REINJECTION EXPERIENCE IN THE PHILIPPINES

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ABSTRACT

Reinjection trials have assisted with the environmentally acceptable disposal of geothermal brine during testing of the Tongonan and Palimpinon fields as well as determining the effects of fluid injection on wells and reservoirs. Well parameters were measured to provide baseline data and well performance has been monitored at appropriate intervals. The performance of injection wells has generally been encouraging with an increase in injectivity as injection has proceeded. In the few trials where a decrease in injectivity has occurred, it has been associated with an interruption to reinjection. This phenomenon is under continuing investigation. Tracer tests have been used to track subsurface fluid movement and the results have indicated rapid communication between injection and production wells although tracer returns have been small. Reinjection testing continues and the accumulation of experience will be expanded substantially by the imminent commissioning of the Leyte I and Palimpinon I power stations.

INTRODUCTION

The disposal of geothermal brine resulting from the exploitation of water-dominated geothermal resources is an area of continuing concern and experimentation in several parts of the world. At the Wairakei field in New Zealand, one of the earliest water-dominated fields developed for large-scale power generation, the waste brine is released into the nearby Waikato River. The same river is also used as the heat sink for the turbine condensors.

The Ohaaki field, downstream of Wairakei, is now under development for power generation. Disposal of neither waste brine nor waste heat to the river is anticipated for this development and brine disposal by reinjection is being investigated (MWD, 1977).

The Ahuachapan geothermal development in El Salvador has successfully used reinjection for brine disposal since 1975 following extensive trials beginning in 1970. The El Salvadorean approach has been to reinject the waste brine immediately after steam separation. The injection wells are adjacent to producing sections of the field and tracer returns have been detected in some producing wells within a few hours of release.

In Japan all five fields developed for power generation are based on water-dominated reservoirs and all use total waste brine reinjection (Horne, 1981).

Japanese experience with reinjection has not been entirely successful, but the variety of approaches to the problem has resulted in the accumulation of considerable reinjection experience.

Brine reinjection is used in the Philippines at the Makiling-Banahaw field and is under consideration for the Tiwi field. A firm commitment to reinjection has been made in the field development strategies at both the Tongonan and Palimpinon geothermal resources.

The Tongonan field is in central Leyte, an island in the Visayan region of the Philippines. The surface streams supplying the Bao River are small and provide water for irrigation (largely rice crops), domestic stock and fish. The Bao River empties into Ormoc Bay through an estuarine area of considerable importance to the region, particularly the nearby city of Ormoc.

The average composition of the Tongonan reservoir fluid is shown in Table 1. Of particular significance from an environmental viewpoint are the concentrations of arsenic (As) and boron (B) although the level of lithium (Li) is also of concern as a potential risk to public health. Many crops including several strains of rice are particularly susceptible to boron toxicity and arsenic has the propensity to concentrate to toxic levels through the animal food chain (KRTA, 1979).

In an early study of power station feasibility (KRTA, 1978) a combination of pipeline and open channel was investigated to transport the waste brine to the sea. The hydrology of Ormoc Bay was studied in sufficient detail to determine the most appropriate discharge points and to calculate anticipated chemical concentrations in the bay.

Apart from the disposal of environmentally damaging heat and chemicals the potential additional benefits of reinjection are largely related to the maintenance of reservoir pressures and enthalpies by hot water recharge. These arguments, with a detailed analysis of mass and energy flows, are presented by Einarsson et al. (1975) and will not be repeated here. Reinjection was adopted as the most economic and environmentally acceptable waste

Table 1: Reservoir Geochemistry of Tongonan and Palimpinon Fields

Field/Sector	Weighted Enthalpy (kJ/kg) at FBD	pH	Li	Na	K	Rb	Cs	Ca	Mg	Cl	B	SO4	SiO_2	As	NH3	HCO_3
			(ppm) at Reservoir Conditions													
Upper Mahiao	1721	4.2-6.9	18.1	4764	1238	6.0	2.3	128	2.20	8929	205	82.0	637	18.1	-	21.1
Mahiao/ Sambaloran	1605	5.8-7.1	18.3	4313	1218	6.2	2.3	119	0.20	8164	157	24.0	641	16.5	-	19.6
Malitbog	1254	-5.8	12.9	3096	758	4.4	1.9	181	0.10	5646	94	26.5	576	7.4	2.9	13.4
Puhagan	1361	≈6.7	9.4	2115	431	2.6	2.0	68	0.50	3834	46	60.3	550	-	-	23.5

disposal option and trials were planned to obtain operational reinjection experience and to determine the effects of waste brine reinjection on the reservoir.

