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Preliminary Evaluation of Well BO-2

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INTRODUCTION

Well BO-2 was drilled in the 1970's by EURAFREP to a depth of 338 m and cased with 7" 26# casing to 288 m depth. A long-term production test was carried out between November 1970 and July 1971. The total flow rate for the well was about 150 t/h (41.7 kg/s) with about 20% steam fraction for pressures in the range of 6-8 bar-a. Some further testing were done in 1982/1983. The well was produced in the years 1987 to 1992. The well was closed in 1993 and 1994 but some production tests were made during that time and other measurements carried out in the well. Total flow rate obtained in a discharge test in November 1994 by CFG was 165-180 t/h (45.8-50.0 kg/s) or a bit higher than in 1970/1971 and 1982/1983, but the steam fraction was similar about 22% for separation pressure between 6-7 bar-a. Wellhead pressure for those flow rates was about 11 bar-a.

Well BO-2 was logged in 1993. Static temperature and pressure profiles were measured and a multifinger caliper log carried out. The caliper log indicated corrosion in the upper most two casing joints and that minor scaling started at the 8^{th} joint (~69 m) and thicker scaling (5-7 mm) from the 9^{th} joint to the 26^{th} joint (~78-247m). Some minor scaling was indicated down to 260 m depth.

Well BO-2 was put in production in July 1996 and has been in production since with only minor stops during maintenance at the power plant.

In 1999 dynamic temperature and pressure profiles were measures in well BO-2 as well as static profiles after a pressure buildup for three days. No flow rate measurements were available at that time. In May 2000 a multifinger caliper log was run down to 75 m depth. At 75 m depth the caliper tool encountered most likely scaling that has reduced the diameter of the well to less than 5.6", which is the minimum diameter of the caliper tool.

EVALUATION OF DATA

Discharge measurements made 1970/1971 and 1982/1983 give the total rate of 150-155 t/h (41.4-43.0 kg/s). In discharge tests in 1994, after about 5 years production, similar or higher total flow rate is obtained or 165-180 t/h (45.8-50.0 kg/s). Some scaling was observed in the well in 1993. The flow rates are measured at 6-7 bar-a separation pressure, but the wellhead pressure in 1994 is about 11 bar-a for that flow. Steam fraction is similar in those discharge tests 20-22%.

Bottom hole temperature was measured in 1993 at 249°C and in 1999 at 251°C. The difference is near the calibration accuracy of the gauge. Bottom hole pressure was said to be 45.3 kg/cm^2 (44.4 bar-g) in 1970, measured 43.0 kg/cm^2 (42.2 bar-g) in 1993 and 43.5 kg/cm^2 (42.7 bar-g) in 1999. These numbers indicate a small drawdown between 1970 and 1993 (~2 bar), but some calibration error could be involved in the bottom hole pressure value from 1970. No drawdown is observed from 1993 to 1999. These number further indicate that the reservoir is liquid dominated.

The dynamic logging in well BO-2 show that during discharge the fluid in the well boils down to the feed zone. Rough simulation of the well BO-2 discharging indicates about 6-8% steam fraction at the feed zone that results in 20-22% steam fraction at about 6 bar-a wellhead/separation pressure. The dynamic logging in 1999 were performed with restricted flow rate or at wellhead pressure of 11.7 bar-g while operating pressure for the well in 1999 was about 7.7 bar-g. The dynamic pressure profile shows a pressure gradient of 2-3 kg/cm^2 per 100 m (2-3 bar/100 m), which is commonly observed in liquid dominated boiling fluid columns. At that time and for the restricted flow the enthalpy of the well seems therefore to be controlled by the fluid temperature in the reservoir.

Data on wellhead pressure and steam rate from the high-pressure separator (separation pressure 6.3 bar-a) has been supplied by CFG for the time interval May 1998 to May 2000. Assuming that the steam rate corresponds to 22% steam fraction, the total flow rate in July 1999 would have been about 114 t/h (31.7 kg/s) around the time when the dynamic logging were carried out. That means that the total discharge rate has declined in 1999 by about 40 t/h (11 kg/s) from the 1970/1971 and 1982/1983 values and about 55 t/h (15.5 kg/s) from the 1994 values. The data supplied shows decline in wellhead pressure by 2 bar (from 9 to 7 bar-g) during these two years of operation and a steam rate decline of 2 t/h (from 26 to 24 t/h).

