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Feasibility Study of Applying Steamflooding in a Reservoir With High Shale/Sand: Teca Field

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Abstract

Colombia is a country with important reserves of heavy oil, located mainly at the “llanos orientales” and at the “Magdalena Valley Medium” basin, the oilfields located in this basin, have been developed using cyclic steam stimulation, showing recovery factors close to 15%, indicating that a large quantity of oil has not been removed yet.

Due to the above reasons, it has been thought in the steam flooding as an alternative for the extraction of remaining oil, but the intercalated shale in the deposits in question, acting as thieves, heat affects the thermal efficiency of the process, why is not clear whether the steam flooding will be viable in the deposits of the Magdalena valley, specifically in the TECA field. Given the above, it is necessary to conduct a study to determine the effect of the intercalated shale on thermal efficiency. This study was carried out using numerical simulation and analytical models in the case of a numerical simulation model was compared with intercalations of shale and a homogeneous model, we conducted a further analysis of sensitivity to the rock and fluid properties, as well as operational parameters for the implementation of a steam flooding, including a scheme of selective injection.

Finally, we found that the thermal efficiency is greatly affected by the intercalated shale is decreasing by up to 30%, a value considerably higher than would seriously affect the technical and economic feasibility of the project but has been observed to implement a scheme of selective injection could increase the efficiency of the process, making this more feasible to perform.

Introduction

Steamflood is a thermal recovery method used in heavy oil reservoirs; it consists on injecting heat through well injector in order to produce oil throughout a producer well that is located in a certain distance, so resulting in the formation of a heat zone that moves toward the superior part of the reservoir, displacing the oil towards the producer well and also decreasing its viscosity, with this method the recovery factors in the order of 40-50 % are obtained.

Among the problems that are commonly presented in a steamflooding roject it is posible to find a low injectivity of the heat at the beginning of the project, por this reason, is common to implement cyclic steam stimulation before steamflooding. It is also frequent that the heat moves through unknown paths inside the reservoir, it is because of the heterogeneties such as the shale intercalation, poor lateral continuity of the reservoir, directional variation of the permeability and porosity among others.

In the Colombian basin called Magdalena Valley Medium, can be found a series of heavy oil reservoir characterized by high shale/sand. in which Teca Field is found, where it is been develop a cyclic steam simulation project (CSS). Nowadays, this project is in a mature stage, with 14 stimulation cycles in the oldest wells. It has been achieved a recovery factor lower to 15%, it indicates high saturation of remaining oil and consolidates this field as a good prospectus for the implementation of steamflooding. In a previous study (Pacheco et. Al., 2008), it was determined that the optimum length of CSS previous to steamflooding to this field is nine cycles, that constitutes an initial motivation to the development of this study.

In due to the high shale/sand present in the Teca Field, it is necessary to do a study that allows the evaluation of the scenarios in which is possible the implementation of steamflooding in this field. In the development of this study, tools such as: screening, analytical models (incorporated in the Steam Software), and also the Numerical Simulator Reservoir STARS of CMG were used in a sequential way

Reservoir Description

Teca Field, located in the Magdalena Valley Medium basin, between the limits of the Antioquia and Boyacá department, as shown in figure 1. Teca Field was discovered in 1967, but was only declared commercial until 1987. The next year, its production was initiated and two years later started the first cyclic stimulation project with steam in this field, where it was reported production peaks of 18000 BIs/day (1986). In 1992, the field was closed for two years, because of the low prices of the oil. After the closure, it was reported a decline in the production for five years, until in 1999 the subsidiary company Omimex (today Manzarovar) considered feasible to take up again the project of cyclic steam injection. In this moment, the field has an average production of 22000 BIs/day, out of 294 wells. Some of these wells have been subjected to 14 stimulation cycles.

The producer interval of hydrocarbon can be divided into two zones: zone A and zone B, before reaching the depth of the producer intervals (1600 feet) it can be found a zone of intermediate salinity called transition zone.

Zone A. the zone A is located in the upper part of the producer interval, immediately under the transition zone; it is composed by a series of shale groups of lateral discontinuity. The depth is between 1400 and 1800 feet with permeability greater than 1080 md, porosity up to 29% and thickness up to 390 feet. In some wells of the field, this zone is closed due to high water saturation.

Zone B. the zone B is located in a depth of 1920 to 2050 feet, with a porosity of 28%, permeability up to 780md and thickness up to 130 feet. This zone provides the greatest amount of oil to the field production, and being open in all the drill wells.

Preliminar Evaluation

It was selected a study region of 20 acres, from the total commercial area of 1700 acres. In this region it is found the formation limit at 1859 feet and a net thickness of 107 feet. The average properties of this zone are presented in the table 1. In table 1, it is evaluated the technical screening for the field, finding that all the criteria are fulfilled, except the initial viscosity, which its above from the maximum value of 1500 cp. However, as it was previously mentioned, nowadays it is done inside the field a cyclic injection of steam process, for which the value of the viscosity has decreased and this is not an impediment for the implementation of steamflood. In the evaluation of development scenes using numerical simulation, it will be done a more precise analysis of this property. Once the satisfactory results were found in the evaluation through screening, it continues to develop the analysis through analytical models.

