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Improving Recovery by Cyclic Steam Injection in Girasol Oilfield

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ABSTRACT: Girasol is a heavy oilfield located in Colombia and operated by mansarovar energy Colombia Ltd (MECL), the oilfield has been produced for several years and the recovery of 5.09 % is considered to be low compared to similar oilfields for this reason the enhancement of Girasol oil field has been studied and analyzed by applying fundamentals of reservoir engineering and numerical simulation by using geological, logging and production data, the field is a heavy oil field (11.5 API°) with good permeability and porosity average values, it is currently at the middle stage of cyclic steam stimulation with remaining reserves of 40.45 MMbbl but the main problem that is encountered is that the heating radius of the steam is 50 m while the well spacing among wells is 150 m so heat loss is present in the field for this reason a potential of infill drilling is studied to decrees the space between the wells for more steam efficiency, another potential for well pattern improvement and horizontal lateral have been studied for higher efficiency of the process 24 horizontal wells have been implemented in the field and they proved success in increasing recovery during cyclic steam stimulation process despite some of the challenges encountered during landing these wells. Since the recovery from the field was only 5 %, five potentials were studied and simulated up to year 2030, these potentials include changing current CSS amount, infill drilling to decrease well spacing, improve lateral length of horizontal wells, well pattern improvement and converting to steam flooding. These potentials are discussed in details in this report.
Keywords: Optimization Algorithms, Big Bang–Big Crunch, Welded Beam Design problem, Constrained Optimization.

1. Introduction

Girasol is a big oilfield in Colombia and it consists of various layers of unconsolidated soft sand which varies in thickness between 15 to 35 ft. Studies showed some heterogeneities in the reservoir, these include some small faults and lateral and vertical facies change, a feasibility study by a pilot test was conducted to test for the role of horizontal wells in improving the recovery during cyclic steam injection process, challenges and complications were studied and analyzed to optimize the oil production at the lowest cost and implementing an efficient horizontal wells system, the reservoir data are summarized as follows:

- Formation type: sandstone.
- Average formation depth = 1300 ft.
- Gross thickness = 252 ft.
- Net thickness = 154.6 ft.
- Formation pressure=680 psi.
- Formation temperature= 100 F.
- Viscosity of the oil=5000-6000 cp.
- Permeability ranges between 300 to 1500 md with average value of 744 md.
- Oil API gravity = 11.5 API° .
- Porosity ranges between 22 % to 35 % with averae value of 26.78 %.
- The oilfield is divided into 2 parts Girasol Norte and Girasol commercial with 286 acres area, OOIP 83.59 MMbbl and 609 acres area, 173.4 MMbbl respectively. OOIP can be calculated using the following formula:

$$N=7758Ah\phi\,(1-S_w)/B_o \quad (1)$$

Where:

- N = original oil in place (STB).
- 7758 = conversion factor from acre-ft to bbl.
- A = area of reservoir in (acres).
- h = height or thickness of the reservoir usually measured by logs.

- ø = porosity (fraction).
- S_W = connate water saturation (fraction).
- B_{oi} = formation volume factor for oil initially.
- Recovery factor:5.09% which can be calculated be the following formula:

RF = OOIP/recoverable oil reserves (2)

- Remaining reserves= 50.54MMbbl and the recoverable reserves can be calculated by:

Recoverable oil reserves=OOIP*RF (3)

Where:

RF: is the recovery factor.

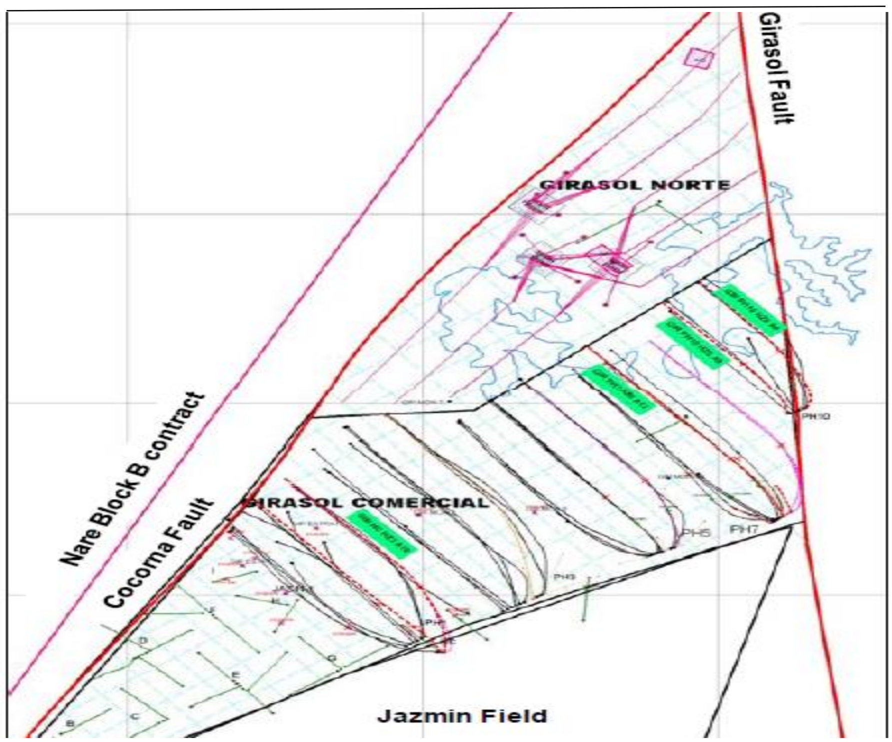

Figure 1 : Girasol oilfield map.

2. Literature review

Cyclic steam injection or stimulation (CSS) is one of the thermal enhanced oil recovery techniques by which oil is assisted to be produced on economical basis. As the name implies steam is injected into the reservoir of interest in cycles and at each cycle a certain amount of oil is recovered, the process is repeated over and over until it reaches an uneconomical level where its application is no longer feasible (Prats, 1985, and Thomas, 2008). Thermal EOR is the most popular and it accounts for 50 % of the market, like other EOR techniques cyclic steam stimulation aims to reduce the residual oil saturation in the reservoir by mainly heating the reservoir in the area close to the wellbore and consequently decrease the oil viscosity for a better flow, in addition, during the CSI process and by some chemical reactions some gaseous components such as carbon dioxide, hydrogen and hydrogen sulfide might form and these gases work as a gas driving mechanism and increase oil mobility for easier flow (Pahlavan et al, 1995). Any cyclic steam process has to go through three stages which are the injection stage in which steam is injected to the reservoir for a period of time until the temperature reaches the amount at which oil starts to flow which is estimated to be 200-300 C and under a pressure of 1 Mpa of injection pressure, and then after an enough amount of steam is injected the soaking stage is initiated in which the well is shut down for several days or weeks in order for the steam to distribute and soak so that it can heat the reservoir and decrease oil viscosity after that the third stage which is the production stage is started in which the production well is opened for production by natural flow until the pressure and the flow rate decreses due to decrese in reservoir temperature then the cycle is repeated until the process is no more feasible.

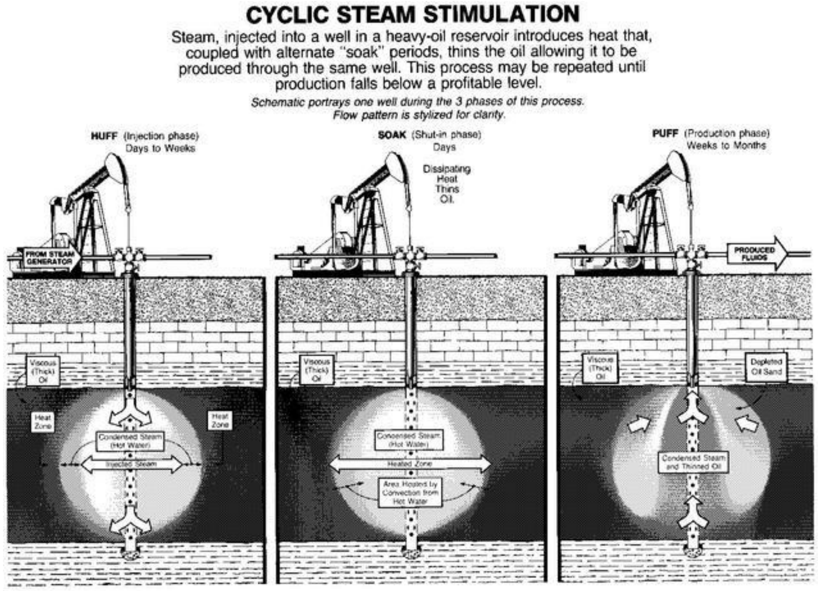

Figure 2: Cyclic steam stimulation stages.

