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USE OF ENVIRONMENTAL ISOTOPES AS NATURAL TRACERS IN A REINJECTION EXPERIMENT AT LARDERELLO

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Abstract Reinjection of the discharge from the power-plants of a geothermal field can cause serious, irreversible damage to the field itself, so that such operations must be mnitored continuously. Tracer techniques are particularly useful for this purpose.

In some reinjection studies tritiated water was used as a tracer, but this methcd has certain disadvantages as well as advantages, one disadvantage being the destruction of the natural tritium balance in the reservoir.

The natural abundances of tritium at Larderello were, and are still, used to study field recharge from meteoric waters, so that another tracing methcd had to be applied to avoid disrupting these studies. The discharge fluid from the power-stations is traced naturally by its ^{18}O and D compositions with respect to the steam ccmposition of the field. As these isotopes do not create the same difficulties as tritium we are checking their possible utilization as tracers.

This paper presents the results obtained by applying this method in the first phase of a reinjection experiment now under way in a central area of the field which has been exploited for long periods. Some limits of this method are also discussed.

Introduction Because of the limited natural recharge of the Larderello geothermal field (Petracco and Squarci, 1975), the decision was taken to study the possibility of recharging it artificially by reinjecting the waste from the geothermoelectric pier-plants back underground in some suitable points of the field itself. This procedure would also solve the problem of getting rid of these effluents whose ccmposition is such that they cannot be discharged into the runoff waters or the shallow aquifers.

In a vapour-dominated field such as that of Larderello, with a heterogeneous reservoir and fracture-derived permeability, one cannot predict with any certainty the effects induced by reinjection. For example, one could expect a decrease in steam enthalpy and/or in the amount of steam produced. In order to avoid eventual irreversible negative effects to the field some experiments must be made prior to launching a full-scale reinjection programme.

These experiments will provide useful information on the complex phenomenology of vapour-dominated systems only if the tools used are adequate.

In this respect the tracer tests assume a role of considerable importance, as they can provide informtion on the processes occurring in the reservoir and on eventual modifications to these processes; they can also be used to calculate the mount of injected water reappearing as steam in the fluids produced and individuate any preferential pathways of the fluids

The problem is to find a routine work method that creates as little disturbance as possible to the system, but which also produces the maximum of data.

In the reinjection tests currently being conducted in a central area of the Larderello field, which has been exploited for the past 20-odd years, a study is being made of the potential of the stable isotopes ^{18}O and D as tracers.

The reasons for undertaking a reinjection programme at Larderello, the problems connected with this programme and the results from the engineering viewpoint are described in a paper by Giovannoni et al. (1981).

Enviromtal isotopes as natural tracers In some geothermal fields tritiated water has been used as a tracer in reinjection studies, as in The Geysers (Gulati et al., 1978) and at

Ahuachapan (Einarsson et al.,1975). As outlined by Gulati et al., this method has its negative as well as positive aspects. Among the former are the fact that the method requires expensive and time-consuming enrichment analyses and that its application destroys the natural tritium balance in the reservoir.

The natural tritium abundance at Larderello has been, and is still, used in studies of field recharge by meteoric waters (Panichi et al.,1974,1978). Another tracer method had thus to be adopted to avoid compromising these studies.

Environmental tracers have, on the other hand, been used for some time now in geological studies in merit of their being natural tracers.

The isotopic abundances of **oxygen-18** and deuterium in the waters have helped to solve m y hydrogeological problems. Problems m r e closely tied to an exploited geothermal field have also been investigated by means of the stable isotopes. During recent years especially, some interesting conclusions have been reached on subjects such as deep temperatures, physical state of the water and origin of some components of the geothermal fluid (Noto et al., 1979; Panichi et al.,1979; Nuti et al.,1980).

In the reinjection experiment now under way at Larderello, in an area with high temperatures and pressures of about 5 ata, the steam from the mnitored productive wells had a composition ranging between -1.5 and -3 in $\delta^{18}O$ and -37 to -42 in δD. All the δ values given in this paper refer to differences permil fran VIENNA-SMOW, the international isotope standard for waters defined by the International Atomic Energy Agency of Vienna (Gonfiantini, 1978).

After leaving the turbines the steam is condensed, and the condensed water passes to the cooling towers where a considerable fraction is lost to the atmosphere in the form of vapour. Because of this process the residual water is greatly enriched in the heavy isotopes **oxygen-18** and deuterium. Throughout the experiment the isotopic ccmposition of the injected water was in fact m r e or less constant with respect to $\delta^{18}O$ and δD, both being near to a value of +5, and far from the value of the "undisturbed" wells. So the discharge water is traced naturally by its stable isotopic canposition and no artificial or radioactive tracers need be added to the system, avoiding all the negative effects this type of interference entails, including those to the environment. The only disturbance i s thus that brought on by reinjection itself.

The sampling and analysis techniques can be carried out as routine field operations, which are *easy* to apply and cheaper than tritium masurements.

