REINJECTION STRATEGY

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ABSTRACT

Because of the complexity of underground conditions within a geothermal reservoir, reinjection is difficult to explain scientifically. Its ultimate purpose is usually for large-scale employment in a field developed and generating electrical energy; therefore, small-scale ad hoc experiments are remote from the final conditions envisaged. The reservoir up-flow of hot water from large discharges of numerous production wells cannot be duplicated except in existing fields such as Wairakei. Hence the argument presented here is that it is only at Wairakei that progressive tests are valid. But parallel tests on the undeveloped Broadlands field should be undertaken with reinjection into the reservoir with production and injection wells interchanged. The emphasis is on maximum scientific returns at minimum cost; otherwise, highly expensive investigations may lead to eventual abandonment of a project.

INTRODUCTION

It seems unlikely that any future geothermal power project will be built without reinjection being an integral part of the design. The United Nations demands it for schemes under study in the undeveloped countries, and no longer will separated well water be discharged into rivers, as at Wairakei, or even into large evaporation ponds, as at Cerro Prieto.

Two projects have used reinjection for some years: the 90 MW(e) station at Ahuachapan, El Salvador, and the 11 MW(e) station at Otake, Japan. For both cases, this was not a voluntary choice but a reluctant necessity. In the case of Ahuachapan, a canal to transport the effluent to the sea was behind schedule, and an alternative disposal method was urgently required. An approach similar to that undertaken at Broadlands--but preceding it by some years--was undertaken. A well drilled close to the geothermal field but ouside it was to be used for the first reinjection well. This penetrated to 1,500 m without permeability, and was abandoned; with some trepidation, a production well was successfully converted to reinjection. The injection water temperature was 153°C, and the flow 590 tons/hour, with the permeability of the well increasing a little since early 1972, according to Einarsson (1975).

At Otake, since early 1972, over 400 tons/hour have been injected into three wells within the reservoir, although one could take up to

600 tons/hour alone. It has been reported that deposition is taking place in these wells, and the disposal water temperature is about 100°C; however, it should be emphasized that the water is not transported under pressure, but is first liberated to the atmosphere within a so-called timing tank in an attempt to inhibit large-scale silica deposition. The purpose of the reinjection program was to halt declining output which, from 1970 to 1972, had fallen from 11 MW(e) to 8 MW(e). Under injection, the discharge increased to 9 MW(e) by 1975, Kubota and Aosaki (1975). To take advantage of the greater density of cooler injected fluid, reinjection wells in both fields were deeper than production wells, with minimum spacing of 300 m at Ahuachapan and 150 m at Otake.

STRATEGY

As a subject for study, reinjection experiments cannot easily be defined logically, and the subject is more within the province of statistics. This is because so little is known about the controlling conditions within the subterranean geothermal reservoir. Although a great many papers have been written and Stanford convenes an annual workshop on Geothermal Reservoir Engineering (of which this is the fifth), no one has yet been successful in predicting the principal parameters of pressure, temperature, and life of existing reservoirs. It is doubtful if reinjection will ease the scientists' predictive ability, such as it is.

There is probably only one way at present to determine if it is a viable proposition, and that is after full-scale operation for about 20 years in a production field. Anything less than this in size and time raises perennial questions about possible detrimental effects to production. Because we do not know the long-term effects and are not sure where the fluid is going and whether a little goes the same way as a lot, flowrate and time are obviously paramount.

If we assume that this view is correct, then the effective approach would be to take an operating project such as Wairakei and progressively extend reinjection while studying steam production. It is little use trying injection on a closed-in field such as Broadlands, where there is no large rate of draw-off, and hence no significant up-flow within the reservoir to retard down-flowing reinjected water. Undoubtedly, injection within the Broadlands reservoir would be immediately "successful," and perhaps so for decades, but would it continue to be so once the field is on full production? The advantage of the progressive approach recommended here is that tracer and other techniques can be used and developed, and feedback data obtained which can gradually increase knowledge of where and when fluid goes. Using different well spacing and different depths of injection in various parts of the field (by employing existing wells), a pattern of the fluid movements should slowly emerge. As the system is heavily buffered in both the chemical and physical senses, rapid changes are not to be expected. Hence there is no requirement to apply catastrophic theory to such a developing reinjection program.

Having given the ideal--and possibly correct--method of studying "power project" injection as opposed to small-scale adhocacy, we are faced with the real-life practical problem of deciding roughly where we should inject in a field such as Broadlands before it is on production. First of all, everyone involved in studying this problem should develop his skeptical faculties to the maximum and distrust all assumptions, or at the very least, question these closely for supportive evidence.

Analogously, if we require five equations to solve a particular problem and one is missing, we probably will get a completely wrong answer, which is worse than no answer at all. Hence it may be that, unless we understand fully the underground system, we may come up with answers which can be expensively wrong and may even lead to the abandonment of a project.

