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Insight of HASD Technology in an Extra Heavy Oil Field in Comparison to Traditional Thermal EOR Processes

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Abstract

HASD (Horizontal Alternating Steam Drive) is a thermal EOR (Enhanced Oil Recovery) process with a mechanism based on the combination of horizontal Steam Flooding (SF) and Cyclic Steam Stimulation (CSS).

This paper presents the potential of HASD to exploit the reserves of one extra heavy oil giant field, located in the Orinoco Oil Belt (OOB), identifying the characteristics and quality of reservoir that are more suitable to use HASD in comparison to traditional EOR technologies based on steam injection, for the typical well configuration schemes used in the OOB, which is based on set of clusters of long horizontal wells.

The field object in the study requires, after an initial stage of cold production, the application of an EOR process to meet the target production plateau of the field development plan. The thermal EOR technologies based on steam injection are the ones more suitable to be applicable in this field, as it was established by a detailed EOR prescreening study, previously performed for this field.

The evaluation of the oil recovery of this giant field is based on a sectoring strategy, considering that the size of the field makes unfeasible a full field reservoir simulation using a thermal EOR process. Considering the different thicknesses and heterogeneities found in the field, the identification of a proper number and type of sectors is required to be able to represent adequately the different reservoir qualities.

The performance of different thermal EOR processes has been evaluated using numerical simulation in all of the sectors selected for the field. The operating conditions of each technology were obtained after carrying out an optimization study based on different reservoir qualities. The detailed analysis of production behavior in the different reservoir quality sectors for an optimized set of operating conditions allows understanding the applicability and potential of the different thermal oil recovery processes in diverse parts of the field.

This paper presents the results from the assessment made on three different sectors of the field, each one characteristic of a specific reservoir quality, to evaluate the potential application of the HASD technology. A comparison with the performance of CSS and SF on the same sectors is presented and the type of reservoir quality more adequate for HASD is identified, together with a recommended set of operating conditions.

HASD process has not any commercial reference up to this moment; the results presented in this study can support the decision to consider the definition of a pilot project that paves the way to the first commercial application of HASD.

Introduction

Repsol is a shareholder in a Joint Venture that operates a new field in the Orinoco Oil Belt (OOB), in Venezuela. This field, in the most prospective geological unit, has a huge amount of resources, with an STOIIP of 34MMM STB, of extra-heavy oil (~8.4°API).

The master development plan of this field imposes big challenges, such as keeping a constant plateau of production of 400,000 STBD for at least 37 years. This plateau is not possible to be kept only with primary (cold) production. Therefore, the application of EOR technologies will be required to meet this production target.

An EOR screening methodology has been developed internally in Repsol-CTR (Nnang-Avomo, T. I. *et al*, 2014) and applied to this field, to select and rank the EOR technologies with more potential to reach the aforementioned objective. The results indicated that Thermal EOR technologies, and in specific those based on steam injection, are the best positioned to be used in this extra-heavy oil field.

A review of the biggest EOR projects existing in the world today, shows that only four fields exceed 50,000 STBD of EOR production using steam injection (Oil&Gas Journal, 2014): Kern River, US (86,000 STBD); Primrose, (70,000 STBD) and Cold Lake, (154,000 STBD) in Canada; and Duri, Indonesia (190,000 STBD). This gives an idea of how challenging our project becomes, aiming at 400,000 STBD of EOR production; the use of innovative processes, operating conditions or well configurations can become critical to meet the target.

Even though in the OOB there were several pilots of thermal processes (Trebolle R. *et al.,* 1993, Vega G. *et al.,* 2011), currently there is not any commercial EOR method extensively used there. Among others, this fact encourages the research for identifying suitable recovery methods, adapted to the current development plan. For our field, a scheme of multiple clusters of long horizontal wells is being used.

Traditionally, Cyclic Steam Stimulation (CSS) or Steam Flooding (SF) are the EOR technologies considered for this area. In the last years, a new EOR process called HASD has been proposed, although barely investigated. HASD was specially defined to be applied in fields with heavy or extra-heavy mobile oil, which are developed through clusters of horizontal wells.

In this paper, the potential of the HASD technology for our field is presented, and its performance is analysed in relation to CSS and Steam Flooding, in different reservoir quality sectors.

HASD Technology

HASD is a recovery process developed for application in heavy oil reservoirs with mobile oil. In the literature there is limited available information about studies, pilots, etc regarding HASD. It is worth mentioning the first study presented by Rodriguez J.R. *et al.,* 2003, where HASD was proposed for application in reservoirs affected by moderately connected aquifers, and the work published by Fernandez, E.A. and Bashbush, J.L., 2008, where the process is studied at specific field conditions in the OOB.

HASD was designed to be applied in a set of horizontal and parallel wells located at the same level in the reservoir sand. The wells are cyclically switching between injection and production phases. The oil recovery mechanism in place is a combination of horizontal steam flooding and cyclic steam stimulation of each of the horizontal wells. In this technology, a steam chamber is created while each well is injecting, and it is laterally driven by the pressure differentials created between the injectors and the adjacent producers. Therefore, the method combines the local stimulation of the CSS and the drive and consecuentely oil saturation reduction of the SF, generating a process that, at efficient operating conditions, should have a higher production than the typical processes of individual CSS followed by SF.

For the case of this studied field, the evaluation of HASD is particularly helpful because this technology could be easily adapted to the current development plan, which is based on clusters of long horizontal wells.

The steam is injected for a period of time, normally several months; once this phase finishes, the injectors and producers switch their functions and they operate for a period equal to the first stage, completing in this way the cycle. Figure 1 represents two different moments of the HASD operation; left graph shows the temperature in the field at the end of the fourth injection period (year 8 of HASD operation) for wells 1, 3, 5, whereas the right graph shows the end of the fifth injection period (year 10 of HASD operation) for wells 0, 2, 4.