Analytical Models. The model set out by Mercado & Muñoz (2008) was selected for the development of this work because it considers a series of horizontal producing zones that are being subjected in a simultaneous way to steamflood and that are separated among them for impermeable formations (figure2). The analytical model indeed, was used to evaluate the effect of the properties of the sands and shales (thicknesses, thermal conductivity, caloric capacity), for which it was stated three cases (table 2). For all the cases it was considered the presence of five producer zones in a pattern of 2.5 acres. It was used as a parameter of evaluation the thermal efficiency, defined as the relation between the remaining heat in the sand and the total injected heat (Ec 1).

$$T.E. = \frac{Q_{remaining\ sand}}{Q_{injected}} \quad (1)$$

The results output that the thickness of the sand and shale are the properties that affect the most the thermal efficiency. Variations in the shale thickness fall directly into the capacity of storing their own heat, affecting significantly the thermal efficiency of the process, as it is shown in figure 3. Analogously, when rising the sand thickness, a bigger portion of the injected heat remains in the interest zone, and with that it favours the thermal efficiency as it is shown in figure 4 (case B). Table 3 present a summary of the effect of each one of the analyzed properties.

Evaluation of development scenes using numerical simulation

Once the effect of the reservoir properties over the thermal efficiency are established, it is proceed to evaluate different scenarios of application of steamflood in a pilot area of the field through numerical simulation. It was started from the construction of a base simulation model with properties similar to TECA field. The cyclic steam stimulation that currently is done in this field was

simulated including the necessary reduction of spacing for the steamflooding implementation. Finally it was evaluated different scenarios of application of the steamflooding, including sensibility analysis to operational parameters and selective injection.

Base model. The base model of simulation consists of two producer sands separated among them for a shale formation. The upper sands or A Sands are composed of three sands bodies separated because of the shale presence. On the other hand, the lower sands or B Sands are composed of five sands bodies separated because of the shale presence. The total shale/sand relation is 3.86. The properties of the base model of simulation are presented in table 4. Figure 5, shows the simulation model appearance.

In the establishment of the base model of simulation, it is not only necessary to define the rock and fluid properties but also the grid properties such as the number of cells, refinement and confinement. In order to select these parameters it was done a sensibility analysis, using as a decision criterion the computation times and the accuracy of the results.

For selecting the number of cells of the model, it was simulated a stimulation cycle for the different cases presented on table 5. Case 2 was selected in accordance with the results presented in figure 6, due to the fact that from here the results can be stabilize in an acceptable computation times.

Once the number of cells of the base model were established, it was studied the convenience of incorporating to the model a confinement ring that allows the simulation of the pressure maintenance and the fluid contribution that in reality is obtained when studying a small sector of a reservoir. Three scenarios were evaluated: a model without confinement, confinement ring with hydrocarbon contribution (porosity of 28% and permeability of 1082 md) and confinement ring without hydrocarbon contribution (porosity of 28% and permeability of 0.00016mD). The behavior of the pressure of each case is presented in figure 7, in which it can be observed that it is only active, a pressure maintenance for the confinement ring with hydrocarbon contribution case.

Finally, it was compared the use of cartesian and hybrid refinement around the wells, obtaining a distribution of the pressure and temperature more uniform and closer to the reality in the case of the hybrid refinement, as it is shown in figure 8. In figure 9, it is presented a summary of the selected grid properties.

Cyclic Steam Stimulation. Once the base model of simulation was established, it is represented the primary production three years and four cycles of stimulation in two patterns of six wells and 10 acres of spacing (red color, figure 10). The stimulation cycle consists of 5 days of injection, three days of soak and a year of production. Table 6 shows the operational parameters used in the stimulation.

Looking for represent inside the model the appropriate conditions for implementing the steamflood, it was done a spacing reduction, which requires the inclusion of new wells. Initially, it was incorporated two new wells with four stimulation cycles each (green color, figure 10), obtaining a spacing of 5 acres. As it has not been obtained appropriated temperature conditions yet to implement the continuous injection, it was incorporated five more wells with four cycles of stimulation (yellow color, figure 10), gaining a 2.5 acres spacing.

At the end of the stimulation process it was had six wells with 12 stimulation cycles (red color, figure 10), two wells with eight cycles (green color, figure 10) and five wells with four cycles (yellow color, figure 10), that allowed to achieve a appropriate temperature to implement the continuous injection of the steam, as it is shown by the viscosity distribution in figure 11, where it can be appreciated that in a stimulation radio between 95 and 132 feet, the viscosity of the fluid is in a range between 0 and 1500cp. The obtained results when referring to the recovery factor and the production rates adjust to the normal behavior of a recovery process of this kind and it is presented in figure 12.

Steamflood. As it was mentioned in the above paragraph, the cyclic stimulation allowed the achievement of the favorable values of viscosity for implementing steamflood. Likewise, it was found a favorable oil distribution to initiate the steamflood, given that the figure 13 is showing values between 0.6 and 0.66 in the target zone. Once the decision criteria for implementing the continuous injection were evaluated, it was incorporated four producer wells for creating four normal patterns of 2.5 acres and a reversed pattern, as it is shown in figure 5. With the purpose of determining the best operational conditions, it was executed a sensibility study for the injection rate and the quality of the steam in the sandface.

The injection rate was determined in sensibility analyses where oil recovery factor was the control parameter. The initial value was 1.5 bbl/acre-ft. The best injection rate was 600 bbl/day; with this value oil recovery factor is 39.26% in four years (figure 14). After this, the study continued with a sensibility analyses of steam quality in the sandface in arrange between 55% and 70%. This

range was selected because is similar to values found in Teca field. Figure 15 shows similar results in this range, and then we decided use a quality of 60%

The economic limit of the project was fixed in an oil steam relation (OSR) of 0.06 Bbl oil/Bbl steam. The time for this OSR is one year and ten months. In this time the oil recovery factor is 26% (figure 16). But, there is high remanent oil saturation in sands B because its permeability is less than permeability in sands A, and high permeability causes steam preferente flow. The remanent oil in sands B could be produced with a selective steam injection.

