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WATER INFLUX IN A STEAM PRODUCING WELL

R. Celati*, V. Cillerai**, R. Marconcini** and G. Neri**

Castelnuovo area, in Larderello geothermal field, was exploited intensively over a period of more than 35 years, with productive wells that are generally 300-500 m deep. As a consequence of this exploitation the formation pressure in the upper part of the reservoir decreased below 4 ata. A few deeper wells, to∼800 m depth, have shown shut-in pressures in the 6 - 10 ata range during these last few years.

In 1974 a deep well, Sperimentale 2, was drilled in this area in order to test steam production possibilities from deep horizons of the reservoir where sufficiently high pressures were still expected to be found. Having reached a depth of 1266 m (Fig. 1) the hole was cased from the surface to 829 m in order to isolate the shallower formations. A circulation loss occurred at 834 m, which represented the only fracture identified during drilling in the open-hole section of the well. No other eventual fractures were noted at greater depths as drilling continued without a fluid return.

The stratigraphic reconstruction of the well is given in Fig. 1.

The stratigraphic and tectonic study of Larderello region shows that the tectonic contacts crossed by this well are connected to regional-type overthrust planes (1).

These overthrusts generally correspond to the most fractured zones of the reservoir.

The well blew out on January 3, 1975. After a short period of steam and liquid water production a first measurement gave:

flow-rate - 26 t/h, no liquid water;
wellhead temperature - 175°C;
wellhead pressure - 7.9 ata.

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*Istituto Internazionale Ricerche Geotermiche, CNR, Pisa, Italy.

**Gruppo Minerario Larderello, ENEL, Larderello, Italy.

In the period from May to October 1975, superheating of the steam increased and wellhead temperature reached 204°C at a delivery pressure of 5 ata. In October the temperature decreased to saturation point and wet steam production began.

A well-testing program was set up to study the phenomenon of two-phase production and to assess well performance. A separation plant was installed and separate measurements taken of the steam and liquid water produced at different back-pressures. The corresponding wellhead and bottom-hole back-pressure curves are shown in Fig. 2.

The pressures plotted in the bottom-hole curve were measured at 1000 m depth because, as will be made clear later, below this depth the hole was, on several occasions, filled with liquid water.

A nearly constant flow-rate of liquid water ($\sim$2 m^3/h) was produced, along with the steam at wellhead pressures below about 9 ata, whereas dry steam only was produced at wellhead pressure above 10 ata.

At a wellhead pressure of about 10 ata the flow regime corresponding to the upper part of the well-head curve became unstable and a slight increase in wellhead pressure was sufficient to cause a sudden drop in flow-rate.

While liquid water was produced with the steam in the upper part, dry steam only reached the wellhead in the lower part. In the latter case large pressure differences were observed between wellhead and bottom-hole. Pressure and temperature logs were also run along the borehole during the back-pressure test.

Fig. 3 shows these logs in flow conditions of point 3, Fig. 2.

The fluid inside the hole is shown to be saturated above 834 m, where the first fracture was found. The pressure drop in this section of the hole is greater than that occurring in the flow of steam only and can probably be attributed to the presence of a two-phase mixture.

The pressure and temperature measured between 834 and 1150 m indicate the existence of superheated steam. The pressure in the final section of the hole is clearly indicative of a liquid phase which, within the limits of error in measurement, seems to be in boiling conditions. Liquid temperature, therefore, is controlled by the pressure and the lowest value is found at the liquid-steam interface (1150 m).

Borehole conditions at point 5 in Figure 2 are represented in Fig. 7. The well was shut-in for an eight-day period. Steam filled the borehole down to a depth of 1130 m below which it was filled with liquid water.

There is no water at the bottom of the hole in the conditions shown in Fig. 8. The measurements were taken during a pressure build-up 24 hours after shut-in.

The liquid observed on some occasions in the final section of the hole is probably due to a complete lack of permeability below 1130 m. The presence of the water depends on several factors, including pressure, temperature and radial temperature gradient at the well sides, the time elapsed with the well in particular flow or shut-in conditions, past history etc.

The low permeability between 1130 and 1000 m probably caused the water-level to rise when the water "rained" on bottom-hole.

In conclusion the following interpretation seems valid in light of the above facts.

