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**Henry J. Ramey, Jr. and Paul Kruger, Editors**
**William E. Brigham, Ian G. Donaldson, Roland N. Horne,**
**and Frank G. Miller, Co-Principal Investigators**
**Stanford Geothermal Program**
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# DISCLAIMER

# An Evaluation of Geopressured Brine Injectability

L. B. Owen, C. K. Blair, *J. E. Harrar and *R. Netherton
Terra Tek, Inc., 420 Wakara Way, Salt Lake City, Utah 84108

## INTRODUCTION

New concepts for the high temperature/high pressure recovery of methane from geopressured brine have been developed by Lawrence Livermore National Laboratory (LLNL).[1-2] The primary objective of these methane recovery processes is to preserve sufficient hydraulic energy to drive the subsequent subsurface disposal of spent brine effluents at substantial reductions in operating and maintenance costs associated with use of injection pumps. However, a key element in determining the feasibility of the overall methane recovery process is the need to quantitatively establish injectability characteristics of geopressured brine at elevated temperature and pressure.

We have developed an apparatus with a capability for evaluating geopressured brine injectability at elevated pressures and temperatures. The apparatus utilizes membrane filters as injection zone reservoir analogs and permits injectability tests to be performed in accordance with Barkman and Davidson Methodology.[3] A field evaluation of geopressured brine injectability was completed during September 22-25, 1980 at the DOE, Brazoria test site in Texas. Membrane filters, with pore sizes of 0.4-μm and 10.0-μm, were used as the basis for obtaining suspended solids data and for developing performance-life estimates of typical spent brine injection wells. Field measurements were made at 130°C and line pressures up to 3800 psig. Scale inhibited (phosphonate-polyacrylate threshold-type, carbonate scale inhibitor), prefiltered-scale-inhibited, and raw (untreated) brine were evaluated. Test results indicated raw brine was highly injectable, while scale-inhibited brine had extremely low quality. The poor injectability of scale-inhibited brine resulted from partial precipitation of the scale inhibitor.

## INJECTABILITY TESTING METHODOLOGY

The most reliable method of establishing water quality in conjunction with full-scale injection tests is based on the use of membrane filters (and core samples) as analogs of the injection formation.[3-11] Membrane filtration data reveal the matrix permeability impairment potential of injected water resulting from scale formation or deposition of suspended solids. Loss of disposal capacity resulting from insufficient disposal formation volume, pre-existing skin damage, or other reservoir insufficiencies, however, cannot be directly identified by filtration tests.

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*University of California, Lawrence Livermore National Laboratory.

Similarly, factors which may favorably impact disposal capacity such as the presence of high permeability thief zones or fractures within the disposal interval cannot be directly accounted for by the membrane filtration methodology.

Selection of membrane filters with the appropriate pore size for the work reported here was based on an empirical method described by Champlin et al,[12] which permits calculation of mean formation pore size if formation porosity and permeability are known. We selected Nuclepore, polycarbonate, 10-μm pore size membrane filters as conservative analogs of shallow, high permeability disposal zones. Nuclepore, polycarbonate membrane filters with 0.4-μm pore size, were also used to obtain baseline suspended solids data and as conservative analogs of deep geopressured disposal zones where formation permeability might be less than 100md.

## TEST APPARATUS DESIGN

A schematic of the injectability test apparatus is shown in Figure 1. The test frame, based on previously field proven designs,[13-14] was connected, as a bypass system, to the main site flow system, shown schematically in Figure 2, via a suitably designed high pressure manifold. Injectability tests were carried out at constant differential pressure across the filtration membrane. Coarse and fine control valves were used to initially set and maintain differential pressure. Cumulative flow and instantaneous flowrate were obtained by direct measurement using 2 litre graduated cylinders. Flashing of the brine following passage through the membrane filter was prevented by use of a water-cooled, Inconel-600 heat exchanger upstream of the final control valve. All system piping was constructed from Inconel-600 high pressure tubing for adequate corrosion control. Valves and fittings were made of 316 stainless steel. The system was designed for in-line testing of geopressured brine at pressures and temperatures to 2000 psi and 150°C, respectively. Inclusion of the by-pass manifold permitted testing geopressured brine at wellhead pressure to 4000 psig.

## INJECTION WELL HALF-LIFE ESTIMATES

Half-life estimates for the Brazoria test site brine disposal well were calculated after the method of Barkman and Davidson[3] for a constant pressure drop process (Appendix I). The calculated half-life is the time required for the injection rate to decline to one-half of its initial value. Disposal well impairment was calculated for the cases of well bore narrowing and invasion. Well bore narrowing results when a filter cake forms on the sand face and then builds inward eventually partially filling the well bore. The invasion model accounts for penetration of the disposal formation by fine suspended solids which ultimately form an internal filter cake within the disposal formation. Relevant formation and injection parameters that form the basis for the half-life estimates are provided in Table 1. Half-life estimates are provided in Table 2.

