

Research

Displacement of Guar Gum in Porous Media to Control Water Mobility

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Abstract

Oil recovery is made, firstly, by primary (natural energy or pumping) and by secondary (water flood) methods. These conventional methods extract only around 50% of the original oil in place. Therefore, enhanced oil recovery (EOR) methods should be used to remove the remained oil. In this work the EOR process studied was polymer flooding, using guar gum. A brine solution of this polysaccharide was injected in a core of Botucatu rock, simulating the polymer injection in oil fields. Rheological measurements were realized with an oil sample from RJ-Brazil and with guar gum solutions to obtain the best solution to remove this specific oil. The characterization of the rock was also realized. The results showed that guar gum interaction with Botucatu rock was very strong, and that multilayer adsorption should have occurred due to the high values of resistance factor (RF) and of residual resistance factor (RRF) found.

Introduction

An oil field is a natural hydrocarbon accumulation in the pores of underground porous rocks, which are called reservoir rocks, or simply reservoirs. The phenomena which lead to the creation of an oil field involves the successive deposit of sedimentary materials layers. The overlay of these layers causes an increase in pressure and temperature inducing various chemical reactions; under favorable conditions, organic materials contained in the sediments are transformed into hydrocarbons [1].

Conventional methods of recovering crude oil include primary and secondary methods. Primary methods use natural reservoir energy (liquid and rock expansion drive, solution gas drive, gas cap drive, natural water influx and

combination of these processes). Secondary methods augment natural energy by fluid injection (gas, water and gas-water combination floods). In general, conventional processes leave behind from one-third to one-half of the original oil-in-place. For this reason, the petroleum industry has been engaged in the research and development of various enhanced oil recovery (EOR) processes needed to produce oil left by conventional methods. EOR processes include all methods that use external sources of energy and/or materials to recover oil that cannot be produced economically by conventional means. **Fig. 1** shows the processes that can be used to recover the oil from a reservoir.

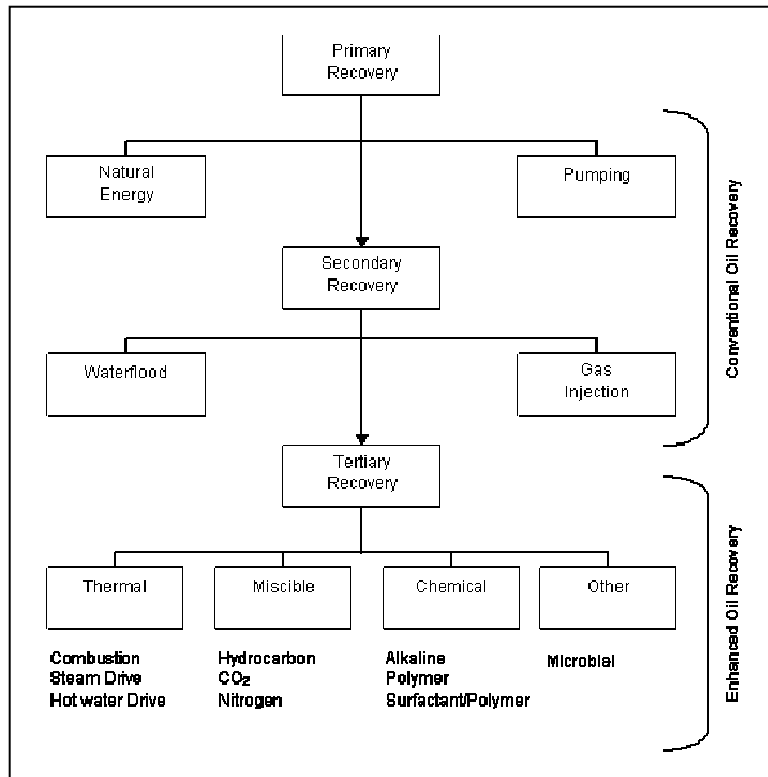


Fig. 1 Oil recovery processes.

In water flood, the most common technique used in secondary recovery, regardless of the amount of water cycled through the system, the oil saturation will not be reduced below the residual oil saturation (ROS). In polymer flooding, a water-soluble polymer is added to the water flood, increasing its viscosity. Polymer flooding does not reduce the ROS, but is a way to reach the ROS more quickly or to allow it to be reached economically [2].

