921	0.2983	0.7433
Std Err of Coef	0.0032	0.0481	0.0219

This statirtical results show that there is a good correlation between the mount of gas in the vapour phase and the difference in the specific volure data, as is expected. The correlation between that arount of gas in vapour to the difference in the mass flow rate is insignificant; this is understandable because the total mass flow rate is also influenced by the liquid flow rate, which was not corrected,

But, it is also found from these reaults that there is a good correlation between tbe amount of gas in the vapour phase and the difference in the discharge enthalpy data, although it is still not clear why the first and the third regression linea do not have an intersection point of (0,0) instead of (0,0.11) and (0,0.02) as shown by the regression calculation.

5. CONCLUSIONS

It has been shown that a gas correction for the separator method used in geotherral well testing is possible to be carried out.

The examples taken from well DMG09 test results showed that tbe differences between the uncorrected and the corrected discharge enthalpy data is directly related to the gas concentratioas in the vapour phase. For a gas conceatration between 1.9 to 3.1 % by weight, the corrected discharge enthalpies will be 1.6 to 2.3 % smaller than the uncorrected ones.

Although these corrections seem to be small, close to the error in the mass flow rate and discharge enthalpy calculations (about 1 %), this method of gas correction is worthwhile to be done, especially for wells with higher gas content.

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