

STATUS REPORT

**IMPROVEMENT OF SWEEP EFFICIENCY AND
MOBILITY CONTROL IN GAS FLOODING**

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ABSTRACT

Improvements for gas flooding require techniques to alter gas flood profiles to improve sweep efficiency. One method is the application of a blocking agent to reduce flow through high permeability zones. Potentially, polymer precipitation could be one mechanism to restrict or block areas of high permeability of a reservoir. Investigations were conducted to determine if polymers could be precipitated from polymer solutions by saturation with CO₂. However, no precipitation was observed from polymer solutions at CO₂ pressures ranging from 1,500 to 2,200 psig. Precipitation was observed from solutions with divalent cations. Polymer precipitation was the result of instability with salts rather than reaction to CO₂ saturation.

Another task was the construction of a large diameter radial coreholder for foam studies. A 12-in.-diameter coreholder was constructed of clear plastic materials to allow visual observation of fluid movement on the top and bottom surfaces.

INTRODUCTION

In gas flooding EOR, operators typically use one of several methods to inject foam into a reservoir to control the mobility of the gas. One method involves injecting pregenerated foam. This is accomplished by mixing the surface active agent (foamer) and the gas either at the surface or downhole and passing them together through a foam generator,¹ or a shearing device. Some operators do this to ensure that foam is generated. Another method is coinjection of gas and surfactant foamer, allowing the fluids to mix and shear as they enter the wellbore face where, presumably, foam is generated. Still another method, preferred by many, is to inject a slug of liquid foamer into the well and chase it with gas. In all the above mentioned cases, foam will exist at the wellbore face and in the reservoir immediately surrounding the wellbore face. Indeed, foam can be used as a near-wellbore treatment by decreasing injectivity into high-conductivity thief zones. In all cases, a wellhead injection pressure increase, due to the significantly decreased gas injectivity, is considered an indication of successful foam generation. However, decreases in injection rate may reduce or eliminate profitability of the EOR scheme when reduced flow rates correspond to reduced oil production rates.

Another goal of this research program was to increase gas injectivity at the wellbore during foam flooding without decreasing beneficial mobility-control effects of foam generated away from

the wellbore. To understand the problem and why this region is so important, one must first study the physical phenomena of radial flow. An experimental radial coreflood program was designed in which injection sequences and slug sizes of the different fluids were varied to determine their effects on gas injectivity and foam generation and propagation. A series of experiments was conducted in a 6-in.-diameter core in FY90. Also, a radial flow model describing the transport of surfactant in porous media was developed. In FY91, a larger diameter (12-in.) core was built for the radial coreflood test (Task 5, DOE Project BE5B).

Another unique approach to improving sweep efficiencies of injected gases proposed for FY91 was based on the premise that the solubilities of certain polymers are reduced by orders of magnitude in the presence of CO₂. When properly placed, this precipitated polymer would effectively block the flow of injected gas from the high permeable zone and improve the sweep efficiency of the overall process. Because polymer injection is a well established procedure in the field, little difficulty is anticipated in applying this technology once a suitable polymer is found. So, although designated as a mid-term task, this technology could become a near-term solution to a difficult problem if a suitable polymer is quickly identified. This procedure would then be implemented in a field test as a means of transferring the technology to oilfield operators.

Results of investigations are summarized in this report on the potential for polymer precipitation to improve sweep efficiency (Task 4, DOE Project BE5B).

Work accomplished for Tasks 1, 2, and 3 for DOE Project BE5B are not included in this status report. These tasks are presented in Topical Report No. NIPER-559.

SCOPE OF WORK

Task 4: Laboratory experiments to investigate polymer precipitation by CO₂

The objective of this task was to investigate the potential applications of polymer precipitation for CO₂ sweep efficiency improvement. Experiments were designed to study the phase change of polymer solutions with respect to the solution pH-value, salinity, and divalent ions.

The effect of pH on polymer precipitation was investigated for DOW Pusher 700 polymer solutions. Solutions of the polymer (500 and 1,000 ppm) in deionized water were titrated with 1N HCl. Polymer precipitation occurred at a pH of 2.49 for the 500 ppm solution and 2.67 for the 1,000 ppm solution. The addition of 1% NaCl slightly increased the pH at which polymer precipitation occurred. Also, the addition of 1% NaCl decreased solution viscosities from 6.03 to 2.23 cP for the 500 ppm solution, and from 9.69 to 4.35 cP for the 1,000 ppm solution.

