PROCEEDINGS, 13th Indonesia International GEOTHERMAL Convention & Exhibition 2013
Assembly Hall - Jakarta Convention Center Indonesia, June 12 – 14, 2013

DEVELOPMENT OF GEOTHERMAL WELL LOGGING TOOLS IN NEW ZEALAND BY MB CENTURY 1950-2012

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ABSTRACT

This paper reviews the development of downhole logging equipment capable of operating at temperatures up to 330˚C in New Zealand over the last 60 years. During the initial period of development there were no off-the-shelf solutions and downhole tools were developed in New Zealand. Instruments to accurately measure downhole temperatures were in use within a year of completing the first wells at Wairakei in 1951 and mechanical downhole pressure gauges were introduced in 1958. Since that time equipment and logging methods have gradually improved, with the introduction of surface readout temperature-spinner logging in 1966 and onwards to simultaneous pressure-temperature-spinner logs in 1995. Probably the most significant improvement was the introduction of downhole memory PTS tools, capable of being run using a small wireline winch, in 2000. By 2003 this method had superseded mechanical PT tools for all routine logs. Since then the reliability and capability of downhole logging has gradually improved with advances in electronics and technology. High temperature PTS logging tools can now be purchased from several different manufacturers. The current MB Century PTS tool provides a cost-effective solution with very high reliability and technical capability and specification sufficient for most geothermal logging programs. MB Century have also developed a robust high temperature casing condition electronic monitoring tool to detect internal and external casing corrosion without the need to quench wells that is not available elsewhere.

1.0 INTRODUCTION

The Wairakei and Kawerau geothermal fields in New Zealand were developed simultaneously in the early 1950's. Kawerau was developed for industrial heat supply in the Tasman wood processing and paper mill, and Wairakei for electricity generation. Both fields had similar temperatures, up to 280˚C, and fluid compositions with TDS <5000 ppm. Although the temperature and fluid properties at the time were considered to be quite severe, compared with many more recently developed resources, these conditions were rather benign and allowed the development problems to be overcome and provided impetus for acceptance of high temperature liquid geothermal fields as an economic energy source. Never-the-less, innovative ideas and designs were required to make the measurements that allowed proper understanding of the resource.

From the time that the first wells were completed¬ the essential elements of a geothermal well measurement program were quickly established. The importance of accurate, quality data, the need to obtain sufficient information to understand the processes occurring in the wellbore and in the formation near the wellbore was appreciated from the beginning (McKree and Banwell, 1951). For downhole logging the most import requirement is the wellbore temperature and pressure. Monitoring casing condition and changes with time was also an important part of sub-surface monitoring.

Note: This paper follows the development of downhole logging tools in New Zealand by MB Century and its predecessor companies. Up until 2007 MB Century was the only company in New Zealand logging high temperature wells. The predecessor companies were: 1950-1987 Ministry of Works and Development, and then from 1987-1996 Works Geothermal Ltd a fully owned NZ Government department responsible for all power development; during 1996-1999, Downers Energy Services Ltd acquired ; 1999 Century Drilling & Energy Services (NZ) Ltd, trading as Century Resources until 2008 when the present MB Century was created by MB Holdings (Oman) purchasing Century Resources from Downer EDI.

2.0 MECHANICAL TEMPERATURE AND PRESSURE GAUGES

Temperature Logging.

The first temperature logs were made using maximum recording thermometers. By insulating these to reduce the heat transfer rate, temperature reversals could be correctly measured, but the method was tedious and investigation of alternatives quickly led to the successful development of the "geothermograph". This was a mechanical instrument using a bimetal strip sensor, adapted from the bathythermograph used to measure underwater temperatures in oceanographic work. In the "geothermograph" the deflection of a bi-metal strip temperature sensor was recorded on a smoked aluminum plate. Initial results were good (McKree and Banwell, 1951) and the geothermograph was used up until mid 1970's for all routine downhole temperature data in New Zealand. Comparing results of many runs, the absolute accuracy of this instrument was about ±3°C. It had the advantage of a rapid stabilizing time, of less than two minutes, so surveys could be completed quickly, but only 15 separate "indexes" could be recorded. However, this instrument was in effect custom-made, and required a lot of tender loving care to perform reliably.