2.1. Changes of Reservoir Properties by CSS and Limitation of the Process

No operation can go 100% smoothly without any losses or obstacles, consequences are always there in any job and in cyclic steam stimulation as well, the change of the temperature of the reservoir due to the injected steam causes expansion of the grains of the rock due to the high heat , in addition to temperature change, change in stresses such as shear and effective may produce deformation to the rock and can therfore cause hetrogenity in the reservoir in terms of permeability and pore volume. (Scott et al., 1994).

Because of the infusion of hot steam can cause shear dialition and in this way the attributes of pore shake would likewise change since their volume is expanded (Wong et al., 2001). This volume enlargment will likewise cause a penetrability change which will along these lines influence steam and hydrocarbon development in the repository. It is avowed that the most critical effect of enlargement because of CSI is an expansion in the porousness to water. This expansion of the pore space is caused by dilatation and portability of the infused liquid. Besides, buildup of high temp water from steam in front of the steam front pressurized the repository. In addition, CSI prompted relocations in the repository because of widening and the recuperation of these unique conditions amid generation activities is a state of supply of store drive activity.

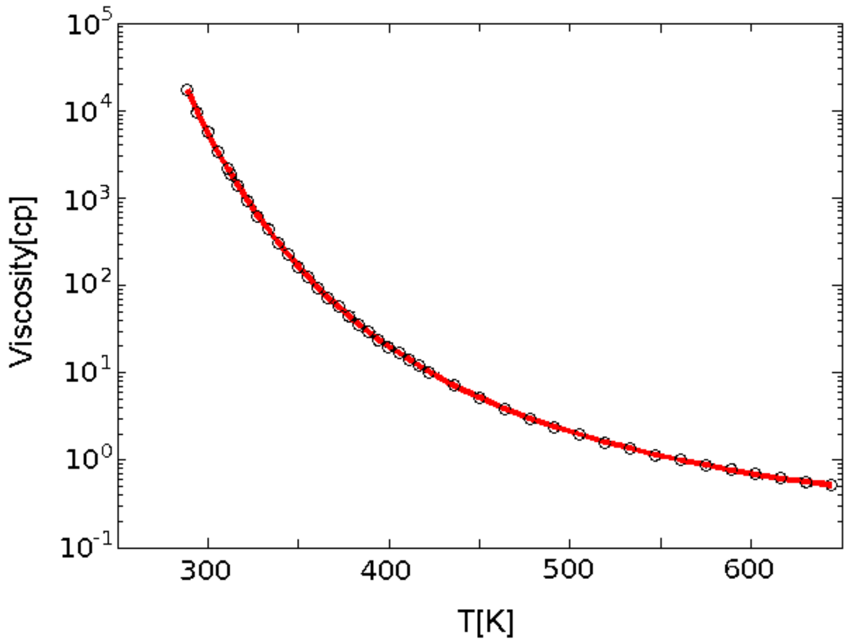

Figure 3: Oil viscosity vs Temperature curve.

2.2. Comparison Between Steam Flooding and Cyclic Steam Injection and Limitations to the Process

Steam injection is classified into two categories one is cyclic and the other is steam flooding and this section will focus on the main differences between these two types of thermal recovery and also the limitation and challenges encountered while applying such kind of EOR techniques such as depth and reservoir thickness limitations. In cyclic steam and as was mentioned earlier steam is injected through the same production well for a couple of weeks or months and the oil surrounding this injected well will be heated and its viscosity is decresed (Kumar et al, 1998) whereas in steam flooding injection and production wells are two different wells as shown in Figure 4, steam is first injected to through the injection well and it will move towards the oil to physically displace it, as steam moves it looses some of its energy in the form of heat therfore it condenses into water which will provide a driving mechanism to push the oil into producing well, and as its name imply flooding a reservoir means a continuous injection in contrast to cyclic injection which is done in cycles therefore much larger amounts of steam is used in flooding than in cyclic ingection so flooding obviously cost more but on the other hand it helps to recover larger amount of oil, thermal recovery is envoronmentally friendly because steam does not have any threat on the environment since it just condenses into water.

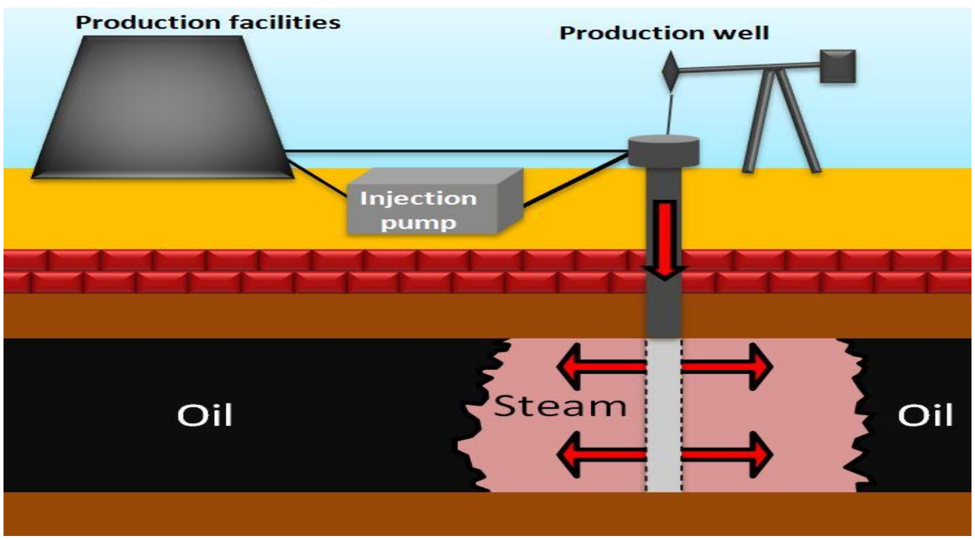

Figure 4: Cyclic steam stimulation.

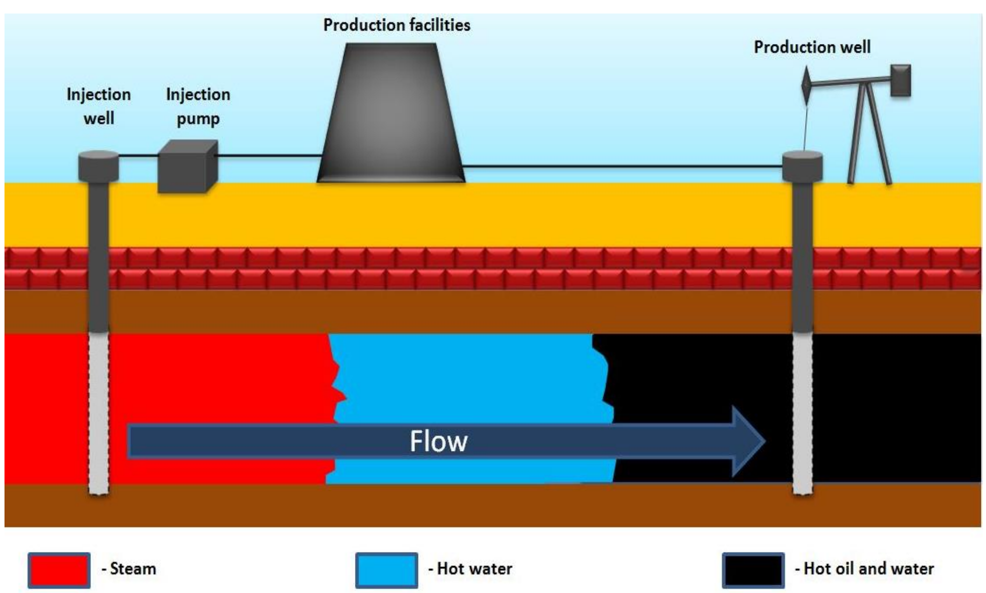

Figure 5: Steam flooding.

