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**VISCOSITY OF BRINES FROM THE SALTON SEA
GEOTHERMAL FIELD,
IMPERIAL VALLEY, CALIFORNIA**

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ABSTRACT

We measured the viscosity of chemically analyzed brines from the Salton Sea Geothermal Field from 5 to 90°C at 100 kPa. Data indicate that these mul-

ticomponent solutions are slightly more viscous than a 3.5 molal NaCl solution in this temperature interval.

INTRODUCTION

Very little information has been published about the transport properties of multicomponent, geothermal brines such as those from the Salton Sea Geothermal Field (SSGF) listed in Table 1. Yet viscosity is particularly critical if heat extraction or reservoir flow characteristics from brines are to be

calculated.

This paper reports viscosities of brines from the Woolsey and Magmamax No. 1 wells in the SSGF (Fig. 1) from 5 to 90°C at 100 kPa (atmospheric pressure). Partial chemical analyses and densities of brines measured are provided in Table 2.

EXPERIMENT APPARATUS

All SSGF brines were collected at approximately 85°C, cooled, filtered to remove suspended solids, then measured in a Brookfield* 4-speed, synchronous LV viscometer equipped with a UL adapter

(see Figs. 2 and 3). During its operation, the instrument was mounted above a Colara constant-temperature bath capable of a maximum temperature of 100°C. All viscosity measurements were made either in an enclosed transportainer or in a trailer located approximately 30 meters from the Magmamax No. 1 wellhead. Temperatures were controlled to $\pm 0.5^\circ\text{C}$ during viscosity measurements. According to the manufacturer (Brookfield Engineering Co.), viscosities are accurate to $\pm 1\%$.²

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Energy Research & Development Administration to the exclusion of others that may be suitable.

Table 1. Changes in brine composition during production of Magmamax No. 1.^a

	Date taken			
	6/29/76	6/30/76	8/8/76	8/10/76
Temperature (°C)	200	214	230	215
Pressure (psig)	225	240	320	235
Composition (ppm by weight):				
Lithium			128	135
Sodium	40,900	42,100	41,200	42,700
Silicon	181	187	190	200
Potassium	6,900	7,000	6,600	6,500
Iron	202	161	199	180
Copper	1	1	1	1
Barium	54	85	115	118
Magnesium	125	125	95	99
Zinc	188	183	275	285
Strontium			360	373
Tin	23	23		
Aluminum				< 1
Chlorine	101,000	105,000	111,000	112,000
Calcium	17,400	16,900	17,900	18,200
Manganese	502	494	565	570
Antimony	4	4		
Lead	22	22	60	59
pH		5.7	5.8	6.1
Oxidation-reduction potential				
(mV vs H ₂)			192	177
Density (g/cm ³)	1.12	1.12	1.13	1.14
Total solids (g/kg brine)				
by evaporation	169	171	197	196

^aSteam quality 10%. Concentrations have not been corrected for flashing. Brine samples were obtained from the LLL separator. Data were obtained from Hill *et al.* (Ref. 1).

Table 2. Partial chemical analyses, density, and ionic strength of filtered brines from Magmamax No. 1 and Woolsey wells.^a

Species	Untreated Magmamax No. 1, July 9, 1977		Acidified Magmamax No. 1, pH = 3.4		Woolsey wellhead, June 9, 1977		Woolsey, U.S. Bureau of Mines, July 9, 1977	
	µg/ml	Molarity	µg/ml	Molarity	µg/ml	Molarity	µg/ml	Molarity
Cl ⁻	8.8×10^4	2.8	8.6×10^4	2.8	8.0×10^4	2.6	7.0×10^4	2.2
Na ⁺	5.9×10^4	5.4	5.2×10^4	4.7	5.1×10^4	4.6	4.0×10^4	3.6
K ⁺	8.8×10^3	0.2	8.7×10^3	0.2	1.0×10^4	0.3	7.2×10^3	0.2
Ca ⁺²	2.2×10^4	0.6	2.1×10^4	0.5	2.2×10^4	0.6	1.8×10^4	0.4
Density (g/cm ³)	1.14	—	1.14	—	1.13	—	1.11	—
Ionic strength	4.73	—	4.25	—	4.38	—	3.42	—

^aAnalyst: S. Deutscher.