To appreciate how the situation of water flooding may be remedied using polymer, it is necessary to define the mobility ratio, M (Eq. 1):

$$M = \frac{\lambda_w}{\lambda_o} = \frac{(\kappa_w / \mu_w)}{(\kappa_o / \mu_o)} \quad (1)$$

where λ , κ and μ are mobility, effective permeability and viscosity respectively, and the subscripts w and o refer to water and oil. Oil is left behind in a water flood either because it is trapped by the capillary

forces (residual oil) or because it is bypassed. The residual oil can only be removed by surfactant flooding, because it decreases the interfacial tension between water and oil. The oil bypassed in the water flooding can be recovered by polymer flooding. In this case, the role of polymer is to reduce the mobility ratio, basically by increasing the water viscosity (μ_w). A secondary effect is a decrease in the water relative permeability (κ_w) in the reservoirs as a consequence of polymer adsorption. Mobility ratio $M \leq 1$ is considered the best since it corresponds to water and oil with similar mobility. The addition of polymer to the injection water decreases water mobility until values near oil mobility [3, 4, 5, 6].

Polymer adsorption occurs when polymer molecules interact with a solid surface, bonding to it mainly by physical forces such as van der Waals and hydrogen bonding forces. Polymer adsorption in petroleum reservoir is desirable to some extent, since it causes water permeability reduction, thus further improvement of mobility ratio, which increases oil production rates. Polymer adsorption represents a loss of polymer that could be used to move the oil bank. Polymer adsorption

can be measured both under static or dynamical conditions. Static adsorption measurements are made by simply contacting a polymer solution with the crushed rock sample until no further change is observed in the supernatant concentration. Dynamic polymer adsorption measurements are made by injecting the polymer solution in a consolidated core sample and by measuring polymer concentration in core effluent [7].

Guar gum is derived from the seed of the guar plant *Cyamopsis tetragonolobus*. Guar gum exhibits compatibility with salts over a wide range of electrolyte concentration because it is nonionic [8]. The objective of this work is to study the interaction between guar gum and Botucatu sandstone through linear core flood tests.

Experimental

Materials. The laboratory test was performed using guar gum HIGUM 55-I, produced by Rhodia (MW ~ 10⁵). The polysaccharide was gently yielded by Plury Quimica Ltda. A core sample of Botucatu rock (sandstone) was used in the displacement test in porous medium. An oil sample named IS from Campos (RJ - Brazil) was used in the rheological tests. A brine with 45 g/l of NaCl was used as solvent to prepare the polymer solutions and in the displacement test. This salt concentration tried to reproduce the total dissolved solids (TDS) present in Saquarema (RJ - Brazil) seawater. The brine was filtered in 0.45 µm Millipore membrane, and the polymer solutions in sinterized funnels n° 2 and n° 4. The air was removed from the brine by vacuum pumping.

Rheological measurements. Rheological tests were realized on a RheoStress RS150 rheometer (HAAKE), coaxial cylinder sensor (DG 41), in the shear rate range 0 to 100s⁻¹ and temperature at 55°C, controlled by water bath K20 DC50 (HAAKE). The temperature choice is according to the temperature reservoir. As no specific reservoir is being studied, 55°C was chosen because this is the temperature used in the laboratory where the displacement test was realized. The oil was

the first sample to be analyzed, because the viscosity of the polymer solution and of the oil of interest has to be in the same level. The point to be compared is the viscosity at 10 s⁻¹ since the shear rates found in the reservoirs are near this value. Therefore, the viscosity of a guar gum solution at 6,000 ppm in brine was measured. Successive dilutions of this solution were realized with brine, until the wanted viscosity at 10 s⁻¹ was reached. After each dilution, the polymeric solution remained under mechanic stirring for, at least, 2 hours.

Rock characterization. A cylindrical core sample was claimed at 600°C, for 24 hours, for organic material remotion. The chemical composition was obtained by x-ray fluorescence and the permeability and porosity determined on a nitrogen permeabilimeter ULTRAPERM^{TM300} and on a helium porosimeter ULTRAPORE^{TM400}, respectively, both produced by Corelab Instruments. Table 1 shows the chemical composition of Botucatu rock and Table 2 the petrophysical characteristics of it.

Displacement test in porous medium. This test defines the interaction between polymer and reservoir rock [9]. The core used in this test was previously saturated with brine and the air present in its porous was removed by vacuum pumping. The laboratory apparatus used in linear core test is exhibited in Fig. 2, and Fig. 3 shows it in a schematic form.

The test started injecting brine (45 g/l NaCl) at 20.16 ml/h which corresponds to a flow of 1 PV/h (porous volume/hour) until the differential pressure is constant. At this moment, brine injection was stopped and polymer solution injection was initiated. This procedure was maintained for several porous volumes, and then brine injection occurred again. During all the tests, the values of ΔP were measured through pressure transducers. The system of displacement of fluids in porous medium is formed by a positive displacement pump PU-1587 from JASCO; FANEM oven, model 320E; acrylic bottles; pressure transducers VALIDYNE; displays from DRUCK Brasil and a computer.