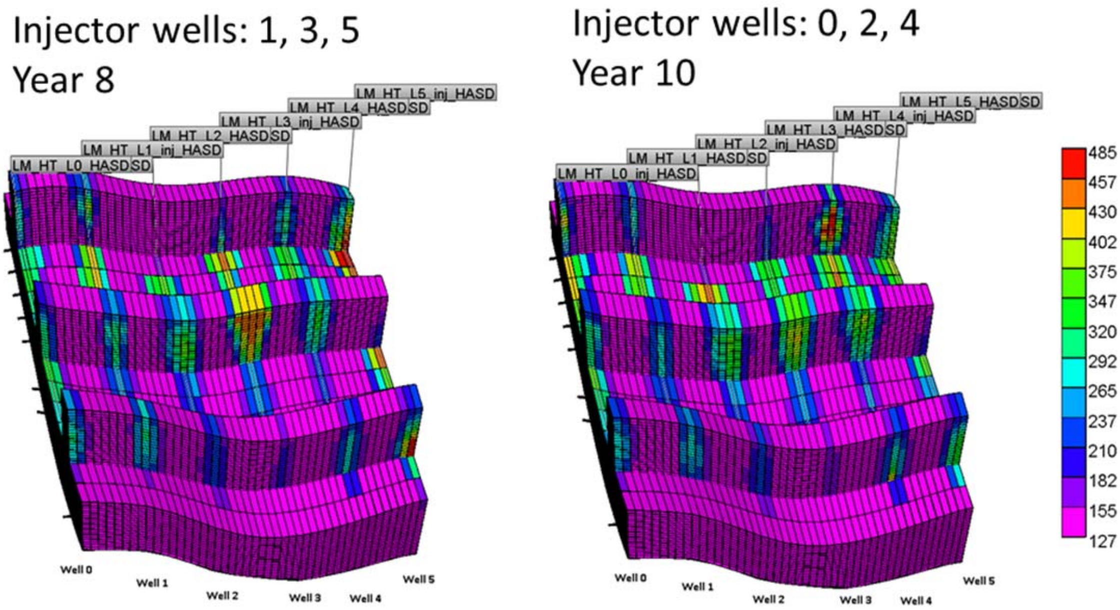


Figure 1. Temperature at two different moments of the HASD cycle

Reservoir Characteristics

The field object of the study is a giant green and heterogenous field. It is formed by unconsolidated sands, Miocene age. The structure is a monoclinal, with a moderate dipping to North. The seismic information is limited and does not provide a good understanding of the fault system; therefore there is a significant geological uncertainty in the field. It consists of 3 different geological units, with the bottom one containing approximately 80% of the total STOIIP of the field, as well as the best reservoir properties. This Main unit is also subdivided in 3 subsections: Lower, Middle and Upper Unit. The depositional environment of Upper and Middle unit is transitional marine-tidal dominated, whereas the Lower unit is fluvial environment represented by braided channels. The field is affected by a regional aquifer, which has been identified mainly in the North part of the Lower Unit. Table 1 summarizes the main average properties of the Main Unit.

Net Pay	3-8 m
Depth	800-1000 m
Average porosity	31-33%
Average permeability	2-4 D
Pressure	84 - 100 bar
Temperature	52 - 58 °C
Oil viscosity @rc	~1000 - 2000 cP
Oil gravity	8.4 °API
Initial Sw	27 - 32%

Table 1. Average reservoir properties of the main unit

This study will be concentrated on the specific areas of the reservoir with better properties to apply steam-based processes. For the assessment of the thermal technologies, three different High, Medium and Low reservoir quality (HQ, MQ and LQ, respectively) sectors (2.3 km^2 each) have been selected in this area, according to the sectoring strategy explained in the next section. For a better comparison of each reservoir tipology, in the Figure 2, it can be observed a lateral view (*IK* direction), of the horizontal permeability. It is clear from the Figure that the lower the quality, the lower the continuous thickness. In the Figures 3 to 6 it is shown the comparison of the STOIIP, average porosity, permeability and thickness for the three reservoir qualities, in the sectors object of the study.

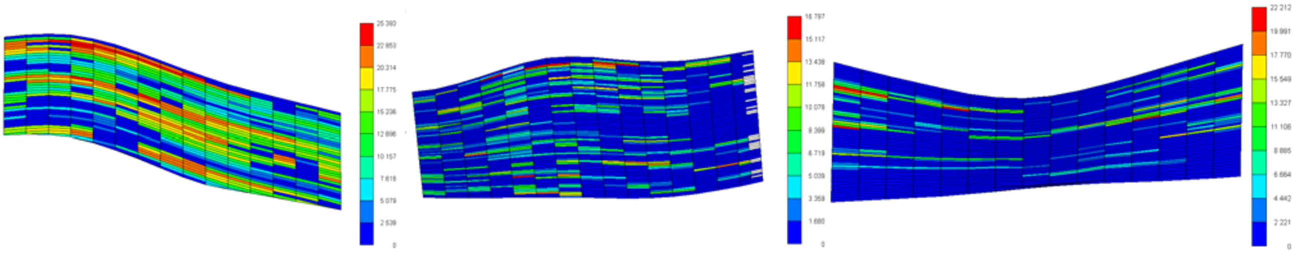


Figure 2. IK view of the permeability of the three sectors (left: HQ, center: MQ, right: LQ)

