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RESPONSE OF RRGI 6 AND RRGI 7 TO INJECTION DURING THE 5MW PLANT OPERATIONS MARCH 25 - JUNE 15, 1982 AT RAFT RIVER, IDAHO

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ABSTRACT

Injection testing conducted between March 25 and June 15, 1982 at the Raft River Site generated a substantial quantity of non-isothermal and various temperature transient pressure data. Injection pressure build-up measured at the wellhead strongly responds to temperature changes of the injected fluid. An increase in the fluid temperature results in an injection pressure increase while a temperature decrease is followed by an injection pressure decline. Data analyses indicate that changes in fluid viscosity and density due to temperature changes do not explain pressure build-up responses. The pressure build-up behaviors are attributed to the reservoir transmissivity changes. The absolute wellhead pressure values are significantly lower than predicted for the cold fluid injection.

INTRODUCTION

The Raft River Geothermal Injection Wells RRGI 6 and RRGI 7 are 1172 meters deep. The open hole interval (injection zone) is between the 514 meter depth and the bottom of the hole in RRGI 6 and between the 619 meter depth and the bottom of the hole in RRGI 7. Both wells are open hole in the Salt Lake Formation which consists of interbeded siltstones and sandstones. Fractures within the Salt Lake Formation are partially filled with calcite. Rock samples and geophysical logs indicate that intergranular porosity and permeability exist in addition to some fracturing in the Salt Lake Formation Dolenc (1981).

Extensive injection into RRGI 6 and RRGI 7 was performed during testing of the 5 MW(e) Raft River Power Plant. Full scale power production tests of the 5 MW Plant were conducted between March 25 and June 15, 1982. During this testing, a total of 2.372×10^8 liters of fluid were injected into RRGI 6 and 3.135×10^8 liters into RRGI 7. This was the most extensive injection ever conducted at the Raft River Site. Injection rates and fluid temperature were variable during these tests. The injected fluid temperature ranged between 35°C and 80°C. Several tests with periods of relatively isothermal injection conditions provided data for calculation of the reservoir transmissivities for the various injection temperatures. The portions of tests with nonisothermal injection conditions are not suitable for analytical evaluation of reservoir parameters. These nonisothermal injection conditions provided material for the general discussion on the thermal effects on the wellhead pressure behavior.

The pressure fall-off data are not discussed in this paper because of incompleteness, lack of temperature measurements, and complexity created by variable injection rates and partial recovery between tests. This partial recovery also effects pressure build-up during injections. However, for simplicity no corrections were made to eliminate partial recovery effects.

TESTS CONDUCTED

Injection pumping into RRGI 6 and RRGI 7 started on March 25, 1982. Sixteen separate injections in both wells were performed between March 25 and June 15. The injection schedule was irregular, dictated by the shut-downs and start-ups of the 5 MW plant and the geothermal water supply system. Duration of the injection pumping ranged between 200 and 18,000 minutes. The injection rates were dictated by the 5 MW Plant production experiment's need to dispose of geothermal fluid. The temperature changes were related to discontinuous heat extraction by the Power Plant. Spent geothermal fluid was directed into the holding ponds near RRGI 6 and RRGI 7; it was then injected into the wells. This procedure resulted in injection fluid temperatures in the 35° to 80°C range. Injection at RRGI 6 and RRGI 7 was conducted at rates ranging between 32 and 75 lps. Well RRGI 7 generally had higher and steadier injection rates than RRGI 6.

The data recorded during injection include: wellhead pressure readings from the 400 psi digiquartz pressure transducer and from a mechanical Heise gauge, temperature and flow rates continuously recorded on a strip chart (based on platimium RTD and ΔP gauge) and temperature readings from the mercury thermometer. No downhole instrumentation was used during testing.

DISCUSSION ON TESTS RESULTS

Data from eight separate injection tests into RRGI 6 were plotted on semilogarithmic graph paper. The data plots for most of these tests represent irregular wellhead pressure response due to changing injection rates. One test conducted in RRGI 6 was selected to illustrate pressure response to the injection. Data from this test conducted on May 16 through 28 are presented in Figure 1.

The pressure build-up follows a straight line trend for the first 260 minutes of the test. During this time, the injection rate was steady at 38.3 lps and the temperature was close to isothermal at 67-69°C. The transmissivity value calculated from this first 260 minutes is 4.8 x 10^{-4} m^2/s. Transmissivity values calculated from previous injections are generally less than 2.0 x 10^{-4} m^2/s for injected fluid at 130°C Dolenc (1981).

