Original Research Article

SIMUALTION STUDY OF POLYMER FLOOD PERFORMANCE ON OIL RECOVERY: EFFECT OF PSEUDOPLASTICITY

ABSTRACT

Polymer flooding is an effective EOR method in controlling the mobility ratio between the displacing fluid and displaced fluid. However, Polymers used in EOR are shear thinning (pseudoplastic). Therefore, the effective viscosity of the polymer solution is highly non-function of shear rate. In assessing the potential of a polymer flood for mobility control, there is need to accurately model the viscosity of the displacement fluid.

ECLIPSE 100, a reservoir simulation was used to investigate the shear thinning effects of polymer solution on the performance of oil recovery under different fluid and rock properties. Results of field oil efficiency, water cut and oil saturation distribution are presented for parameters of rock wettability, permeability heterogeneity, layered reservoir with cross flow.

The pseudoplastic polymer behavior reduced and delayed oil recovery for all heterogeneous reservoir cases. There was a 5% decrease in recovery for an average permeability of 550md. For homogeneous reservoirs, shear thinning of polymer had no effect on production performance. This is because there is no heterogeneity; hence no velocity contrasts for the thinning to exacerbate. For stratified reservoir with crossflow, lower oil recovery and rapid increase in Field Water Cut were obtained with smaller Kv/Kh value. As the vertical permeability increased, oil migrates to other layers more easily, where it is swept by the displacing water to the producing well. For the wettability studies, oil-wet reservoir produced more water than water-wet in excess of 8% at the end of the simulation. Lower recovery and higher water cut were observed for oil-wet reservoirs than those of water-wet reservoirs especially for non-Newtonian cases makes polymer flooding of oil-wet reservoir less attractive.

KeyWords: polymer, pseudoplasticity, enhanced oil recovery, simulation, heterogeneity

1.0 INTRODUCTION

Polymer flooding is one of the chemical enhanced oil recovery methods and has been introduced in late 1960s. In this chemical EOR method, polymer is added to injected water in order to increase injected fluid viscosity, improve oil displacement in the reservoirs, decrease in volume of capillary trapped oil, decrease in water and oil mobility ratio, hence a more stable displacement and a sharper front (Lake, 1989; Littmann, 1988; Sorbie, 1991). The main polymer used for this purpose: polysaccharide and polyacrylamide are shear thinning (pseudoplastic) (Lake, 1989). Although shear thinning behavior is desirable from injectivity point of view, it is undesirable in terms of sweep efficiency especially in heterogeneous reservoirs. In this paper, ECLIPSE 100 was used to study the effect of shear thinning behavior of polymer on oil recovery.

Polymer Introduction in Eclipse Simulator

Polymer flooding is presented in Eclipse simulator as follows: The option is activated by the keyword POLYMER in the RUNSPEC section. The mixing parameter data is obligatory and should be defined using the keyword TLMIXPAR. The maximum polymer and salt concentrations to be used in calculating the effective fluid component viscosities are entered under the keyword PLYMAX. The polymer adsorption data should be entered using the keyword PLYADS in the PROPS section. Other polymer-rock parameters such as the rock mass density used in the adsorption calculation, the dead pore space, and the residual resistance factor are input using the keyword PLYROCK. The shear thinning model is activated if the PLYSHEAR keyword is present in the PROPS section. The definition of the polymer/salt well injection streams should be set using the keyword WPOLYMER in the SCHEDULE section.

2.0 LITERATURE REVIEW

Gleasure, R.S (1990) conducted an experimental study of new Newtonian polymer rheology effects on oil recovery and injectivity. The authors investigated the effect of Non-Newtonian displacing-fluid rheology on the oil displacement process. The core samples were displaced with polymer solution at fixed imposed pressure gradient. They concluded that Non-Newtonian behavior does not affect oil production performance; however, this is probably due to the variations in pressure gradient which was not large enough to result significant change in the aqueous phase viscosity

Abdulkareem Alsofi et al (2009) concluded that most polymers used in EOR exhibit shear thinning behavior. But shear thickening will improve sweep while shear thinning (pseudo-plasticity) will impair it by exacerbating the velocity contrast and/or inducing instability. Streamline simulator was used to handle the polymer flooding with Newtonian and non-Newtonian behavior. In their work, they investigated the thinning effect of polymer in a homogenous and heterogeneous reservoir 5 spot pattern. It was established that the pseudo-plastic nature of polymers lead to less recovery.

3.0 METHODOLOGY

ECLIPSE 100 was used to evaluate the performance of polymer flood on oil recovery. Appropriate keywords describing the polymer flooding was imputed in the simulator and different sensitivity scenarios were investigated. 3D flooding of stratified reservoir with communicating layers, 3D flooding of heterogeneous reservoir. All the cells are active with no faults. The results gotten were validated by comparison with published ones.

3.1 Method of Solution

The flow equations are actually partial differential equations (PDEs) since the unknowns, P(x,t) and Sw(x,t), say, depend on both space and time.

Simplified pressure equation is given by:

$$\frac{dP}{dx} = \frac{k}{øuc}\frac{d^2P}{dx^2} \qquad (1)$$

Where constant $D_h = \frac{k}{øuc}$ is the hydraulic diffusivity

Assuming D_h=1 then

$$\frac{dP}{dt} = \frac{d^2P}{dx^2} \qquad (2)$$

The form of discretized pressure and saturation equation are as follows:

$$\frac{[\lambda_T(S_o^{n+1})]_{i-1/2}}{\Delta x^2} P_{i-1}^{n+1} - \left\{\frac{[\lambda_T(S_o^{n+1})]_{i-\frac{1}{2}}}{\Delta x^2} + \frac{[\lambda_T(S_o^{n+1})]_{i+\frac{1}{2}}}{\Delta x^2}\right\} P_i^{n+1} \frac{[\lambda_T(S_o^{n+1})]_{i-\frac{1}{2}}}{\Delta x^2} P_{i+1}^{n+1} = 0 \qquad (3)$$

$$S_{oi}^{n+1} + S_{oi}^{n} - \frac{\Delta t}{\phi}\left\{\frac{\left[\lambda_T(S_o^{n+1})\right]_{i+\frac{1}{2}}}{\Delta x^2}(P_{i+1}^{n+1} - P_i^{n+1}) + \frac{\left[\lambda_T(S_o^{n+1})\right]_{i-\frac{1}{2}}}{\Delta x^2}(P_i^{n+1} - P_{i-1}^{n+1})\right\} = 0 \qquad (4)$$