A simulation model with the similar rock and fluid properties and similar operation constraint but with only one shale intercalation using the same relation shale/sand was builded (figure 17). The thermal efficiency of this homogeneous model and the base model were compared in figure 18. The thermal efficiency increase around 30% in the homogeneous model. Additionally, an inverted patron increases the thermal efficiency around 4% in comparison with a normal patron. The results show that shale intercalations act like heat thief because its thermal properties are greater than sand properties.

Finally, selective steam injection was evaluated. Table 7 shows a greater thermal efficiency in sands A; but, oil recovery factor is greater in sands B because the oil saturation in the moment of implement steamflood is not equal in sand A and B. The oil saturation difference is because in the cyclic steam stimulation sands A received more steam than sands B. Then, in this case production of sands A and B are not comparables; but, selective steam injection show better results than global injection.

Conclusions

From a sensitivity analysis of variables affecting the thermal efficiency in a process of continuous injection of steam using analytical models, was determined that thickness of the shale and the thickness of the sands the properties have a greater influence in steamflood results.

The intercalated shale in a reservoir subject steamflooding, adversely affects the thermal efficiency of the process as it requires a greater amount of heat to recover the same amount of oil if the process was implemented in a homogeneous reservoir.

The difference in permeability between the two groups TECA field producing sands allowed the channeling of steam through the upper sand thus preventing the injection both cyclical and continuous injection had good results in the lower sands. This problem was solved by a scheme of selective steam injection.

From the analysis of the recovery factor, the oil-steam ratio and thermal efficiency, it was determined that a selective steam injection scheme is the best scenario for the implementation of steamflood in TECA field.

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Figure 1. Geographical location: Teca Field

Property	Zone A	Zone B	Screening
Depth ft	1400 - 1800	1920 - 2050	< 3000
°API	11.5 – 12.5	11.5 – 12.5	11 - 25
Net Pay ft	33	74	> 20
Viscosity Cp	4031	4031	< 1500
Permeability mD	1080	780	> 250
Porosity %	29	28	> 20

Table 1. Comparison of the Zone A and Zone B with the steamflood screening

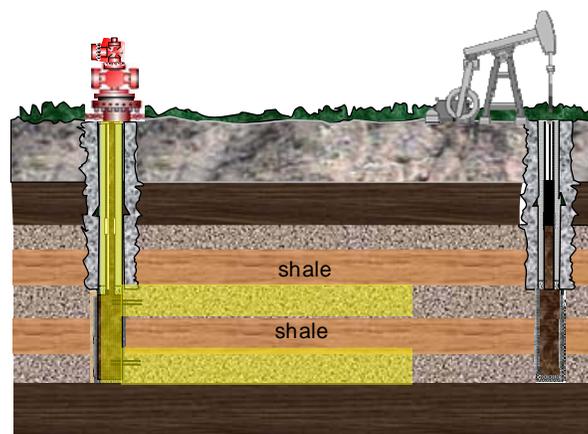


Figure 2. Analytical model assumptions

Property	Case Base	Case A	Case B
Shale thermal conductivity (BTU/h*ft*°F)	1.25	0.5	2
Shale volumetric heat capacity (BTU/ft*°F)	40	37.5	42.5
Shale thickness (ft)	20	10	30
Sand volumetric heat capacity (BTU/ft*°F)	37.5	35	40
Sand thickness (ft)	20	10	30

Table 2. Case Evaluated with the analytical model.