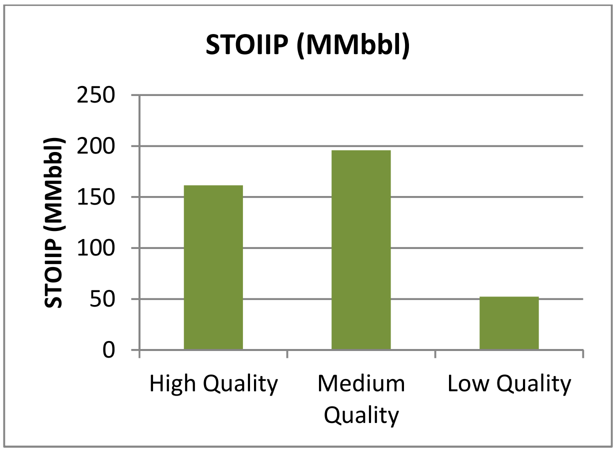


Figure 3. STOIIP

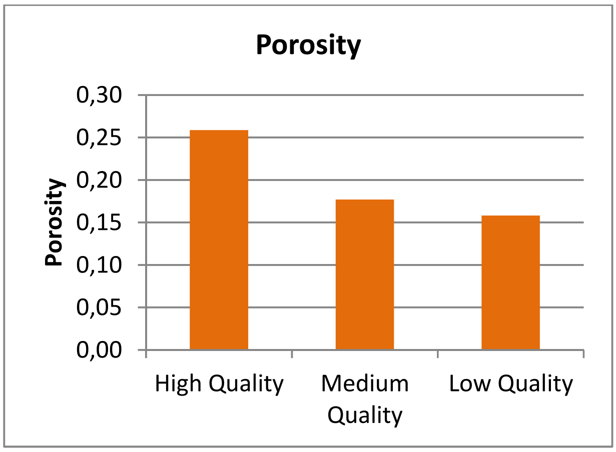


Figure 4. Average Porosity

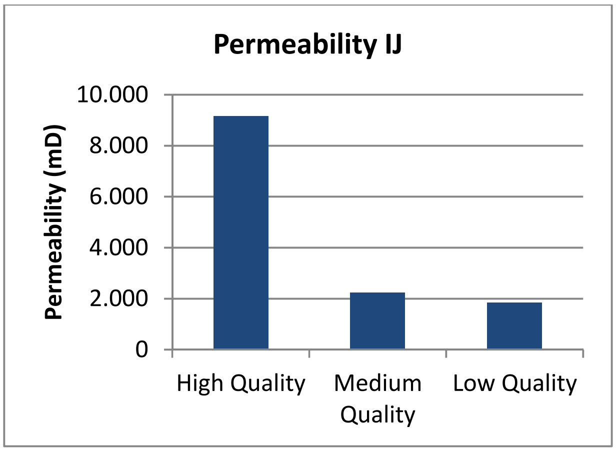


Figure 5. Average Permeability

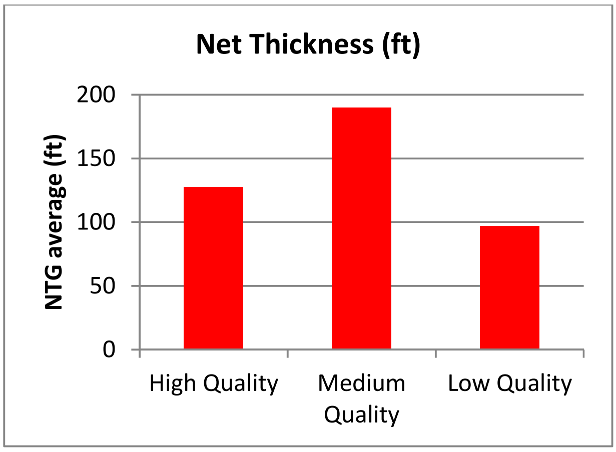


Figure 6. Average Thickness

Sectoring

From a numerical simulation point of view, the giant dimensions of this field represent a challenge to capture the fullfield behavior of any thermal processes in relative short computing time. To overcome this drawback, CTR developed a sectoring approach (Escobar *et al*., 2015 and Leon-Carrera, M. F. *et al*., 2015), which allows the identification of a minimum number of representative regions of the field, considering the definition of a "Reservoir Quality Index" (RQI), especially defined for extra-heavy and green fields, as a modification of the index developed by Molina A. and Rincon A., 2009. The Index is a function of 3 normalized (0 to 1) reservoir parameters: *STOIIP*, Transmissibility (kh/μ_o) and net thickness (h) (Equation 1), and it is discretized in three categories: high, medium and low.

$$RQI = \sqrt[3]{STOIIP \times \frac{kh}{\mu_o} \times h}$$

Equation 1. Reservoir Quality Index (RQI)

RQI helps to select representative sectors of the field that are used in numerical evaluation for each EOR target process.

The application of this methodology in this large, heavy oil, green field resulted in the identification of 18 different representative sectors, for the three geological subunits considered in this study. The ones selected for the work presented in this paper represent around 16% of the total STOIIP of the field (Main Unit).

It is important to mention that the results of this study are part of an integral methodology to evaluate and rank EOR development strategies for heavy oil fields, at different levels, sector, reservoir and fullfield, as it is described by Coll R. *et al*., 2015.

Simulation Model

The well clusters considered have a similar configuration; they consist of 10 horizontal wells, that are 1000m long each, and with a spacing of 300m; the cluster is divided in 2 branches of 5 wells each. This configuration is fixed and follows the basic guidelines given by the Master Development Plan of the field. Wells are preferentially oriented West-East or East-West increasing the opportunity to cross the higher amount of sand channels. To ensure the symmetry, the configuration used in the simulation model, that covers one of the cluster branches, is the one shown in the Figure 7; it can be seen that the sector includes 6 wells, with simulation of half wells located at the North and South boundaries, for a total of 5 effective horizontal wells per sector.

The horizontal wells are drilled in a close range of depth in the same layer, selected as the lowest of the largest continuous thickness area.

The original cell size in the static model is 100m x 100m x 4ft. For the optimization stage, explained in the next section, no refinement has been applied; whereas for the final assessment, a global refinement in *J* direction (North-South direction, perpendicular to the wells trajectory) has been used, being the final size of the cells 100m x 33m x 4ft.

All the simulation forecasts were extended to 40 years, including the first stage of primary (cold) production.

The simulator used for the study was STARS, and CMOST was the tool used for the Optimization Study; both are provided by CMG (Computer Modeling Group).