Table 1 Chemical composition of Botucatu rock.

Sample	SiO ₂ (%)	Al ₂ O ₃ (%)	MgO (%)	Na ₂ O (%)	P ₂ O ₅ (%)	Fe ₂ O ₃ (%)	MnO (%)	TiO ₂ (%)	CaO (%)	K ₂ O (%)
Botucatu	88.82	1.57	0.23	0.04	0.02	0.79	0.0	0.05	0.14	1.28

Table 2 Petrophysical characteristics of Botucatu rock.

Parameter	
Length (cm)	9.60
Diameter (cm)	3.54
Weight (g)	208.40
Total volume (ml)	94.49
Porosity (%)	21.37
Porous volume (ml)	22.15
Permeability (mD)	587.71

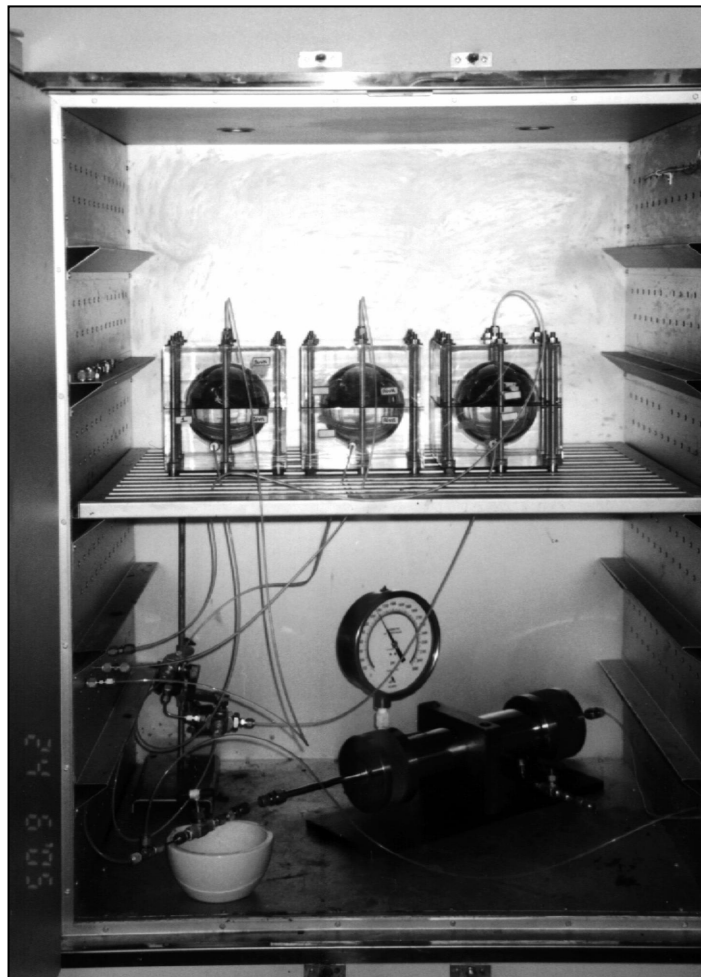


Fig. 2 Laboratory apparatus used in linear core test.

