PERMEABILITY OF KAYENTA SANDSTONE TO HYPERSALINE BRINE AT 10.3 MPa CONFINING PRESSURE AND TEMPERATURES TO 90°C*

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The ability to inject "spent" geothermal brine may be a critical and perhaps limited factor in the development of fluid-dominated geothermal resources. In order to understand and evaluate changes in formation permeability and porosity at depth as a result of injection of brine effluents, experiments were carried out (70°-90°C at 10.3 MPa confining pressure) in conjunction with the ongoing brine chemistry and materials evaluation effort at the Lawrence Livermore Laboratory Field Test Station located in the Salton Sea Geothermal Field, Imperial Valley, California.

SAMPLES, APPARATUS, AND EXPERIMENTAL METHOD

The sedimentary rock investigated was the Kayenta sandstone (Chan, 1977; Piwinskii and Netherton, 1977). Core samples (10.2 cm long, 2.5 cm diameter) were dried at approximately 80°C for 48 to 72 hours at a pressure of 10 kPa. After cooling, specimens were saturated with 1 M NaCl solution and stored under this solution in a desiccator. Core samples were jacketed with tygon and pressurized to 10.3 MPa (Piwinskii and Netherton, 1977). When the specimen attained thermal equilibrium, geothermal brine was admitted to the core and flow rates were measured at a series of differential pressures in order to establish that data were being collected in a laminar flow régime. Permeability was evaluated from $k = \eta QL/A[P_2 - P_1]$ (Wycoff et al., 1934; Muskat, 1937). P_2 and P_1, upstream and downstream pressure, respectively, were measured via Bourdon tube gauges, and Q, flow rate, was determined by noting the time of brine flow into a burette using a stop watch. Length (L) and Area (A) of the samples were measured and brine viscosity (η) was determined using a Brookfield LV viscometer with UL adapter (Piwinskii et al., 1977; Piwinskii and Netherton, 1977).

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EXPERIMENTAL RESULTS

Magmamax No. 1 brine, acidified in some cases upstream of the core sample, was the fluid used in the investigation. The experiments were conducted in three basic modes:

1) no filters operational upstream of the core,
2) one 10 μm cartridge filter operational upstream of the core,
3) one 10 μm cartridge filter and one 10 μm depth-type filter operational upstream of the core.

When the experiments were conducted with one filter or no filter in operation, the permeability calculated is a composite of the rock and a 2 to 3 mm thick filter cake composed of amorphous silica and iron which is formed on the top face of the core sample. The thickness of the filter cake is not fixed but is a function of time of sample exposure to the brine. All samples run in modes 1 and 2 show this type of cake buildup. As a result, it is very difficult to assess the intrinsic permeability of the sandstone, or the permeability of the sludge layer on the core face.

Data provided in Figure 1 indicate that the permeability of K-4 when conducted in mode 1 (no filters operational) decreased from 50 md to 1 md after 5.2 hours of flow of acidified brine (see Table 1 for inlet pH). Sample K-10 was run initially with two filters operational (mode 3). After approximately 1.6 hours of flow, the permeability decreased to 60 md. After removal of the disc filter, the permeability of sample K-10 decreased sharply from 60 md to 15 md after two hours flow of untreated brine (mode 2). When both 10 μm filters were inserted upstream of the core (mode 3), the permeability of sample K-A decreased from 700 md to 65 md after 1.5 hours of flow of brine which had been acidified to pH = 3.58 (see Table 1). It is interesting to note that after approximately 1.5 hours flow of filtered brine (see samples K-10 and K-A in Figure 1), 1360 pore volumes of pH = 3.58 brine flowed through K-A while only 421 pore volumes of pH = 5.8 (untreated) brine permeated sample K-10.

DISCUSSION

Unmodified Magmamax brine contained about 140 ppm suspended silica solids. In acidified brine, however, silica suspended solids concentrations were ≤15 ppm. Depending on pH, acidified brine effluents have long-term (20-200 hours) stability with respect to silica precipitation. In unmodified brine, suspended solids levels reach 300-400 ppm within two hours at 90°C. Rapid permeability decline occurred when *untreated and unfiltered* brine permeated sample K-4, and when *acidified and filtered* brine passed through samples K-10 and K-A (see Figure 1). The permeability loss exhibited by K-A deserves further comment. Data given in Table 1 reveal that the pH of brine leaving K-A is much higher than the incoming brine pH. This suggests that the rock's matrix calcite cement is being dissolved by the hot, permeating acid brine, thereby yielding a carbonated exit brine of high pH. Furthermore, the SiO_2 content of brine exiting the core sample is much lower than that of the entering brine (see Table 1). This suggests that precipitation of amorphous silica occurred in the sandstone, presumably decreasing the size of pore throats and causing permeability loss.

Some evidence exists that small calcite particles resulting from the dissolution of the matrix cement and/or colloidal silica deposits are plugging pore throats. Grens (1977) measured the particle size distribution in the Magmamax No. 1 brine as it exited Kayenta sample K-4 by means of a laser light-scattering particle analyzer. He found that there was a tremendous increase in particles in the 2 to 5 μm size range in brine which had flowed through Kayenta sandstone after 0.83 hours. This suggests that small calcite particles were being generated in large quantities and/or colloidal silica particles were precipitating from the permeating brine. The combined effect on permeability is clearly observed in Figure 1.

