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FIRST RESULTS OF A REINJECTION EXPERIMENT AT LARDERELLO

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Abstract Reinjection, which began at Larderello in 1974 as a means of disposing of excess steam condensate, is now envisaged as a method for improving heat recovery.

The behavior of the geothermal field when subjected to production and injection is difficult to predict because of the very heterogeneous fractured reservoir. More information is needed on circulation patterns and heat sweeping processes to estimate the long-term behavior of the reservoir and to avoid detrimental effects. A series of reinjection experiments is now under way in different parts of the Larderello reservoir, aimed at improving knowledge of these points before starting a wide-scale injection program.

This paper presents the results of about one year of injection in an area that has been exploited intensely for over *20* years.

During this test the following were noted:

- almost complete vaporization of the injected water;
- significant production increases and no temperature decrease in the wells around the injector.

Introduction Production from the Larderello field, under exploitation for more than *50* years, has been kept more or less constant during the last 30 years by drilling new wells.

This policy has proved to be less than satisfactory during the last few years because of the large decrease in pressure throughout the field (Fig.1), and in the more productive zones in particular (Ferrara et al.,1970; Celati et al.,1977a; Baldi et al.,1980).

The success of the new wells is tied to the possibility, still to be verified, of recovering fluids from zones outside the present margins of the field and from deep horizons of the reservoir (more than 2 km depth).

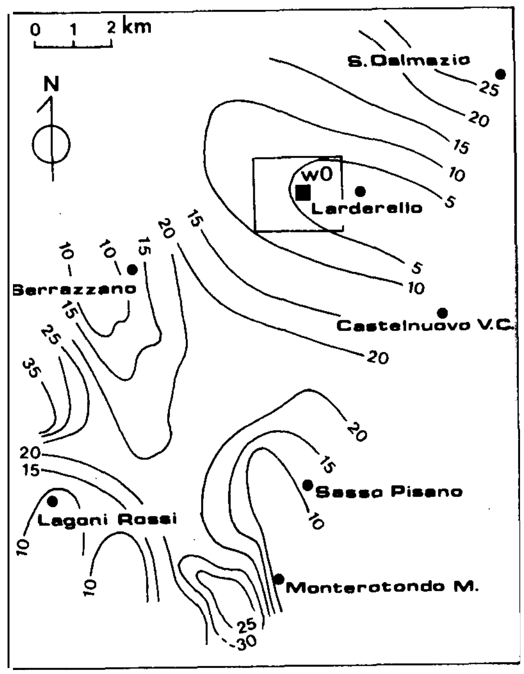

Figure 1 Pressure distribution at the top of the reservoir in the Larderello field, showing injection well wO and the study area. Pressure in bar.

Another possible approach is to inject large quantities of water back into the reservoir. Theoretically a "secondary recovery" of heat from this greatly depleted reservoir is possible as the temperature in most of the explored volume is still within the 240°-260°C range;

temperature values of more than 300°C have also been recorded more or less everywhere at depths below 2 km.

Mathematical models and a limited field experience (Celati et al.,1977b; Celati and Ruffilli,1980; O'Sullivan and Pruess,1980; Schroeder et al.,1980) have shown that it is possible to increase both the recovery factors in the long term and the production rates in the short term, by exploiting reservoirs with pressures below saturation values.

Favourable conditions for obtaining significant production increases can be found in the horizons most exploited nowadays, over the wide zones of Larderello characterized by high permeability and low pressures.

In the present energy situation this seems to be a highly attractive possibility. At the moment, however, we have not a sufficient knowledge of the spatial distribution of the fractures, nor, consequently, of the path taken by the injected fluid in the reservoir and the sweep efficiency attainable. "Short-circuits" have frequently occurred between wells at the drilling stage, after a circulation loss, and productive wells.

For these reasons, before defining a large-scale injection program for the Larderello field, the decision was taken to run a series of tests in different places and situations. The objectives of these tests are to study field behavior, select the most suitable sites for injection wells and develop some tracing methods capable of throwing light on the evolution of the phenomena.

