

ELECTRONIC TEMPERATURE, PRESSURE AND SPINNER LOGS IN GEOTHERMAL WELLS — PNOC-EDC APPLICATIONS

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ABSTRACT

Accurate wellbore measurement was made possible with the use of electronic Temperature-Pressure-Spinner (TPS) equipment in PNOC-EDC geothermal wells.

Combined waterloss, injectivity and pressure fall-off data are derived in a single completion survey. Various wellbore phenomena such as downflows, upflows and gas feeds are detected through the logs.

Downhole measurement of the non-condensable gas content of production fluids is also made possible at any depth above the flashpoint.

Stand-alone spinner logs are also used regularly for measurement of well injection capacities.

Examples of various applications are presented.

BACKGROUND

The Philippine National Oil Company-Energy Development Corporation (PNOC-EDC) started the use of electronic temperature-pressure-spinner equipment (TPS) in its geothermal operations in late 1992. Its first application was in the measurement of baseline injection capacity of wells in BacMan I Geothermal Production Field prior to the commissioning of the 110 MWe power plant. Its application picked up in 1993 when the company started its acidizing program and its regular use incorporated in all acidizing programs.

With the advantages of a TPS equipment over conventional downhole measurement tools fully appreciated, the company decided to buy and operate its own sets of this equipment for its various geothermal applications.

PNOC-EDC's use of the Hot Hole Instruments TPS equipment (codenamed PATS) officially commenced on June 24, 1996 with a successful log of test well MN-1 in the Leyte Geothermal Power Project. From then on dozens of TPS covering various applications have been conducted by the company's Reservoir and Resource Management Department. Prior to the PATS commissioning, PNOC-EDC was hiring the services of an independent wireline company for its production logging applications.

From 1992 until the end of 1996, a total of 57 TPS logs were conducted in 35 PNOC-EDC wells. This paper highlights the TPS applications in these wells and discusses the various wellbore phenomena observed from some of the logs.

GENERAL FEATURES OF A TPS TOOL

The TPS tool is a downhole equipment which provides simultaneous records of depth- or time-indexed temperature, pressure and spinner data. Tool responses are transmitted to the surface via a single conductor logging cable and are graphically displayed and digitally recorded by either desktop or laptop computers. The recorded data can be retrieved and processed any time after the log for detailed analysis and interpretation. The tool comes either as a memory type of equipment or an on-line surface read-out type. PNOC-EDC operates the latter type.

Its best advantage over mechanical gauges rests on the accuracy of the **logs**. The on-line surface read-out type is also preferred over the downhole memory type because of the inherent flexibilities it provides the operator. These flexibilities can be in the form of total control over log sequencing, repetition, depth selection and the ability of the operator to modify

the survey program based on immediately analyzable downhole data provided by the tool. This latter flexibility becomes extremely handy and cost-effective when wellbore or equipment condition calls for unscheduled log termination.

PNOC-EDC's PATS system has an accuracy of 0.2% of full scale and pressure resolution of 0.2 psi. The spinner section uses interchangeable impellers to accommodate different ranges of flow velocity. Flow direction is also indicated in the logs. It is rated for use at a maximum temperature of 700°F (371°C) and a maximum pressure of 15,000 psi (103 MPa).

TPS LOGS IN COMPLETION TESTS

The TPS tool was found very useful in the completion testing of geothermal wells. Primarily, the objectives of the tests are: a) to identify potential feed zones; b) to determine the overall permeability and hence an estimate of injection capacity; and c) to initially quantify reservoir parameters such as temperature and pressure (PNOC-EDC, 1990). The completion interval of the well is the slotted portion of the production liner.

Completion testing with TPS tool is more flexible because data is monitored at the surface while logging. Data analysis may be done immediately so that the tests can be revised or extended to allow for optimum data acquisition. Tests such as waterloss, injectivity and pressure fall-off are combined in one continuous survey without having to pull out the tool, such as in the case of mechanical gauges.

The combined interpretation of temperature and spinner data from the TPS enables discrete identification of payzones while a more accurate determination of injectivity index is possible from the pressure data.