The equations above would result to a set of linear equations if the coefficients were known at the current time step (n) rather than at (n+1) which is unknown time level. ECLIPSE solve these equations simultaneously by time-lagging the coefficients. This would result to the first iteration and the unknown quantities, ${P_{i+1}}^{n+1}, P_i^{n+1}, {P_{i-1}}^{n+1}$ is found. This also applies to the saturation

3.2 Treatment of Fluid Viscosities

The viscosity terms used in the fluid flow equations contain the effects of a change in the viscosity of the aqueous phase due to the presence of polymer and salt in the solution. To account for physical dispersion at the leading edge of the slug and the fingering effects at the rear edge, the fluid component viscosities are calculated using the Todd-Longstaff technique. The effective polymer viscosity is taken to be

$$\mu_{p,eff} = \mu_m C_P^{\omega} . \mu_P^{1-\omega} \qquad (5)$$

Where ω is the Todd-Longstaff mixing parameter.

In order to calculate the effective water viscosity to be inserted into (3), the total water equation is written as the sum of contributions from the polymer solution and the pure water.

The following expression then gives the effective water viscosity to be inserted into (3)

$$\frac{1}{\mu_{w,eff}} = \frac{1-C}{\mu_{w,e}} + \frac{C}{\mu_{p,eff}} \qquad (6)$$

$$C = \frac{C_p}{C_{p,max}} \qquad (7)$$

Where C is the effective saturation for the injected polymer solution within the total aqueous phase in the cell.

3.3 Treatment of Permeability Reductions and Dead Pore Volume

The adsorption process causes a reduction in the permeability of the rock to the passage of the aqueous phase and is directly correlated to the adsorbed polymer concentration.

The actual resistance factor can then be calculated:

$$R_k = 1.0 + (RRF - 1.0)\frac{C_p^a}{C_p^{amax}} \qquad (8)$$

In this study, multiphase relative permeability is modeled with Corey-type functions. Corey-type relative permeability is expressed with relative permeability on residual saturation, exponent defining the curvature of relative permeability, and residual saturation determining normalized saturation. Corey-type relative permeability equation is given as follows:

$$K_{rw} = E_w . S^{*nw} \tag{9}$$

$$K_{ro} = E_o - (1 - S*)^{no} \tag{10}$$

Where

$$S^* = \frac{S_w - S_{wc}}{1 - S_{wc} - S_{orw}} \tag{11}$$

Capillary pressure is strong function of saturation as presented by Leveret derived capillary pressure scaled by soil permeability and porosity for homogeneous reservoirs. Reflected on previous relations, Brooks and Corey capillary pressure-saturation is calculated as follows:

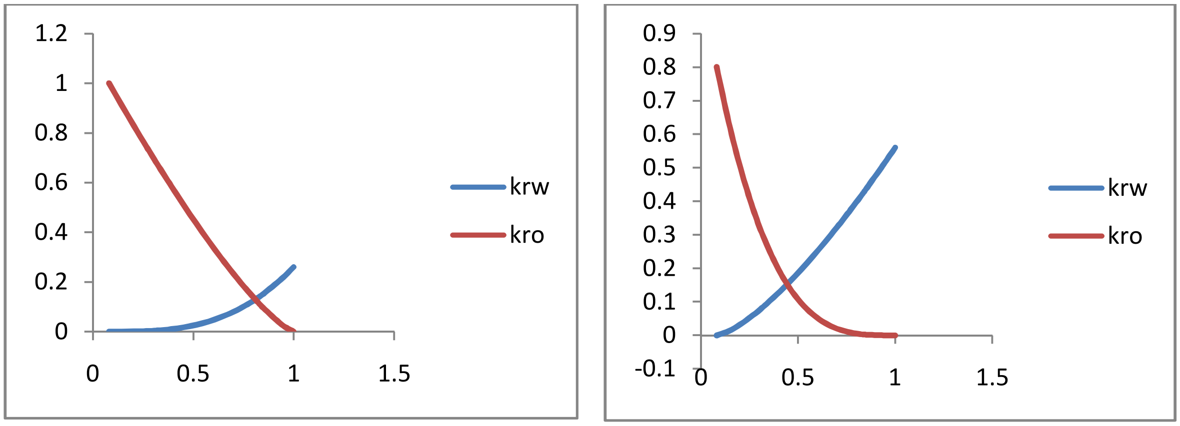
$$P_c = P_b \sqrt{\phi / k} \tag{12}$$

$$P_b = C_{pc} (1 - S*)^{E_{pc}} \tag{13}$$

3.4 FLUID PROPERTIES

Table 1. Rock and fluid properties for Simulation

PORV	660000M^3
OOIP	550957M^3
Viscosity of Oil	20cp
Swi	0.2 fraction
Sor	0.3 fraction
Water Viscosity	0.5cp
water density	64 lb/cuft
Oil density	52 lb/cuft
Porosity	0.22 fraction
Permeability	100md
Rock Compressibility	0psi^{-1}



(a) (b)

Figure 1. Oil and water relative permeability based on Corey type function (a) water-wet rock (b) oil-wet rock

RESULT AND DISCUSSION

4.1 NON-NEWTONIAN EFFECT OF POLYMER

Polymers used in EOR exhibit shear thinning. Shear thinning (pseudoplasticity) impairs sweep. It is important to take polymer non-Newtonian behavior into account for the successful design and evaluation of polymer flooding projects. This is because pseudoplasticity will impair sweep which can deteriorate the whole economic picture of the polymer flood projects. As shown from **Figure 2 (a) and (b)**, pseudoplastic fluid decrease oil recovery by 5% and it delays recovery

