HYDROTHERMAL INJECTION EXPERIMENTS AT THE RAFT RIVER KGRA, IDAHO

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ABSTRACT

The optimal development and management of a geothermal resource requires a knowledge of the hydrological characteristics of the reservoir. Reservoir engineering analysis techniques for permeable aquifers have been undergoing development for several decades but little attention has been paid to fracture-dominated systems. The Department of Energy funded a joint EG&G Idaho, Inc./Univ. of Utah Research Institute program to test the ability of "Huff-Puff" tests to help characterize a fracture-dominated reservoir. Several series of these injection ("Huff")-backflow ("Puff") tests were conducted at the Raft River KGRA in Southern Idaho. These test series are described and preliminary results and interpretations are discussed.

INTRODUCTION

In early summer 1982, the Department of Energy (DOE) funded a hydrothermal injection project to investigate new and novel techniques which could improve the ability of commercial well field operators to plan development and management strategies for fractured geothermal systems. The objective of the experimental program was to explore the feasibility of acquiring meaningful information from single well tests using a combination of geochemical and geophysical techniques. The Raft River facility was selected for the initial testing because of its immediate availability and extensive monitoring capability. One major limitation, however, was that testing had to be completed by December 1, 1982 in order to allow the facility to be turned over to the U.S. General Services Administration (GSA) for sale. The program was funded as a joint effort between EG&G Idaho, Inc. and the University of Utah Research Institute (UURI).

The proposal that was presented to DOE outlined a series of "Huff-Puff" tests in which the "Huff" phase consisted of injecting a fluid of distinctly different chemical composition down the test well and the "Puff" phase consisted of backflowing the test well and monitoring changes in chemistry. Raft River Geothermal Production well no. 5 (RRGP-5) was chosen as the test well. The production aquifer in RRGP-5 is a fracture system at 1382 m. Due to drilling problems, this aquifer had to be cemented off but was later reopened via a near vertical hydraulically induced fracture from the bottom of the casing (1398 m). The concentrations of dissolved solids in this well is very low for geothermal wells in this area and the specific conductivity is 2700 μmho/cm. Geothermal fluids from RRGP-3 were chosen for injection into RRGP-5. This fluid is the hottest at the well head and will, therefore, be near reservoir temperature at delivery to site five. RRGP-3 fluids also contain higher total dissolved solids (μ = 8000 μmho/cm). This RRGP-3 fluid in the primary tracer in all of our tests.

In addition to the RRGP-3 fluid, selected chemicals were injected into the formation to act as secondary tracers. At least one secondary tracer was added during each test. The chemicals selected as secondary tracers had to meet several criteria: (1) they had to be able to withstand the reservoir temperature (135°C) without decomposing, (2) their reactivity with the formation had to be kept at a minimum, and (3) they had to be inexpensive (<$20.00/lb). This last condition was necessary because of the large mass of water and, therefore, tracer that would have to be injected during long term tests.

EXPERIMENTS

Three series of experiments were conducted at Raft River between early September and early December 1982. Each series was designed to provide information on a different aspect of the Raft River reservoir. The object of each test and parameters that were varied are listed in the summary below. The injection and backflow rates were maintained at 9.46 L/s (150 gpm). This rate was chosen because both RRGP-3 and RRGP-5 can consistently supply this amount by artesian flow.

Baseline data on chemistry and downhole logs were collected on each of the wells previous to its being used for experimentation. The downhole logs included temperature, spinner flowmeter, and conductivity. Well head instrumentation included temperature, pressure, flow rate, pH, conductivity and redox potential. These instruments were either recorded on a strip chart or on a digital printout data logger.

RAFT RIVER INJECTION TEST SUMMARY

Test	Phase Duration			Object(s)
	Injection	Quiescence	Backflow	
2A-1	1 hr. (bore only)	---	1.33 hrs.	o Test downhole T/μ probe (200 ft.). o Determine tracer recovery rates from bore hole.
2A-2	2 hrs.	---	12.4 hrs.	o Test downhole T/M probe o Determine tracer (I^-) recovery from near well formation.
2C	46.5 hrs.	---	110 hrs.	o Explore a larger volume of the reservoir. o Determine the position in the open bore where the fluid is leaving. o Determine tracer (Mg^{2+}) recovery from a larger volume of the reservoir.
2D	96.5 hrs.	---	237 hrs.	o Explore a larger volume of the reservoir. o Determine the response of the reservoir to multiple injection of tracer slugs. o Clean up reservoir in preparation for test 5.
4A	0.3 hr.	28 hrs.	6.0 hrs.	o Determine whether a natural hydrologic flow system was removing injected solutions from the immediate vicinity of the injection well.
4B	0.3 hr.	2 hrs.	10.5 hrs.	
4C	0.3 hr.	12 hrs.	8.5 hrs.	
4D	0.3 hr.	50 hrs.	48.5 hrs.	
5	min. 432 hrs. max. 504 hrs.	48 hrs.	min. 0 hrs. max. 120 hrs.	o Determine whether breakthrough from RRGP-5 to RRGE-1 can be accomplished in 18 to 21 days. o Determine whether the extent of fluid flow can be traced using spontaneous potential or resistivity surveys. o Determine reservoir pressure recovery as a function of flow rate.

