McDougall School of Petroleum Engineering

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Project 5

PE 7083 Modern Reservoir Engineering

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Introduction:

Thermal injection is one of the most popular methods of Enhanced Oil Recovery, which accounts for about 40 per cent of the EOR methods used in the industry. This method involves the heating of crude oil to reduce its viscosity and/or vaporize part of the oil decreasing its mobility ratio. The increased heat also reduces the surface tension and increases the permeability of oil. The most popular methods of thermal injection are Cyclic Steam Stimulation (CSS) or ‘huff and puff’ and the steam flooding. These two methods have been studied in the current project.

Simulation: Reservoir Description

The simulation is performed on a 2000ftx1000ftx50ft heterogeneous reservoir with distinct permeability in the x, y and z direction. The reservoir is discretized into 10,000 equally sized grid blocks. The porosity is same throughout which is equal to 0.2. Fig 1 shows the reservoir permeability distribution. The details are as follows:

1. Permeability in the top zone (Region 1) = 75 to 141 mD
2. Permeability in the middle zone (Region 2) = 38 to 95 mD
3. Permeability in the lowest zone (Region 3) = 4.70 mD being the least permeable

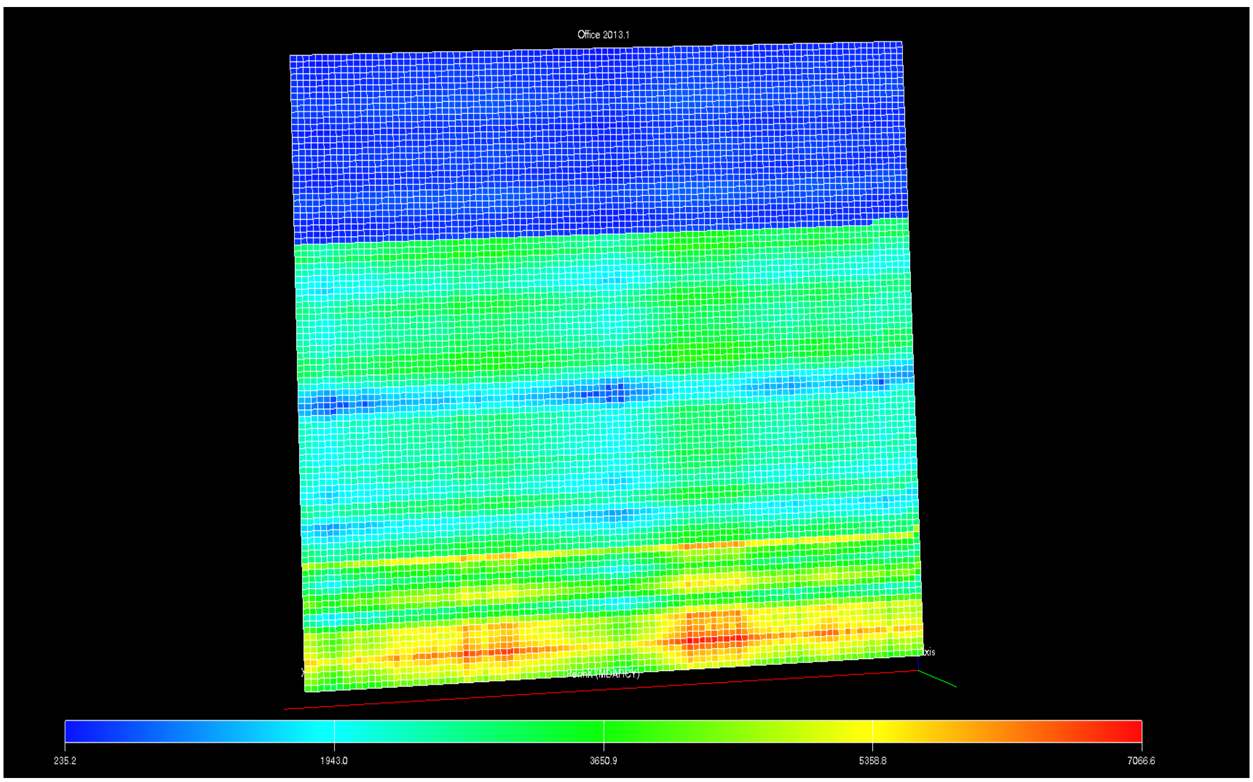


Fig 1. Reservoir Permeability Distribution

The initial oil saturation is same throughout the reservoir as shown in figure 2.

