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OUTPUT TESTS OF SHALLOW ROTORUA WELLS

Harri J Siitonen

Rotorua Geothermal Group
P O Box 1245, Rotorua

ABSTRACT

Production from the Rotorua geothermal field is predominantly from 400 shallow, medium enthalpy, 100 mm diameter wells. Over the last three years considerable expense and effort has been put into the testing of these wells. The output testing was carried out using a total flow calorimeter while continuously recording the well head pressure.

Information about the output characteristics of over 30 wells has been collected. The wells are categorised as either high pressure (3 bar g -9 bar g) or low pressure (0.5 bar g -3 bar g) depending on the flowing well head pressure.

The output characteristics of two typical wells are described. Results are also presented to show the effect of calcite deposition on the mass flowrate from a low pressure well.

INTRODUCTION

There are approximately 400 wells that are used for production from the Rotorua geothermal field. The majority of the wells have 100 mm diameter casings. A casing diameter of 100 mm has been adopted .to provide a reasonable period of time between servicing, or reaming of the well, to remove calcite deposition. The average cased depth is 100 m, with an open hole to 140 m.

The wells can be classified into two categories, high pressure and low pressure based on their flowing well head pressure (ref 1).

TYPE	WELL HEAD PRESSURE (bar g)	MASS FLOWRATE (kg/s)	ENTHALPY (kJ/kg)	STEAM FRACTION (%w/w)
1. High pressure	3-9	0-10	750-950	6-10
2. Low pressure	0.5-3	0.5-4	500-750	2-7

High pressure wells in the static situation have a 'positive well head pressure, and are generally self-starting. Low pressure wells sit with a water level in the casing and require air-lifting, of the colder water in the upper part of the well, to start them self-flowing. It has also been known for a long time that the low pressure wells have limited turndown capabilities and can produce an abundance of hot water.

All the wells produce a two-phase steam/water mixture, with a steam fraction in the region of 2%-10% (w/w), at the well head.

It is the difference in density between the two phases of the fluid that allow the wells to self-flow. The vapour forms bubbles that rise up through the liquid because of the much lower density of the vapour phase. The velocity of the vapour phase increases up the well, and becomes substantially greater than the velocity of the liquid phase. The greater vapour velocity causes the liquid to flow up the well.

When the vapour cannot lift the liquid phase up the well, collapse of well production occurs, normally at low mass 'flowrates. The flowrate at which collapse occurs is known as the minimum flowrate.

The pattern or flow regime of vertical two-phase flow in a shallow well varies depending on the mass flow, the steam fraction, and the well diameter. At low mass flows which are above the minimum flow, slug flow will be present at the well head. For slug flow, the vapour forms large diameter bubbles which extend over most of the well cross-sectional area. The bubbles can be very elongated with a mean vapour velocity substantially greater than that of the liquid phase. The flow is of a pulsing nature.

With an increased mass flow, churn flow will become the two-phase flow regime that is present at the well head. Churn flow is an unstable form of slug flow. The phases mix together in a more-or-less chaotic manner, but part of the liquid phase is continuous and being displaced towards the casing walls.

When the mass flow is increased further, the two-phase flow regime present at the well head becomes annular flow, where a proportion of the liquid is carried as small droplets in the vapour phase. The remaining liquid flows at a relatively slow velocity within a thin film on the inside perimeter of the casing.

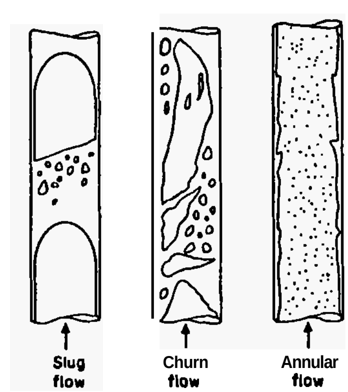

Fig 1: Flow patterns for vertical two phase flow.

The vertical two-phase flow pattern changes as the steam fraction x, increases. The different flow patterns that occur, at varying steam fractions, is shown in the following chart (ref 2). Slug and churn flow are likely to be the most common flow regimes seen in the Rotorua wells.

