DISPLACEMENT OF VISCOUS OIL BY POLIMERIC SOLUTION - EXPERIMENTAL EVALUATION

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ABSTRACT

The objective of this work was to investigate physical mechanisms related to displacement of saturated viscous oil formation by non-Newtonian fluid. Twenty five tests results are reported using two viscous oils (~100 cp and ~300 cp @ 25°C), two types of polymers: a natural one (XC) and a synthetic one (PHPA), two levels of injection pressure (~200 psi or ~100 psi) and three conditions of porous media (natural, previous polymer adsorbed or previous wettability changing treatment). Linear displacement tests were performed using a laboratory apparatus specifically designed, assembled and calibrated for this study. To observe repeatability, some samples were run under same test conditions. Mass and differential pressure were recorded on time. During experiments, injected pressure, ambient temperature, produced volume and polymer solution weighting were also monitored. X-Ray data allowed determining final saturation profile and tomography images completed the extensive quantity of registered parameters. This research can contribute to understanding of filtration phenomena and displacement dynamics of fluids in porous. Most applications related to fluids based on polymers in petroleum exploitation activities are enhanced oil recovery techniques and cutting of reservoir formation by drill in fluids. In the first case, a reduction on water mobility is aimed to improve volumetric sweep efficiency, and consequently, reduce residual oil saturation behind washed zone. However, during drilling and completion operations, polymeric solutions are used as to avoid damage on reservoir formation by minimizing invasion of well fluids. Processes efficiency is strongly dependent on polymer characteristics, solution formulation, displacement conditions and costs. Results allowed observing adsorption, diffusion, convection and rheologic behavior influences. Insights of physical mechanisms related to invasion process were pointed out. Repeatability of results was also evaluated over the huge volume of data.

INTRODUCTION

Polymer applications have gained special attention by the petroleum industry. Increase of sweep volumetric efficiency and anticipation of oil production are the primary goals of polymer addition to water flooding processes (Dong et al, 2006; Garrouch and Gharbi, 2006; Sorbie, 1991; Yin et all., 2006). Reservoir damage control during drilling operations was also pointed out as a very important task. Interferences on well productivity and on core analyses are not desired (Longeron (2000), Mandal et al (2006), Martins et al (2005), Van der Zwaag (2000)). Invasion control of drilling polymer based fluids (drill-in fluids) and affecting mechanisms have been studied by many researchers (El Essawy et al (2005), Guerrero et al (2006), Hodge et al (1997), Kadaster et al (1992), Liao and Siems (1990), Martins et al (2005), Moreno et al (2007)). Although intense investigation has been done, affecting mechanisms are not completely understood.

This paper presents experimental results of 25 one-dimensional displacement tests. Runs were planned to cover oil viscosity, polymer type, differential injection pressure and rock surface condition influences on polymer invasion through oil saturated porous media. Affecting mechanisms and their relative importance are compared and discussed.

MATERIALS AND METHODS

Natural or previous treated Botucatu sandstone cores (such as R12) were 100% saturated with nujol (N) or Lubrax® (L) and submitted to PHPA (P) or Xantham (X) solution injection, under ~100 psi or ~200 psi (see Table 1, Test 2, sample R12NX-200). Some samples were submitted to previous polymeric adsorption, such as R23LXt-196, and others were treated in order to acquire hydrophobic characteristics, for example R26LPq-2003. Experimental apparatus is shown in Photo 1 and Test Cell can be seen in Photo 2. Volumes, weight, pressure and temperature data were registered and final profiles saturations were obtained by X-Ray and tomography scanning of samples under different saturation conditions (dry, 100% oil saturated and after polymeric solution injection) (see Table 2). Core properties and test characteristics are presented in Table 1. Oils viscosities and polymers rheology are shown in Figs 1 and 2, respectively. Detailed information about experimental set-up and test protocol can be found in Moreno et al (2007). Wettability change treatment is described in Moreno et al (2005).

