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EVALUATION OF TESTING AND RESERVOIR PARAMETERS IN GEOTHERMAL WELLS AT RAFT RIVER AND BOISE, IDAHO

D. W. Allman, D. Goldman
and W. L. Niemi

EG&G Idaho, Inc.
Idaho Falls, Idaho 83401

ABSTRACT

Evaluating the Raft River and Boise, Idaho, resources by pump and injection tests requires information on the geology, geochemistry, surficial and borehole geophysics, and well construction and development methods. Nonideal test conditions and a complex hydrogeologic system prevent the use of idealized mathematical models for data evaluation in a one-phase fluid system. An empirical approach is successfully used since it was observed that all valid pump and injection well pressure data for constant discharge tests plotted as linear trends on semilogarithmic plots of borehole pressure versus time since pumping or injection began. Quantification of the pressure response prior to 600 minutes is not always possible. Short-duration (<24-hour) injection or pump tests are conducted with the drilling rig equipment, and long-duration (21-day) injection and pump tests are then conducted with the permanent pumping facilities. Replicate instrumentation for pressure, temperature, and flow rates are necessary to ensure quality data. Water quality and monitor well data are also collected.

INTRODUCTION

Experience at the Raft River and Boise, Idaho, KGRAs has provided valuable insight into the problems of defining the hydrologic and thermal characteristics of a geothermal resource. These are moderate [272-298°F (133-148°C)] and low [172°F (77.8°C)] temperature resources which are being developed principally for power generation and space heating respectively. The principal objectives of an aquifer evaluation are to: (1) define drawdown-discharge or buildup-inflow relationship for each well, (2) determine the expected temperature trends, if possible, that will result for each well, (3) define the geochemical characteristics of the geothermal fluids and irrigation and potable waters in the vicinity of the resource, (4) determine the expected beneficial and adverse impacts of the project on the hydrologic system(s), (5) determine the life expectancy of injection wells as related to the physical and chemical characteristics of the injected fluid, and (6) obtain information on the resource that will minimize the development cost.

Data of suitable quality must be collected with the evaluation techniques used depending on the specific-site hydrogeologic conditions. It must be recognized that quantification of some of the hydrologic data may not be possible because of complicating test and hydrogeologic conditions. This paper presents some of the difficulties encountered in testing the Raft River and Boise KGRAs and describes methods used to obtain useful data.

PRETEST INFORMATION

Before testing the Raft River, Boise, or any other KGRA, information is required on the geologic, hydrologic, and hydrogeochemical characteristics of the geothermal resource and surrounding area. Information is also needed on well construction, pretesting construction, and the water level history of the production, injection, and monitor wells. The interpretation of apparent boundary effects and the response(s), if any, in the monitoring wells will be facilitated by background information on the principal subsurface features controlling the hydrothermal flow system(s) and any normal-temperature flow systems. Information on the hydrogeology can be obtained from drill cuttings, lost circulation zones, chemical logging of drill return fluids (McAtee, 1979), and cores. Borehole geophysical logs provide additional subsurface information on aquifers and aquitards.

Construction characteristics of all wells used in the evaluation program must be known, including construction methods and well development procedures. Well development information is particularly important in injection wells where testing will tend to force any mud or cuttings on the borehole wall into receiving zones. Casing schedules of all wells must also be known to determine the aquifer(s) affected by or monitored by each well.

All springs and accessible wells which penetrate a geothermal resource or surrounding aquifers should be monitored prior to and during aquifer testing for flow rate, temperature, and water quality. Physical parameters monitored at observation wells include, but are not necessarily limited to, wellhead pressure or depth to water, wellbore temperature profiles, and water chemistry. Fracture-flow dominated geothermal systems require monitoring at numerous positions in the hydrologic system(s) affected by resource utilization.