There were two individual experiments in the 2A test. The first experiment, 2A-1, was a training exercise for the operations personnel and consisted of pumping RRGP-2 fluid laced with a tracer cocktail down the cased bore for a period of one hour. This injection was followed by a backflow for 1.33 hrs. Based on the criteria outlined in the previous section and the need for the tracers to provide a contrast with the native reservoir fluids, four tracers were chosen for experimentations: I^- as NaI, Br^- as NaBr, Mg^{2+} as $MgCl_2$ and B^{3+} as borax ($Na_2B_4O_7 \cdot 10H_2O$). In addition, the organic dyes fluorescein and rhodamine B were tested in later experiments. The tracer cocktail injected during experiment 2A-1 had the following concentrations: 20 ppm I^-, 20 ppm Br^-, 20 ppm Mg^{2+} and 10 ppm B^{3+}. The recovery on the I^-, Mg^{2+} and B^{3+} was greater than 96%. Analytical problems were encountered in analysing for Br^- in the high chloride (2200 ppm) geothermal brines using a Br^- selective ion electrode. This problem can be overcome using ion chromatography but this method is time consuming and not conducive to being conducted in the field.

Experiment 2A-2 was the first time that fluid from RRGP-3 was injected into the formation at RRGP-5. Injection time into the formation was two hours. The tracer selected for this experiment was I^- and was injected at a concentration of 150 ppm. The high temperature conductivity/temperature probe was inserted into RRGP-5 at a depth of 1396 m (about 2 m from the bottom of the casing). This instrument performed very well during the short term tests and showed exactly when the injection fluid started entering the formation. Backflow was initiated within a few minutes of the termination of injection. Based on downhole conductivity measurements, the influx of undiluted RRGP-3 fluid into the bottom of the casing lasted less than 4 minutes. Figure 1 is a plot of the tracer concentration and downhole conductivity as a function of time. These plots follow each other very closely and indicate that simple dilution is the major mechanism at work.

Test 2C had a longer term injection period--46.5 hours into the formation--and a different tracer, Mg^{2+}. Figure 2 is a plot of the tracer concentration and conductivity as a function of time for test 2C. The concentration of Mg^{2+} and the uphole conductivity both decrease as soon as the well bore has been cleared. The magnesium concentration, however, decreases much more rapidly than does the conductivity. A plot of the calcium concentration shows a significant increase (20%) at the initiation of backflow and then decreases at a rate less than that of the conductivity. This suggests that ion exchange of Mg^{2+} for Ca^{2+} is the dominate rock-water interaction and that this reaction is superimposed on the dilution curve.

Because dilution is a major effect and it starts immediately without respect to the injection time, it was decided to conduct a series of tests in which there were quiescent periods between injection and backflow. These experiments would help us determine whether or not an overall hydrologic flow was sweeping some of our injected fluids away from the sphere of influence of the test well. This test 4 series consisted of a 20 min. injection into the formation, a variable length quiescent time--2 to 50 hrs--and enough backflow to recover the tracer. Nearly all of the tracer was recovered in these experiments. This led to the conclusion that there was little or no natural hydrologic flow through the RRGP-5 fracture system.

