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Model-based Analysis to Evaluate the Effect of Polymer Properties and Physical Phenomena on Polymer Flooding Operations

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"This work enhances the comprehension of physical phenomena and non-Newtonian behavior in tertiary polymer flooding on heavy oil reservoirs and its impact on the production forecast."

Introduction

This text is a summary of the article published by Silveira et al., (2024) where we highlight several physical phenomena presents in polymer flooding application that are absent in waterflooding processes:

- Non-Newtonian behavior.
- Rock-fluid interaction by retention and adsorption effects.
- Injectivity loss.
- Rheological impairment due to the harsh condition in the reservoir (salinity and temperature).

Given the complications of this EOR method, work evaluated the importance and impacts of polymer solution viscosity, shear rate, adsorption, and injectivity loss on production forecast.

Methodology

The methodology applied to evaluate the main effects that act during the polymer flooding is summarized in Figure 1.

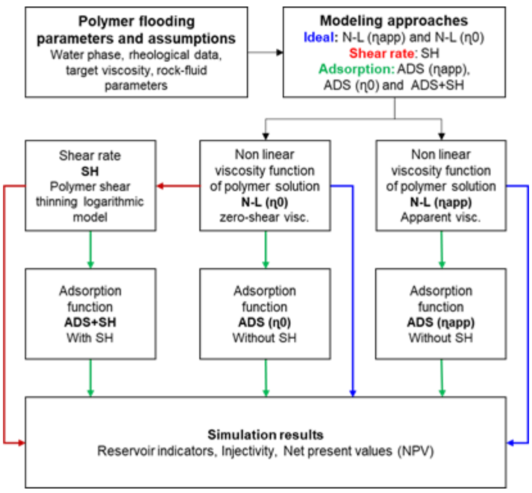

Figure 1: Flowchart of viscosity, shear rate, and adsorption modeling approaches for polymer flooding simulations.

Polymer flooding was modeled considering three effects associated to the viscosity (ideal approach), shear rate and adsorption, explained as follow:

- The viscosity effects are coined here as "ideal approach" because only the displacing fluid viscosity increased due to polymer addition. For this purpose, two non-linear viscosity functions are applied: One considering apparent viscosities (η_{app}) and the other considering zero-shear viscosities (η_0).
- The shear rate (SH) is modeled taking into consideration the η_0 data as viscosity function and shear thinning logarithmic model, with multiple flow curves, to represent the pseudoplastic behavior of the polymer solution.
- The adsorption (ADS) effect is modeled according to the adsorption function with and without the presence of the SH effect. Without the SH effect, the ADS is modeled with η_{app} or with η_0 data as polymer viscosity functions.

Application

The simulation model used in this work, named EPIC001, was based on a case of offshore heavy oil reservoir (13° API) with heterogeneities on permo-porosity properties.

Figure 2 presents the well's placement and model parameters. There are three injectors placed near the bottom of the reservoir, and four producers in the middle of the model.

As the field development process was implemented with waterflooding, polymer flooding was evaluated as tertiary mode. The injection schemes applied in the simulation model are presented in Figure 3.

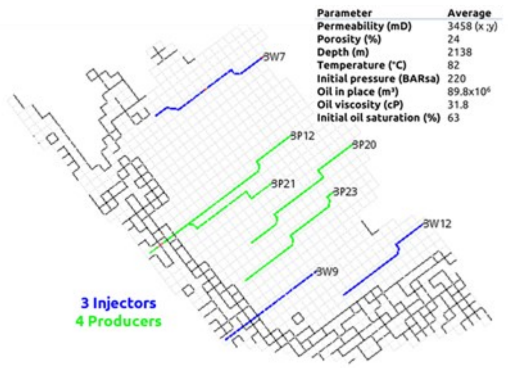

Figure 2: EPIC001 model parameters and well placement (2D view of top reservoir).

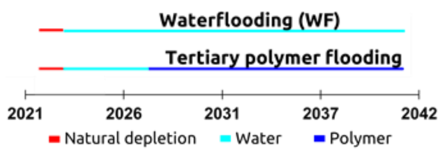

Figure 3: Timeline of the injection schemes of water flooding and tertiary polymer flooding.

Results

The results provide the base data to perform a sensitivity analysis with the goal of evaluating the impact on the injectivity and field indicators for each effect that was incorporated into

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the polymer flooding modeling for heavy oil recovery. Figure 4 and Table 1 summarize the results.

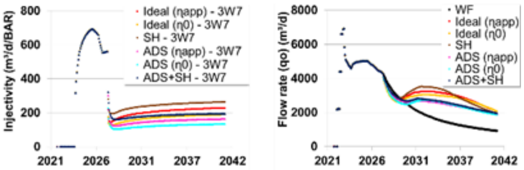

Figure 4: *(a) Injectivity for a representative well; (b) oil production rate.*

Table 1: *Simulation time, polymer BT, recovery factor, and final NPV.*

Strategy/ effects	Simulation time (min)	Polymer BT	Rec. Factor	NPV (normalized by WF case)			
WF	23	-	21.6%	1.00	75% of the ADS values	50% of the ADS values	25% of the ADS values
Ideal (ηapp)	62	07/2029	27.3%	1.13			
Ideal (η0)	47	07/2031	27.9%	1.11			
SH	2985	08/2029	28.2%	1.15			
ADS (ηapp)	55	02/2034	25.6%	0.94	0.99	1.03	1.08
ADS (η0)	47	03/2036	25.7%	0.97	1.01	1.04	1.08
ADS+SH	1956	03/2034	26.2%	0.97	1.02	1.06	1.11

In simulation results, increasing the displacing fluid viscosity using apparent or zero-shear functions, oil production and economic returns show improvements over waterflooding. The shear rate effect slightly increases oil production and enhances injectivity loss due to shear-thinning in polymer flow. However, modeling it increases computation costs, as it extends simulation run time from minutes to days, making it impractical for intensive processes like production optimization. An analysis of the method's effectiveness shows that it varies based on the adsorption level considered. At its highest value, even with a higher oil recovery factor, the economic return was lower than using waterflooding. Combining shear rate and adsorption has a minimal impact on field indicators when compared to adsorption alone.

Conclusions

Based on the results of the polymer flooding effects, viscosities and adsorption modeling approaches presented higher impact on the indicators analyzed. The shear rate modeling approach did not impact the oil production and NPV data significantly, but it changed the simulation runtime scale from minutes to days, which can be unfeasible in computational-intensive processes such as production optimization. So, considering such purpose, the polymer flooding effects can be represented by the adsorption with non-linear apparent viscosity function due to the intrinsic value of shear rate in the viscosity data and the similar NPV results when compared to the adsorption with shear rate approach. However, the shear rate effect can be implemented in the optimized strategy to obtain a more accurate NPV data.

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Silveira, B. M. O., Santos, S. M. G., Botechia, V. E., Schiozer, D. J., 2024. Model-based analysis to evaluate the effect of polymer properties and physical phenomena on polymer flooding operations. BJPG, 18, p.31-52. http://dx.doi.org/10.5419/bjpg2024-0003.

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"This work also highlights important considerations for modeling-based procedures."

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