A number of challenges migt arise during the process and they are as follows:

- When steam cools it condenses into water which forms emulsions with the oil. This adds extra operational costs since we have to separate these fluids, a dehydration facility is needed either on the surface or downhole separators to separate these fluids and send a free water oil to the pipelines for shipment.
- In reservoir that are susceptible of structure rearrangements due to tectonic actions, huff and puff can be a damaging factor to the well structure downhole this would put lives of workers under risk, equipment also can be damaged in these reservoirs therefore precautions must be taken before applying steam injection to such reservoirs because it might complicate the problem instead of solving it.
- Economic challenge also play a role in steam injection , at the beginning of the injection process each barrel of steam is able to recover 30 barrels of incremental oil but as the process continue its efficiency decreases with time until it reaches a level where it is only able to recover 0.2 barrels of oil and since the cost of one barrel of steam ranges between 20 to 30 dollars the process is no longer economical and the well is shut until oil prices gets higher or another feasible method is applied(Kumar et al, 1998).

A number of limitations of the thermal process is there as well and the first one is the depth at which the reservoir is located because if the depth exceeds 3000 ft then the efficiency of the process will significantly drop because of heat losses due to the high depth so by the time the steam reaches the desired depth it will have lost its heating effect so it cannot heat the oil and decrease its viscosity, another concern when talking about steam is the reservoir thickness.

2.3. Buckley Leverett Theory and Energy Loss

Buckley's theory also called fractional flow theory is basically used in water flooding reservoirs to estimate the rate of movement of the injected water in the porous medium, it also determines the fluid front position at different times, fluid front is defined as the contact point between two immiscible fluids when the displacing is sweeping the displaced, this theory is based on some assumptions and they are as follows:

The flow is horizontal (no inclination).

The displacing and displaced fluids are immiscible.

Gravity and capillary pressures are not significant.

This theory can be used in steam flooding as well but it should be noted that the difference between water flooding and steam flooding is that as steam moves in the reservoir it loses some of its energy and water will start to condense gradually, for this reason we have also to consider energy conservation equation to account for the losses throughout the system, as a result as long as energy loses are considered Buckley's theory can be applied to steam flooding as well. The equation states that the saturation of water is a function of time and saturation because as water moves in the reservoir its fractional flow and therefore saturation increases. The final form of Buckley's Leverett equation can be written as:

$$-\frac{afw}{ax} = \frac{A\emptyset}{q}\,\frac{aSw}{at} \tag{4}$$

Where:

- Fw: Water fractional flow for displacing fluid.
- Sw: Water saturation.
- A: Area of flow.
- q: Flow rate.
- Ø: Porosity.
- X: Is the dimensionless position.
- T: Is the dimensionless time.

Energy balance equation must be conducted to calculate the total heat loss throughout the system starting from the surface and across the tubulars down to the reservoir these losses must be equal to the total energy provided by the source. The biggest loss can be seen in the reservoir to the rocks there, that is why reservoir depth is a concern in steam injection because if the reservoir is not thick enough, heat will be lost to the neigbouring formation leaving the formation of interest unheated, the total energy loss in the system can be determined by conservation of energy equation:

$$\frac{\partial}{\partial t}((1-\emptyset)U_r+\sum_{j=1}^{np}\emptyset\rho jSjUj) + \nabla.\sum_{j=1}^{np} hj\,\rho jUj + \nabla.(-\alpha\nabla T) = qh \tag{5}$$

Where:

- Ur: Is the internal energy of the rock.

- Uj: Is the internal energy of phase j.
- Hj: Is the enthalpy of phase j.
- ᶏ: Is heat conductivity.
- Qh: Is the heat source.
- ((1- ø)Ur+$\sum_{j=1}^{np} \o \rho j S j U j$)= the total energy of the grid block.

3. Girasol Field Stratigraphic Distribution

The stratigraphic distribution shown in figure 3 shows a monotonous series of upper tertiary continental sand _shale interbedding unconformably overlying a pre-tertiary igneous metamorphic basement.

The main reservoir of the average thickness of about 450 ft and of the a friable fine to coarse grained sandstone is named A zone. In Figure 5, the sandstone layers occupy a 35 ft thickness only and the sand interval is saturated with oil and/or salty water.

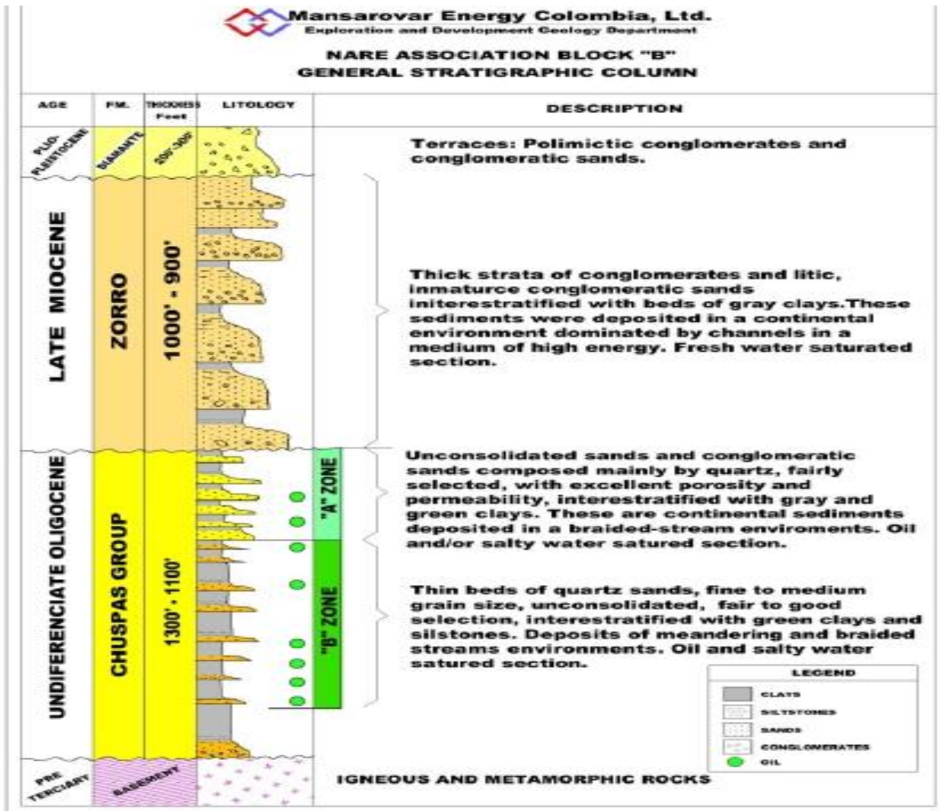

Figure 6: Stratigraphic column.

The Field is limited by a fault to its west, the fault is called Cocorna fault and to its east by girasol fault, the reservoir channels are given names as shown in Figure 7 they are named from sand 9 which is the deepest layer to sand 13 which is the shallowest, the significant characteristics of the sand in the field is that it is unconsolidated sand, girasol oil field has gone through huff and puff process which we will discuss in the next section.