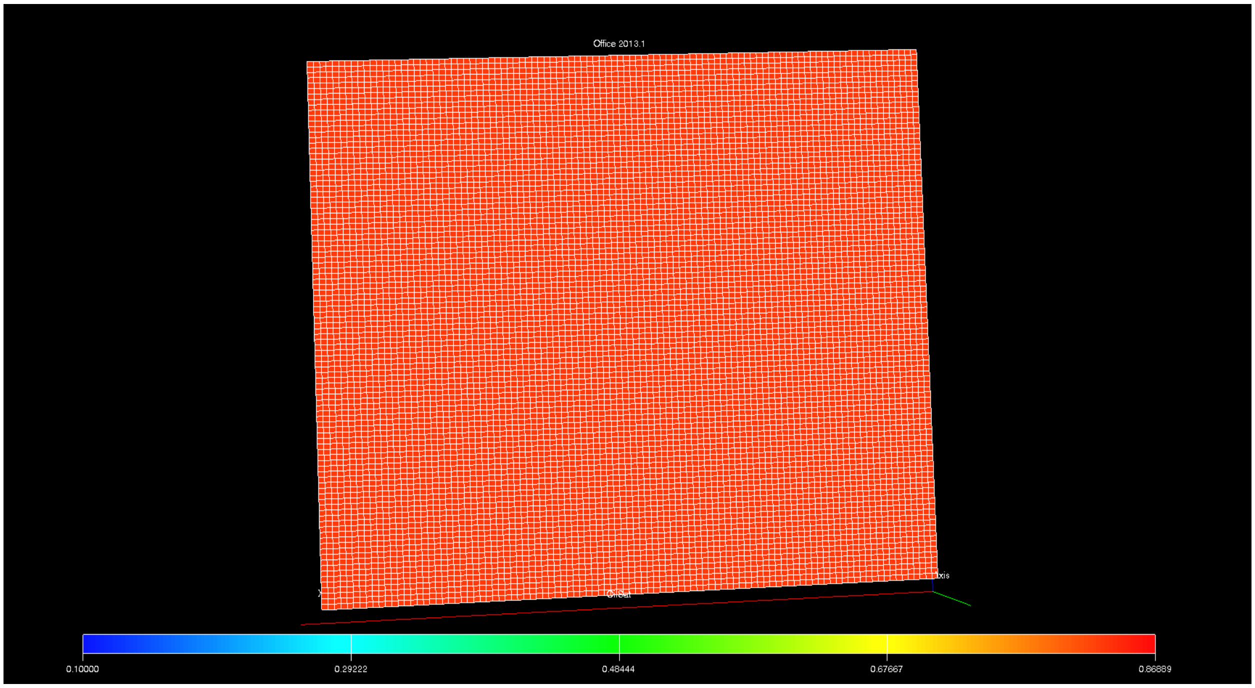


Fig2. Initial Oil saturation

Objective:

The objective of this project is to make modifications in the data file provided for thermal injection and study the impact of the changes in the efficiency as well as the recovery. Data has been provided for the two types of the thermal injection methods used. There are 2 wells referred to as well 1 and well 2. Initially, cold production is done where about 20% of the OOIP is recovered. This is followed by the CSS cycles ending with steam flooding. Usually, the steam flooding results in the highest recovery. In the CSS method, the same well acts as the producer as well as injector. It basically consists of three stages- Injection stage or "huff" where heat is injected in the well, soaking phase where heat is allowed to be absorbed by the oil and the production phase or "puff'. Usually when one well is in the huff phase, the other well is in the puff phase and hence, two peaks in the production rate comprises of one cycle of huff and puff. Steam flooding is more like water injection, where steam injected from one well pushes the oil towards the other well for production.

In the given data file, the cold production is done for 90 days followed by approximately 700 days of CSS ultimately followed by 360 months of steam flooding. This is the base case and many modifications can be done to optimize the oil production and recovery.

Extension A: Changing the number of cycles in the Huff and Puff phase

The number of cycles in the data file is changed by adding two new cycles as case (i) and four new cycles as case (ii). Simulations are performed after modifying the case and the results are compared with the base case given. I can be seen from Fig 3 that there is hardly a 1% increase in the efficiency and four additional cycles add 0.9%, which is a decreasing trend. Therefore, we can say that addition of more cycles is not very efficient. Similarly, as it can be seen from the table below, there is not much increase in the production in stb/day with the increase in the number of cycles and therefore it is not economically feasible.

CASE	FOE	FOPR
Base Case	0.4196	60941
Additional 2 cycles	0.4278	62142
Additional 4 cycles	0.4309	62590