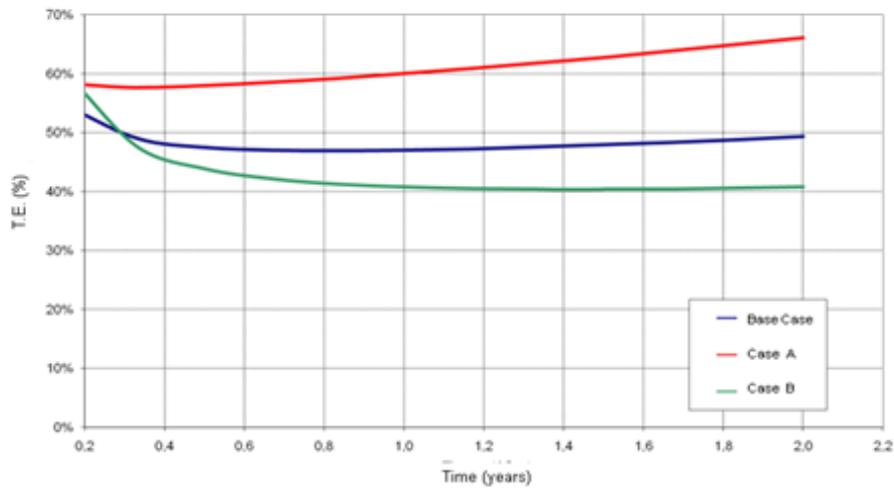


Figure 3. Shale thickness sensibility in the analytical model

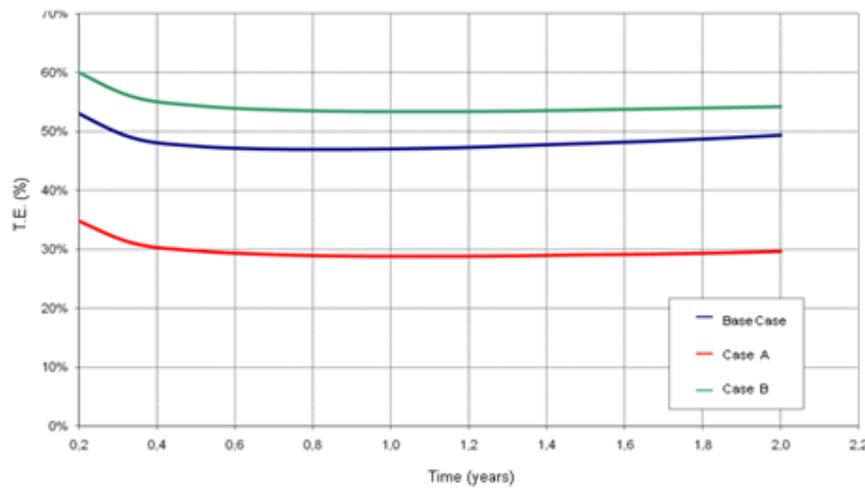


Figure 4. Sand thickness sensibility in the analytical model

Property	Case Base	Case A	T.E.	Case B	T.E.
Shale thermal conductivity (BTU/h*ft*°F)	1.25	0.5	Decrease	2	Increase
Shale volumetric heat capacity (BTU/ft*°F)	40	37.5	Increase	42.5	Decrease
Shale thickness (ft)	20	10	Increase	30	Decrease
Sand volumetric heat capacity (BTU/ft*°F)	37.5	35	Decrease	40	Increase
Sand thickness (ft)	20	10	Decrease	30	Increase

Table 3. Results of the analytical model sensibility

Property	Sand A	Sand B	Shale
Horizontal Permeability (mD)	1080	780	0
Vertical Permeability (mD)	360	206	0
Porosity (%)	29	28	0
Compressibility of the Formation (1/psi)	5e-4	5e-4	34.67
Thermal conductivity (BTU/dia*ft*°F)	36	36	40
Volumetric heat capacity (BTU/ft*°F)	37.5	37.5	40
Fluids Properties			
Molecular Weight (lb-mol)	600		
Oil Density (lb-mol/ft ³)	61.2		
Compressibility (1/psi)	5 e-06		
Thermal expansion coefficient (1/°F)	3.8 e-04		
Oil Viscosity (cp)	4031		
°API	12.8		

Table 4 Properties of the simulation base model

CASE	GRID	CELL SIZE (feet)	COMPUTATION TIMES (minutes)	CELLS NUMBER
1	25x13x15	50.77	1.416	4875
2	33x17x15	38.82	3.28	8415
3	41x21x15	31.43	6.68	12915
4	49x25x15	26.4	8.4	18375

Table 5. Evaluated cases in the establishment of the simulation grid.