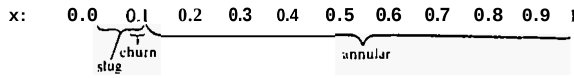

Fig 2: Flow patterns for varying steam fraction x, in vertical two phase flow.

The relationship between mass flow and well head pressure can be described by an output curve. The Task Force showed that the output curves for the shallow Rotorua wells have certain characteristics; normal production from the wells was below the maximum discharge pressure, with slug and churn flow seen at the well head. (See figure 3)

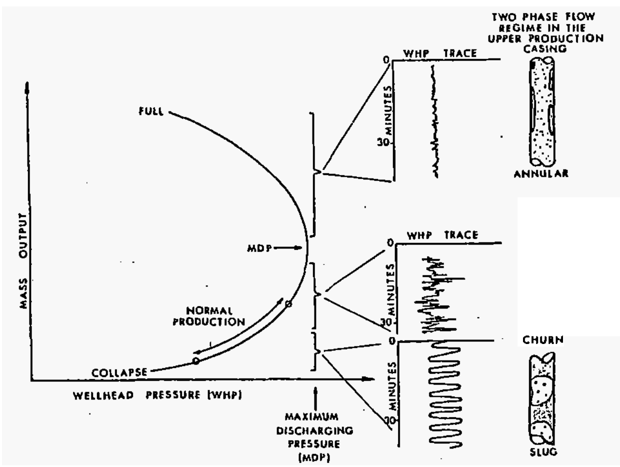

Fig 3: Output curve for a well showing the associated WHP and flow regime.

The pattern of the well head pressure can help to indicate the stability of the flow, and in which two-phase flow regime the well is operating. Flow measurements taken during the Task Force work were able to confirm that most of the production wells normally operate below the maximum discharge pressure (MDP).

PROCEDURE FOR WELL OUTPUT TESTING

A total flow calorimeter is used for output testing, and is connected directly to the well head. A three-way-valve allows the well to discharge to atmosphere between tests, and while it is stabilising between set flow changes.

A 1200 1 trailor mounted calorimeter is suitable for most of the wells, except the larger diameter high pressure wells. 80 mm diameter piping is used to connect the calorimeter to the well head.

The following assumptions are made while testing:

1. That the steam fraction is fully condensed.
2. Conditions are the same if the well is discharging to atmosphere or into the calorimeter.
3. Heat loss from the calorimeter and associated piping is negligible.

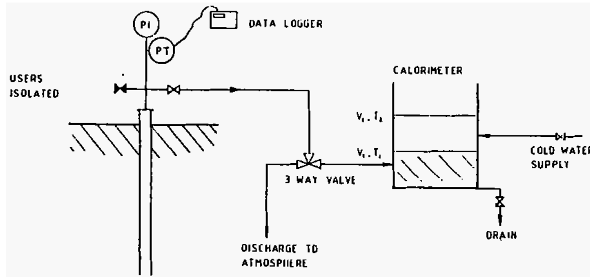

Fig 4: Flow diagram of calorimeter set up at the well head.

To carry out an output test the well is allowed to discharge, into cold water in the calorimeter, for a period of time. The duration of the test depends on the mass flow and the temperature increase of the water in the calorimeter.

The discharge enthalpy and mass flowrate can be calculated from the change in volume and temperature of the fluid in the calorimeter over the period of the test.

Runs are carried out at each flow until at least three consistent enthalpies have been measured.

The well head pressure is measured using a pressure transducer mounted at the well head. The pressure is then continually recorded every 30 seconds by a data logger.

RESULTS FROM TWO OUTPUT TESTS

The output characteristics of two Rotorua production wells are described:

1. High Pressure Well

A calorimeter test was carried out on a new well located in Kuirau Park; well RR913.