Simple calculations of reservoir volume required for long-term reinjection have been revised and updated as additional information on reinjection volumes and reservoir parameters became available. These calculations are intended to be nothing more than an attempt to visualise the reservoir volume requirements for brine disposal and do not propose or imply any thermodynamic or hydrological mechanisms within the reservoir.

At a current mean field enthalpy of 1460 kJ/kg the quantity of waste brine for reinjection, at a rated station output of 75 MWe, would be around 260 kg/s. A potential reservoir volume for brine disposal was calculated on the basis of an area of 0.63 km^2 delineated by reinjection wells 1R3, 1R4, 1R5, 2R2, 2R3 and 2R4. This area corresponds to approximately 15% of the areal extent of the Tongonan field allocated to the Leyte I development. A vertical interval was determined by formation permeability encountered between -400 m and -1500 m MSL. Using a formation porosity of 0.1 the time taken to fill this reservoir volume with waste brine is approximately eight years.

REINJECTION TESTS

The reinjection tests conducted or still underway in the Tongonan and Palimpinon geothermal fields are sumnarised below. Most of the tests have been planned using high temperature fluid from separators operating at pressures ranging from 0.6 to 1.0 MPa resulting from the requirements of small back-pressure turbines already operating in the fields or corresponding to the design pressures of the fluid collection systems for power stations now approaching completion.

Upper Mahiao Reinjection Test at 4R1

Well 4R1, originally labelled TGE-10, was a shallow well drilled to a depth of 590 m to test the low resistivity anomaly at the northern end of the Mahiao Valley. The well was completed in April 1976 and was successful in confirming the existence of a high temperature resource although poor permeability prevented the well from sustaining a discharge. A deep exploration well, 401, was drilled 250 m to the east of 4R1 and was completed in January 1977 to a depth of 1942 m. A maximum temperature at 324°C was measured at hole bottom and the discharge was equivalent to an electrical output of greater than 9 MWe.

A 3 MWe back-pressure turbo-alternator was available and within six months well 401 was supplying steam for power generation and the separated waste brine was being discharged into a cooling pond for subsequent disposal into the Mahiao River. Drilling and testing of further delineation and production wells continued and it was soon apparent that environmental considerations would impede the rate and extent of well output testing unless an alternative could be found to river disposal of the waste brine. One solution, prompted by the proximity and relative elevations of the wells, was to reinject the waste fluid directly from the 401 separator into 4R1. A waste water line was constructed and reinjection began in February 1978; reinjection has continued with minimal disruption since that time at flowrates ranging from about 3-22 kg/s. (Dobbie and Menzies, 1979).

Waste brine was taken from the separator outlet at a temperature of around 180% and reinjected directly to minimise the likelihood of silica deposition. The injectivity of well 4R1 was measured at 2.3 l/s MPa during completion testing but it is anticipated that the injectivity would have increased somewhat on discharging the well.

Injectivity during the early stages of brine disposal was measured at 5 l/s MPa and increased to a level of approximately 13 l/s MPa by the end of 1981. Early 1982 saw the first indication of decline in injectivity which by July 1982 had fallen to a level of 6 l/s MPa. The reason for this decline in injectivity is the subject of a continuing investigation.

Tracer Testing

A tracer test was conducted on well 4R1 by the Philippine Atomic Energy Commission (PAEC) on 21 June 1981. A modified Klyen sampler was used to release 0.64 Curies of 1-131 into well 4R1 while it was accepting waste brine from 401, 404 and 108, although the flow from 108 was bypassed to its silencer on 22 June due to flooding of the separator.

The three producing wells 401, 404 and 108, separated from 4R1 by horizontal distances of around

310, 250 and 90 m respectively, were sampled regularly as were the Kapakuhan hot springs. Tracer returns were detected in samples taken from the producing wells within seven hours of tracer release confirming a suspected communication and providing a possible explanation for the observed enthalpy decline in both 401 and **404.** Tracer returns were not anticipated from the Kapakuhan hot springs as these are steam heated waters and the radio-tracer was in a non-volatile form. PAEC reported "a very low concentration of Iodine" from these springs.