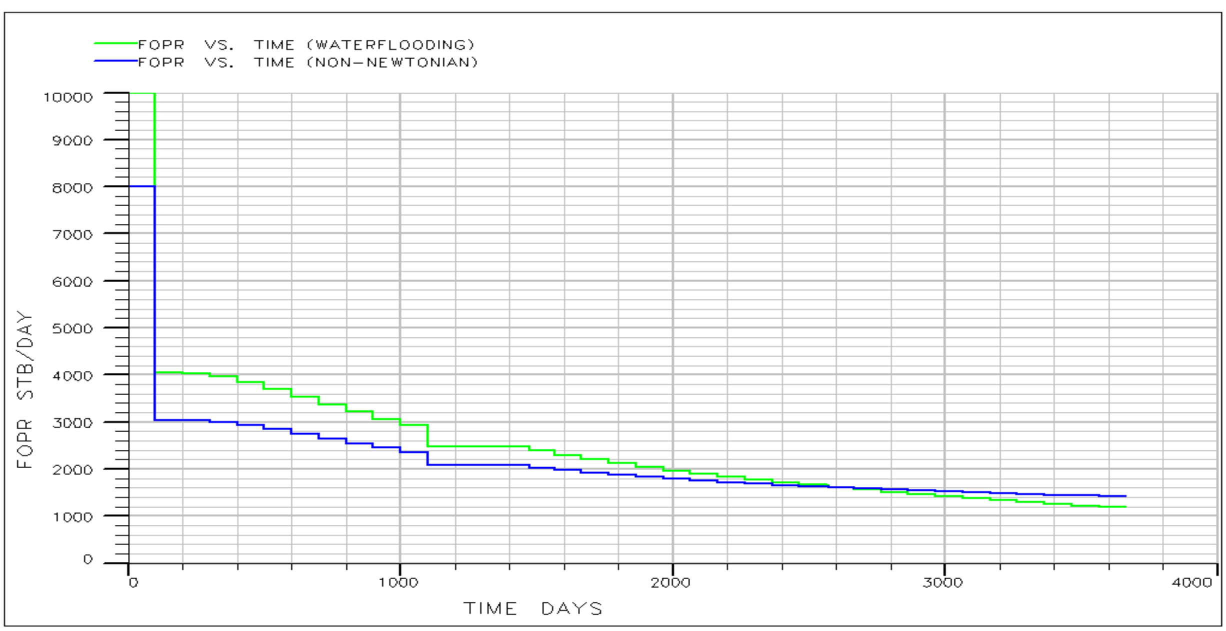
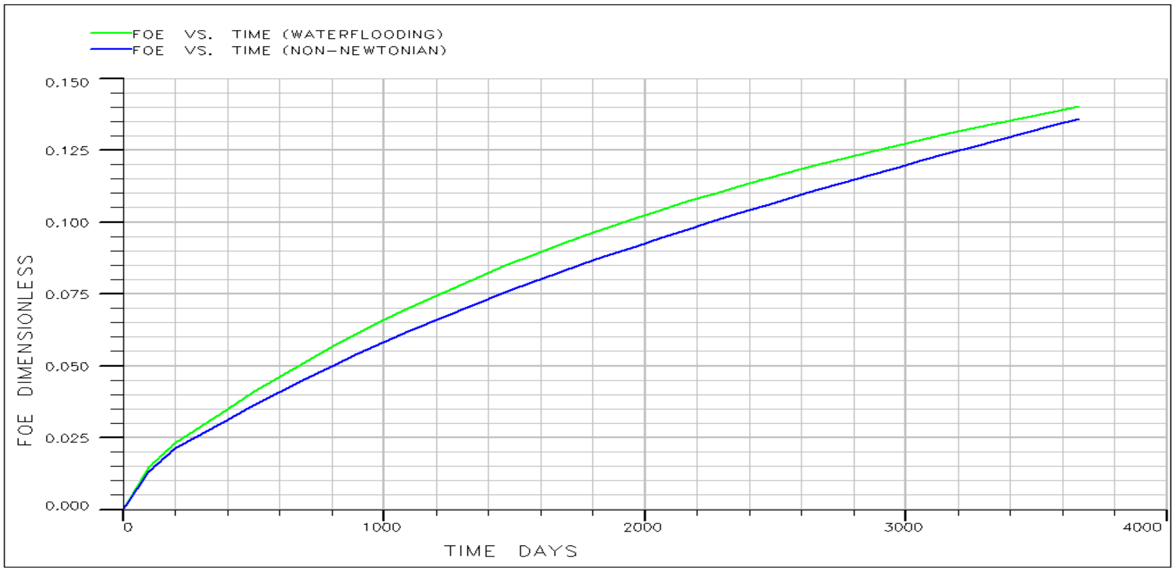


Figure 2: (a) Field Oil Production Rate vs. Time for Newtonian and Non-Newtonian Fluid

