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Sustainability analysis of geothermal resource for electricity generation: the example of Ischia Island (Southern Italy)

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ABSTRACT

We analyze the possible disturbance on temperature and pressure filed in the shallow geothermal reservoir of Ischia Island, due to the heat withdrawal for electric production related to small geothermal power plant size (1-5MWe). Such analysis has been performed by using numerical simulations based on a well known thermofluid-dynamical code (TOUGH2®). Obtained results show that such geothermal exploitation generates a perturbation of temperature and pressure field which, however, is confined in a small volume around the well. At shallow level (0-100m) the exploitation does not produce any appreciable disturbance, and can be made compatible with local spa industry, which is the main business of the island. Such results are crucial for the general assessment of geothermal resource sustainability.

Key Words: *geothermal plants, Ischia Island, sustainable energy*

1. INTRODUCTION

The active volcanic island of Ischia has been the site of many hydrogeological, volcanological and geothermal studies since the early XVI century, which provided important data on volcano dynamics and tectonics [1]. The presence of a shallow magma body beneath the island, whose top is located at a depth of about 2km, produced a well developed geothermal system, whit many surface manifestation (fumaroles and hot springs). These features pushed the SAFEN Company to investigate the geothermal system of the island for geothermal exploitation aimed to electric production, since 1939 [2]. The data obtained by the SAFEN researchers highlighted that a large amount of the potential resource is related to vapor dominated systems and that useful temperatures for electric production can be generally found just few hundreds meters below the sea level. In 1950 a 300 kW binary cycle plant, the first one of this kind worldwide, was installed in the Island, on the Forio beach. The endeavor was abandoned later due to practical problems related to incrustations and corrosion, which the adopted technology at that old time was not able to solve [1]. At the present, the geothermal resource is used just for baths and wellness, with more than 180 spa and 130 thermal pools, fed by about 200 shallow wells, and in some cases for house heating. In recent times the interest towards the geothermal-electric exploitation at Ischia is largely increasing, since a number of exploitation leases has been submitted to the Ministry for Economic Development of Italy. In order to understand the possible effect of geothermal fluids extraction, for electric production, on the shallow hydrothermal system of the island, which is exploited for spa industry of the island, we performed a numerical using TOUGH2®. We show that thermal and pressure perturbations, after 30 years of fluids withdrawal, does not affect significantly the shallow hydrothermal system.

2. THE GEOTHERMAL RESERVOIR OF ISCHIA ISLAND

The geothermal system of Ischia Island can be defined from a semi-quantitative point of view by using the literature data [1-2]. The main features of the Ischia geothermal system are accordingly summarized here. The average temperature gradient involves the onset of water critical condition

(374°C, 22MPa) at a maximum depth of about 2km, very close to the top of the cooling magma source. The high average temperature gradient (~180°-220°Ckm^{-1}), which is recorded in the western and southern sector of the island, generates a quickly decreasing of permeability (k), above 370°C [3], thus the expected value of *k* is lower (or equal) than 10^{-17}m^2 below the brittle-ductile transition, which occurred at about 2km of depth. The permeability from about 150m to about 800m, is calibrated on the temperature-depth curves and is of the order of 10^{-15}m^2 [1] which promotes the advection of fluids. Above this layer, a less permeable zone of pyroclastic deposits occurs, whose permeability is probably about 10^{-16}m^2. It should be noted that minimum permeability of magma chamber wall rocks for volatiles escaping is 10^{-20}m^2 to 10^{-18}m^2, while above value of 10^{-16}m^2 advection processes can occur causing fluid mass transfer [3]. Both drilling and geochemical data, provided for the western and south-western sector of the island, allow us to obtain a fairly reliable picture of the geothermal reservoir in this sector. A first shallow geothermal reservoir is located from 150m to at least 500m, with temperature between 150°C and 200°C and pressure of about 4MPa (40bar). A second and deeper reservoir is hypothesized at depth > 900m, with temperature of 270°C to 300°C and pressure of 9MPa (90 bar) [4]. The latter is not well constrained, due to the lack of drilling data, whose maximum depth is about 1000m. The aquifer in the eastern sector of the island is probably deeper than in the western one, and also the isotherms sunk of few hundreds of meters. The depth and the fluid circulation of the geothermal reservoirs are also controlled by the volcano-tectonic of the area. The shallow reservoirs are influenced by the sea and rain water contamination, as testified by the large increase of TDS from the center of the island towards the coast. Isotopic data, actually, show that the main source of H_2O is meteoric water, while the magmatic source supplies most of CO_2 and He. The rising of the deeper geothermal reservoir, which was just inferred from geochemical analysis of gases and thermal waters, is, of course, most enriched in magmatic gases and vapor phases. Periodically, the deeper aquifer can reach the condition for separation of the vapor phase, which rises up along the fracture and faulting of the island[4]. It is also likely that the most of the geothermal reservoir has been developed within the fractured trachitic lavas and welded tuffs, which have a high relative permeability.