First injection test The zone chosen for the first reinjection test is that shown in Fig.1. The main reasons for choosing this zone were:

- high permeability tied to a diffuse fracturing. The initial flow-rate in some of these wells exceeded 300 t/h;
- high density of productive wells and, hence, possibility of studying the propagation of the effects of injection (Fig.2);

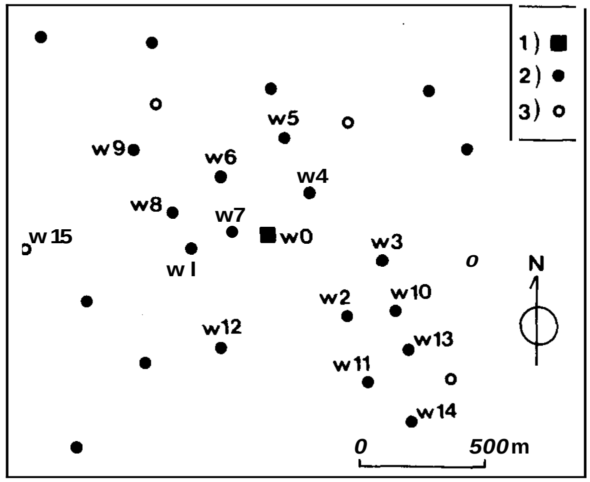

Figure 2 Location of the wells 1)injection well; 2)productive wells; 3) shut-in wells.

- marked decrease in production and reservoir pressure with time (Fig.3), with temperatures remaining around 240°-260°C;
- marked stability of the chemical characteristics of the fluids during the last few years, and more or less uniform spatial distribution of the isotopic composition around the injection well.

All the wells in the area vary in depth from 400 to 600 m, their steam entries lying within the carbonate-evaporitic formation.

The first test was conducted from January to August 1979, keeping the flowrate of the injected water on quite low values (usually 30 and 50 m^3/h, and about 105 m^3/h for a short period only). After a 3 month break injection began again with higher flow-rates.

All the wells from w1 to w14 in Fig.2 were affected to varying degrees, in the form of production increases and changes in fluid composition. The most significant changes were those affecting the isotopic composition of the fluid (Nuti et al.,1981).

Figure 4 shows the flow-rate of the injected water, the total production increase of wells w1-w14, the wellhead

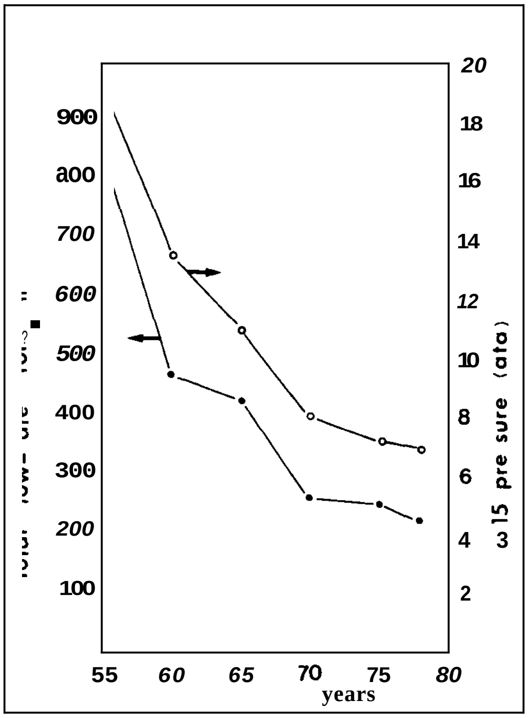

Figure 3 Decline in total flow-rate in wells w1 to w14 and in shut-in pressure in well w15.

pressures and temperatures of the seven most productive wells in the area and the average gas content of wells w1 - w14. The steam flow-rate was strongly affected by the variations in wellhead pressure, which increased notably during this period as a result of certain operations in the power-plants. The increase in flow-rate was lower than the amount of water injected. Wellhead temperature in the productive wells varied very little, even in the wells nearest the injector. The average gas content of the fluid decreased to 70% of its pre-injection value, which, along with increased pressure, led to an increase in conversion efficiency. The variations in the gas/steam ratio appear to be tied to the flow-rate of injected fluid. The latter has a negligible gas content so that the steam it produces merely dilutes the gas in the original steam.