RESULTS AND DISCUSSION

Tests results are presented and discussed here. Comparative analyses cover influence of oil viscosity, polymer type, injection pressure level and rock-surface conditions.
Figure 3 and **Figure 4** show comparative saturation profile after ~30% PV injection at ~200 psi of polymeric solutions through natural saturated porous media. Displacement of nujol was fast and oil sweep was high close to the injection face, for both polymers, however saturation profile was sensitive to polymer type. Invasion into Lubrax® saturated samples was deep in both cases and retention mechanisms behind advance front were very similar to Xanthan and PHPA. Negligible retention effects behind swept porous volume and a diffusive-convective advance front was registered for Xanthan displacing Nujol. In the case of PHPA injection, low polymer was retained very close to the injection face, followed by high polymer entrapment and a diffusive advance front.

Under a low differential injection pressure, saturation profiles after xanthan injection show similar tendencies (see **Figure 5**), however Lubrax® displacement was very slow compared to that of nujol. On the other hand, PHPA solution injection took almost the same time to displace ~30% PV for both oils but presented different final saturation profiles. Nujol sweep was higher in the first half of sample length and end effects were significant, while water breakthrough was observed for Lubrax® saturated samples (see **Figure 6**). When displacing nujol, polymer saturation bank showed similar profile to those observed for under high pressure level test (R13NP-198), indicating same affecting displacement mechanisms with different relative scales. Although low oil was mobilized, polymeric front was more invasive (Test 9: R08NP-98).

Aiming to minimize retention by polymer adsorption during injection flooding, previous treated samples were run and the final saturation profiles can be seen in **Figure 7** for Xanthan injection and in **Figure 8** for PHPA injection. Although retention effects were less expressive when displacing nujol, performance behind advance front shows opposite trend for Xanthan (R16NXt-198) relative to PHPA (R05NPt-200). Variations on observed profile can be due to size entrapment of polymer molecules and elongational effects. More relative effects were registered by PHPA invasion data and the magnitude of observed mechanisms seems to be related to relative phase mobilities, polymer molecule characteristics and local displacement velocities. Injection of ~30% PV into Lubrax® saturated samples took twice the time of nujol.

Figure 9 and **Figure 10** show saturation data from polymeric flooding throughout hydrophobic porous sample. Water breakthrough and longer time injection were registered for samples saturated with Lubrax®. End effects were significant for nujol saturated samples and PHPA- Lubrax® run shows low oil sweep due to solution bypass. This effect seems to be more a consequence of the displacement conditions than due to polymer molecule characteristics.

CONCLUSIONS

- Invasion process is affected by fluids mobility, displacement pressure and polymer type.
- Convective, diffusive and retention mechanisms influence polymer invasion, but relative magnitude depends on the fluids, the porous media characteristics and the displacement conditions.
- Adsorption is an important retention mechanism, while rock wettability surface shows no-significant influence on polymer invasion.
- Elongational mechanism associated with PHPA invasion can increase oil sweep and the relative effect influence is strongly dependent of the displacement velocities.

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Table 1- Basic Samples Properties and Test Characteristics

