Asian Journal of Applied Sciences (ISSN: 2321 – 0893)
Volume 07 – Issue 04, August 2019

Polymer Optimisation- Shear Thinning or Thickening?

Gloria Gyanfi*, Wilberforce Nkrumah Aggrey, Ernest Ansah Owusu, Kofi Ohemeng Prempeh

Department of Petroleum Engineering
Knust, Ghana

**Corresponding author's email: alisonproud14 [AT] gmail.com*

ABSTRACT---- ***With most polymers employed in polymer enhanced oil recovery exhibiting one or both non-Newtonian behaviours that is shear thickening and thinning at different shear rate, it is expedient to analyse the impact of these non-Newtonian behaviours in polymer optimisation. CMG simulation suite was employed to analyse the permeability pinch-out formation with a five (5) spot injection well pattern for a 360days simulation run using a 90days polymer injection well cycling. Shear thinning polymer was found not to be conducive for lower permeable formation due to high retention percentages of the polymer. The findings concluded that the net present value (NPV) was ultimately affected by polymer injection rate which controlled polymer optimisation.***

Keywords--- Non-newtonian; Polymer;,Optimization; Shear Thinning ; Shear Thickening

1. INTRODUCTION

Remaining oil and gas left after primary recovery and secondary recovery remains high and numerous interventions are made to maximise production (Alvarado and Manrique, 2010; Thomas, 2008) . Chief among these interventions is polymer flooding (Abdulbaki et al., 2014;AlSofiand Blunt, 2010; He et al., 2008; Jung et al., 2013; Liu et al.,2015; Wang et al., 2000; Wei et al., 2014) capable of maximising the sweep efficiency, mobility control, and fluid diversion effect among others reported in the literature (Al Ayesh et al., 2016; Bai et al., 2015; Li et al., 2010;Yan et al., 2006)

Majority of polymers are easy to deform under shear force during fluid displacement. Consequently they take on the form of non-Newtonian fluids . Non-Newtonian Fluids are liquids that behave like a solid and remains in a semi-solid or highly viscous state. Such fluids do not follow the Newton's Law of viscosity. As per rheology, non-Newtonian fluids have varying viscosity and can be deformed from one shape to another when force or stress is applied on them. Non-newtonian fluids deployed in the oil and gas sector have key characteristics that define their performance and effectiveness. For most polymers either shear thinning or thickening behaviours are observed, while for various kinds of polymers, both shear-thinning and shear-thickening behaviours are observed (Wever et al., 2011). The impact of these fluids on enhanced oil recovery process are huge and therefore necessary to understand the roles of shear-thinning and shear-thickening properties in order to maximise production and increase total recovery. In the literature there are two blocks on the subject as to which ; shear-thinning and shear-thickening is important and sometimes even better. As early as 1980, Jones (1980) pointed out that shear-thickening is more feasible for stratified rocks with various permeabilities, while shear-thinning is better under uniform displacement front conditions. Zhu et al. (1998) postulated that the shear-thinning property of foam allow for lower injection pressures near the highly sheared wellbore area and does was more effective than the latter. Zhang et al. (2000) proposed that the shear rate in a large pore throat is lower than in a small pore throat, thus shear-thinning could lead to a relative smaller resistance in low permeable core and contribute greater oil recovery in heterogeneous reservoir. In view of the varying views on the subject the aim of this study is to analyse the non-Newtonian behaviour of polymers to improve its sweep efficiency and recovery while considering the economic benefits in addition to higher recovery to ascertain the concept of shear thinning and or thickening on recovery.

2. METHODOLOGY

2.1 Model Building and Running

The model was built using data from X-field as well as some stochastically generated data. The model was run for 360 days using the CMG stars with 5days time step to observe and compare their recovery factors and fluid pore volume and also analyse the dynamic grid properties. Three models were initially run namely shear thickening, shear thinning, polymer without any thinning or thickening effect. CMG CMOST simulator was the major simulation tool for the analysis. CMOST was employed to enhance and accelerate optimisation, sensitivity analysis and uncertainty analysis. Maximum injection rate of 10,000STB and a minimum injection rate of 1000STB were assigned for all injection wells for the sensitivity and optimisation analysis. For the economic analysis an oil prize of $50 per barrel was employed and a total polymer injection cost of $702 per STB of injection water pumped.

A regular Cartesian (21 *21* 1) grid block was employed, with a constant dimension of 39.34 ft in the I and J direction and 30 ft in the K direction and a constant porosity of 25%. The reservoir is made up of a heterogeneous pinch-out array of permeability as shown below. The producing limestone grades up-dip into an impermeable limestone that is barren. Later arching of the sediments formed the Carthage pool that covers nearly 250,000 acres.

A four (4) component model was adopted namely; Water, Calcium, Polymer and Oil. All components except oil are aqueous based. Table 1 shows the property definition of the components present and Figure 1 shows the flow (permeability) distribution of the model.

Figure 1 Permeability distribution of model

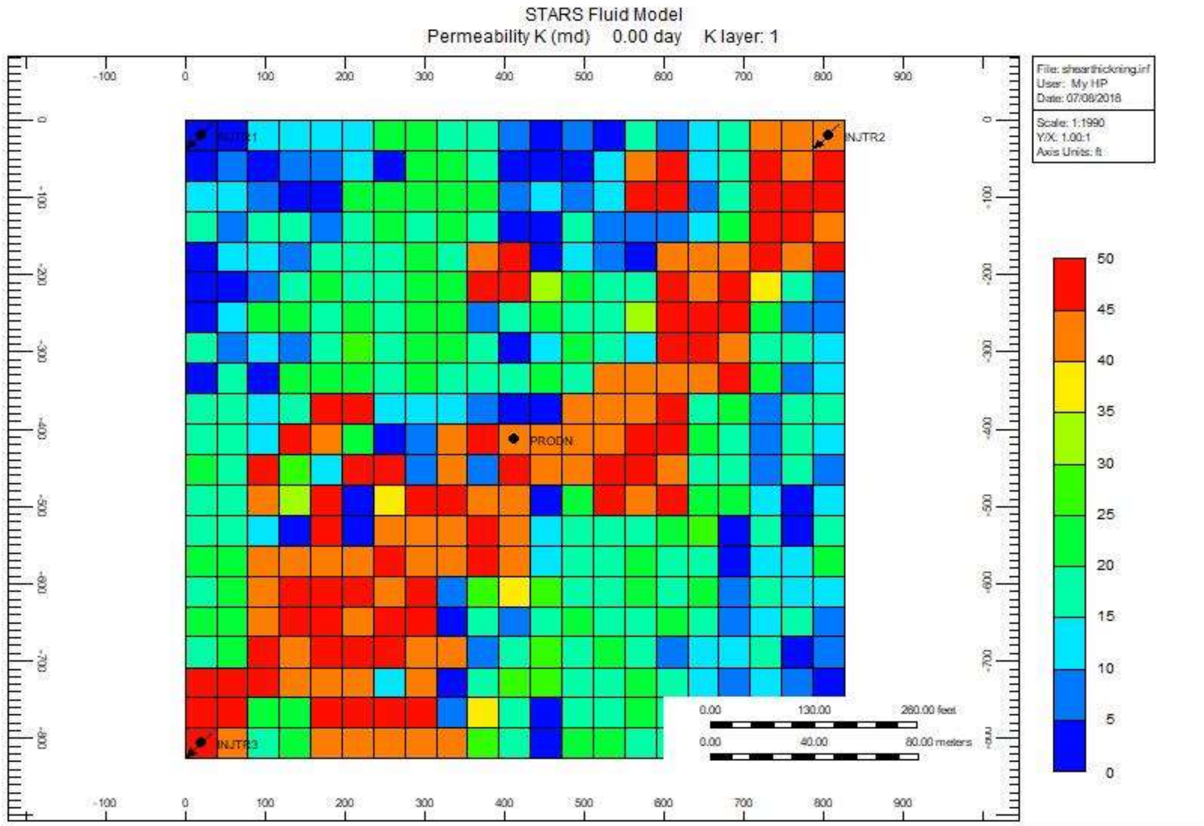


Table 1 property description of component present

Property	Water	Calcium	Polymer	Oil
Molecular Weights	**18.02**	**40.08**	**8000**	**400**
Mass Density	**62.970**	**62.970**	**62.970**	**58.20**
Viscosity	**0.5875**	**0.5875**	**10**	**9.8**
Compressibility	**3e-6**	**3e-6**	**3e-6**	**1.0e-5**

