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3.3
GEOTHERMAL ENERGY TECHNOLOGIES AND STRATEGIES FOR A SUSTAINABLE DEVELOPMENT: THE LARDARELLO CASE HYSTORY

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Abstract

The first world experiment of power production from geothermal resources was performed in 1904 in Larderello, Italy. In the same area the first com-mercial power plant (250 kW) started production in 1913. The installed capacity has been increasing con-tinuously during the subsequent years and, up to 1958, when a first unit was installed in New Zealand, Italy has been the sole country in the world that had developed this technology. Subsequently, the utiliza-tion of geothermal resources for power production has been developed in several other countries, with a significant increase in the period 1980-2000 (at a rate of about 1,000 MW every 5 years). At present, the total capacity is about 8,000 MW in 24 countries, with about 50,000 GWh/y energy production.

Over the last 20 years, technological develop-ment has been particularly significant for ex-ploration methodologies, reservoir characterization, drilling technologies, power plant efficiency, im-provement and reduction of environmental impact. The development of binary cycle technologies has opened new prospects to the utilization of medium temperature resources. This technology is at present widely utili-zed. New technologies for the H2S and Hg abatement and environmental impact mitigation have also been developed.

Of great relevance are the research and develop-ment activities carried out in Larderello since the 70's (deep exploration and reinjection) that have allowed the reassessment of the geothermal potential in areas already in exploitation since several decades, and to implement new exploitation strategies aimed at the resource sustainability. The strategies adopted for the Larderello area are now considered as a case history worldwide, and are taken as reference from the geothermal operators.

1. Foreword

Geothermal resource utilization for industrial purposes was begun in the first half of 1800 at Lar-derello, with boric salts production and exploiting the steam, as a substitute of wood, to boil dry the brine.

The first experiment in the World of electricity production took place in 1904, when a steam engine supplied by geothermal fluid was coupled with a dynamo and allowed the lighting of five bulbs in a boric chemical farm. In 1913 the first 250 kW geothermal unit was installed at Larderello marking the start of a brand-new industrial activity. Electricity production was kept to low levels up to 1938, but afterwards it had a steady and fast increase.

The Italian experience in this field was the only example of the kind up to 1958, when the first gene-ration unit was installed at Wairakey in New Zealand, followed by a unit installed in 1960 at The Geysers (USA). By that time the yearly production at Lar-derello had already reached 2 billion kWh, with an installed capacity of 300 MW. Since the '50s, also the geothermal fields of Bagnore and Piancastagnaio, located at Monte Amiata, and then the Travale/Ra-dicondoli field, that occurs some 20 km eastward of Larderello, have been developed.

The historical trend of electricity generation from geothermal resources in Italy is given in *Figure 1* , where two different increase phases are shown: the first in the period from '30s and mid

'70s related to the development of the shallow carbonate reservoirs; the second from the beginning of '80s up to now, where the fluid production has been increased with the deep drilling activity and the artificial rec-harge of the reservoirs with the reinjection of the condensed steam.

In the year 2003 the electricity production has picked-up to 5 TWh that represent 10% of geothermal electricity generation worldwide and 25% of electricity needs in Tuscany ([1] and [2]).

From '60s on the exploration, development and utilization of geothermal resources has been increased also in several other countries, with a significant growing rate of 1,000 MW/five years in the period 1980-2000 (*Figure 2*). At present the total installed capacity is around 8,000 MW in 24 countries, with a yearly electricity generation of 50,000 GWh. The higher power production is in USA, Philippines, Mexico, Indonesia, Italy.

In the same period the direct uses have been also increased and now the total thermal power is 15, 000 MWt in 55 countries, with an yearly energy production of 53,000 GWh.