The studies of the isotopic composition of the fluid have shown that it is possible to calculate the contribution of the injected water to the production of the various wells (Nuti et al.,1981). Systematic analyses of the isotopic composition of the fluid have been made on four wells only (w1, w2, w7 and w11). We can thus estimate how much of the steam produced by the injected water joins the fluid produced by these wells. Figure 5 shows that they produce about 60% of the injected water and that this contribution alone is higher than the increase in flow-rate observed throughout the area.

Towards the end of the injection period (204th day in Fig.5) an isotopic survey was made of all the wells affected by reinjection. According to the results of Nuti et al., more than 90% of the flow-rate of injected water was reproduced by the wells. The variations in the gas/steam ratio can also be used to evaluate, albeit approximately, the contribution of injected water to production in the area, assuming that the fluid produced is a mixture of original steam with a constant gas content and injected water containing no gas. This calculation, however, is incorrect as the gas content in the original steam flowing to any given well is not constant because the flow pattern in the reservoir is altered by reinjection. The error made in computing gas dilution can be reduced by using the average gas/steam ratio in the fluid produced from all the wells in the area, but it cannot be eliminated altogether. Nevertheless, the gas/steam ratio is known for all the wells affected by reinjection and for the entire duration of the test; we can thus estimate approximatively the fraction of the water injected in the total fluid produced in the area. Figure 5 shows that the contribution of injected water to production, calculated in this way, is more or less the same as the injection rate.

On the whole we may conclude that, in this first test phase of small injection rates, almost all the water injected is vaporized and joins the fluid produced. The total increase in flow-rate, however, is much smaller than this contribution, which means that the flow of original steam towards the wells decreased during injection. In this case, the phenomenon was mainly

