Geothermal Resources Council, TRANSACTIONS, Vol. 2 July 1978

APPARATUS FOR THE FIELD EVALUATION OF GEOTHERMAL EFFLUENT INJECTION

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Abstract

Methods for evaluating subsurface disposal systems, based on data derived from membrane filtration tests and core flooding experiments, have been described in the literature. Utilizing these techniques, we have developed and successfully tested equipment for evaluation of injectability of any geothermal effluent including hypersaline brine from the Salton Sea Geothermal Field (SSGF).

Work performed under the auspices of the U. S. Dept. of Energy, Contract No. W-7405-Eng.-48.

Introduction

Direct injection of low temperature effluents into porous media may not be feasible at many geothermal fields because of high suspended solids loading and resultant plugging of primary porosity in the reservoir. If effluents are supersaturated with respect to silica, calcite or other phases, scaling of the injection line or completion interval may also limit injection. Various pre-injection clarification techniques including settling, chemical pretreatment, reaction clarification and pressure filtration utilizing packed columns or precoat additives are currently being evaluated for use at the SSGF by Magma Power Company and Lawrence Livermore Laboratory. We are supporting these activities with filtration and core flooding tests to establish the relative injectability of effluents. Results of our preliminary analyses are reported elsewhere.[1-2]

Filter tests are useful in establishing the size distribution of suspended solids, the scaling potential of brine at the sand face, and in developing estimates of the useful lifetime of injection wells.[3-4] Tests are simple to execute, inexpensive, and are an efficient means of rapidly comparing injectivity of different effluents. Filter tests can also be used subsequently as a quality control monitor during full-scale operation of disposal systems[5]. Injection estimates derived from filter data generally pertain only to problems caused by particulate plugging or scaling, and estimates of injection well performance tend to be conservative because membrane filters with 0.45 μm pre size are normally used.

Core flooding experiments provide a means of studying the effects of brine-rock interaction on injection.[6-7a] Changes in core matrix properties resulting from particle invasion, chemical alteration, dissolution, precipitation, or authigenic mineralization can be resolved during subsequent analyses with the scanning electron microscope. While representative core samples from the injection interval are most desirable for testing they are not always available. Standard cores, matched with respect to reservoir rock composition, texture, porosity and permeability are often chosen for study. Subsurface disposal is assumed to be viable if 2 to 12 thousand pore volumes of effluent can be flowed through a core (typically 2.54 cm diameter and 10.16 cm long) at a representative flow rate with negligible permeability decline.

Apparatus

A schematic diagram of the prototype system for filtration and core flooding is shown in Figure 1. The system has the following capabilities:

a) Filter tests
b) Core tests with unfiltered brine
c) Core tests with filtered brine
d) In-line backwashing of membrane filters
e) Pumping capability for testing non-pressurized effluents
f) Brine-resistant flow monitor

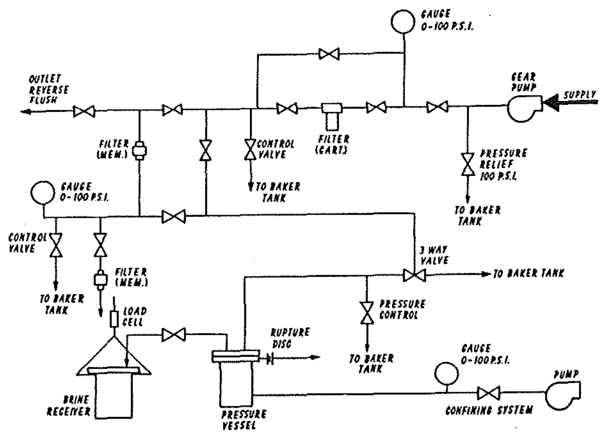

Figure 1. Filtration and Core Flooding Apparatus

The system was designed to minimize temperature flucuations and residence time as a means of controlling precipitation of extraneous solids during experiments. Temperature control was effected by insulating all piping and by-passing the total inlet brine flow to the system via pressure control valves located adjacent to the membrane filter and core pressure vessel. Corrosion-resistant 316 stainless steel tubing and valves with Teflon inserts were used exclusively to prevent formation of corrosion products that might bias test results. The brass covers of the cartridge filter housings were nickel-plated for the same reason. A pump was provided to permit testing non-pressurized effluents. We found that Oberdorfer model no. 2136 (10 GPM, 100 PSI) gear pumps with W88 gears and Teflon packing operate reliably for sustained periods at temperatures up to $100^{\circ}C$.

Filter Tests

Membrane filters are provided for particle size determinations, measurement of suspended solid concentration and for evaluation of injection well performance utilizing test procedures and analytical models developed by Barkman and Davidson.[3] For the latter application, 0.4 μm Nuclepore 47mm polycarbonate membrane filters, mounted in Nuclepore in-line holders, are operated at 50 PSI pressure differential for 60 minutes. Either membrane or fiber-wound cartridge filters are available as prefilters to establish minimum clarification criteria for successful operation of core samples. Manifolding is provided to permit in-line backwashing of membrane filters with hot brine clarified by flow through cartridge filters. During filter tests, input brine temperature is obtained with a calibrated thermocouple mounted on the respective filter input line.

