Gas Content of a Hot-Water Reservoir Estimated from Downhole Pressure and Temperature Measurements

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ABSTRACT

Vertical flows of pressurized hot water were found to lose temperature as they rose in Turkish geothermal boreholes. This was not due to heat losses or to gross steam production as the column pressures everywhere exceeded the saturated vapor pressure. The temperature drops (of the order of 10 to 15°C) between a depth of 500 m and the wellheads were due to the bubbling of gas out of the hot water. Measurements of the pressure and temperature of the flowing columns were used to determine the gas content of the feed water to the holes and were found to be in the range 1.6 to 2.0% gas in the total fluid. The gas was mainly CO_2 with only small amounts of H_2S.

INTRODUCTION

The boreholes of the Kızıldere geothermal field in southwestern Turkey tap a reservoir of hot water at a depth of from 500 to 850 m and with a pressure very close to that produced by a column of cold water of equal depth. Water temperatures are not entirely uniform within the reservoir but are generally within the range 195 to 205°C. The quantity of dissolved gases in the pressurized hot water appears to vary within the range 1.5 to 2.0% and consists of mainly carbon dioxide with a very small proportion of hydrogen sulfide and other gases (order of a few percent). The boreholes which tap the hottest water also discharge steam-water mixtures containing the least quantity of gas; conversely, the cooler reservoir waters have the highest gas concentration.

This gas almost completely enters the steam phase which is produced when the bores are discharged to the atmosphere or into low-pressure vessels. Hence at a pressure of say, 5 kg/cm² g, the gas proportion of the vapor-gas phase generated is within the range 11 to 19% on a weight basis. This is rather a high concentration for a field being considered for electric power generation using the conventional approach in which the vapor phase is separated mechanically from the water and then is used in a steam turbine followed by a condenser. The reason is that the noncondensable gases would have to be pumped out of the low-pressure condenser; otherwise they would rapidly accumulate and spoil the vacuum required to produce the high-velocity steam within the turbine.

When the wells were first tested, some puzzling features were observed. For example, when discharged wide open vertically, flows exceeded theoretical maxima as estimated from James (1970) for flashing steam-water mixtures; in practice it was found that over 500 tonnes/hr was measured in 9-in. wells. Large flows were obtained even when the well was throttled sufficiently to keep the flowing water under a pressurized condition right up to the wellhead so that no steam was believed to exist in the column. Pressure and temperature profiles taken in the rising fluid as indicated in Table 1 (for one of the wells) confirmed this but also showed that the water temperature declined by as much as 10 to 15°C from the well bottom to the wellhead. As the flow rates were extremely high (over 300 tonnes/hr in the example), such temperature falls could not possibly be explained by heat losses to water or rock surrounding the well casing, as these effects would produce a decline in temperature which would be immeasurably small.

Both strange effects were, in fact, explained by the presence of gas bubbling out of the water in the rising column and caused by the falling pressure. The flow rate was enhanced by this gas-lift effect, which explained the excessively high discharges; also the temperature decline could be explained by the fact that each gas bubble would also contain steam supplied by the column water. In fact, it was found possible to calculate the quantity of gas present in the discharge from a knowledge of the water temperatures and pressures and to check the results by sampling the steam from the wellhead equipment followed by chemical analysis of the noncondensable constituents. Hence it was found possible to avoid the tedious chore of surface sampling and gas analysis by evaluations based solely on the pressure and temperature profiles of the flowing well. However, it should be pointed out that this can only be accomplished if the gas concentration is of a magnitude comparable to those mentioned here; if the gas content is low, it would be difficult to measure the very small decline in temperature of the rising hot water.

Table 1 gives the results of temperature and pressure measurements in Well No. KD-13 at 50-m depth increments when the discharge was steady at 326 tonnes/hr. During the running of the subsurface instruments, the wellhead pressure was constant at 203 psig (14.28 kg/cm² g) and it should be noted that for water to boil at this pressure, the temperature has to attain 198°C. Hence it is seen that even at the wellhead, steam generation was not taking place, as the temperature at a depth of 50 m was below this (at 185.2°C).

Table 1. Pressure and temperature profile of flowing well (KD-13).

Depth (m)	Temperature (°C)	Pressure (psig)	(kg/cm² g)
50	185.2	216.75	15.24
100	188	242.25	17.03
150	189.8	270	18.98
200	191	302.25	21.25
250	192.2	337.5	23.73
300	193.1	375	26.37
350	193.9	414	29.11
400	194.9	463.5	32.59
450	195	512.25	36.02
500	195.4	562.5	39.55
550	195.6	615	43.24
600	195.9	670.5	47.15
650	196.2	728.25	51.21
700	196.2	786.75	55.32
750	194.2	844.5	59.38

GAS CONTENT CALCULATIONS

Pressure at a depth of 50 m = 216.75 psig = 231.25 psia, assuming atmospheric pressure as 14.5 psia at the altitude of the Kızıldere field. Temperature at a depth of 50 m = 185.2°C = 365.36°F. At this temperature, data from Perry et al., 1963, is as follows:

Saturated vapor pressure $P_s = 163.5$ psia
Specific volume of steam $V_s = 2.78\ \mathrm{ft^3/lb}$
Water enthalpy $h_f = 337.5$ Btu/lb
Steam enthalpy $h_{fg} = 1196.5$ Btu/lb
Carbon dioxide enthalpy at 185.2°C = 410 Btu/lb according to Perry (1963).

$$\text{Gas constant for } CO_2 = \frac{1.985\,J}{M}$$

where J = Joule's equivalent
= 778 ft-lb/lb (°F)
and M = molecular weight of CO_2
= 44
and 1.985 = universal gas constant.

