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# DEVELOPMENT OF AN ELECTRONIC MEMORY TOOL FOR LOGGING GEOTHERMAL TEMPERATURE AND PRESSURE PROFILES

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**SUMMARY - A** downhole memory, simultaneous temperature-pressure logging tool for use in geothermal wells has been developed and tested by Contact Energy Ltd., with Spinks Energy Systems Ltd. An electronic log of depth and time on the wireline winch used to run the downhole instrument is recorded on a surface data logger, at the same time as the logging instrument is recording temperature and pressure. By merging the downhole and surface data, logs of time, depth, temperature and pressure are obtained. Thus, profiles of temperature and pressure versus depth or time can be derived. The instrument has an accuracy of better than 0.25°C and 0.03 bar.

## 1. INTRODUCTION

Downhole well logging instrumentation for geothermal applications has always been beset with difficulties caused by high temperatures and pressures, problems with seals in the containment vessels, with electronic designs, with power supplies and with the transmission of data to the surface. Electronic memory tools eliminate the problems of data transmission via the wireline, and have been used in the hydrocarbon resource exploration industry for some years. Hostile environment versions developed for that industry are capable of operation to 260°C, but have not been readily accepted for use in the geothermal environment. With improvements in electronics and digital technology, memory tools are now being developed to meet the needs of the oil exploration and geothermal industries, and are capable of operation up to 400°C (Lysne, 1992). Commercial memory tools to meet that specification are costly. The objectives for the present development were:

- to develop an inexpensive tool, using readily available off-the-shelf electronic components and transducers,
- to achieve a technical specification at least as good as that of Kuster mechanical temperature and pressure instruments,
- to eliminate the tedious manual extraction of data, and to improve on the accuracy by storing the data in digital form, and
- to produce an instrument at a similar cost to that of mechanical instruments.

The above objectives have been achieved in the logging system described here. The system has been developed by Contact Energy Ltd. at Wairakei, with consultants Spinks Energy Systems Ltd., Wellington, for making downhole surveys in the geothermal wells at Wairakei and Ohaaki fields. It was designed to be interchangeable with existing mechanical downhole recording instruments, and to utilise the same surface wireline equipment. While the temperature and pressure conditions at Wairakei and Ohaaki are not as high as those found in some other fields, the specifications for the final instrument developed in the programme would be suitable for most geothermal applications.

The electronics are sealed within a Pyroflask (Blanton, 1985). This is a high technology integral pressure housing and vacuum flask designed to withstand pressures and temperatures up to 20 MPa and 400°C. It is described in one of a collection of papers compiled by Dennis (1985) for the Los Alamos National Laboratory. The papers provide a good review of current well logging technology.

The logger has a multi-channel analogue-to-digital converter (ADC) for reading the probe transducers and the battery voltage, 32K of static memory, a real-time clock and an RS-232 interface for communicating with an external computer. The interface is used to set up the probe, to start and stop data logging and to read the log data. At present, the probe measures the temperature of the geothermal fluid fiom 0 to 300°C, and absolute pressure up to 14 MPa (2,000 psia). The logger and signal conditioning circuits use very little power. Thus, the internal batteries can be small and internal heating is kept to a minimum. The internal temperature and battery voltage are recorded to enable corrections to allow for drift in the electronics.

The data is logged into internal memory. This is large enough to record about eight hour's worth of data with the readings at ten second intervals. A crystal-controlled real-time clock provides date and time readings which are recorded along with the temperature and pressure data. The clock also provides start and stop commands to the logger, set previously by the external computer prior to inserting the probe down the borehole.

As the probe is lowered down the borehole, a rotary encoder on the cable depth counter keeps track of the depth. This data is recorded on a computer at the surface, along with the time and date. When the probe is retrieved, the winch and probe logs are merged by matching the time stamps on the data. This gives a file of time, depth, temperature and pressure.

## 2. PROBE DESCRIPTION

The downhole probe is mounted inside a stainless steel vacuum vessel, with nominal external dimensions of 1.3 m long and 75 mm diameter. The well pressure is measured with an absolute pressure strain gauge transducer, and the temperature is measured with a class 1 platinum resistance thermometer.

The vacuum vessel contains the pressure transducer, signal conditioning amplifiers and data logger, battery pack, a heat sink and another platinum resistance thermometer for measuring internal temperature.

The logger is controlled by its own program stored in read-only memory (ROM). The logged data is stored in static random-access memory (RAM). More than one log can be stored at a time. This memory also holds the control settings for the logger, set by the external computer. The RAM contents depend on battery power being available all the time. Before the battery voltage reaches 4V, the logger will shut down automatically to preserve the data already collected. The pressure transducer and signal conditioning amplifiers have separate batteries, so they do not affect the memory battery.

