

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 flashpoint 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 deep feed prior to mixing with fluid from shallower zones can be calculated. Changes in the gas partial pressure profile thus enable discrimination of high-gas feeds.

Two examples from the Mahanagdong field in Leyte, Philippines are presented.

INTRODUCTION

Geothermal fields with a significant non-condensable 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. In contrast, wells feeding from a deep upflow of saturated liquid will have lower initial NCG levels which will change little during the 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 CO₂) in the 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.

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 the separated steam to

obtain the vapor pressure, and measured the differential pressure compared to the total line pressure, which is a direct measurement of the gas partial pressure.

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

The current method uses a precision 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 be due to CO₂) 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.

The mole fraction of CO₂ in the vapor phase is assumed to follow the ideal gas law, which is a reasonable approximation at high temperatures.

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

The mole ratio is also corrected to account for the gas/liquid distribution at the measured temperature (Barnett, Brodie, 1995). This CO₂ 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 the surface. The calculated level of CO₂ is then plotted versus depth. High-gas feed at entry depth is indicated by a step change in the calculated CO₂ 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 the well, data handling efficiency of the 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 underway, and is expected to capture the 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 approximation, 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.

RESULTS

The well chosen for the initial trial (MG3D) is in the Mahanagdong sector of the Leyte Geothermal Field. This well is situated near the perceived upflow and has a relatively high NCG content. The intention was to measure the NCG content of the deep feed which should be representative of the hot recharge fluid of the field and thus 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 the surface.

The 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 the 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. The spinner log in Figure 3 further indicates that the two-phase fluid is entering the 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. This is taken as an indication of higher NCG feeds coming from zones above 1800 m. Corollarily, it also suggests that the fluid from the deeper zones beyond 1800 m has a relatively lower NCG level than the shallow feedzones.

The gas sample at the surface taken at the same flowing condition measured 2.72 % w/w of NCG, in reasonable agreement with the calculated value above 1300m on the up-log, although the down-log average is lower. It is possible that the 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 the logs when the well was flowing 26 kg/s with a discharge enthalpy of 1220 kJ/kg.

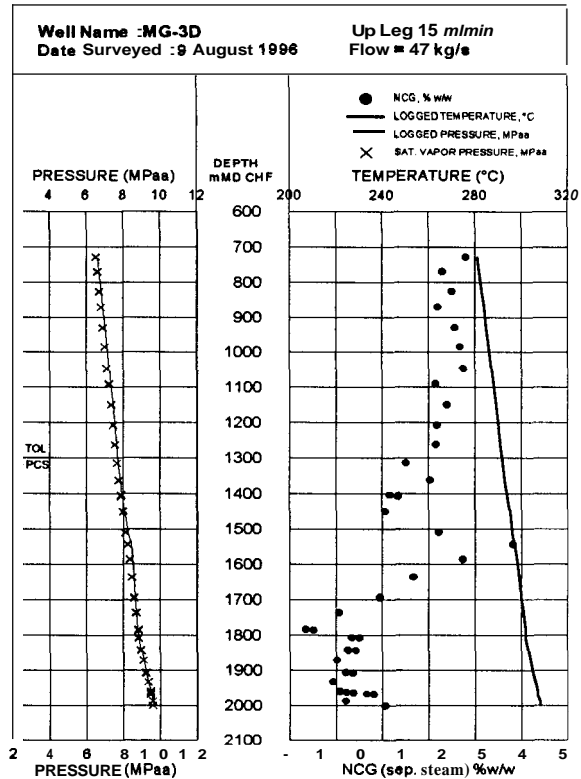


Figure 2. MG-3D up-log.

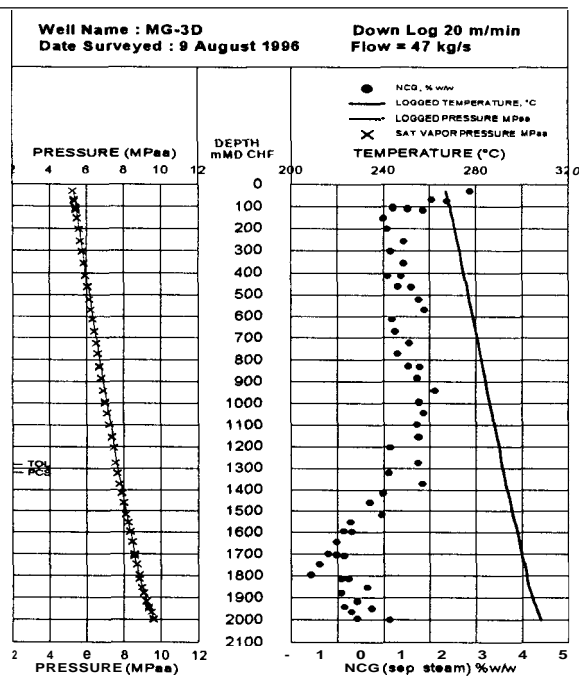


Figure 1. MG-3D down-log.