Moreover, this method, as opposed to the pulse techniques, permits us to mnitor the system systematically throughout the reinjection test, so that we can immediately obtain information on any variations underqone by processes occurring in the reservoir. Theoretically some negative aspects could exist in this method. There could be an isotopic exchange between the water and the rocks, but this phenomenon, if it did take place, would affect the oxygen only. **Again**, an isotopic re-equilibration could take place between the water and gas species, but this is a theoretical possibility only, as the latter represents only 2.8 m les percent of the geothermal fluid at Larderello and could, therefore, have little effect on the isotopic ccmposition of the water. Furthermore, 90% of the gas is CO_2, *so* that the hydrogen would, again, be unaffected.

The last, and most serious, negative aspect is the possibility of an isotopic fractionation of the water during phase change.

Results of the tracing experiment   The injection well chosen for the experiment, W0, lies in a central area of the field, where exploitation has been under way for m r e than 20 years but temperatures have remained high (more than 240°C in the reservoir).

The monitored wells are distributed all round well W0, at distances of 150 to m r e than 700 metres (Fig.1). The isotopic composition of the steam produced by the wells in this zone is nearly uniform, so that it would be only sliqhtly affected by any chanqe in the original fluid flow pattern ensuing frcm reinjection.

In the first phase of this experiment a total of 30-35 m^3/h of water was injected for about 3 mnths, 105 m^3/h for about 20 days and 50 m^3/h for another 3 months.

After iiijection began the isotopic composition of the fluid in the mnitored wells shifted towards the positive values of the reinjected water, and began decreasing when reinjection was reduced to 50 m^3/h.

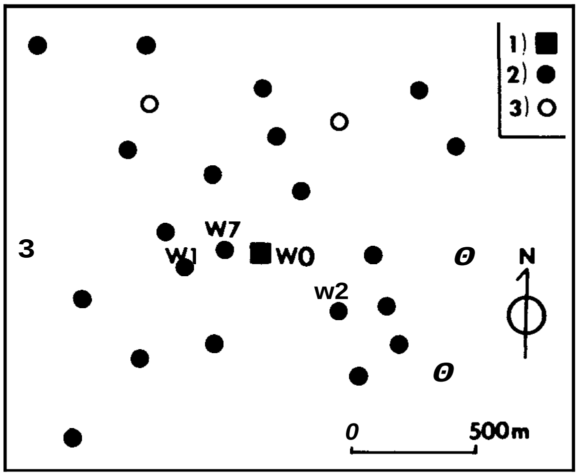


Figure 1 Location of the wells in the area west of Larderello affected by the reinjection test. 1) reinjection well; 2) production wells; 3) shut-in wells.

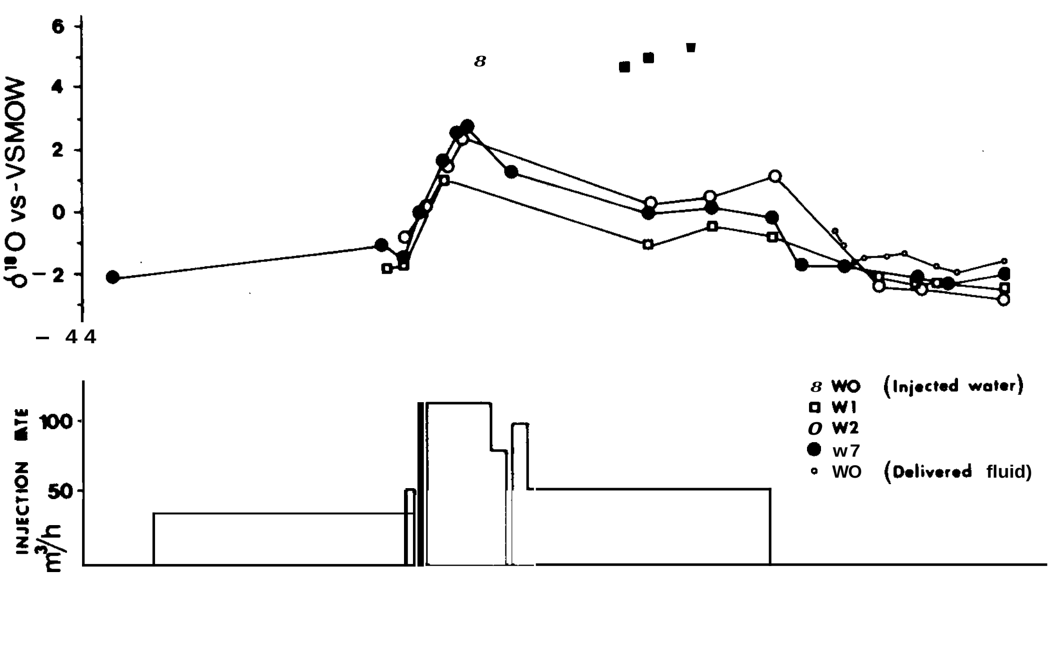
Once the test ended the canposition returned to its earlier "undisturbed" values, while well WO **started** producing steam whose isotopic composition was slightly more positive than that of the nearby wells (Fig.2). The deuterium showed the same behaviour as the oxygen-18. This alone shows that at least part of the injected water vaporizes and that this steam joins the fluid produced by the surrounding wells.