Low Temperature Reinjection Experiment at Well 105

Choice of turbines and turbine operating conditions for geothermal fields is strongly influenced by field pressures and the characteristics of the produced fluid. Although steam for the 112.5 MW(e) Leyte I station will be supplied at a single pressure it has been recognized that the fluid characteristics of other Tongonan field sectors and other Philippine fields may differ sufficiently to warrant dual pressure operation for possible future development.

Separation of geothermal fluids at lower pressures implies a lower temperature for the rejected water and as such an increased risk of silica deposition in pipework and injection wells. Although reinjection at relatively high temperatures has been practiced in several countries with mixed success there is a paucity of information concerning experiments at lower temperatures. A series of experiments was therefore carried out at the Tongonan geothermal field over the period October 1979 to April 1980 to investigate the feasibility of reinjection at 'low' temperatures.

Construction activity limited the choice of suitable wells and those chosen, 101, 102, 103 and 105 all lie along the Mahiao Valley towards the assessed western margin of the field. The separated injection well 105 was completed to a depth of 1796 m and cased to 613 m. Maximum measured temperature and injectivity prior to injection were 318°C and 76 l/s MPa respectively. Production has been identified from zones at 800-1070 m and 1600-1700 m. Drilled depths of the producer wells range from 1402 to 1796 m and maximum measured temperatures from 312°C to 317°C.

Experiments were carried out at two flowrates. Initially separated water at approximately 115°C was fed from a single well, 101 at a rate of approximately 9 kg/s but this was later increased some four-fold by the addition of fluid from wells 102 and 103. Total mass injected during the experimental period was approximately 2.51×10^5 t. The experiments met with intermittent success. Injection failed twice and on both occasions was due to a decline in injectivity of bore 105. Results obtained for downhole scraper surveys confirmed that failure was caused by the exsolution of silica. The loss of injectivity was not permanent however, and well performance was rapidly regained during subsequent discharges.

Less apparent however, was the cause of the amorphous silica gel and deposits. A possible explanation is suggested by the pattern of results and corresponding operating conditions.

The decline in injectivity on both occasions followed a quench after a successful period of injection. Consideration of downhole temperatures at the assessed depth of silica precipitation and silica concentration of the supersaturated water implied that the saturation ratio of the injected water, (the ratio of its concentration in solution to the equilibrium concentration) was close to 2 a condition which Harvey et al. (1976) and Midkiff and Foyt (1976, 1977) suggested may lead to massive precipitation of silica. Experimental results of Weres et al. (1979) suggest that such precipitation may not be immediate but instead take place after a period of time the length of which is considered to depend upon the degree of supersaturation. During injection, highly supersaturated fluid would be swept away from the bore and diluted by hotter reservoir fluid. Interruption to the flow of fluid would lead to slower mixing and although some fall in the degree of supersaturation could be expected as the well temperatures recovered, available evidence suggests that the rise in well temperature one day after injection would have been relatively small. Furthermore, delays to reinjection of seven and nineteen hours were considerably longer than the one hour induction period for silica precipitation suggested by Weres et al. (1979) for 100°C fluid with a silica saturation ratio of about 2 and pH of 7. An additional factor was the cold river water used to quench the bore. Although some dilution would have occurred it is conceivable that the resulting fall in temperature of the bore fluids was sufficient to raise the saturation ratio still further. There is also some evidence to suggest that the amount of silica scale formed is increased in the presence of oxygen. (Rothbaum et al. 1979). This condition would no doubt have been met during the repeated quenching of well 105.

Reinjection Trial at Well 2R2

Well 2R2 was drilled in March 1979 as the first dedicated reinjection well for the Sambaloran sector of the Leyte I fluid collection system. The well was drilled vertically to a depth of 1532 m and satisfactory disposal well characteristics were indicated with an initial injectivity of 44 l/s MPa and an equivalent power potential of nearly 7 MWe on production test.

During an output test of nearly sixty days the enthalpy increased to around 1800 kJ/kg and following this test the injectivity was found to have increased to around 100 l/s MPa, a very substantial improvement.

The urgent need for reinjection well testing was coupled with an equally urgent need for a sector output test to determine the longer term performance and interaction of a group of discharging wells and the response of the reservoir to a sustained discharge. Shortages of materials and manpower delayed both the sector and reinjection testing until early 1981 and by this time the construction of pipelines for the Leyte I power station was already under way. A very limited test of only five months duration was possible before increasing construction activity and the requirement of access to wellheads and pipeline routes for the construction teams resulted in the test being abandoned. The reinjection test was reported in detail by Sarit (1981) and is summarised below.