The effect of CO₂ on polymer precipitation was tested at 2,000 psig and 120° F. The polymer solution (1,000 ppm Pusher 700 in deionized water) was placed in a high pressure PVT cell; CO₂ was then injected into the cell and compressed to the testing pressure. The polymer solution was circulated from the bottom of the cell through a filter (0.5- μ m) to the top of the cell.

The pressure difference across the filter was measured during the circulation of the polymer solution. No increase in the differential pressure was measured across the filter. After 2-days of circulation, the polymer solution in the PVT cell was then allowed to flow out through the filter. The filter was blocked after flowing 50 mL of the polymer solution, and a polymer film was found in the filter. Viscosity measurements on the solution before and after CO₂ saturation showed a drop from 8.6 to 1.0 cP.

Another experiment to test the possibility of CO₂-induced polymer precipitation was conducted in a high pressure PVT cell. A polyacrylamide-water solution of 1,000 ppm concentration was saturated in the PVT cell under 1,500 psig pressure at 120° F. After 1 week, no precipitation was observed at these conditions. However, if salts (CaCl₂ and MgCl₂) were added to the polymer solution (no CO₂), precipitation occurred after several days. Other tests were conducted using a 70% hydrolyzed polymer solution that contained 10,000 ppm Cypan in deionized water. Polymer precipitation was immediately formed by titration with CaCl₂ and MgCl₂ at ambient conditions without CO₂. However, no precipitation was observed in the PVT cell when the polymer solution (70% hydrolyzed, no divalent ions) was saturated with CO₂ under pressures ranging from 1,500 to 2,200 psig and temperature from 120° to 160° F without adding any divalent ions. From these tests, it was concluded that polymer precipitation is generated by salting out by divalent cations.¹

Task 5: Design and construct apparatus for measuring foam flow using cores of large diameter.

A 2-in.-thick by 12-in.-diameter radial core was cut and machined from Berea sandstone core to be used for radial coreflood studies. A coreholder was fabricated from clear nylon stock. The coreholder, constructed of clear plastic materials, allows visual observation of fluid movement on the top and bottom surfaces. Also, the coreholder was designed to allow cores to be changed if necessary. Pressure taps were installed at 1, 2, 3, and 5 in. from the center of the core to allow for measuring radial differential pressures across the core.

The radial core assembly was initially tested with a dye-colored brine to permit visual observation of fluid movement and radial flow patterns. The brine flood also was recorded with a VCR camera. Although observations are limited to the upper and lower surfaces, clear indications from visual observations show that fluid flows through the core in a nonideal sweep geometry. An uneven flow distribution was observed in frontal boundary. The unsymmetrical flow pattern likely was due to variations and changes in porosity and permeability of the core.

After saturation of the core with brine, a 0.2 PV of surfactant was injected. The surfactant was 1 % alpha olefin sulfonate in a 2% KCl brine. Nitrogen was then injected at a low pressure (3 psi) to produce a foam flood. Foam was observed principally around the perimeter of the core, and no foam was observed on the core surfaces toward the gas inlet in the middle of the core.

Probably, the nitrogen flowed and channeled inside the core until reaching the perimeter of the core. Also, pressure differentials were monitored in three segments across the core. Most of the pressure drop was located in the middle third of the core with only small differential pressures in the inner and outer third of the core. The experiments were conducted to demonstrate the operation and visual observation of flow patterns with large diameter radial corefloods. Visual observations provided information on flow variations caused by core heterogeneities.

Other Work Related to DOE Project Number BE5B

Recently, an electromagnetic or piston-style viscometer was acquired for use in gas flooding projects at high pressure and temperature conditions. The capabilities of the viscometer include measuring liquid viscosities at pressures to 10,000 psi and temperatures to 400° F. The principle of operation is based on a technique in which a magnetic force is applied to a piston immersed in a test fluid. The motion of the piston is a measure of the viscous drag of the piston, and the piston travel time over a predetermined distance is a measure of the absolute viscosity. The sensor of the viscometer contains two coils to magnetically force the piston back and forth inside the measurement chamber and to measure piston travel time. The stroke is about 0.3 in., and the cycle time varies between 1.3 and 26 seconds, depending upon the viscosity of the fluid. The viscometer has four viscosity ranges: 0.1 to 2.0, 1.0 to 20.0, 10 to 200, and 100 to 2,000 cP. Each range requires a different piston and calibration.

