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Impact of Polymer Properties on Field Performance of Reservoir Development Projects

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"Optimization of field operations usually requires consideration of economic indicators, such as net present value (NPV) so polymer and other costs are included in the decision process."

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Introduction

Polymer flooding is an EOR technique implemented successfully in many projects. To understand its mechanisms is very important to manage field operations. Optimization of field operations usually requires consideration of economic indicators, such as net present value (NPV) as objective function including all investments, revenues and costs (CAPEX and OPEX). This is still more important in polymer flooding projects, where additional oil can be recovered by injecting more polymers. Additional costs from polymer, however, may lead to negative economic results. In this work, we present the numerical modeling of polymer retention and the reversibility, inaccessible pore volume, shape of the curve of viscosity vs. polymer concentration, salinity, permeability reduction, non-Newtonian behavior and degradation. We first tested these properties in simple cases. Then each property was applied to two synthetic field cases. The goal is to estimate the impact of each property on field performance indicators, such as NPV, Np, Winj and Polymer Mass.

Mathematical Formulation and Initial Tasks

In this section, the polymer properties considered in this paper are briefly discussed, and some results for simplified cases are shown, to illustrate the concepts.

- Retention and Reversibility

Polymer retention can be modeled by Langmuir isotherms, as shown by Eq. 1. Fig. 1 shows cumulative produced polymer mass for different retention levels. Higher retention levels result in smaller produced polymer mass, once more mass stays adsorbed in the rock.

$$Ads = \frac{(tad1 + xnacl.tad2).C_p}{1 + tad3.C_p} \qquad \text{Eq. 1}$$

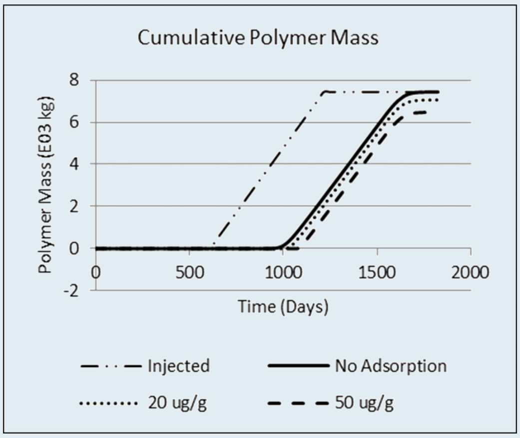

***Figure 1:** Cumulative Polymer Mass for different retention levels*

Regarding to reversibility of retention, polymer desorbs only after the polymer bank, when the oil mobility has already decreased due to its smaller saturation, meaning that very small additional oil can be expected.

- Inaccessible Pore Volume

When the retention is fully satisfied, polymer molecules are transported faster than inert tracers. The term Inaccessible Pore Volume (IPV) was first introduced due to the interpretation that the rock consists of pores which have a broad distribution of pore sizes and large polymer molecules are unable to penetrate into the smaller pores. A different explanation states that polymer molecules aggregate in the center of the channel, while fluid near the walls has lower velocity than that in the center of the pores due to friction. Either one of the interpretations, however, leads to the same effect: polymer molecules flow faster than water. Its impact on cumulative produced fluids is expected to be negligible, because the polymer bank in each case is similar. The curves are shifted in time, changing also the oil production. This difference is compensated during the water injection, after the polymer bank.

- Polymer viscosity vs. concentration

The viscosity of polymer solution depends strongly on polymer concentration. Different equations were developed to model this relationship, but the relationship tends to be somewhat like an exponential. Four different viscosity-polymer concentration curves were tested to evaluate their impact on field indicators.

- Effect of Salinity on Polymer Viscosity and Adsorption

The viscosity of polymer solution is very sensitive to water hardness and salinity. The hardness is the concentration of multivalent cations such as Ca^{2+} and Mg^{2+}. The salinity refers to the concentration of salt in the water, usually sodium and chloride. Although salinity and hardness have different impact on polymer, they can be grouped as an effective salinity. Salinity affects polymer flooding because of three different phenomena: positive impact on brine viscosity, negative impact on polymer solution viscosity, and positive impact on adsorption. Variation of adsorption is already modeled by Eq. 1. Eq. 2 presents variation of viscosity with salinity.

$$\mu_{pol} = \mu_{pol}^{0}\left(\frac{X_{NaCl}}{X_{min}}\right)^{sp} \qquad \text{Eq. 2}$$

Fig. 2 shows the variation of some indicators with increase of salinity. Due to decrease in polymer viscosity, water injection and production increase drastically, and oil production does not increase proportionally resulting in a strong decrease in NPV.

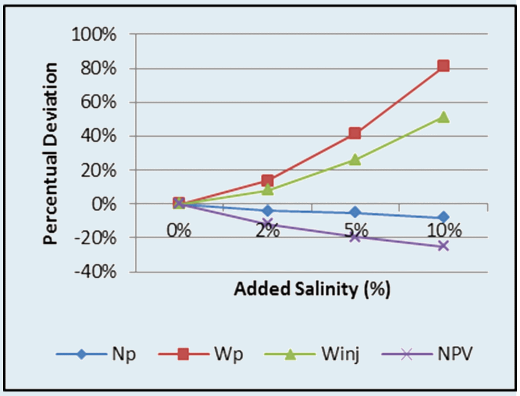

***Figure 2:** Evolution of indicators with increase of salinity*

- Polymer Rheology

The shear thinning effect can be described with the power law model, shown in Fig. 3.