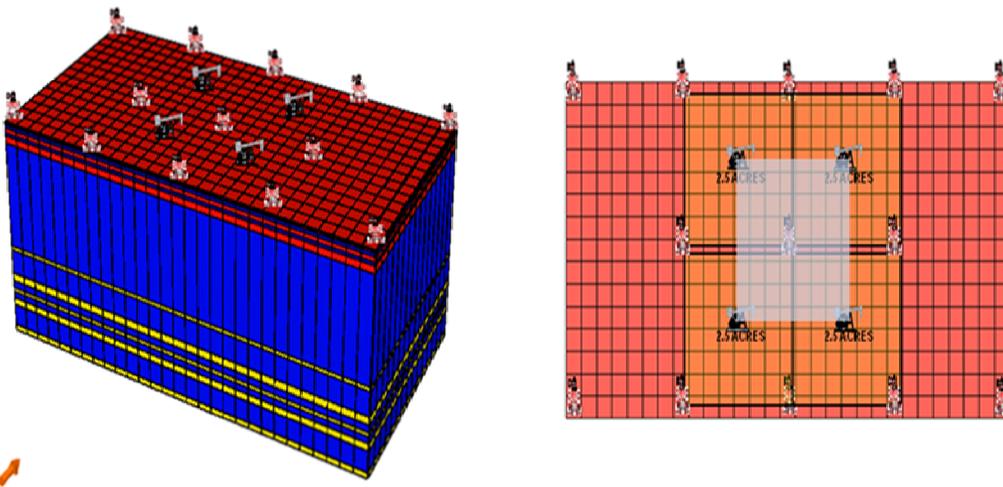


Figure 5. Simulation model appearance

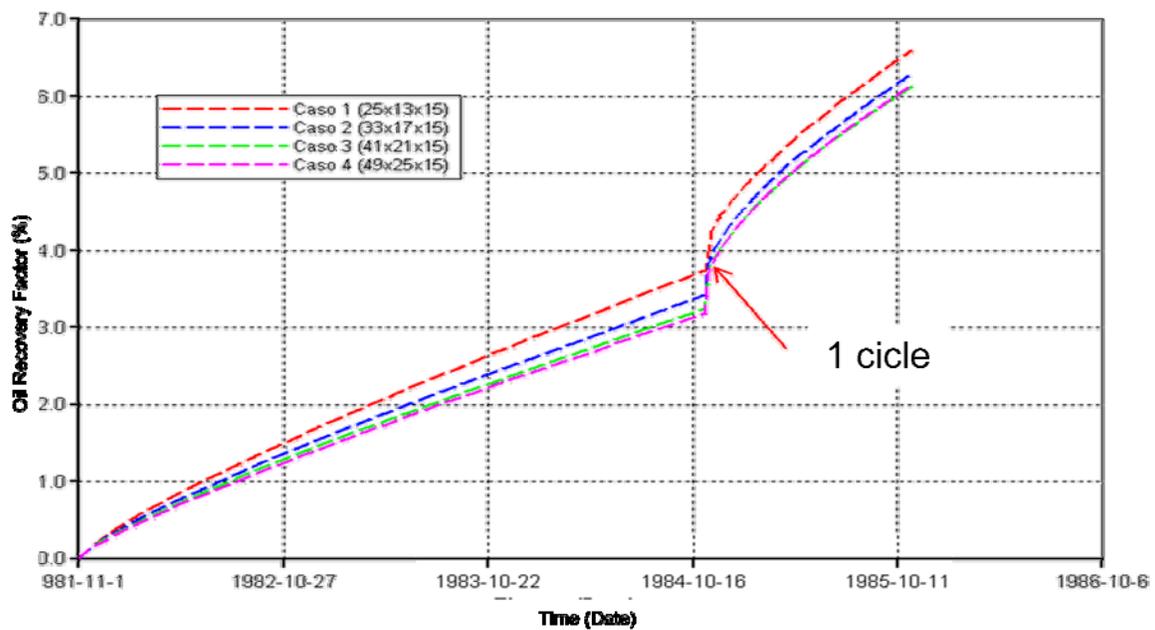


Figure 6. Sensibility to the cells numbers of the simulation model

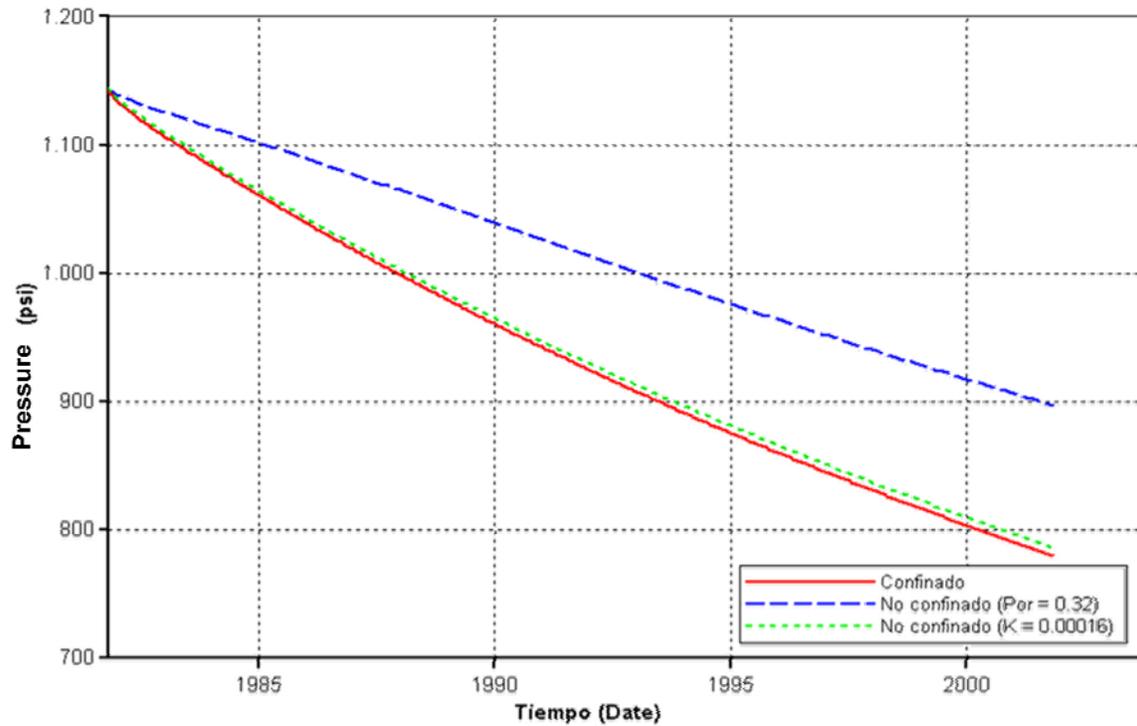


Figure 7. Confinament ring effect over the pressure behaviour

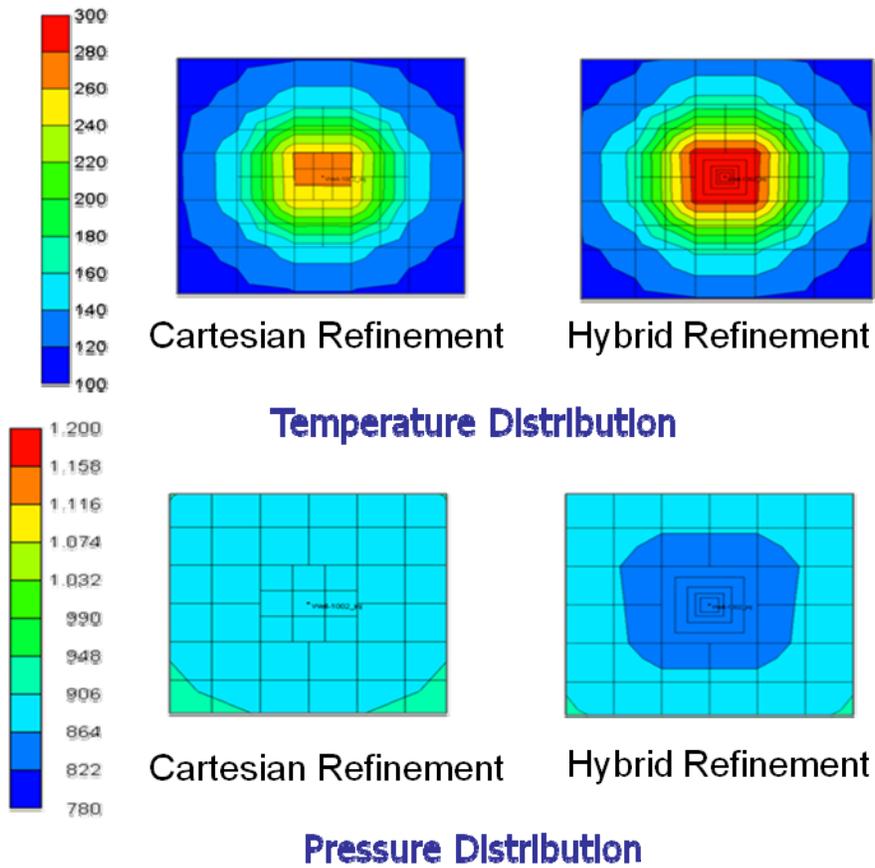


Figure 8. Type Refinement effect over the pressure and temperatura distribution

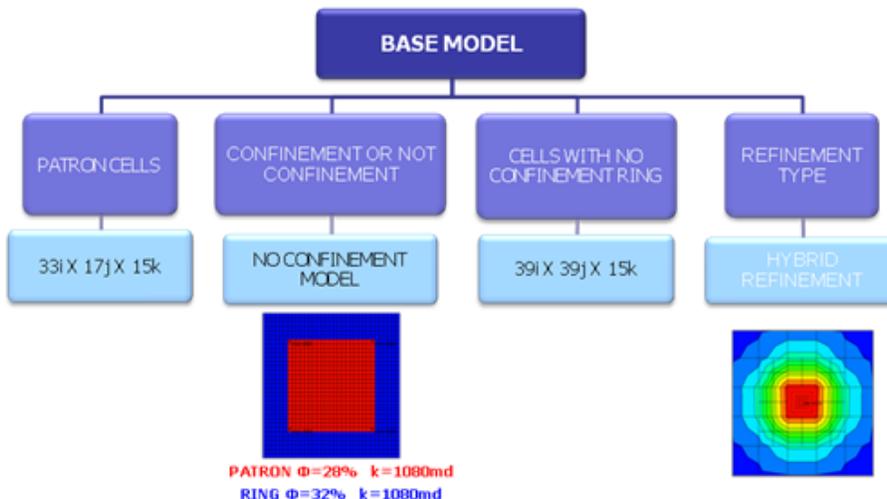


Figure 9. Grid properties of the base simulation model