The viscosity of most fluids is strongly dependent upon the fluid temperature. Because the sensor contains electrical coils, operation of the sensor generates heat which increases the temperature of the measurement chamber. A linear resistance temperature detector built in the sensor allows for temperature measurements of the viscosity chamber. For these tests, sensor temperatures measured about 4° to 6° C above the test temperature. When using this device, to permit heat transfer and stabilization of the liquid and sensor temperatures requires about 15 to 30 minutes.

Some initial tests were made at ambient conditions to test the accuracy of the device. The results are shown in Fig. 1 for a variety of liquids in the range of 0.3 and 1.8 cP where measurements of different liquids are compared with viscosity data from the literature.²⁻³ As shown in Fig. 1, there was a reasonably good comparison between the viscometer measurements and the literature values for different liquids.

The viscosity of two liquids also was measured at higher pressures and temperatures. Fig. 2 shows the results of measurements for 2-ethylhexanol with pressures ranging from atmospheric to 3,000 psig at 35.7° and 39.7° C. The sensor viscosity range for these measurements was 1.0 to 20 cP. Data were not available in the literature for the temperature range of these results.

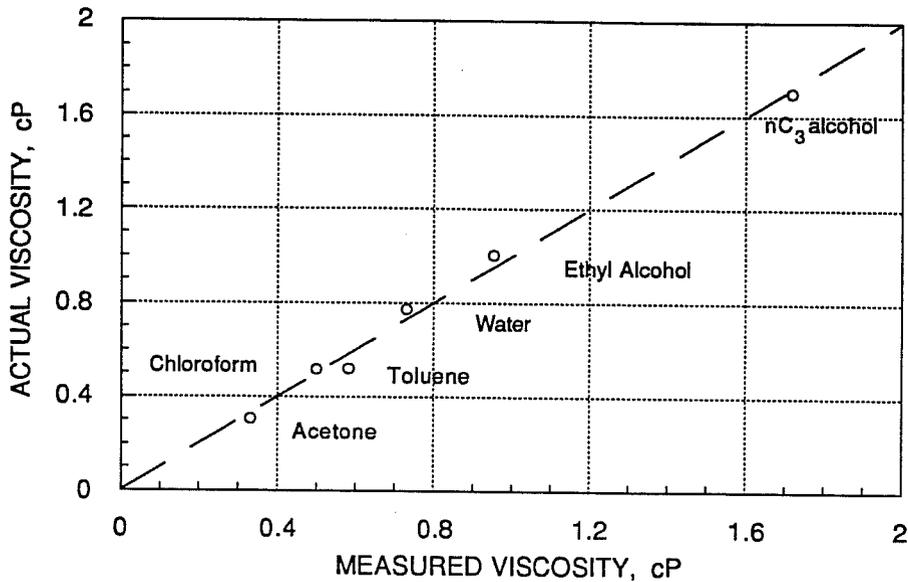


FIGURE 1.- Viscosities of different liquids measured at atmospheric pressure and temperatures ranging from 28° to 31° C. These are compared with the liquid viscosity extrapolated from the literature¹⁻² to the measurement temperature.

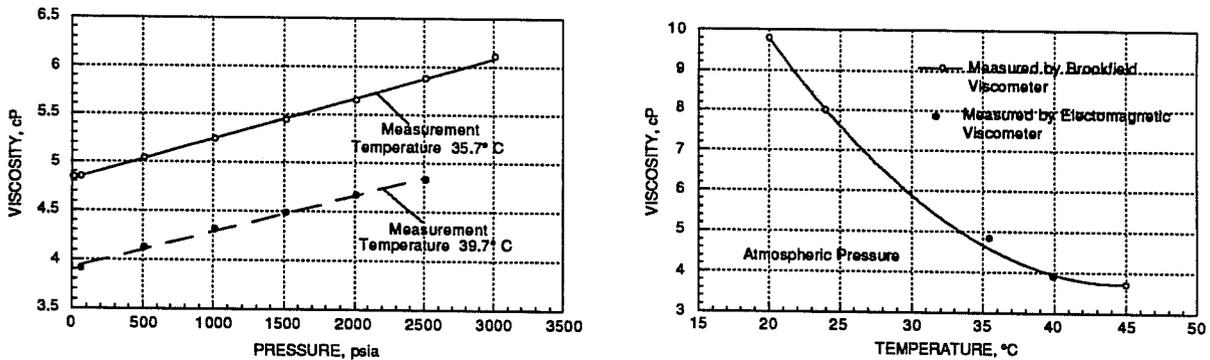


FIGURE 2.- Viscosity measurements of 2-ethylhexanol for changes in pressure and temperature.