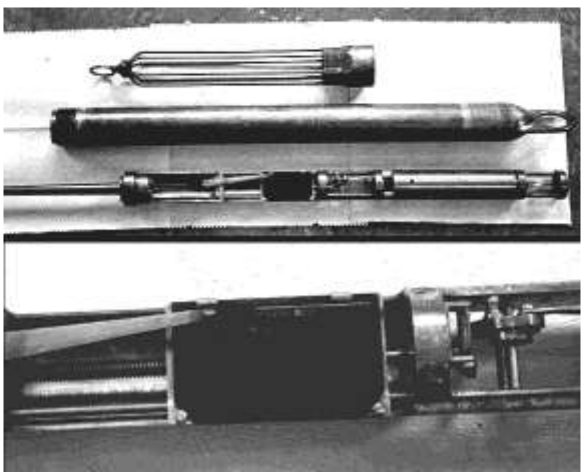

Figure 1: Geothermograph

At the same time as the geothermograph was being developed, other methods for measuring downhole temperatures were also being investigated and trialed. In 1950 an attempt was made to use resistance thermometers, but this was unsuccessful as no cable suitable for repeated high temperature operation was available (McKree and Banwell, 1951). A metal-sheathed thermocouple ("Pyrotenax") cable was trialed. This was a copper-constantan thermocouple enclosed in a copper jacket with mineral insulation. The problems of cable self support and stretch were partially overcome by enclosing the pyrotenax cable within a standard wire rope using a home-made device to insert the copper-jacketed pyrotenax thermocouple cable within the wire rope armor. This system was not successful for routine logs, but was used in 1956 to measure temperatures down to a depth of 620m in a flowing well where a 2" hangdown tubing string had been installed in the 8-5/8" production casing.

The Kuster KPG temperature gauge using an enclosed capsule to monitor temperature via the vapor pressure was also trialed in the 1960's, but not put into regular use because of the limited temperature range and strongly non-linear response. In the mid-70's the Kuster KT bi-metal sensor temperature recording instrument superseded the geothermograph for routine temperature logging, as by that time it was a reliable and robust off-the-shelf solution.

Pressure Logging

The first downhole pressure logs in New Zealand were made using Amerada RPG pressure gauges in 1954 by Brown Brothers, an American Company who had been contracted to drill the production wells for the Kawerau field development. Unfortunately no record of these logs remains. When Brown Brothers completed their contract in 1956, the company left a set of Amerada downhole pressure gauges in New Zealand. These gauges were modified to operate reliably in high temperature wells – the major modifications being improving the clock reliability and improving the housing seals - and were first used in Wairakei in 1960. The Amerada gauges were later replaced by Kuster KPG equipment and run as the standard downhole pressure equipment for routine logging up to 2003. Over this time there was considerable cooperation between the Kuster Company and Ministry of Works to improve the reliability of these gauges in high temperature wells, with some of the "home-made" solutions developed in New Zealand becoming standard features – such as the use of metal sealing gaskets.

3.0 ELECTRIC "E-LINE" LOGGING

In 1966 a steel-armored, Teflon-insulated, three-core logging cable, capable of operating at temperatures up to 300˚C was purchased from Vector Cable Company. Trials with a test cable quickly showed that the critical design issue was the development of a cable termination system capable of handling high temperatures and preventing the well fluids penetrating up the electrical conductor insulation. By this time exploration wells with temperatures more than 310˚C had been drilled, and if the wellbore fluid entered the conductor insulation, when the cable was reduced to a lower pressure when logging upward, or through the lubricator gland, the fluid inside the conductor insulation could boil and destroy the insulation. This was overcome using a novel pressure-equalizing feed trough and immersing the terminated conductors in low vapor pressure silicone oil. A temperature-spinner tool with no downhole electronics (using a simple Wheatstone Bridge circuit) was designed for use with this cable. Accurate and detailed temperature logs could be made, although the surface "log" was obtained by manually balancing the circuit.