PRODUCTION	
Bottom Hole Pressure	700 psi
Liquid Producer- Rate	500 bbl/día
INJECTION	
Bottom Hole Pressure	1400 psi
Steam Rate Injection	2300 bbl/día
Steam Quality (Sandface)	0.65
Steam Temperature	587.43 °F

Table 6. Operational parameters used in the stimulation process

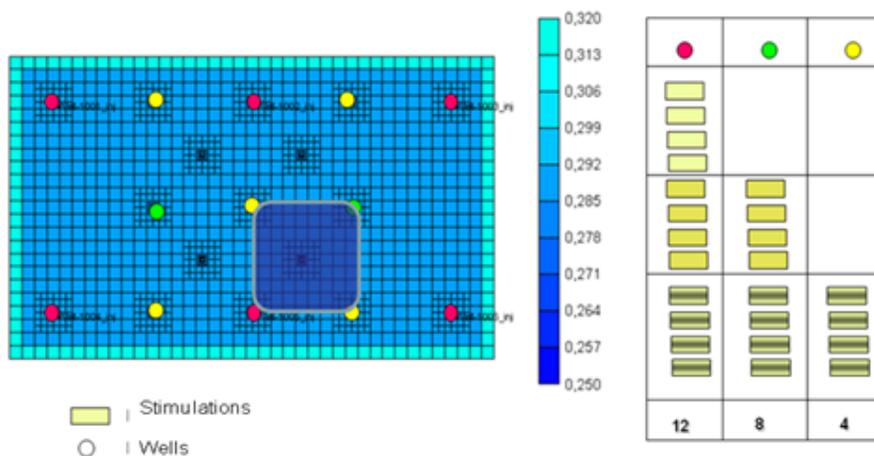


Figure 10 Representation of the cyclic steam stimulation

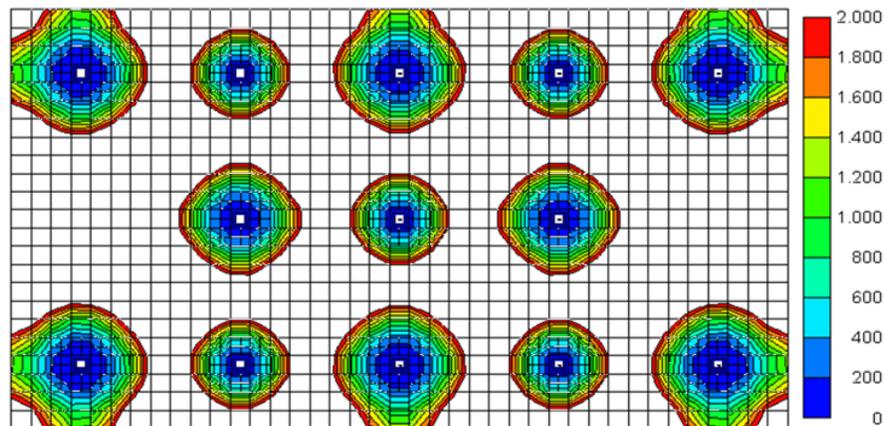


Figure 11. Areal viscosity distribution at the end of the cyclic steam stimulation.