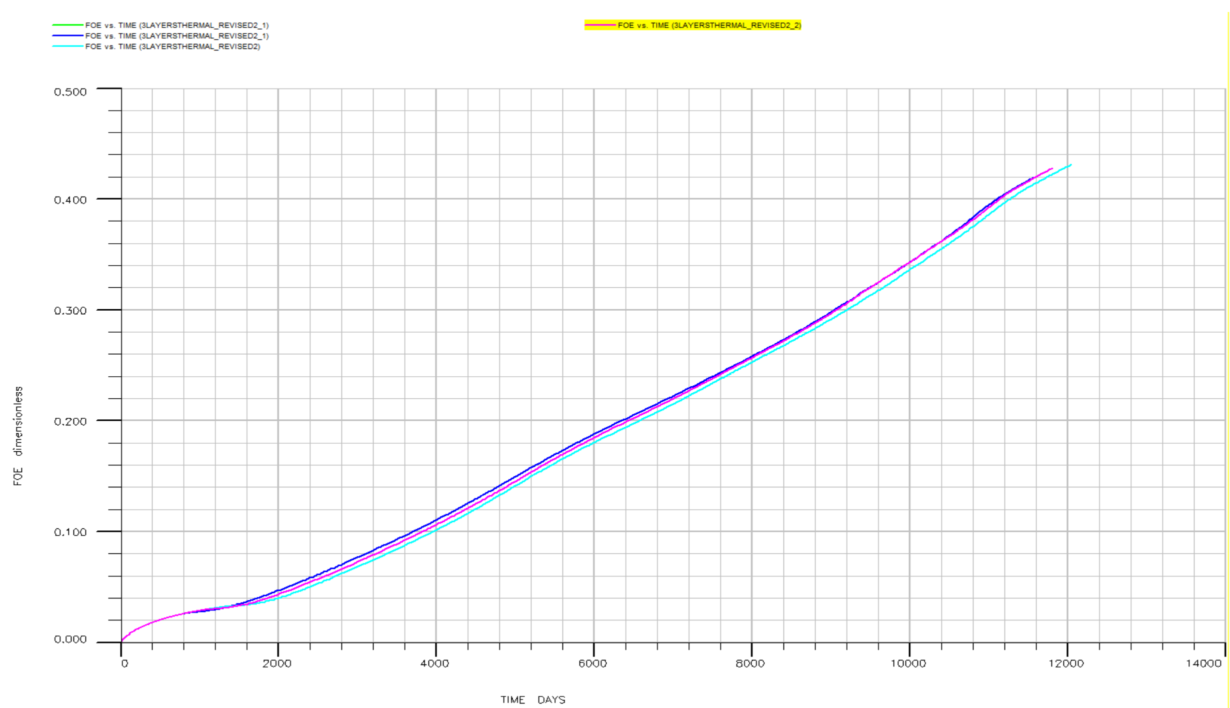


Fig 3. Graph showing comparison of the FOE for different cycles

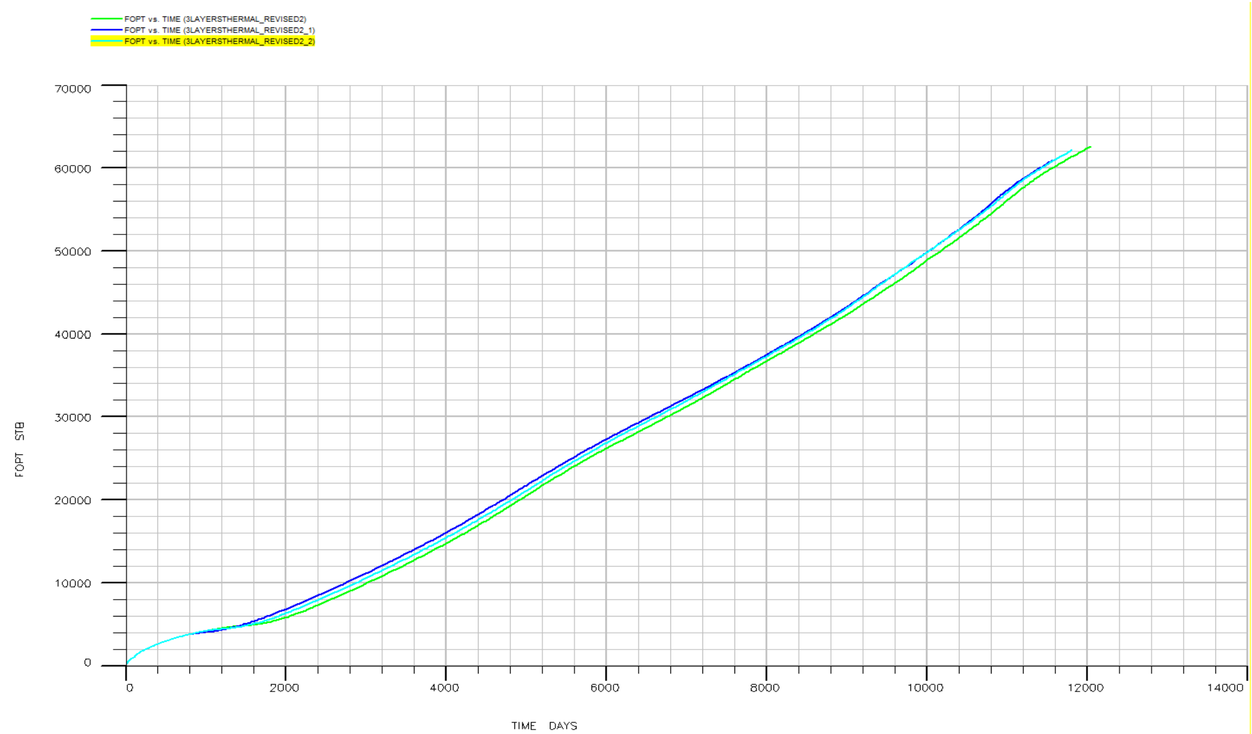


Fig 4. Graph showing comparison of the production for different cycle

Extension B: Variation in the cycle durations

In this section, the CSS duration is first doubled and reduced to half. As shown in fig 5, the production rises very fast when the CSS duration is doubled, however, it also reduces to zero very quickly. Therefore, overall it may not be very advantageous to increase the CSS duration. On the other hand reducing the CSS duration to half gives almost the same result as the base case, therefore, it may be more economical to reduce the CSS duration while maintaining the same efficiency and recovery. These results are further bolstered by the results shown in fig. 6, As expected, the FOE for the case where CSS was doubled rises and becomes constant very fast, while it shows the same behavior as the base case when the CSS duration is reduced to half. Also, fig 7 shows the bottom-hole pressure for one of the production wells. It can be clearly seen that the production reduces well. My interpretation of this observation is that longer production/injection time can lead to steam condensation which reduces the efficiency of thermal injection.