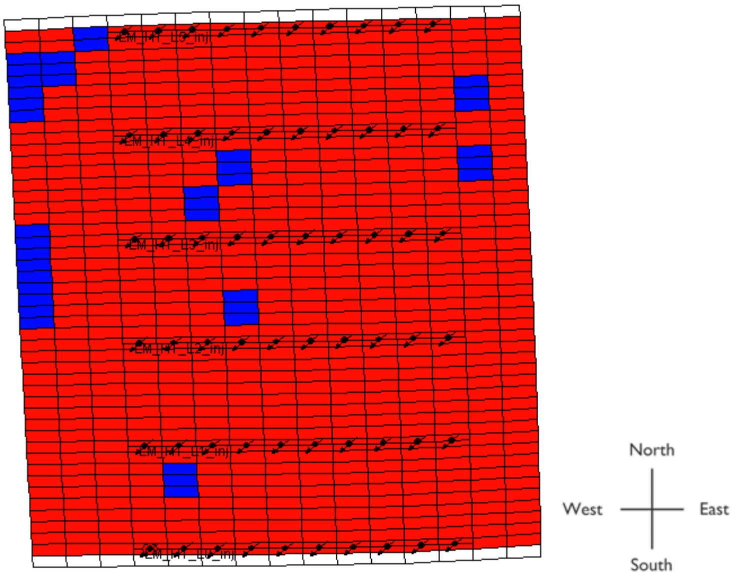


Figure 7. Top view of the position of the wells (property NTG)

Evaluation Methodology and Data

This work compares the behaviour of the traditional Thermal EOR processes tested in the Orinoco Oil Belt, CSS and SF, with the HASD potential. In order to perform the comparison on the same basis, an optimization study based on maximizing NPV was made for every technology, to determine the best set of operating conditions that should be applied for each reservoir quality. The premises of the optimization study are indicated below:

- Global Objective Function: NPV, based on a yearly discount rate of 10%, a Brent value of 50US$/bbl and a steam cost of 3.33 US$/bbl. The calculation of this function includes the consideration of a workover cost in each CSS cycle. No tax considerations at this point
- All technologies start with a primary (cold) production stage, followed by a number of cycles of CSS (to be optimized)
- The SF technology is based on the continuous injection of steam through vertical injectors; 2 vertical injectors are drilled between 2 horizontal wells, so that each sector has a total of 10 vertical injector wells. The cost associated with a new vertical well has been estimated in 4MMUS$
- The criterion to trigger EOR stage is based on a minimum oil rate produced by the well cluster
- The parameters included in the optimization study are the following: oil rate to trigger steam injection, number of CSS cycles, CSS injection time, CSS soaking time, CSS production time, steam injected, HASD cycle duration time

Results

Operating Conditions optimization

As mentioned before, HASD will start after an initial stage of CSS, and the number of cycles of this stage is one of the variables to be optimized. The rest of the parameters of this stage (steam rate and injection time) are a result of the optimization performed for CSS as a single technology.

Below, the variables considered in HASD optimization and their ranges of variation are detailed:

- Number of CSS cycles: 3, 4, 5
- HASD duration (injection time/production time): 182d, 365d, 730d, 1095d (the complete HASD cycle would be double this time)
- Steam rate to be injected during HASD stage: 300bbl/d, 1000bbl/d, 1500bbl/d, 2000bbl/d, 3000bbl/d

The Table 2 shows the set of HASD operating conditions that have been obtained from the optimization study with the indicated premises in the previous section. This Table also shows the conditions used for the CSS and CSS + SF simulations, obtained in an earlier study and following the premises of the previous section. In this regard, although this is out of the scope of the present paper, it is worth mentioning that the CSS optimization study gave as a result a high steam injection rate, 10,000 bbl/d, due to the fact that long horizontal wells and big interwell spacing are utilized, that require higher stimulation rates than the ones used in other commercial references. High reservoir permability and mobile oil conditions, together with a big injection tubing diameter allow the injection of this high rate for CSS process. It is important to remark that the specific steam injection rate is in the order of magnitude of typical values (3-4 bbl/d·ft).

For all the cases, the final oil rate at the end of the cold production to start EOR is 1,500 bbl/d per cluster.

	CP + CSS	CP + CSS + SF	CP + CSS + HASD
High Quality	9 cycles Steam Injected: 3 bbl/d·ft per well Injection Time: 60 days Soaking Time: 10 days Production Time: 365 days	CSS: 5 cycles, 3 bbl/d·ft per well, 60 days injection time, 10 days soaking time, 365 days production time SF: 750 bbl/d per vertical injector well	CSS: 5 cycles, 3 bbl/d·ft per well, 60 days injection time, 10 days soaking time, 365 days production time HASD: 2000 bbl/d per well, 730d injection/production time
Medium Quality	9 cycles Steam Injected: 3 bbl/d·ft per well Injection Time: 60 days Soaking Time: 10 days Production Time: 365 days	CSS: 5 cycles, 3 bbl/d·ft per well, 60 days injection time, 10 days soaking time, 365 days production time SF: 500 bbl/d per vertical injector well	CSS: 5 cycles, 3 bbl/d·ft per well, 60 days injection time, 10 days soaking time, 365 days production time HASD: 1000 bbl/d per well, 1095d injection/production time
Low Quality	3 cycles Steam Injected: 3 bbl/d·ft per well Injection Time: 15 days Soaking Time: 10 days Production Time: 365 days	CSS: 3 cycles, 3 bbl/d·ft per well, 15 days injection time, 10 days soaking time, 730 days production time SF: 300 bbl/d per vertical injector well	CSS: 5 cycles, 3 bbl/d·ft per well, 15 days injection time, 10 days soaking time, 730 days production time HASD: 300 bbl/d per well, 182d injection/production time

Table 2. Optimum operating conditions for the 3 Thermal EOR process for the 3 reservoir qualities

As an example, in the Figures 8 to 11 the results of the optimization for the Medium Quality sector can be observed. Figure 8 shows the Sobol analysis of the parameters, analyzing their impact on NPV. The Sobol method is a powerful method to quantify the relative importance of input factors as well as their interactions. The first-order index (indicated by the green bar in the graph) represents the main effect contribution of each input factor to the variance of the output; second value, indicated by the red bar in the graph, measures how much each parameter interacts with other input factors. The Sobol analysis shows that the steam rate injected during the HASD stage is the most important parameter to be taken into account in this reservoir quality, whereas the duration of each HASD cycle has a very limited influence on the output.