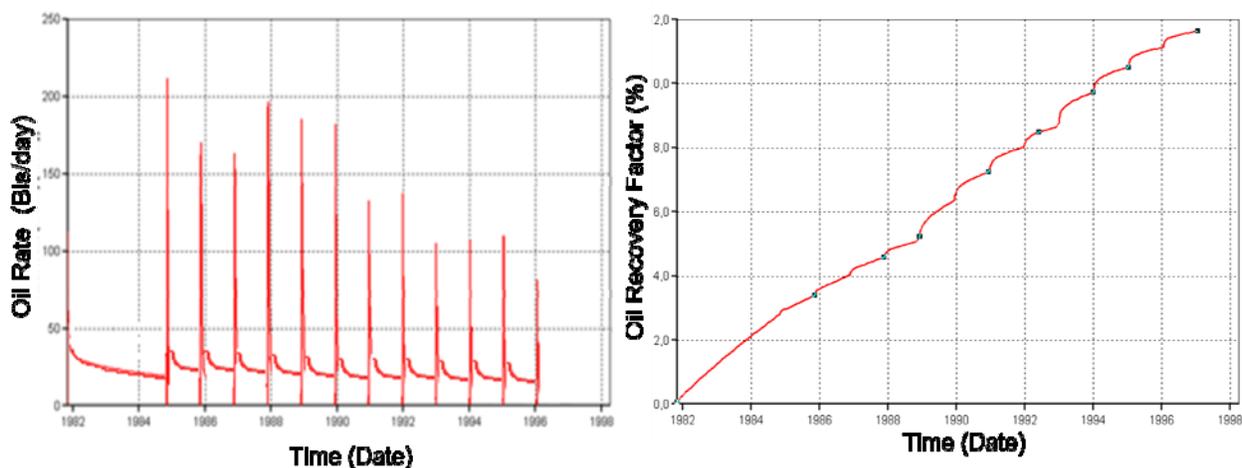


Figure 12. Production rate and recovery factor achieved at the end of the cyclic steam stimulation.

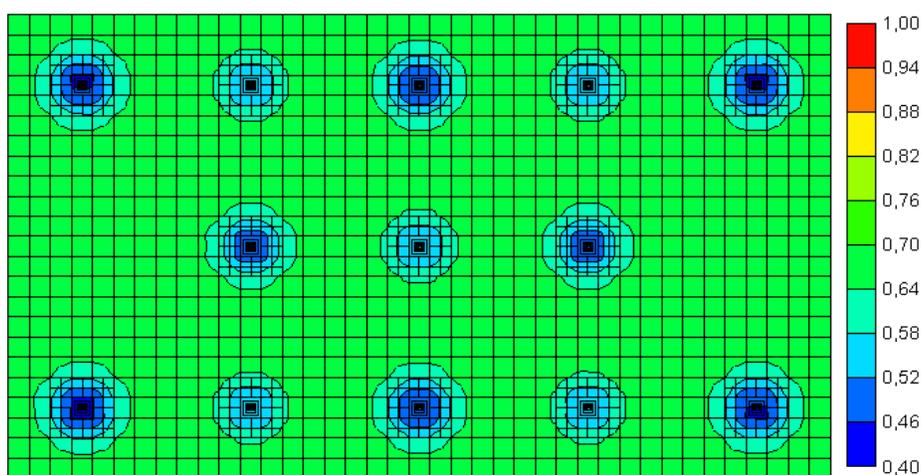


Figure 13. Areal distribution of the oil saturation at the end of the cyclic steam stimulation.

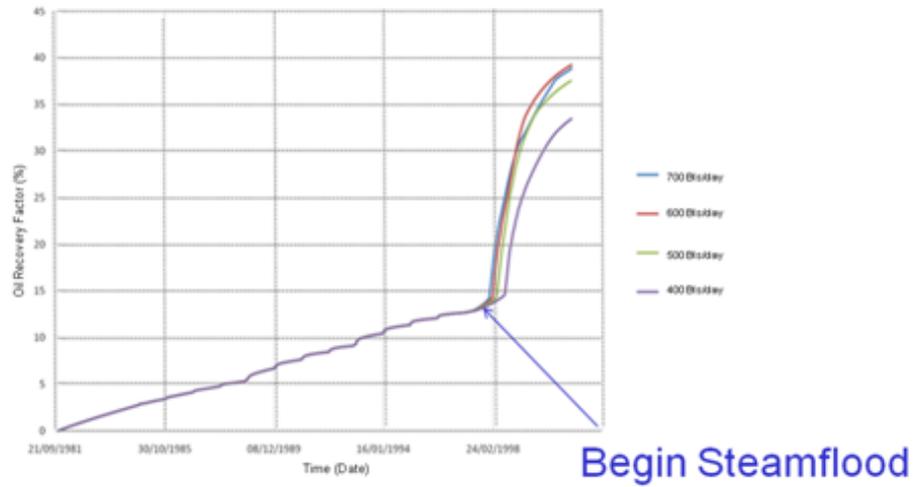


Figure 14. Sensibility Analyzes Steam Rate Injection.