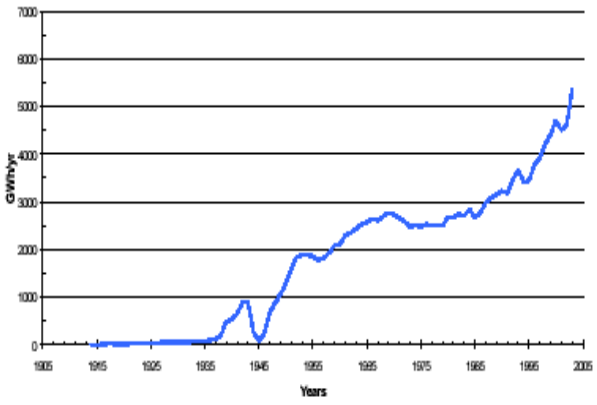

Fig. 1 - Power generation from geothermal in Italy

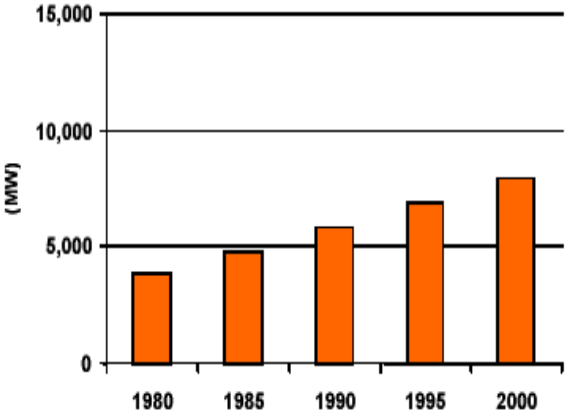

Fig. 2 - Growing of geothermal installed capacity in the world

2. Technological developments in geothermal over the last twenty years

As for mining activity, the developments of new technologies in geothermal have being growing together with those of the oil sector.

In fact, in the past 20 years also the geothermal research has moved toward deeper systems having more complex geological and structural characterristics; this progress has therefore required new methodologies to identify the mining targets.

The search of such systems, although opening new and wide perspectives to future developments, has nevertheless considerably increased drilling costs and, therefore, the need of new investigation technique to reduce the mining risk (rate of successful production wells vs. drilled wells). Indeed, the poorer is the geothermal model knowledge the higher is mining risk.

Hence, over the past decades, exploration technologies ever more refined (MT, 2D and 3D Seismic, in-well Geophysical Logs) have being employed alongside of the traditional exploration methodolo-gies based on the large-scale detection of thermal, gravimetric, magnetometric and resistivity anomalies. The aim was a better characterisation of the deep geological/ structural assets (*Figure 3*).

As a consequence, over the years, the prominent mining groups and international geophysical service companies have being investing conspicuous capitals and resources in the development and upgrading of investigation technologies, either at scientific level and for field application.

With the decrease of computer costs and the development of data elaboration software, the sound reliability, full potentiality and integration capacity over different data, an extensive use of the new methodologies has taken place, and undeniably so in the case of reflection seismic.

Currently, reflection seismic together with other geophysical methodologies, including those utilised directly in exploration/production wells, makes up the basis for characterising the deep structural asset and allows the definition of drilling targets.

As for drilling activity, besides the dynamic adjustment of plant characteristics and potentiality aiming at reaching greater depths, new technologies, specific for geothermal, were developed for fracture plugging and for cementation of casings in high temperature environments (around 300°C). New cement slurries have been developed

and employed and new materials, (Titanium and 13Cr) that can withstand fluid corrosion, are under testing for casings.

Aiming at cost reduction in drilling activity, especially in deep horizons with moderate productivity, a new technology has been envisaged and ap-plied, in particular at The Geysers (USA), entailing boring wells having more production branches, two-three for example (multilateral).