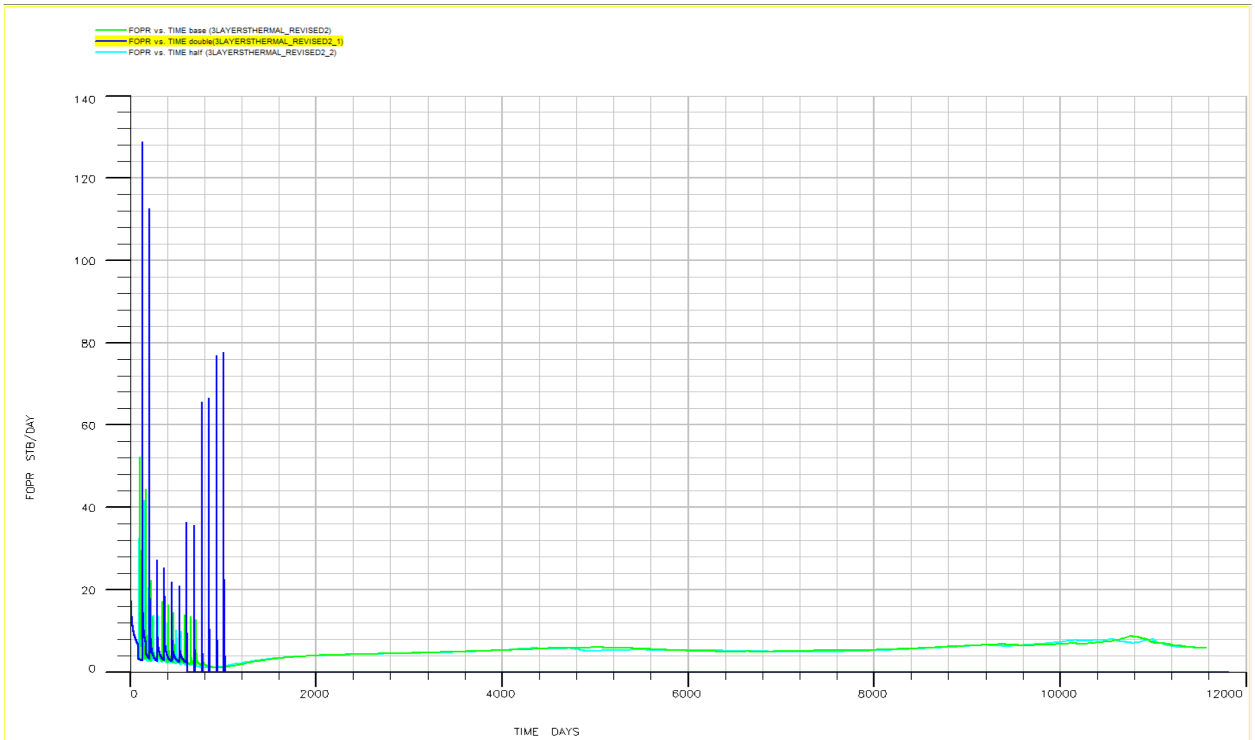


Fig 5: The comparison of FOPR for different CSS duration

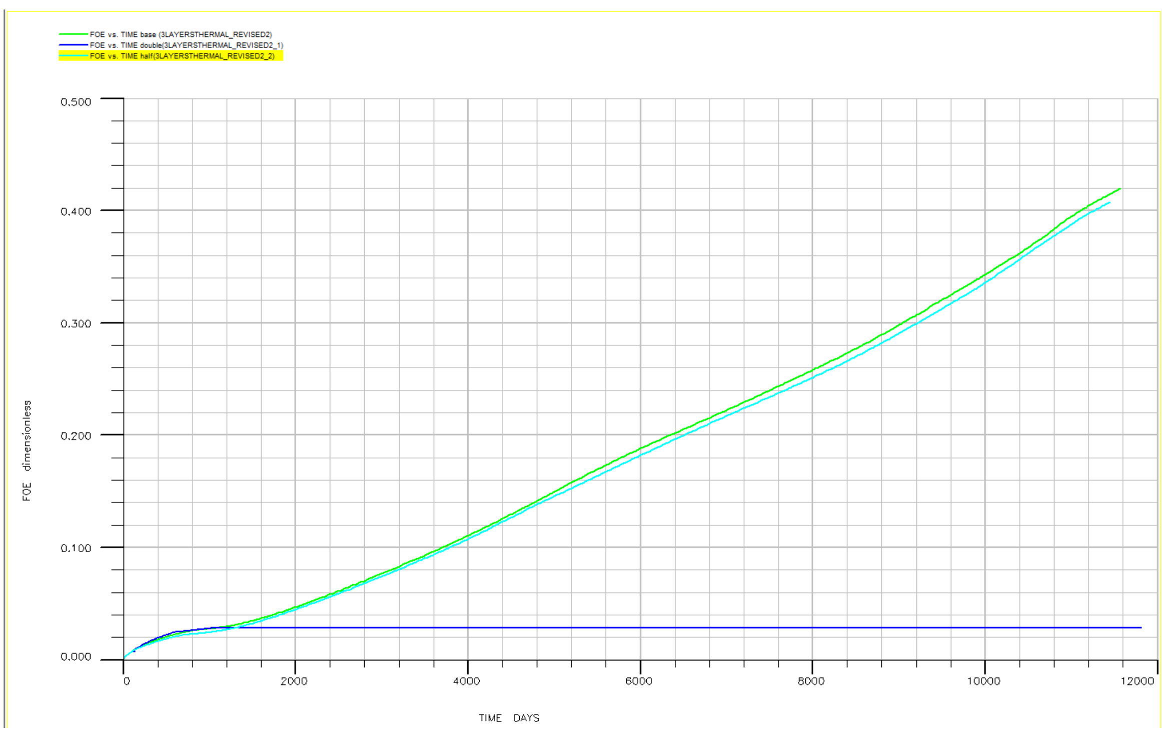


Fig 6: The comparison of FOE for different CSS duration

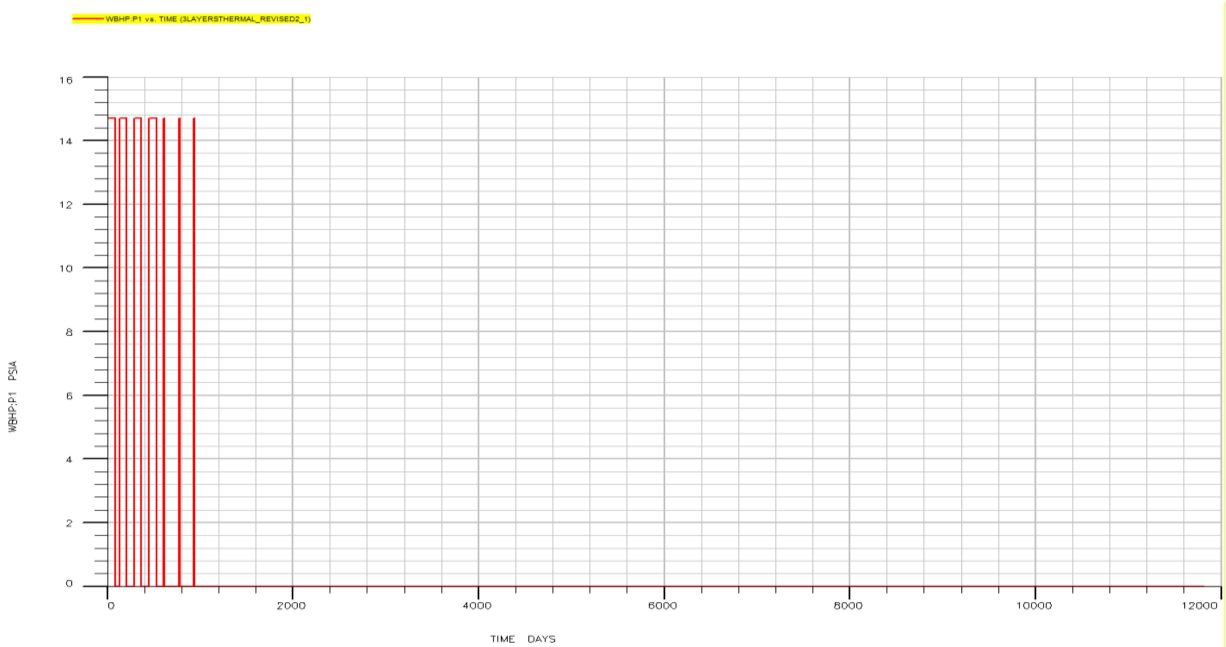


Fig 7: Bottom-Hole pressure in production well for double CSS

Extension C: Variation in soaking time

In this section, the soaking time has been modified to see the effect on the efficiency and the oil recovery. As seen from the fig 8, when the soak time is doubled there is no significant change in the recovery and hence, there is not economic feasibility in increasing the soak time as it gives comparable results to the base case. However, since reducing the soak time is comparable to increasing the production duration of another well, we can see similar results as seen in the above case. The efficiency increases very fast and becomes constant very soon. These observations can be further bolstered by the production graph shown in fig 9 for the three different cases.