Figure 1. SIMPLIFIED SCHEMATIC OF THE MEMBRANE FILTRATION INJECTABILITY TEST APPARATUS

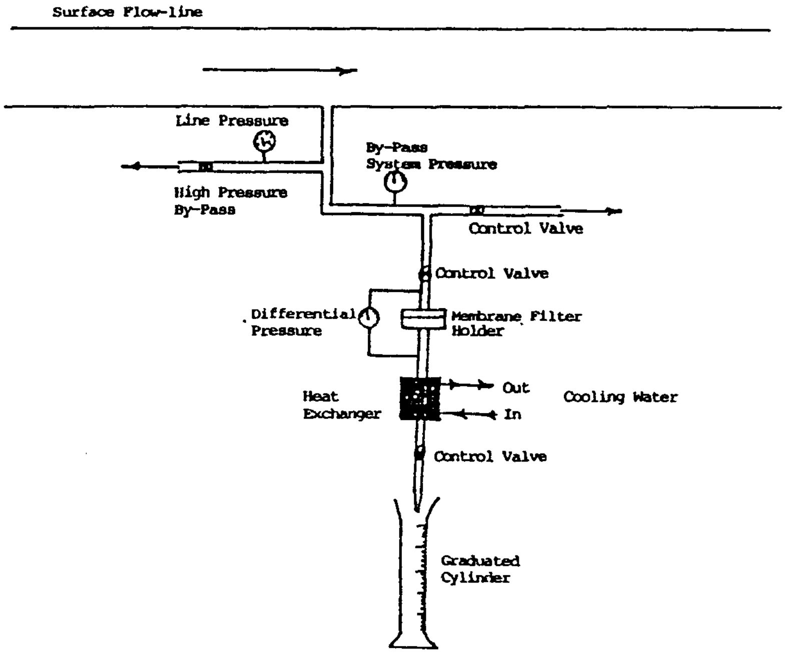

Figure 2. GENERALIZED SCHEMATIC OF DOE'S BRAZORIA GEOPRESSURED -GEOTHERMAL TEST SYSTEM

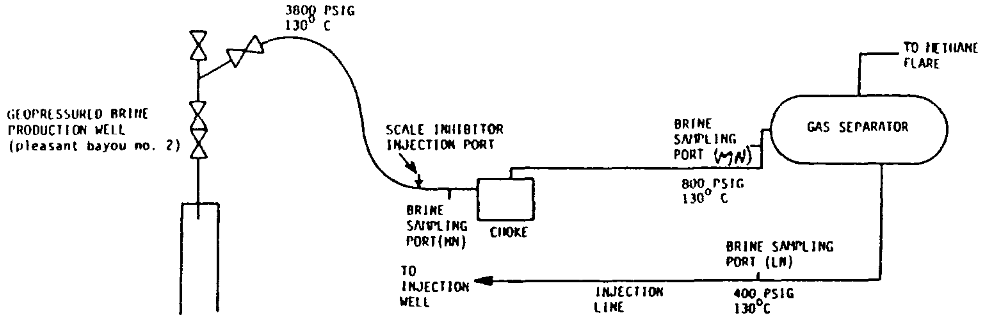

TABLE 1

ASSUMED DISPOSAL FORMATION AND INJECTION PARAMETERS: DOE'S BRAZORIA GEOPRESSURED-GEOTHERMAL TEST SITE

| | |
|---|---|
| Brine Temperature | 130°C |
| Brine Salinity | 13.5 wt % NaCl |
| Brine Density | 1.1 g/cc |
| Brine Viscosity | 0.32 cp |
| Injection Rate | 22,000 BBL/Day |
| Radius of Injection Tubing | 0.0699 m |
| Length of Injection Interval | 53 m |
| Injection Formation Permeability | 1000 md |
| Injection Formation Porosity | 20% |
| Radius of Effect | 182.9 m |
| Invasion Radius | 3.05 m |
| Filter Cake Density | 2.70 g/cc |
| Exposed Area of Membrane Filters | 13.2 $cm^2$ |