1. Two-phase production derives from the mixing of fluids entering the borehole at different depths. Fractures below 834 m produce superheated steam, whereas liquid water or a water-steam mixture enters the borehole near the top of the open-hole section of the well.

   It is possible that the water eventually mixed with the steam came from the fracture at 834 m depth. In this case the water carried after a few months of superheated steam production could be tied to the drop in pressure and change in flow patterns in the zone around the borehole consequent to production.

   Another possibility is that water enters the well from the bottom of the casing due to a failure in casing cementing after a work period in high temperatures.

   It is well-known that the shallower permeable geological formations (mainly the sandstone outcropping over a wide area very near the field) carry the meteoric waters into the field (2). We can thus assume that the water came from the sandstone and reached the borehole by seeping down along the casing.

2. There are probably several fractures at different depths in the open-hole section of the well. The fluid in these fractures has probably different pressures and no separate

From the temperature and pressure distribution it can be deduced that the water enters the hole near the fracture at 834 m depth and, in these flow conditions, all the water is carried upwards along with the steam.

Between 834 and 1000 m there would seem to be some fractures that produce superheated steam; between 1000 m and the steam-liquid interface, on the other hand, the temperature is probably controlled by the weak steam flow produced by the boiling liquid.

Figure 4 gives the temperature and pressure distribution inside the hole at point 2 of Figure 2.

The temperature log is incomplete as no measurements were taken in the section of the borehole characterized by the two-phase mixture.

In this case superheated steam exists from 834 m down to bottom-hole and the trend taken by the still unstabilized temperature distribution is still affected by the distribution resulting previously from the boiling of the liquid. The temperature and pressure distribution in the hole in flow conditions of point 4, Fig. 2, is given in Fig. 5.

The pressure loss in the cased section of the borehole increased even though the flowrate decreased. The steam at wellhead is slightly superheated, whereas it is saturated in the uncased section above the water-level. The water-level rose to about 1030 m.

The pressure distribution in the borehole is given in greater detail in Fig. 6, which represents a pressure log run one day after that shown in Fig. 5. The low pressure gradient from about 400 m to the surface indicates a steam flow separated from the liquid. The steam velocity is so reduced as to be incapable of carrying the liquid to wellhead.

The 830-1030 m section is now also affected by the two-phase flow: the water entering the borehole in the zone between the bottom of the casing and the first fracture is partly held up by the rising steam and partly falls to bottom-hole, so causing the water-level to rise. The high pressure gradient between 834 and 900 m may indicate that most of the steam produced originates in this section.

The temperature distribution in Fig. 3, on the other hand, would appear to be evidence of a very low steam supply from the formation below 1000 m.

The temperature distribution near bottom-hole in Fig. 5 is probably still affected by a previous flow regime with the water-level at 1130 m.

pressure measurements for them are available. From some build-up tests run on the well, a final shut-in pressure of about 20 ata may be inferred.

This pressure is certainly affected, to an unknown degree, by fluid flow inside the borehole from one fracture to another. However, there is obviously a considerable vertical component of pressure gradient in the zone, due to the long and intensive exploitation by relatively shallow wells.

3) Several problems still remain unsolved as regards the contribution to production from the different depth intervals in the open-hole section. A flow-meter log, which is now in project, will provide some useful information in this regard.

References

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(2) R. Celati, P. Noto, C. Panichi, P. Squarci, L. Taffi, "Interactions Between the Steam Reservoir and Surrounding Aquifers in Larderello Geothermal Field," Geothermics, V. 2, Nos. 3-4, 1973.

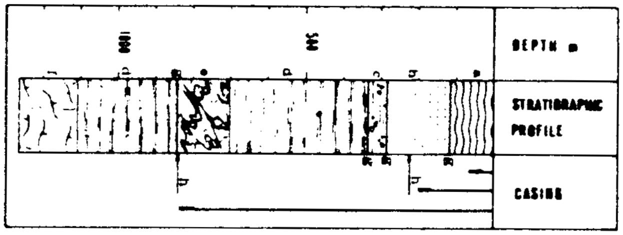

Fig. 1 - Stratigraphic profile of Sperimentale 2 well (1).