ANALYTICAL APPROACH

Field Conditions

Usually, the principal hydrologic objective is to predict the drawdown or pump inlet pressures that will result after pumping at a constant rate for a specified period of time. At the sites investigated to date, complex hydrogeologic field conditions preclude the use of a simple mathematical model to analyze data from production wells. At Raft River and Boise, Idaho, factors complicating the evaluation of aquifer test data are:

- More than one major producing or receiving zone results in commingling effects between zones.
- Turbulent flow is important in fractured producing zones.
- Distorted 3-dimensional drawdown surfaces result due to heterogeneity of producing and receiving zone(s).
- Multilegged wells are presumed to have drill cuttings in at least one leg.
- Laminar flow is probably more important than turbulent flow in receiving zones at Raft River.
- Fluids are injected at a temperature different from native fluids.
- Caving wells can result in temporally dependent well losses and hydraulic characteristics.
- Partial penetration of a receiving aquifer affects pressure buildup.
- Flow stabilization requires from 1.5 to 5 minutes after pump start-up.
- Wellbore storage changes affect initial test data from production wells.
- Drainage from the pump riser pipe into the wellbore can occur after pump shut-off.
- Pretest warm-up flow of 100 to 140 gpm (6.31 to 8.83 l/s) affects initial test data.
- Inaccurate wellhead shut-in pressure data results due to wellbore temperature-density effects.

ANALYTICAL METHOD

An empirical approach was used because of the complex and somewhat unknown boundary conditions. No simple theoretical method is known that will result in valid numeric values for all the parameters necessary to mathematically quantify the hydrologic system. The simplest empirical approach is to conduct constant flow pump and injection tests. At the Raft River and Boise KGRAs, it was observed that the wellbore pressure data appeared as straight-line segments, on semilogarithmic plots of pressure versus time, for all data collected at least 600 minutes after initiating pumping (fig. 1). A change in

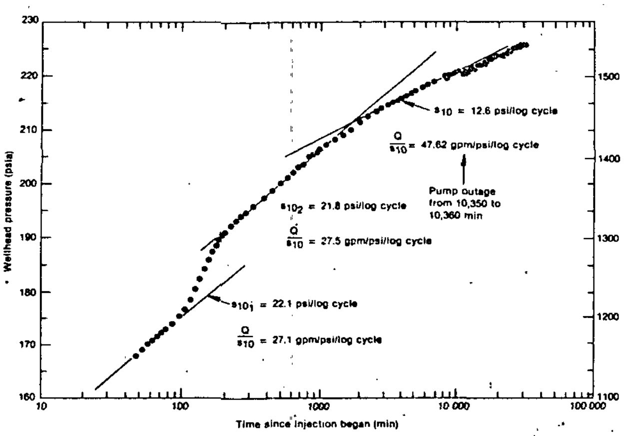

Fig. 1 Semilogarithmic graph of wellhead pressure buildup at RRGI-6 during 600 gpm test beginning March 20, 1979 vs time since injection began.

the slope of the data on a semilogarithmic plot could result from hydrologic discontinuities in the aquifer(s) penetrated, commingling effects between aquifers, temperature-induced changes in wellbore fluid densities, and changes in the receiving zone fluid temperature.

Complex hydrologic conditions must be presumed, until proven otherwise, to result in drawdowns that do not vary directly with the flow rate. Consequently, several constant-discharge or injection tests of sufficient duration must be completed throughout the range of the well's expected flow rates. Values for the ratio Q/s_{10} or $Q/\Delta s$, where Q is the flow rate and s_{10} and Δs are the drawdowns or buildups per log cycle, may be used to describe the slopes of the linear data segments. The techniques for summarizing the data to define the drawdowns after a specified period of pumping must be tailor-made to incorporate as much as possible of the data available for each well.