The following are examples of the application of TPS data obtained during completion tests of some PNOC-EDC geothermal wells.

Baseline Data for Newly Drilled Wells

Completion tests of newly drilled PNOC-EDC geothermal wells are conducted immediately after cessation of drilling activities. Gathered information serve as baseline data and are used as references for any future work to be done on the well. Completion testing of newly drilled wells at PNOC-EDC using TPS tool is currently done but only on selected wells,

The typical completion test process when using TPS tool is as follows:

1. First, start the first pump rate (4BPM) and stabilize for two hours.
2. Then, run in TPS tool and record data while logging down at 20 m/min to the maximum allowable depth. The water level can be determined from this log.
3. From the maximum allowable depth, log up 20 m/min to about 200 meters above the top of slotted liner.
4. Next, determine payzones from the recorded data. More moving logs of different line speeds may be run on the completion interval as required to resolve ambiguity in the interpretation. This is also helpful in isolating tool glitches.
5. Make stationary reading at points above and below each identified payzones and at the estimated pressure control point where injectivity index will be computed.
6. Repeat the process for each pump rate (4, 8, 12 and 16 BPM). Pressure fall off test is conducted after completion of moving logs at the last pump rate.

Characterization of Wells for Acid Stimulation

When PNOC started the acid treatment of its geothermal wells in 1993, a more precise downhole instrument was deemed necessary to determine improvement in the wellbore in terms of injectivity indices, changes in temperature and pressure profiles, and payzone thicknesses indicative of enlargement of original payzones or opening up of new ones. It is also necessary to accurately determine the payzones to be acidized for proper spotting of acid. The acid stimulation program of the company was still at its experimental stage then and it was necessary to have an accurate gauge on the success or failure of the acid treatment. Downhole tests using the TPS tool were thus used in the pre- and post-acid completion tests of the acidized wells.

Pre-acid TPS measurements were conducted after mechanical workover to serve as baseline data. Initial results of completion tests using TPS data prior to acidizing indicated large differences in estimated payzone thicknesses estimated from indexed temperature profiles. Figure 1 shows a plot of indexed Kuster temperature (KT) data used to estimate permeable zones compared with estimates from TPS data. In most cases of completion testing using TPS tool, identification of payzones is done

with the aid of the spinner profile recorded over the completion interval. This is especially helpful in wells exhibiting near isothermal temperature profile during cold injection as shown in the same figure. The TPS data gathered prior to acidizing helped refine these estimates and locate the proper depth for acid injection to optimize delivery to target zones.

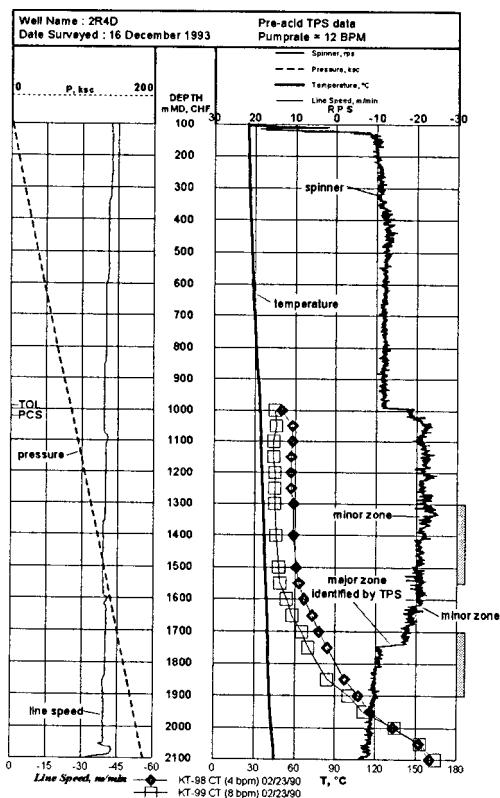


Figure 1 Comparison of estimation of payzones based on Kuster temperature data and TPS data.

Completion tests using the TPS tool were conducted immediately after acidizing to determine the changes in the well brought about by acid stimulation. Correlation of pre-acid and post-acid TPS logs helped determine improvement in the wellbore. Figure 2 is an example of the plots of TPS data of well 2R4D conducted before and after acidizing.