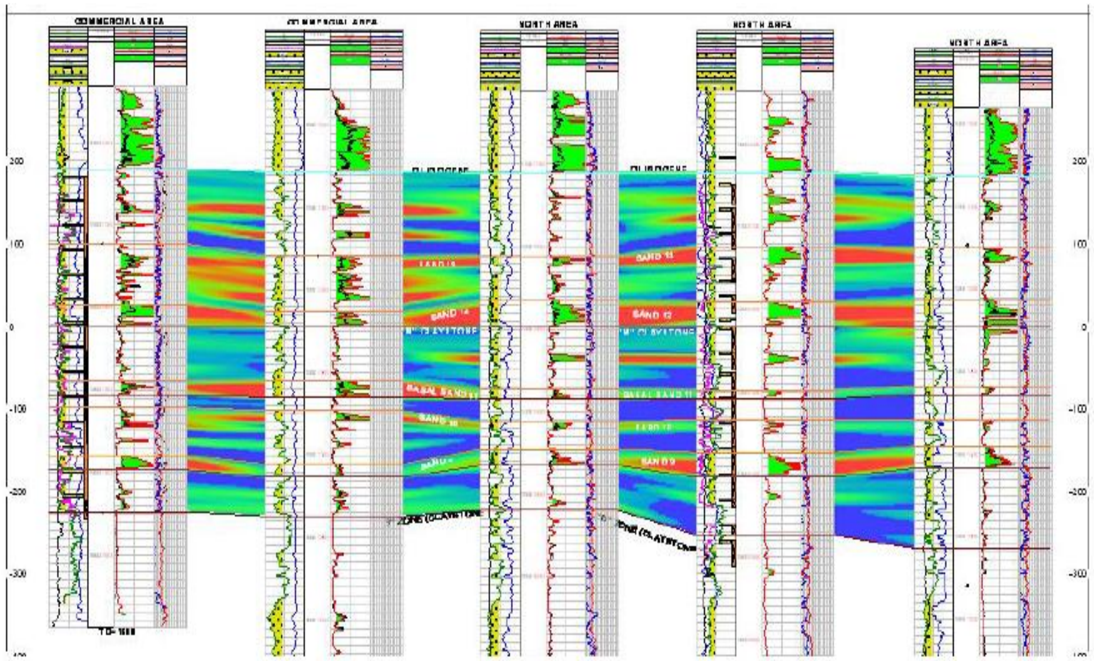

Figure 7: Stratigraphic cross section to show sand layers.

As was mentioned earlier steam is injected through the same production well to reduce oil viscosity, studies showed that the inclination of the wells in Girasol neighboring oilfields like Jazmin oilfield is approximately 30 degrees, these low inclination wells are low cost to drill but they can only deliver 40 bbl/day by primary recovery and 100 bbl/day after steam injection, while horizontal wells have proved a higher recovery factor and production rates , they have also proved a more efficient heat distribution throughout the reservoir as well as a more efficient drainage, for these reason and despite the high cost of construction horizontal well Mansarovar has decided to study the feasibility and applicability of horizontal wells in Girasol field and this can be seen from the development plan of the field in the next section.

3.1. Development Plan of Girasol Oilfield

From the first stages of Girasol developing plans the plans included executing horizontal wells for the application of huff and puff process. Before starting any process a pilot test is applied to a small area of the field to test how successful is the process before risking the whole field and that also was applied to Girasol field, the pilot test included drilling two horizontal wells with two multilateral fishbone wells but one of the horizontal and fishbone wells was geosteered by using bed boundary mapping technology, the length of the horizontal section was 1690 ft with rate of penetration of 1100 ft/hr, the wells were placed in the target that was 18 ft thick.

After evaluating the pilot test, Mansarover decided to extend the project by implementing horizontal wells to the field as shown in Figure8, the horizontal wells are laterally parallel with an average spacing of 490 ft, the strategy includes 9 horizontal wells by pad basically three wells on top of each other at three different locations which adds up to 9 wells, each set of the three wells is designed to drain a reservoir as shown in Figure 8.

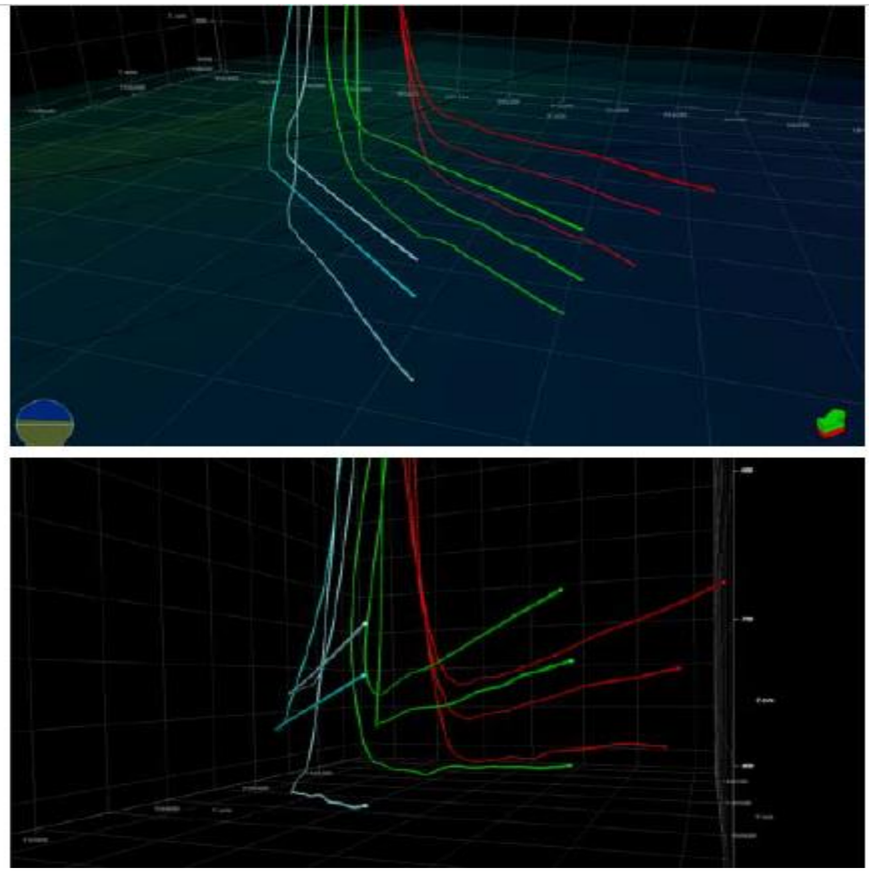

Figure 8: Horizontal wells at the same pad in three target sands.

3.2. Challenges of Horizontal Well Placement in Girasol

- placing wells precisely in the target: since the wells are horizontal, well trajectory and BHA designs were such complicated that they had to hit the target reservoir precisely, furthermore, setting the casing shoe at the correct angle (inclination) to avoid any challenges that might occur in the next section required drilling aggressive directional trajectories, in addition, changing angle from 0 to 90 degrees with the bit of 4 1/2 inch diameter required a dog leg severity of about 8 degrees/ft, so the most cost effective method under this scenario was to use mud motors.
- casing shoe placement: due to poor consolidation of sand in the reservoir casing could dive into the soft unconsolidated sand because of weight of the casing, this might cause the well to hit and enter the next shale interval and loosing the required inclination. There might be a solution which is to increase DLS but this will complicate the completion process for this reason and for a better casing and cementing integrity the casing shoe was placed within the previous shale section 1 to 2 ft above the target sand.
- accuracy in positioning wells to avoid interference among them: since each pad in the reservoir contains three sets of lateral parallel wells and each set has three wells on top of each other which adds up to 9 wells, positioning these wells in a manner that guarantee a good separation was required to avoid collision and interference between the well in the reservoir and to ensure an effective drainage as well.
- Geological uncertainties: Analyzing the geological models which was created at the beginning of the development plan mostly relied on some simple seismic studies and some offset wells drilled at the boundaries of the field, the studies showed the presence of some geological uncertainties such as faults, lateral and vertical facies heterogeneities and shale layers across the reservoir. To decrease such uncertainties and instead of the geosteering techniques that were not successful to identify these changes in the reservoir, a more reliable approach had to be used. The approach

basically rely on logging while drilling and software that allows immediate decision making during drilling to optimize the placement of the horizontal wells accurately in the sand reservoir.