SITE OBSERVATION AND DISCUSSIONS

On a site visit in May 2000 Mr. Omar Sigurdsson and Mr. Herlander Correia observed that the steam rate from the high-pressure separator is about 24 t/h (6.7 kg/s) as measured by the power plant, which results in about 3 MWe production. Furthermore, the plant indicated about 9-10 t/h (2.5-2.7 kg/s) of steam from the low-pressure separator. Two-phase fluid was observed to come from the well. Liquid level indicator on high-pressure separator indicated few cm heights for the liquid level, but when drainage valve from the indicator was opened only steam was observed. Liquid level indicator on the low-pressure separator showed zero level or that the level was below the indicator. When the drainage valve on the indicator was opened only steam was observed. Venturi flow gauges on the liquid pipes from the separators can not be relied on as they are calibrated for single-phase liquid flow.

Evolution of geothermal wells is often so that the steam rate from the wells at a given wellhead pressure remains fairly stable over long periods while at the same time the water rates decreases so the total output from the wells declines with time. As the steam rate remains about the same while the water rate declines the well becomes dryer with time and the enthalpy increases. Apparently, the steam to water ratio for well BO-2 has been about the same or with small increase over the past decades as the discharge tests in 1970/1971, 1982/1983 and 1994 show.

It is recognized that the permeability near well BO-2 is in the lower range for a productive geothermal well. For restricted flow conditions the drawdown in the well at the dynamic logging in 1999 was 19.1 bar and is most likely more at full flow operating conditions. The well was boiling into the reservoir at this restricted flow. As boiling reaches further out into the reservoir and especially if permeability is reduced slightly near the well causing increased drawdown, mobility effects can rather quickly quench the water flow rate making the well almost dry. Even if the discharge from a well is initiated as liquid dominated two-phase flow this evolution can happen in few days or weeks.

Assuming that steam escapes from the high-pressure separator to the low-pressure separator and given the steam flow rates measured by the power plant from the separators the total discharge from the well needed is only 38.5 t/h (10.7 kg/s). The enthalpy of the fluid at 6.3 bar-a would be about 2000 kJ/kg. At those conditions the flow from the well would be steam dominated with steam fraction about 64% at the high-pressure separator. Pressure gradient in a steam dominated well can be expected to be about 1 kg/cm^2 per 100 m or less (1 bar/100 m).

CONCLUSIONS

The available data does not allow us to determine which flowing conditions prevail at well BO-2, i.e. water dominated or steam dominated. However, this can be determined in several ways by direct measurements.

- A measurement on the total discharge rate of the well will determine if the total rate is around 110 t/h (30.5 kg/s) for water dominated flow or if the rate is around 40 t/h (11.1 kg/s) for steam dominated flow.
- A reliable measurement on the separated water flow from the high-pressure separator would also confirm the quantity and state of the flow.
- A dynamic pressure profile in well BO-2 could give the density of the two-phase flow in the well and thereby indicate which conditions prevail.
- Chemical methods can possibly be used to determine the enthalpy of the discharge from well BO-2.

At the moment BO-2 is the only producer for the power plant. Considerable scaling has occurred in the well over the past seven years, which can explain the declining wellhead pressure and consequently declining total output. Possible scaling at the reservoir and inflow zone could explain a flipping of the flowing conditions of the well from being water dominated to steam dominated. As the generation of electricity has not changed much over the past few years and not during the possible change in flowing conditions of well BO-2 **it is our recommendation to leave the well as it is for the time being**.

However, steps should be taken to determine the flowing conditions of well BO-2 and investigation and preparation made for cleaning and stimulating the well. The flowing conditions need to be determined by direct measurements as soon as it is convenient. The outcome from that determination will affect the cleaning operation for the well. If the well is steam dominated it will not be enough to clean the scale from the inside of the casing. To restore the well to its former conditions it will be necessary to clean or stimulate the well at the reservoir. As corrosion is known to exist on the upper part of the casing careful investigation for the most appropriate method for cleaning/stimulating the well is necessary. Results for this should be available soon so appropriate action can be taken when and if the discharge from well BO-2 starts to decline at accelerated rate.

RECOMMENDATIONS

Main recommendation in order of importance and preference:

1. **Leave well BO-2 as it is for the time being.**
2. **Determine flow conditions at the well.**
3. **With information on flowing conditions in hand evaluate the necessity for cleaning/stimulating the well.**
4. **Make necessary preparations and perform the cleaning/stimulating operation when the discharge from well BO-2 starts to decline at an accelerated rate.**

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