PRELIMINARY ANALYSIS OF TRACER TESTS IN ROTORUA

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ABSTRACT - Three tracer tests of doublet systems (pairs of production and injection wells) have been carried out during 1991 in the Rotorua geothermal field, New Zealand. These tests are part of an investigation in the use of doublet system for the exploitation of the Rotorua geothermal resource. The main objective of the tests was to establish whether or not there is a direct connection between the production and injection wells of the doublets. Fluorescein Sodium and Rhodamine WT were selected as tracer materials for the tests since these materials are inexpensive, easy to use, and nontoxic. Tracer breakthrough was observed in the production well of the Kingsgate hotel doublet 20 hours after a 30 minutes tracer slug injection. No tracer was detected in the other two doublet systems. This paper presents the tracer test procedure, the results of the tests and a preliminary analysis of the results.

1. INTRODUCTION

The term "doublet" applies to a system which includes two wells, the first for production coupled with the second well through which all the produced water is reinjected into the original aquifer after extraction of its heat. If the geothermal aquifer is homogeneous without regional flow, a gradually expanding zone of cold water around the injection well will be created. After some time it will reach the production well causing the production temperature to progressively decrease. The time from the start of the operation of the doublet until the injected cold water front in the aquifer reaches the production well is known as thermal breakthrough time. Careful design of a doublet system to avoid the thermal breakthrough during the system life time is very important.

There are two advantages of a doublet system: (1) It maintains pressure in the geothermal field throughout the production period and thereby maintains the yield; (2) It disposes of saline water which cannot be discharged into the surface environment.

The utilisation from doublet systems has been used in France, USA and New Zealand. France first developed a doublet scheme in 1969 at Melun, a town of 50,000 inhabitants 50 km southeast of Paris (Coudert 1985). More than 40 doublet wells have been drilled and are exploited in the Paris Basin. These are all of the low temperature ($T<100\,^{\circ}C$) type. Generally, one geothermal doublet provides heat for 1000 to 5000 housing units (or their equivalent in hospitals, schools, swimming pools or greenhouses). A housing unit has a consumption of 1 to 1.5 tons of oil per year, or the equivalent in natural gas, coal or electricity (Coudert 1984). Several doublet system are used for space heating in Klamath Falls, Oregon, USA. The hot water is pumped from the production well and then cooled in a surface heat exchanger. The wells in the doublet systems in Klamath Falls are all of similar depth and design and they are closely spaced (Sammel 1984 and Gudmundsson et al 1984). About 30 doublet systems are operating in Rotorua, New Zealand (DSIR 1990). The flow of geothermal fluid used by these doublet systems is estimated to be 1500 tonnes per day in the winter. Even though no detailed work has been done on these doublet systems they appear to work well and have very few problems

2. TRACER TEST

A tracer test is a convenient experimental method of determining the internal characteristics of a reservoir flow system. For a doublet system chemical material is injected into the injection well and then the chemical concentration-time relationship is monitored at the production well. The tracer test is particularly important for the doublet system because the chemical transport is a precursor of thermal transport. Thus if the tracer arrives quickly and in large quantities, the likelihood is that the thermal breakthrough will also be rapid and strong. If a tracer does not arrive at all, it may be presumed that no direct flow connection exists between the injection and the production wells.

The design of the Rotorua doublet tracer test is presented in Pan et al (1991). This paper describes the objectives of the test and the Rotorua geothermal field. It also discusses the various tracer materials which could be used in the tracer test. It was decided that the tracer material should have the following properties: (1) water soluble and chemically stable under the temperature and the pressure of the Rotorua geothermal reservoir, (2) not adsorbed by and not reactive with reservoir rock and geothermal fluid; (3) detectable in very low concentration (and a detection instrument is available); (4) environmentally safe and inexpensive to use. Because of the licensing and safety complexities associated with the use of radioactive tracers and cost and complex facilities associated with the use of the chemical tracers it was decided that fluorescing tracers, Fluorescein Sodium and Rhodamine WT, should be used in the Rotorua geothermal tracer test. The toxicity of the two selected tracers was also *studied.* It was concluded that both fluorescein sodium and rhodamine WT have no known hazards associated with their use as tracers.