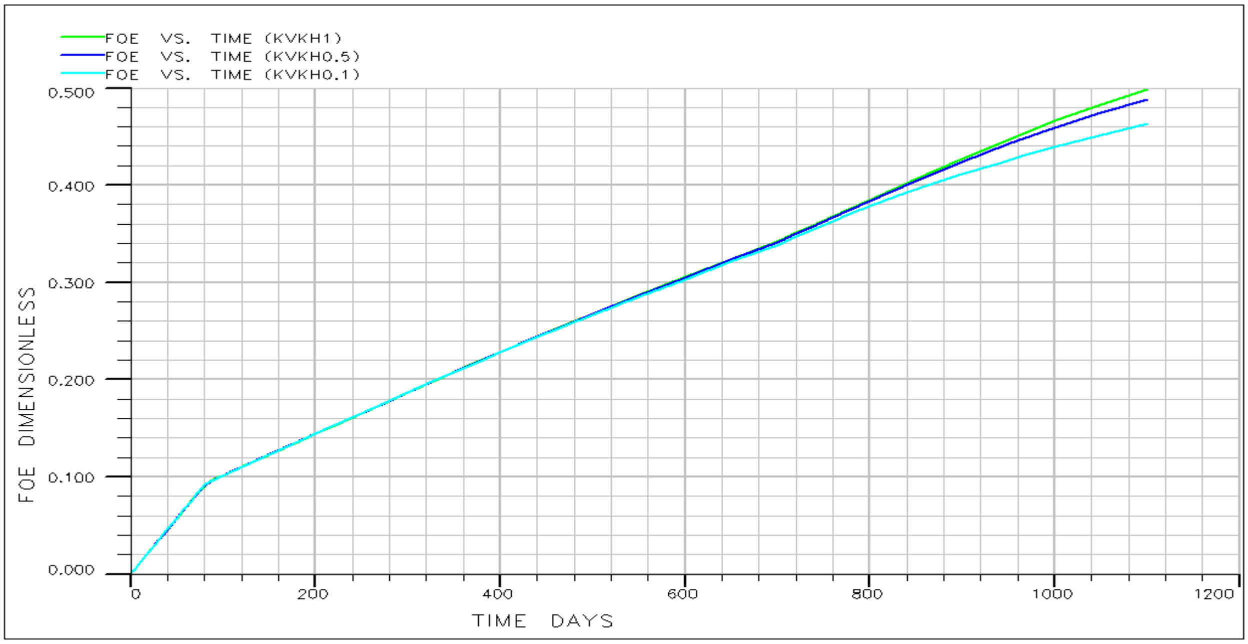


(b) Field Oil Efficiency vs. Time for Newtonian and Non-Newtonian Fluid

4.2 STRATIFIED RESERVOIL WITH CROSS FLOW

Figures 3 and **4** shows that lower oil recovery and rapid increase in FWCT are obtained with smaller Kv/Kh value. When polymer solution is injected into a stratified reservoir with layers of widely differing permeability, the oil recovery is dominated by crossflow due to combined effects of viscosity-derived pressure gradients and gravity. For non-Newtonian polymer flood, the oil recovery and FWCT, **Figures 5 and 6,** are lower than the Newtonian case. This is due to polymer shear thinning effect. Sufficient vertical permeability allows injected fluid to induce crossflow in reservoir

As the vertical permeability increases, **Figures 7 (a) and (b),** oil migrates to other layers more easily, where it is swept by the displacing water to the producing well. An increased oil recovery and decreased FWCT is obtained due to an increase in the degree of crossflow.