Fig. 1. Location of geothermal wells in the Salton Sea Geothermal Field. Base map is from a U. S. Geological Survey topographic map. Well information was supplied by the California Division of Oil and Gas.

Fig. 2. Brookfield LV viscometer with component parts and constant-temperature bath.

Fig. 3. UL adapter assembly for Brookfield LV viscometer.

EXPERIMENT RESULTS

Prior to measuring viscosities of the filtered SSGF brines, we measured the viscosity of 1 *M* NaCl, 3.5 *M* NaCl, and Barnstead distilled water. Data presented in Fig. 4 show that, above approximately 45°C, evaporation causes the viscosities of the 1 *M* NaCl solution that were measured in open beakers to yield erroneous results. To minimize these high-temperature evaporative losses, we covered our containers with specially machined, tightly fitting plastic lids. Furthermore, after consultation with the manufacturer, we ran approximately 34-55 kPa of argon through the top of the

viscometer to prevent volatile vapors evaporating from the heated solutions from damaging the beryllium-copper spiral spring in the viscometer housing (see Figs. 2 and 3). The results of these modifications are illustrated by closed-beaker data in Fig. 4. However, despite these precautions, we could not obtain reproducible data above approximately 65-70°C.

After measuring the viscosity of 1 *M* NaCl, we measured the viscosities of 3.5 *M* NaCl, Barnstead distilled water, and filtered brine from the Magmamax No. 1 and Woolsey wells. Results of

Fig. 4. Viscosity of 1 M NaCl solution as a function of temperature. 1 cP = 1 kPa·s.

Fig. 6. Viscosity of filtered Woolsey and Magmamax No. 1 brines as a function of temperature. 1 cP = 1 kPa·s.

these measurements are portrayed in Figs. 5 and 6, respectively. Two points are noteworthy:

- Viscosities obtained for distilled water and 3.5 M NaCl are systematically higher than published values for these solutions plotted in Fig. 5.

- Viscosities of SSGF brines from the Woolsey and Magmamax No. 1 wells are similar, and both are higher than for 3.5 M NaCl.

The first point indicates that a systematic error was present in all our measurements. As a result, we could not use the viscometer as an absolute instrument. Using the above standards for comparison and taking advantage of the linear relationship between the log of the viscosity and the reciprocal of the temperature in the Arrhenius plot of Figs. 5 and 6, we corrected the raw data in Fig. 6 to obtain the viscosities shown in Fig. 7. Clearly, both untreated and acidified Magmamax No. 1 brines are slightly

Fig. 5. Viscosity of distilled water and various salt solutions as a function of temperature. 1 cP = 1 kPa·s.

Fig. 7. Corrected viscosities of Magmamax No. 1 brines as a function of temperature. 1 cP = 1 kPa·s.

Fig. 8. Viscosity of various salt solutions, Magmamax No. 1 brine, and Woolsey brine as a function of ionic strength at 30°C and 80°C. 1 cP = 1 kPa·s.

more viscous than a 3.5 molal NaCl solution, and substantially more viscous than water in the temperature interval 5 to 90°C. This has important consequences in any theoretical calculation which uses viscosity as an input variable.

A more explicit relation between brine composition and viscosity is shown in Fig. 8, which plots viscosity as a function of ionic strength at 30°C and 80°C. These data suggest that, if complex natural brines are analyzed for major constituents, viscosities can be estimated fairly accurately within the measured temperature interval.

CONCLUSION AND RECOMMENDATION

We measured the viscosity of chemically analyzed brines from the Salton Sea Geothermal Field from 5 to 90°C at 100 kPa. Because of evaporation problems, we could not obtain reproducible data above approximately 65-70°C. Corrected data indicate that the untreated and the acidified

Magmamax No. 1 brines are slightly more viscous than a 3.5 molal NaCl solution. Because viscosity data on geothermal brines are unavailable for higher temperatures, future studies should extend these measurements to 300°C.

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