STRATEGIES FOR SUSTAINING PRODUCTION AT LARDERELLO

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ABSTRACT

Fluid production in Larderello geothermal field reached its peak level of about 830 kg/s in the early 1960s. For the next decade production was kept stable by drilling wells over increasingly large areas.

The problem of the sustainability of production came up in the mid-1970s, when the boundaries of the productive area were reached. Two different strategies were planned: drilling of deep wells and reinjection.

In the south-central zone of the field the fluid tapped by the deep wells made it possible to increase output, offsetting the decline of the wells already in production.

In the Larderello - Valle Secolo zone, where exploitation had been more intensive and prolonged, reinjection played a decisive role in maintaining production at the levels reached in the mid-1970s.

INTRODUCTION

For all practical purposes the exploitation of Larderello geothermal field began in 1926 when the wells reached the top of the reservoir (Tuscan Nappe). These wells were located in areas near natural manifestations where the extraction of fluid for the boron industry had begun 100 years before, with wells a few tens of meters deep.

In 1940 the explored area was less than 4 km^2 but fluid production (steam and gas) had already reached 420 kg/s. By 1950 the productive area was about 7 km^2 and production stood at 610 kg/s. However, the high production rapidly declined due to the close spacing between the wells: in this limited area 140 wells were in production, with an average depth of less than 300 m.

Beginning in 1950 the drilled area was expanded. Wells reached the top of the reservoir in structurally deeper, less permeable zones. In the early 1970s the drilled area was around 180 km^2 (Figure 1) and had reached the boundaries of the potentially productive area.

Figure 2 shows the temperature distribution at the top of the potential reservoir. The areas characterized by the rapid attenuation of temperature mark the boundary of the Larderello geothermal system. The temperature decline in the southeast area is due to the inflow of meteoric water, while in the north it is due to a sharp drop in permeability.

Figure 3 contains a schematic of the NNE-SSW geologic section of the Larderello field showing the temperature distribution.

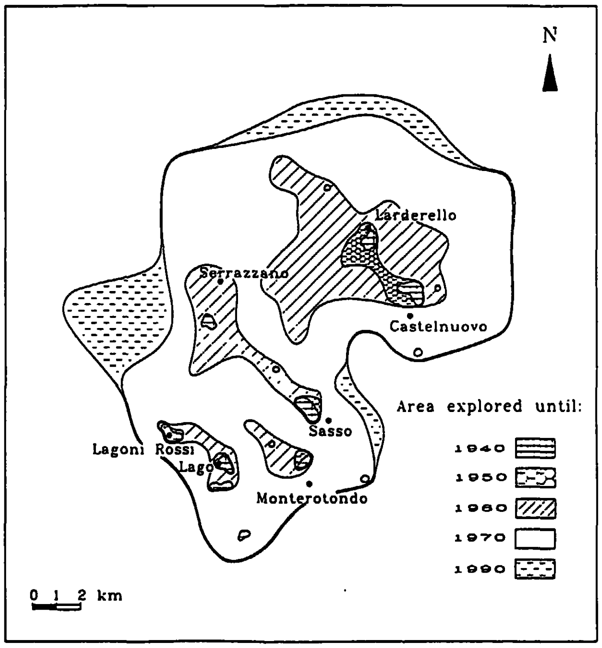

Figure 1. Areas explored by periods.