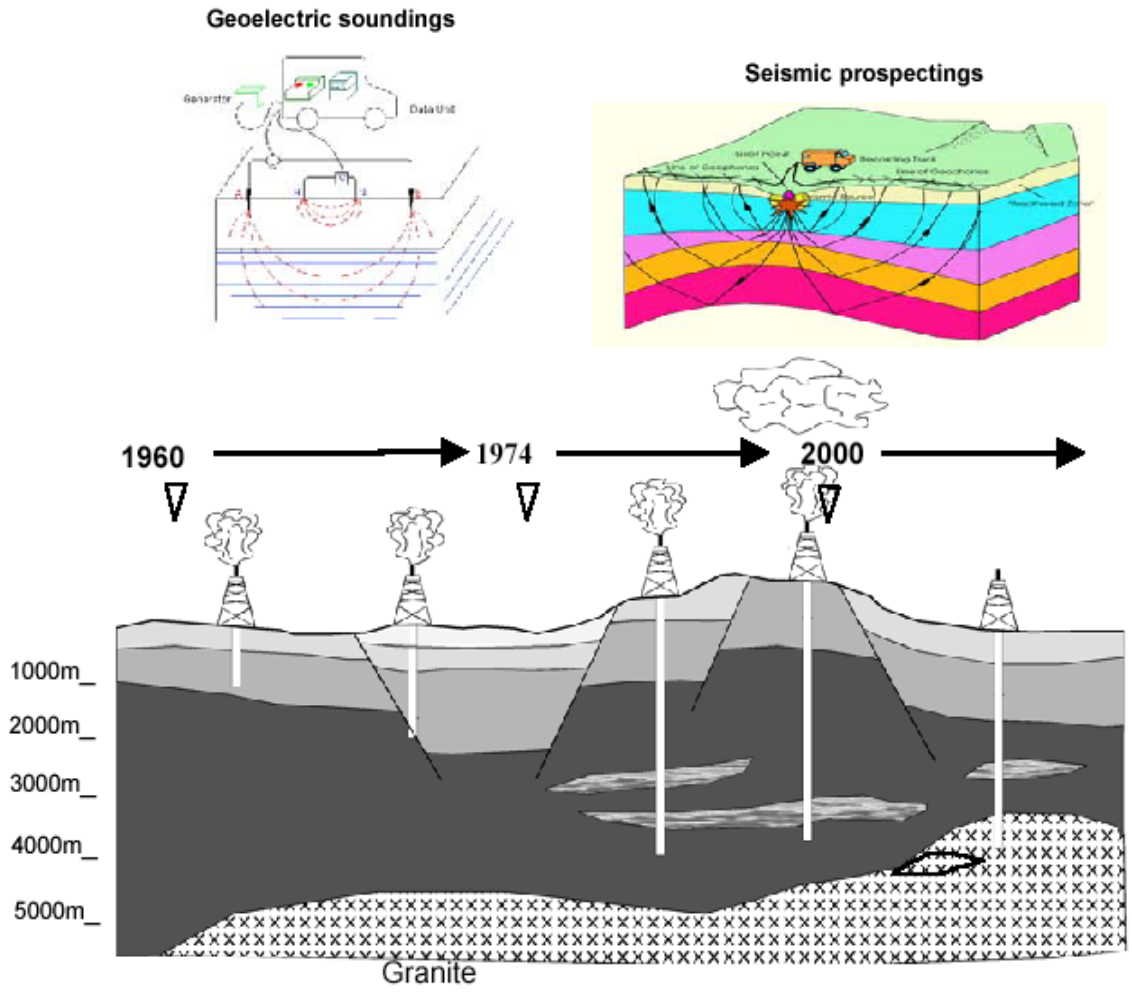

Fig. 3 - Development of exploration technologies

It must be noted, however, that with respect to the developments achieved in the oil sector the occurrence of higher temperatures strongly thwarts the use of some equipment in geothermal.

Unfortunately, due to the limited size of geothermal market in comparison with the oil one, the companies' interest towards the development of equipment and instruments capable of operating at high temperatures and coping with corrosive fluids is scant. As for power plants with condensing units, the specific consumption has considerably decreased (kg steam /kWh) due to:

- Progress in fluid - dynamic design of turbines (blade profiles, betterment of seals);
- Use of new materials, enabling the increase in length of the last stages blades (single flow 40 MW turbines are now considered standard) and, besides other considerations, these blades are more resistant to corrosion;
- Adoption of high speed centrifugal compressors allowing a better vacuum in the condenser.