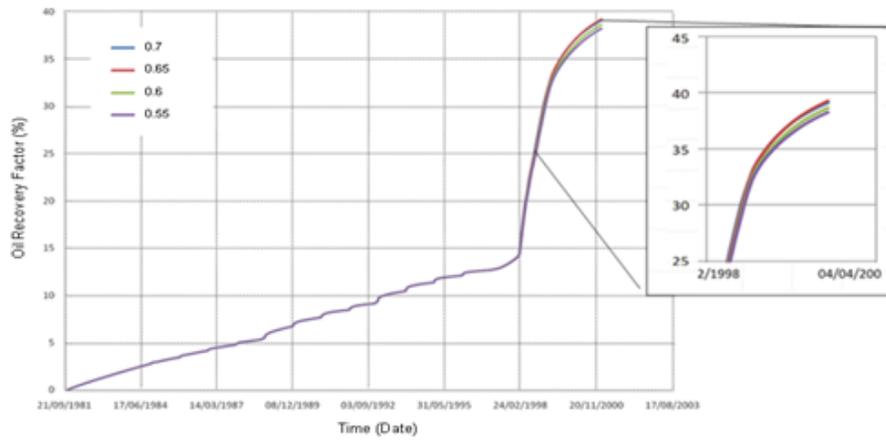


Figure 15. Sensibility Analyzes Steam Quality.

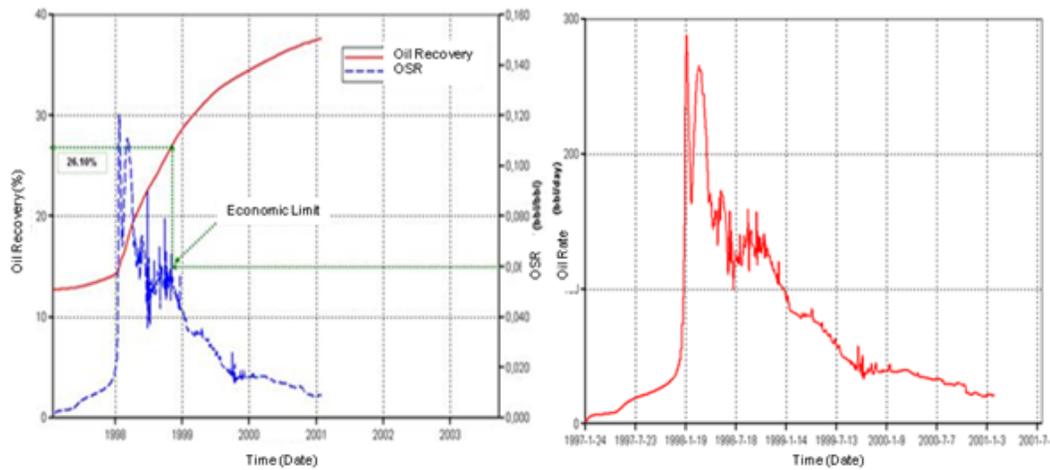


Figure 16. Oil Recovery Factor and Oil rate in the economic limit.

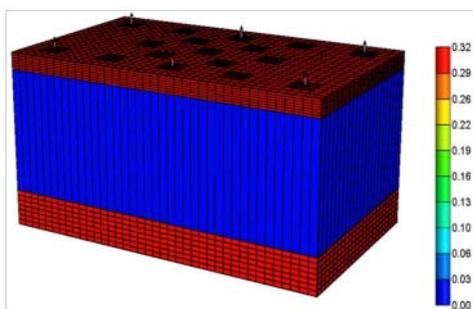


Figure 17. Homogeneous Model.

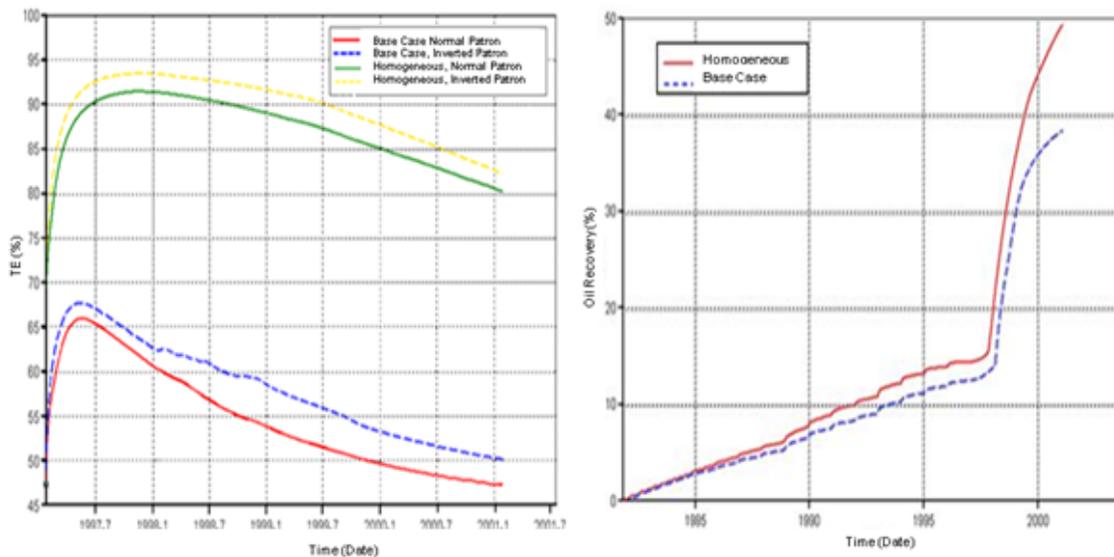


Figure 18. Difference between Homogeneous Model and Base Case.

PROPERTY	BASE CASE	HOMOGENEOUS MODEL	SAND A	SAND B
Oil Recovery Factor (%)	26.1	37	32	47
OSR (%)	0.06	0.06	0.06	0.06
Max Thermal Efficiency (%)	67	94	65	52
Rupture Time (months)	9	16	12	11

Table 7. Final Results.