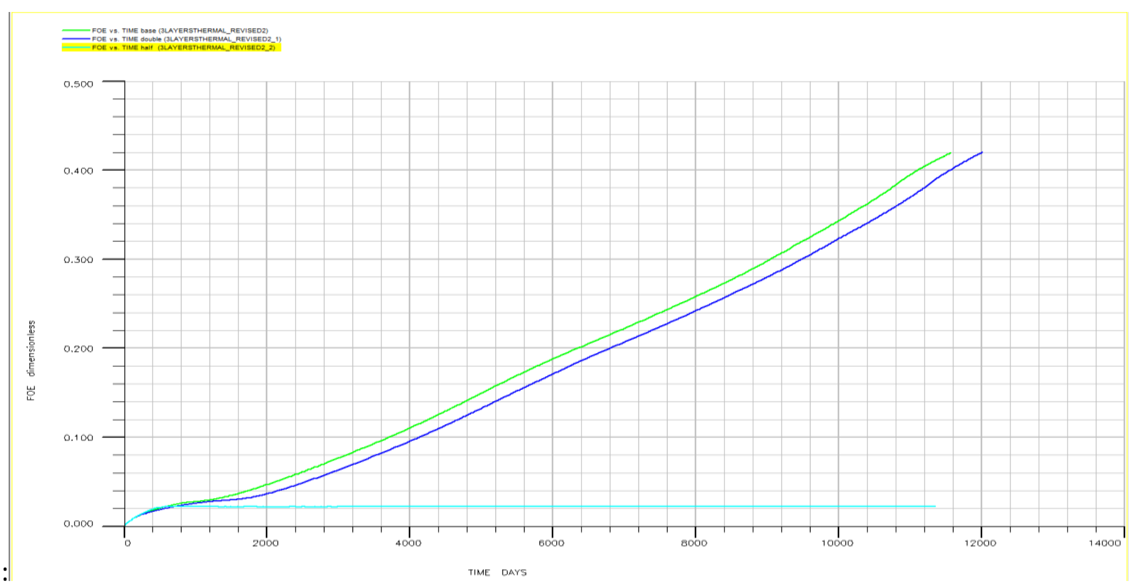


Figure 8: Comparison of the effect of the soaking time on the efficiency

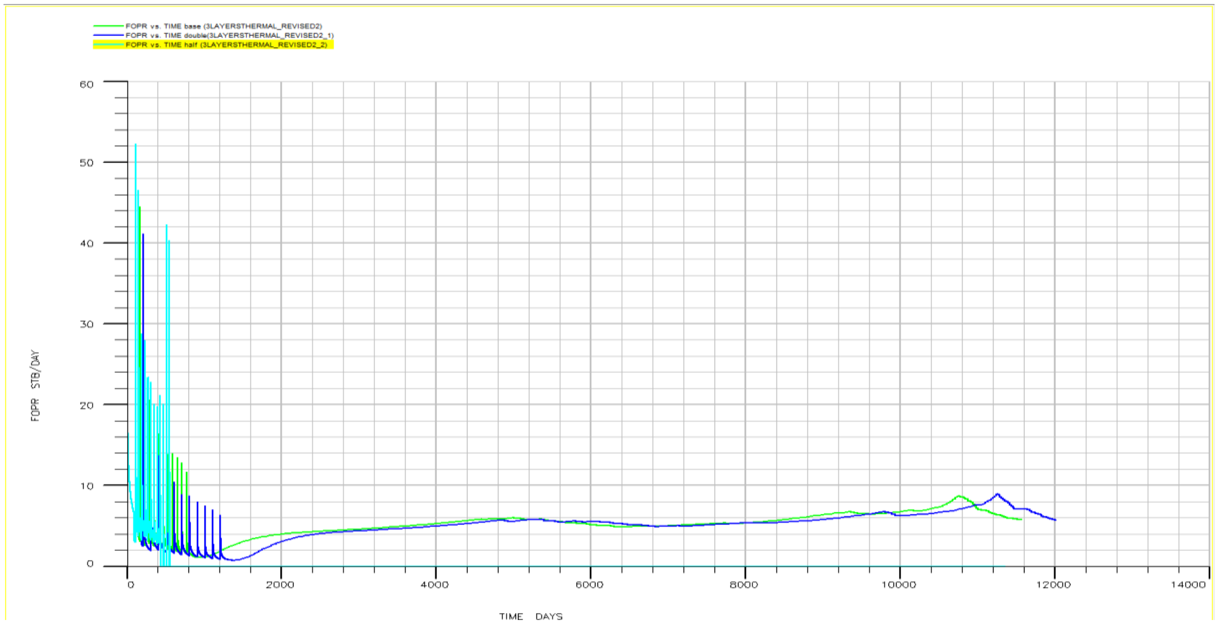


Figure 9: Comparison of the effect of the soaking time on the production

Extension D: Variation in steam flooding duration

From the previous discussion, it can be concluded that the CSS and soak time duration does not significantly affect the efficiency of the thermal injection. In fact, the CSS is able to recover about 20% of OOIP. Steam flooding or steam injection on the other hand is very effective. It can recover about 50 % of the OOIP. This fact can be supported from the observations shown in figure 10. The FOE increases steeply with the increases in the steam flood duration. However, it can be increased only up to a certain point and becomes constant afterwards. Hence, there is a need to optimize the duration of steam flooding from economic point of view. This conclusion can be further bolstered by from the production behavior shown in figure 11. The production is high up to a certain point with the increase in the steam flood duration, but drops afterwards.