The logs show changes in the temperature and spinner profiles of the well suggesting that the zone below the production casing shoe opened and the lower zone was enlarged. Near bottomhole pressure declined by about 3.75 MPa coupled with a 250-m drop in water level, indicating increased acceptance by the well. The post-acid injectivity index of the well was calculated to be 170 li/s/MPa, which is almost a tenfold increase compared to the pre-acid injectivity index of 17.6 li/s/MPa. These

observations led to the conclusion that the acid stimulation of the well was successful.

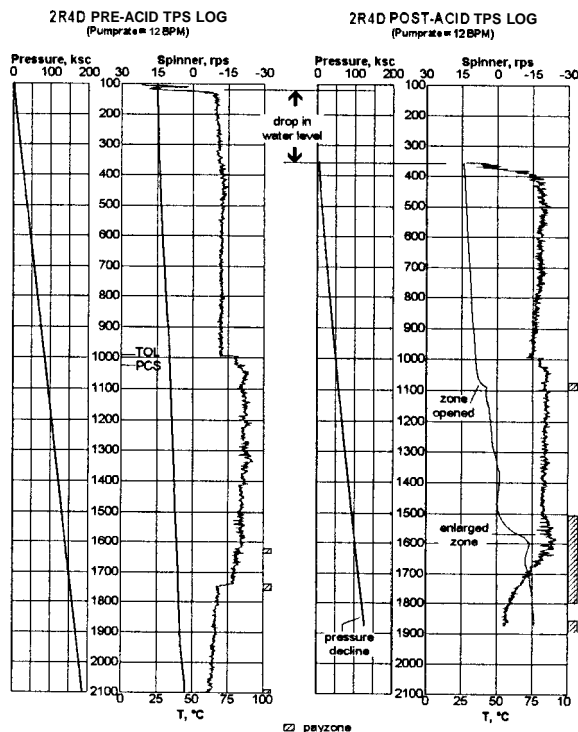


Figure 2 Comparison of TPS data before and after acidizing of well 2R4D

The recent acidizing experiences of PNO-C-EDC revealed that an accurate estimate of payzone thicknesses is a key factor in the optimization of acid volume for wells with confirmed temporary wellbore damage. Such accuracy may be provided by TPS measurements during completion test of the well.

Post-perforation Tests

Perforation of the production casing of well SK-2D in Mindaiiao was carried out to tap possible two-phase zones cased off when the well was completed. The zones targetted for perforation were delineated from a TPS log conducted six months earlier.

A TPS survey was then conducted after perforation to test the permeability in the newly opened up zones and determine the success of the perforation job.

The plot of TPS data in Figure 3 confirmed that the perforation was successful. The temperature and spinner profiles clearly show that the perforations were able to penetrate permeable horizons. Most remarkable is the perforated zone at around 700 mMD which showed an entry of lighter fluid as indicated by a slight change in pressure gradient of

the well. This inanimation was further reinforced by an increase in temperature gradient indicating that a higher temperature fluid entered the casing. The spiked spinner response is typical of gas or two-phase flow into the wellbore.

The perforation at around 1060mMD indicated fluid loss to formation based on the decreased spinner response and change in temperature gradient at this depth. The well was plugged above the top of liner at around 1200 mMD when the survey was conducted.