In summary, the data portrayed in Figure 1 indicate that large permeability losses occurred in Kayenta sandstone (porosity, 20.7 ± 1.66%) when *unfiltered, untreated* Magmamax brine and *filtered, acidified* Magmamax brine were the permeating fluids. In the former case, permeability decline was due to the accumulation of a thick filter cake on the top face of the core sample which was composed of amorphous silica and iron. In the latter situation, loss of permeability was caused by the precipitation of amorphous silica and generation of large quantities of calcite particles from the dissolution of the matrix cement. The experimental results thus show that if the Salton Sea Geothermal Field were composed of porous sedimentary formations similar to Kayenta sandstone, long-term injection of unmodified Magmamax brine is not feasible. In the case of acidified brine, most of the permeability decline may result from the mobilization of calcite. Additional experiments will be carried out in the future at lower flow rates to test the possibility of long-term injection of filtered, acidified geothermal brine.

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Table 1. Data on pH and SiO_2 Composition of Brine

	Kayenta Sandstone		
	K-4	K-10	K-A
Mean inlet pH	5.00±0.20	5.80±0.08	3.58±0.60
Mean outlet pH	5.95±0.35	5.65±0.09	4.78±0.24
Inlet SiO_2 composition of brine (ppm)	445	425	477
Outlet SiO_2 composition of brine after 0.38 hr flow (ppm)	---	267	---
Outlet SiO_2 composition of brine after 0.90 hr flow (ppm)	---	---	400
Outlet SiO_2 composition of brine after 3.55 hr flow (ppm)	---	172	---
Outlet SiO_2 composition of brine after 5.33 hr flow (ppm)	---	---	353
Outlet SiO_2 composition of brine after 15.75 hr flow (ppm)	181	---	---

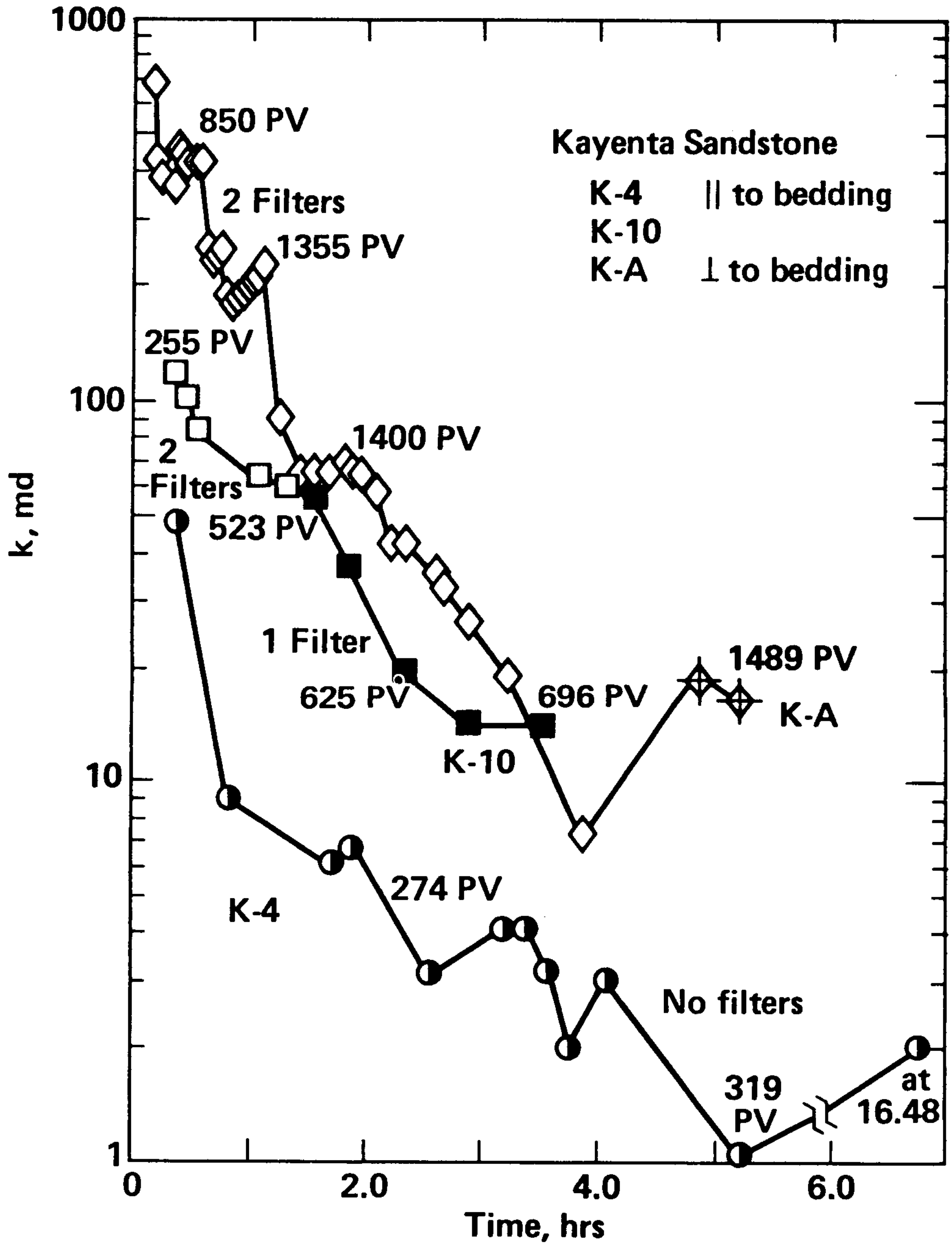

FIGURE LEGEND

Figure 1. Permeability of Kayenta sandstones, K-4 and K-10, parallel to the bedding, and K-A, perpendicular to the bedding, as a function of the total time of flow of brine through the core. Also plotted are the number of pore volumes (PV) of brine which passed through the core samples at the time indicated. Data on the mean pH and SiO_2 content of brine entering and leaving each core are given in Table 1.