The general truth of these remarks is, I think, shown by the various arguments which have prevailed at geothermal meetings about the best location of reinjection wells. Inside the reservoir or outside? Peripheral or central, shallow or deep? Perhaps, if we do not with confidence know the answers to these questions, we should use Occam's razor to cut the Gordian knot of complexity (to employ some mixed literary metaphors), as follows. Unable to grade the problem technically, we instead grade it economically. By this means we obtain an "order of merit." We then tackle it experimentally, taking the most attractive economic version first. If this fails, we take the second, and so on down the line of merit. This is a better approach than letting the tail wag the dog and making some wild guesses on which is the best technically.

For reinjection, the order of merit economically is self evident, being: (1) drilling shallow centrally within the field; (2) drilling deep within the field (below the level of production wells); (3) drilling shallow at the field periphery, but within the reservoir; (4) drilling deep at the field periphery, but within the reservoir; (5) drilling outside the field, shallow; and (6) drilling outside the field, deep.

It is ironical that the starting point in El Salvador was point (6), with a depth to 1,500 m without finding permeability. Also at Broadlands, after some initial in-field testing, a deep well for reinjection is being drilled and has attained a depth of 2,200 m by now (20 April 1979), without finding acceptable permeability. This well (BR34) is located outside the field.

Let us make a few questionable assumptions to "technically" support the economic order of merit given. We can start by regarding a hot water reservoir as heated from below so that cold water comes in horizontally and hot water moves up vertically, seeking and flooding an existing permeable zone, or even forming one by dissolving rock. The surrounding cold water zone is comparatively impermeable. If it were not, it would also fill with hot water. Hence the difficulty in finding suitable injection wells outside the reservoir.

As the whole system depends on density differences to function, a corollary is that, for cool water injection into a hot water reservoir, a reinjection well must be extremely permeable, and is, in fact, interchangeable with a powerful production well. The old idea of relegating a poor production well to duty as a possible reinjection well should be discarded. It is worth noting that quenching powerful production wells is not easy, and the cold water used disappears from the bottom of the hole very rapidly, so that hot bore water discharges within minutes (or even seconds), even after hours of injecting fresh water at 600 GPM.

Taking this into account, one can assume that point (1) should be the start of the reinjection experimental program, and, in fact, if the flow down Wairakei well 107 is true (estimated at about 200 tons/hour of water at 150°C), then over 3 million tons has entered the reservoir at the center of production without apparent detrimental effect over the last two years.

A very permeable reinjection well would also reduce the effects of mineral deposition from the down-flowing cooler fluid, although it should be noted that in both El Salvador and Broadlands, injection into the reservoir has led arguably to increase in permeability with the former well using water at 153°C and the latter at 105°C.

Contrarywise, injecting hot water into a cool reservoir, as at reinjection well BR34, has led to a decrease in permeability. It would be hard to think of a worse kind of test than the BR34 tests, because not only were they outside the reservoir, but they completely ignored the use of density currents. In injecting hot water at 94°C into underground water at 60°C, they ensured that the input water spread out, not down. And for the paucity of useful data obtained, the cost has been very high indeed. Reducing permeability has led to deepening the well; the total cost of the experiment thus far probably approaches 0.5 million dollars. In the worsening financial climate, greater emphasis should be given to the economic ramifications of field testing to derive maximum scientific results from minimum costs. The progressive testing program suggested for Wairakei would have a moderate cost spread over the years; however, there may be some difficulty in overcoming the innate cautious conservatism of the Electricity Department to cooperate on this venture.

For Broadlands, some production wells can be used for reinjection. Later on, the situation should be reversed so that injection wells become producers, and vice versa. Only one separator would be required between two such wells, with a versatile piping arrangement to give flow reversal. As has been pointed out, it is not possible to obtain satisfactory results in a complete sense on this field which can be used confidently to predict power production. However, coupled with results from the recommended Wairakei program, we shall certainly be stronger in understanding these systems and in our ability to apply this to full-scale projects.

In a paper on well spacing (James, 1975), it was found that at a distance of only 50 m from a production well, the pressure gradient due to flow was extremely small; but is far less than the gradient due to the density of a cold water intrusion into a hot water reservoir. Hence the argument that injection fluid should be liberated below the level of the production wells. Because of the viscosity differences between the reservoir water and the injection water, there is also a tendency for production wells to draw only the hot water and ignore the cooler. Taking these various aspects into account, one comes to the conclusion that the larger the temperature difference between the reservoir water and that injected, the better. In a production field, the bottom limit of injection fluid is about 100°C, where a double flash system is employed. This should be accepted unless the tests now underway demonstrate that a higher temperature of injection water is necessary to inhibit silica deposition.

Finally, it may be mentioned that efficient testing of a reinjection well might entail drilling eighteen wells at different radii and depths to successfully monitor the flow and reduce ambiguities. This shows the complexity involved.

CONCLUSIONS

Perhaps two laws on reinjection can be formulated, as follows:

1. Production wells and injection wells are interchangeable.

2. Maximize the temperature difference between injection water and the hotter reservoir water, commensurate with taking mineral deposition into account.

Although one is tempted to give a third low regarding the desirability of injection below the level of the production wells, this is uncertain and has to be demonstrated.

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