**Table 2.**

# INJECTION WELL HALF-LIFE ESTIMATES FOR THE DOE-BRAZORIA GEOPRESSURED TEST SITE

| Run | Date (Sept, 1980) | Membrane Filter Pore Size (µm) | 1 µm Cuno Cartridge Prefilter | Pressure (PSI) Source | Pressure (PSI) Memb. Filter | Membrane Filter ΔP(PSI) | Temperature (°C) Source | Temperature (°C) Filter | Scale Inhibitor (PPM) | Filtered Volume (ml) | Suspended Solids (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LN-1 | 22 | 0.4 | No | 360 | 360 | 50 | 130 | 90 | 50 | 2,598 | 10.0 |
| LN-3 | 22 | 10.0 | No | 350 | 350 | 50 | 130 | 90 | 50 | 2,920 | 6.0 |
| LN-5 | 22 | 0.4 | No | 360 | 360 | 50 | 130 | 107 | 50 | 1,920 | 6.8 |
| LN-7 | 22 | 10.0 | No | 360 | 360 | 50 | 130 | 122 | 50 | 2,300 | 8.7 |
| LN-11 | 23 | 10.0 | Yes | 300 | 300 | 0.03 | 130 | 126 | 50 | 39,490 | 0.05 |
| LN-13 | 23 | 0.4 | No | 370 | 370 | 50 | 130 | 119 | 50 | 1,620 | 14.8 |
| LN-14 | 23 | 10.0 | No | 400 | 400 | 50 | 130 | 115 | 50 | 1,610 | 9.9 |
| LN-15 | 24 | 10.0 | No | 400 | 400 | 50 | 130 | 115 | 50 | 1,960 | 8.0 |
| LN-16 | 25 | 10.0 | No | 400 | 400 | 0.03 | 130 | 130 | 0 | 28,310 | 0.021 |
| MN-1 | 23 | 0.4 | No | 800 | 800 | 50 | 130 | 112 | 50 | 2,530 | 13.5 |
| MN-2 | 23 | 10.0 | No | 800 | 800 | 50 | 130 | 120 | 50 | 3,340 | 11.8 |
| MN-3 | 23 | 10.0 | Yes | 760 | 760 | 0.03 | 130 | 129 | 50 | 36,000 | 0.031 |
| HN-1 | 24 | 0.4 | No | 3000 | 400 | 50 | 130 | 120 | 50 | 2,630 | 1.4 |
| HN-2 | 24 | 10.0 | No | 3000 | 400 | 5 | 130 | 128 | 50 | 19,300 | 0.067 |
| HN-3 | 24 | 0.4 | No | 3000 | 1000 | 70 | 130 | 119 | 50 | 4,320 | 0.69 |
| HN-4 | 24 | 10.0 | No | 3000 | 1000 | 0.1 | 130 | 130 | 50 | 13,540 | 0.27 |
| HN-5 | 25 | 0.4 | No | 3000 | 1800 | 50 | 130 | 120 | 15 | 4,620 | 1.3 |
| HN-6 | 25 | 10.0 | No | 3000 | 1100 | 1 | 130 | 120 | 15 | 5,360 | 1.3 |
| HN-7 | 25 | 10.0 | No | 3800 | 1500 | 20 | 130 | 125 | 50 | 10,110 | 0.41 |
| HN-9 | 25 | 10.0 | No | 3000 | 1000 | 1 | 130 | 127 | 50 | 5,850 | 0.48 |
| HN-8 | 25 | 10.0 | No | 3000 | 1000 | 0.03 | 130 | 129 | 0 | 31,000 | 0.026 |