2.2 Shear Thickening and Shear Thinning Behaviour Modelling

In modelling the shear thickening behaviour, a 1500ppm of hydrolysed polyacrylamide (HPAM) polymer was used which showed a shear thickening effect with time when injected into the reservoir under increased velocity and shear rate. Data for shear verses viscosity reading was taken from an experiment conducted by Stavland et al. (2010). Though the HPAM can exhibit both the shear thickening and thinning effect, the concentration of this research was on the shear thickening behaviour of the HPAM. In modelling the shear thinning behaviour, Scleroglucan polymer as shown in Figure 2 and 3 was used which showed great shear thinning property at a similar shear rate reading and 1500ppm concentration as the HPAM used for modelling the shear thinning. Shear rate verses viscosity data was obtained from Scleroglucan SW 58C. (Shields & Beteta)

Figure 2 shear behaviour of HPAM

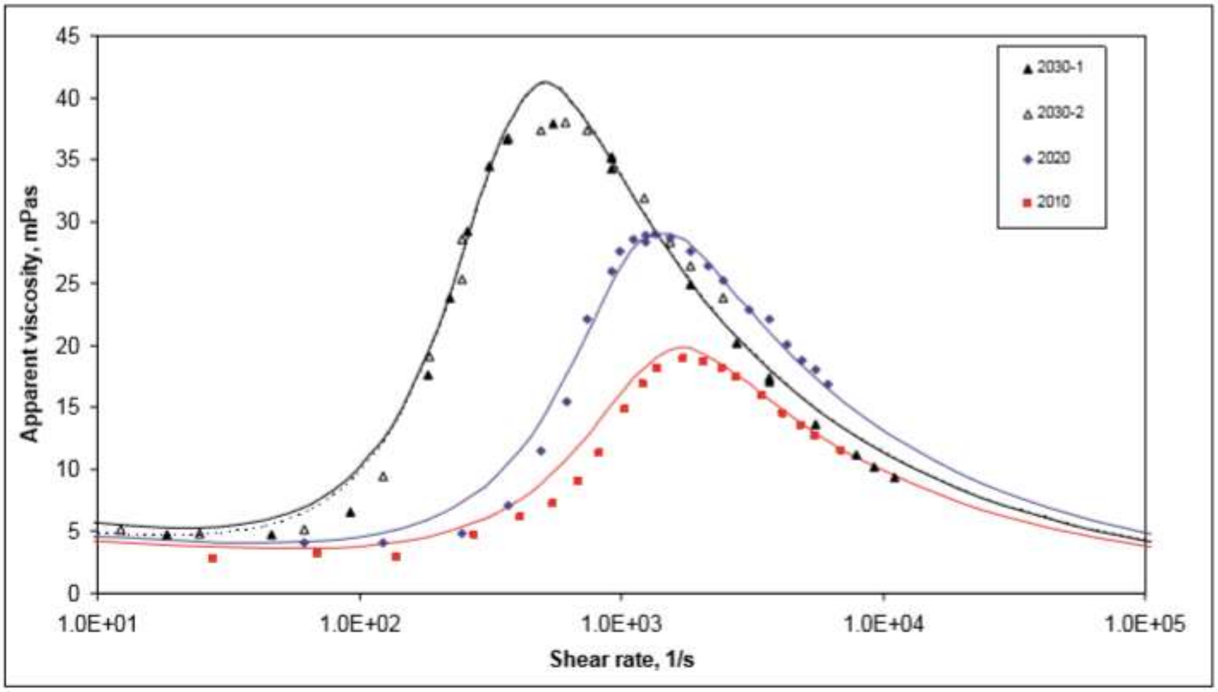
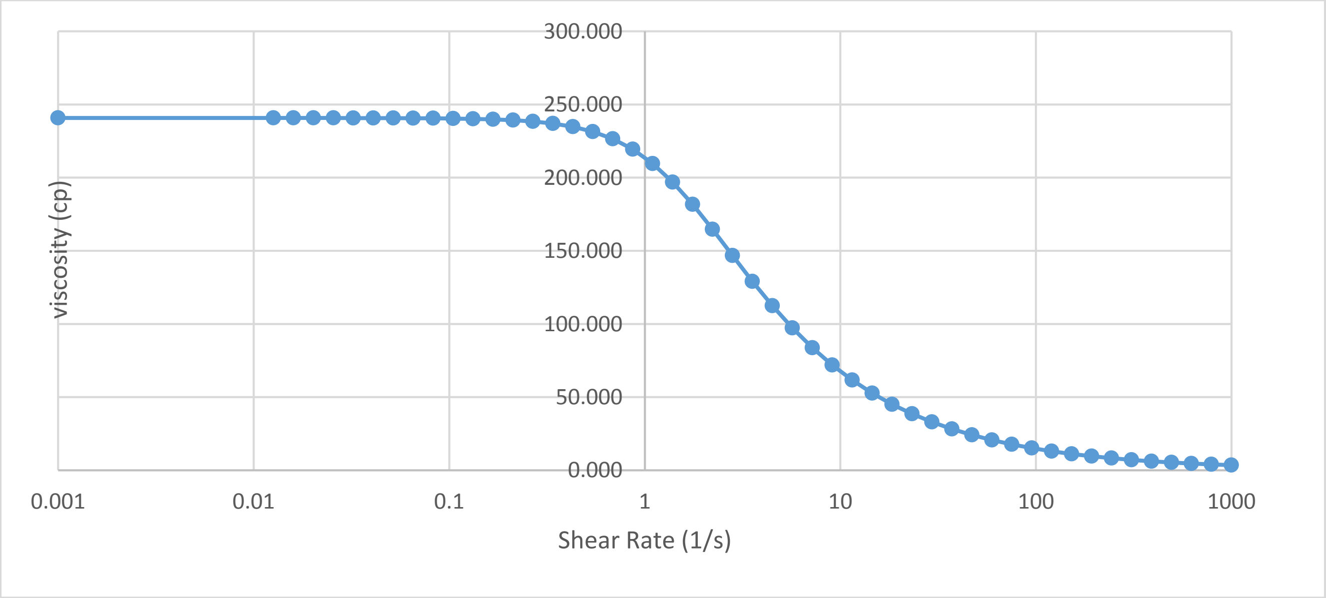


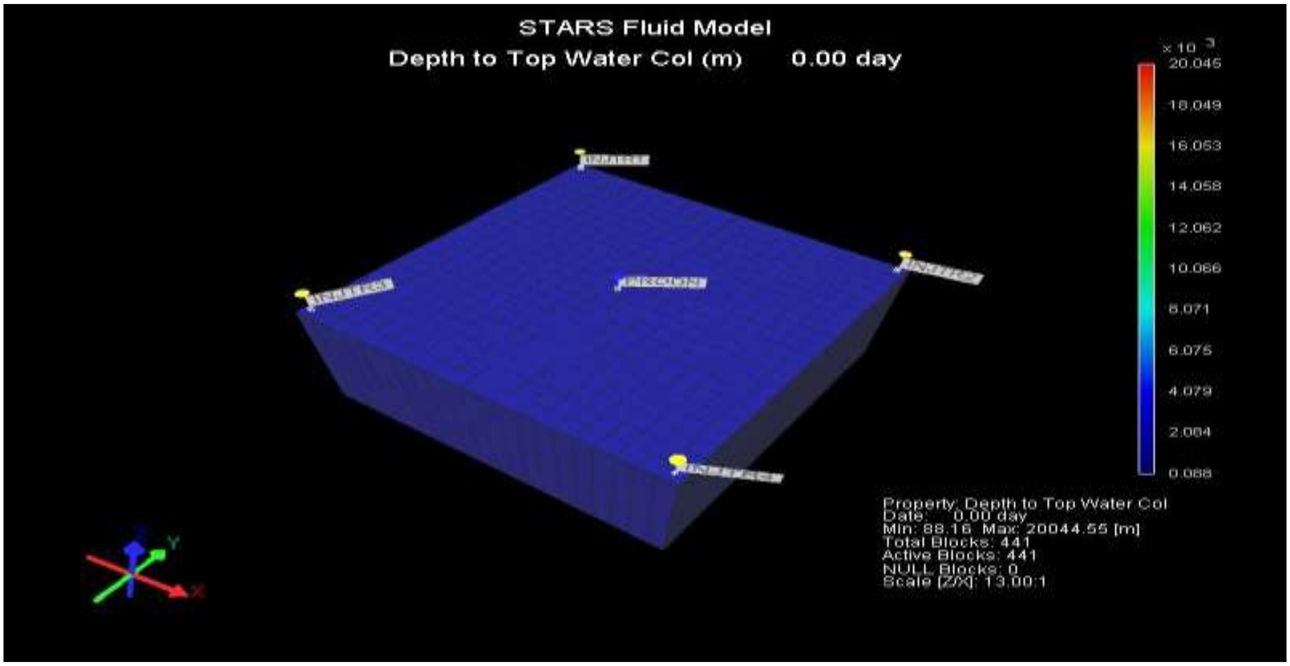
Figure 3 shear behaviour of scleroglucan polymer