Always in the machinery sector a noteworthy development has interested the design and installation of binary cycle plants, that have found wide application in the use of medium temperature geothermal resources (between 200 -100°C). This technology allowed the development of new projects in water dominated geothermal fields with moderate temperatures.

At high temperature water dominated fields, with flash plants and condensing stations, binary units are widely used to recover thermal energy down-stream to pressure separators (in general there are high flow-rates with temperatures in the

range 180 - 130 °C). Such applications (bottoming cycle) are par-ticularly important because lead to a net increase in produced energy (about 20%), with the same total flow-rate of fluid from wells.

Of strong relevance is also the growing attention toward environmental aspects: the power station building and the cooling towers have more limited size and are designed and realized so as to reduce the impact on the territory. The noise level is sensibly de-creased too, and new technologies have been developed for the abatement of sulphide acid and mercury, which are in general associated to geothermal fluids.

3. The development in the exploitation strategies: the Larderello-Travale/Radicondoli geothermal system

In addition to the technological aspects, the ex-ploitation strategies have been strongly improved in these last 20 years and the methodologies developed at Larderello are considered a case history for the other operators.

In this area the utilization of geothermal steam for electricity production was begun at the beginning of last century and has been increased progressively as given in *Figure 4*.

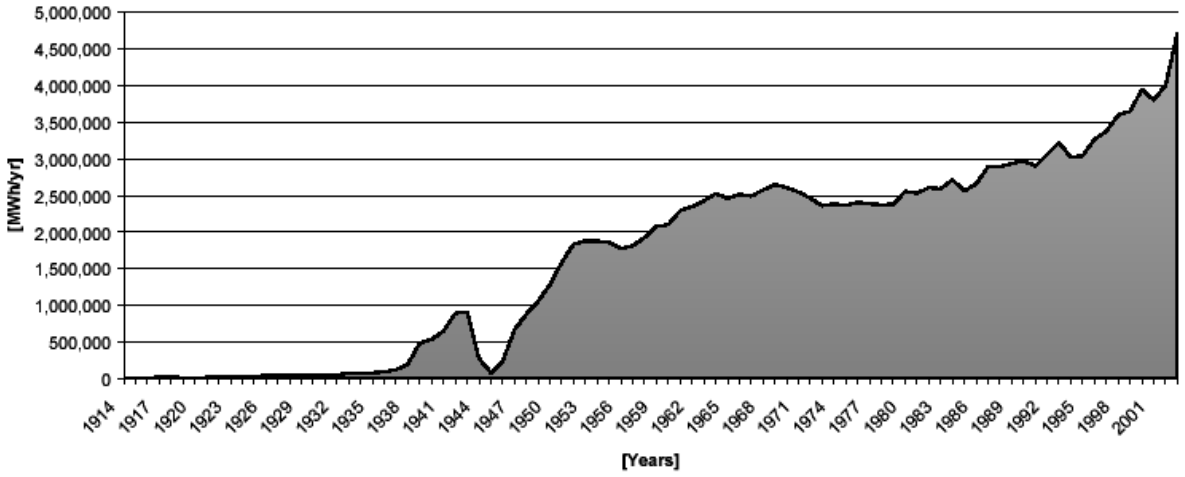

Fig. 4 - Historical trend of geothermal production in the Larderello - Travale/Radicondoli field

A significant and steady production growth has begun at the end of the '30s and lasted up to the beginning of the '70s, with one only break in 1944 because of the war, when the plants were destroyed.

During this lapse of time the wells drilled in the areas of Larderello and Travale/Radicondoli were aimed at getting fluid production from the shallow carbonate reservoir (constituted mainly by anhydrites and dolomites) underlying the cover formations made up mostly by shales, with depths less than 1500m.

In this period the drilling activity, that was started in the central most productive areas, was progressively extended interesting more wider areas up to reach the boundaries (drop of temperatures) of the shallow carbonate reservoir (*Figure 5*).

In the mid-'70s the production decline became evident due to the long and strong exploitation of the fields, pointing out the problem of sustainability, not to speak of any further increase, of production.