| Filtration Curve Intercept (ml) | Filtration Curve Slope (ml/√min) | Water Quality (PPM/md) | kc (md) | F-Factor (22,000 B/D) | Gψ-Factor (No Invasion) | *Halflife (YRS) | Gψ-Factor (Invasion) | *Halflife (YRS) | Run |
|---|---|---|---|---|---|---|---|---|---|
| - 1.4 | 624.2 | 2801.2 | 0.0032 | 0.17 | | | 0.0061 | — | LN-1 |
| + 510.5 | 640.2 | 2662.9 | 0.0021 | 0.29 | | | 0.0038 | — | LN-3 |
| - 91.1 | 482.9 | 4680.3 | 0.0013 | 0.75 | $3.0\times10^{-}$[illegible] | — | | | LN-5 |
| + 365.3 | 534.9 | 3814.5 | 0.0021 | 0.20 | | | 0.0038 | — | LN-7 |
| -20627.2 | 13579.4 | 0.0036 | 12.8 | 34.4 | 0.27 | 9.3 | 20.8 | 717.3 | LN-11 |
| - 507.2 | 546.1 | 3659.7 | 0.0037 | 0.12 | 0.0001 | — | | | LN-13 |
| - 3.9 | 383.2 | 7432.5 | 0.0012 | 0.17 | $3.0\times10^{-}$[illegible] | — | | | LN-14 |
| + 71.8 | 462.1 | 5111.1 | 0.0014 | 0.22 | | | 0.0031 | — | LN-15 |
| -23497.7 | 14853.9 | 0.0030 | 6.4 | 81.9 | 0.14 | 11.8 | 11.0 | 902 | LN-16 |
| - 770.9 | 708.7 | 2173.0 | 0.0057 | 0.13 | 0.0001 | — | | | MN-1 |
| - 157.1 | 740.5 | 1990.9 | 0.0054 | 0.15 | 0.0001 | — | | | MN-2 |
| -29990.0 | 17009.7 | 0.0023 | 12.5 | 55.5 | 0.26 | 14.7 | 20.3 | 1129 | MN-3 |
| - 325.4 | 737.7 | 2005.5 | 0.00064 | 1.23 | $<1\times10^{-}$[illegible] | — | | | HN-1 |
| -17272.7 | 9090.9 | 1.32 | 0.046 | 25.7 | 0.0011 | 0.028 | | | HN-2 |
| - 1400.8 | 1447.2 | 729.6 | 0.00086 | 2.5 | $2\times10^{-}$[illegible] | — | | | HN-3 |
| +15300.0 | 833.3 | 3.14 | 0.078 | 6.4 | | | 0.14 | 0.89 | HN-4 |
| - 1587.0 | 1527.7 | 467.6 | 0.0025 | 1.3 | 0.0001 | — | | | HN-5 |
| - 2474.0 | 740.4 | 39.8 | 0.030 | 1.3 | 0.0007 | — | | | HN-6 |
| + 5250.6 | 944.0 | 409.9 | 0.0008 | 4.2 | | | 0.0015 | 0.0063 | HN-7 |
| + 4467.5 | 792.0 | 256.0 | 0.0017 | 3.6 | | | 0.0030 | 0.011 | HN-9 |
| -30202.8 | 15676.7 | 0.0027 | 8.9 | 66.2 | 0.20 | 12.8 | 14.9 | 985 | HN-8 |

* Half-life Estimates Denoted By — Are Less Than One Day

A summary of average suspended solids data for the Brazoria system is provided in Table 3. If we assume an average suspended solids concentration of 11.8 mg/l is supplied to the injection well at a brine flow rate of 22,000 BBL/day, then approximately 91 pounds of solids would be deposited in the injection well on a daily basis (16.5 tons per year). The suspended solids data suggest that about 24% of the suspended solids in the injection line are less than 10-μm in diameter.

The test results indicated, as shown in Figure 3, that brine treated with scale inhibitor had extremely low quality even after passage through the gas separator. Brine which was prefiltered with a 1-μm pore size Cuno cartridge filter had high quality. Ultimately it was demonstrated, by temporarily interrupting the injection of scale inhibitor, that the scale inhibitor itself was the cause of the poor injectability characteristics of the brine. Untreated brine had equivalent or higher quality than prefiltered scale-inhibited brine!

The solids collected on several of the membrane filters were analyzed by x-ray diffraction and by energy dispersive x-ray fluorescence (EDAX) in conjunction with scanning electron microscopy. When no inhibitor was being injected, the small quantity of solids were mostly silicon, perhaps sand from the formation, and some particles of $BaSO_4$. When the inhibitor was being injected, a large amorphous component was present in the solids, which was rich in phosphorous, calcium, sodium, and chlorine. This is a strong indication that the phosphonate inhibitor either precipitated directly or reacted with the brine calcium to form a precipitate, and in the process occuluded some of the brine NaCl. Calcite could not be identified in the solids from the brine being injected.

## CONCLUSIONS

Test results and subsequent analysis of filtered solids demonstrated conclusively that the threshold carbonate scale inhibitor, which was injected into the top of a two-phase (noncondensable gases-brine) mixture, upstream of the wellhead choke, caused precipitation of up to 15 ppm of suspended solids. The suspended solids carried through the gas separator and ultimately were deposited within the injection well and/or the injection formation. In the absence of scale inhibitor, the raw geopressured brine had extremely high quality.

Based on these results, it can be concluded that Brazoria brine has high injectability at pressures varying from 380 to 3800 psi, even after gas separation, provided scale control additives, if required, do not degrade brine quality.

It is of interest to speculate about the fact that the injection well at the Brazoria site (Pleasant Bayou No. 1) continued to accept low quality brine with a moderate rate of back-pressure buildup while half-life estimates predicted an extremely short operating life for the well. A plausible explanation for this apparent anomalous behavior is related to the rather unique completion of the injection well.