Between February and July 1981 around 1 x 10^6 tonnes of waste brine was injected into well 2R2 from various combinations of wells 202, 209, 212, 213 and 214. Flowrates ranged from approximately 27- 117 kg/s. At no stage were all five producing wells able to dispose of waste brine simultaneously to 2R2 but four wells discharged over 10,000 m^3/day for a period of twelve days in a successful test of high injection rate capacity. Transient pressure tests were scheduled before, during and after the reinjection experiment and on every occasion analysis of the results was complicated by inconsistent data. Such interpretation as could be performed indicated that there had been no detectable change in transmissivity over the period of reinjection testing.

An 1-131 trace of 0.718 Ci was injected into well 2R2 on 28 March 1981 while waste brine from 202 and 212 was being injected. Brine from 213 and 214 was subsequently injected also and monitoring of all producing wells in the vicinity of 2R2 continued until 25 April. Tracer returns were detected in wells to the north and east of 2R2, namely 202, 209, 212 and 213, but no tracer was detected in well 214 to the south of 2R2, 303 to the southeast or 101 to the northwest. Table 2 gives the horizontal distances of producing wells from 2R2, transit time of the initial tracer peak and proportion of tracer return.

Table 2: Details of Well 2R2 Tracer Test Results

Well No.	Distance from Well 2R2 (m)	Transit time for initial tracer peak (d)	Total Tracer Return (%)
101	630	n.d.	0
202	470	6.4	0.54
209	350	5.7	0.17
212	580	4.7	n.a.
213	240	5.6	1.68
214	270	n.d.	0
303	1030	n.d.	0

n.a. = not available   n.d. = not detected

Malitbog Reinjection Trial, 5R7-D

Well 5R7-D was drilled as a delineation well deviated to the south from a wellhead located near the confluence of the Malitbog and Matinao rivers. The well was completed in April 1981 to a vertical depth of 2586 m with a deviation of 1155 m. Relatively few losses of drilling fluid were recorded and the completion testing indicated a well with poor permeability. The well was subsequently found to have a maximum temperature of 260°C at a vertical depth of 1600 m and a pronounced temperature inversion below that depth.

Reinjection experiments began on 5 May with a flowrate of 40 kg/s of separated geothermal fluids from well 508-D. This flowrate was not sustained as the pipelines and separator flooded. With only 6 m head available between the wells it was not possible to apply a greater wellhead pressure to assist with fluid disposal. Reinjection was continued at a flowrate of approximately 30 kg/s until 20 May when gas was noticed leaking from the anchor/surface and surface/conductor casing annuli. The gas was analysed and found to be 90% carbon dioxide with some hydrogen sulphide and methane. The well was shut in for these analyses to be completed and was found to be developing a positive wellhead pressure for the first time. This well showed evidence of some formation breakdown during completion testing at a casing shoe pressure of 8.5 MPa. This pressure was reached when the casing was full of waste brine from well 508-D and the appearance of gas at the casing annuli may be further evidence of formation breakdown. At the end of August 1982 waste fluid disposal by injection was continuing at a rate of 20 l/s with well 5R7-D indicating an injectivity of 6 l/s MPa.

Reinjection Trial at 1R5-D for Leyte I Power Station Commissioning

Well 1R5-D was completed in January 1982 and is the most recently drilled reinjection well for the Leyte I power station. The wellhead is located in the Mahiao River Valley, around 300 m from the Mahiao separator station. The well was drilled to a vertical depth of 2321 m with a southeasterly deviation of around 540 m. The well did not encounter substantial permeability and the injectivity at completion was measured at 15 l/s MPa. The well was first discharged on 29 March 1982 and a brief output test indicated an equivalent power potential of only 1.7 MWe.

Brine injection commenced on 30 July from well 214 and the injectivity calculated from a flowing survey on 6 August, with an injection rate of 28 l/s, was 45 l/s MPa. This test will continue into the Leyte I power station commissioning phase and a tracer test is anticipated in the near future.

Reinjection Trial at Okoy-2

Okoy-2 was drilled as an exploration well at the Southern Negros geothermal project and was completed on 29 May 1978. Completion tests indicated a permeable zone between 925 and 975 m and an initial injectivity of 13 l/s MPa. The well was discharged a month later and with an equivalent electric power output of 2.8 MWe it confirmed the existence of a resource accessible from the upper Okoy watershed. The well was drilled to a depth of 1164 m and a maximum temperature at 257°C was recorded.