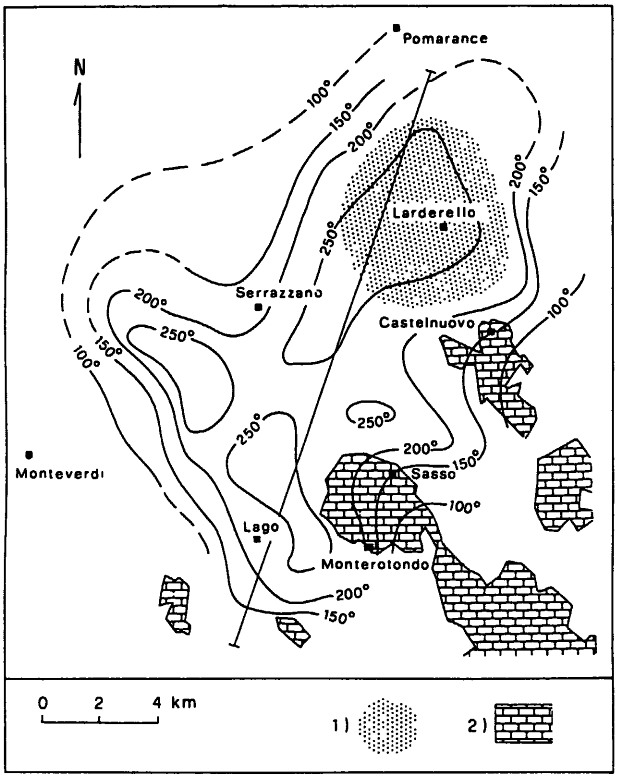

Figure 2. Temperature (°C) distribution at the of the geothermal reservoir and line showing section. 1) Larderello-Valle Secolo zone.
2) Outcropping of reservoir rock formations.

The drilling performed in the period 1926-1970 is shown in Table 1. A total of 480 wells were drilled and the average depth increased from 213 to 992 m. It is interesting to note the sharp reduction in well spacing starting in the early 1950s.

Fluid production increased gradually, reaching its peak level of about 830 kg/s in the early 1960s. Expansion of the productive area and greater spacing between wells made it possible to keep the total fluid production constant, offsetting the continuing decline in the zones of initial, intensive exploitation. This stability was maintained for about a decade (Figure 4), until the completion of exploration over the whole area.

STRATEGIES FOR SUSTAINING PRODUCTION

The problem of the sustainability of fluid production posed itself in the mid-1970s when the boundaries of the productive area were reached.

Starting in about the same period, studies showed a partial recharge of the field by the inflow of meteoric water through permeable reservoir rock formations outcropping at the southern and eastern edges (Figure 2). This recharge steadily increased as a consequence of the reservoir pressure drawdown caused by the exploitation. At present its contribution to the total flow rate is estimated at about 40%. However, production continued to fall because the recharge was insufficient to offset the amount of fluid extracted.

Two different strategies were designed to sustain production at Larderello:

- getting steam from deeper, undrained or only partially drained levels;
- producing new steam by reinjecting water into the most permeable, most exploited areas of the field.