TEST PROGRAM

At the Raft River KGRA, initial well testing occurs with the drill rig on site. Production wells have sufficient wellhead pressure to permit approximately 100 psi (689 kPa) of drawdown before flashing occurs in the pipeline. If injection wells at Raft River had sufficient wellhead pressure to permit flow rates in excess of 100 gpm (6.31 l/s), the preliminary tests would be identical to those for production wells. Prior to testing, the wellbore fluid temperature is increased by flowing the well at approximately 100 gpm (6.31 l/s). If available, a downhole pressure-temperature probe is installed near the major producing zone. The wellbore warmup flow is generally terminated before a flow test and partial recovery is permitted. Recovery from warmup flows generally occurs within 30 minutes. Several one-hour pulse tests, with intervening recovery periods of the same duration as the discharge period, precede the longer-duration test, which is an 8- to 24-hour flow test with subsequent recovery. The results of these tests permit a preliminary evaluation of the well's water-yielding characteristics.

Initial Injection Tests

For wells with wellhead pressures inadequate to sustain a flow rate of 100 gpm (6.31 l/s) for one hour (all of the injection wells at Raft River), air lifting is followed by an injection test. Air lifting must continue until the water quality stabilizes (usually about three wellbore volumes). This is needed to get samples of formation fluid. Recovery data following the air lift tests have not resulted in acceptable estimates for well performance. The injection tests using the drill rig pumps consist of short-duration pulse tests followed by a constant rate test lasting from 8 to 24 hours. The temperature of the injection water is difficult to control, but should be as close as possible to that of the native fluids in the principal receiving zone. Care must be taken to prevent the injection of suspended and/or dissolved solids which could form a filter cake on the wellbore or plug the receiving zone(s) due to precipitation. The injection tests conducted to date using the drill rig pumps have resulted in satisfactory preliminary estimates of the well injectability.

Long-Term Pump and Injection Tests

Combined pump-injection tests are used whenever possible. Approximately four weeks of data are desirable for the period preceding the test and five weeks of data are desirable following a test. Pressure response lags on the order of four days are not uncommon in monitor wells. Prior to initiating high flow rates, the asbestos-cement pipelines must be preheated to prevent thermal shock in excess of 50°F/hr (28°C/hr). The preheat flow which continues for approximately seven days at 100-140 gpm (6.31 to 8.83 l/s) results in wellhead temperatures at the injection well of 180-210°F (82.2-98.8°C), while the production wellhead temperatures are between 230-270°F (110-132°C). Wellbore cooling-density effects often result in declining wellhead pressures after wellhead shut-in. The analytical errors caused by pretest flows are assumed to be negligible compared to errors introduced by other nonideal conditions for elapsed time of more than one-half hour after flow shut-in.

The long-term pump test program is similar to that for the initial pump or flow tests. A series of approximately two-three pulse tests of 1- to 24-hour duration are conducted to confirm drawdown predictions based on the initial injection or flow test data. The selected flow rate is generally close to the long-term production rate. Recovery data are collected with the wellhead completely shut-in if possible. Wellhead recovery data are generally collected until wellhead pressures decline due to cooling of the wellbore water. The long-term tests provide the basis for predicting well drawdowns during power plant operations.

INSTRUMENTATION

Rigid specifications on instrumentation resolution and accuracies have been found necessary for aquifer evaluation at the Raft River KGRA. Data collection specifications include continuous recording of flow (resolution ±1%, accuracy ±3% flow rate), pressure [resolution ±0.5 psi (3.4 kPa)], temperature [resolution 0.2°F (0.01°C)], well logs (prelog and post-log on-site tool calibration), and real-time geochemical data. Most resulting data exceeded the specifications, allowing confident analyses.

Control of flow rate of a single-phase fluid is critical in the analysis of well testing data. Current testing of RRGI-6 at Raft River has utilized an electro-hydraulically controlled Fisher flow control valve with Cavitrol One Trim. The flows appear to be controlled within <5 gpm (<0.2 l/s) on a 600-gpm (37.8 l/s) test. Beveled orifice plates with Fisher/Rosemont delta pressure transducers with adjustable full-scale outputs are used at both the production and injection wells. The pressure transducers have an integral square root extractor in the flow transmitter. Flow rate data are recorded continuously by a dual-pen Hewlett-Packard 7132A analog recorder and indicated on a digital readout whenever possible. The relative accuracy of the electronic system is checked by a dead-weight field-calibrated differential pressure gauge and by two Parascientific digiquartz pressure transducers, coupled to a Parascientific model 600 computer and a Hewlett-Packard 5150A thermal printer. Meriam model 1124 differential pressure gauges will be used which have resolution greater than 0.1 psi (0.7 kPa). The flow rate data are temperature-corrected. The combination of duplicate orifice plate duplicate differential pressure measurement devices at each site and duplicate recording/readout device at each site provide sufficient system replication to allow quality data collection throughout an entire test.

