

GEOHERMAL WELL COMPLETION TESTS

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ABSTRACT

This paper reviews the measurements that are typically made in a well immediately after drilling is completed – the Completion Tests.

The objective of these tests is to determine the properties of the reservoir, and of the reservoir fluid near the well. A significant amount of information that will add to the characterisation of the reservoir and the well, can only be obtained in the period during and immediately after drilling activities are completed.

INTRODUCTION

Immediately after completion of the drilling of a geothermal well, a slotted or perforated liner is run into the open hole production section of the well; the blow out preventer stack is removed from the wellhead; and, if not previously fitted, the master valve is attached to the wellhead. At this point drilling operations are finished, but it is usual practice to carry out a series of tests on the well, utilising the drilling rig equipment, and in particular the rig pumps, before rigging down and removal of the rig from the wellsite. These tests, the completion tests, are designed to identify potential feed zones in the well, to provide an estimate of the total effective permeability of the well, and to establish a baseline dataset of the casing condition.

OBJECTIVES

For the geothermal reservoir engineer the objective of the completion tests is to determine the properties of the reservoir, and of the reservoir fluid in the proximity of the well. In addition there is generally a wide interest in the ability of the well to deliver fluid to the surface, which to a large extent will depend on the reservoir and well properties.

For the geothermal production engineer the objective is to obtain a ‘thumbprint’ of the well casings in their ‘as new’ condition in the well, for comparison at a later date to determine if there has been corrosion or failure of any of the casing components.

The suite of tests carried out that comprise the ‘Completion Tests’ typically involve:

- a spinner test to identify the location of the permeable zones within the well and to quantify the relative permeability of each of the zones identified. In addition, the spinner tool also measures and records the downhole temperature and pressures as well.
- A water pumping test to obtain an ‘injectivity’ and thus the gross permeability of the well.

- A casing condition survey, to obtain an initial graphical image of the casing in the well.

IDENTIFICATION OF PERMEABLE ZONES

The initial tests carried out in the well after completion are designed to identify the location and thickness of the permeable zones; and to quantify the associated permeability in relative terms. This is usually carried out using an electronic spinner (flow velocity indicator) tool, either a real time electric wireline tool, or a slick line memory tool – usually temperature and pressure transducers are also incorporated into this tool.

With a constant volume flowrate of water pumped to the well, the spinner instrument is lowered into the hole at a constant velocity, and then retrieved, again at a constant velocity. The spinner measures the liquid flow velocity in the well over the range of depth that the instrument is run, changes in flow velocity not associated with hole diameter changes (either passing through a casing shoe, or through an area of enlarged or washed out formation) indicates either an inflow or outflow at that point. It is usual that spinner runs are carried out at two or three different pumping rates, as well as at a zero pumping rate to identify if there are any internal flows within the well that can distort the pumped volume flowrates. This data, correlated with the temperature and pressure data collected on each run, will allow reasonable characterisation of the permeability in the well.

A typical set of downhole spinner data, collected from Well MK-11, Mokai geothermal Field, New Zealand, was carried out with two pumping rates, one double the flowrate of the second, and is illustrated in Figure 1 below. Data is collected only in the open hole production section of the well, below the production casing shoe, which in this case was set at 748 m depth.

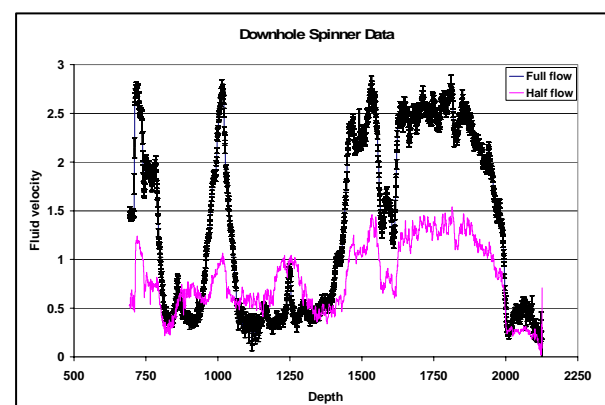


Figure 1. – Downhole Spinner Data. Well MK-11 Mokai.

June 2008

The down hole temperature data recorded at the same time is illustrated in Figure 2. below.