Simulation of the tracer tests was conducted before the tests (Pan et al 1990 and 1991). The objective of the modelling work was to determine when the tracer breakthrough could be expected to arrive. Also the modelling studies were used to find out which parameters significantly influence the tracer arrival time. The RESSQ programme (Javandel et al 1984) was used for the modelling work. The RESSQ programme can be applied to two dimensional contaminate transport by advection in a homogeneous, isotopic confined aquifer of uniform thickness. It uses a steady flow field created by a regional flow, the production wells and the injection wells. It calculates the streamline pattern in the aquifer and tracer concentration at the production well as a function of time. From the simulation work it was concluded that the doublet well spacing; the regional flow velocity and direction in the reservoir, the aquifer thickness and porosity all significantly affect the tracer breakthrough time.

2.1 Doublet system selection

As mentioned above, there are 30 geothermal doublet systems that are currently operating in Rotorua. The doublets for the tracer tests were selected from these. The selection was based on the following considerations: (1) Both the production and the injection wells are of similar depth. The depths of the wells at the geothermal aquifer are about 100 meters . The production water comes fiom the geothermal aquifer rather than shallow ground water, and the used geothermal water will return to the Same aquifer; (2) The main regional flow direction in the aquifer is fiom the south-east to north-west (that is from Whakarewarewa area to the lake of Rotorua) across the field (Bradford, E. 1992). The direction of aquifer regional flow is thought to be from the injection well to the production well, with an angle of less than 90°, so that the injected tracer material will spread with the regional flow towards the production well and can be detected at the production well after a period of time. (3) There are no fault(s) so far identified between the production and injection wells. Therefore the tracer is not expected to be blocked.

Five doublet systems were selected as candidates for tracer testing. Three doublets were used for the tests and the other two for monitoring. The final decision was made after contacting the owner of the well and the Energy and Resources Division, Ministry of Commerce.

The doublet well information is shown in Table 1, and the locations of the doublets indicated in Fig. 1.

2.2 Tracer injection

Tracer can be introduced into the geothermal reservoir either continuously or as a single "slug". Since the slug injection results in a greater increase in the concentration of the tracer in the reservoir (although over a small volume), it is commonly used for artificial tracer tests for which amounts (and cost) need to be minimized. For all the tracer tests mentioned in this paper, slug injection was used.

For most of the Rotorua injection wells, the injected fluid can be introduced into the well by gravity. For the relatively high pressure (higher than 3 bar) doublet system of the Kingsgate hotel, the injection well could turn into a production well if the pipeline is opened to the atmosphere. In this case, a dosing pump was used.

The details of tracer injection for the three tests carried out are:

Test 1: 80 grams or 0.4 litres of 20% Rhodamine WT solution was injected in 7 minutes by gravity into the Holland street doublet on 01 August, 1991.

Test 2: 1 kg or 10 litres of 10% Fluorescein Sodium solution was injected in 5 minutes by gravity into the Boulevard Motel doublet on 03 August, 1991.

Test 3: 1 kg or 8 litres of 12.5% Fluorescein Sodium solution was injected within 30 minutes using a dosing pump into the Kingsgate hotel doublet on 17 September,

Table 1 Doublet well information for tracer tests

	Well apart (m)	Status of the well	Depth of the well	Depth of casing	Address of the well	Owner of the well
1	7.9	Production	121.9	99.0	265 Fenton St	Boulevard Motel
		Injection	125.0	100.0	Seddon St	Boulevard Motel
2	58.0	Production	134.2	96.8	50 Holland St	C.N.Leslie
		Injection	124.4	98.0	46 Holland St	J.D.Glengarry
3	71.2	Production	164.3	144.5	6 Eruera St	Travelodge Hotel
		Injection	209.7	150.0	6 Eruera St	Travelodge Hotel
4	39.1	Production	130.1	120.7	41 Seddon St	G.Snow
		Injection	138.7	123.0	41 Seddon St	G.Snow
5	20.5	Production	123.5	83.7	Eruera St	Kingsgate Hotel
		Injection	123.0	85.0	Eruera St	Kingsgate Hotel