Flow rates during an injection test, using either drill rig positive displacement pumps or grouting contractor injection pumps, are determined by pump stroke rates. Pump malfunctions may result in erroneous flow rate data. A submerged weir in the supply water pond will be used in the future to verify the rate of fluid flow into the well.

Pressure data for aquifer evaluation are obtained at: (1) the wellhead in the pump riser pipe (2) the wellhead in the annulus around the pump riser pipe, (3) near the pump inlet in the annulus using a nitrogen bubbler system, (4) the bottom of the submersible pump, when used, and (5) a specified depth in a well using a downhole pressure-temperature probe. Data at locations 1 to 3 inclusive were obtained using Heise pressure gauges and intermittently with a Parascientific digiquart pressure transducer. The digiquartz system provid the base for the pressure data collection system. The only problem to date with the digiquartz system has been an apparent pressure lag at pressures less than 200 psia (1.38×10^6 Paa) following nitrogen purging on a bubbler system when using a 900-psia (6.20×10^6-Paa) pressure transducer. A Reda psi pressure-temperature unit mounted on the base of the submersible pump has provided limited data to date. Large steps in the pressure data limit the utility of the data. Downhole pressure data in wells without pumps have been obtained with a Hewlett-Packard temperature-compensated pressure probe. Temperature-induced errors in pressure result whenever temperature changes exceed 0.01°F/minute (0.006°C/minute). Several hundred minutes of injection are required to obtain valid pressure data. Invalid data also result during recovery. In general, three pressure-measuring devices at both production and injection wells have been necessary to provide quality pressure data during aquifer evaluation programs.

Temperature data are collected at the wellhea and downhole in both the production and injection wells. The best wellhead temperature data have been collected with a Fisher platinum resistance thermometer device (RTD) using a Hewlett-Packard 7132A dual-pen analog recorder with a 250-300°F (121-149°C) partial-scale range. Temperature changes on the order of 0.2°F (0.1°C) can apparently be resolved. Calibrated mercury thermometers having a resolution of 0.4°F (0.2°C) located at th wellheads provide a backup system for the RTD. In a production well having a submersible Reda pump, downhole temperature data can be obtained with a Reda psi pressure-temperature unit. The limited data collected to date appears to be accurate to ±3°F (±2°C). Downhole temperature trends in a wel without a pump can be obtained with an HP pressure-temperature probe. However, data collected to date indicate errors approaching 10°F (5.6°C). Downhole temperature data may also be obtained using borehole geophysical temperature logging equipment. Since it is not unusual to have errors of 15°F (8.3°C) in commercial temperature logs, discretion must be used when interpreting the data. On-site calibration with a hot oil bath is necessary if accurate data are required. With sensitive and accurate downhole and wellhead temperature data, quantification of the crucial thermal characteristics of the resource is possible.

Water quality data are also collected during testing; pH, oxidation-reduction, and conductivity have been continuously recorded at Raft River. A Balsbaugh model 910 conductivity probe has performed satisfactorily for 21-day tests. Water samples are periodically withdrawn from the pipeline at the injection well and determinations made for pH, conductivity, Cl, F, Ca, hardness, alkalinity, and Si. Suspended solids are determined at both production and injection wells using a 0.45-micron filter. Absolute values for water quality parameters as well as temporal trends are being monitored to aid in defining the geothermal hydrologic systems and to provide data used to determine the useful life of the well.

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REFERENCE

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