Test	Sample	Poros. [fr]	Permeability Gas [mD]	Permeability Oil [mD]	Differ. Pressure [psi]	Produced Pore Vol. [%]	Polymer Saturation [fr]	Injection Time [min]	Test Temper. [oC]	Treatment	Polymer	Np [cc]	Wp [cc]
1	R14NX-200	0,244	917	955	200	34,0	0,662	8,0	24	No	Xanthan	19,4	
2	R12NX-200	0,246	895	830	200	31,6	0,680	7,0	25	No	Xanthan	18,0	
3	R15NX-105	0,244	912	985	105	32,9	0,683	21,0	25	*No*	Xanthan	18,8	
4	R11NXt-180	0,241	393	389	180	34,6	0,657	29,0	24	XC Adsorption	Xanthan	18,0	
5	R16NXt-198	0,243	375	402	198	32,7	0,672	20,0	25	XC Adsorption	Xanthan	18,2	
6	R17NXq-200	0,244	890	962	200	29,1	0,705	7,0	24	Hydrophobic	Xanthan	16,8	
7	R13NP-198	0,248	870	789	198	26,7	0,724	11,1	24	No	PHPA-1	16,0	
8	R09NP-198	0,243	975	727	198	28,0	0,723	10,1	25	No	PHPA-1	15,4	
9	R08NP-98	0,243	788	625	98	29,4	0,710	48,0	28	*No*	PHPA-1	16,0	
10	R06NPt-200	0,238	648	458	200	31,5	0,684	13,0	25	PHPA Adsorption	PHPA-1	17,0	
11	R05NPt-200	0,233	530	363	200	32,0	0,678	20,0	26	PHPA Adsorption	PHPA-1	17,4	
12	R10NPq-198	0,240	880	986	198	33,0	0,672	9,1	28	Hydrophobic	PHPA-1	17,8	
13	R01LX-200	0,232	539	327	200	29,9	0,728	51,0	27	No	Xanthan	14,8	1,8
14	R02LX-200	0,231	565	314	200	32,0	0,704	44,0	27	No	Xanthan	15,6	1,2
15	R03LX-100	0,235	619	393	100	29,9	0,695	245,0	28	*No*	Xanthan	16,6	
16	R22LXt-196	0,241	315	220	196	30,6	0,697	80,0	28	XC Adsorption	Xanthan	16,9	0,1
17	R23LXt-196	0,241	544	330	196	30,6	0,700	39,0	26	XC Adsorption	Xanthan	16,9	0,1
18	R04LXq-200	0,232	680	464	200	30,9	0,710	33,0	27	Hydrophobic	Xanthan	15,4	1,0
19	R24LP-204	0,249	720	412	204	30,4	0,753	23,0	26	No	PHPA-2	13,6	3,4
20	R25LP-204	0,246	655	318	204	29,9	0,762	42,0	26	No	PHPA-2	13,4	3,2
21	R07LP-100	0,241	749	344	100	31,3	0,738	42,0	27	*No*	PHPA-2	14,6	2,6
22	R27LPt-200	0,238	329	228	200	32,9	0,679	43,0	27	PHPA Adsorption	PHPA-2	17,5	0,1
23	R28LPt-200	0,233	312	215	200	33,1	0,676	57,0	28	PHPA Adsorption	PHPA-2	17,3	0,1
24	R26LPq-203	0,239	684	421	203	31,5	0,760	23,0	29	Hydrophobic	PHPA-2	13,0	4,0
25	R29LP1-198	0,236	542	146	198	31,9	0,689	105,0	27	No	PHPA-1	17,1	0,1

Table 2- X-Ray and Tomography - Specifications and Scanning Protocol

Equipment	Characteristics	Scanning Protocol
Oxford X-Ray	Average Values of sections (23 positions 1-D)	Voltage: 60 kV; Amperage: 60 mA, Resolution: 0,005 m; Slices: 0,012m, Scanning Time: 2 sec.
Siemens Tomography	Sections Images (25 Images 2-D)	Voltage: 130 kV; Amperage: 170 mA; Resolution: 512 x 512; Slices: 0,01m; Scanning Time: 2 sec; Bonny Reconstruction Algorithm