.Figure 3 Field Oil Efficiency for Newtonian Polymer at Different Kv/Kh

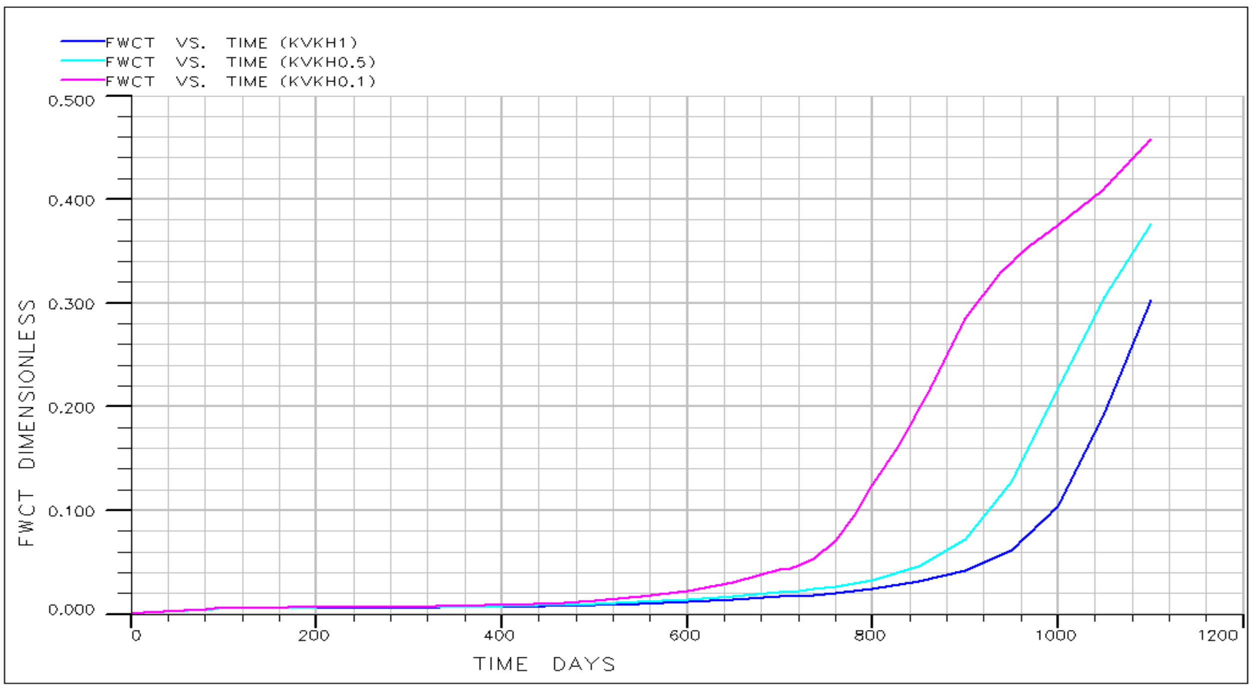


Figure 4 Field Water Cut for Newtonian Polymer at Different Kv/Kh

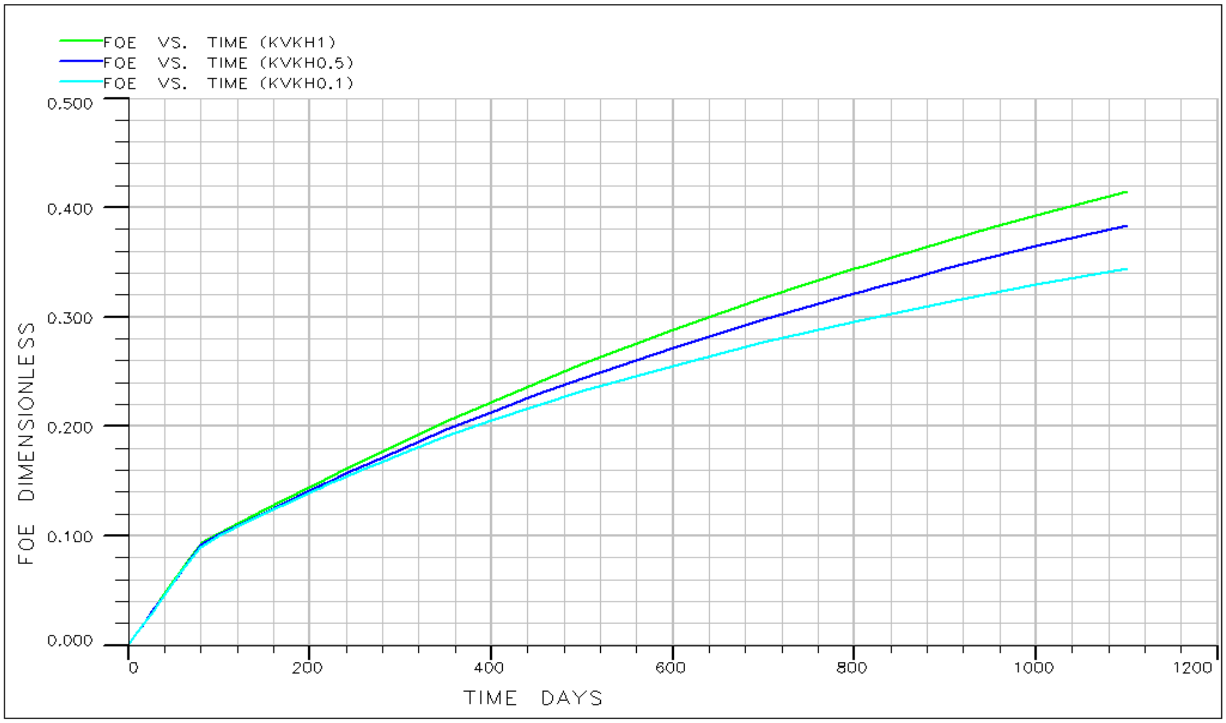


Figure 5 Field Oil Efficiency for Non-Newtonian Polymer at Different Kv/Kh

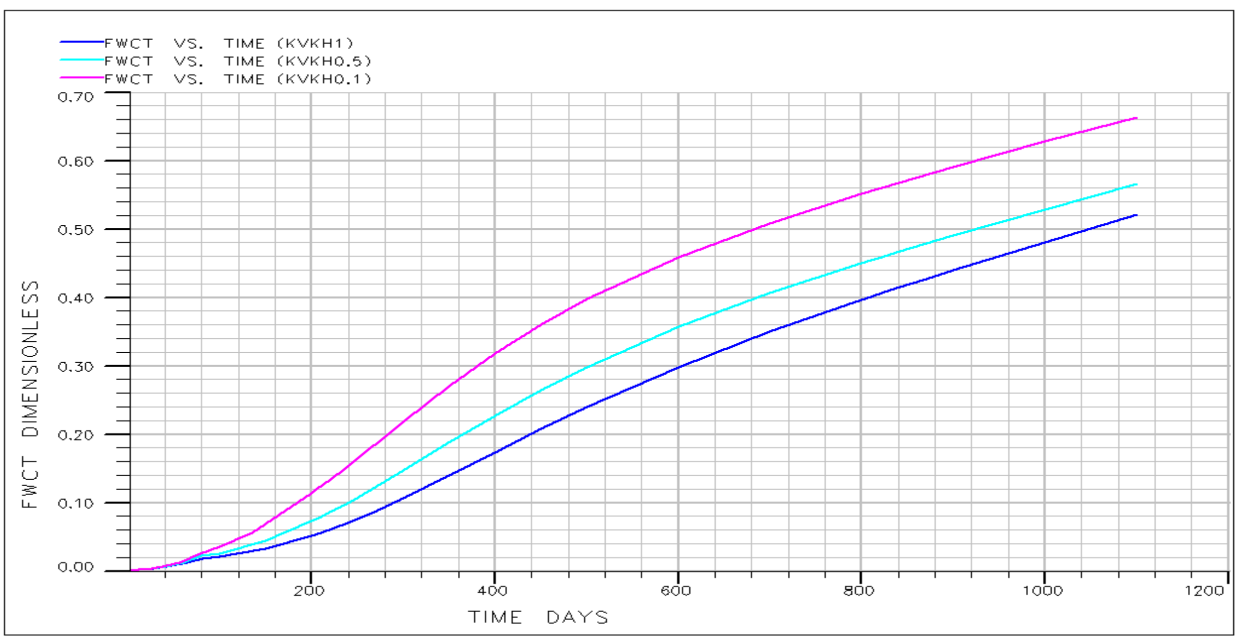
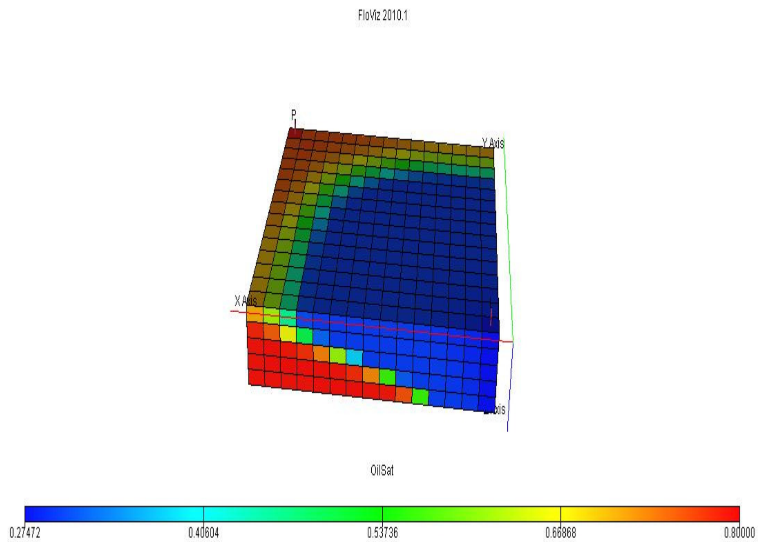
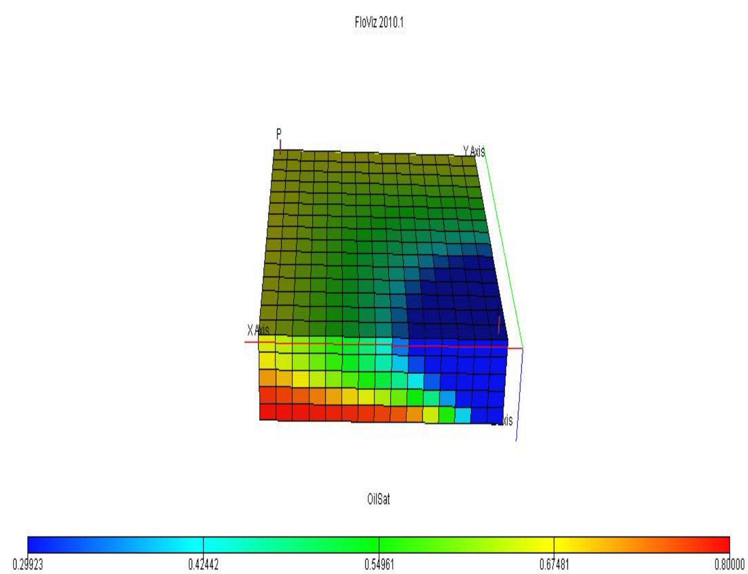