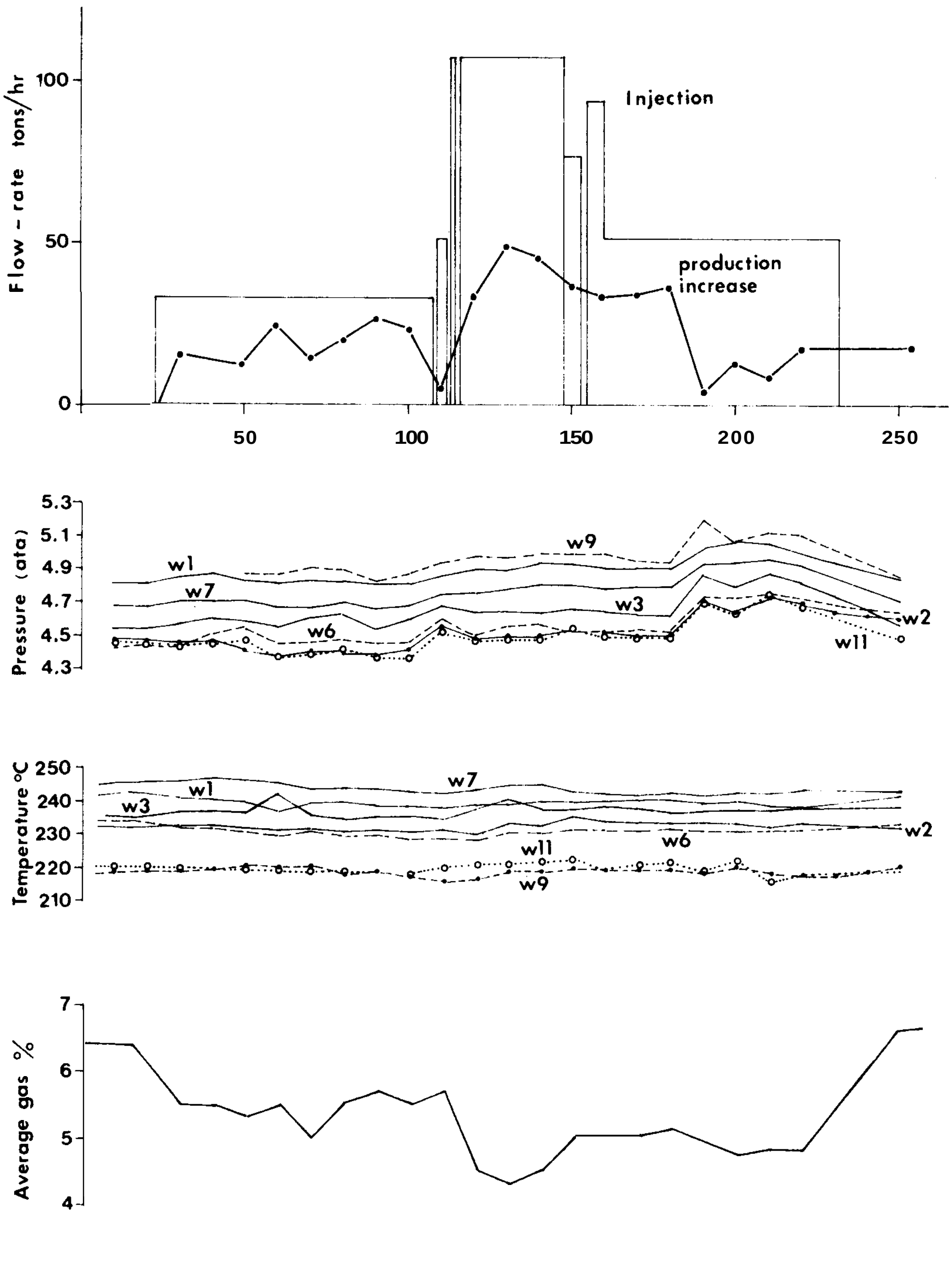

Figure 4 Injection rate in well w0 and total production increase in wells w1 to w14. Wellhead temperature and pressure in the seven most productive wells of the area. Average *gas* content in wells wl to w14.

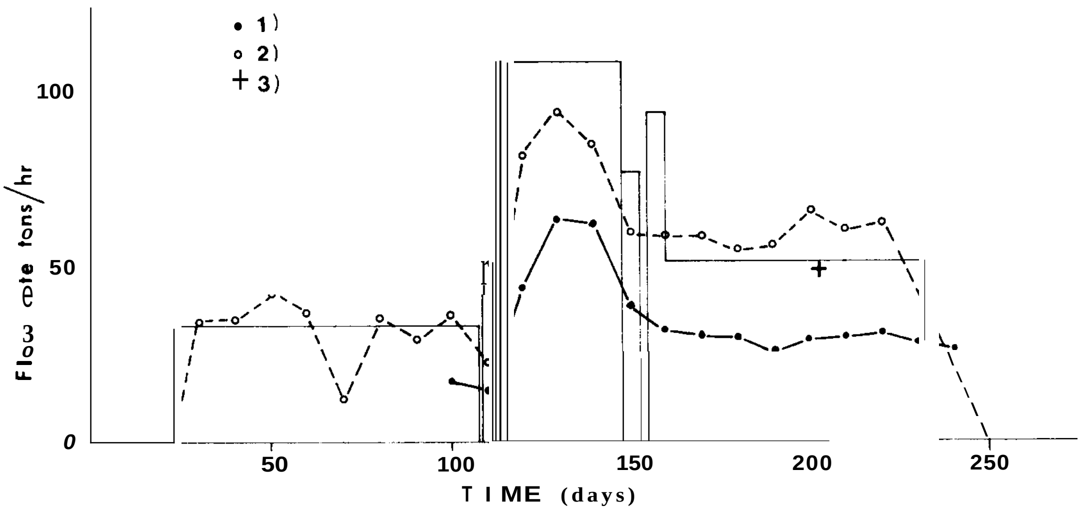

Figure 5 Injected water recovered through wells w1,w2,w7 and wl , from isotopes,1); injected water recovered through wells w1 to w14, from gas content,2) and from isotopes,3).

caused by the back-pressure increases on the wells, deriving from operations in the power-plants. These back-pressure increases have a considerable effect on the rise of steam from great depths and a much lesser effect on the steam coming from the shallower, very permeable formations. These observations are in agreement with the results of the numerical simulation (Schroeder et al.,1980), indicating that effects of this type can also have a certain importance when producing at constant wellhead pressure.

Figure 6 shows the trend of fluid flow-rate and the contribution of injected water to production for wells w7 and w9. In w7, which is very near the injection well, this contribution is much higher than the increase in flow-rate, whereas in w9, relatively further away from the injection point, the increase in flow-rate is higher than in w7, but the contribution of injected water is very low. The flow of original steam thus decreases in w7, and increases in w9 as a consequence of an increase in reservoir pressure.