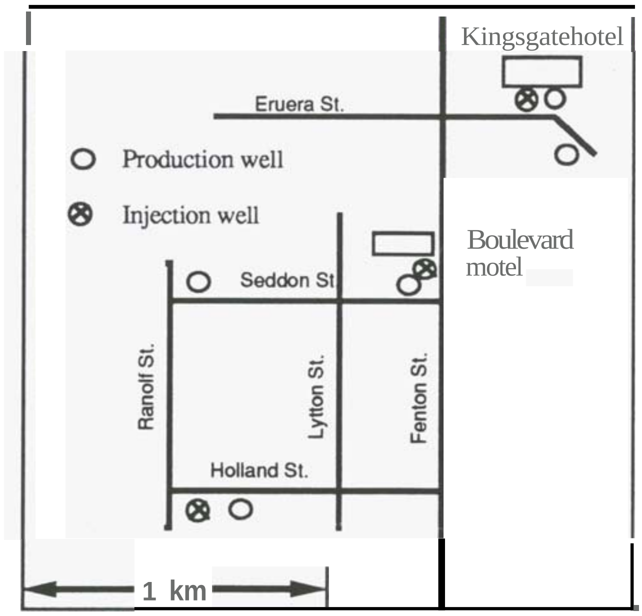

Fig 4.3 Doublet Location for Rotorua tracer test

1991.

2.3 Sampling

In order to take samples from the production well, a small valve installed at the wellhead is needed. Since the temperature of the geothermal fluid is normally over 110°C, and pressure is over 2 bars, a cooling coil was designed and used to condense the fluid.

Samples were taken several days before the injection of the tracer. This was done to obtain information on the level and stability of the background concentration of the selected tracer materials.

From modelling studies (Pan et al 1991), it was determined that the injected tracer may arrive at a production well in less one day, or it may take weeks, even months to arrive. In order to interpret the tracer arrival information, it is necessary to have samples both before and after the peak breakthrough concentration. The longer the peak concentration takes to arrive the more dispersed it is, thus frequency of sampling can be decreased with time.

For each tracer test in Rotorua, samples were taken daily three or four days before the test. Immediately following the injection of tracer samples were taken every 15 minutes for the first six hours, and than every half hour. After the first day sampling was reduced to hourly, after the second day two hourly, and so on. After three weeks sampling was taken two or three times per week. For each of the tracer tests sampling was conducted for up to two months.

It was expected that each sample collected represents the instantaneous tracer concentration of the production geothermal fluid at present time. However, if the sampling valve is opened and the sample taken immediately, the sample may be the old fluid rather than present fresh fluid. So that the production well was discharged (about ten litres of the fluid was drained) using the sampling valve about three minutes before taking the sample.

2.4 Tracer detection and results

Each sample taken from the production wells was analysed in a laboratory of Geography Department at the University of Auckland, using a Turner 111 fluorometer. The fluorometer had been previously calibrated with the tracer materials which were used for the test.

For the three tracer tests, in only one was a return detected. The results are:

Test 1: No return within 60 days.

Test 2: No return within 57 days.

Test 3: Return was observed in the production well, 20 hours after a 30 minutes tracer slug injection. The tracer return (breakthrough) curve is shown in Fig. 2. The first 200 hours of the same tracer breakthrough curve is shown in Fig. 3.