2.3 Wells and Cycle of Injection

The model consists of a five (5) spot pattern with four (4) injectors and one centrally positioned producer as shown in *Figure 4* . The injectors had a constant maximum injection rate of 5000STW and a maximum bottom hole pressure of 10000 psi. A cyclic polymer injection pattern of 90 days for each well followed by normal water injection for the rest of the life of the model run. The polymer injection cycle was performed for injector -well1 through to well4 all at the same rate.

Figure 4 3D view of 5 spot model



3. RESULTS

After running and simulating the models for 360 days as shown in Figure 5, it was observed that the shear thick polymer has the highest recovery factor with the shear thin polymer having the least recovery factor. It can be inferred that the shear thickening polymer due to its increasing viscosity with increasing shear offered a higher viscosity to drive the hydrocarbon towards the producer. The no shear effect however proved better than the shear thinning polymer also due to its constant viscosity as compared to the shear thinning whose viscosity reduced with increasing shear. Results from pore volume analysis as shown in Figure 6 indicates a constant in polymer pore volume from the start of simulation to the hundredth (100) day. After the hundredth (100) day, the shear thinning polymer reduces rapidly even with continual injection of polymer. Shear thickening and the no shear effect models increases and reduces step-wisely with the injection of polymer in each well. The mass injected water in the reservoir was constant for all the models till after 100 days as shown in Figure 7. Shear thickening and no shear effect increased and reduced with shear thinning increasing gradually throughout the simulation period.