Reinjection was always conducted with

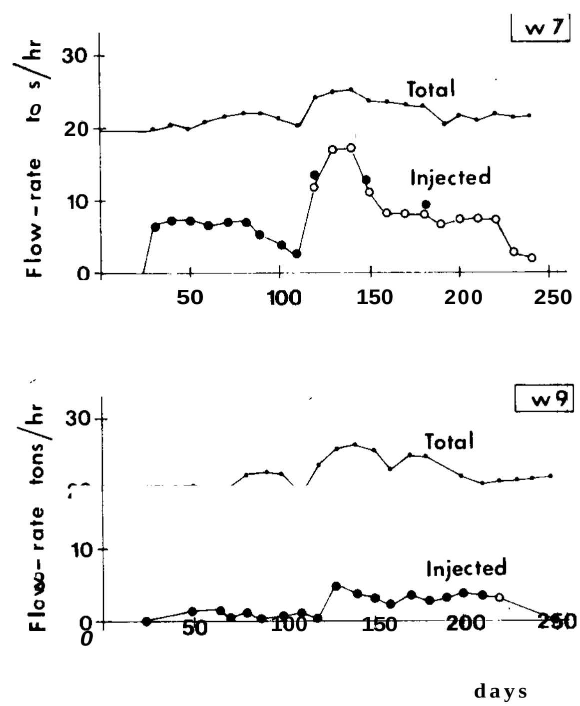

Figure 6 Fluid production and injected water recovered in wells w7 and w9. 'From isotopes. *From gas content.

no back-pressure at the wellhead, and

the injectivity of the well showed no variations throughout the duration of the test; the pressure at the top of the permeable sector of the borehole never varied more than 0.5 ata from static pressure.

Despite the fact that a total of 2.3 x 10^5 m^3 of water was injected into well wO during this first phase, at an average rate of 50 m^3/h, the well had already reached its usual shut-in pressure at wellhead 10 minutes after injection ended, and no liquid phase was found in the borehole. The well was kept shut for twenty days, during which the pressure remained constant and the temperature in the bore was at saturation values. On opening the well the steam rapidly became superheated and the wellhead temperature quickly rose to 185°C after only 8 days (Figure 7), and 220°C at wellbottom after 40 days production.

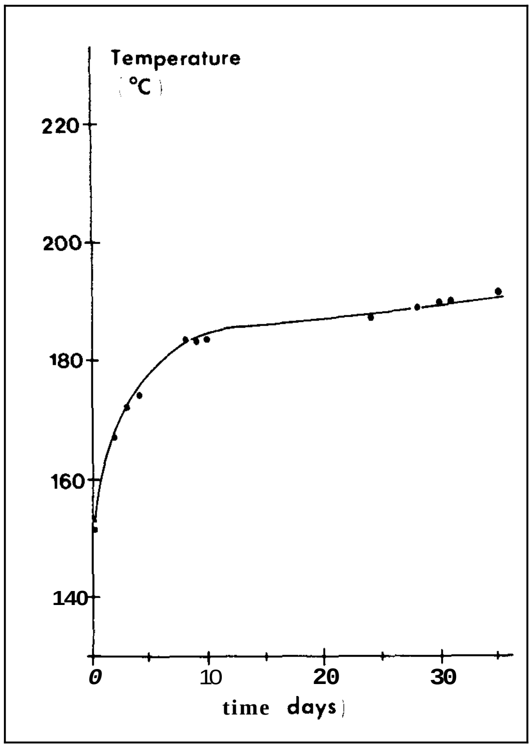

Figure 7 Wellhead temperature in wO, producing at the end of the injection period.

<u>Conclusions</u> No breakthrough phenomena were observed during this first phase of the experiment with low injection rates, even with such a reduced well spacing. On the contrary, the conditions appear to be favourable for a good penetration of the water into the fractured medium, and for a good rock-fluid thermal exchange.

A second injection phase is now under way to verify the earlier results when injecting at higher flow-rates. Other experiments are beginning in nearby areas with productive wells deeper than the injection wells. These tests hopefully will also shed light on the penetrating capacity of the injected fluid at depth.

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