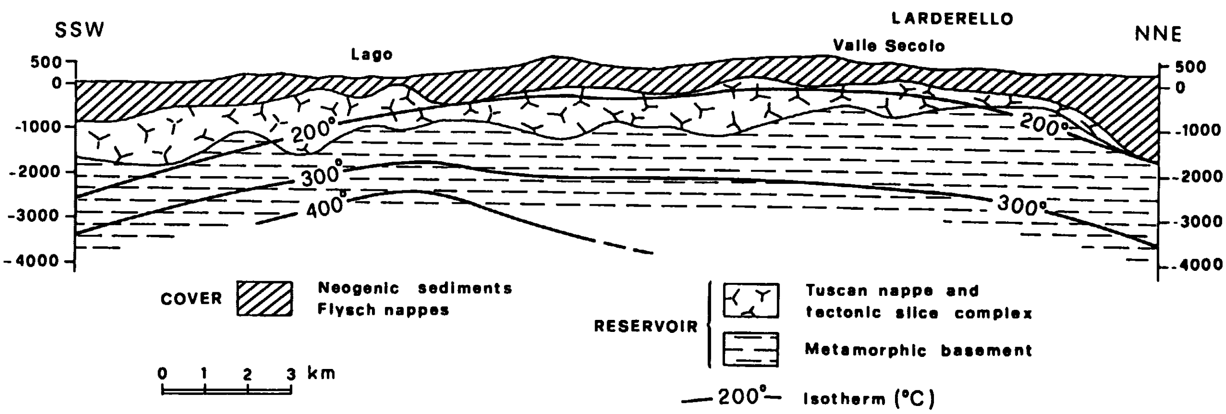

Figure 3. Geologic section of Larderello field

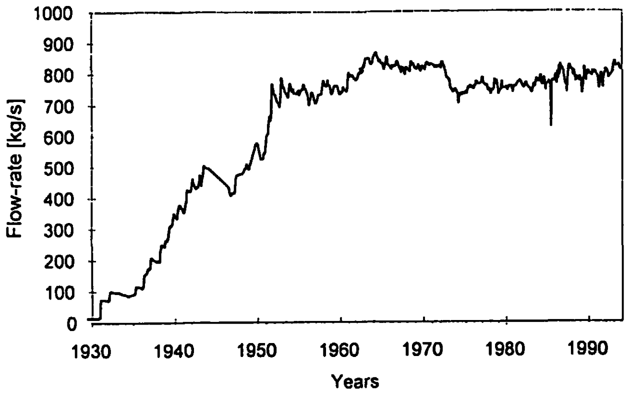

Figure 4. Flow rate trend of the whole Larderello field.

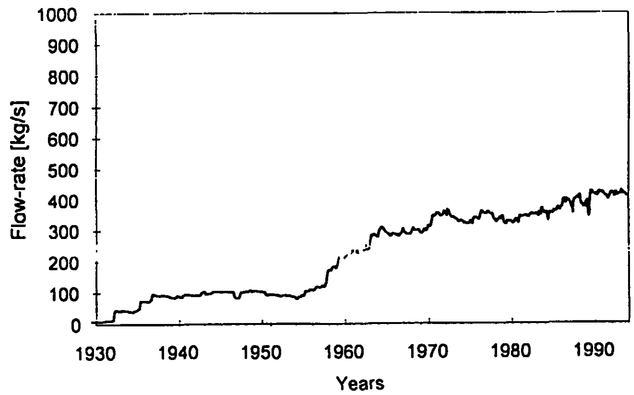

Figure 5. Flow rate trend of south-central zone of Larderello field.

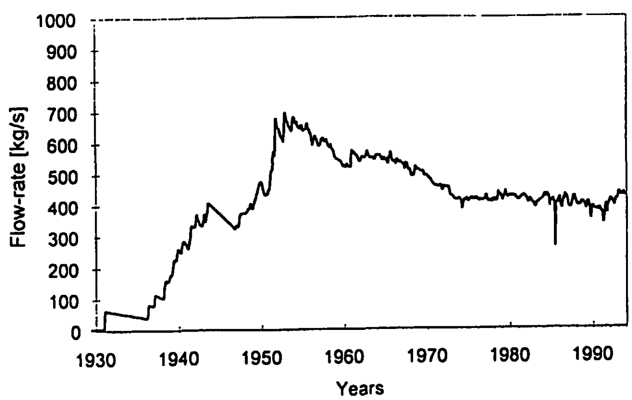

Figure 6. Flow rate trend of Larderello-Valle Secolo zone.

DEEP DRILLING

The first experimental deep wells had shown an increase in fluid pressure and temperature with depth. This trend was due to the distribution of the fracture-derived permeability in the reservoir. Highly permeable layers are separated by layers with low permeability which reduced or prevented the diffusion at depth of the pressure drawdown caused by the producing wells.

The results of the deep drilling were very positive in the south-central zone and at the margins of the geothermal field, and only slightly positive in the north zone (Larderello - Valle Secolo).

In the *south-central zone*, fractured levels were identified between 1500 and 2500 m depth, with high productivity and reservoir pressures of about 3 MPa. The steam obtained made it possible to increase the production of the area and to offset the decline of the wells already in production (Figure 5).

The deep wells drilled at the east, south and west borders of the field identified fractured levels at depths between 3000 and 3500 m, with reservoir pressures of 6-7 MPa and temperatures ranging between 300 and 350°C. The fluid found in these zones will be utilized in additional geothermal power plants.

To the north, in the *Larderello - Valle Secolo zone*, the deep wells drilled in the most productive area showed the presence of numerous interconnected fractures also in the metamorphic formations which permitted extension of the drainage effected by the producing wells at depth. In this area the reservoir pressure does not exceed 3.5 MPa at the depth of 3000 m and the average productivity of the deep wells is about 6 kg/s. The additional fluid from these wells was insufficient to offset the production decline of the area.