To face this problem the following R&D activi-ties were launched:

- deep exploration (3000 – 4000 m) to check the presence of new productive levels within the Metamorphic Basement underlying the shallow carbonate reservoir;
- reinjection of condensed steam and water into the reservoir to increase steam production in the most depleted areas.

Both the activities have been successful and have made it possible to increase the fluid production and therefore the electricity generation in areas already on exploitation from many years ([3] and [4]).

The deep exploration program has allowed to verify the presence of permeable layers inside the Metamorphic Basement (3000-4000 m depth), with temperature and pressure increasing with depth, up to values of 350°C and 70 bar, and high productivity [5]. On the basis of these positive results new development programs have been implemented.

The additional fluid production from deep wells drilled in the in the central and more exploited areas have made it possible to compensate the production decline of the shallow carbonate reservoir wells.

The deep wells drilled at the margins of the two fields have allowed to verify the larger extension of the thermal anomaly, if considered at 3000 m depth, and to increase significantly the steam production also in areas considered, up to some few years ago, out of interest for geothermal exploration.

Based on the temperature data collected from the deep drillings, it's clear that the Larderello and Travale/Radicondoli fields, considered separated at the shallow carbonate reservoir, belong to the same geothermal system: at the depth of 3000 m, the 300°C isotherm contour line includes both areas (*Figure6)*, with a total extension of about 400 km2 ([6] and [7]).

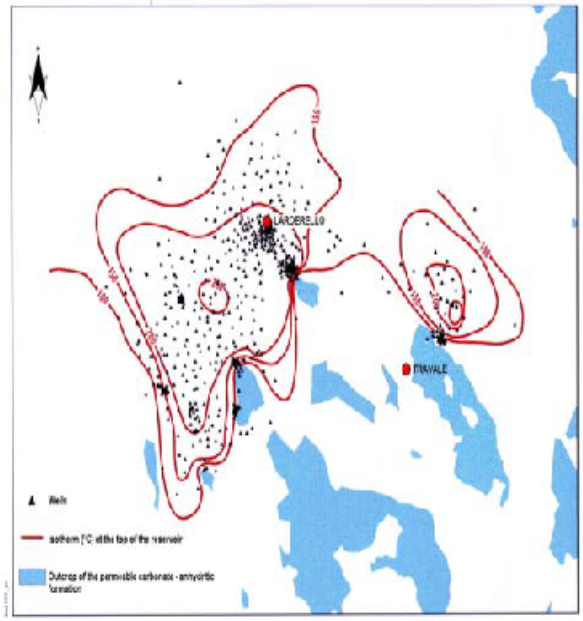

Fig. 5 - Temperature distribution at the top of the shallow carbonate reservoir.

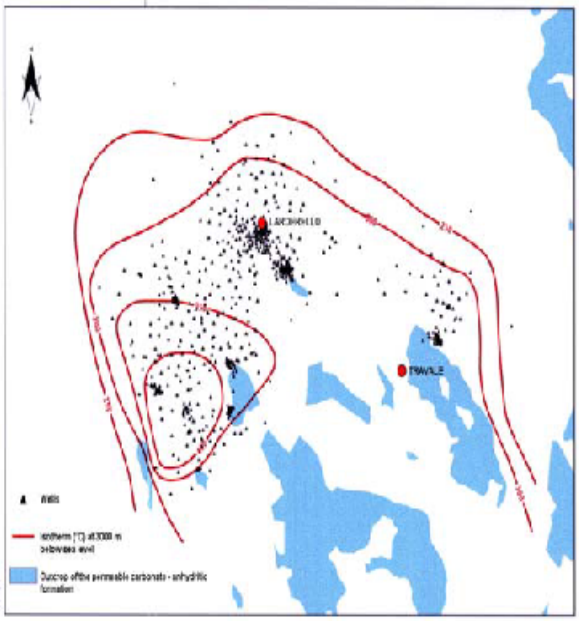

Fig. 6 - Temperature distribution at 3000 m b.s.l.

The reinjection was begun at the end of '70s in the Larderello field and has allowed to verify the possibility of increasing the steam production in areas strongly depleted due to the long and intensive exploitation (Valle Secolo).

