MEASUREMENT OF NON-CONDENSABLE GAS CONTENT PROFILES IN DISCHARGING WELLS USING TEMPERATURE / PRESSURE LOGS

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Abstract

Precision production logging *tools* ***enable*** *the non-condensable* ***gas*** *(NCG)* ***content*** *to* ***be*** *measured* ***at any point in*** *the* ***two-phase*** *column* ***above the jlaslipoint*** *in* ***a discharging well. Pressure and temperature*** *logs* ***are used to derive partial pressures*** *at* ***various depths*** *from* ***which*** *the* ***NCG content*** *of the* ***fluid is calculated.*** *The NCG* ***content*** *of* ***the deepfeed prior to mixing*** *with* ***fluid*** *from* ***shallower zones*** *can* ***be calculated. Changes in tlie*** *gas* ***partial pressure*** *profile* ***thus enable*** *discrimination of* ***high-gas feeds.*** *Two examples from* ***the*** *Mahanagdong field in* ***Leyte, Pliilippines are presented.***

1.0 INTRODUCTION

Geothermal fields with a significant non-condensible gas (NCG) content suffer a penalty in the form of reduced efficiency of electrical generation and hence a higher steam consumption rate. It is therefore important to understand the source of the NCG and how its concentration **will** change with time during production **from the** field.

In many fields there is an accumulation of gas underneath a low permeability cap above the two-phase zone from where steam has migrated upward and then partially condensed. Wells tapping this gassy layer will have high level of NCG initially which can normally be expected to decline with production time. Th contrast, wells feeding from a deep upflow of saturated liquid will have lower initial NCG levels which will change little during tlie production period.

The presence ***of*** multiple gassy two-phase feedzones in a well makes it impossible to determine the sources and relative feed quantities of NCG through chemical sampling of the steam at the surface. Spinner surveys can provide an indication of the relative contribution of each zone to the total flow but not the gas content. It is however possible to determine the variation in partial pressure of gases (assumed here to be mainly CO_2) in tlie fluid while the well is flowing through an analysis of the temperature and pressure profiles in the hole. This results in the estimation of the relative concentration of NCG along the wellbore while it is flowing.

Corrections for gas/liquid distribution at the measured temperatures can be applied to arrive at NCG concentration in the source fluid or in the separated steam at the surface.

2.0 METHODOLOGY

The partial pressure of NCG can be measured directly by subtracting the vapor pressure of pure water from the total measured pressure. This method has been used experimentally by McDowell (1974) at Wairakei to measure the NCG content in the separated steam. He used a container of pure water at the same temperature as tlie separated steam to obtain the vapor pressure, and measured the differential pressure compared to the total line pressure, which is a direct measurement of tlie gas partial pressure.

Tlie partial pressure of gas can also be estimated by measuring the tcmperature and total pressure and then subtracting the vapor pressure from steam tables for tlic given temperature. This method was uscd by PNOC-EDC during tlic 1980's, when Kustcr tools were used for flowing surveys. The results however were not consistent bccause of the requirement for both the temperature and pressure gauges to bc freshly calibratcd and run in tandem.

The current method uses a prccision logging tool (the PATS tool **from** Hot Hole Instruments) to measure the flowing temperature and pressure simultaneously in a discharging well over a range of flow rates. Spinner data is also obtained.

The NCG partial pressure (assumed to bc due to CO_2) is then plotted against depth from the logged data.

$P_{CO_2} = P_{tot} - P_{vap,H_2O}$, where P_{vap,H_2O} is estimated from a curve fit to steam table data for pure water.

Tlie mole fraction of CO_2 in the vapor phase is assumed to follow the ideal gas law, which is a reasonable approximation at high temperatures.

$$\frac{n_{CO_2}}{n_{tot}} = \frac{P_{CO_2}}{P_{tot}}$$

Tlie mole ratio is also corrected to account for the gas/liquid distribution at the measured temperature (Barnett, Brodie, 1995). This CO_2 concentration applies at flowing conditions and must be corrected back to total concentration in the reservoir liquid phase or to concentration in separated steam at tlie surface. The calculated level of CO_2 is then plotted versus depth. High-gas feed at entry depth is indicated by a step change **in** the calculated CO_2 concentration.

The method is simple in principle but obtaining good quality data is less straightforward. It is difficult to guarantee the required high level of accuracy of the temperature and absolute pressure data. Practical difficulties include cyclic behaviour of tlie well, data handling efficiency of tlie logging software, and possibly thermal lag of the temperature sensor element.