The injection well was originally designed as a production well. However, problems encountered during drilling necessitated plugging of the borehole back from 15,675 ft. to about 8,500 ft. The hole was then recompleted for use as a disposal well.

Our half-life estimates were based on an injection interval of about 160 feet. However, if brine was able to flow past the cement retainer, at the bottom of the completion interval, via an annulus behind the casing, then the actual injection interval could have been literally thousands of feet in length. Altering the injection interval length by a factor of 20 to 30 would be sufficient to yield much longer half-life estimates.

## ACKNOWLEDGEMENTS

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Figure 3. 10.0 MICRON MEMBRANE FILTRATION DATA
LOW PRESSURE INJECTION LINE
(380 PSI; 130C)

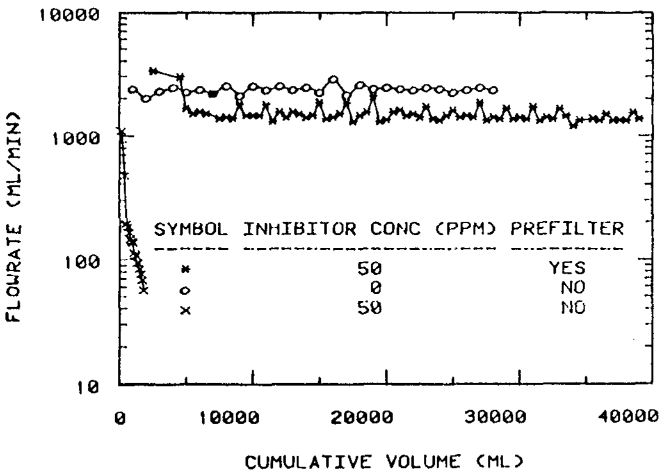

TABLE 3

SUMMARY OF SUSPENDED SOLIDS DATA FOR THE
DOE-BRAZORIA GEOPRESSURED TEST SITE

| Brine Source | Membrane Filter Pore Size (μm) | 1-mm Prefilter | Carbonate Scale Inhibitor (PPM) | Suspended Solids (mg/l) |
|---|---|---|---|---|
| LN-Series<br>Low Pressure Injection Line (400 PSIG; 130°C) | 0.4 | No | 50 | 10.8 |
| | 10.0 | No | 50 | 8.2 |
| | 10.0 | No | 0 | 0.02 |
| MN-Series<br>Moderate Pressure Production (800 PSIG; 130°C) | 0.4 | No | 50 | 13.5 |
| | 0.4 | Yes | 50 | 0.07 |
| | 10.0 | No | 50 | 11.8 |
| | 10.0 | Yes | 50 | 0.03 |
| HN-Series<br>High Pressure Wellhead (3800 PSIG; 130°C) about 5 feet upstream of scale inhibitor injection port | 0.4 | No | 50 | 1.1 |
| | 10.0 | No | 50 | 0.5 |
| | 10.0 | No | 0 | 0.03 |

## APPENDIX I: HALF-LIFE CALCULATIONS

$$T_{\frac{1}{2}} = (F)(G) \qquad (1)$$

where: $T_{\frac{1}{2}}$ = Injection well halflife

$$F=(1.723\text{x}10^4)\left(\frac{\pi \cdot r_w{}^2 \cdot h \cdot \rho_c}{i_o \cdot w \cdot \rho_w}\right) \qquad (2)$$

where: F = time to fill the wellbore with solids at the initial flow rate (years)

$r_w$ = wellbore radius (meters)

h = injection interval (meters)

$i_o$ = initial injection rate (STBD)

w = concentration suspended solids (μg/g)

$\rho_c/\rho_w$ = density ratio, filter cake: brine

Estimates of the permeability of filter cakes were developed from calculation of the water quality ratio given by:

$$\frac{w}{K_c} = (8166.11)\left(\frac{1}{S^2}\right)\left(\frac{2\rho_c A^2 \Delta P}{\mu \rho_w}\right) \qquad (3)$$

where: w = weight concentration of solids in water (μg/g)

$K_c$ = filter cake permeability (md)

S = slope of cumulative volume vs. square root of time (ml/√min) S is determined by linear regression of the linear portion of the filtration curve.

$\rho_c$ = bulk density of filter cake (gm/cm³)

$\rho_w$ = density of water (gm/cm³)

A = exposed area of filter cake (cm²)

ΔP = total pressure differential across filter (psi)

μ = fluid viscosity (cp)

Equations yielding exact G-factors for wellbore narrowing and invasion are given in Reference 3.