Figure 6 Field Water Cut for Non-Newtonian Polymer at Different Kv/Kh



(a)Newtonian polymer



(b) Non-Newtonian polymer

Figure 7. Oil Phase Saturation

4.3 HETEROGENOUS RESERVOIR

For the heterogeneous reservoir, the permeability ranged from 200md to 1000md and porosity ranged from 0.18 to 0.22. From **Figure 8**, Non-Newtonian polymer under recover 3% of oil. It also delays recovery. It shows that more pore volume must be injected to attain full sweep

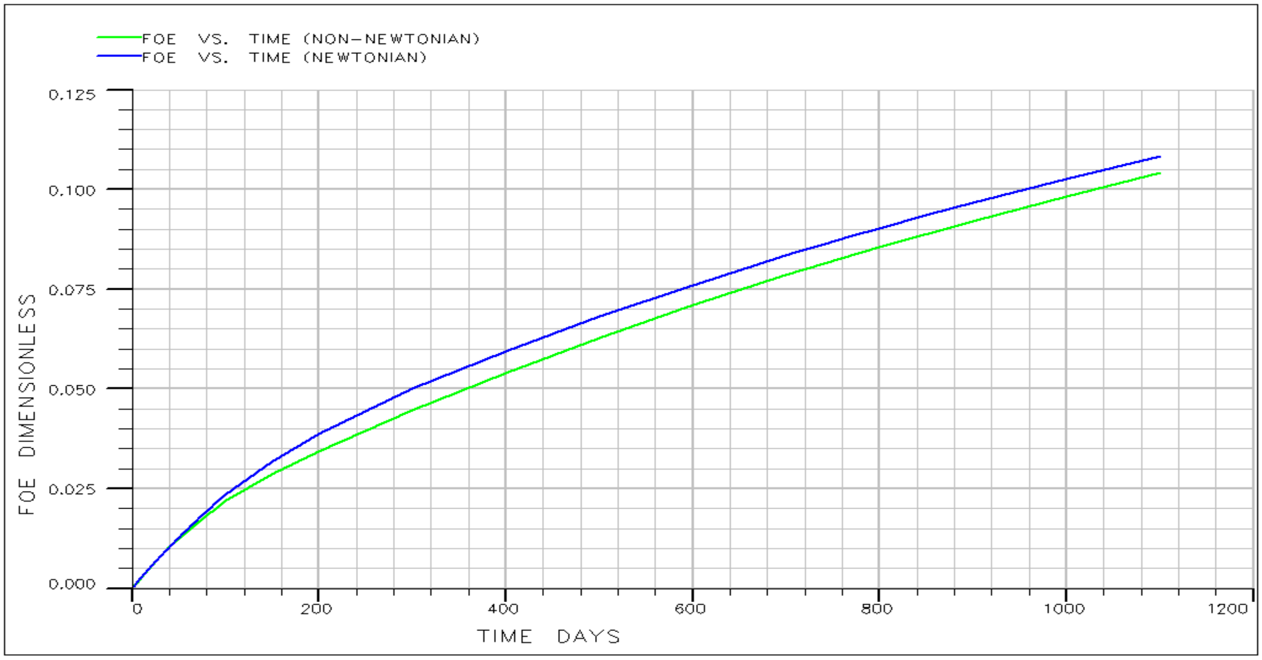


Figure 8. Field Oil Efficiency for a Heterogeneous Reservoir

4.4 ROCK WETTABILITY EFFECT ON POLYMER FLOOD PERFORMANCE

Figure 9 and 10 below present the cumulative oil recovery and water cut for Newtonian flow of polymer for water-wet and oil-wet reservoirs .As can be seen, the cumulative oil recovery in water-wet is 0.48, which is considerably higher than the oil recovery in oil-wet, 0.32, at the end of production for Newtonian flow.

The non-Newtonian case in **figure 11,** water-wet reservoir gives 0.42 as against 0.48 in Newtonian flow of polymer. For oil-wet, non-Newtonian gives 0.28 as against 0.32 in Newtonian flow. This confirms that shear thinning of polymer impairs sweep and must be considered while considering polymer flooding option.

Figures 12 and 13 compare the oil saturation distribution at 1100 days for Newtonian and Non-Newtonian polymer for both water-wet and oil-wet Reservoirs. Due to the favorable mobility ratio by polymer flood in water-wet reservoir, relatively higher contrast of oil saturation between swept and unswept regions exits in reservoir. On the other hand, there is a lower contrast between swept and unswept region in the oil-wet reservoir. For oil-wet reservoirs, remained oil saturation is still higher than residual oil saturation for both cases of polymer flood