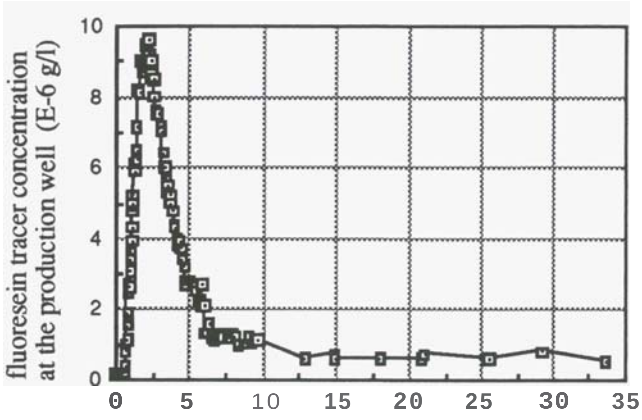

Fig. 2 tracer test breakthrough curve at Kingsgate Hotel, Rotorua.

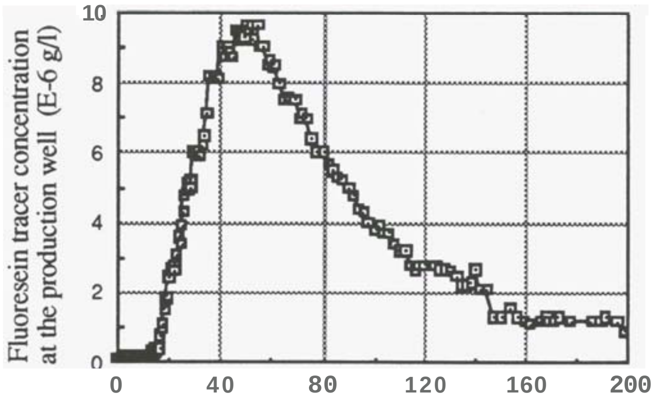

Fig. 3 The tracer test breakthrough curve for the first 200 hours.

In a previous study two tracer tests were carried out at Post Office (Rotorua central) doublet system in September 1986 (Bowman 1986). The depth of the production and the injection wells are 101 meters and 91 meters respectively and the distance between these two wells is 35 meters. For the first test 0.5 litres of 20% Rhodamine WT solution were injected in the system in less than a minute. After the first test seven days, 2.5 litres same tracer material were added into the system. Samples were taken frequently up to 48 hours for test 1 and up to 216 hours for test 2. No return was observed in either tests.

These are the only tracer tests, known to the authors, which have been conducted at the Rotorua city area. The results of these tests are summarised in Table 2. Only one of the tracer tests produced a breakthrough and the tracer recovery was very small. Therefore there does not appear to be a direct connection (or a strong connection) between the injection and the production wells in these Rotorua doublet systems.

Table 2 The Rotorua tracer test result

No.	Well apart (m)	flow rate (kg/s)	Production Pressure (bar)	well head temp. (°C)	Tracer used for the test	Tracer injection date	Break-through
1	58.	1.38	0.8	124. 85.	0.4 1 Rhodamine-WT	01 Aug. 1991	No
2	7.9	1.68	2.5	136. 90.	1.0 kg Fluorescein Sodium	03 Aug. 1991	No
3	20.5	3.47	4.0	140. 120.	1.0 kg Fluorescein Sodium	17 Sept. 1991	Break-through observed
1*	35.1	1.389	0.75	130. No info.	0.5 1 Rhodamine-WT	03 Sept. 1986	No
2*	35.1	1.389	0.75	130. No info.	2.5 1 Rhodamine-WT	10 Sept. 1986	No