Therefore, viscosity measurements were made with a Brookfield viscometer for comparison, and the results are shown in Fig. 2. The results show a linear increase in viscosity with increasing pressure, and measurements of the two viscometers indicate good agreement.

Other measurements were made for the lowest viscosity range of 0.1 to 2.0 with isooctane. These results, compared with literature data,⁴ are shown in Fig. 3. The viscosity measurements made with the piston viscometer were about 0.05 to 0.07 cP or about 10 to 15% higher than the

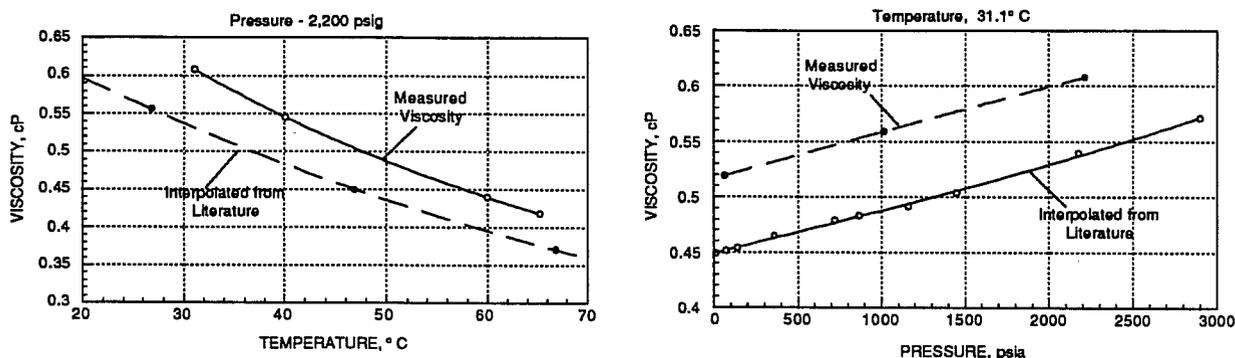


FIGURE 3 - Viscosity measurements for isooctane for changes in temperature and pressure.

literature values. However, the curves for the two data sets are closely parallel for changing pressure with about a 15% discrepancy. The viscometer appeared to accurately measure the change in viscosity although the absolute viscosity was in error. With changing temperature, the difference ranged from about 15% at 31° C to about 10% at 60° C. The reason for viscosity discrepancy at this low viscosity range was not apparent. However, the most reasonable explanation was the frictional drag of the piston on walls of the measurement chamber. The drag becomes proportionately greater when compared with viscous resistance at these low viscosities.

In summary, the electromagnetic viscometer provides a capability for measuring viscosities at high pressures and temperatures. This will be a valuable device for studies at these conditions. One disadvantage of the device is the increase in temperature above the process or test temperature. It may be possible to partially immerse the sensor in a liquid at the test temperature to facilitate heat transfer and minimize the increase in temperature of the sensor. Also, less absolute accuracy was measured for liquids at low viscosities. However, the viscometer would still be useful to indicate relative viscosity changes of a process.

SUMMARY

NIPER's study provides an initial evaluation of the potential for polymer precipitation by direct saturation with CO₂. For the polyacrylamide polymers used in this study, no precipitation was observed as the result of direct CO₂ saturation. Rather, precipitation of polyacrylamide gels resulted from instability with divalent cations. Unless other polymers or indirect mechanisms, such as small changes in solution pH, can be found, this technique is not a viable approach for inducing mobility control.

REFERENCES

1. Gao, Hong Wen. Mobility Control in Oil Recovery by Chemical Flooding—State-of-the-Art Review. Dept. of Energy Report No. NIPER-146, October 1986.

2. Dean, John A. Lange's Handbook of Chemistry. McGraw-Hill Book Company. 12th Edition, 1979.

3. Weast, Robert C., and Melvin J. Astle. CRC Handbook of Chemistry and Physics. 60th Ed. CRC Press, Inc. Boca Raton, Florida, 1980.

4. Stephan, K. and K. Lucas. Viscosity of Dense Fluids. Plenum Press. New York and London, 1979.