Figures 9 to 11 show the cross plots that represent the objective function NPV versus the different evaluated parameters, for all the experiments analysed in the optimization study. These graphs allow extracting a trend of the impact of each parameter on this objective function, but their absolute value is not taken into account in this study. Thus, it is observed that a higher number of CSS cycles before HASD stage is positive to increase NPV (Figure 9), that the duration of HASD cycle does not present a clear optimum (Figure 10) and that steam rate to be injected during HASD stage presents an optimum in the middle of the considered range (Figure 11).

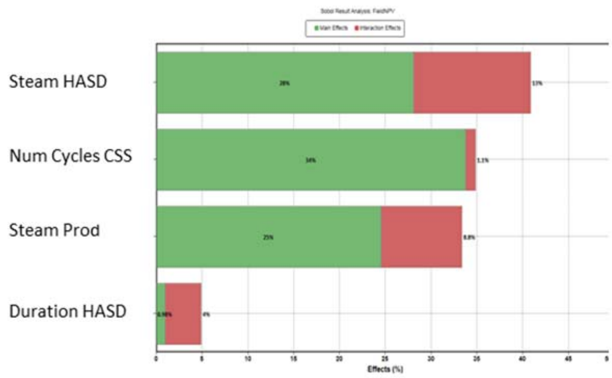


Figure 8. Sobol analysis – impact of parameters on NPV

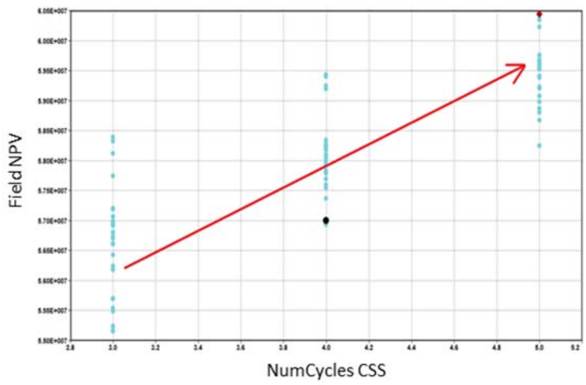


Figure 9. NPV vs. number of CSS cycles

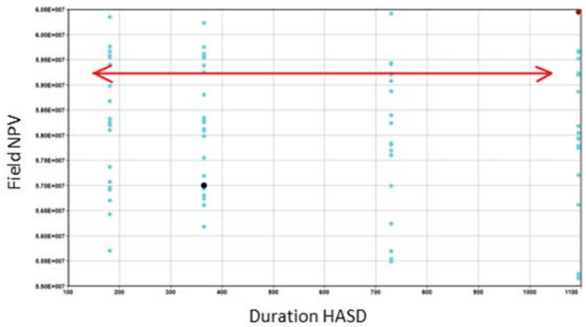


Figure 10. NPV vs. HASD duration cycle

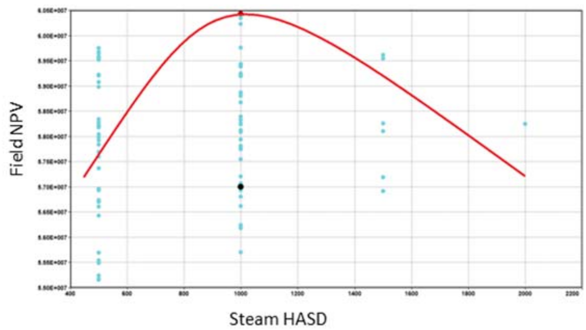


Figure 11. NPV vs. HASD steam injection rate

As it can be seen in the Table 2, the lower the quality of the reservoir, the lower the optimum steam quantity to be injected. This is especially relevant on the low quality sector; in this case, the study reflects that it does not result economical to inject steam in this type of quality with a configuration of cluster of horizontal wells, due to the low areal and vertical sand continuity in this sector, something that can be observed in the relative NPV results for CSS + HASD technology, shown in Table 3; these relative figures are incremental, referred to the cold production case. Considering these results, the detailed analysis of HASD and other Thermal EOR processes performance has not been done for the low quality sector, where alternative well architecture and pattern should be assessed (out of the scope of this paper).

	High Quality	Medium Quality	Low Quality
NPV	+17%	+8%	-22%

Table 3. Relative NPV of CSS+HASD in comparison to cold production

As commented before, all the simulation forecasts were extended to 40 years. This is also an important factor to be considered when determining the optimum operating conditions and that has been studied using CMOST. Table 4 shows the optimum conditions obtained in the case of considering a reduced operating time. From these results, it can be derived that the optimum steam rate is lower in the 20 years case, with a more periodic intervention in the wells (with the consequent operational difficulties), for an NPV of the same order of magnitude.

The convenience of introducing some cycles of CSS previously to the HASD stage was also analysed in CMOST through an independent study. In this study, considering the same range of parameters, the conclusion was that eliminating the CSS step would imply a decrease in NPV results. Table 4 shows the comparison between the optimum parameters for the high quality sector in both cases and the impact on the NPV results; to be noted that the steam injection rate, which is the most significant parameter, is the same. The advantage of incorporating a CSS stage before HASD is a logical result, since CSS allows decreasing the pressure of the reservoir and accelerating the recovery, improving the economics; in addition, it offers a better understanding of the field characteristics, in a way that this knowledge can be used to improve the performance with the second EOR technology to be used, in this case HASD.