Figure 5 oil recovery vrs time

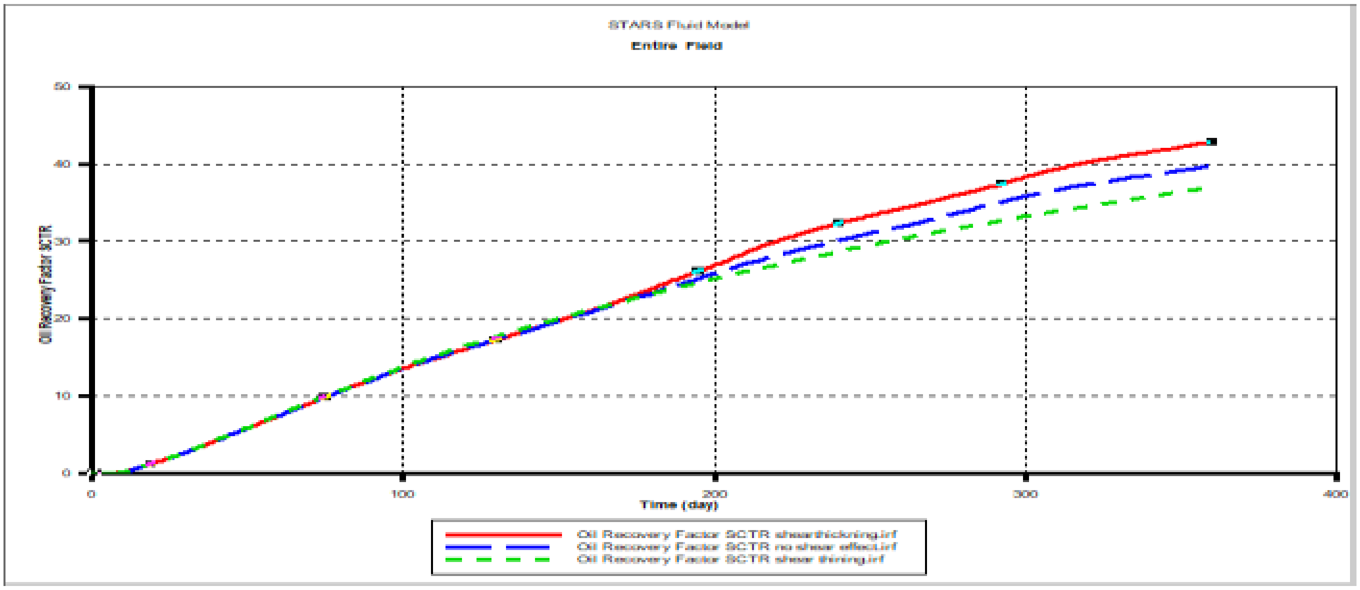


Figure 6 pore volume vrs time

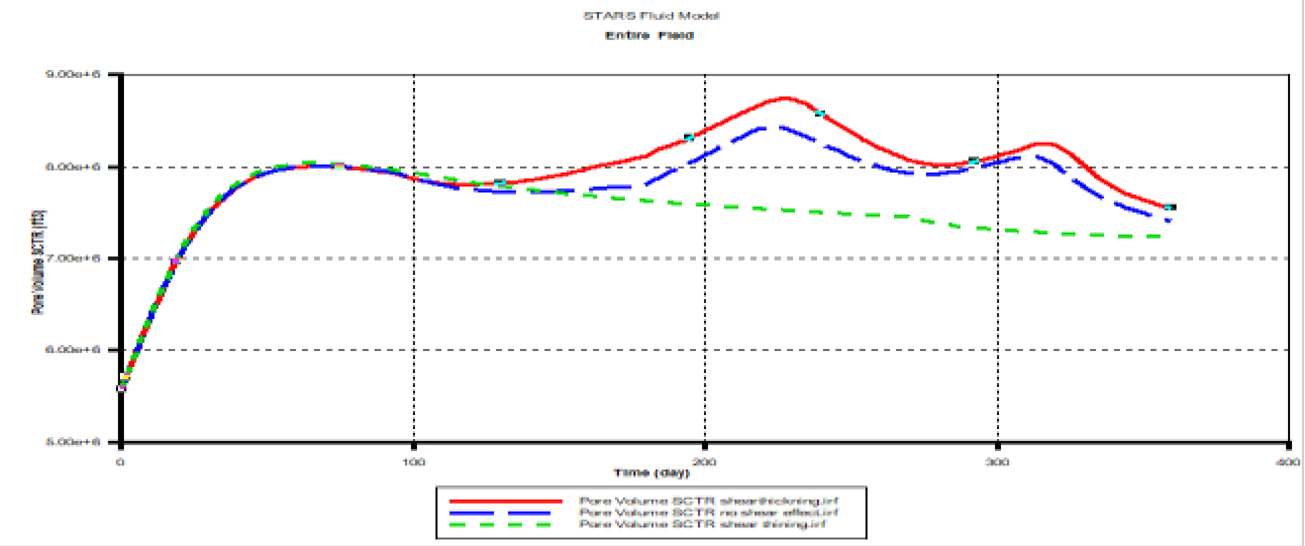
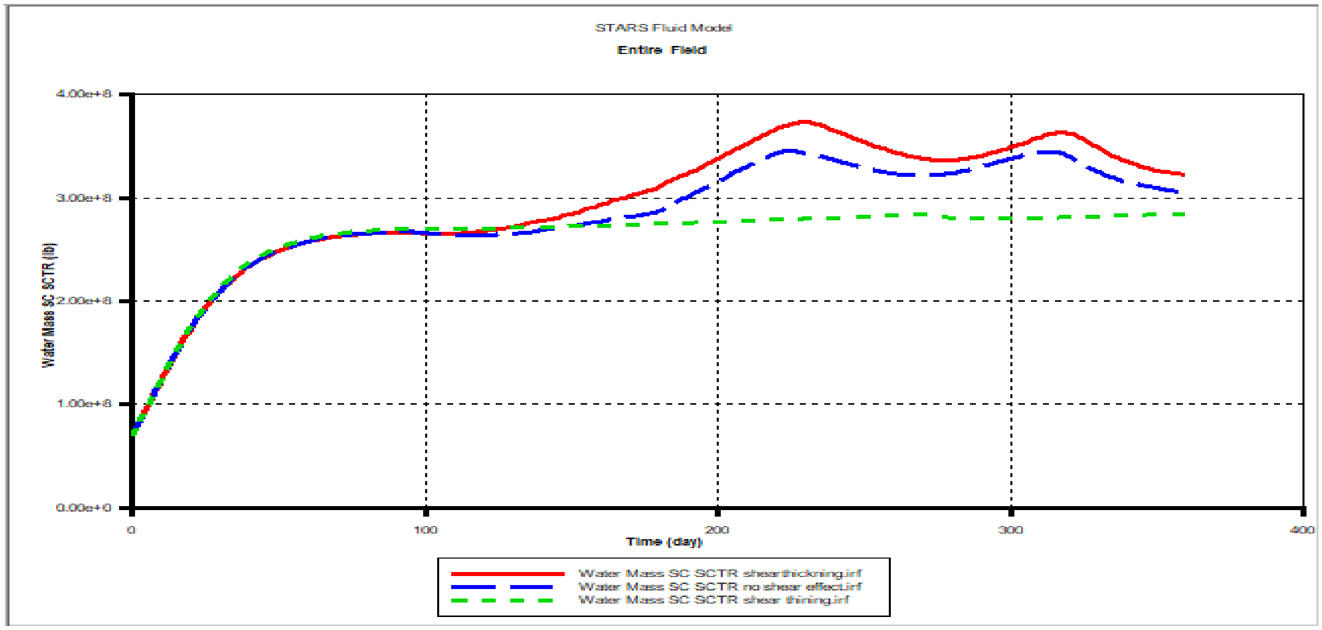


Figure 7 water mass vrs time



Results from water cut analysis as shown in Figure 8 showed shear thinning having an increased water cut compared to shear thickening between day 100 and day 360 with both recording the same percentage from day 0 to day 100 and day 360. It is however interesting to notice that with just 360days of run is recoding such a high water cut. The sharp increase in water cut was observed just from the day 10 suggest that other well placements options needs to be considered which can reduce the water cut.

Results from shear thinning for water viscosity as shown in Figure 9 indicates a higher concentration around grid blocks of lower permeability. The path of grid blocks with higher permeability recorded a as low as 0ppm of polymer concentration. Results from shear thickening indicates as low as 0ppm of polymer concentration around regions of the wells except injector well 4 which records a higher concentration. An unexpected increased concentration was observed in grid blocks in between the wells.

Result from shear stress analysis as shown in Figure 10 after the 360 days simulation run showed a higher shear stress along the path of the high permeability and producer for both polymers. A high shear stress is however observed around injector well4 for shear thinning polymer and around injector well1 for shear thickening polymer as seen from the plot below.