a - flysch: shales, marls, marly limestones (U. Jurassic-Eocene)

b - sandstone "macigno" (Oligocene)

c - brecciated magnesian limestones and anhydrites (U. Trias)

d - Triassic quartzites and phyllites

e - Paleozoic quartzites and phyllites

f - marbles and magnesian limestones (of unknown age)

g - tectonic contacts

h - circulation losses

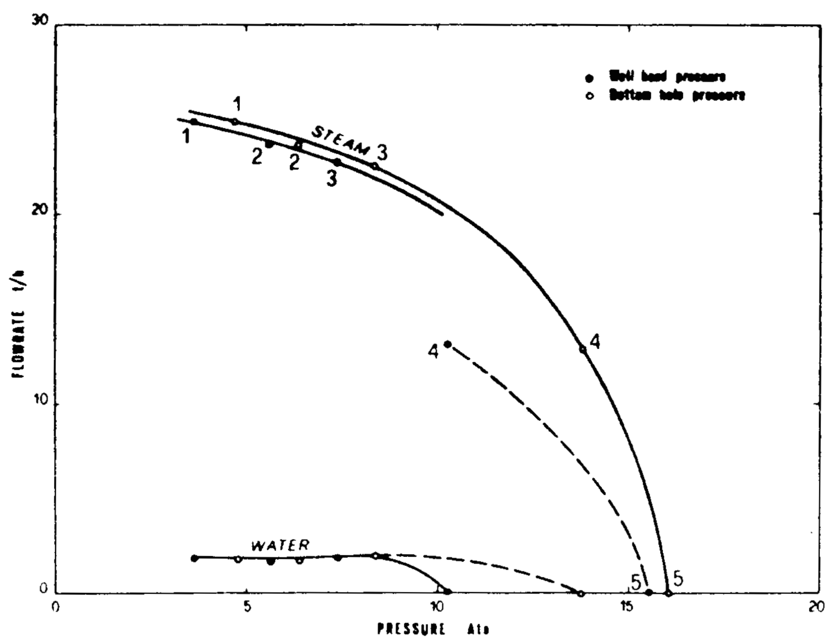

Fig. 2 - Back-pressure curves of Sperimentale 2 well.

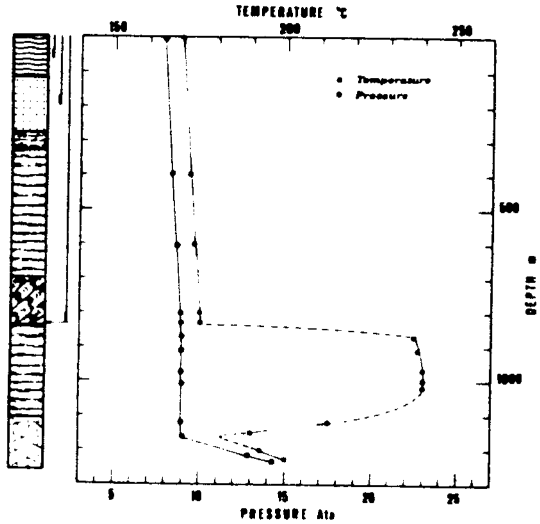

Fig. 3 - Pressure and temperature logs in flowing conditions of point 3 in Fig. 2.

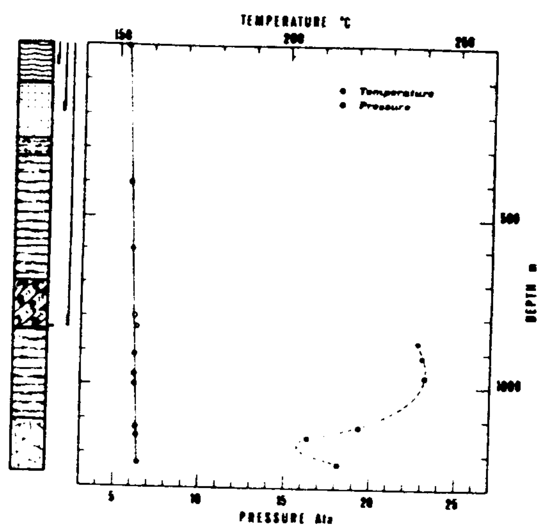

Fig. 4 - Pressure and temperature logs in flowing conditions of point 2 in Fig. 2.