The control commands fiom the external computer are:

- Set and read real-time clock date and time.
- Set log start and stop time. The log can be started immediately and stopped on memory full, or can be started and stopped at specific times.
- Set logging rate. Data can be read once per second, once per hour, or anywhere in between.
- Read memory contents.
- Clear memory to prepare for a new log.
- Calibrate sensors.

### 2.1 Specifications

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|---|---|
| Maximum pressure: | up to 20 MPa (2,800 psia) with suitable transducer. |
| Normal operating pressure: | 1.4 - 10 MPa (200 - 1,400 psia) |
| Maximum Temperature: | 400°C |
| Normal operating temperature: | 0°C - 300°C |
| Accuracy: | Better than 0.1% F.S. |
| Data recorded: | Date & time<br>Internal temperature<br>External temperature<br>External absolute pressure |
| Memory: | 32K bytes installed |
| Battery life: | 12 hours at full operation. |
| Surface recording: | Date & time<br>Depth (0 - 9,000 m) |

### 2.2 Analogue Circuit

The downhole probe contains two class 1 platinum resistance sensors, one for the external temperature and one for the probe's internal temperature. These are interfaced to the ADC via precision low drift signal conditioning electronics.

The other analogue device within the probe is an absolute pressure transducer, temperature compensated. It is supplied by its own 12 volt battery, so that its operation does not affect the operation of the temperature measuring circuits or the data logger.

### 2.3 Digital Circuit

The digital circuit is based on a single-chip microcontroller. This device incorporates ROM (containing the probe software), RAM (for storing control parameters), a communications interface, a clock and some security systems all on the one chip. The microcontroller is a very low power device.

Connected to the microcontroller are an analogue-to-digital converter (ADC) containing noise filtering and giving a resolution of 0.002% of full scale, an additional RAM chip to store the logged data and the time and date stamps, a power supply chip, and an RS-232 interface, compatible with standard serial ports on external computers.

### 2.4 Depth Encoder

The depth encoder keeps track of how deep the probe is in the well. It consists of a small optical rotary encoder attached to the depth counter. The encoder provides 256 pulses per revolution and is bidirectional. It is enclosed in a small waterproof case containing the counting circuit which is connected to the external computer. A depth encoder pulley of 150 mm diameter gives a depth resolution better than 2 mm, and a total measuring range of 0 to 9,000 metres.

## 2.5 Downhole Software

The probe has two separate software components: the uphole software and the downhole software. The downhole software controls the logger directly. It tests and initialises the different hardware components of the probe when the power is first applied, clearing the memory and resetting the ADC. The software also interacts with the user through the probe's serial port, maintains the real-time clock and records sensor data during a log.

The downhole software starts with an initial set up and test mode. It automatically tests each hardware component, and then waits for user commands coming through the serial port. Commands are acted on as they are sent to the probe. A sample list of commands is included above.

The probe's other mode of operation is the logging mode. In this mode, the probe reads the sensors at the required rate and stores their data in memory. The logging mode can be entered in one of two ways: either by direct command (e.g. Start Logging Now) or by scheduled start (when the Log Start time is reached). The probe will stay in the logging mode until the Log End time is reached, the memory is full or by external command. The selected sensors are read and stored in memory during this time, at intervals determined by the Log Rate parameter.

At the end of a log, the probe goes from the logging mode back to the command mode, and commands are once again acted on. Typically, one of the first commands after returning from the logging mode is to read the memory contents. This command comes fiom the external computer connected to the probe through the **RS-232** serial port.

## 2.6 Uphole Software

The uphole software runs on the external computer and provides the user interface to the probe. This software is based on a menu paradigm and is designed to be user-friendly. All the parameters of the probe are presented on one screen, so the state of the probe can be taken in at **a** glance. Each of the parameters can be selected by moving a highlight bar, and changed in various ways. For example, by selecting the probe time and date the user can synchronise the probe's clock to the computer's clock. This is important to correctly correlate the winch and probe logs.

The uphole software also allows the user to set the log start and stop times. **A** single keystroke will start the probe logging immediately, or alternatively the user can enter a specific time for the log to start. Similarly, the log rate can be entered as the number of seconds between readings. This rate (or rather, period) can be set in increments of a tenth of a second fiom one second to one hour (3,600 seconds).

Straight-line calibration can be performed for the probe's sensors with the uphole software, by setting the probe to transmit the readings directly into the external computer. In this mode the temperature and pressure readings are continuously updated on the screen.