Figure 8 water cut vrs time

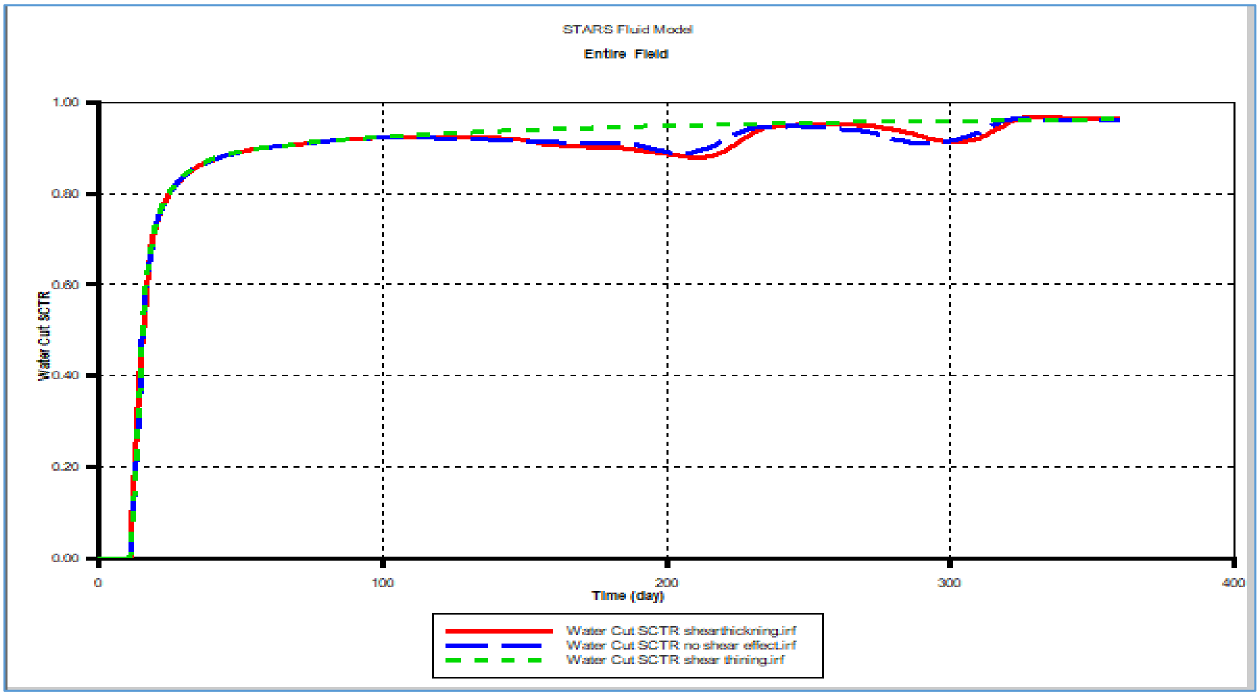


Figure 9 grid view of polymer concentration

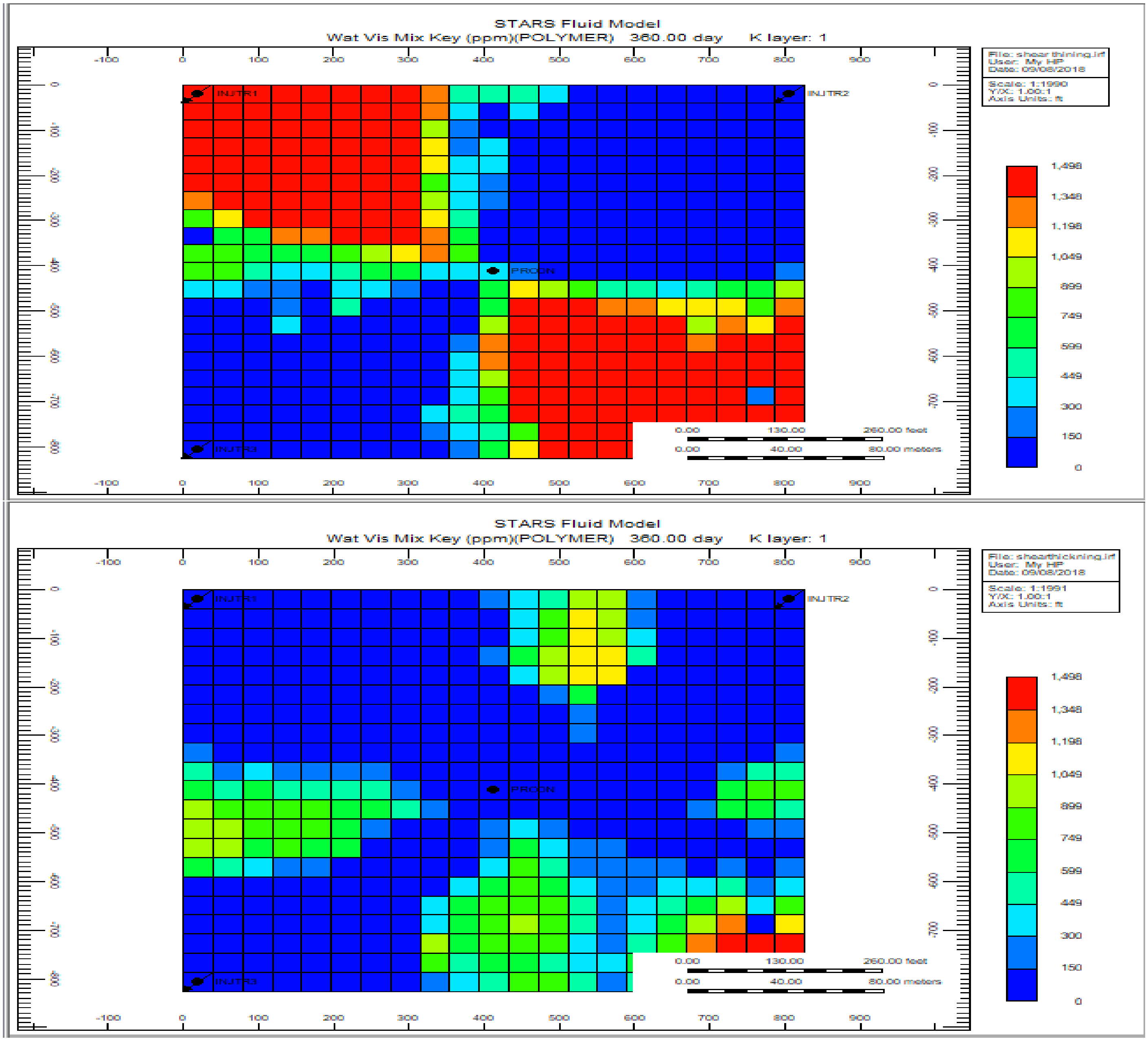


Figure10 grid view of shear rate

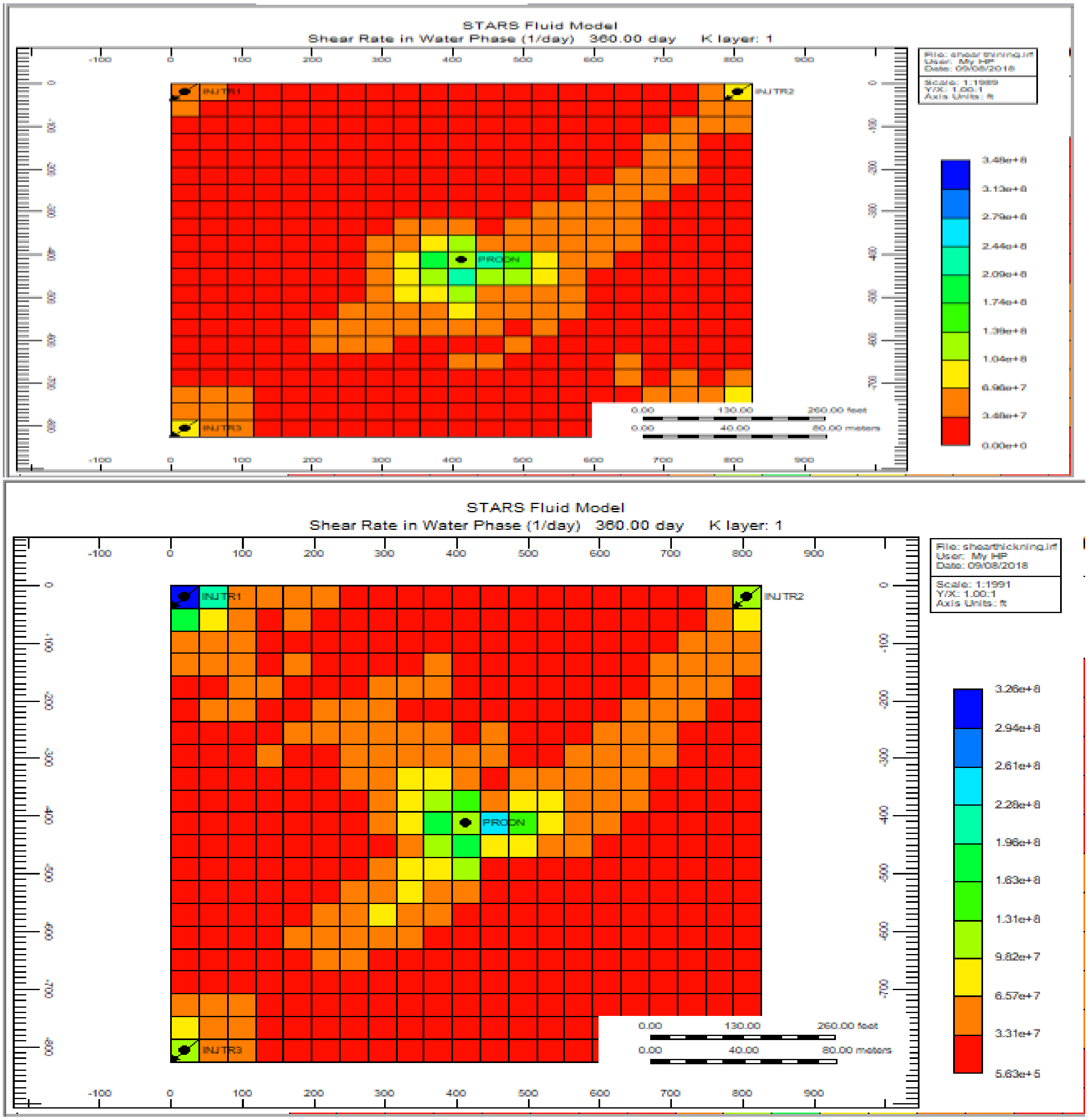
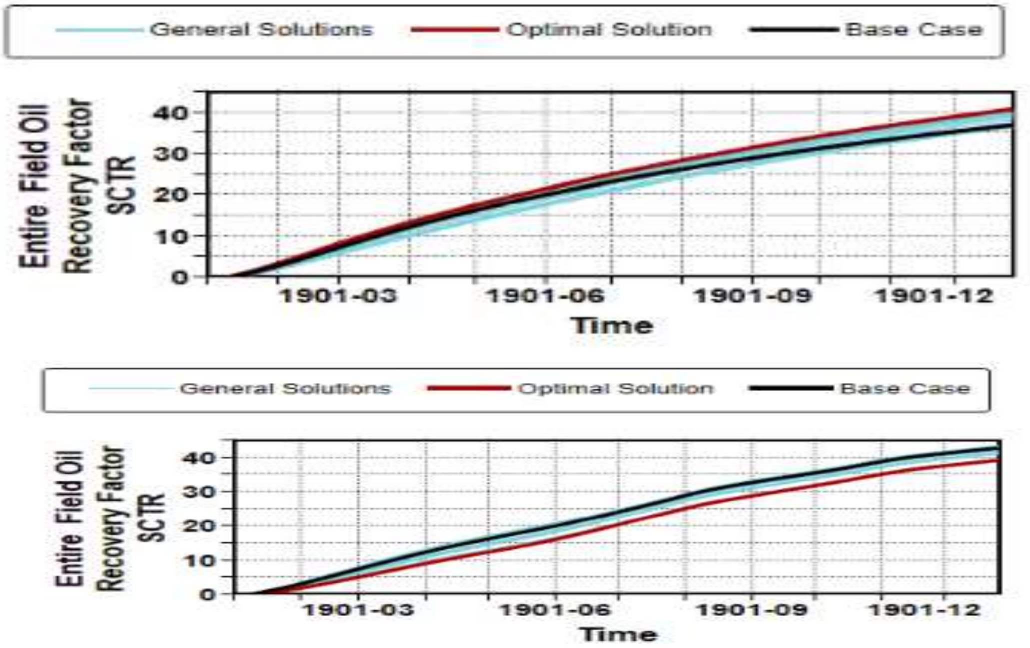