Gas constant for CO_2 = 35.1
At 50 m depth, partial gas pressure = 231.25 − 163.5 = 67.75 psia

$$\frac{\text{lb of gas}}{\text{lb of steam}} = \frac{144\,(67.75)\,2.78}{35.1\,(460 + 365.36)} = 0.94$$

$$\%\ \text{gas}/(\text{gas} + \text{steam}) = \frac{0.94}{0.94 + 1}(100) = 48.5\%$$

Deep water maximum temperature (flowing upwards at over 300 tonnes/hr) = 196.2°C.

Because of the large flow, heat loss to cooler horizons is negligible, hence the heat content of the water at depth (650 to 700 m) is equal to the heat content of the water at 50 m depth plus the sum of the heat contents of the gas and steam phases. In the case of 100 lb flowing upwards,

Heat content of all water at 196.2°C approximately = 1.8(196.2) Btu/lb
Let amount of steam at 50 m depth = x lb, then the amount of associated gas = $0.94x$ lb
Total weight of steam + gas = $1.94x$ lb.
Heat content of x lb of steam at 185.2°C = $(1196.5\ x)$ Btu/lb.
Heat content of $(0.94x)$ lb gas at 185.2°C = $(0.94x)410$ Btu/lb
Amount of water at 50 m depth = $(100 - 1.94x)$ lb
Heat content of this water = $(100 - 1.94x)185.2(1.8)$

The heat balance between all water at depth and water-steam-gas at 50 m depth is:

$$1.8(196.2) = (100 - 1.94\,x)185.2\,(1.8) + (1196.55\,x) + 410\,(0.94\,x)$$

Therefore $x = 2.12$ lb steam, and gas = 0.94(2.12) = 2.0 lb gas.

Hence at 216.75 psig (15.2 kg/cm² g), there is 2% of gas present in the total mass flowing together with 2.12% of steam, giving a gas concentration of 48.5% in the steam-gas mixture.

GAS CONCENTRATION AT LOWER PRESSURES

To determine the gas concentrations at other lower pressures, take for example a steam vapor pressure of 80 psia where

$V_s = 5.472$, $h_f = 901.9$, steam vapor temperature 155.5°C (312°F).
Steam present at 155.5°C = steam at 185.2°C + extra steam evolved in lowering water temperature from 185.2 to 155.5°C

$$= 2.12 + \frac{337.5 - 282.1}{901.9}(100) = 8.27\%$$

$$\%\ \text{gas}/(\text{gas} + \text{steam}) = \frac{2}{2 + 8.27}(100) = 19.5\%\ \text{assuming}$$

gas in water is negligible.

$$\text{Lb gas/lb steam} = \frac{2}{8.27} = 0.242$$

$$\text{Partial gas pressure} = \frac{0.242\,(460 + 312)35.1}{144\,(5.472)} = 8.3\ \text{psi}$$

Total pressure = 8.3 + 80 = 88.3 psia (5.18 kg/cm² g)

Hence at a pressure of 5.18 kg/cm² g, there is a gas concentration of 19.5% in the steam-gas mixture.

Similar calculations are performed for steam vapor pressures from 20 psia to 140 psia; results are shown in Table 2.

Similar downhole tests were conducted on other flowing wells in the Kızıldere field with calculations to determine the gas concentrations in the steam fraction flowing in the

Table 2. Gas concentration at lower pressures.

Steam vapor pressure (psia)	Partial gas pressure (psi)	Total gas pressure (psia)	(kg/cm² g)	% gas in (gas + steam)
20	1	21	0.455	10.65
40	2.6	42.6	1.98	13.4
60	4.95	64.95	3.55	16.2
80	8.3	88.3	5.18	19.5
100	13.2	113.2	6.93	23.5
120	21.1	141.1	8.95	28.7
140	34.4	174.4	11.2	36

wellhead equipment, as shown in Table 2. Agreement was reached with the results obtained by the conventional methods employed where a steam sample is extracted from the by-pass pipe, condensed, and analyzed for gases.

CONCLUSIONS

The results of these tests and calculations may be of assistance in other geothermal fields where high gas contents exist and where downhole pressures and temperatures can be used to evaluate the concentrations. The fluid flow rate should, of course, be large in order to render negligible the heat loss from the water column to rock and to water outside the well casing.

Also, the concentration of gas should be high enough to give a reasonable decline in temperature of the rising water. The generation of gas bubbles in the rising water had a marked influence on the discharge and increased it above the theoretical maximum as calculated for a flashing hot-water well of the same source temperature, but low gas content.

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