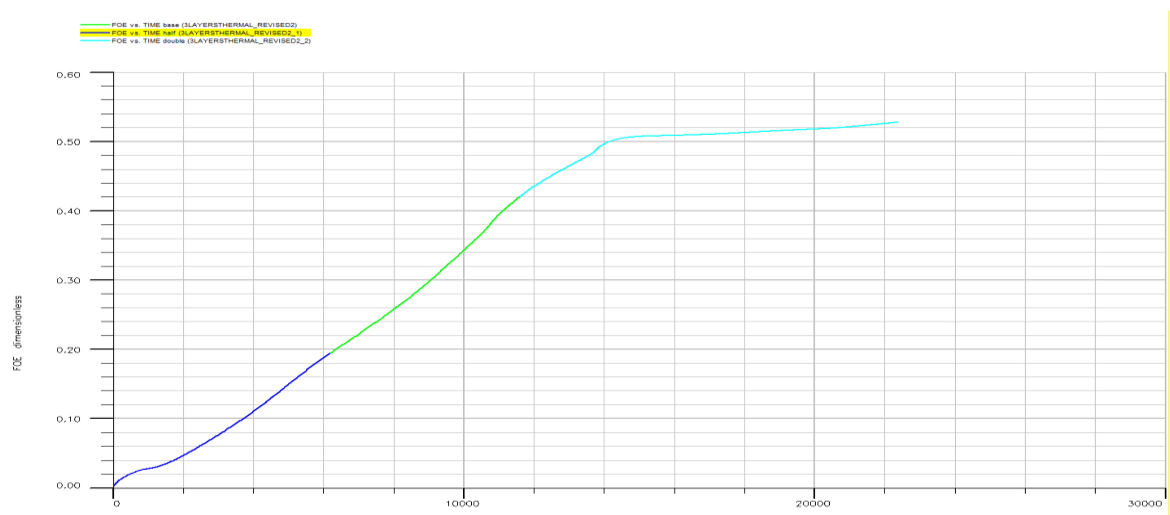


Figure 10: FOE comparison for three different cases of steam flooding duration

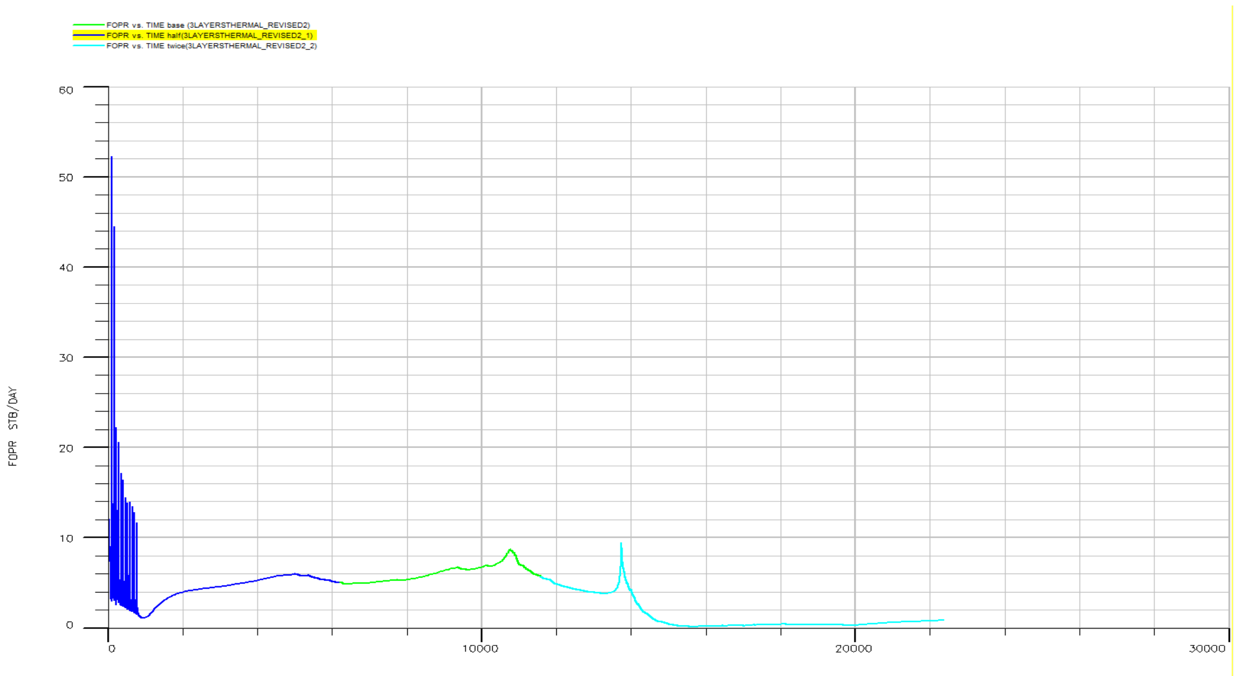
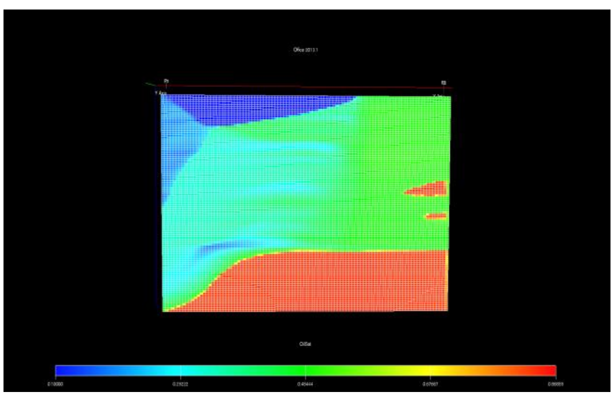
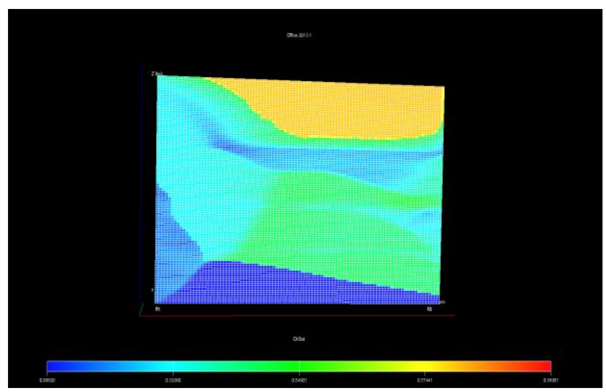


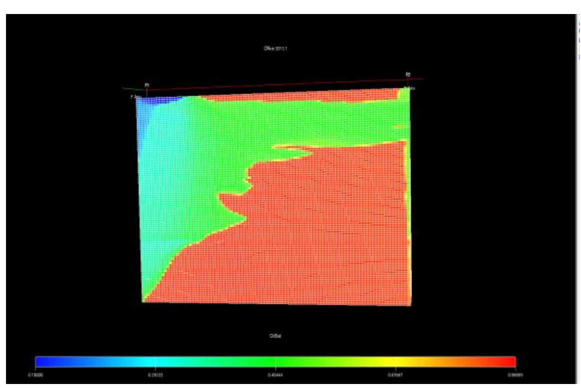
Figure 11: FOPR comparison for three different cases of steam flooding duration



(a) Final SOIL for the base case steam flood



(b) Final SOIL steam flood twice



© Final SOIl half steam flood

Extension E: Variation in steam quality

In the base case, the steam quality given is 0.7. In this section, the effect of changing this steam quality has been studied by taking two different cases. One is increasing the steam quality to 0.9 and the other is reducing it to 0.5. The FOE for the base case as well as the other two cases is shown in fig 12. It can be seen that the efficiency increases with the decrease in steam quality. However, the increase is not that significant when the steam quality is changed from 0.7 to 0.5. Therefore, even though the change is not that significant, the steam quality can be reduced for economic optimization. The production behavior, fig 13, also shows that the production is more or less the same for different steam quality, however, it is the maximum for 0.5.