Between 900 minutes and 4500 minutes, the injected fluid temperature declined from 70°C to 49°C. This temperature decrease resulted in the estimated wellhead pressure decrease of 400 kPa. The estimated pressure decrease is based on the difference between projected and measured wellhead pressure. The density difference between 70°C and 49°C fluid would produce a decrease in wellhead pressure of approximately 90 kPa. This is due to the hydrostatic pressure increase within an 843 meter length of the wellbore. Viscosity of the injected fluid at 49°C is approximately 1.4 times higher than the viscosity of 70°C fluid. This higher viscosity should result in an increase in the wellhead pressure Mangold (1979). It is apparent that the density and viscosity effects do not explain the wellhead pressure responses to the temperature changes.

Relatively steady injection rates and continuous temperature readings provide better data for RRGI-7 than the data collected for RRGI 6. Data from five tests conducted in RRGI are presented in Figures 2 through 6. All the data plots demonstrate similar pattern in the wellhead pressure responses to the temperature changes.

Transmissivity values calculated from these plots are listed in Table 1. The transmissivities for each test were calculated from portions of the data plots where temperature was nearly constant. The fluid temperature during these injections ranged from 48.3°C to 80°C. Transmissivity values plotted against injected fluid temperature are presented in Figure 7. The transmissivity values, as shown in Figure 7, represent both rock and fluid properties. Thus if rock properties remain constant , for lower temperatures, fluid transmissivity values should be lower due to higher viscosity. On the contrary, however, observed transmissivity values are higher for the lower temperature fluid. Apparently, injection of lower temperature fluid results in an increase in the transmitting capacity of the aquifer. The wellhead pressure behavior during the nonisothermal injection conditions follows a pattern described for the RRGI 6 test, discussed previously.

During the injection conducted on May 2-5 (Figure 3), between 300 minutes and 1400 minutes of the test, the temperature decreased from 64°C to 45°C. This temperature decrease resulted in an estimated wellhead decrease of 270 kPa. More examples of the wellhead pressure changes due to injected fluid temperature changes are listed in Table 2.

Further indication of the transmissivity increase due to the cold water injection is demonstrated by the absolute wellhead pressure data. The wellhead pressure of 2585 kPa was predicted for 52°C water and 63 lps injection rate after 3 days of pumping Petty (1980). The recorded pressure was below 1600 kPa for similar injection conditions (Figure 3). The predicted wellhead pressure was based on the viscosity change. Apparently the effects of viscosity changes were overrun by the changes in aquifer properties.

INTERFERENCE BETWEEN RRGI 6 AND RRGI 7

Injection pumping into RRGI 6 and RRGI 7 was conducted simultaneously. Because of this parallel pumping schedule, no interference effects could be detected from well data. Additionally, the frequent changes in the injection rates and temperatures resulted in highly irregular wellhead pressure plots. Any interference effects would be masked by this irregularity.

CONCLUSIONS

The responses of RRGI 6 and RRGI 7 to nonisothermal and variable temperature fluid injection lead to the following conclusions:

1. Decrease in injected fluid temperature results in a significant decrease in the wellhead pressure build-up.

2. The lower temperature fluid injections result in an increase in reservoir transmissivity.

3. The effects of viscosity changes are overrun by the changes in transmitting properties of the rock.

4. Specially designed variable temperature and nonisothermal injection tests and numerical modeling are needed to fully understand the relation between changing properties of fluid and rock.

ACKNOWLEDGEMENT

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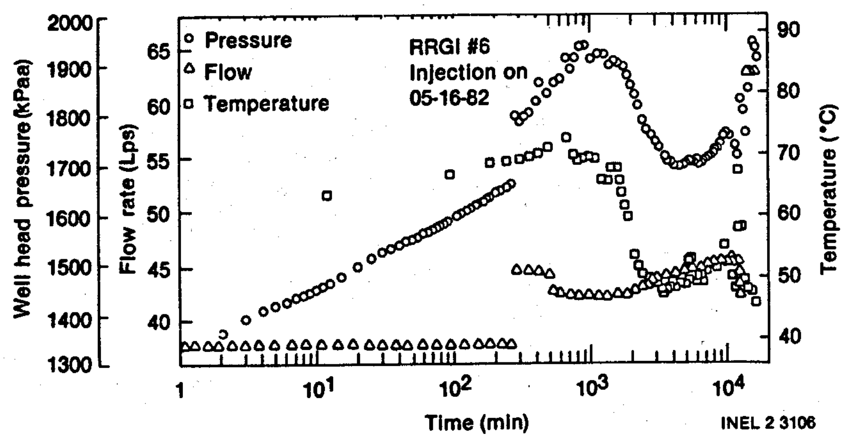

Figure 1. RRGI 6 injection data, test conducted 5/16-5/28, 1982.