The water injected into some of the shallow wells (carbonate reservoir) are converted into steam inside the reservoir, drawing heat from the rocks, and thus increasing reservoir pressure and production yield in the nearby wells. Moreover this "secondary" steam, devoid of gas, dilutes the "primary" steam, allowing a reduction of the weighted average gas content, with considerable energy savings for gas extraction from power plant condensers. After a first testing period in some selected wells the reinjection is now a sound strategy to sustain/increase the steam production in strongly depleted areas [8].

In *Figure 7* production history of some 28 wells in the Valle Secolo area is given: it is clear the strong decline in the period from mid-50' to mid-70', and then the production improvement due to reinjection.

For the same wells, in *Figure 8*, is given the comparison between actual steam production and the one extrapolated in case of no reinjection: the increase in power is about 50 MW, without significant decline in steam temperature after more than 20 years of reinjection operation.

The positive results of both activities have allowed a reassessment of the potential of the Larderello-Travale/Radicondoli geothermal system and to implement new projects related both to further developments (drilling of additional wells and construction of new power plants) and to the repowering of plants in operation.

New exploitation strategies have been also studied and set up aimed at resource sustainability: production and reinjection are managed to sustain the reservoir pressure and, therefore, steam production.

In the last thirty years a strong change of exploitation strategies has then occurred: from "intensive" to "sustainable".

A new exploration program has recently been implemented to verify the possibility of a further increase of steam production from deep layers located both inside and at the margins of the Larderello-Travale/Radicondoli geothermal system. This program includes 3D seismic surveys and drilling of eleven exploratory wells.

4. Conclusions

Significant technological developments have been realized in geothermal in these last decades

and made it possible to implement exploration and development programs for deep resources (3000-4000 m), characterized by high temperature.

As for the power plants, in addition to increase in efficiency at condensing units, the development of binary cycle units has opened new perspectives for the utilization of medium temperature geothermal resources (≤ 200°C).

Important improvements have occurred in the area of resource assessment and in exploitation strategies with sound management of production and reinjection. The positive results of deep exploration and artificial recharge with reinjection, started in the Larderello area since mid-'70, have made it possible the reassessment of geothermal potential in areas already under exploitation since many years and to implement additional development projects.

In the same area new production and reinjection strategies aimed at resource are now utilized, hence shifting from intensive to sustainable exploitation.

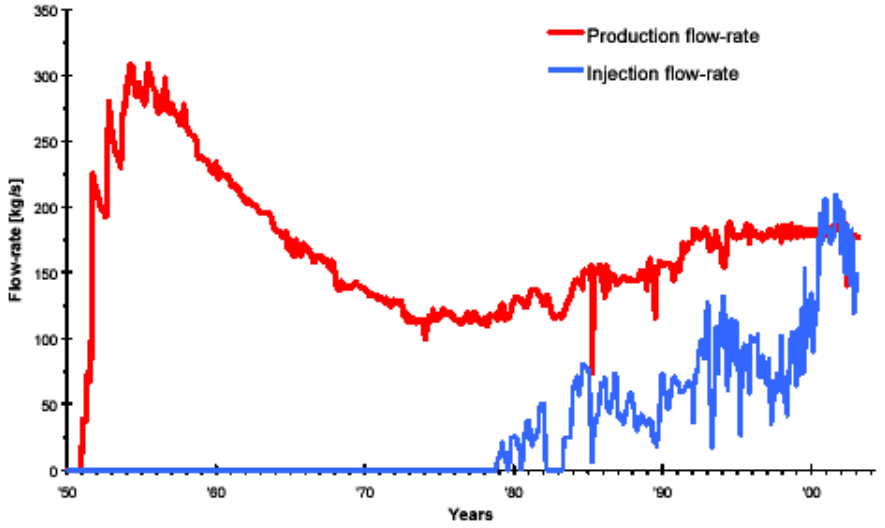

Fig. 7 - Influence of the reinjection on the steam flow-rate of 28 wells in the Valle Secolo area (Larderello)