Well details:

Well Depth : 146.5 m
Cased Depth : 88.0 m
Casing Diameter : 100 mm
Date Drilled : October 1985

Table 1 : Results of Output Test on Well RR913

RUN	WELL HEAD PRESSURE (bar g)	MASS OUTPUT (kg/s)	ENTHALPY (kJ/kg)	STEAM FRACTION AT WELL HEAD (% w/w)
1	5.7	2.7	743	2.6
2	6.0	4.1	828	6.3
3	5.5	4.7	873	9.1
4	4.25	0.7	738	4.3
5	5.25	5.1	865	9.1

The maximum discharge pressure for the well was at 6 bar g, and the maximum mass flowrate, through 80 mm diameter piping into the calorimeter, was measured at 5.1 kg/s.

The lowest flowrate measured was not the minimum flowrate, as the well may have been turned down still further, to very low bleed flows.

An output curve is plotted from the results.

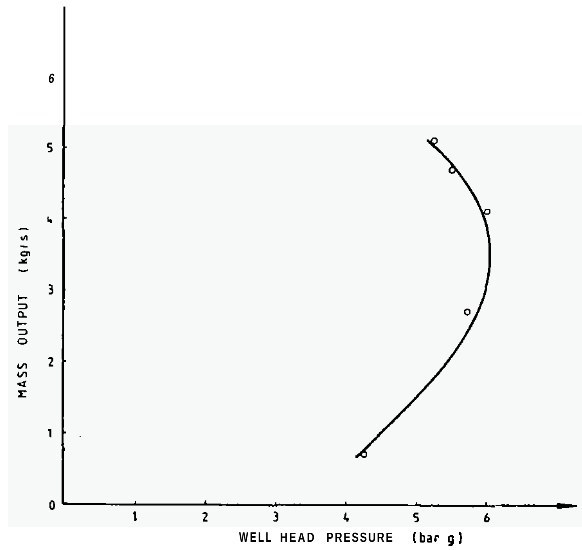

Fig 5: Output Curve for Well RR913.

The well head pressure was continually logged during testing. At a mass flowrate of 2.7 kg/s (Run 1), cycling of the well head pressure was observed. This indicated the occurrence of slug flow at the well head.

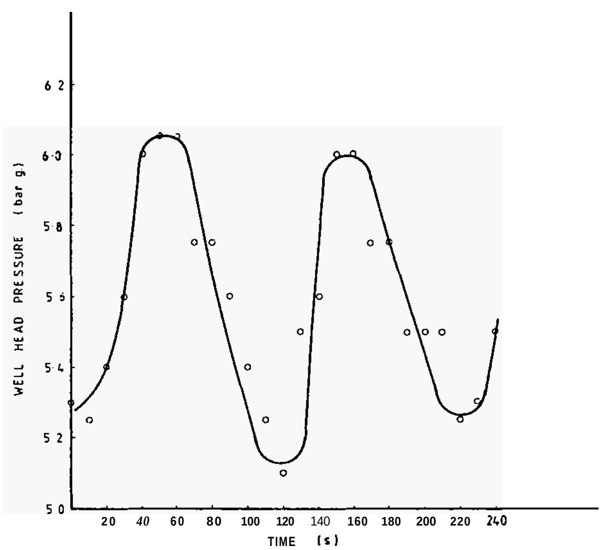

Fig 6: Cycling of well head pressure during Run 1.

The plot of the well head pressure recorded from the pressure transducer during the remaining runs is shown below, indicating where churn and annular flow may be present.

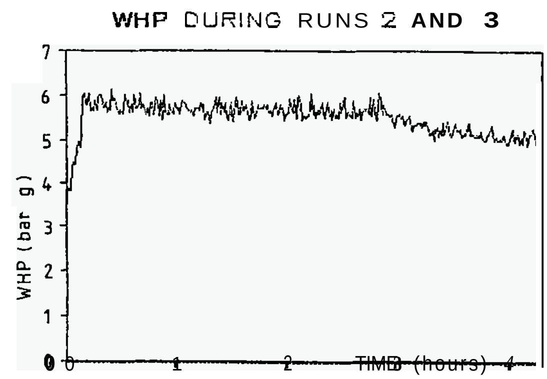

Fig 7a: Plot of WHP for well RR913 during Runs 2 and 3.