Figure 2: 1978 temperature-spinner instrument – no downhole electronics

This system (no downhole electronics) was subsequently improved with surface electronics for processing the temperature signal, providing continuous temperature and simultaneous spinner data such that fluid velocities in the wellbore could be determined using the "cross plot" method from multiple survey passes. This equipment became the standard method used for well completion testing to identify permeable zones during cold water injection and in other wells to confirm inter-zonal flows (Syms and Syms, 1981).

In 1980 simultaneous temperature-pressure ("STP") logging was introduced, using downhole electronics contained in a dewar flask. This system initially used multi-conductor cable but was subsequently improved so a less expensive mono-conductor cable could be used to transmit both temperature and pressure data. This tool continued in regular use until the mid-1990's.

By this time there were other high temperature logging systems available on the market (e.g. Madden and Hot-Hole Instruments) and it was decided to purchase an off-the-shelf system with full PTS (simultaneous Pressure-Temperature-Spinner) capability, rather than continue with in-house development.

In 1995 a Madden PTS flasked tool, capable of operating in either e-line (surface readout) or memory mode, was purchased to run in conjunction with a deep drilling project at Ohaaki and for routine operations where simultaneous PTS data was required (flowing surveys in injection and production wells). The flow measurement capability was an important factor in the decision to purchase this tool as the in-house tool design at that time could log either temperature-pressure or spinner-temperature, but not all three together. Although initially successful the Madden tool proved to be unreliable when operating in memory mode. Following several attempts to repair the system, the dewar flask failed during a test run and the internal electronics were severely damaged.

With this tool beyond economical repair, in 1997 specifications were drawn up by Century Resources (now MB Century), for a new PTS instrument using proven features of existing equipment and correcting known problems. The new instrument commissioned in 2001 was designed to ISO 9000 quality assurance for calibration with electronic stability and repeatability, and did not need calibration or compensation with variable operating temperatures. The communication system between surface and downhole electronics was also modified to match that used in other logging equipment operated by MB Century, such as the HTCC casing monitoring tool. In the spinner section four reed switches were incorporated to provide redundancy and improved reliability of the spinner data. This design became the basis for today's PTS tool that can used in either surface readout or memory capability.

Although initially designed to operate in e-line (surface readout) mode via an armored conductor cable, there was obvious potential to improve data quality and quantity for routine logs that were being run using mechanical temperature and pressure tools. In 1999 a wireline PTS memory tool was introduced. For this tool the downhole PTS data is merged with a record of depth-time obtained from the logging winch to provide a complete dataset of PTS data keyed to both time and depth. Since 2003 this tool has become the standard logging system for all routine downhole measurements in New Zealand. The memory PTS tool, run on wireline is also invaluable for logging very high temperature wells (>280˚C) as the insulation in the armored logging cables starts to break down around this temperature and needs to be cut-off after each survey to maintain reliability. These memory tools have a proven high reliability factor even when used at temperatures up to 320˚C. MB Century have logging operations set up in Papua New Guinea, the Philippines and Indonesia using their in-house PTS tools with capability in both memory and e-line mode.

Since 2000 improvements in electronic hardware has allowed significant reduction in both the physical size of downhole components and the heat generated by the electronics which has resulted in reduced internal heating rate of the dewar flask and instrument package, thereby increasing the downhole logging time available in high temperature wells. In 2012 MB Century upgraded the PTS tool, increasing the tools ability to operate for longer periods of time in today's hotter and deeper wells.

Several different high temperature PTS logging tools are now available on the market. The MB Century PTS tool provides a competitive, cost-effective solution with very high reliability and technical capability and specification sufficient for most geothermal logging programs.

4.0 CASING CONDITION MONITORING

Since the first deep wells were completed at Wairakei in 1953, the ability to monitor casing condition has been considered as a high priority. The first deep wells suffered from damage associated with poor cementing and thermal stress and to assist in monitoring these changes an Otis casing caliper was purchased in 1958. This tool was in continuous use until about 1990, collecting baseline logs on all new wells with repeat logs depending on changes detected by other downhole logs such as go-devils. The Otis caliper provided a good record of the internal casing condition and had no temperature limitations.