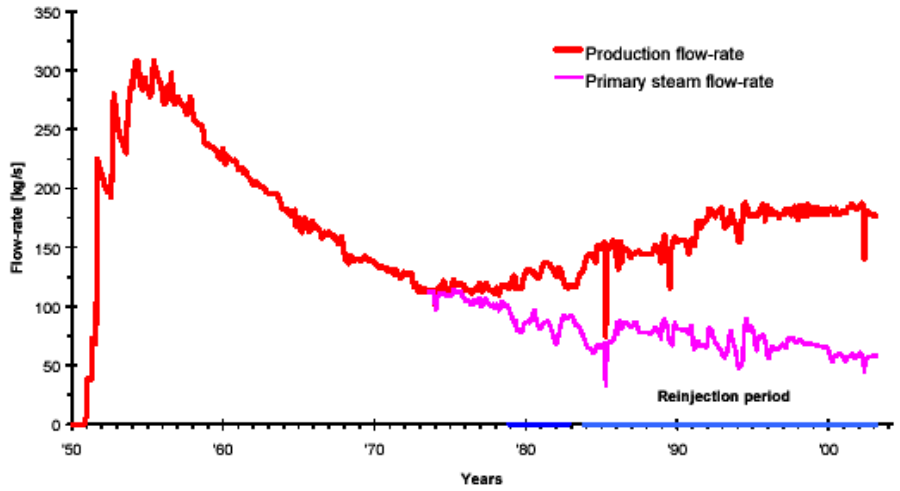

Fig. 8 - Comparison between the effective steam flow-rate and the primary steam flow-rate of 28 wells in the Valle Secolo area (Larderello)

5. References

[1] Cappetti, G., Passaleva, G. and Sabatelli, F., 2000. "Italy country update report 1995-1999". *Proceedings of the World Geothermal Congress WGC2000*, Kyushu-Tohoku, Japan, May 28-June 10, 2000. pp.109-116.

[2] Cappetti, G., 1998. "Geothermal power generation in Italy". *Proceedings of the World Renewable Energy Congress V*, Florence, Italy, September 20-25,1998.

[3] Billi, B., Cappetti, G. and Luccioli, F., 1986. "ENEL activity in the research, exploration and exploitation of geothermal energy in Italy". *Proceedings of the 1st Afro-Asian Geothermal Seminar*, Chiang Mai, 4-9 November 1985. Geo-thermics, vol. 15, No. 5-6, pp. 765-779.

[4] Cappetti, G. and Stefani G., 1994. "Strategies for sustaining production at Larderello". *Proceedings of the 1994 G.R.C. Annual Meeting*, Salt Lake City, USA, Transactions, vol.18, pp. 625-629.

[5] Cappetti, G., Celati, R., Cigni, U., Squarci, P., Stefani, G.C. and Taffi, L., 1985. "Development of deep exploration in the geothermal areas of Tuscany, Italy". 1985 *International Symposium on Geothermal Energy*, Kailua-Kona, Hawaii, Intl vol., pp. 303-309.

[6] Barelli, A., Cappetti, G. and Stefani, G., "1995. Results of deep drilling in the Larderello-Travale/Radicondoli geothermal area". *Proceedings of the World Geothermal Congress WGC95*, Florence, Italy, May 18-31, 1995. vol. 2, pp. 1275-1278.

[7] Barelli, A., Bertini, G., Buonasorte, G., Cappetti, G. and Fiordelisi, A., 2000. "Recent deep ex-ploration results at the margins of the Larderello
Travale geothermal system". *Proceedings of the World Geothermal Congress*, Kyushu-Tohoku, Japan, May 28-June 10, 2000. pp.965-970.

[8] Cappetti, G., Parisi, L., Ridolfi, A. and Stefani, G., 1995. "Fifteen years of reinjection in the Larderello- Valle Secolo area: Analysis of the production data". *Proceedings of the World Geothermal Congress*, Florence, Italy, May 18-31, 1995. vol. 3, pp. 1797-2000.