3. RESULTS OF NUMERICAL MODELING

The evaluations reported in the previous sections allow us to obtain useful constrains to estimate the thermodynamic effects of fluids withdrawal from geothermal reservoir and reinjection, during production phases. To this aim the numerical code TOUGH2® has been used for numerical evaluations of Temperature and Pressure changes due to geothermal exploitation via a finite Volumes resolution of Mass and Energy balance equations in a region of space, discretized in a mesh grid. The reservoir has been modeled as a porous and fractured medium characterized by volume V=18 km^3, porosity ϕ=0.2 and average rock density ρ=2400kgm^{-3} . A saturated two-phases mixture of water and vapor flows in this interior, due to the fixed porosity, with fluid maintaining thermal equilibrium with surrounding rocks matrix. The simulation takes into account the fluid density variation with temperature. The thermal gradient is comparable with the one experimentally measured and reaches a T=320°C temperature at a depth of 2km; the thermal conductivity is fixed 2.1 Wm^{-1}K^{-1} (the average of upper and lower values generally used in literature) and the pressure gradient is essentially hydrostatic. The considered volume for the simulation is formed by a surface thick layer of 150m with permeability k =10^{-16}m^2, where the temperature gradient is roughly purely conductive; an intermediate layer, from 150m to 800m, characterized by permeability k=10^{-15}m^2, which represents the advection dominated zone and a deeper layer, below 800m, with k=10^{-18}m^2, where the thermal regime is conductive again. The first case simulates the extraction of fluid from a 600m deep well, with flow rate of 22kgs^{-1}, and temperature at well head of about 150°C (it is assumed a production of about 1-2 MWe for each well). The temperature and flow rate data are those related to SAFEN productive test [2]. In such a way, we are firstly simulating a productive well without re-injection. Our simulation ends as soon as the system becomes steady, i.e. when changes of temperature and pressure fields do not occur anymore; we noted that after about 30 years of fluid withdrawal, the system reaches a roughly steady state. Figure 1 reports temperature changes, indicating that the maximum cooling effects (-6°C) on fluid occur in correspondence to the shallower permeability contrast, over a volume of about 0.02km^3, centred at the vertical well axis. A loss of pressure (less then 10bar) is observed in the whole shallow reservoir, up to a distance of 2km from the well. A more depressurized zone, up to a value of -30bar (3MPa) appears confined within a conic-shaped volume around the well, with radius of 150m, centered at 600m of depth.

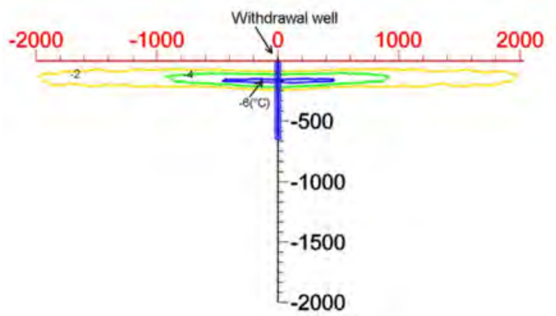

FIGURE 1. Maximum temperature variation after 30 years of heat withdrawal which indicates that maximum cooling effect occurs in correspondence to the shallower permeability contrast.