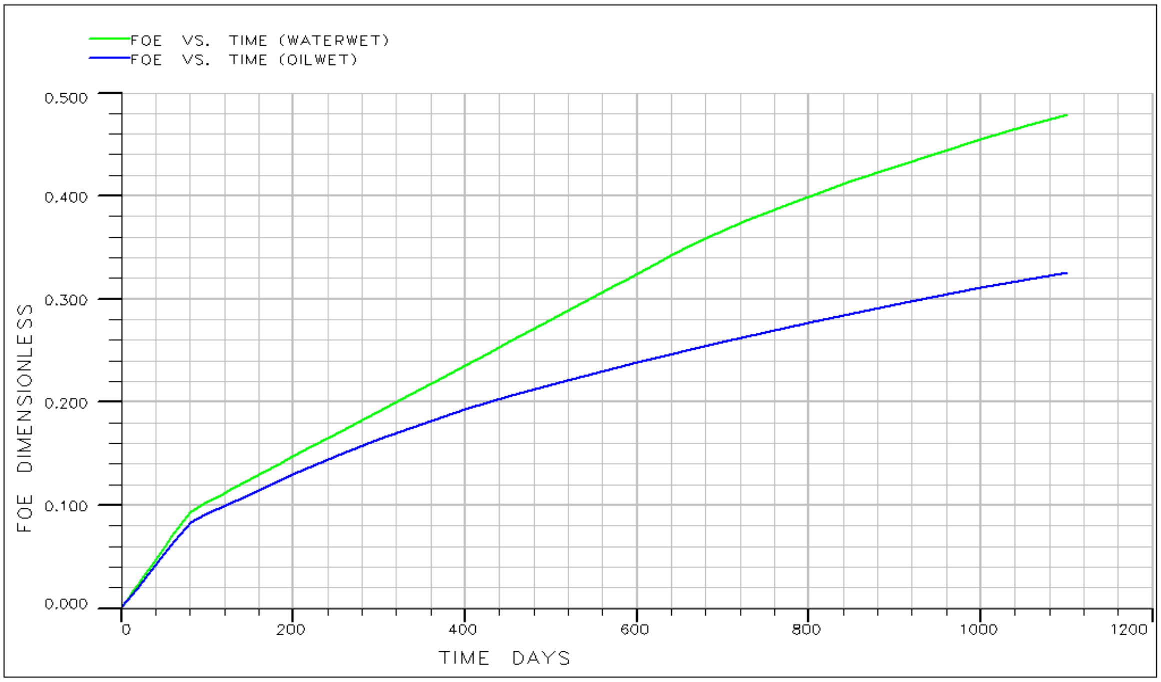


Figure 9 Field Oil Efficiency for Newtonian Polymer Flooding In Oil-Wet and Water-Wet Reservoir

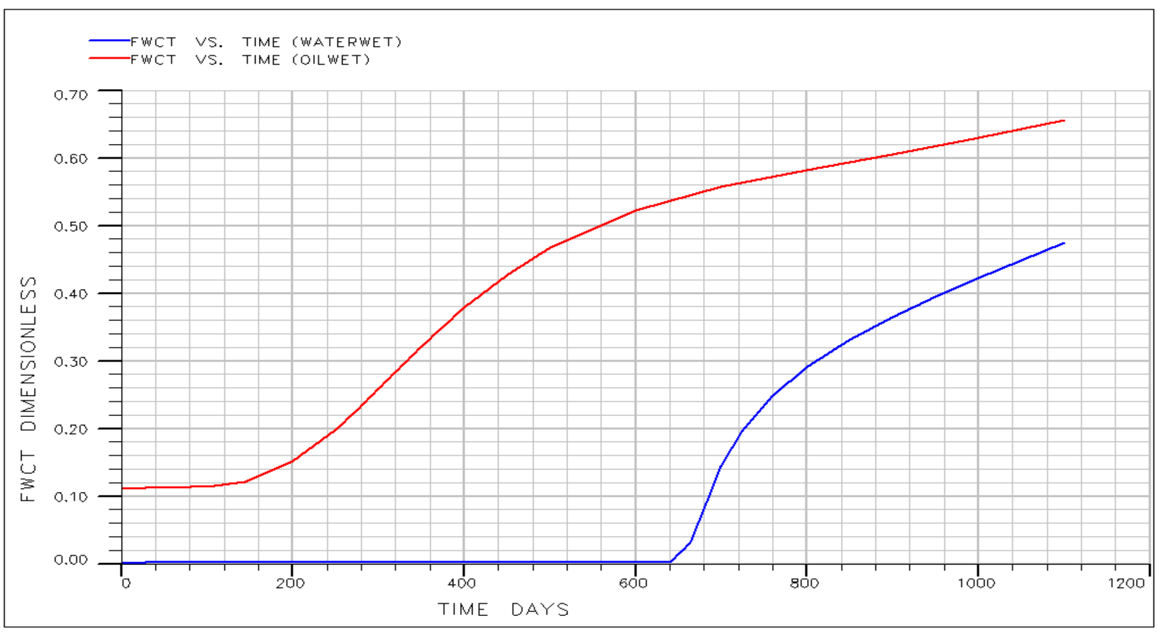


Figure 10 Field Water cut for Newtonian Polymer Flooding In Oil-Wet and Water-Wet Reservoir