Figure 3 shows the trend of the isotopic composition of the fluids produced in wells W2 and W7 during **this phase** of reinjection, in a δD-$\delta^{18}O$ diagram. The **high** linear correlation coefficients and the position of the points along straight lines joining the "undisturbed" canposition of the wells to that of the reinjected water suggest that a simple mixing process has taken place, with no disturbing phenomena related to isotopic exchange or fractionation. The fact that no isotopic fractionation has occurred suggests that the vaporization process does not produce two phases but a steam **phase** only, i.e., every portion of the injected water participating in the boiling process is completely vaporized.

In these conditions the m u n t of injected water returning in the fluid produced by the wells can be calculated by the following balance equation:

$G_I = G_{WH} (\delta_{WH} - \delta_R / \delta_I - 6,)$, where G is the flaw-rate, I, WH and R are subscripts representing the fluid caning from injected water, fluid produced by the wells and original fluid respectively.

Figure 4 shows the the spatial distribution of the fraction of injected water versus the to-



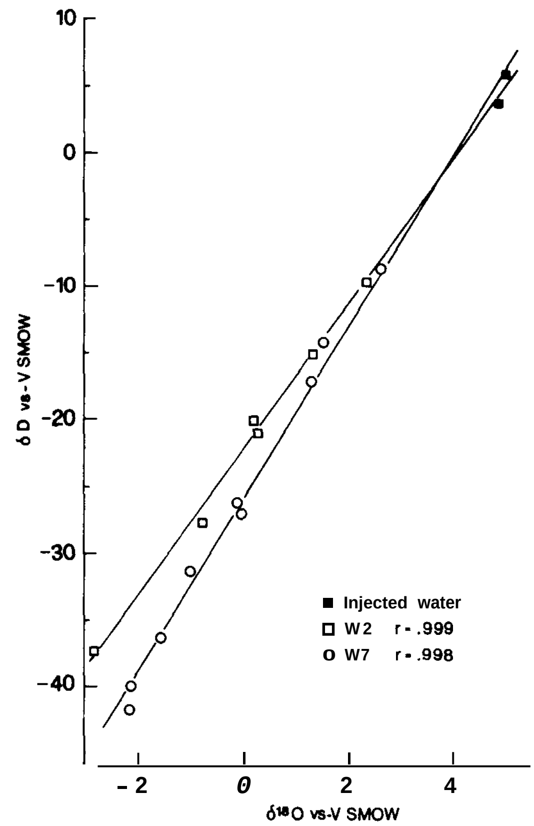


Figure **3** Variation in isotopic composition, in a $\delta D - \delta^{18}O$ diagram, of the condensate of the fluid produced by wells W2 and W7 during the reinjection test.

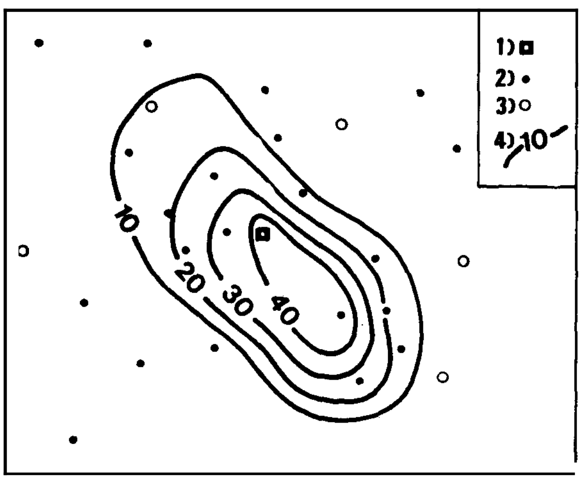


Figure **4** Contribution of injected water to production. 1),2) and 3) as in Fig.1; 4) percentage ratio of injected water recovered as steam to the total fluid produced by the wells.

tal fluid produced by the wells about **20** days before the test ended.

The fact that the wells most affected by reinjection lie *along* a NW-SE alignment, the lack of correlation between the distance from the reinjection well to the others and the contribution of reinjected water in their steam *show* that the injected water has found preferential pathways in the underground.

This consequently confirms that the reservoir cannot be compared to a homogeneous and isotropic porous medium.

In conclusion, artificial tracers are unnecessary in vapour-dominated fields with certain favourable conditions, as the stable isotopic composition of the reinjected water already acts as a natural tracer. By mnitoring the isotopic composition of the condensate of the productive wells in the area affected by reinjection we were able to ascertain that the injected water vaporizes and contributes to production, to calculate the amount of injected water re-entering the surrounding wells and to individuate the preferential pathways taken by this water in the underground.

In *our* opinion these results prove that tritium is not always the best tracer for reinjection studies **in** vapour-dominated geothermal systems.

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