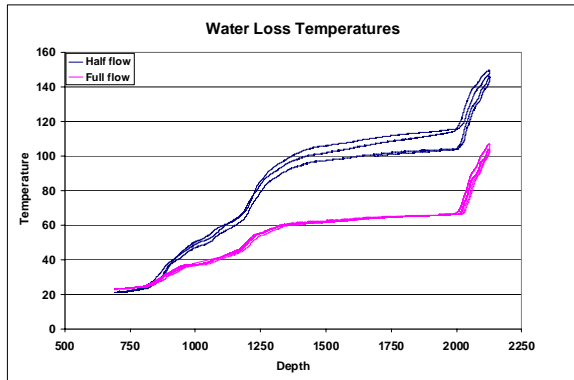


Figure 2 – Downhole Water Loss Temperatures. Well MK-11, Mokai.

The interpretation of this type of data is not simple, and often not conclusive.

There is considerable detail and complexity in both spinner runs, and either an enlarged wellbore down to 1500m or inflow exists at around 1500m. The temperatures, shown in Figure 2 argue against any inflow at 1500m. They also support a major loss at 2000m. The variations in fluid velocity with depth are consistent between the two runs (the larger flow has proportionately larger velocity) over 700-800m, and below 1400m, but show contrasts over 800-1400m that are not readily explained.

The greater temperature gradient above 2000m in both runs is best explained by minor inflow over this depth. This is supported by the reduction in gradient with increasing injection rate.

The major loss zone is therefore at 2000m, with minor fluid gain above 2000m in both runs. The strong variations in velocity above 1600m indicate major variations in wellbore diameter between the casing shoe at 700m and 1600m. The wellbore is contracted to normal diameter at 1010m and over 1450-1550m, but is otherwise enlarged over 700-1600m.

Prior to the development of electric wire-line tools suitable for deployment in geothermal conditions, this test was carried out using mechanical slick-line instruments, and typically only temperature and pressure measurements were carried out. A water loss test was carried out by stopping pumping water to the well for a period to allow a mild heating in the well. With a mechanical temperature and pressure recording instrument (Kuster or Amerada) in the well, pumping of cold water was commenced at a constant rate, and by moving the temperature instrument up and down the well, the advancing cold front of fluid could be tracked down the well. Permeable zones were identified at the points where advancement of the cold front ceased (in the case of a single permeable zone) or slowed in the case of multiple permeable zones. The method allowed only an indicative and rough characterisation of the permeability.

QUANTIFYING THE PERMEABILITY

A simple indicator of the likely productivity of a well may be gained by evaluating the stable down hole pressures at a constant depth, against a number of injection flowrates. This stable pressure – flow relationship provides the ‘injectivity’, which has been shown to be a reasonable reliable index of well performance.

The pressure element must be set at some representative depth down the well, and ideally this is at the depth of the major permeable zone – which of course is not always confirmed at the time this test is carried out, however, data from the previous ‘spinner tests’ can provide a good indication.

It is usual that water is pumped to the well at three or four different pumping rates, with the duration of each step sufficient to allow a stable downhole pressure condition to have been established – typical the durations of each step is in the order of one hour.

For the ‘injectivity’ tests for Well MK-11, Mokai, the well as indicated above, the pressure element was set at a depth of 1980 metres depth in the well. The test was commenced with water being pumped to the well at a rate of 12 litres per second for a period of 1 hour. The pumping rate was then increased to 24 l/s for one hour, 36 l/s for one hour, then 48 litres per second for one hour. The pumps were then shut off and the instrument left in place for one more hour.

The stable pressures for each of the pumped rates were:-

Flow Rate (l/s)	Pressure at 1980 m. (MPa)
12	16.168
24	16.264
36	16.360
48	16.456

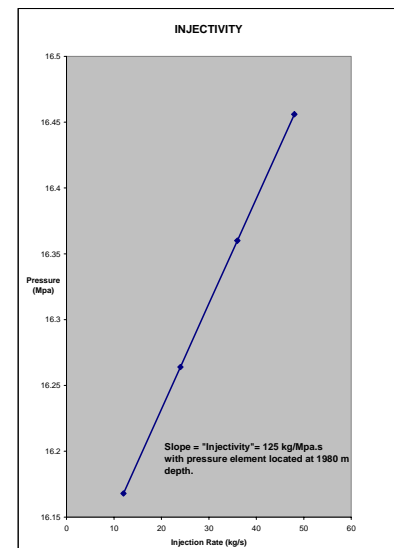


Figure 3. The relation between injection flowrate and downhole pressure at the major permeable zone.