Photo 1. Experimental Apparatus

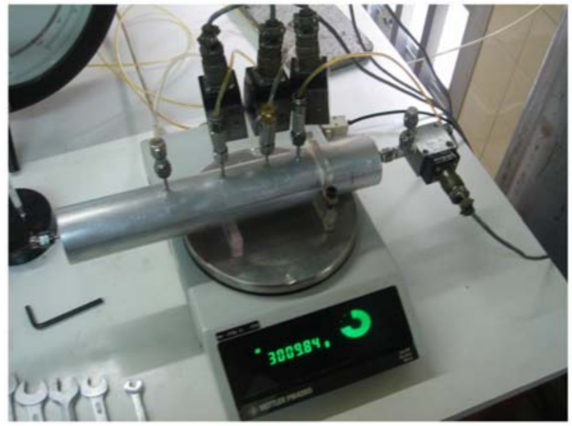

Photo 2. Test Cell

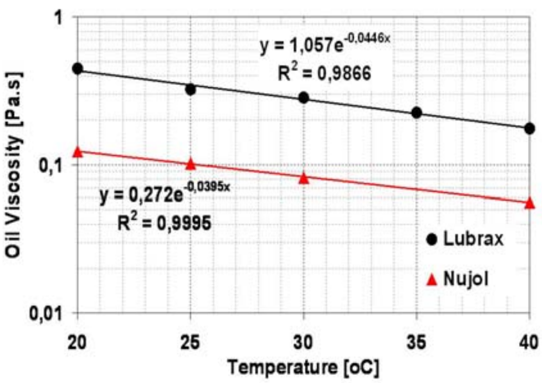

Figure 1. Oil Viscosity vs. Temperature

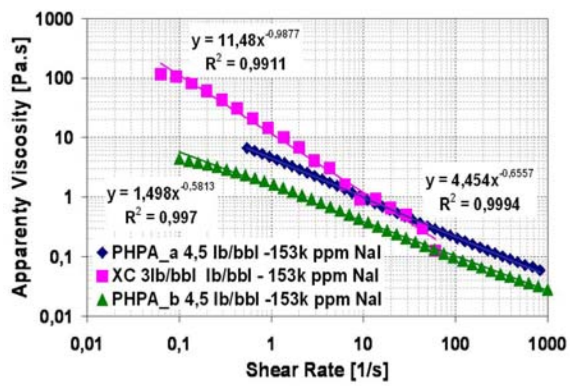

Figure 2. Polymer Viscosity vs. Shear Rate

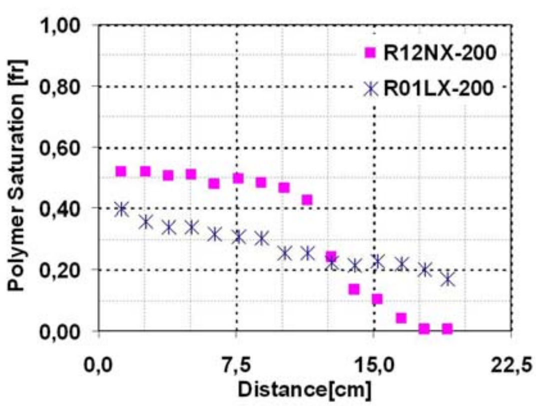

Figure 3. Injection of Xanthan into Natural Rock with Nujol or Lubrax® at ~200 psi

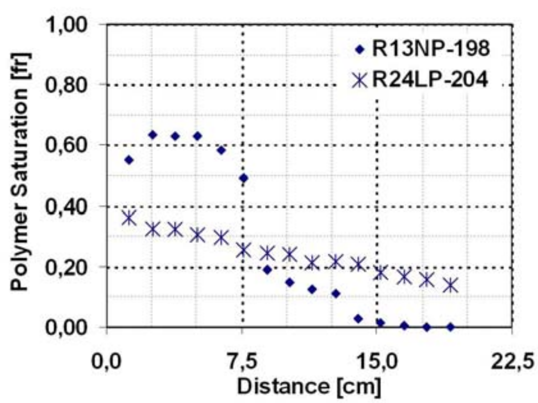

Figure 4. Injection of PHPA into Natural Rock with Nujol or Lubrax® at ~200 psi

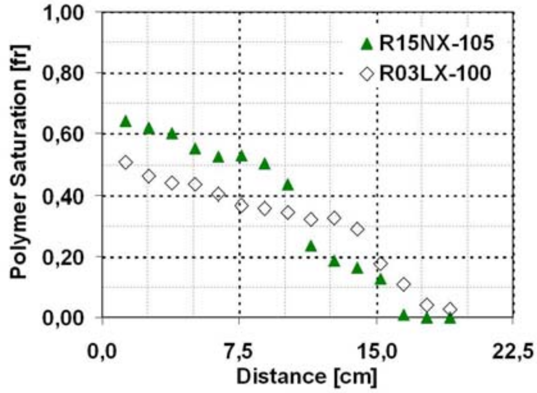

Figure 5. Injection of Xanthan into Natural Rock with Nujol or Lubrax® at ~100 psi