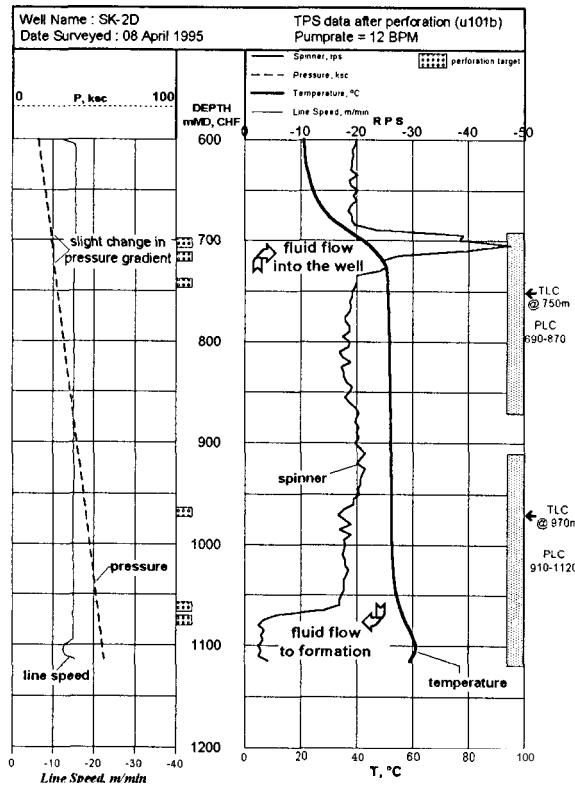


Figure 3 Post-perforation TPS log of well SK-2D confirming successful perforation of production casing.

Identify Hydraulic Fracturing Targets

Hydraulic fracturing jobs were conducted on 4 wells at Leyte Geothermal Power Project. One of the requirements before the hydrofracturing job is the accurate determination of permeable zones, primarily to determine the amount of proppant to be used. It is also necessary to establish how the other zones respond at higher pumprates to determine possible sources of leak off to formation. Accurate bottomhole pressure measurement is also desirable during step rate test. Step rate test is conducted to determine the flowrate to be used during the

treatment. It will also give information on the pressures to be encountered at the operating flowrate to be used.

The TPS tool was used to gather the necessary information. A completion test was also conducted to determine the permeable zones and to observe from the logs how these zones responded to increased flowrates. The data were also used as baseline for comparison with tests to be conducted after hydrofracturing.

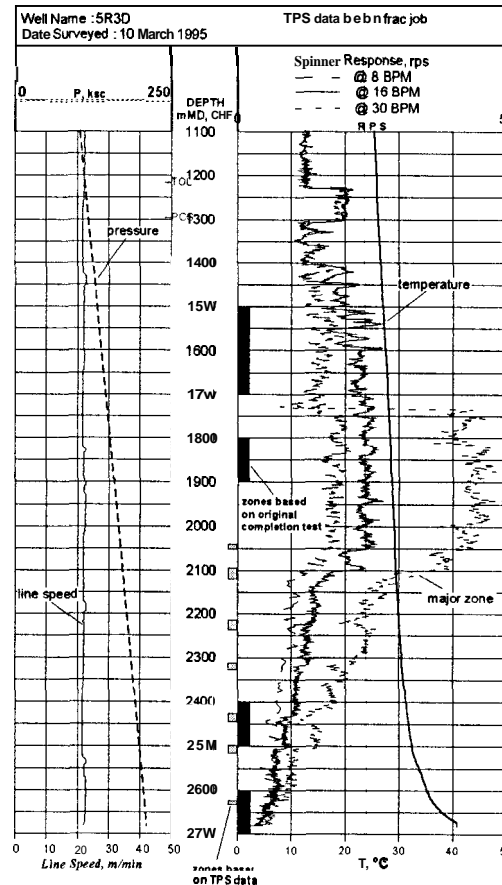


Figure 4 Plot of TPS data before hydrofracturing of well 5R3D.

Figure 4 is a plot of TPS data from well 5R3D. The log shows the temperature, pressure and line speed data recorded at 16 BPM pumprate. The spinner responses at 8 and 30 BPM are plotted for comparison. The locations of the pre-hydrofracturing payzones were based on the original completion test data from Kuster measurement. Payzones estimated from the TPS data were interpreted mostly from the spinner responses. The zone at around 2110 mMD was not reported in the original completion test but is clearly identifiable from the spinner logs. This and the zone at around

2010 mMD were eventually programmed as targets for hydrofracturing while the lower zones were isolated by spotting protective gel below the target zones. The well was relatively tight, with 2.65 MPa g WHP at 30 BPM pump rate.

OTHER APPLICATIONS OF TPS DATA

The TPS data were also used in other applications with different objectives. In the following examples, the logs were conducted while the well was either discharging or under hot injection.