	Operating conditions	Duration	NPV
CP + CSS + HASD (40 years)	As in Table 2	CP: 5 years CSS: 6 years HASD: 29 years	Reference
CP + CSS + HASD (20 years)	CSS: As in Table 2 HASD: 1200 bbl/d per well, 182d injection/production time	CP: 5 years CSS: 6 years HASD: 9 years	-2%
CP + HASD (40 years)	HASD: 2000 bbl/d per well, 1095d injection/production time	CP: 5 years HASD: 35 years	-6%

Table 4. Impact of the CSS stage before HASD stage and impact of the lifetime on the performance of a high quality sector

Comparison of Thermal EOR Technologies performance

Considering the operating conditions mentioned in the previous section, a comparison of the performance of the 3 different EOR technologies is presented, for the high and medium quality sector in Figures 12 to 19.

In the Figures 12 and 13, a reference with the results of the oil recovery in cold production (no steam injection) is included to show the potential of these EOR technologies, in the studied sectors of this field. Cold production recovery factor is 9% STOIIP for the high quality sector, and just 2% STOIIP for the medium quality one. This low value for the medium quality sector anticipates that the wells configuration, based on clusters of horizontal wells drilled at the same depth, is not the most convenient one.

Two important parameters used for assessment of EOR performance are the incremental recovery factor (RF) and the incremental steam-oil-ratio (SOR), both using as a reference the cold production. These parameters are defined according to the formulas indicated below, where the cumulative oil production, N_p, injected water, W_{inj}, and STOIIP are expressed in barrels.

$$\Delta RF = \frac{N_p(CP + EOR)}{STOIIP} - RF\ (CP)$$

Equation 2. Incremental RF definition

$$\Delta SOR = \frac{W_{inj}(EOR)}{N_p(CP + EOR) - N_p(CP)}$$

Equation 3. Incremental SOR definition

In general, EOR processes provide a better performance with respect to cold production, as it can be observed in Figures 12, 13. Comparing high and medium quality areas, EOR performance is considerably better in high quality sector, with higher incremental RF and lower SOR. The technology that offers a highest recovery for both qualities is SF, although the differences in the recovery obtained with the EOR processes are minimum in the medium quality sector. Regarding HASD performance, it is observed in these figures that this EOR process requires a minimum number of cycles to exceed the CSS oil recovery, in both qualities.

Figure 14 and 15 show the comparison between the cumulative water to be injected according to the optimum theoretical conditions of Table 2 and the real injected water (allowed by the simulation). Figure 14 shows that for the high quality sector, both theoretical and real curves match perfectly, which demonstrates that this type of quality has a very good injectivity and allows a good drainage of the area thanks to the good continuity of the sands. On the other hand, Figure 15 reflects the important discrepancies that, for the medium quality sector, appear between the theoretical water injection rate optimum and the real one; this is due to the lack of continuity of the sands, which prevents the sector from a proper drainage and explains the reduced performance of EOR in this case with the well configuration analysed in the study.

This fact can also be observed in Figure 19, which shows the temperature distribution after 25 years of SF/HASD operation, in the layer where the producing wells are drilled, reflecting the different performance of these technologies depending on the quality of the reservoir. In the high quality sector, the good permeability and continuity of the sands allow a good propagation of the steam and a continuous distribution of temperature around the wells. However, in the medium quality sector, the low permeability sands and the lack of continuity prevent from the generation of a continuous steam chamber that connects the wells. Thus, in SF, the steam is propagated around the injectors, but it results in an unevenly heating of the surroundings of the horizontal producers. On the other hand, HASD produces a local heating around the horizontal producers, but this heat is not propagated to the adjacent horizontal wells.

Figure 18 shows the detail of the incremental RF for both reservoir qualities. In particular for CSS+HASD technology, the incremental RF is 11% for the high quality sector (total RF for CP+CSS+HASD of around 20%) and 3% for the medium quality one (total RF for CP+CSS+HASD of around 6%). With regards to incremental SOR, the maximum value ranges from 4 to 8, when moving from high to medium quality (Figures 16, 17).

To give a more complete view of the potential of each EOR process, a relative comparison of the calculated incremental NPV, referred to the case of no injecting steam, is shown in Table 5. This point is particularly relevant due to the fact that SF requires the drilling of additional wells, whereas the other technologies use the same wells as producers or injectors, depending on the moment of the cycle. To calculate the values in Table 5, all the premises indicated in the section “Evaluation Methodology and Data” have been used. This Table reflects that, despite the CSS+SF allows a higher recovery, it offers the worst NPV of the analysed EOR processes, due to the requirement of drilling additional wells. In the case of the medium quality sector, the impact is even bigger due to the low oil recovery, making CSS+SF a not suitable option for this quality. In this medium quality case, although CSS presents a better NPV than CSS+HASD, the considerably higher oil recovery than HASD provides should be taken into account to extract final conclusions about its potential in this quality.