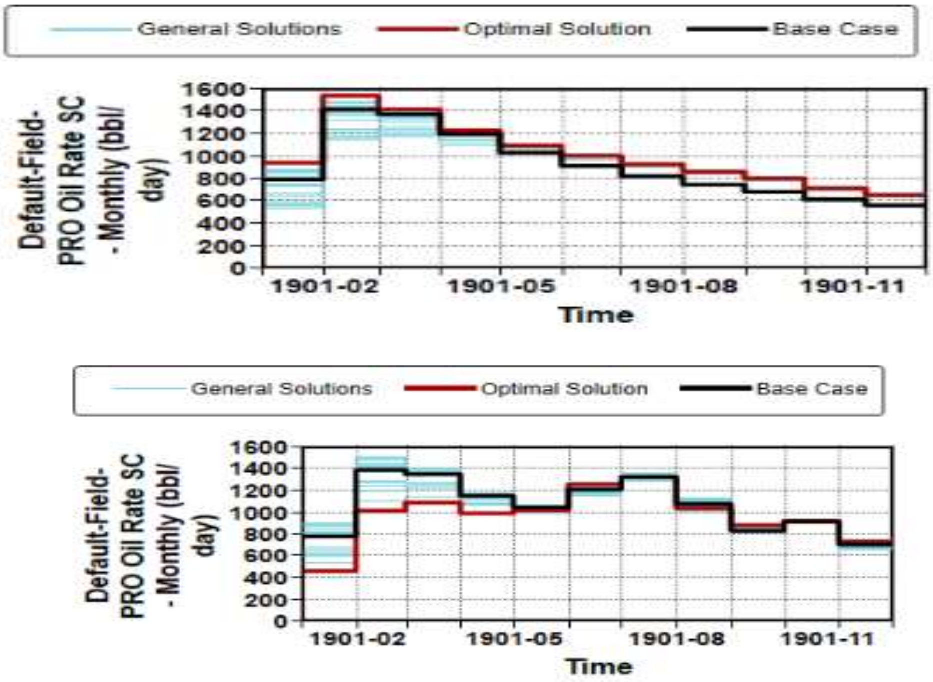
Figure 11 Cmost Analysis of optimal solution for recovery factor



Result from the CMOST optimisation simulation as shown in Figure 11 for the 360 days showed an optimal recovery factor of 41% for shear thinning which was an increase from the base case recovery factor of 35%. Results from shear thickening however showed an optimal solution to be 39% which was a reduction from the base case value of 47%. An even interesting observation was that the optimal solution was the highest recovery factor for the shear thinning polymer and the lowest reading for the shear thickening.

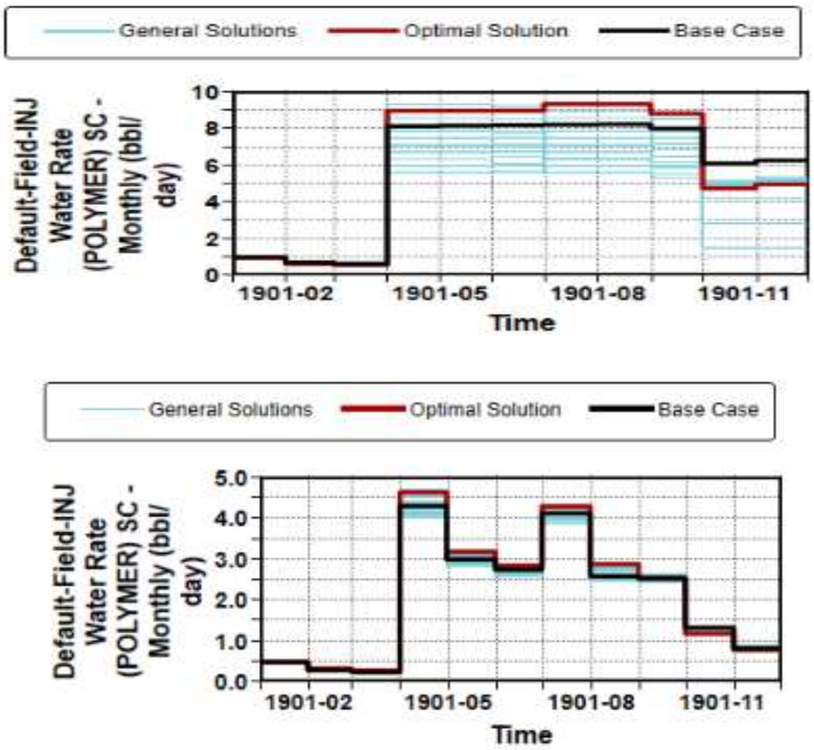
Results from the optimal field production rate as shown in Figure 12 for the shear thinning polymer gave a rate of an approximately 1000bbl/day for the first month and increased massively to 1600bbl/day from where it reduced gradually to 600bbl/day. For the shear thickening polymer, a lower optimal rate of 400bbl/day was recorded for the first month. The rate increased in some months and decreased in other month in no particular pattern. A maximum optimal rate of 1200bbl/day was recorded after which it decreased to 700bbl/day at the end of the 360days.

Figure 12 cmost prediction of optimal production oil rate



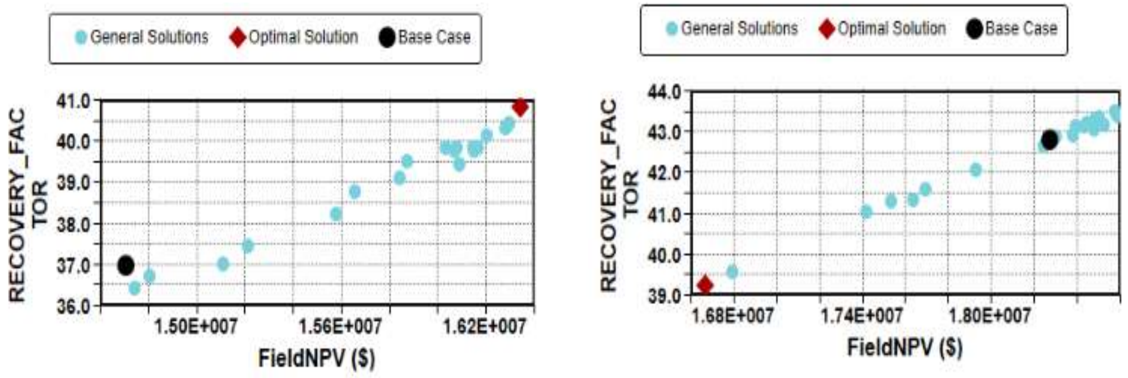
Analysis of the polymer injection rate in Figure 13 showed that for the optimal case for shear thinning polymer gave a polymer rate of 1bbl/day which increases to 9bbl/day and remains fairly constant for 6 months after which it reduces to 5bbl/day.The shear thickening polymer however gave fairly low polymer rate reading with a maximum rate of 6bbl/day been recorded with a no pattern increase and decrease rate records.

Figure 13 cmost prediction of water rate



Results from CMOST optimisation simulator as shown in Figure 14 showed that for the 360 days simulation run although shear thinning fluid gave a high optimal recovery factor of 41% it gave the least net present value of 16.4MM as compared to 16.8MM gave by shear thickening polymer with just 39% recovery factor.

Figure 14 cmost prediction of optimal net present value



Results from the CMOST as shown in Figure 15 optimisation analysis on the maximum flowrate for injector well1 showed that for the optimal solution for NPV, the maximum flowrate for injector well 1 should be approximately 4800bbl/day and 4200bbl/day for shear thinning and shear thickening polymer respectively. Results as shown in Figure 16 from the CMOST optimisation analysis on the maximum flowrate for injector well12 showed that for the optimal solution for NPV, the maximum flowrate for injector well 2 should be approximately 6000bbl/day and 4200bbl/day for shear thinning and shear thickening polymer respectively.