Stationary temperature readings agree **with** the moving logs in the surveys conducted at wells MG-3D and MG-23D; so thermal lag does not appear to be a real problem. Variations in pressure reading between up and down logs past the same depths have been noted, however. These are now being looked at in detail, with the initial source of the discrepancy suspected to be the induced (additional) turbulence created by pressure drops through the spinner, particularly during down-logs when the pressure sensor is bound to catch it.

Improvement in the logging software is currently undenvay, and is espected to capture tlie inherent precision of the PATS tool and introduce more flexibility in data treatment. **As** it is at the time of this writing, the software captures the raw signals generated by the tool but subsequently rounds off the data before storage to save on space. This has therefore forced the authors to introduce some data filtering, as a first approsimation, in the temperature logs to achieve consistency in NCG calculations. Another apparent weakness of the current software, which is being addressed in the modification, is the fixed logging time constant **of 2** seconds. That is, the **software** gives instructions to the tool to read every 2 seconds instead of 1 second or shorter time interval, which may result in the loss of critical borehole information at high line speeds.

3.0 RESULTS

Tlic well chosen for tlie initial trial (MG3D) is in the Mahanagdong sector of tlie Leyte Geothermal Field. This wcll is situated near tlie perceived upflow and has a rclativcly high NCG content. Tlic intention was to measure tlie NCG content of tlie deep feed which should be representative of tlie hot recharge fluid of tlie field and tlws provide an estimate of the long-term **gas** level. MG3D is a naturally two-phase producer with deep and shallow feeds so only mixed chemistry is obtained at tlie surface.

Tlie well was allowed to flow at **47** kg/s total massflow, with a corresponding discharge enthalpy of 1706 kJ/kg. Figures 1 and 2 show tlie down and up logs, respectively, at this flow condition. The liquid column is only present from about 1800m and two phase condition exists **up** to surface. Tlie spinner log in Figure **3** further indicates that tlie two-phase fluid is entering tlie wellbore between 1730-1810m and 1540-1560m.

The NCG level (Figures 1 and 2) appears lower around the feedzone at 1800m but increases gradually from just above it to about 1300 m from where it appears to stabilize up to surface. Tliis is taken as an indication of higher NCG feeds coining from zones above **1800** in. Corollarily, it also suggests that tlie fluid from the deeper zones beyond 1800 **in** lias a relatively lower NCG level tlian tlie shallow feedzones.

The gas sample at tlie surface taken at tlie same flowing condition measured 2.72 % w/w of NCG, in reasonable agreement with the calculated value above 1300m on tlie up-log, although the down-log average is lower. It is possible that tlie gas level varied with time but only one gas sample was taken so there is no evidence of cyclic variation.

Another well (MG23D) was surveyed while on throttled discharge. Figures 4 and 5 **show** tlie logs when tlie well was flowing 26 kg/s with a discharge enthalpy of 1220 kJ/kg.

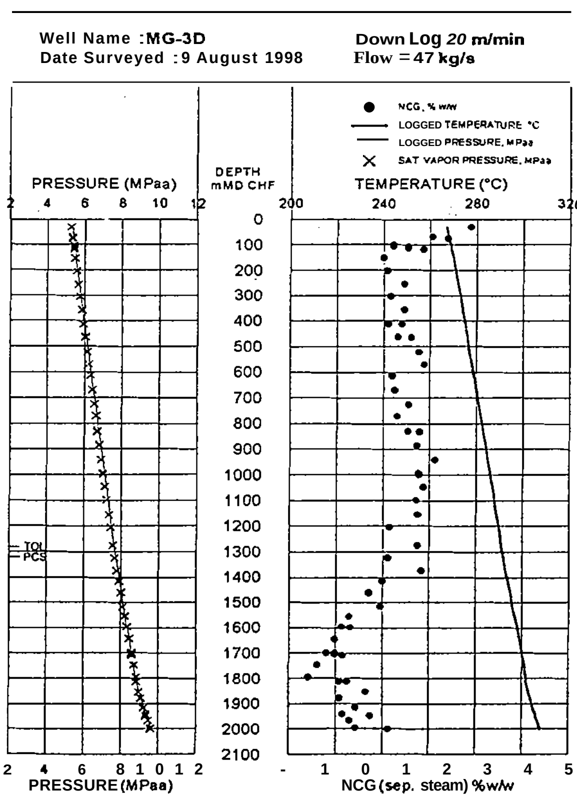

Figure 1. MG-3D down-log.