- Drilling performance: some precautions had to be taken into account to increase the drilling performance by implementing some practices like:

1. Reaming up a section of the hole to avoid accidental sidetracking
2. Low mud flow and trying to enhance bottom hole assembly as well as optimizing total flow area TFA to achieve predictable steering response.
3. A MWD telemetry system which is able to transmit a big amount of data is required in order to avoid limited ROP for obtaining data the logging system should be able to log up to 1200 ft/hr while drilling.

- Optimizing well placement:

According to (Bashbush,2008), the maximum production for huff and puff technique by using horizontal wells can be achieved by placing the wells at the bottom of the reservoir, therefore, an accurate placement of wells is critical in such a case and to decrease uncertainties associated with horizontal drilling. Bed boundary mapping technique was suggested to be used in this case, this technique helps set the wells at the correct position required for the success of the process, the mapping system enables to understand the reservoir in a better manner by analyzing the geometry around the borehole.

3.3. Results after horizontal wells placement

As shown in Figure 9 the number of horizontal wells placed in Girasol oilfield using the geosteering and bed mapping techniques which, helped to optimize well placement process, the average net pay was 96% and the results were as follows:

- during landing the horizontal wells there were no targets missed and casing shoe was at the desired inclination, no casing shoe was placed at low inclination either.
- The plan was to drill horizontal well of 12 1/4-inch vertical section and 8 1/2-inch horizontal section and to the shallow target reservoir 1100 to 1600 ft TVD. The process was successful.
- Accidental sidetracks were eliminated in girasol field by conducting the best drilling practices and therefore there was no need to obtain deep directional data.
- As mentioned earlier the production from neighboring fields was 40 bbl/day and 100 bbl /day for primary and after steam stimulation respectively, while after implementing the horizontal well plan in Girasol field the recovery reached 100 bbl/day for primary recovery and 700 bbl/day after steam stimulation.

So, most of the problems in the field were eliminated and despite the high cost of implementing horizontal wells at the beginning of the project, it turns out to be economical as it its succeeded in achieving a higher recovery amount compared to low inclination wells.

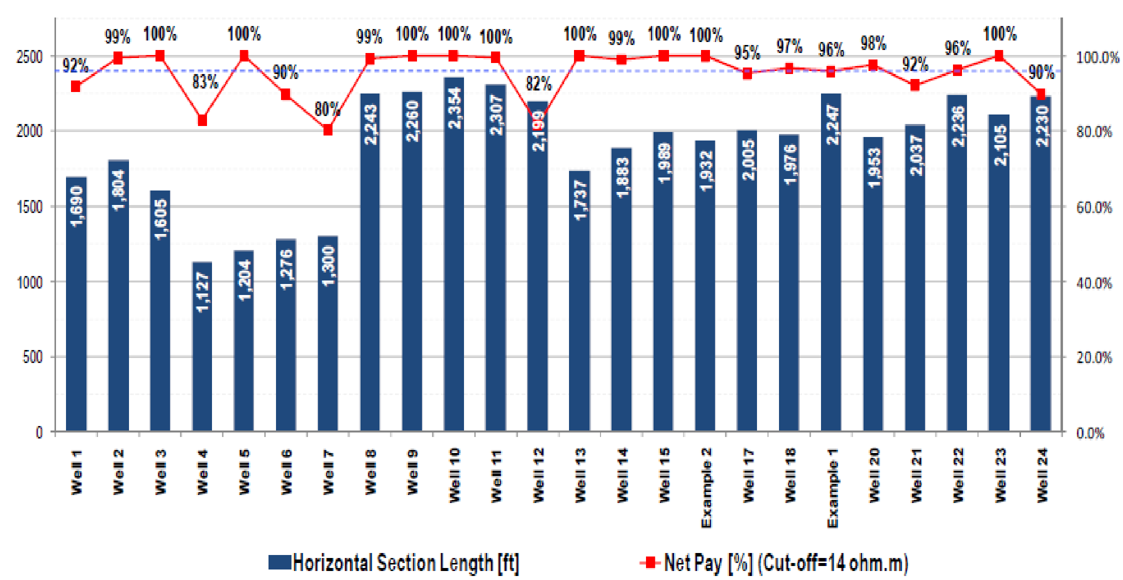

Figure 9: Horizontal section length vs net pay.

4. Analysing and Improving CSS in Girasol Oilfield:

In girasol the well spacing is too high for an effective huff and buff process the spacing between the wells is about 150 m but the effective heating radius of steam is 50 m and here comes the importance of infill drilling, because large amount of hydrocarbons will remain unexploited especially in the areas between the wells. Infill wells are wells drilled among existing wells to decrease the space between an injector and a producer and increase the continuity between wells, however, these wells must be drilled in the right position to achieve an ultimate recovery value, besides drilling infill wells, dead producers can also be converted to injectors and it should be noted that producers should always be drilled in areas in the reservoir where stream line density is low and saturation of hydrocarbons is high.

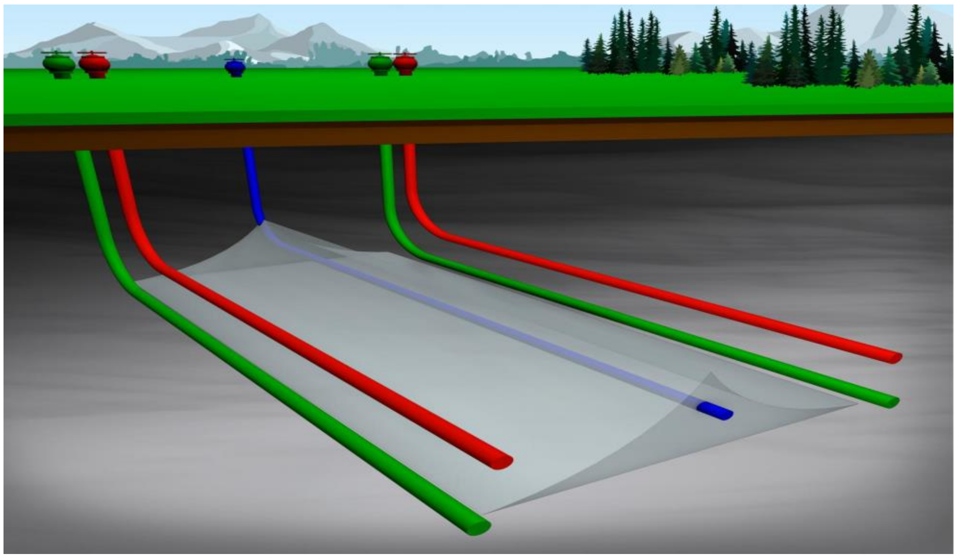

Figure 10: Infill well.

Five simulations for introducing infilling horizontal wells with lateral lengths of respictevely, 200 m, 300 m, 400 m, 500 m, and 600 m were run as shown in Figure 11, the results show an increase in cumulative oil but a decrese in the cumulative oil per unit lateral length, so to utilize horizontal wells effictively the lateral length of infilling horizontal well is recommended to be 400 m.