The “Injectivity” is the slope of the plot of stable pressure versus flow.

The pressure differences between the four injection rates at the depth of 1980 metres gives an injectivity of

125.0 kg/MPa.s, which in this case is good to excellent. With an expected temperature of the production zone of over 300°C as measured in nearby wells, and by comparison with previous well injectivity results, a stable flow of around 300 tonnes per hour was estimated.

DOWNHOLE CASING CONDITION

The production casing string in a geothermal well is the primary conductor of the geothermal production fluids from the formation to the surface and is thus subject to extreme conditions both from thermally induced stress conditions and from continuous exposure to formation fluids both internally and externally.

In the past, monitoring the condition of these casing strings has been extremely difficult and limited to occasions when the well has been totally quenched with cold water to allow introduction of instrumentation such as callipers and tele-viewers. Recently an electromagnetic tool, capable of being operated in hot well conditions – 300°C for several hours, has enabled the accurate measurement and periodic monitoring of both the internal and external condition of the casing string.

The Hot Hole Casing Corrosion (HHCC) tool, developed by Century Drilling and Energy Services, of New Zealand provides a capability of obtaining an ‘as new snapshot’ of the casing condition immediately after completion of the drilling activities, which can be compared with subsequent surveys carried out on a periodic basis throughout the well life – typically annually.

After the spinner - water loss tests, and the injectivity testing procedures have been completed, it is now usual practice to run a Casing Condition Survey to provide this basis for later casing corrosion and condition monitoring.

The Hot Hole Casing Corrosion (HHCC) tool is an electromagnetic instrument which measures the casing wall thickness, the internal diameter, and surface roughness of both the inside and outside surfaces of the casing.

Figure 4 is an example HHCC plot of a section of 9⁵/₈” casing indicating metal loss at 397 m and 405 m.

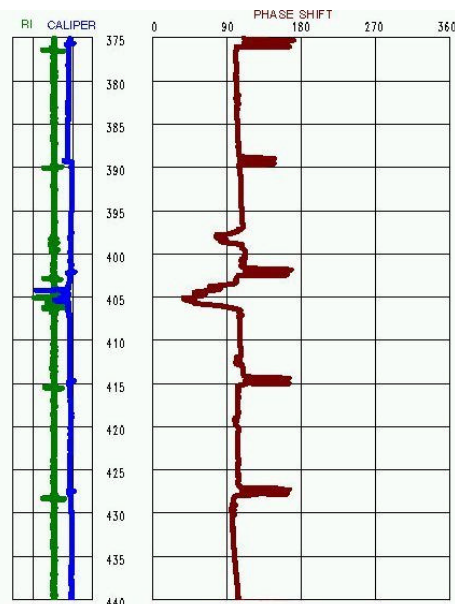


Figure 4. HHCC Plot (after Stevens L, Century Drilling & Energy Services (NZ) Ltd, “Monitoring of Casing Integrity in Geothermal Wells”, WGC paper R0253.

The casing collars can be clearly identified on the phase trace. The calliper trace indicates a decrease in internal diameter at 405 m, and the roughness (RI) trace indicates that the inside surface is corroded at both the 397 m and 405 m depths.

POST RIG MOVE TESTS

When the spinner tests, water loss and injectivity tests have been completed, the downhole casing condition survey is optionally carried out before the rig is moved, or can be completed using the rig lifting equipment to simplify the operation.

At this point the drilling rig is disassembled and moved from the wellsite, and the well is allowed to heat up. This heat-up period provides an additional opportunity to collect data that may no longer be available once the system has been altered by discharge of the well. The heat up process is not linear with time, initially heating occurs rapidly, then slows with passing time. It is usual that the series of heating temperature and pressure profiles are taken on an expanding time scale – typically profiles will be run on days 1,2,4,7,15, and 28 after pumping water to the well has ceased.