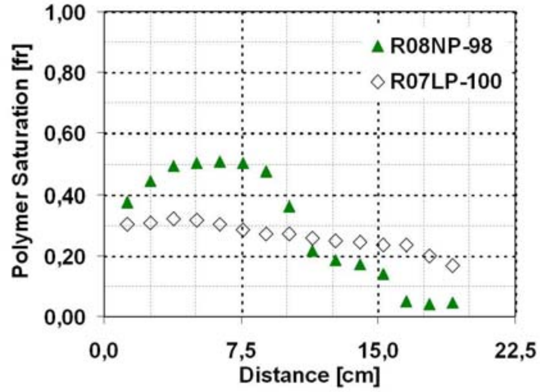

Figure 6. Injection of PHPA into Natural Rock with Nujol or Lubrax® at ~100 psi

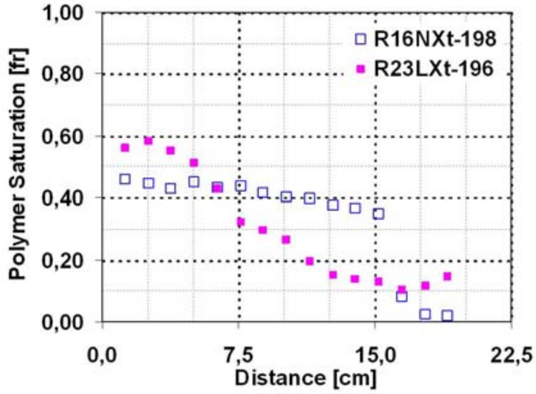

Figure 7. Injection of Xanthan into Treated Rock with Nujol or Lubrax® at ~200 psi

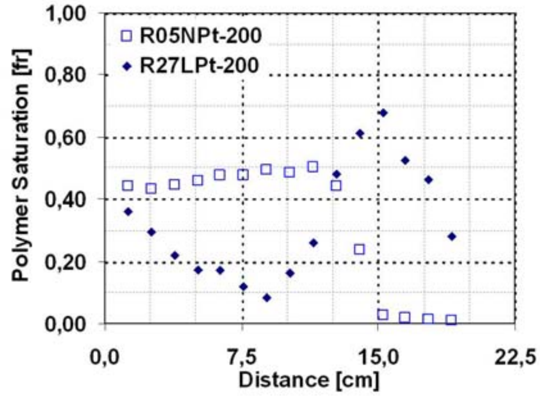

Figure 8. Injection of PHPA into Treated Rock with Nujol or Lubrax® at ~200 psi

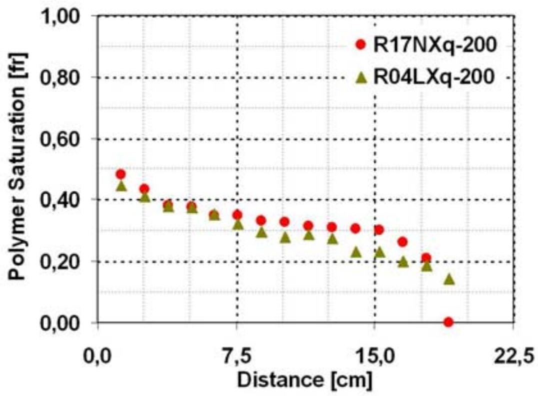

Figure 9. Injection of Xanthan into Hydrophobic Rock with Nujol or Lubrax® at ~200 psi

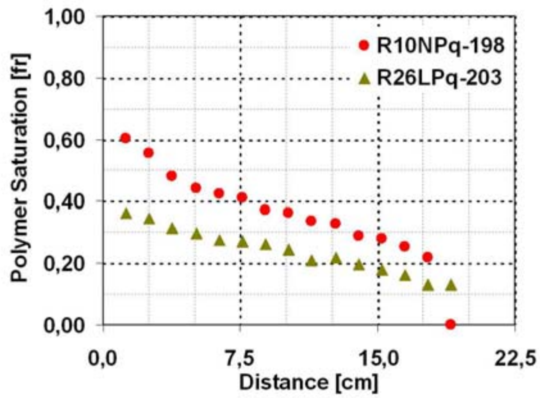

Figure 10. Injection of PHPA into Hydrophobic Rock with Nujol or Lubrax® at ~200 psi