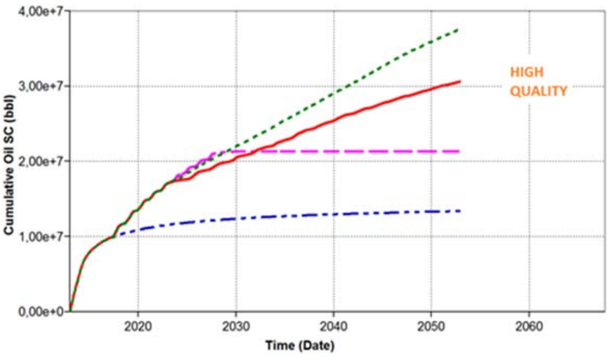


Figure 12. Cumulative oil– HQ sector

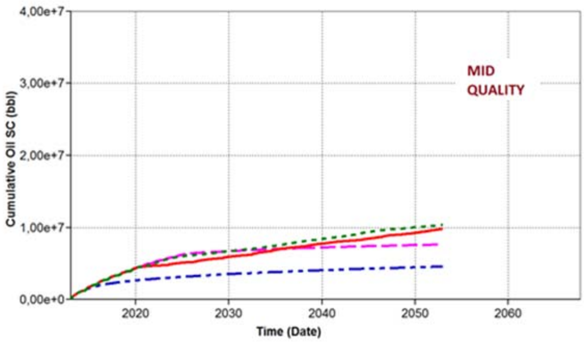


Figure 13. Cumulative oil– MQ sector

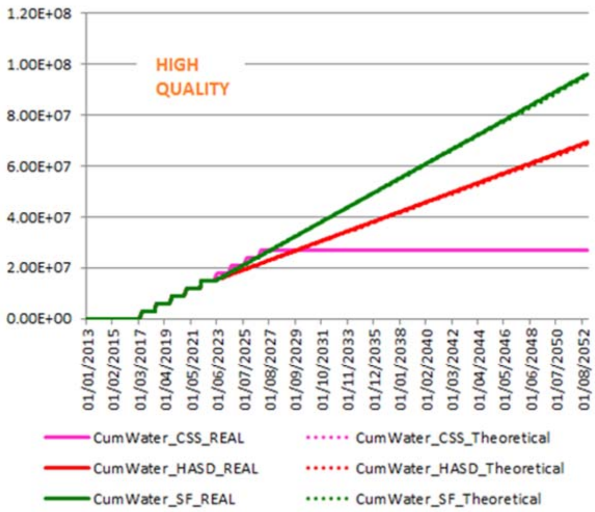


Figure 14. Cumulative injected water – HQ sector

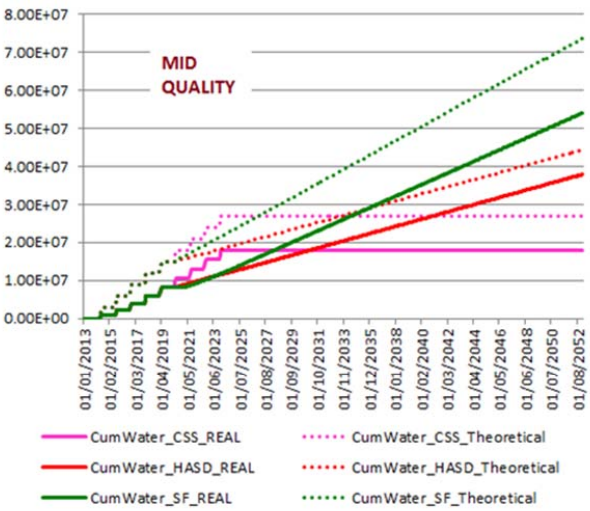


Figure 15. Cumulative injected water – MQ sector

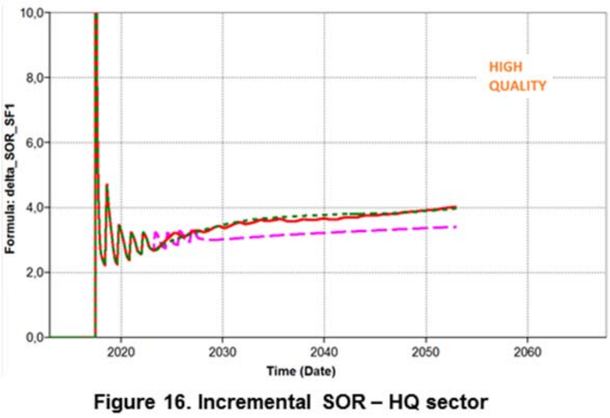


Figure 16. Incremental SOR – HQ sector

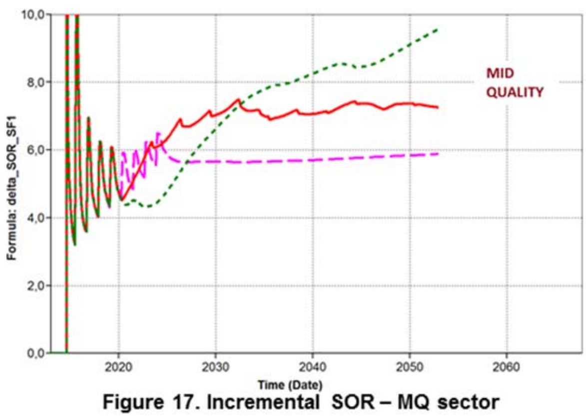
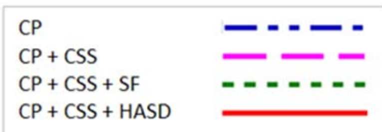