Pressures During Initial Heating

As the well heats up, the pressure gradient in the well decreases. The pressure profiles pivot about a particular pressure point, indicating the location of a single major permeable zone, or at the mean permeability point between two or more permeable zones.

Figure 5 illustrates the temperature and pressure profiles of Well MK-14, Mokai Geothermal Field, New Zealand. The pressure profiles clearly pivot about a point at around 1650 m depth – the major permeable zone in the well.

Temperatures During Initial Heating

At the completion of the spinner, water loss and injectivity tests, when pumping of cold water to the well is finally ceased, the formations surrounding the well are in a cooled state. The impermeable zones have been cooled conductively, and the permeable zones cooled by the acceptance of the drilling fluids and the completion test fluids.

AS the well heats, there are four heating mechanisms that are occurring:-

- Conduction through the surrounding formation.
- Flow of fluid into the wellbore at one level and out into the formation at another – interzonal flow.
- Convection cells within the wellbore.
- Flow directly across the well bore.

The convective processes transfer significantly greater quantities of heat than the conductive processes. The temperature profiles from a well heated with predominantly conductive heating at all depths, which is most often seen in wells with little or no permeability, will be smooth and featureless, and the heating process will be very slow.

Interzonal flow, the flow of fluid from one level in a well to another through the wellbore is indicated by rapid but uniform heating of one section of the well more quickly than other sections in the wellbore.

The temperature profiles of Well MK-14, presented below in Figure 5, illustrates such an interzonal flow occurring between 1650 m, the major permeable zone, and 1800 m depth, were a second somewhat less permeable zone exists.

Cross flow within a wellbore is characterised by a single isolated temperature peak in the heating profiles – this is not seen in the Well MK-14 profiles. However, the very rapid heating rate occurring from 2200 metres depth to the bottom of the hole could be indicative of the cross flow phenomena.

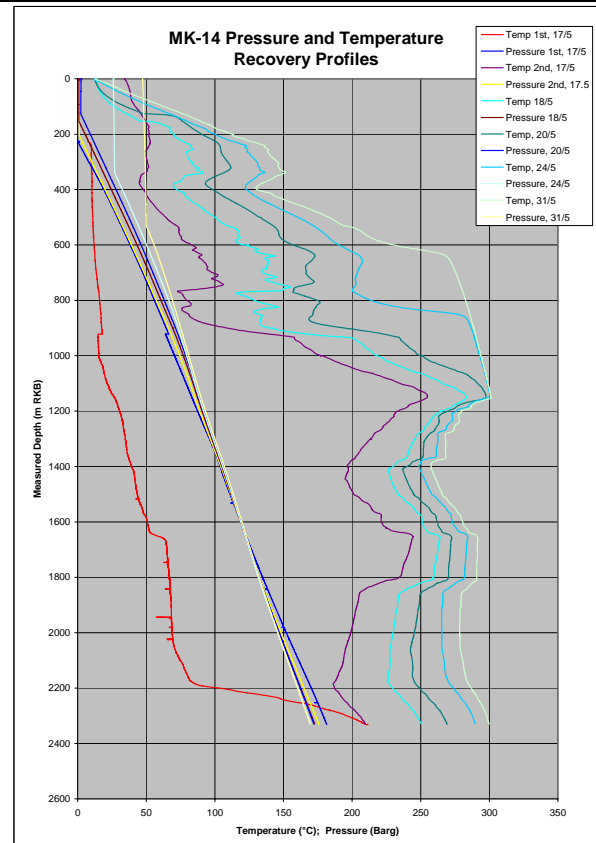


Figure 5. Mokai, Well MK-14 Well Heating Temperature and Pressure Profiles.

CONCLUSION

The “Completion Tests” carried out on a geothermal wells immediately after completion of the drilling activities provides for the collection of data which characterises the well, the formations surrounding the well, and the geothermal resource into which the well has been drilled. These tests allow for an early assessment of the likely production or injection capacity of the well, for the development of understanding of the characteristics of the geothermal resource, and benchmark information on the casing condition of the newly completed well.

ACKNOWLEDGMENTS:

I thank Tuaropaki Power Company, owners and operators of the Mokai Geothermal field, New Zealand, for the use of field data and information.

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