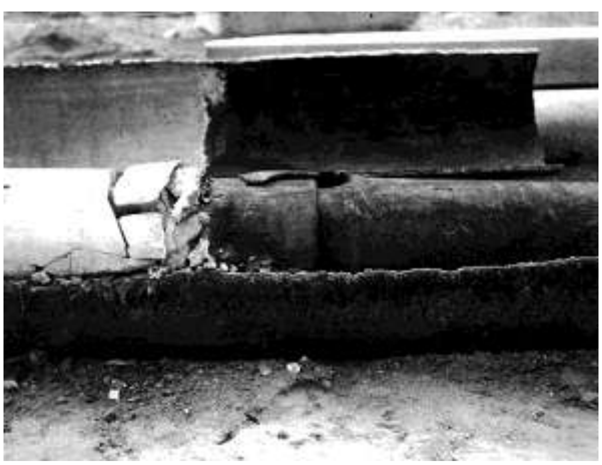

Figure 3: Damaged casing recovered from WK18, 1954

However in the mid-1980's several wells, less than 20 years old in different geothermal fields, were found to have severe external casing corrosion (Bixley et al, 1985). A series of casing condition logs were run on 10 wells at Ohaaki using the Schlumberger PAL (pipe analysis log) and ETTA (electronic thickness) systems. These are both electromagnetic logs which can be used to determine external corrosion, but require that the well is cooled to <130°C before logging.

Figure 4: Corroded 8-5/8" casing recovered from BR25, 1983. In foreground is corroded casing (dark color) attached to cement grout (light color)

In 1986 the Atlas Magnelog (an electromagnetic tool equivalent to the Schlumberger ETTA) was purchased by Ministry of Works (now MB Century) as at that time there were approximately 200 deep high temperature geothermal wells in New Zealand that required monitoring for external corrosion. The Magnelog provides readings of phase change (which can be correlated with average casing thickness), internal casing diameter, and internal roughness. The Magnelog required that the well is cooled for logging, and apart from the additional cost of quenching the wells for logging, there is also potential for additional casing damage by the cooling process.

There was an obvious need for a high temperature casing evaluation tool that could monitor external corrosion without cooling the well. The first electromagnetic tool capable of operating at up to 350°C (HTCC High Temperature Casing Caliper), using the same principles as the Magnelog and ETTA equipment was completed in 1993 (Wilson & Gould, 1992). The amount of data collected by the electromagnetic tool is significantly greater than for a relatively simple PTS tool and considerable effort was needed to develop downhole electronics capable of processing and transmitting the required information, while still being constrained by the size of the insulating dewar flasks. This tool was run successfully and various improvements have been made with time to improve reliability. The main changes have been enclosing the section containing the sensor coils inside a welded stainless steel pressure vessel and converting the communications to fully digital output with capability of using a memory module to log the tool output downhole. This allows wells with casing temperatures greater than 300˚C to be logged where the use of armored electric cable is not possible. Two models of this tool are currently in use: One capable of logging 4-1/2 to 7" casing and the other 7-5/8 to 13-3/8". These are the only casing monitoring tools available that can operate at temperatures in excess of 300˚C.

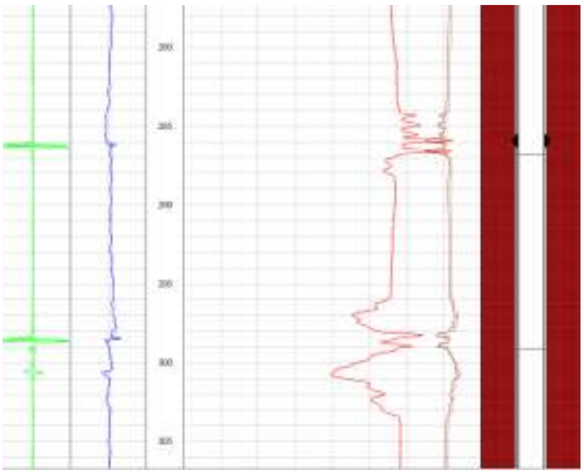

Figure 5: Typical HTCC log showing normal casing on left and casing with external corrosion on right.

5.0 ACKNOWLEDGEMENTS

The assistance of MB Century (NZ) Ltd. for providing access and permission to their historical information and photo collections is greatly appreciated.

6.0 REFERENCES

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