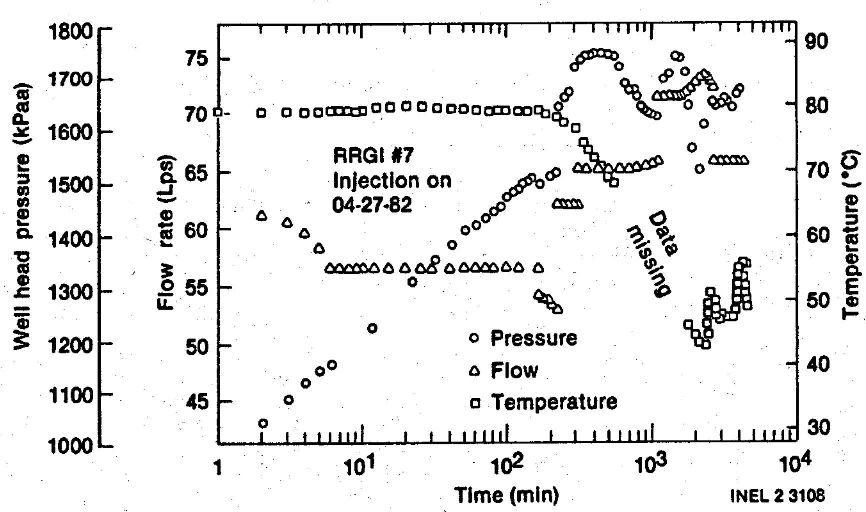

Figure 2. RRGI 7 injection data, test conducted 4/27-4/30, 1982.

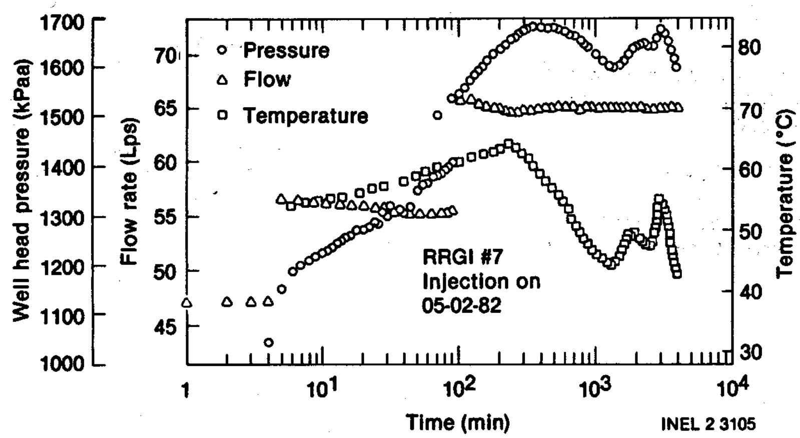

Figure 3. RRGI 7 injection data, test conducted 5/2-5/5, 1982.

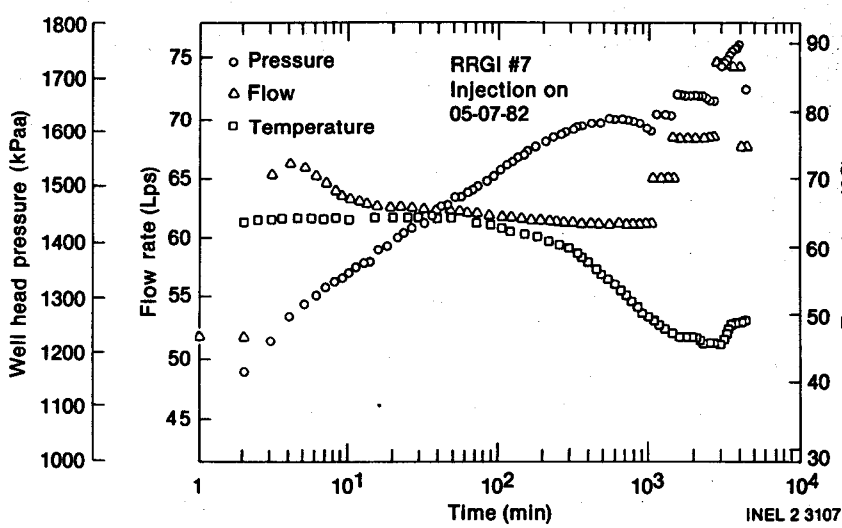

Figure 4. RRGI 7 injection data, test conducted 5/7-5/10, 1982.