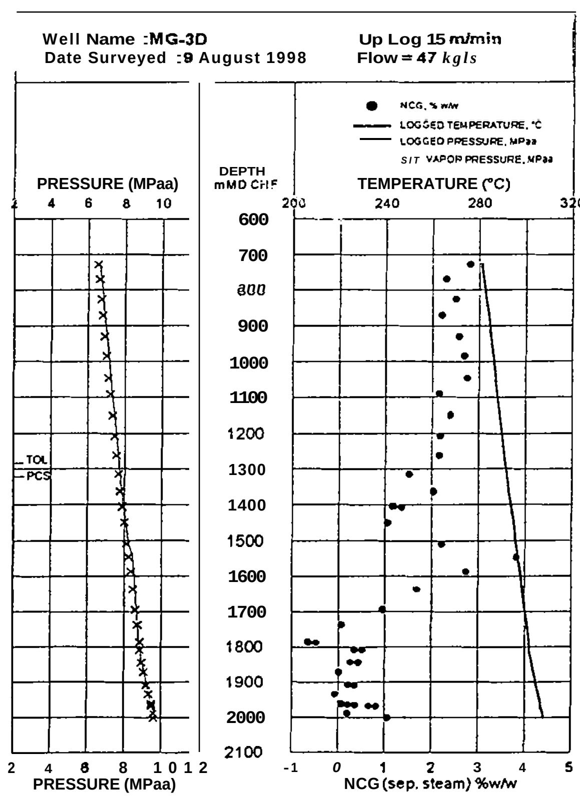

Figure 2. MG-3D up-log.

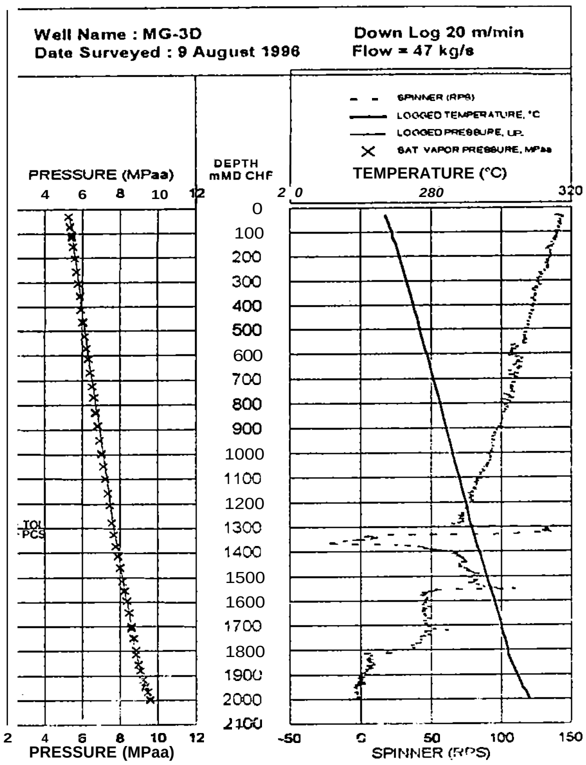

Figure 3. PATS log of MG-3D at high flow.

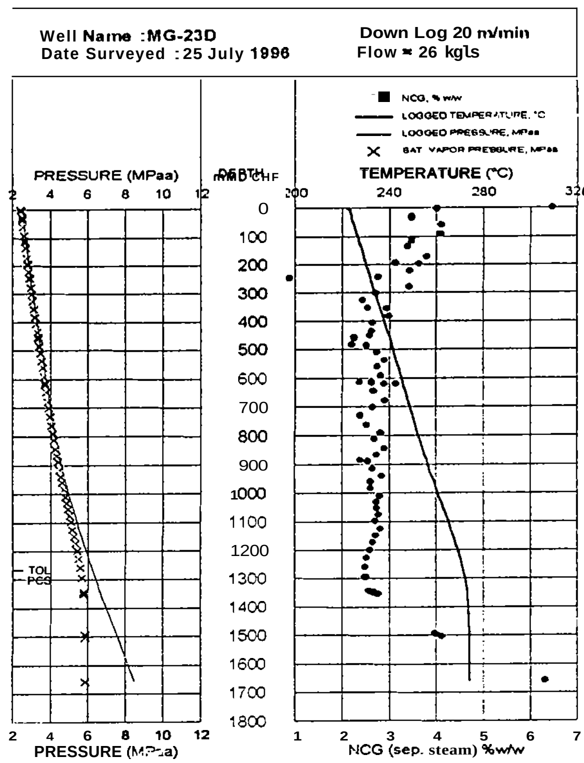

Figure 4. MG-23D down-log (throttled)