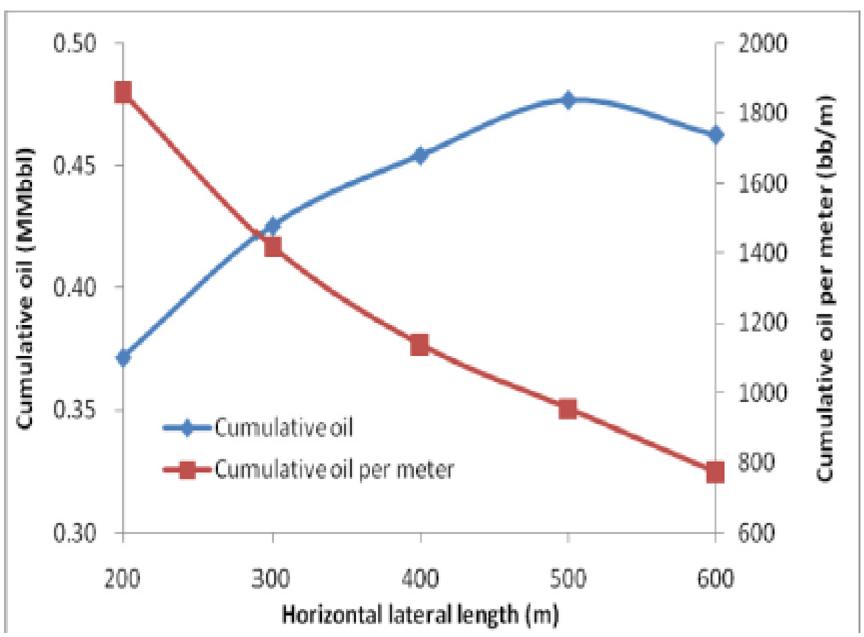

Figure 11: Cumulative Oil and cumulative oil per meter in 6 CSS cycles. (Pang et al, 2015).

4.1. Potential for Well Pattern Improvement

Due to the increased well spacing of horizontal wells in the field, thick areas with high oil saturation exist in girasol oilfield especially in the transition areas between the vertical and horizontal wells and most of these tranition zone lack well pattern control, for this reason a high potential for well patern improvemrnt is suggested, for example a thick sand layer in girasol field is called A 13 layer, its thickness is approximately 13.51 ft with high oil saturation and reserves, however, the recovery factor there is only around 2 % which shows a high potential for well pattern enhancement in the field, the wells must neither be dense so interference between them might occur nor too sparse so areas between wells remain unswept which results in low recovery, therefore, a suitable well pattern must be proposed in accordance with the reservoir characteristics which at the same time can assure optimum production from the reservoir. The south part of girasol field develops by vertical wells, the vertical wells model is shown in Figure 12. The model shows a nine spot well pattern with original oil in place (OOIP) 12.8 MMbbl.

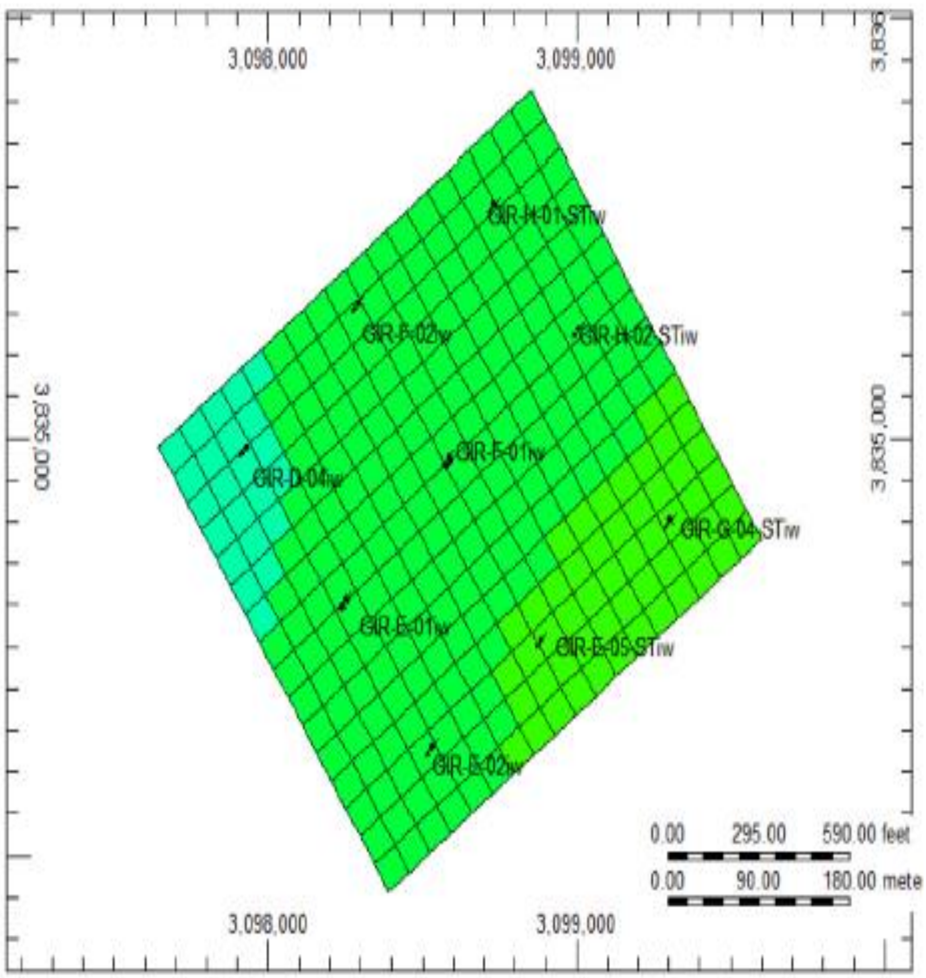

Figure 12: 9 spot vertical wells pattern sector model, (Pang et al, 2015).