During a log, the uphole software records the probe depth as provided by the depth encoder. Once the probe has been retrieved and reconnected to the external computer, the software will download the probe's memory contents and automatically merge the two logs: the temperature, pressure and depth readings will combine into a single file. The respective times (and dates) are also put alongside each reading. All this data is saved as a tab-delimited text file, which can be read by all the popular spreadsheet, database and word processing programs. The plotting features of these

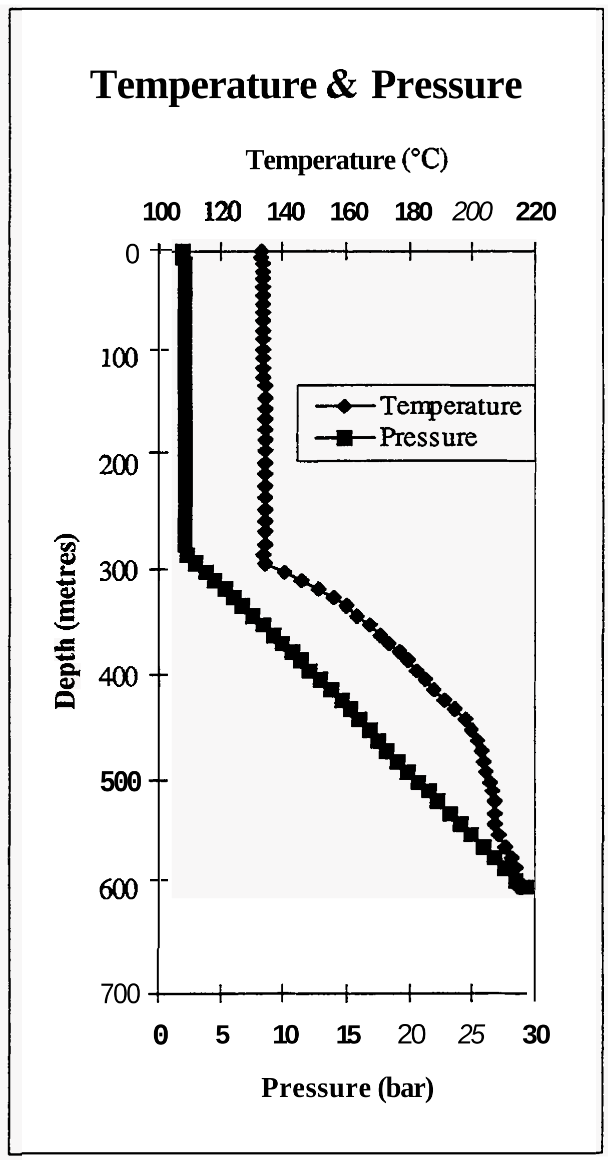


**Figure 1 – Well temperature and pressure plotted against depth.**

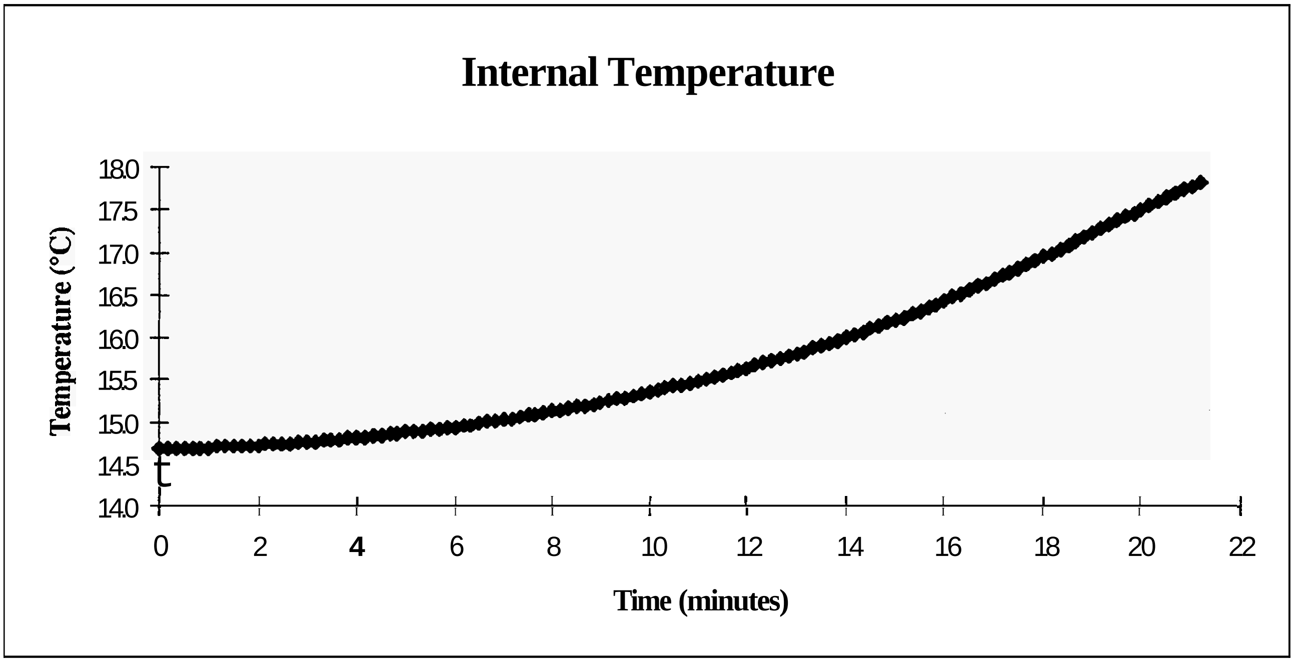


**Figure 2 - Internal probe temperature during the test.**

packages can then be used to chart the well temperature versus depth, or pressure versus depth. Sample charts are given in this paper.

Note that during a log the winch can be started and stopped at any time, and can be run at varying speeds. Annotations can also be entered by the user to record details of particular interest at the time (e.g. "Start down log at 300m"). These notes are time-stamped and stored along with the time and depth.

## 3. RESULTS

Test runs were performed with the probe at the Wairakei geothermal field. Before a run, the probe electronic assembly in its protective sleeve is removed from the vacuum vessel and programmed via its serial port, with the external computer. The memory is cleared, and the log start and stop times and the logging rate are set. The start time is typically advanced to give sufficient time to reach the test site, set up the winch and prepare to lower the probe into the well. Once set, the electronics are unplugged from the external computer and inserted into the vacuum vessel. The vessel is then sealed ready for the downhole test.

For the well test, the lowering rate must be slow enough to allow the temperature sensor to reach equilibrium with well temperature as each reading is taken. The sensor is encased in the stainless steel cap of the vacuum vessel, which gives it an equivalent heat capacity of about 450 J/kg·°C.

After retrieving the probe, it is taken back to the workshop and opened to download the data.

Figures 1 and 2 show the results obtained from a single well test. Figure 1 shows the temperature and pressure of the geothermal fluid in the well. The probe was lowered to a depth of about 600 metres at a rate of almost one metre per second, taking readings every ten seconds. Thus, readings were taken approximately every ten metres. The temperature ranged from 130°C at the top of the well to about 210°C at the bottom of the probe's run. The sudden rise in temperature at about 300 metres depth occurs when the probe reaches water level. The steam pressure remains constant at almost 2 bar until the probe reaches water at 300 metres. From this point the pressure increases linearly with depth.