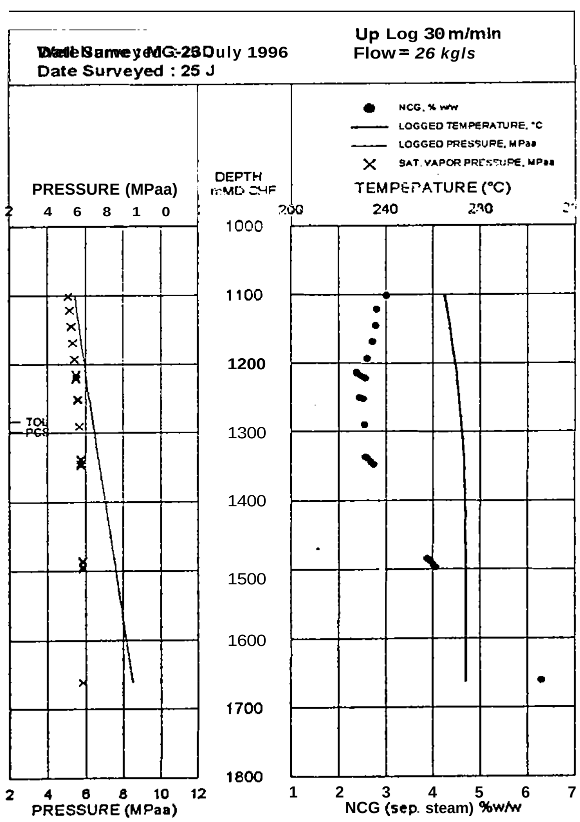

Figure 5. MG-23D up-log (throttled)

This well is located in tlic outflow region of the field and lias a liquid-dominated feed. It lias a single major liquid fced near 1800m (below the deepest point in the survey) and produces liquid water which flaslics near 1350m, as evidenced by the isothcrmal profile below 1350m and deviation of total and saturatcd prcssures.

Tlie calculated NCG content is similar between tlie down-log and tlie (abbreviated) up-log and agrees with gas samples taken **3** days before and after the survey **(2.55** and **2.29** %, respectively). The down-log sliows an increase in gas partial pressure in the top **200** m, which was probably related to the temporary throttling of the well to facilitate entry of the tool into the wellbore.

4.0 DISCUSSION

Tlie results obtained have shonn that the technique of using precision logging of discharging temperatures and pressures can provide useful information which supplements standard gas sampling and well discharge interpretation.

Tlie surveys at well MG-3D have slionn that the high gas contribution is coming from tlie upper feed and is not inherent in the deep fluid recharge. This lias implications on future drilling strategy and ficld management.

The surveys at well MG-23D show good agreement between the calculated NCG content and the gas sampling for a less complex well having **a** single inajor liquid feed.

The apparent variation between **up-** ***and*** **down-logs** in MG-3D may be due to cyclic variations in gas content or induced turbulence between the pressure port and tlie spinner cage of tlie PATS tool, and additional experience nith future surveys 1\41 clarifv tliis. There **does not** appear to be a problem with thermal **lag** in the temperature measurement.

More confidence in the NCG estimates is anticipated with the completion of modifications in the logging software which brings it up to tlie inherent precision level of the logging hardwares.

The sensitivity of the partial pressure calculations also calls for a high quality calibration of the logging tool. An error of 0.5°C is equivalent to 0.1 to 1.1 % NCG over the enthalpy range of 1200 to 1800 kJ/kg. A 0.05 MPa error has the same order of magnitude effcct.

Further refinement in the calculations will also be incorporated in tlie future with introduction of degassing mechanisms in the flowing liquid phase.

5.0 CONCLUSIONS

Precision temperature and pressure logs in flowing wells can provide a reasonable estimate of tlie partial pressure of non-condensable gases in the two-phase column above tlie flash point in a discharging well. Tlie equivalent level of NCG in the separated steam can bc determined from these measurement.

Tlic variation in estimated NCG content with dcpth provides an indication of tlie location of gassy feeds in a well. This cannot be obtained through surface sampling.

Knowledge of the location of the source of high gas fccd zones in a rcscrvoir is useful for targeting and managing production wclls in a field where high gas levels are an economic problem.

High prccision tools arc rcquircd to obtain rcliablc **NCG** profiles. Mechanical tools are unlikely to providc thc rcquisitc prccision undcr normal ficld conditions. Tcsts on two wclls in thc Mahanagdong ficld in Lcytc have shown that high tcmpcraturc electric logs do now provide this capability.

6.0 REFERENCES

Barnett, P.R and Brodie, **A.**J. 1995 *Personal Communication.*

McDowell, G.B. **1974.** An Instrument for Mcasuring thc Gas Concentrations **in** Geothermal Wells. *Geothermics, Vol.3,* ***No.*** *3.*