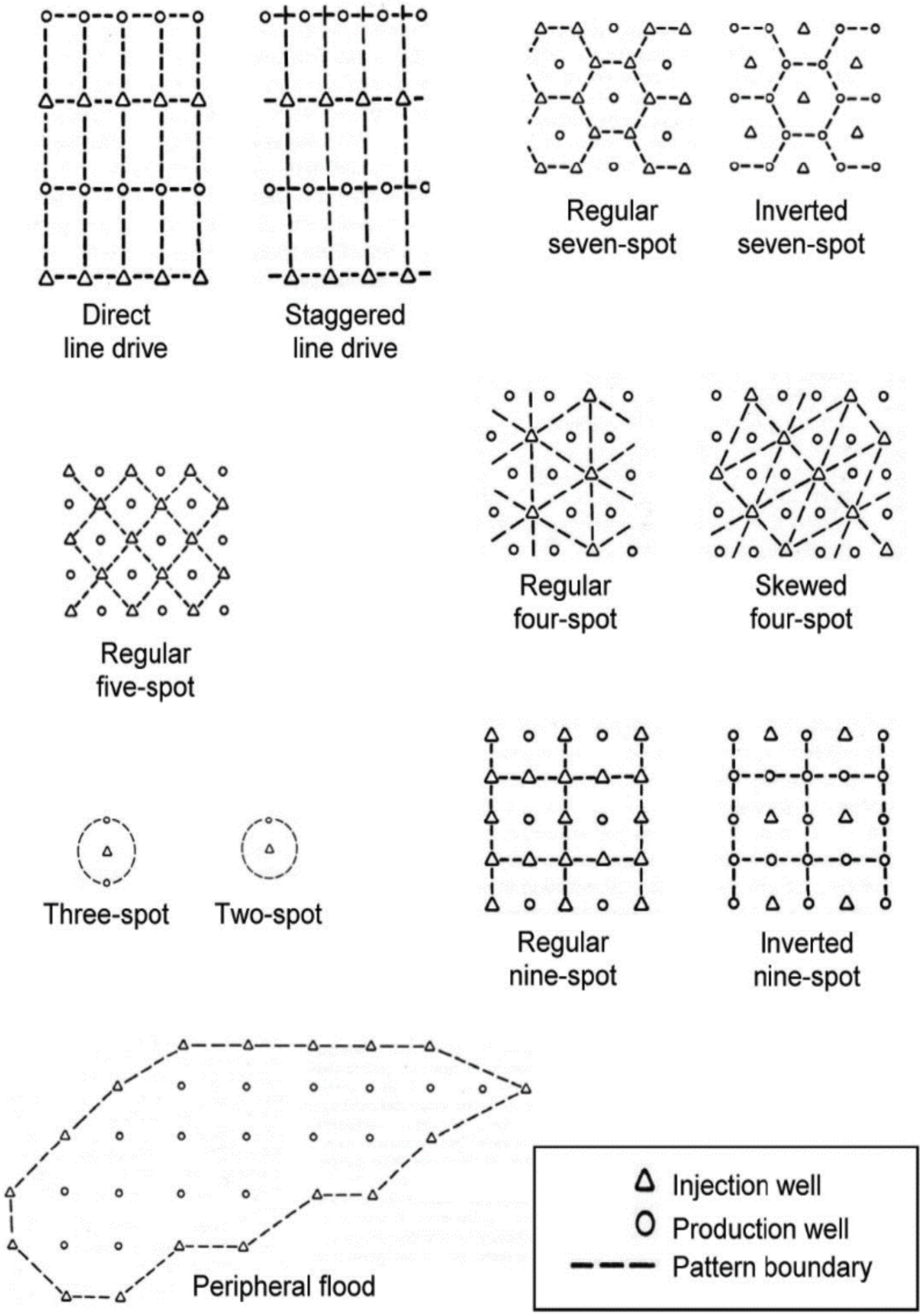

Figure 13: Different well patterns, (Courtesy PetroWiki).

4.2. Potential for CSS Parameter Optimization

By comparison of horizontal wells CSS parameters between Girasol oilfield and similar oilfield XZ South 3, it is found that cyclic steam injection every meter for this oilfield is less than 50% of XZ South3, and that every-meter cyclic cumulative production is less than 65% of XZ South 3, the comparison between injected steam per meter and produced oil per meter are illustrated in Figure 13 and Figure 14 respectively.

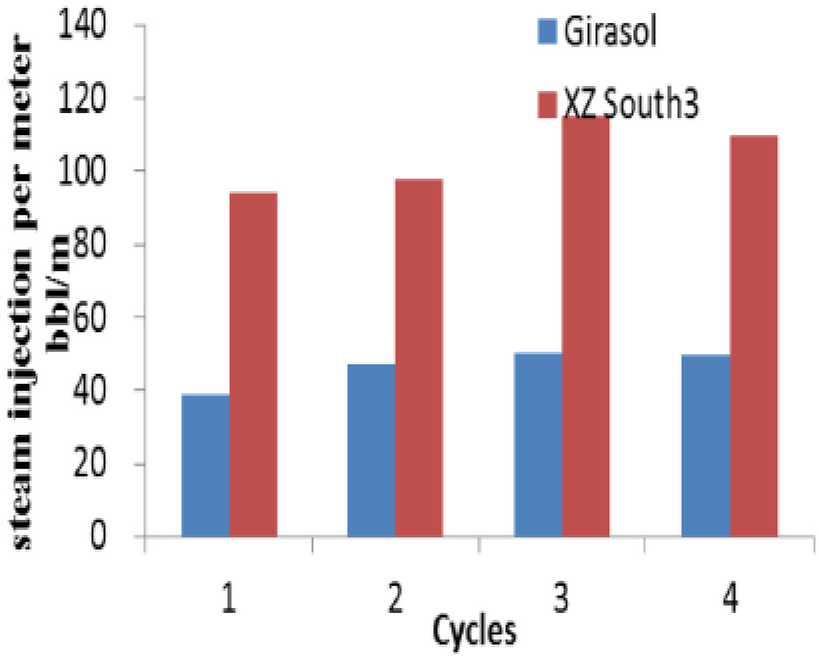

Figure 14: Comparison of Injected Steam per Meter, (Pang et al, 2015).

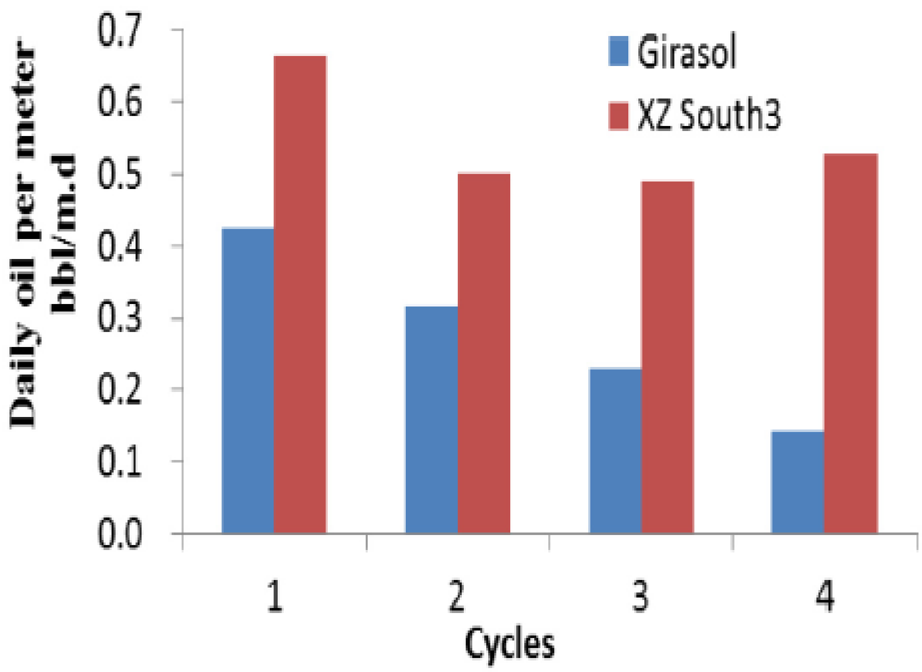

Figure 15: Comparison of Daily Oil per Meter, (Pang et al, 2015).

Vertical wells CSS parameters of girasol was compared with another similar oilfield called YQ3, the steam intensity for girasol was found to be considerably low, it is 21.7 % of that of YQ3. This is an indication that the low steam amount and intensity are direct reasons for inefficient heating of the oil and production. Thus, the current steam parameters under current well pattern have to be enhanced to optimize the efficiency of the production process. Figure 15 illustrates the increase in oil recovery when increasing the amount of steam to 1.5, 2, 2.5 and 3 times of the currently used steam amount.

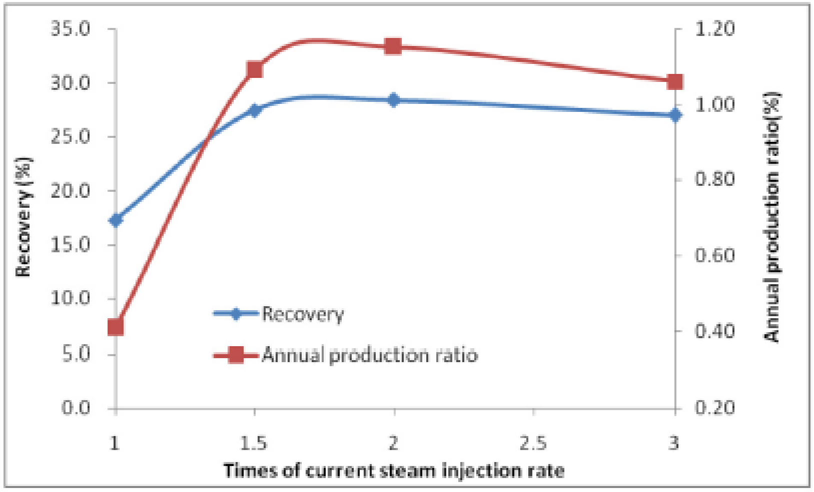

Figure 16: Recovery and annual recovery vs increasing steam rate, (Pang et al, 2015).

4.3. Potential for Converting to Steam Flooding

Currently, the horizontal lateral is as long as 600 meters and there are severe limitations for the current CSS technique to improve the producing performance. Steam flooding is considered to be a method to significantly increase the recovery of heavy oil reservoirs and Girasol oilfield meets the qualification criteria for steam flooding selecting. There is a high potential for Girasol to undergo steam flooding.