Environmental stresses from continued drilling and well testing activity were exacerbated in early 1981 by the installation of two 1.5 MWe back-pressure turbines to be run on steam from OK-5 and OK-7. The latter well was located only 200 m from OK-2 and at a higher elevation and it was decided that OK-2 be used as a trial for shallow reinjection as well as a means of alleviating the problems of excessive discharge of geothermal brine to the local streams.

Reinjection from OK-7 began on 23 April 1981 and from the assessed injectivity in OK-2 of about 60 l/s MPa it was apparent that the injectivity had improved substantially since completion testing in May 1978, probably as a result of the extensive output testing at the well. Reinjection continued throughout 1981 at a rate that increased from around 25 l/s to 29 l/s by the end of the year. Injectivity during the same period decreased steadily to around 25 l/s MPa.

Tracer Testing

A radioactive tracer comprising 0.5 Curies of 1-131 was introduced into OK-2 on 15 August by Klyen sampler. OK-7 was on power station supply, with reinjection into OK-2. Ok-12 and PN-13 were being discharged to silencers with surface discharge of brine. Samples were taken at two-hourly intervals from the flowing wells and shut in wells OK-9 and OK-10 were also sampled as were the Ticala and Buahagan hot springs.

Minor tracer returns were detected in OK-7, OK-12 and PN-13 amounting to less than 0.4% of the tracer injected. Arrival times of sixteen days for all three producing wells were surprisingly long and surprisingly similar considering the relative locations at producing and reinjection wells. No tracer was detected in fluid from the shut wells or hot springs.

Reinjection Trial at Okoy-12D

Okoy-12D was the fourth directional exploration well drilled in the Southern Negros geothermal field. It was completed on 21 April 1981 and discharged forty days later with a power potential equivalent to 1.8 MWe. The total drilled depth was 2796 m but a stuck drillstring left the well with a clear depth of only 2021 m. The maximum temperature of 297°C was recorded at 1300 m with a pronounced temperature inversion below this depth. Completion tests indicated there are two major permeable zones lying between 1500 m and 1700 m and below 2020 m. Injectivity at completion was approximately 30 l/s MPa. The well was discharged for 105 days before it was shut and during the discharge test the equivalent power potential increased to 4.4 MWe.

Reinjection trials commenced on 3 April 1982 using waste brine from well PN-13 which was supplying steam to a 1.5 MWe turbine. The initial trial lasted for 3 weeks before the well was shut. Reinjection was resumed on 10 May 1982 from Okoy-7 and has continued through August 1982 without interruption. Over this period the injectivity has remained at around 50 l/s MPa.

No tracer tests have been run in Okoy-12D although a test has been recommended and is expected in the near future.

DISCUSSION

In excess of 4 x 10^6 tonnes of separated brine have been injected into Tongonan and Palimpinon wells over a period of approximately 5 years. Flow-rates have ranged from about 3 to 117 kg/s and injection periods from 2 months to 5 years.

With two exceptions the high temperature trials have proceeded without any apparent problems and in several, assessed injectivity of the injection well has increased. This result contrasts with the fall in injectivity measured in 4R1 and OK-2 following an extended period of injection. The reason for this decline is the subject of continuing investigation. However some observations are possible. The two wells are the shallowest of those tested to date and with the exception of 5R7 had the lowest injectivities at completion. Temperatures at the producing horizon in both wells were generally lower than those corresponding to the deepest production zones in the other injection wells. Furthermore, the flow of brine to both wells was interrupted on numerous occasions for various reasons.

Large reductions in the injectivity of well 105 also followed a series of interruptions to injection. Temperature of the separated brine in this case was however lower and the degree of super-saturation with respect to amorphous silica correspondingly high. Nevertheless, in view of the lower permeability and temperature of the injected formation in 4R1 and OK-2 it is conceivable that the decline of injectivity measured in the three injection wells has a comn cause, the exsolution of silica.

Definitive tracer returns were obtained in two of three trials. Time for the first returns to neighbouring producing wells was considerably less for 4R1 than 2R2. It is postulated that the proximity of 4R1 and monitored producing wells to the Mahiao fault is at least in part responsible.

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