Core Tests

The core flooding apparatus was modified after a design suggested by Piwinskii and Netherton. Core samples 2.54 cm in diameter by up to 15.24 cm in length are jacketed with TYGON tubing and emersed in an oil-filled 316 stainless steel pressure vessel. The vessel is rated to 5000 PSI and oil pressure is applied via a pump. In the original design, the vessel cover was fabricated from 1020 carbon steel. We found that these covers corroded rapidly on exposure to either brine or to the humid atmosphere at the test site. We subsequently replaced the covers with units fabricated from Ti-6Al-4V alloy, a material that has been shown to be compatible with SSGF brine at temperatures to $200^{\circ}C$.[14]

A schmatic diagram of the pressure vessel is shown in Figure 2. Oil temperature is automatically maintained with $\pm 2^{\circ}C$ of the desired temperature by a heating tape, wrapped around the pressure vessel, and its associated power supply and thermostat control. Core temperature is monitored via an oil-filled orifice tube that penetrates into the oil-filled portion of the pressure vessel. Input brine temperature is monitored with a calibrated thermocouple located on the pressure vessel input line.

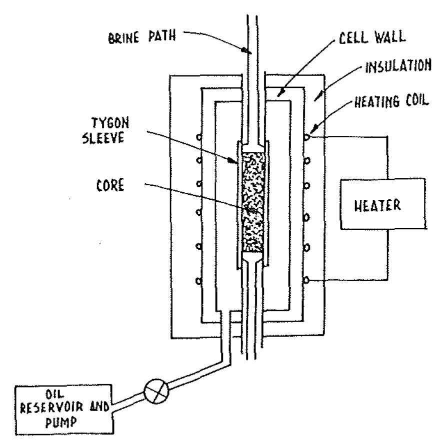

Figure 2. Schematic Detail of the Pressure Vessel

Each core sample is fitted with perforated inserts as shown in Figure 3. The inserts provide support and also simulated the completion interval in the injection well. Post run analysis of the inserts provides data on downhole slot or perforation plugging. Prior to a run, cores are evacuated for 30 minutes with a vacuum pump connected directly to the output line of the pressure vessel. This procedure insures rapid saturation of the core and eliminates possible brine-rock interactions that might occur if cores are saturated in salt solutions prior to exposure to geothermal brine.

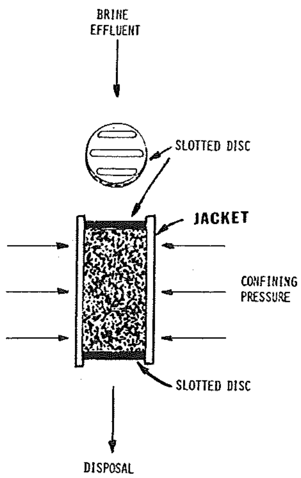

Figure 3. Schematic Detail of the Core Mount

Flow Monitoring

We designed a brine-tolerant flow monitoring system to avoid potential scaling problems that might influence the accuracy of conventional flow meters. Brine effluents from either cores or filters are stored in a container suspended from a load cell. The load cell output is continuously read with a digital voltmeter. Prior to runs, linear calibration curves are obtained by transferring known volumes of brine to the storage container and recording the corresponding load cell response. A schematic of the system and a typical calibration curve are shown in Figures 4 and 5, respectively.

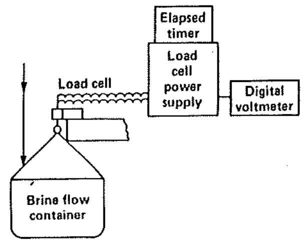

Figure 4. Flow Monitoring Equipment

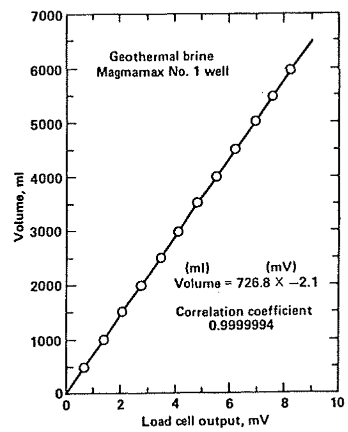

Figure 5. Typical Load Cell Volume Calibration

Testing Procedure

In establishing the relative injectability of various effluents, we first measure the concentration of suspended solids and particle size distributions with membrane filters. Water quality ratios and the effect of filter cake formation on injection well performance are then established after the method of Barkman and Davidson. We then began core tests initially utilizing either 0.45μm membrane or 1.0μm cartridge-type prefilters. Subsequently, other filters are substituted to establish core response to different concentrations and size distributions of suspended particulates. These tests are useful in establishing the minimum clarification requirements for injection.

It should be emphasized that the chemical stability of effluent should be known as a function of time prior to filter or core tests. If this information is unavailable, erroneous interpretation of test data may result because of the potential for additional precipitation following filtration or flow through a short length of core.

Conclusions

The prototype system works extremely well, but requires constant attention by an operator for data collection and periodic pressure adjustments; variations in input brine temperature, flowrate and pressure cause flucations in differential and confining pressures. We are modifying the system for unattended operation. The modifications which should be completed by early summer 1978 include automation of data acquisition and installation of pressure regulators. Data readout via a multichannel recorder will include input brine temperature, core temperature, differential pressure, confining pressure, load cell output and time.

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