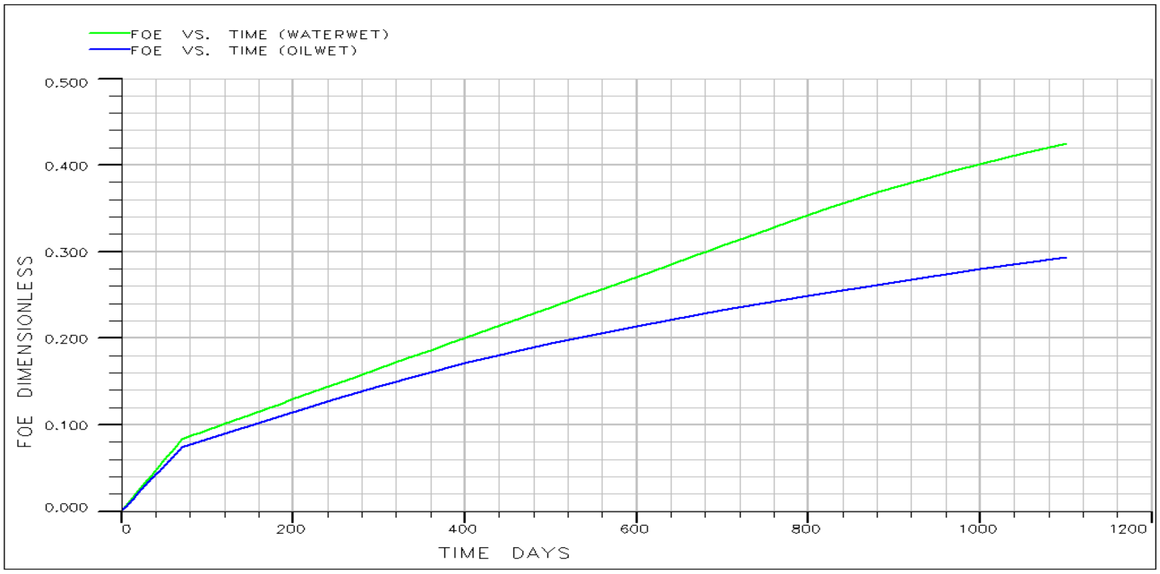
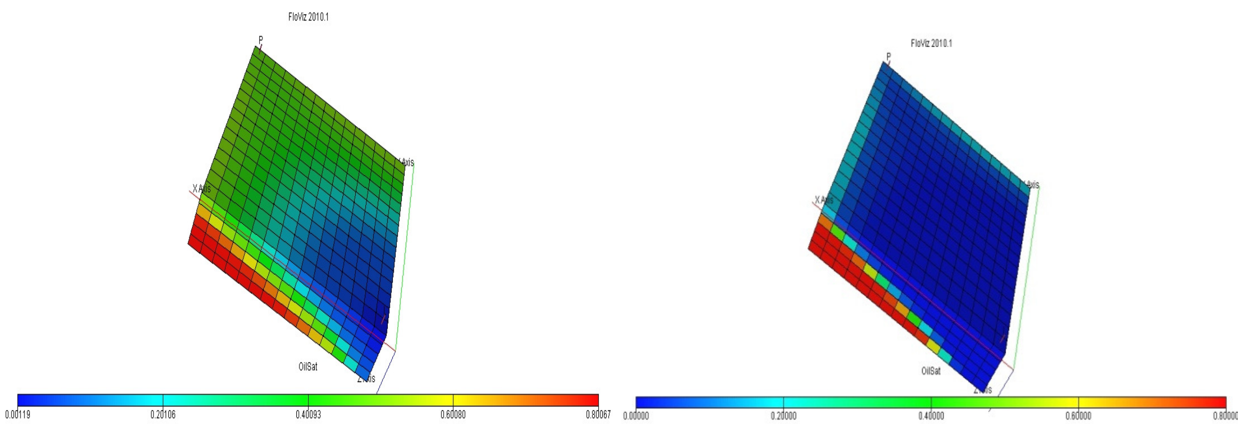
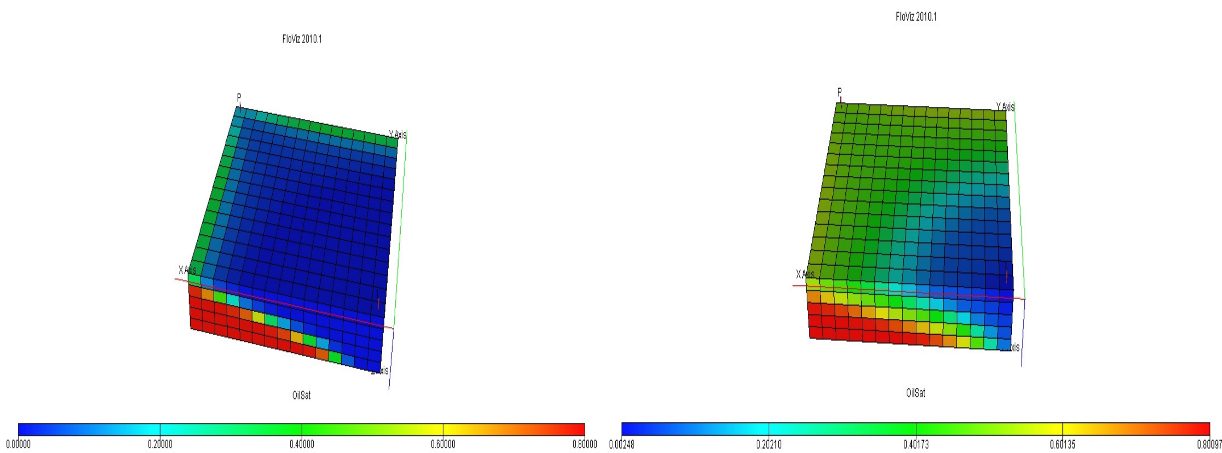


Figure 11 Field Oil Efficiency for Non-Newtonian Polymer Flooding In Oil-Wet And Water-Wet Reservoir



(a) Water-wet rocks (b) Oil-wet rocks

Figure 12 Oil Saturation Distributions at 1100 Days for Newtonian Polymer



(a) Water-wet rocks (b) Oil-wet rocks

Figure 13 Oil Saturation Distributions at 1100 Days for Non-Newtonian Polymer

NOMENCLATURE

K_{rw} - Relative permeability to water

K_{ro} -Relative permeability to oil

$S*$ -Normalized water saturation

E_w - Water relative permeability at residual saturation

E_o - Oil relative permeability at residual saturation

nw - Water Exponent of the relative permeability

no -Oil Exponent of the relative permeability

P_c -Capillary pressure

P_b - Constant

C_{pc} - Constant

E_{pc} -Constant

CONCLUSION

Non-Newtonian flow of polymer leads to lowering of recovered oil. The viscosity of polymer in the mixed fluid are sheared at high velocity or high flow rate leading to unfavorable mobility ratio the displacing fluid and oil; hence the bypassing of oil. Lower recovery and higher water cut are observed for oil-wet reservoirs than those of water-wet reservoirs for Newtonian and non-Newtonian cases makes polymer flooding of oil-wet reservoir less attractive. An oil-wet formation tends to hold back more oil in its minute pores and produce reservoir water. This is exacerbated in Non-Newtonian case.

REFERENCE

Abdulkareem M. A., Tara C. L., Martin J. B. :(2009). 'Sweep Impairment due to polymer shear shinning'. SPE paper presented at the 2009 SPE Middle East Oil and Gas show and conference15-18 March 2009

Gleasure, R.W.; Phillips, C.R. (1990) An experimental study of non-Newtonian polymer rheology effects on oil recovery and injectivity. *SPE Reserv. Eng.*, *5*, 481–486

kun sung lee (2011). 'Performance of polymer flood with shear-thinning fluid in heterogeneous layered system with crossflow'. Department of natural resources and environmental Engineering, Hanyang University.

Obuekwe Mogbo (2011).'Polymer flood simulation in a heavy oil field: Offshore Niger-Delta experience'. SPE EOR Conference Kuala Lumpur, Malaysia. 19-21, July 2011.
OK, 22–24 April

Slater G.E., Farouq-Ali S.M. simulation of oil recovery by polymer flooding. Technology, Oct Dec 1970. Montreal.

Schlumber Eclipse Reference Manual pg 777-798. 2009.2

Schlumberger**.** Eclipse Technical Description Manual. 2009.2

Wang D., Seright R.S., Shao Z., Wang J. (2008). 'Key aspect of project design for polymer flooding at the Daqing oil field'. SPE Res Eval &Eng, 11(6), 1117-1124, December, (SPE 109682)