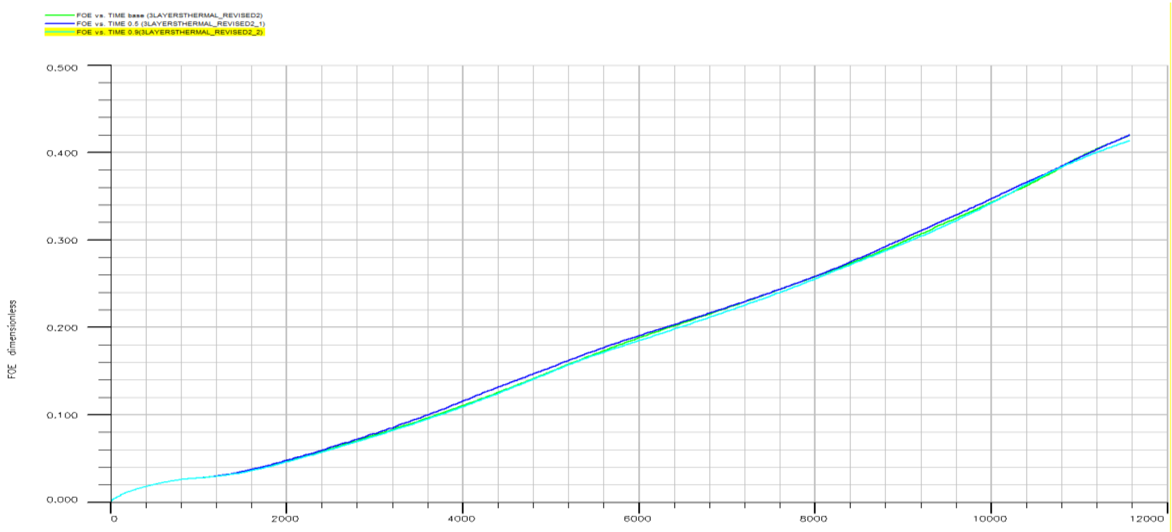


Figure 12: FOE comparison for three different cases of steam quality

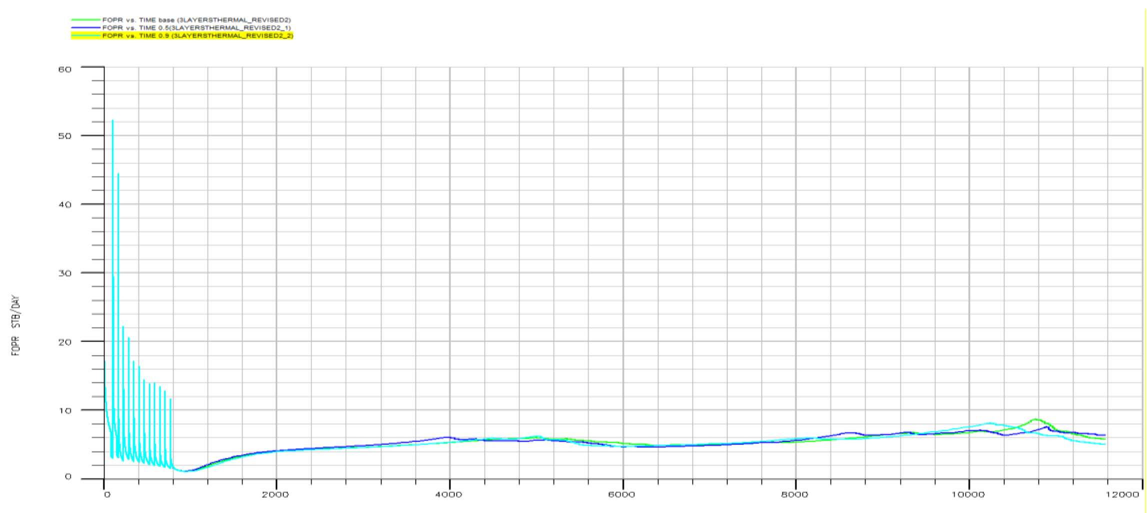


Figure 13: FOPR comparison for three different cases of steam quality

Extension F: CSS conversion to steam flood

In this section, the cold production is immediately followed by the steam flooding. Two cases are studied. In the first case, the steam flooding is done for the same steamflooding duration as the base case, that is, 360 months. In the second case, in order to have a better comparison, the steam flooding is performed for the total duration similar to the base case that is including the CSS duration, which is about 390 months. As it can be seen in fig 14, the production behavior is similar for steam flooding except for the initial fluctuation in the beginning for the base case because of CSS. Also, the ultimate efficiency is almost the same as shown in fig 15, which further bolsters our conclusion that the thermal recovery is mainly affected by steam flooding