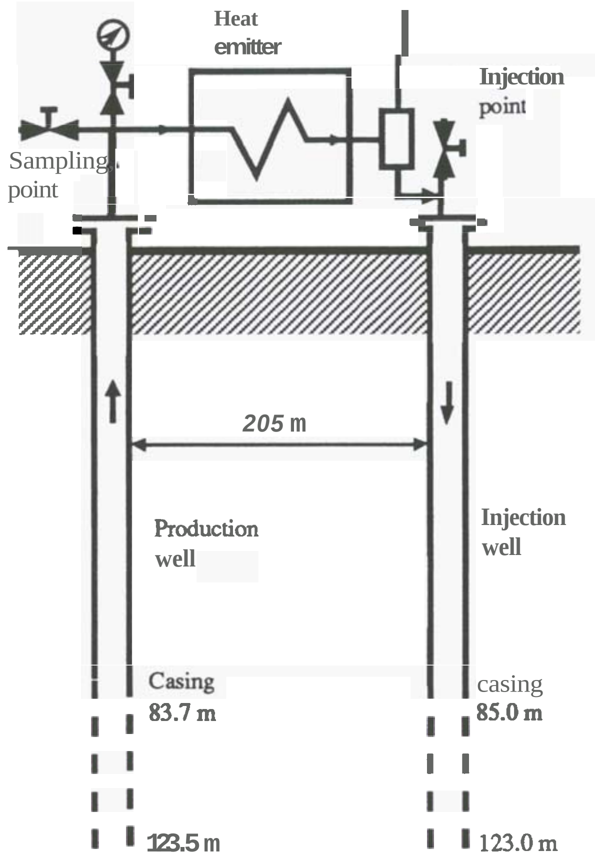

Fig. 4 Sketch diagram of Kingsgate hotel, Rotorua

3. PRELIMINARY TEST ANALYSIS

The analysis of Rotorua tracer test work has been divided into two steps: preliminary test analysis and computer simulation. In the preliminary analysis described here the tracer speed, recovery and mixing volume are calculated. The breakthrough curve obtained was from the tracer test of Kingsgate Hotel. The sketch of this doublet system is shown in Fig. 4

3.1 Tracer speed

As mentioned above, tracer breakthrough was observed in the Kingsgate doublet production well 20 hours after the 30 minutes injection of a tracer slug. The breakthrough curve is the plot of concentration of Fluorescein at the production well versus time. The distance between the injection and the production well for the Kingsgate hotel doublet is 20.5 meters. So the fastest speed of the tracer travelling through the geothermal aquifer is 1.025 meters per hour. However, the peak concentration of the breakthrough curve was detected at 50 hour time *(see* Fig 2.2), and this indicates that the mean speed of the tracer movement is 0.41 meters per hour.

Table 3 shows typical tracer speed from slug injection test in geothermal reservoirs world wide. It shows that the speed of tracer movement for the Rotorua tracer test is within the range shown in the Table.

3.2 Tracer Recovery

The quantity of tracer recovery in the production well can be found by integrating the return profile over time. For a slug injection test, the total tracer recovered, Q, can be calculated using equation (1) (Home 1987).

$$Q = \int_0^\infty q(t)c(t)dt \quad (1)$$

Here $q(t)$ is production well flow rate and $c(t)$ is the tracer concentration measured at the production well as a function of time.

For the Rotorua geothermal tracer test, the production well flow rate q is constant. Thus equation (1) *can* be written:

$$Q = q \int_0^\infty c(t)dt \quad (2)$$

Clearly it is not feasible or necessary to monitor the tracer recovery for infinite time. Since the tracer concentration becomes small later in the test it is reasonable to integrate over whatever period measurements were made.

The quantity recovered as a fraction of that tracer injected is an important parameter in tracer test analysis. It is defined by

$$f = Q/Q_{inj} \qquad (3)$$

From Fig. 3, it can be estimated that the average of the tracer return is approximately 5xE-6 gram/litre at the beginning of 200 hours. After 200 hours, a very low tracer concentration was still present in the samples (see Fig.2), but it is likely that this is the tracer recirculated in the close loop system not the injected tracer. The circulating flow rate in the doublet system is 300 m^3/day or 3.48 litres/second. Based on these data the calculated total tracer return for the first 200 hours is 1.25 grams. The injected Fluorescein Sodium was 1.0 kg or 1000. grams, and so the tracer recovery is approximately 1.25%. This result indicates that there is not a strong connection between the injection well and the production well. Some typical values of tracer recovery fraction for geothermal reservoirs are indicated in Table 4. The value for the Rotorua tracer test is lower than average in comparison with other tests. This low value may be due to a regional flow effect. In addition, these tracer tests shown in Table 4 are not only for doublet system, there may have many production wells operating during their tests.