Tracer & Conductivity Plot as a Function of Time: Test 2A-2

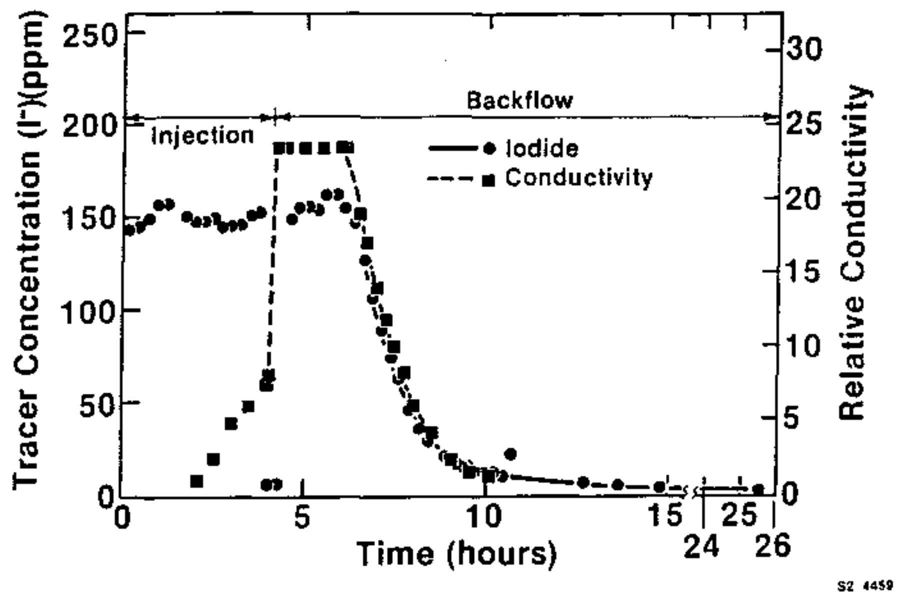

FIGURE 1

Tracer & Conductivity Plot as a Function of Time: Test 2C

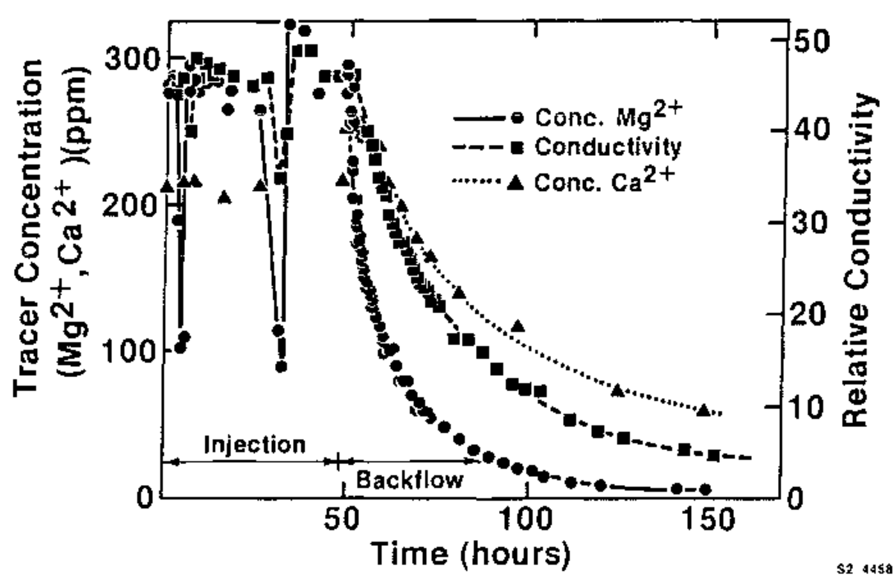

FIGURE 2

Test 2D was the final experiment of the series and had the longest term injection and backflow. Because continuous injection of tracer would require a very large amount of chemical, it was decided to inject slugs of tracer at the beginning of injection, after 24 and 48 hours of injection and just previous to backflow. A 1200 kg slug of either an individual tracer or combinations of chemical tracers or dyes were injected at a rate of 100 kg/min. The tracers started to return almost immediately and all of them reached concentrations well above background levels within the first 20 hours of backflow. Even though some of the tracers were injected as much as 48 hours apart, they all started coming back very soon and show approximately the same bimodal concentration maxima.

Test 5 is the final experiment to be conducted before the Raft River site has to be vacated. Test 5 is a long term (20 day) experiment to determine whether fluid break through could be obtained between two adjacent wells--RRGP-5 to RRGE-1. This test is underway at the time that this paper was submitted and no results will be available until the workshop presentation. In addition to the monitoring for well-to-well break through, Test 5 will be used to determine whether subsurface fluid movement can be detected by geophysical means. A team of geophysicists from UURI will be conducting a spontaneous potential survey during injection and a resistivity survey at the conclusion of injection to try to delineate the interface between the higher conductivity RRGP-3 fluid and the lower conductivity native fluids. Preliminary geophysical results from test 2C showed promise but the short term injection period of that test did not allow sufficient time for a definitive survey.