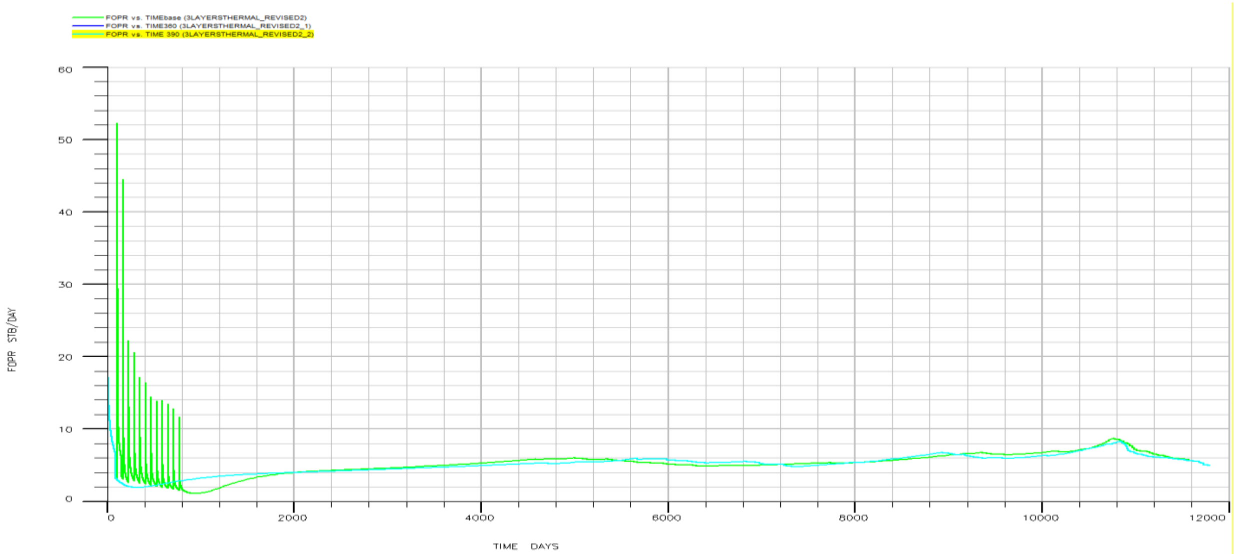


Figure 14: FOPR comparison for CSS conversion to steam flood for 360 months and 390 months with the base case

Figure 15: FOE comparison for CSS conversion to steam flood for 360 months and 390 months with the base case

Extension G: Timed Recompletion

The heterogeneity and gravity plays a major role in steam flooding and hence, in this section the effect of timed recompletions is observed. For the first 360 months, steam is injected in all of the 100 grids and after 360 months, the injection well is recompleted and steam is injected to the lower 50 grids for 360 months. The final saturation is shown in figure 16. It can be seen that even after the recompletion technique, the lower region remains unswept and as shown in figure 17, the overall efficiency is also reduced. Hence, we can conclude that the recompletion technique is not very effective in increasing the efficiency of the reservoir.

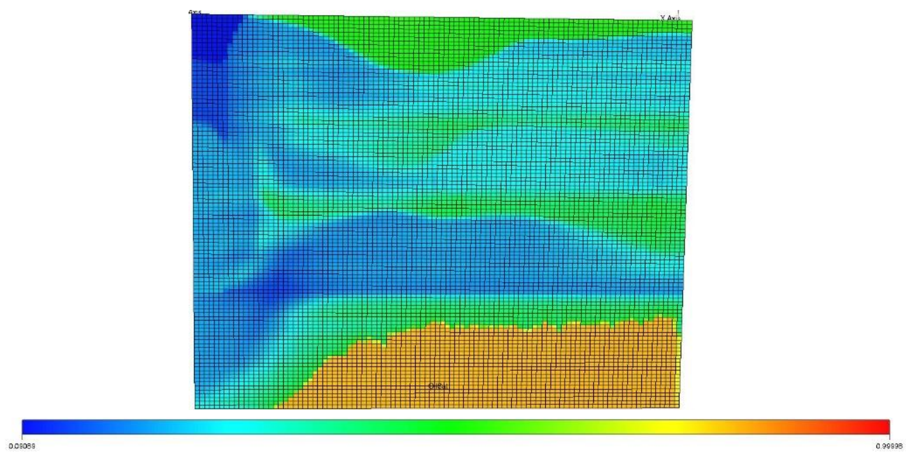


Figure 16: Final Oil saturation after recompletion technique

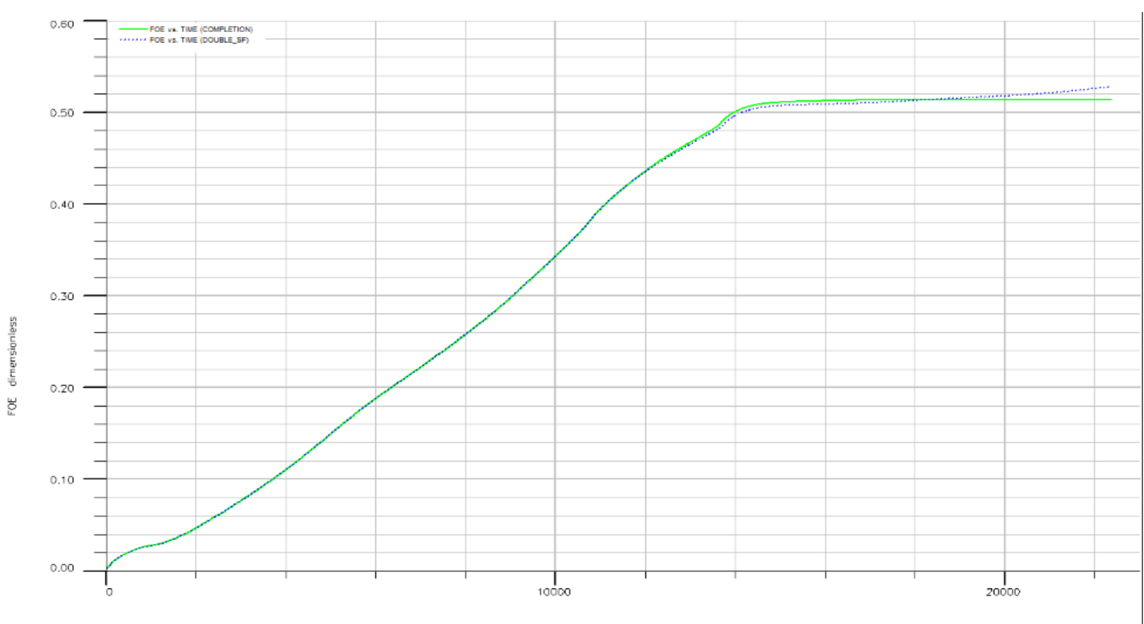


Figure 17: FOE comparison for recompletion

Conclusion:

The conclusion for each extension has been given in the individual section. Overall, we can conclude that thermal recovery is a very effective EOR technique which can increase the recovery significantly. From the cases studied for this project, steam flooding seems to play a major role in the overall efficiency, However, CSS can play an important role in premobilizing heavy oil after cold production and before beginning steamflooding. Also, it was seen that the change in cycle duration, soaking time and steam quality did not have a very significant effect on the efficiency, however, they are important parameters to be evaluated from economic point of view.