3.3 Mixing volume

Table 3.1 Tracer return speed in geothermal reservoirs.

Geoth. reservoirs	Country	Speed m/h	Reference
Ahuachapan	El Salvador	8.0	Einarsson et at (1975)
Broadland	New Zealand	0.023 0.07 0.4 0.8	McCabe et al (1983)
Dixie Valley Nevada	USA	1.4 5.0	Adams et al (1989)
Hatchobaru	Japan	78.0	Horne (1982)
Klamath Falls	USA	0.81 27.6	Culver (1989)
Onuma	Japan	4.0	Ito et at (1977)
Otake	Japan	0.3	Hayashi et at (1978)
Palinpinon	The Philippines	1.7 3.0 7.1	Urbino (1986)
Reykjavik	Iceland	3.3 5	Gudmundsson at al (1984)
Rotorua	New Zealand	1.03	This paper
Southeast Geysers	USA	13.3 33.3	Adams et al (1991)
Tongonan	The Philippines	57.0	PNOC (1981)
Wairakei	New Zealand	7.0 17.0 21.0	McCabe et al (1983)

Table 4 Typical values of tracer recovery fraction in different geothermal reservoirs

Geoth-ermal reserv.	Country	Reco-very Frac-tion %	Reference
Broadland	New Zealand	1.2 5.0 12.0	McCabe et al (1983)
Geysers	USA	18.0	Gulati et al (1978)
Hatchobaru	Japan	6.3	Horne (1982)
Klamath Falls	USA	7. 11. 54	Culver (1989)
Palinpinon	The Philippines	0.4 3.9 29.2	Urbino (1986)
Reykjavik	Iceland	0.5 15.0	Gudmundsson and Hauksson (1984)
Rotorua	New Zealand	1.25	This paper
Tongonan	The Philippines	12.0	PNOC (1981)
Wairakei	New Zealand	0.05 0.06 0.09 0.24 0.4 5.8	McCabe et al (1983)

For a doublet system in which the injection/production wells are connected at the surface, the produced fluid, which contains tracer material, is circulated in a closed loop. This material, if it does not degrade, or is destroyed or absorbed by the reservoir racks, will reach a steady concentration as illustrated in Fig. 2. In this case the volume of fluid over which the tracer has been mixed can be estimated. This volume is called the mixing volume.

If the mixing volume V_{mix} was originally at concentration C_0 and fiially reaches concentration C, , then the total mass M_{inj} of tracer injected is given by (Home 1987)

$$M_{inj} = M_{mix} (C_1 - C_0) \qquad (4)$$

or

$$V_{mix} = V_{inj} / (C_1 - C_0) \qquad (5)$$

For this tracer test, the injected tracer mass M_{inj} is 1000 grams, C, and C_0 are , 10^{-6} grams/litre and zero respectively, so the mixing volume, V_{mix} , is 10^9 litres or

10^6 m^3. If the reservoir aquifer thickness is assumed to be 20 meters, then the area of the reservoir mixing is approximately 5.0×10^6 m^2 or 0.5 km^2. This calculation and consumption is only valid that the aquifer is at steady state without regional flow. Whether or not there is any regional flow and its influence on the tracer test results will be studied using computer simulation.

3.4 Temperature and pressure

The five tracer test listed in Table 2 indicated that only one of the tracer tests produced a breakthrough and the tracer recovery was very small. Therefore there does not appear to be a direct connection (or a strong connection) between the injection and the production wells in these Rotorua doublet systems. Most doublet systems, including those investigated in the tracer tests have been used for years, and the pressure and temperature at the production wells have not changed with time. This demonstrates that the production wells in the Rotorua geothermal field are not suffering thermal drawdown even when the production and the injection wells are very close (7 meters to 50 meters apart). The explanation of this phenomenon could be that there is a very strong regional flow across the geothermal field.