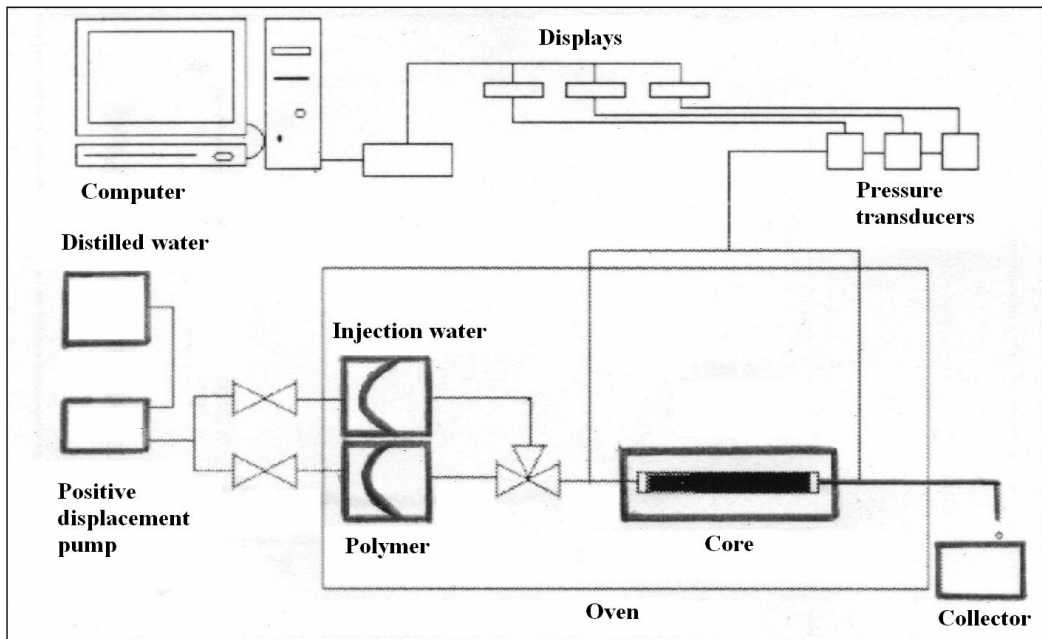


Fig. 3 Schematic diagram of the apparatus used in linear core test

Results and discussion

Rheological measurements. Fig. 4 presents viscosity curves of the oil sample and of guar gum solutions in different concentrations. All polymeric solutions exhibited pseudoplastic behavior, while oil viscosity remained constant, a fact that makes it Newtonian. Comparing the viscosity values at 10 s^{-1} , the best

sample for removing the oil IS (40 mPa.s) would be guar gum at 3,000 ppm. This solution was still very viscous, and the transducers would not be able to support the pressure. Therefore, guar gum at 2,700 ppm solution was chosen to conduct the displacement test in porous media.

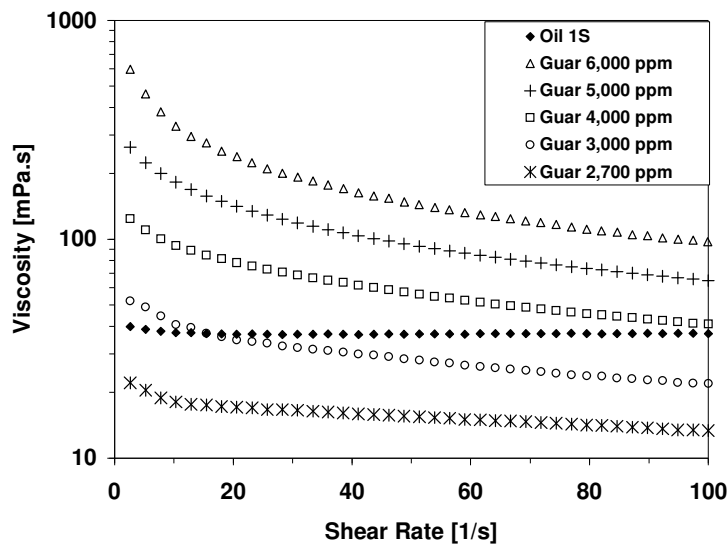


Fig. 4 Viscosity curves of the oil and of guar gum solutions.

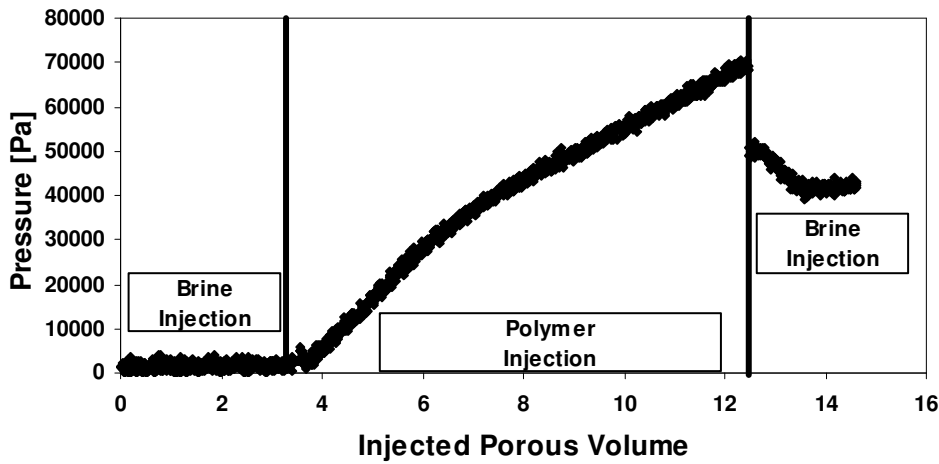


Fig. 5 Guar gum displacement test in porous media.