Figure 15 cmost prediction of max flow rate for well 1

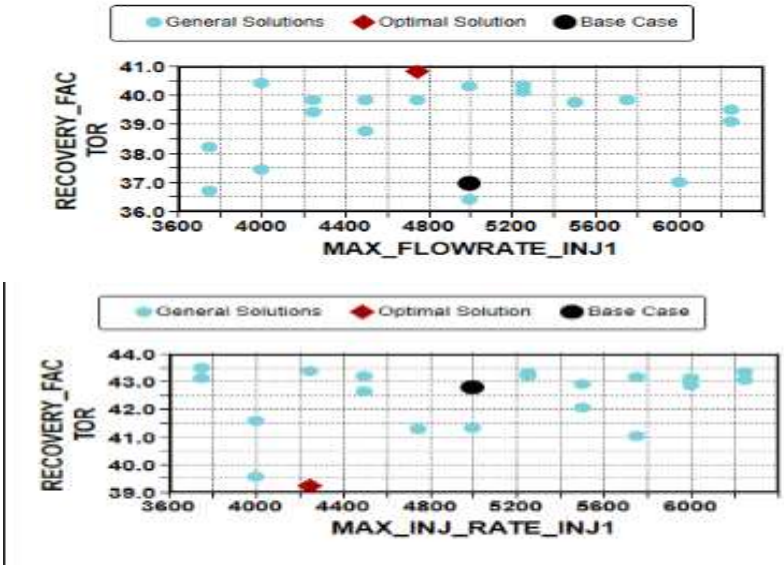
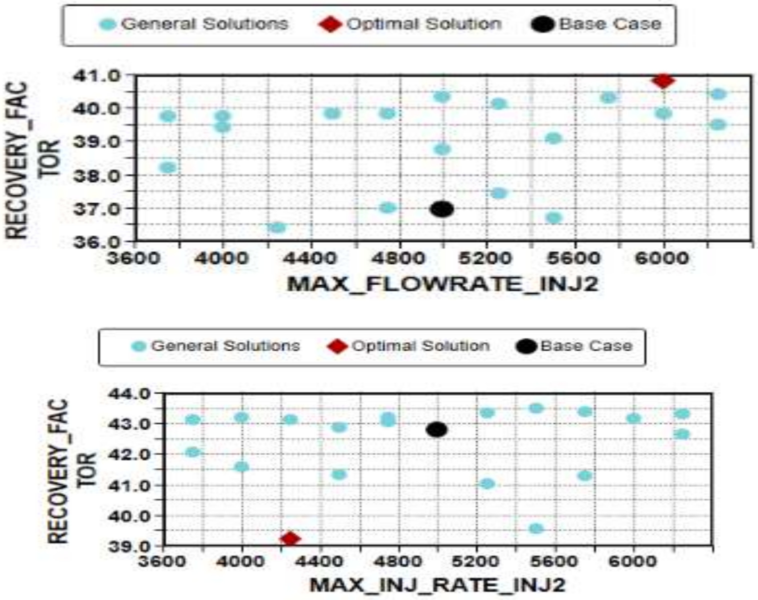


Figure 16 cmost prediction of max flow rate for well 2



Results as shown in Figure 17 from the CMOST optimisation analysis on the maximum flowrate for injector well3 showed that for the optimal solution for NPV, the maximum flowrate for injector well 3 should be approximately 6200bbl/day and 4200bbl/day for shear thinning and shear thickening polymer respectively. Results as shown in Figure 18 for injector well4 showed that for the optimal solution for NPV, the maximum flowrate for injector well4 should be approximately 7200bbl/day and 1000bbl/day for shear thinning and shear thickening polymer respectively.

It is clear from the foregoing results that for polymer optimisation with regards to shear thinning and thickening effect that it is not only how much oil is being produced or how much is been recovered but also how much polymer is been injected. As observed from the results though shear thinning has a higher optimal solution for recovery compared to shear thickening it yields a lower optimal net present value compared to shear thickening due to the highly low optimal solution for maximum injection rate of all injector wells which invariable decreased the polymer cost leading to a higher net present value.The analysis of the shear thinning polymer suggests that for an optimal net present value, a higher polymer injection rate is needed. This reveals that for a permeability pitchout formation, higher injection rate is required for shear thinning polymer optimisation. An equivalent analysis on the shear thickening polymer studies suggests that for optimal solution for net present value, a lower injection rate is preferred. It was however interesting to observe that the first three (3) injection wells had a fairly constant injection rate of 4200bbl/day but the fourth well required a very low rate of 1000bbl/day. This suggest that though viscous force is the major driving force of polymer injection it is evident that gravity force is also prevalent in the shear thickening polymer. From the results it is also evident that both shear thinning and shear thickening is a good sweep in the high permeability zones as observed from the polymer concentration 2D plot. It is however evident from the plot that shear thinning has a high retention of polymer after the 360 days in the low permeability zones. This therefore suggest that with the high injection rate for the optimal solution for net present value from the optimisation studies of the shear thinning fluid, a high percentage of the polymer was retained in the lower permeability zones as compared to shear thickening polymer which had a relatively lower retention in the lower permeability zones.

3.1 Sensitivity

A sensitivity analysis performed on the effect of each injection well as shown in Figure 19 portrayed that injector well 2 had the most effect of 39% for shear thinning polymers whiles the shear thickening polymer has a 99% effect. This suggests that for shear thinning fluid the injectors in the high permeability zones has a greater effect on the net present value. This can be used to conclude that shear thinning fluids is preferred for a high permeability formation whiles a shear thickening polymer is preferred for low permeability formation.

4. CONCLUSIONS

From studies conducted, it can be concluded that polymer optimisation with regards to shear thinning and thickening polymer is not only dependent on how much oil is being produced or how much is been recovered but highly dependent on how much polymer is been injected. The analysis of the shear thinning polymer suggests that for an optimal net present value, a higher polymer injection rate is needed. An equivalent analysis on the shear thickening polymer studies suggests that for optimal solution for net present value, a lower injection rate is preferred. This suggest that though viscous force is the major driving force of polymer injection it is evident that gravity force is highly prevalent in the shear thickening polymer. Finally, from the studies conducted it was concluded that a high percentage of the polymer was retained in the lower permeability zones when shear thinning polymer was used as compared to shear thickening polymer which had a relatively lower retention in the lower permeability zones.