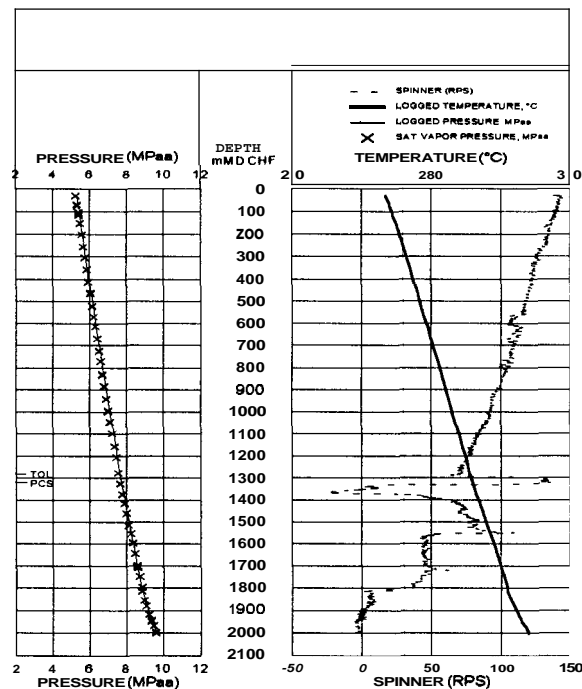


Figure 3. PATS log of MG-3D at high flow.

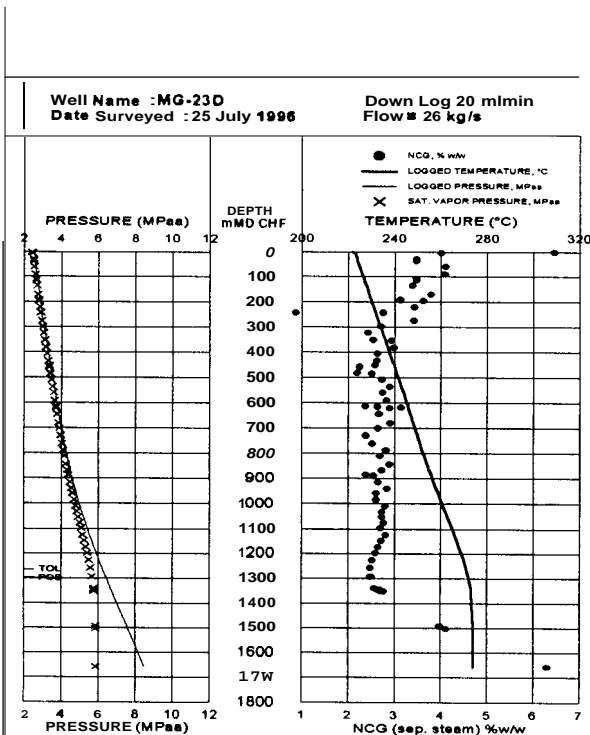


Figure 4. MG-23D down-log (throttled)

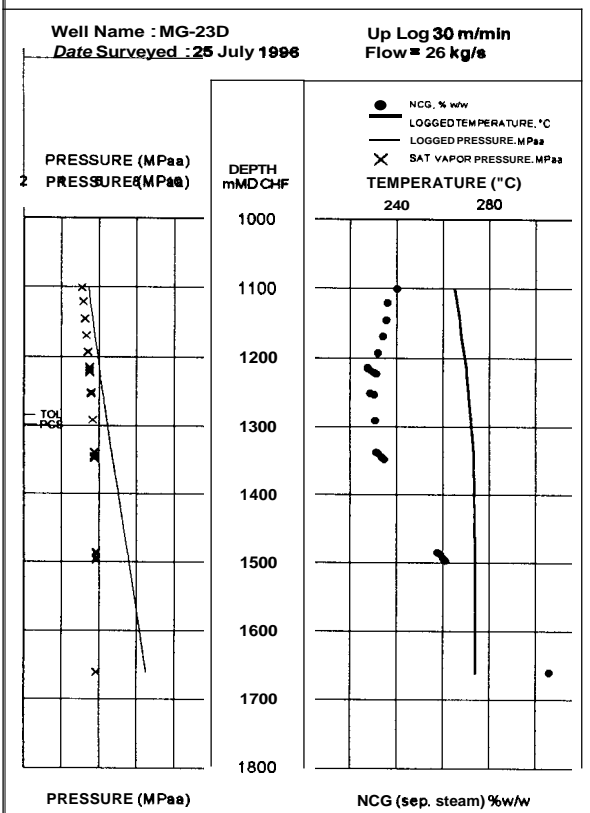


Figure 5. MG-23D up-log (throttled)

This well is located in the outflow region of the field and has a liquid-dominated feed. It has a single major liquid feed near 1800m (below the deepest point in the *survey*) and produces liquid water which flashes near 1350m, as evidenced by the isothermal profile below 1350m and deviation of total and saturated pressures.

The calculated NCG content is similar between the down-log and the (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 shows 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.

DISCUSSION

The results obtained have shown 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.

The surveys at well MG-3D have shown that the high gas contribution is coming from the upper feed and is not inherent in the deep fluid recharge. This has implications on future drilling strategy and field 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 major 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 the spinner cage of the PATS tool, and additional experience with future surveys will clarify this. 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 the 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 effect.

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

CONCLUSIONS

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

The variation in estimated NCG content with depth provides an indication of the location of gassy feeds in a well. This cannot be obtained through surface sampling.

Knowledge of the location of the source of high gas feed zones in a reservoir is **useful** for targeting and managing production wells in a field where high gas levels are an economic problem.

High precision tools are required to obtain reliable NCG profiles. Mechanical tools are unlikely to provide the requisite precision under normal field conditions. Tests on two wells in the Mahanagdong field in Leyte have shown that high temperature electric logs do now provide this capability.

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