The deep wells, drilled in the same northern zone but outside the most productive area, crossed low-permeability metamorphic formations.

REINJECTION

The first reinjection experiments were conducted in the Larderello - Valle Secolo zone, which was the most favorable due to the extensive distribution of fractures in the reservoir and the presence of highly superheated steam. The reinjection program provided for the testing of wells with different depths located in various points of the zone.

TABLE 1 - WELLS DRILLED TO THE RESERVOIR TOP

Period	Drilled area km^2 Incr.	Drilled area km^2 Tot.	Wells drilled # Incr.	Wells drilled # Tot.	Success ratio in the period %	Wells/km^2 Incr.	Wells/km^2 Tot.	Average well depth m	Average flow rate of the wells drilled in the period kg/s/well
1926-1940	3.5	3.5	136	136	82	39	39	213	3.6
1941-1950	3.3	6.8	69	205	70	21	30	433	6.4
1951-1960	41	48	150	355	73	3.6	7.4	751	5.3
1961-1970	130	178	125	480	50	1.0	2.7	992	6.1

There was particular interest in evaluating the effects of injecting water into the productive layers located at the top of the reservoir and in deeper layers.

The injection tests at the top of the reservoir proved to be positive in the area where the metamorphic formations are fractured. In this case the reinjected water can penetrate to depth and find large heat exchange surfaces. On the contrary, where the metamorphic formations are not fractured, there is breakthrough between injection and production wells. In this second case the reinjected water does not penetrate to depth.

Deep reinjection did not yield positive results and the reinjected water was not vaporized in appreciable amounts, despite the long experimentation period.

Beginning in 1983 all the condensate from the power plants (about 80 l/s) was reinjected at the top of the reservoir in the most favorable area (Valle Secolo). After 15 years of operation the results can be summarized as follows:

- an increase in the overall flow of steam (over 80% of the reinjected water was vaporized);
- a sizable reduction in the average non-condensable gas content, leading to an increase in power plant efficiency;
- an increase in the reservoir pressure by about 0.2 MPa;
- nearly constant temperature values of the produced fluid, even in wells close to the reinjection wells.

In early 1994 it was decided to increase reinjection using water from outside the field. The water reinjection rate rose from 80 to 140 l/s.

The long experimentation period made it possible to define the limits and modes of reinjection. In particular, to achieve rapid evaporation of the water it is necessary to:

- reinject in the zones where the wells produced considerable amounts of fluid in the initial phase and where the well spacing is closest. Indeed, the productivity of the wells is linked to the permeability and to the distribution of the fracturing, while the closeness of the productive wells allows the maximum recovery of evaporated water;
- reinject at the top of the reservoir, using wells that were excellent producers.

The above remarks are synthesized in the graph of Figure 6, where the trend of fluid production in the Larderello - Valle Secolo zone is reported.

As will be noted, the overall flow rate increased until halfway through the 1950s, then dropped sharply when drilling was suspended in the area and no new steam was contributed.

Beginning in the mid-1970s this decline slowed due to a reduction in flow rate following the shutdown of a geothermal power plant and to the contribution of the natural recharge which affected the highly productive zone in that period.

Starting in the early 1980s, the reinjection made it possible to stabilize the production of the entire Larderello - Valle Secolo zone.

CONCLUSIONS

The short- and medium-term programs for sustaining the production of Larderello geothermal field call for continuing the two lines of action described above: drilling deep wells and reinjection.

The number of deep wells will be reduced in the future when the whole potentially productive area will be covered, with optimum spacing for the exploitation of the productive layers.

Reinjection, on the other hand, will be intensified and extended to the other zones of the field, including those currently considered less favorable. In particular, in the zones characterized by poor reservoir fracturing but high temperatures (300 - 350°C), it is planned to alternate the use of the single wells as both injection and production wells. In this way it will be possible to recover the heat stored in reservoir rocks which are poorly fractured and hence poorly connected with other wells. Experiments in this direction have already achieved positive results and are still in progress.

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