Figure 17 cmost prediction of max flow rate for well 3

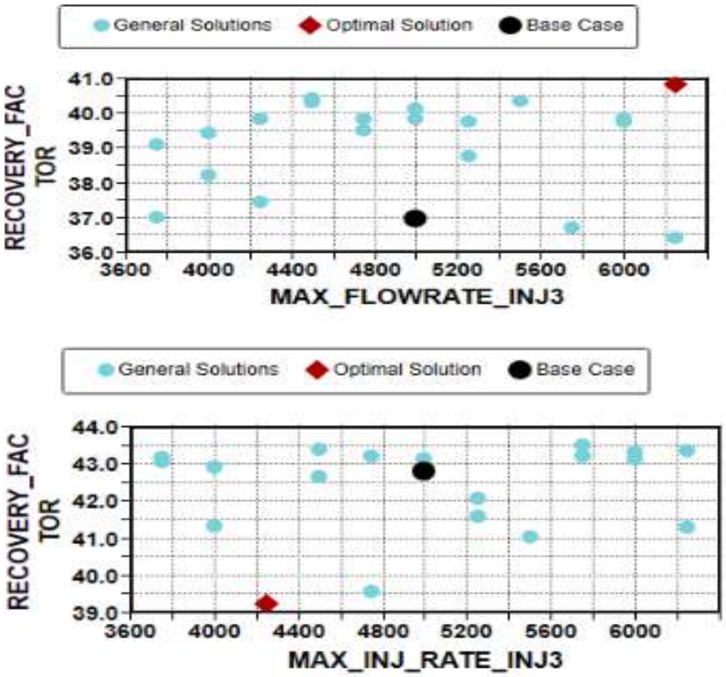


Figure 18 cmost prediction of max flow rate for well 4

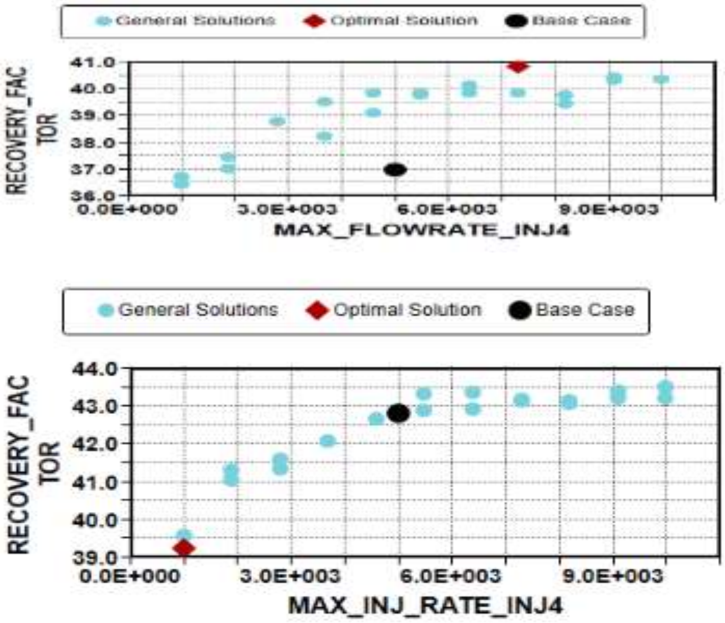
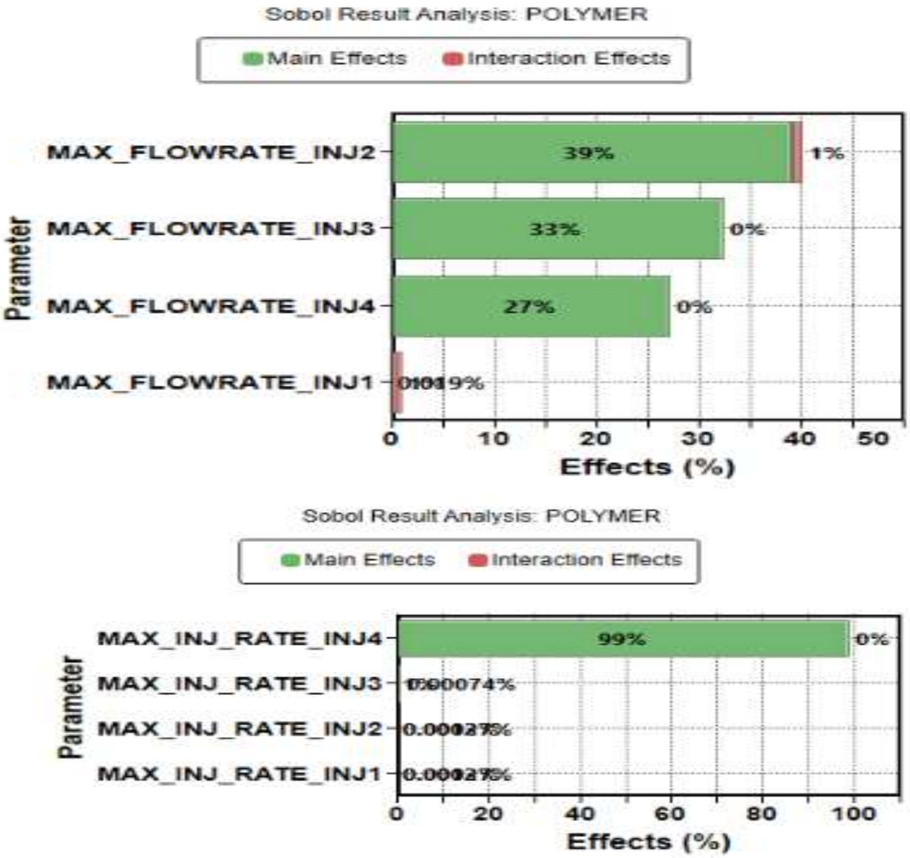


Figure 19 cmost sensitivity of effect of max flowrate of injector wells



5. REFERENCES

- Abdulbaki, M., Huh, C., Sepehrnoori, K., Delshad, M., Varavei, A., 2014. A critical review on use of polymer microgels for conformance control purposes. J. Petroleum Sci. Eng.122, 741–753.
- Al Ayesh, A.H., Salazar, R., Farajzadeh, R., Vincent-Bonnieu, S., Rossen, W.R., 2016. Foam diversion in heterogeneous reservoirs: effect of permeability and injection method.In: SPE Improved Oil Recovery Conference. SPE-199650-MS, Tulsa, Oklahoma, USA.
- AlSofi, A.M., Blunt, M.J., 2010. Streamline-based simulation of non-Newtonian polymer flooding. SPE 15 (04), 895–905.
- Alvarado, V., Manrique, E., 2010. Enhanced oil recovery: an update review. Energies 3(9), 1529–1575.
- Bai, Y., et al., 2015. Gelation study on a hydrophobically associating polymer/ polyethylenimine gel system for water shut-off treatment. Energy Fuels 29 (2), 447–458.
- He, J.Y., et al., 2008. Size effect on mechanical properties of micron-sized PS-DVB polymer particles. Polymer 49 (18), 3993–3999.
- Jones, W.M., 1980. Polymer additives in reservoirflooding for oil recovery: shearthinning or shear thickening? J. Phys. D Appl. Phys. 13 (5), L87.
- Jung, J.C., Zhang, K., Chon, B.H., Choi, H.J., 2013. Rheology and polymerflooding characteristics of partially hydrolyzed polyacrylamide for enhanced heavy oil recovery. J. Appl. Polym. Sci. 127 (6), 4833–4839.
- Li, R.F., Yan, W., Liu, S., Hirasaki, G., Miller, C.A., 2010. Foam mobility control for surfactant enhanced oil recovery. SPE 15 (04), 928–942.
- Liu, Y., Zhong, H., Peng, X., Zhao, C., 2015b. Factors influencing micro sweep efficiency when flooding a formation with viscoelastic polymer solutions. Chem. Technol. Fuels Oils 51 (2), 160–167.
- Thomas, S., 2008. Enhanced oil recovery - an overview. Oil Gas Sci. Technol. - Rev. IFP 63 (1), 9–19.
- Stavland, A., Jonsbraten, H., Lohne, A., Moen, A., & Giske, N. H. (2010, January 1). Polymer Flooding - Flow Properties in Porous Media versus Rheological Parameters. Society of Petroleum Engineers. doi:10.2118/131103-MS
- Shields, R., & Beteta, A. (n.d.). *Scleroglucan for EOR.* Heriot Watt University. In Press (unpublished) 2017
- Wang, D., Huang, D., Sunf, G., Uang, D.,., 2000. Viscous-elastic Polymer Can Increase Microscale Displacement Efficiency in Cores. SPE-63227-MS.
- Wei, B., Romero-Zer, Rodrigue, D., 2014. Oil displacement mechanisms of viscoelastic polymers in enhanced oil recovery (EOR): a review. J. Petroleum Explor. Prod. Technol. 4 (2), 113–121.
- Wever, D.A.Z., Picchioni, F., Broekhuis, A.A., 2011. Polymers for enhanced oil recovery: a paradigm for structure Cproperty relationship in aqueous solution. Prog. Polym. Sci.Top. Energy Relat. Mater. 36 (11), 1558–1628.
- Yan, W., Miller, C.A., Hirasaki, G.J., 2006. Foam sweep in fractures for enhanced oil recovery. Colloids Surfaces A Physicochem. Eng. Aspects 282–283, 348–359.
- Zhang, Y., Yue, X., Dong, J., Yu, L., 2000. New and Effective Foam Flooding to Recover Oil in Heterogeneous Reservoir. SPE-59367-MS.

- Zhu, T., Strycker, A., Raible, C.J., Vineyard, K., 1998. Foams for Mobility Control and Improved Sweep Efficiency in Gas Flooding. SPE 39680.