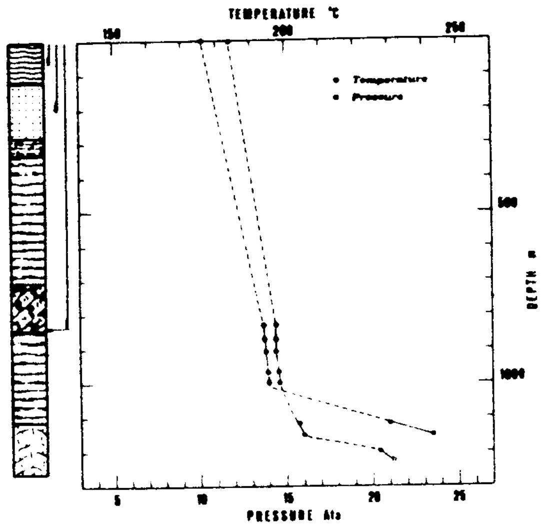

Fig. 5 - Pressure and temperature logs in flowing conditions of point 4 in Fig. 2.

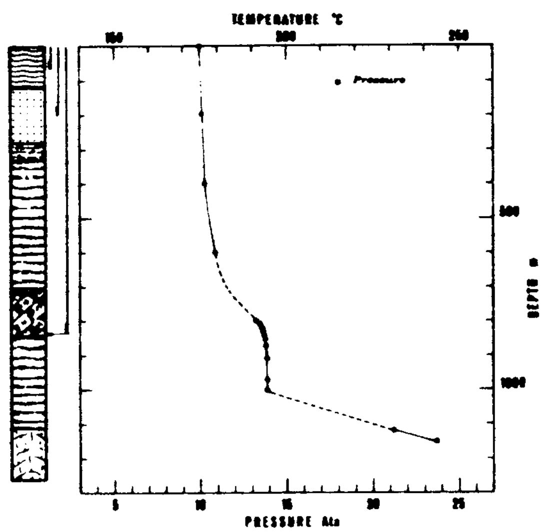

Fig. 6 - Pressure log in flowing conditions of point 4 in Fig. 2.

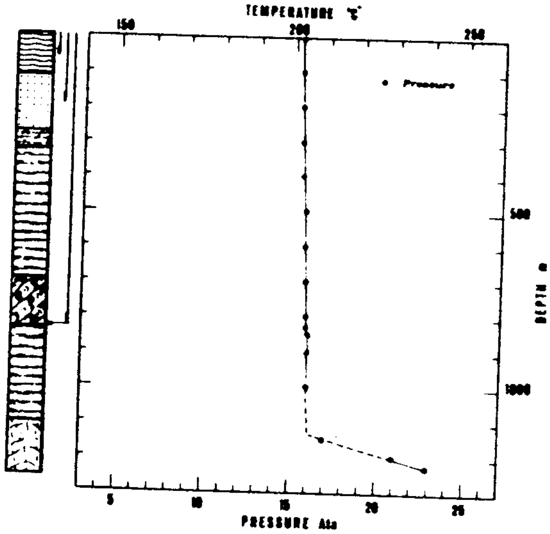

Fig. 7 - Pressure log in conditions of point 5 in Fig. 2.

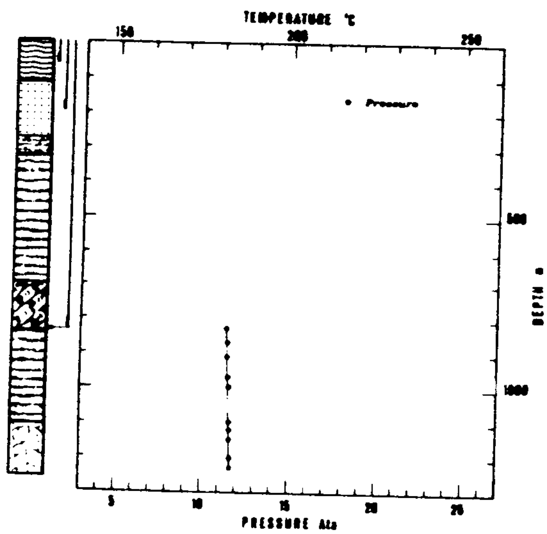

Fig. 8 - Pressure log 24 hours after well shut-in.