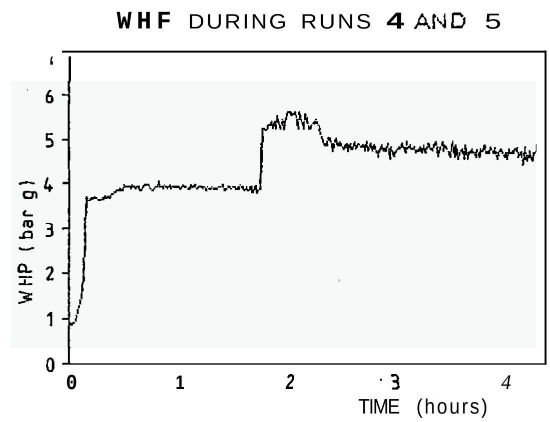

Fig 7b: Plot of WHP for well RR913 during Runs 4 and 5.

A significant change in the enthalpy was observed as the mass flowrate increased. A plot of enthalpy vs. mass flow shows a step-change in the enthalpy close to the maximum discharge pressure.

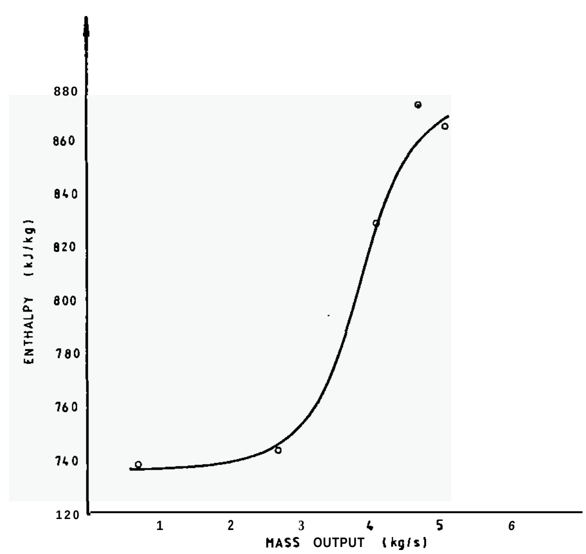

Fig 8: Change in Enthalpy with increasing Mass Flow.

2. Low Pressure Well

An output test was carried out on a low pressure well RR506, which is used by the Rotorua Post Office.

Well Details:

Well Depth : 100.6 m
Cased Depth : 86.9 m
Casing Diameter : 100 mm
Date Drilled : June 1964

Two tests were performed:

1. When the well performance was affected by calcite deposition.

2. After the calcite had been cleaned from the well.

The results of the tests were:

Table 2 : Test 1 : With Calcite Deposition in Well

RUN	WELL HEAD PRESSURE (bar g)	MASS FLOW (kg/s)	ENTHALPY (kJ/kg)
1	0.20-0.25	2.7	538
2	0.20-0.30	0.45	544
3	0.30-0.40	2.2	530
4	0.40-0.50	1.1	547

Mean Enthalpy = 540 kJ/kg

Table 3 : Test 2 : After Cleaning of the Well

RUN	WELL HEAD PRESSURE (bar g)	MASS FLOW (kg/s)	ENTHALPY (kJ/kg)
1	0.45-0.65	3.5	547
2	0.15-0.20	1.6	561
3	0.25-0.40	2.3	544

Mean Enthalpy = 550 kJ/kg

The enthalpy remained constant over the flowrate range of the test, and corresponds to the enthalpy of water at a temperature of 130°C, which was the measured downhole temperature.

The output curves for the two tests show a marked difference.