For the Boulevard motel doublet, the distance between the production and injection wells is only 7.9 meters. For the tracer test carried out using this doublet no breakthrough was observed within a two month period. This indicates that there is not a connection between the production well and the injection well. The well owner exchanges the production well and injection well every six months. However, the wellhead temperature and pressure is always constant. These facts indicate that the injected cold water would not create a cold zone around the injection well

4. COMPUTER MODELLING

To help in analysing the results of the tracer test, three computer programmes/packages are currently being used for the interpretation of the test results. There are a analytical method (2D-MODEL) (Pan et al 1990), a semi-analytical method (RESSQ) and a full numerical method (MULKOM) (Pruess 1988). Three features of the tracer test breakthrough curve are considered. They are: (1) the tracer arrival time; (2) magnitude of the tracer concentration at the production well; (3) the shape of the breakthrough curve. Reservoir variables investigated in this modelling work are the thickness of the aquifer, the regional flow velocity and direction, and the porosity. The depth of the feed zones in the production well and the injection well are also considered. Some results of the modelling work have been obtained but not yet completed. The detail of the modelling work will be published at a later date.

5. COMMENTS AND DISCUSSIONS

The comments and discussions from the tracer tests are summarized as follows:

(1) The doublet tracer tests in Rotorua were carried out (Table 2), while these tests cannot be used to predict the behaviour of other doublet systems in this geothermal field. It is significant that of the five tests conducted only one of these produced a breakthrough and the tracer recovery was very small. It seems that this is a positive result in which shows that development of doublet systems in this field is feasible.

(2) The rapid return of the tracer and small recovery rate during the test indicates that the geothermal reservoir around this doublet may be fractured in a direction approximately perpendicular to the line joining the two wells. However, the information is not sufficient to determine whether the entire reservoir is fractured or not.

(3) The tracer recovery is small (or there is no return) which indicates that there is not a strong connection (or a direct connection) between the injection and the production wells for the Rotorua doublet systems tested.

(4) The utilization experience for these doublet systems shows that the well pressure and temperature have not changed with time for several years. This demonstrates that the production wells are not suffering thermal drawdown even when the production and the injection wells are very close (7 meters to 50 meters apart).

(5) From the long term equilibrium of tracer concentration in the doublet system, the mixing volume was calculated. Assuming the reservoir aquifer thickness to be 20 meters, the mixing area is 0.5 km^2. However, this calculation and assumption is only valid if the aquifer is in a steady state without regional flow

(6) The tracer test analysis in this paper is preliminary. Further computer modelling work will be *carried* out.

REFERENCES

Adams, M.C., Ahn, J. H., Bentley, H., Moore, J.N. and Veggeburg, S. (1986) Tracer developments: results of experimental studies. Proc. *of 11th Workshop on Geothermal Reservoir Engineering,* Stanford, California pp 97-102

Adams, M.C., Beall, J. J., Enedy, S. L., Hirtz, P. (1991) The application of halogenated alkanes as vapor - phase tracers: A field test in the southeast Geysers. ***Geothermal Resources Council Trans.*** Vol. 15. pp.457 - 463

Adams, M.C., Benoit, W. R., Doughty, C., Bodvarsson, G. S. , Moore, J. N. (1989) The Dixie Valley, Nevada tracer test. ***Geothermal Resources Council Trans.*** Vol. 13. pp.215-220

Bowman, E. (1986) Soak bore investigation - Rotorua central post office. Report of Job No. 7G403. Water Resources Survey, DSIR, Rotorua, NZ. P.25

Bradford, E. (1992) Pressure changes in Rotorua geothermal aquifers 1982 - 1990. In preparation for ***Geothermics.***

Coudert, J.M. (1984). Geothermal Direct Use in France - A General Survey. ***Geo - Heat Centre. Quarterly Bulletin,*** Summer 1984, Vol 8, No. 3, pp. 3 - 5.