The rate of descent used for this test allowed the external temperature sensor to reach equilibrium with the steam, but was too great for the sensor to reach equilibrium with the water, where the temperature gradient was much higher. Temperature changes greater than 0.5°C/sec produce measurement errors due to thermal lag. For the previous well test, a descent rate of 0.5 m/sec (half the actual rate) would allow equilibrium with the water to be achieved. The response of the pressure transducer is much faster, and the descent rate has a minimal effect on pressure measurement.

Figure 2 is a plot of the rise in temperature inside the vacuum vessel versus time during the well test. The temperature rise is due to heat leaking into the vessel from the external fluid and to heat dissipated by the electronics inside. The non-linear rise in internal temperature indicates that heat leaking into the vessel from the external fluid is the predominant factor in internal heating. Overall, the temperature only rose about three degrees in the entire run, a period of just over twenty minutes. In this well, a run of up to three hours is allowed before compromising the operation of the electronics (i.e. before the interior temperature reaches 70°C). This would permit logging to a depth of over 4,000 m, assuming a descent rate of 0.5 m/sec. In case of emergency, the vessel could stay in this well for up to ten hours before permanent damage occurred to the electronics. In this case, though, the log data would be lost. In a hotter well (300°C), a run of almost two hours would be possible, with logging to about 2,800 m.

## 4. CONCLUSIONS

The probe meets all the required performance criteria in its current implementation. It is a robust tool capable of recording the temperature and pressure of geothermal wells to a high degree of accuracy. Further refinements can be made to the uphole software's user interface. In particular, the software could be expanded to include plotting capabilities. This would eliminate the step of transferring the data to another software package in order to visualise the data in a graphical form.

The constraints on operation time and the consequent achievable depths have been extrapolated fiom data gathered during test runs. The calculations indicate satisfactory performance of the vacuum vessel, but longer, deeper runs are needed to verify this performance.

## 5. ACKNOWLEDGMENTS

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