Figure 17. Incremental SOR – MQ sector



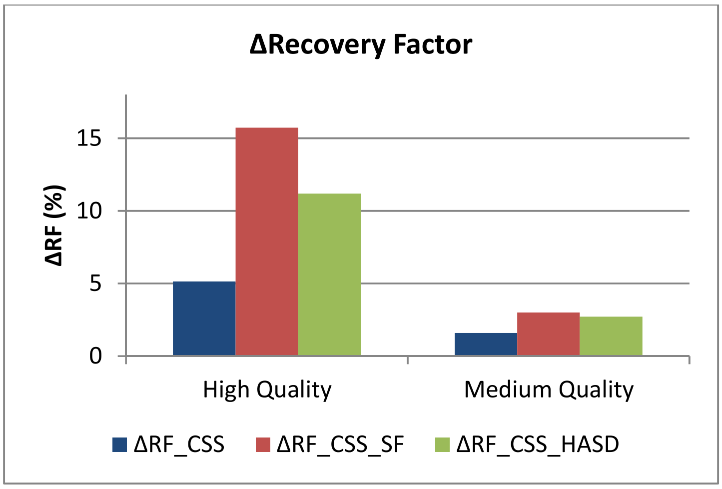


Figure 18. Incremental Recovery Factor

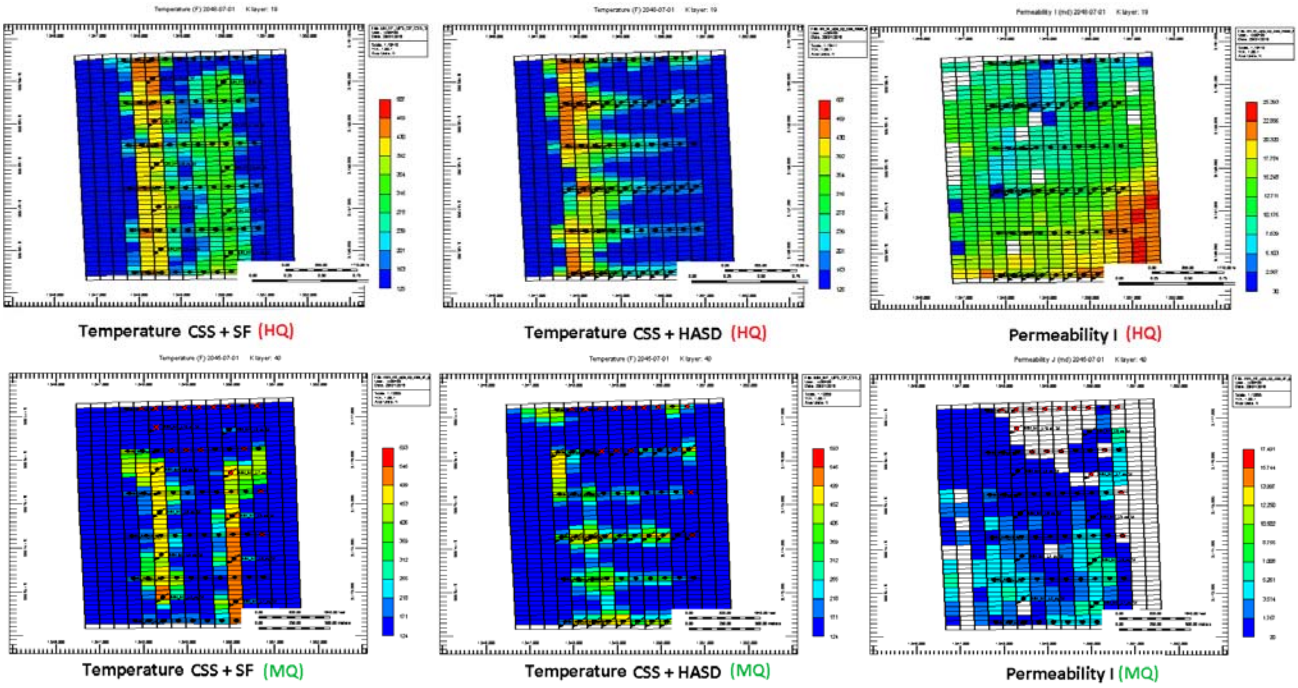


Figure 19. Temperature distribution around producers after 25 years of HASD/SF operation (top: HQ; bottom: MQ)

	NPV - High Quality	NPV - Medium Quality
CP	Reference	Reference
CP + CSS	16%	34%
CP + CSS+SF	13%	-36%
CP + CSS+HASD	17%	8%

Table 5. Relative NPV for the different EOR technologies

Conclusions and Recommendations

This study has allowed extracting the following main conclusions:

- HASD is an EOR technology that presents a high potential, to be applied in high continuity sands in the Orinoco Oil Belt
- HASD avoids the need of drilling additional injector wells (in comparison to SF with vertical steam injection wells) and is relatively easy to be deployed in horizontal well clusters
- It is recommended to apply a number of CSS cycles before starting with HASD
- The sequence of an initial stage of cold production, followed by a CSS stage plus HASD could reach a recovery factor of around 20% STOIIP for a high quality sector
- HASD has a great potential in comparison to traditional EOR technologies, such as CSS and SF (with vertical injectors) for the studied reservoir characteristics of the Orinoco Oil Belt
    - In comparison to CSS (alone), the combination of CSS+HASD always offers higher oil recovery, with comparable incremental SOR
    - In comparison to CSS+SF with vertical injectors, the simplified economical analysis reflects that CSS+HASD, in spite of its lower incremental recovery factor, is more advantageous than CSS+SF
- Low quality areas of the field, characterized by a very low sand continuity, seem not suitable for being developed through clusters of horizontal wells. Therefore, HASD is not recommended

Some recommendations can be extracted from this study:

- For low quality areas, it is recommended to assess other well configurations (e.g. vertical, deviated or multilateral wells), together with their corresponding EOR processes
- For medium quality areas, a more detailed analysis should be carried out, investigating additional alternatives to reduce the incremental SOR, such as drilling additional wells, at the same or different depth. In general, a sensitivity study to determine the optimum spacing among wells should be carried out
- It is recommended to perform an experimental R&D study in HASD to support and fully understand the oil recovery mechanism of this process, to take the maximum advantage of this understading to deploy HASD at commercial scale
- Finally, a very well controlled and successful pilot test should pave the way to the first commercial application of HASD

Nomenclature

CTR	Centro de Tecnología Repsol
CP	Cold Production
CSS	Cyclic Steam Stimulation
EOR	Enhanced Oil Recovery
HASD	Horizontal Alternate Steam Drive
HQ	High Quality
MQ	Medium Quality
Np	Cumulative Oil Production
NPV	Net Present Value
OOB	Orinoco Oil Belt
RF	Recovery Factor
RQI	Reservoir Quality Index
SF	Steam Flooding
SOR	Steam-Oil-Ratio
STB	Stock Tank Barrels
STBD	Stock Tank Barrels per Day

STOIIP Stock Tank Oil Initially in Place
Winj Cumulative Water injected

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