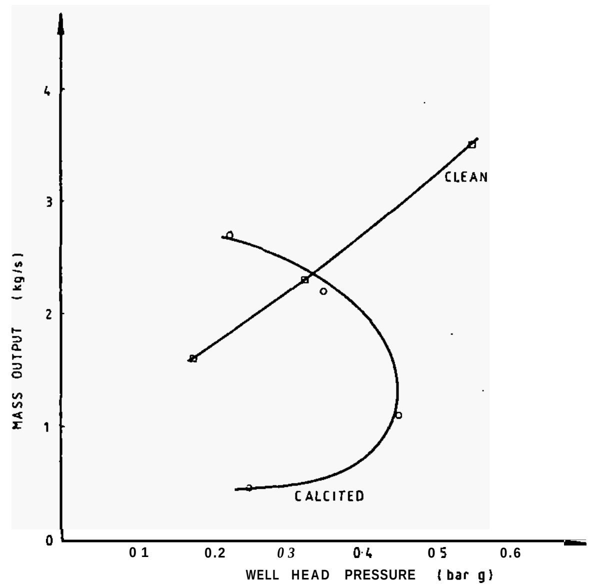

Fig 9: Output Curves for Well RR506

The well head pressure logged during test 2 is shown. The well head pressure during test 1 is not shown due to inconsistent readings from the pressure logging equipment when compared to readings from the pressure gauge on the well head.

WHP DURING TEST 2.

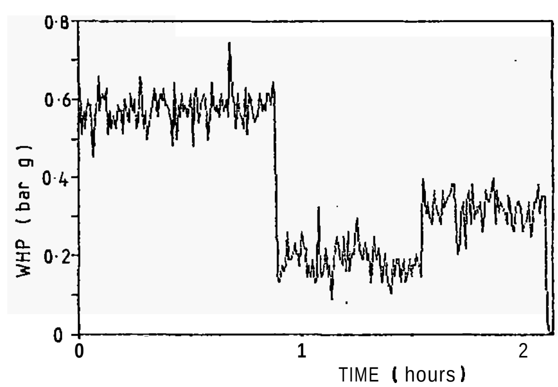

Fig 10: Plot of WHP for well RR506 during Test 2

DISCUSSION

The high pressure wells with good permeability are generally capable of greater mass flows than low pressure wells. This is because of their higher feed temperatures and reservoir pressures which provide greater driving forces for production. Well RR913 was able to be turned down to low bleed flows, and this is common with other high pressure wells. The maximum flow from the well could have been increased by using larger diameter piping from the well head to the calorimeter. Use of larger diameter piping would not change the output curve below the maximum discharge pressure. The average enthalpy for well RR913 was 810 kJ/kg, this corresponds to a hot water feed temperature of 190°C, although this has not been confirmed by measurement. The Task Force showed that the high pressure wells in the south-eastern part of the field exhibited boiling conditions down to bottom hole, so the feed from the formation would be two phase. It was observed that the enthalpy underwent a step-change as the mass flow increased. The reason for this is not fully understood, but it has also been observed for other high pressure wells in Rotorua, RR280 and RR864. Further work is needed to understand the two phase flow from the formation into these wells.

The low pressure well, RR506, had much lower well head pressures. It was in the range of 0.2 bar g -0.7 bar g. The enthalpy was also significantly lower at 550 kJ/kg, but remained reasonably constant at all flows. This confirmed that production is from a liquid dominated resource at 130°C, with boiling or flashing part way up the casing. The output curve obtained for the clean well was below the maximum discharge pressure. The clean well also had a high minimum flow of 1.6 kg/s. If the well was turned down any further it would cease production. As the well is throttled by calcite deposition. the output curve changes shape. The well produces above the maximum discharge pressure, but both the maximum and minimum flows had decreased substantially. The calcite is in effect decreasing the well diameter, in the flashing zone, and causes this reduction in the mass flows.

The main emphasis in the drawoff conservation work in Rotorua, has been in the operation of heating systems without an oversupply of geothermal fluid. The use of smaller diameter liners along with the injection of calcite antiscalant chemicals, may be one way of limiting mass flows without the need for large and expensive piping distribution systems. More work is required to understand the outputs from lined or smaller diameter wells.

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