Coudert, J.M. (1985) Reinjection - a French approach. Proc. of ***7th New Zealand Geothermal workshop.*** pp. 75-78.

Culver, G. (1989) Direct use injection wells. *Geo - Heat Centre. Quarterly Bulletin,* Summer 1989, Vol 11, No. 4, pp. 1 - 5.

DSIR (1990). *Geothermal* well *information data base.* Rotorua, DSIR

Einarsson, S. S., Vides-R, A.and Cuellar, G., (1975): Disposal of geothermal waste water by reinjection. Proc. of 2nd U.N. Symposium on Geothermal Energy, San Francisco, California, pp. 13-49

Gudmundsson J.S., Hauksson,T. , Thorhallsson, S., Alertson, A., and Thorolfsson, G. Injection and tracer testing in Svartsengi fiels, Iceland. *Proc. of the 6th New Zealand Geothermal Workshop,* Auckland, Nove. 7 - 9 1984, pp. 175 - 180

Gudmundsson J.S., S.E. Johnson, R.N. Home, P.B. Jackson, G.G. Culver. (1984).Doublet tracer testing in Klamath Falls. *GHC Quarterly Bulletin.* winter 1984. pp. 12- 17

Gulati, M. S., Lipman. S. C. and Strobel, C. J. (1978) Tritiu tracer survey at the Geysers. *Geothermal Resources Council Trans.* Vol. 2, pp 237-239.

Hayashi, M., Mimura, T., and Yamasaki, T. (1978) Geothermal setting of reinjection wells in the Otake and the Hatchobaru geothermal field, Japan. Geothermal Resources Council Trans., V01.2 pp. 263 - 268

Home, R.N. (1982) Geothermal reinjection experience in Japan. Journal *of Petroleum Technology* Vol.34 pp. 495-503

Home, R.N., (1987) *Tracer test.* Stanford University U.S.A.

Ito, J., Kubota, Y. and Kurosawa, M. (1978) Tracer tests of the geothermal hot water at Onuma geothermal field. *Japan Geothermal Energy Association Journal* No. 15,1978. pp. 87 - 93. (in Japanese)

Javandel, I., Doughty, C. and Tsang, C. F. (1984) Ground water transport: Handbook of mathematical models. American Geophysical Uion, Washington, DC 20009

McCabe, W.J.,Barry, B.J. and Manning, M.R. (1983) Radioactive tracer in Geothermal underground water flow studies. *Geothermics* N0.12 1983 pp. 83 - 110

Pan, H., Bullivant, D.B.,O'Sullivan, M.J. and Freeston, D.H. (1990) Computer modelling of a production/ injection doublet system. *Proc. of 12th New Zealand Geothermal Workshop,* pp *63* - 70

Pan, H., Freeston, D.H. , OSullivan, M.J. (1991) Tracer test design for the Rotorua geothermal field. Proc. *of 13th New Zealand Geothermal Workshop,*pp 105 - 114

PNOC (1981) *Reinjection tests ai Tongonan Geothermal Site.* Energy Development Corporation Report, Philippines National Oil Company, Manila, Philippines.

Pruess, K. (1988). Shaft, MULKOM, TOUGH: A *set of numerical simulators for multiphase fluid and heat flow.* Lawrence Berkeley Laboratory Report LBL - 24430, Berkeley CA, USA.

Sammel, E. A. (Editor) (1984). *Analysis and interpretation of data obtained in test of the geothermal aquifer at Klamath Falls, Dregon, USA.* U.S. Geo. Survey, Water Resources Inve. Report 84-4216. DOE Cont. No. DE-AC03-835F11928.

Urbino, M.E.G., Zaide, M.C., Malate, R.C.M. and Bueza, E.L. (1986) Structural flow paths f reinjected fluids based on tracer test - Palinpinon I, Philippines. Proc. *of 8th New Zealand Geothermal Workshop* pp 53-58