Identification of Inflows, Upflows and other Wellbore Phenomena

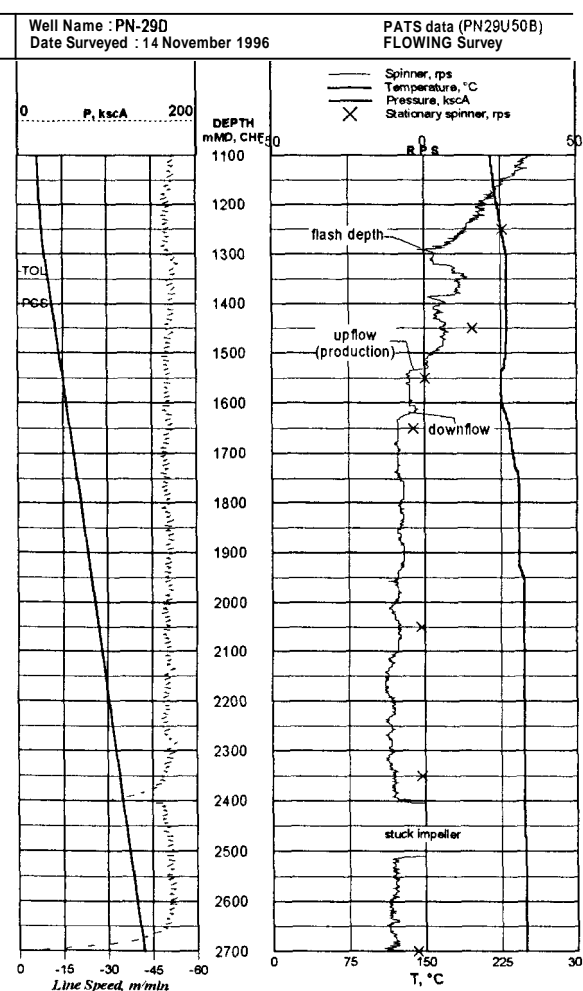


Figure 5 Flowing TPS data of well PN-29D showing downflow during discharge.

The acid treatment of some reinjection wells in Palinpinon I Production Field (PIPF) resulted in increased capacity of the wells. However, this eventually led to rapid reinjection returns to the production sector and induced thermal degradation

at PN-29D, one of the production wells in the area (Buiing, et al, 1995). Tests were made using TPS tool in some of the affected wells in the area to confirm presence of inflow. Decisions may be made later to workover the well in order to mitigate the thermal degradation brought about by reinjection fluid returns.

Figure 5 shows a plot of flowing TPS data from well PN-29D. The temperature and spinner data confirmed production from 1490-1550 mMD and downflow coining from 1625-1640 mMD. (Also shown in the log is a portion where the spinner was stuck - a common problem with spinner measurements.) Flashing occurs at around 1300m, as shown by the pressure, temperature and spinner data. Flashing flow in a geothermal well causes velocity to increase continuously as it flows up the wellbore, and intervals of constant velocity do not exist above the flashpoint (Spielman, 1994). A downflow of 14 kg/s calculated from the spinner data using an assumed holesize of 8 inches is believed to mask the potential production from the bottom zone.

Two nearby production wells, PN-18D and OK-7D, were logged during shut condition. The TPS data also showed fluid downflow at about the same horizon observed from well PN-29D.

Downhole NCG Measurement

Downhole measurement of the non-condensable gas content of production fluids at any depth above the flashpoint was experimented using data from TPS logs conducted while the well was discharging. This application requires accurate simultaneous measurement of temperature and pressure data. The moving TPS logs conducted along the well served as the source of data in the correlation. Stationary logs were conducted in strategic points to re-check the accuracy and repeatability of the logs.

The NCG partial pressure which is assumed to be due mainly to CO₂ is calculated from the following equation (Clotworthy, et al, 1997).

$$P_{CO_2} = P_{tot} - P_{vap,H_2O}$$

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

Clotworthy, et al (1996), who conducted the study on this subject, are optimistic that the current electronic temperature-pressure-spinner tool owned by PNOG-EDC can sufficiently provide the required data after improvement in its operating software is