Displacement test in porous medium. Fig. 5 shows the result of the displacement test. The pressure variation during the passage of each fluid was measured by pressure transducers and put in a computer to plot the graph of pressure as a function of time. As the flow of injection was 1 PV/h, one can substitute the time variable for the injected porous volume.

This graph allows the determination of flow parameters such as resistance factor (RF) and residual resistance factor (RRF) that can be calculated from Eqs. 2 and 3, respectively [4].

$$RF = \frac{\Delta P (polymer)}{\Delta P (brine\ before\ polymer)} \dots\dots\dots(2)$$

Where: $\Delta P(polymer)$ is the pressure variation during the polymer flow and $\Delta P(brine\ before\ polymer)$ is the pressure variation during the brine flow before polymer flow.

$$RRF = \frac{\Delta P (brine\ after\ polymer)}{\Delta P (brine\ before\ polymer)} \dots\dots\dots(3)$$

Where: $\Delta P(brine\ after\ polymer)$ is the pressure variation during the brine flow after polymer flow.

The resistance factor increased continuously with guar gum injection, not reaching a constant level until the

injection of 12.5 porous volumes. At this point, corresponding to an RF equal to 38.77, the injection of brine was started again, and a reduction in the resistance factor was observed.

The fact of polymer injection do not reach a constant level during the injection of nine porous volumes suggests that guar gum interacted with Botucatu rock and that the adsorption/retention was very strong. The continuous increase in pressure and in the resistance factor (RF) is an indication of multilayer adsorption. In other words, the adsorption is not limited to the covering of the free rock surface, and the polymer molecules in solution could adsorb on the polymeric layers already adsorbed [10]. The elevated value of the residual resistance factor obtained (23.33) showed that the brine injection, that should push the polymer front through the core rock, do not managed to draw great part of the polymer retained. In Fig. 6, one can see a comparison of the viscosity of the guar gum solution injected in the core and of the first three fractions collected during the second brine injection. The solution viscosity should decrease as more brine was injected, and it did not happen. Furthermore, the high adsorption is confirmed by the viscosity values of the solutions in the exit of the core that are much smaller than the viscosity of the polymeric solution in the core entrance.

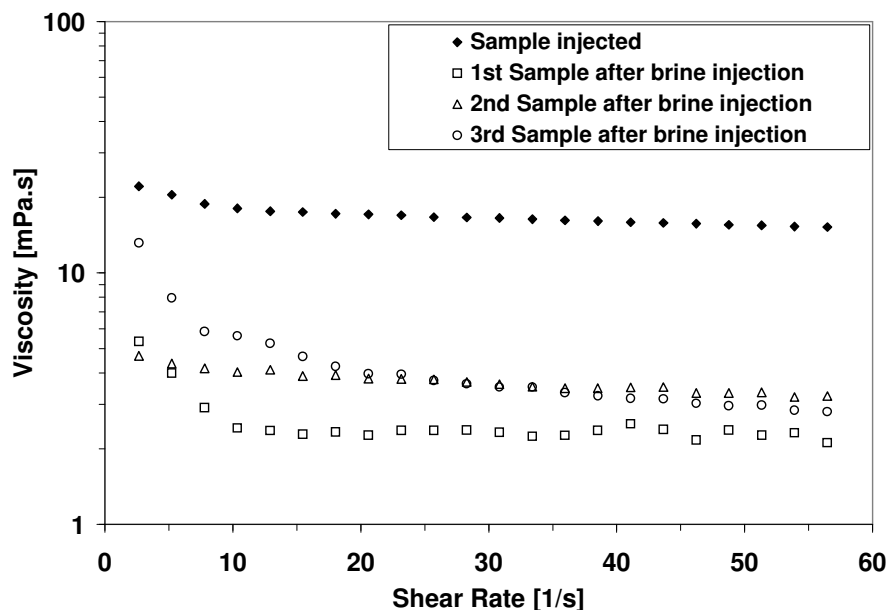


Fig. 6 Viscosity curves of the guar gum solution injected in the core and of the first three fractions collected during the second brine injection.

Conclusions

Guar gum displacement in Botucatu sandstone showed that this polysaccharide had a strong interaction with this rock. The elevated values of RF and RFF suggest multilayer adsorption. The viscosity of the effluents during the flow of the second brine increased as it was being injected; this means that as more brine is injected, more adsorbed polymer is drawn. The use of guar gum in EOR projects at the concentration studied should not be safe, due to the high reduction of rock permeability to water that could cause core plugging. It could be recommended to water shut-off operations in producer wells.

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