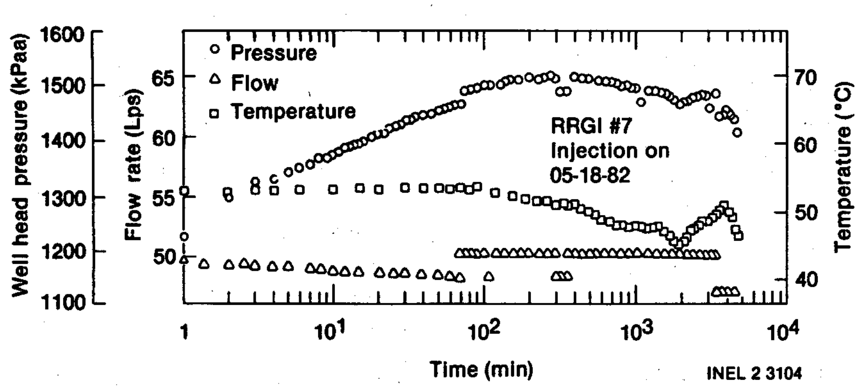

Figure 5. RRGI 7 injection data, test conducted 5/18-5/21, 1982.

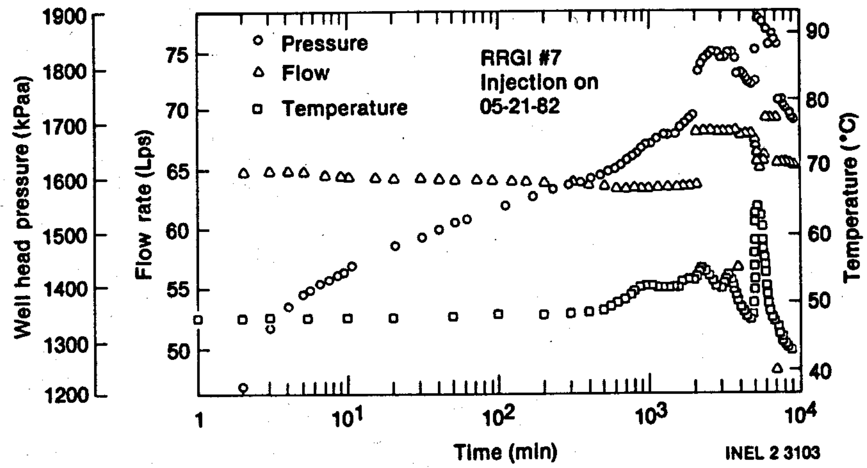

Figure 6. RRGI 7 injection data, test conducted 5/21-5/27, 1982.

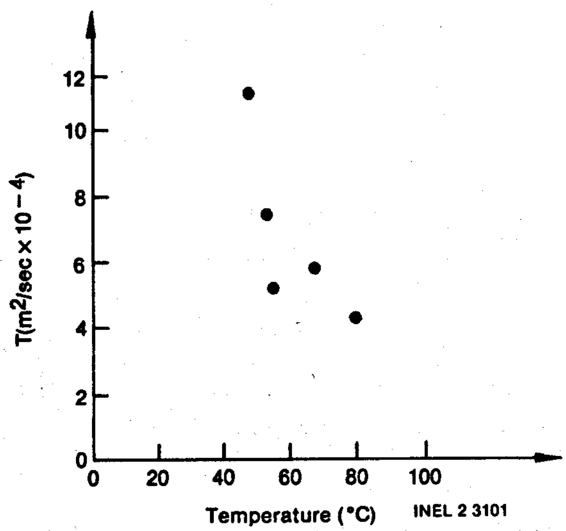

Figure 7. RRGI 7 transmissivity versus temperature

TABLE 1. TRANSMISSIVITY VALUES RRGI-7

Test Date	Injection Rate = Q (Lps)	Q/ΔP (Lps/Pa/log cycle)	Transmissivity (M^2/s)	Temperature (°C)	Remarks
4/27-4/30	56.5	2.40×10^{-1}	4.3×10^{-4}	80.0	Early time, temperature steady
5/02-5/05	55.8	2.93×10^{-1}	5.2×10^{-4}	56 to 59	Early time, temperature increasing
5/02-5/05	65.1	2.32×10^{-1}	4.2×10^{-4}	59 to 64	Temperature increasing flow slightly decreased
5/07-5/10	62.2	3.27×10^{-1}	5.8×10^{-4}	64	
5/18-5/21	49.5	4.13×10^{-1}	7.4×10^{-4}	53.2	Flow slightly decreased
5/21-5/27	64.5	6.45×10^{-1}	1.15×10^{-3}	48.3	Time 20 to 500 min. effected by recovery

*$T = 1.79 \times 10^{-3}$ Q/ΔP
*Units as shown in the Table 1

TABLE 2. WELLHEAD PRESSURE DECREASE DUE TO TEMPERATURE DECREASE

Test	Time Interval (min.)	Temperature change from-to; Δt (°C)	Wellhead pressure change; estimated, (kPa)	density effect, (kPa)	net (kPa)
RRGI 6 May 16-28	900-4500	70-49, 21	400	90	310
RRGI-7					
May 2-5	300-1400	64-45, 19	270	85	185
May 7-10	300-1000	60-50, 10	120	40	80
May 8-21	200-2000	525-45, 7.5	180	30	150