In a second simulated case a reinjection well, again 600m deep, is also introduced at a distance of 650m from the productive one. Water extracted from the productive well at T=150°C is re-injected with a flow rate of 22kgs^{-1} and a temperature of 90°C. After 30 years of a similar production-reinjection cycle, a substantial thermal perturbation around the reinjection well appears, due to the effect of cooled water on the rocks, resulting in a temperature decrease of more than -35°C (Figure 2). This effect is evidently confined around the bottom of the reinjection well, very close to the well axis (within a ray of 30m the maximum temperature drop is about -50°C). As the distance from the well increases the thermal perturbation decreases, and vanishes at distance of about 300m. Around the productive well, the temperature variation is lower than, and is just of few Celsius degrees. Around the reinjection well, as said before, the effect of cooled water create a strong thermal gradient. Anyway, no significant temperature variations, with respect to the initial conditions, appear close to the surface, where thermal springs are confined. Regarding the pressure changes, the production-reinjection cycle generates a pressure drop of the geothermal system in a roughly spherical volume at the bottom of productive well and a pressure increase at the bottom of the reinjection well. ΔP larger than 2MPa and smaller than -2.5MPa, for injection and production respectively, occurred into a volume of $1.7 \cdot 10^7$m^3 for each well. In general, the pressure drop associated with the fluids withdrawal, can induce a decreasing of hot springs occurrence at the surface, particularly when the geothermal system is water dominated. This effect is mitigated by the presence of reinjection wells, which guarantee the water recharge of the system. The drop of pressure, otherwise, can cause also consistent increment of vapor infusion from vapor dominated zones, towards the surface, which is due to the increment of vapor saturation and mobility [4]. This process, which is considered in our analysis as a part of complex thermo-dynamic processes occurring during fluid withdrawal, produces a slight increment of temperature in the infusion zone due to vapor latent heat releasing. Furthermore, since the drop of pressure is confined around the axis of the well, a slight decrease of water table is expected to occur just in the proximity of the well, while its effect becomes negligible as the distance increases in respect to the perturbation centre. It is important to consider here how the thermodynamic system, during heat extraction, behaves to the variation of fundamental parameters, such as thermal conductivity (λ) and permeability (k). These parameters are in fact not univocally defined, so that their possible variation ranges have to be considered. In order to get a more reliable picture of the sustainability, a sensitivity study of the system has been done by varying λ and k in the possible range of values inferred from literature and from this study, and observing the response of the system. We considered the upper and lower limit of the values range of λ (1.5 to 2.7 Wm-1K-1) and spanned the permeability of the reservoir (advective zone) over an order of magnitude, considering the limit values of $5\cdot10^{-15}m^2$ and $5\cdot10^{-16}m^2$ respectively. The results show that the system is low sensitive to variation of thermal conductivity (no appreciable variations occur) and is more sensitive to the variation of the permeability in terms of temperature and pressure field change. The maximum variation of temperature and pressure, for the above values of thermal conductivity is $\Delta T\sim1.5K$ and $\Delta P\sim1bar$. On the other hand, permeability variation produces a significant drop of pressure and only a minor decrease of temperature (this simulation was performed fixing the average value of $\lambda = 2.1$ $Wm^{-1}K^{-1}$.

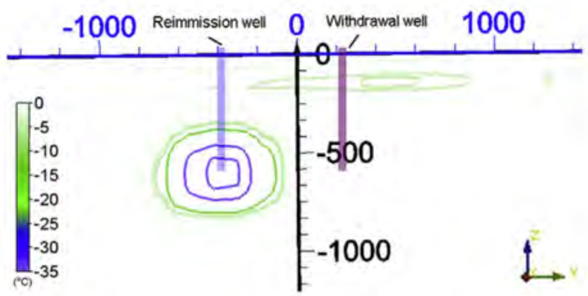

FIGURE 2. Thermal perturbation around the withdrawal and reinjection well after 30 years of fluid extraction. Around the productive well, the temperature variation is negligible. Around the reinjection well the effect of cooled water creates a strong thermal gradient. The effect of cooled water on the rocks results in a temperature variation up to 35 °C. This effect is confined around the bottom of the reinjection well.

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