- Permeability Reduction

Typical polymer projects have a pre-flood stage, when water is injected. This stage is followed by a polymer slug, and usually, water post-flush. Due to polymer adsorption, the second water flooding experiences a lower permeability than that of first water flooding. The difference between initial and final permeability to water is characterized using residual resistance factor (RRF).

Fig. 4 shows the water injection rate. The rate drops significantly with the increase in viscosity, due to polymer, and rises again only after the polymer breakthrough. For the case where permeability is reduced, water level rises less than that in the case without this reduction.

- Polymer Degradation

Polymer degradation occurs when the long molecular

"Polymer properties affect polymer flooding in three ways: polymer velocity, polymer viscosity and molecular retention."

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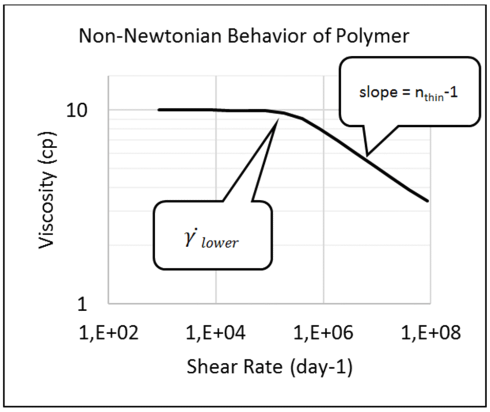

Figure 3: *Parameters for Power-Law model*

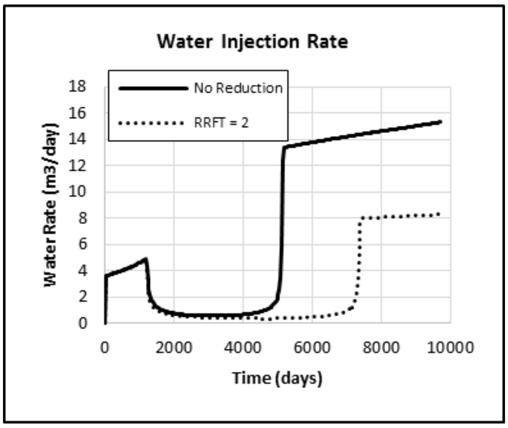

Figure 4: *Example of permeability reduction*

chains of polymers break, due to a variety of phenomena (e.g., thermal decomposition, mechanical degradation, etc). This cracking reduces the average molecular length and finally leads to a reduction in its viscosity. The molecules can be degraded due to different agents. The presence of cations or oxygen can lead to chemical degradation.

A simple way to model polymer degradation is to consider a first order chemical reaction, where polymer molecules are turned into water (to ensure the material balance).

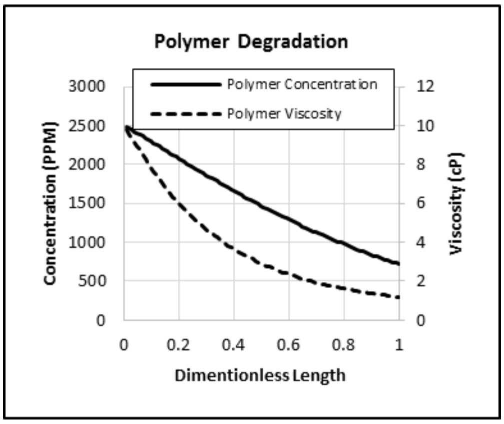

Figure 5: *Variation in polymer concentration and viscosity*

Fig. 5 shows the decrease in concentration and viscosity observed for this case. Note that near the injector, concentration is near the maximum injection value, and it decreases as polymer solution moves away from the injector. It also shows the effect of polymer concentration reduction on viscosity, where one can observe that viscosity decreases much faster than the concentration.

Summary

Fig. 6 summarizes the effect of tested cases on field indicators.

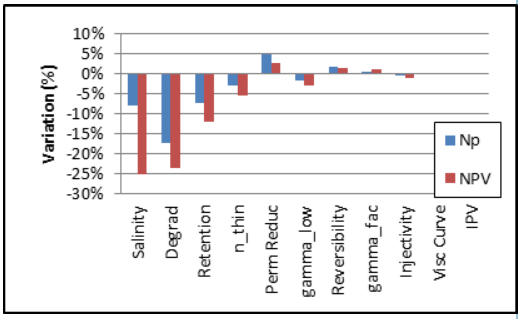

Figure 6: *Summary of variation in Np and NPV for different polymer properties*

Conclusions

Polymer properties affect polymer flooding in three ways: polymer velocity (retention and IPV), polymer viscosity (salinity, degradation and rheology) and molecular retention (retention, permeability reduction and salinity). The factors with higher influence on reservoir performance are viscosity and retention levels.

Retention of polymer, salinity, polymer rheology and degradation can decrease 25% of the NPV when compared with ideal behavior. As the value is high, the polymer flooding may not be an advantageous technique and comparison with water flooding would be recommended in such a case. Comparisons with water flooding would demand reoptimization of G2 variables, as shown by Lamas (2016-b) and is out of the scope of the present text. Permeability reduction, adsorption reversibility, inaccessible pore volume and selection of a correlation curve for the function of viscosity vs. concentration can influence NPV by less than 3%.

References

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About author

Luís Fernando Lamas holds an Electronics Engineering degree from Paulista University, a Physics degree and a MSc. in Petroleum Engineering, both from UNICAMP. He is currently a PhD candidate in Petroleum Sciences and Engineering at UNICAMP, focusing on Polymer Flooding modeling and strategy selection.

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