5. Results Esults of CSS and Simulations up to Year 2030

Different production schemes are studied for comparing production difference for different cases and parameters, the production schemes are as follows:

Scheme V-1: shows the production with the current CSS parameters and well pattern.

Scheme V-2: shows the production after increasing the steam amount two times of its current value without changing the well pattern.

Scheme V-3: shows the production after increasing steam amount and changing the well pattern from 5 spot to 9 spot patterns be converting the center well into injection well.

Scheme V-4: shows the production after drilling five infilled wells with using the 9 spot patterns as well as the optimized stem amount.

Scheme V-5: drilling four infilling wells, using the 9-spot pattern and converting the cyclic steam to steam flooding.

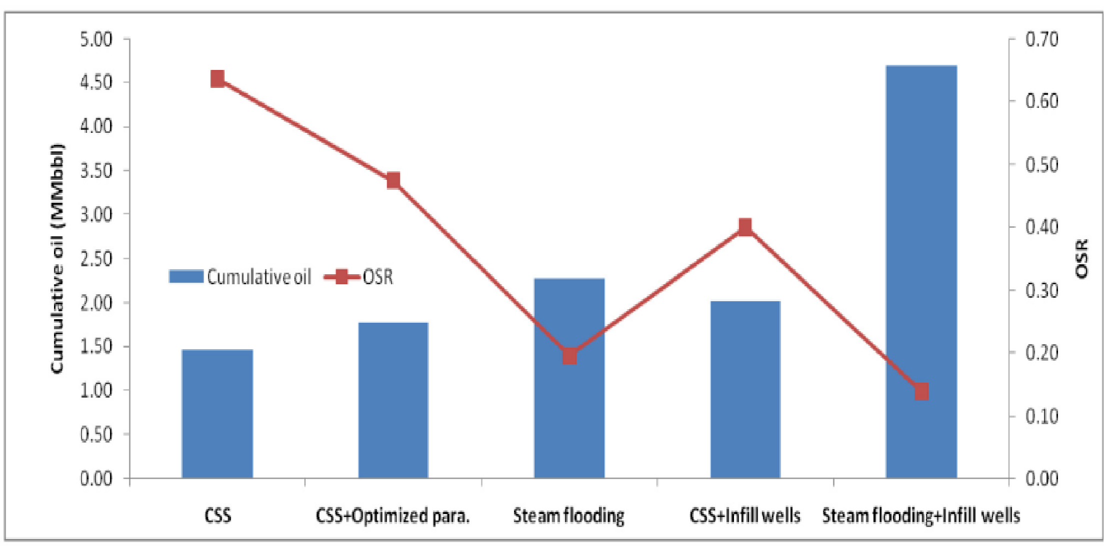

Figure 17: production performances from worst to best, (Pang et al, 2015).

5.1. Production Scheme Analysis in Horizontal Well Area

As in the vertical area, the production in the horizontal area is studied as well, seven schemes were simulated up to year 2030, these schemes are:

Scheme HZ-1: cyclic steam stimulation with the current amount and well pattern used in horizontal wells.

Scheme HZ-2: cyclic steam stimulation with using optimized steam amount which was found to be two times of the current amount under current well pattern.

Scheme HZ-3: convert steam injection to steam flooding with the optimized amount of steam and under current pattern.

Scheme HZ-4: drill two horizontal length with effective horizontal length, and then inject steam with the optimized amount.

Scheme HZ-5: like in scheme 4 drill two infill wells with effective horizontal lateral length and inject steam with the optimized amount (2 times of the current amount) then produce by steam flooding.

Scheme HZ-6: infill 8 vertical wells between the field's horizontal wells with the enhanced spacing and then use cyclic steam stimulation with the optimized amount.

Scheme HZ-7: infill 8 vertical wells between the horizontal wells of the field, then we use steam flooding using the 8 vertical wells as injection wells for the steam with optimized parameters.

The schemes discussed above are illustrated in the following figure:

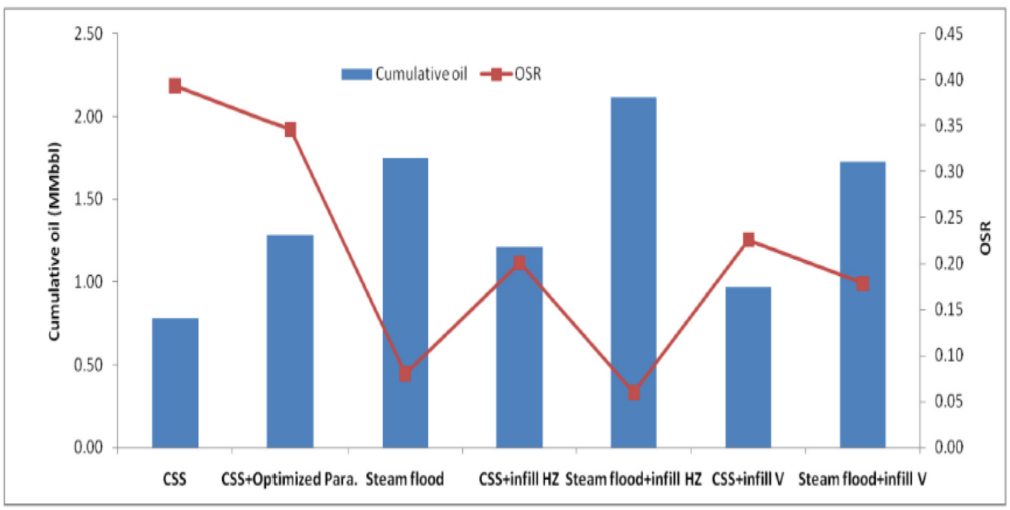

Figure 18: cumulative oil and OSR up to 2030 (Pang et al, 2015).

The chart shows that steam flooding is much superior than CSS in horizontal wells no matter if infill drilling is there or not, furthermore infill vertical well does not affect how much oil is gained by steam flooding, so the amount of oil produced will not be increased by infill vertical wells. With optimizing current CSS parameters the production scheme shows that oil production can pe increased by 65 % more than when using current steam parameters, so there is a good potential for optimizing current steam parameters to increase the recovery.

5.2. Full field EOR Design

Combining the schemes both for horizontal and vertical wells, the sector model is applied into whole field, seven designs are made and simulated up to 2030 with optimized CSS parameters, the 7 base designs are:

P1: CSS with current parameters (amount and rate).

P2: CSS with optimum steam parameters enhancement.

P3: converting to steam flooding in areas where the pressure is low and using CSS for other areas.

P4: converting CSS to steam flooding in the whole field.

P5: some oil is very hard to drain at the edges of the layers and between the wells under current well pattern, therefore this base design suggests improving the well pattern with using CSS.

P6: current well spacing is 150 m and heating radius is only 50 m so there is a huge amount of oil can't be recovered especially between the horizontal wells for this reason this base design suggests drilling infill wells to decrease the well spacing and recover the undrained oil between the wells.

P7: converting to steam flooding with infill wells.

The results of the simulation of these designs are illustrated in the Table1.it can be seen from the table that the highest production amount can be achieved by steam flooding and infill wells (scheme P7), but P7 is not that much better than P4 in terms of cumulative oil production, therefore infill wells shouldn't be implemented urgently in the field if steam flooding is used.

Comparing P1 and P2 schemes we can see the t recovery by CSS is only around 12 % while recovery by steam flooding is approximately 74 % so converting to steam flooding is a promising enhancement for the oilfield however its implementation feasibility must also be studied.

Table 1 : Simulation Results for Fullfield EOR Design to Year 2030, (Pang et al, 2015).

	P1	P2	P3	P4	P5	P6	P7
Cumulative oil (MMbbl)	31.76	35.40	42.27	112.40	46.03	62.57	117.62
OSR	0.68	0.48	0.32	0.14	0.56	0.52	0.12
Recovery (%)	12.36	13.78	16.45	43.73	17.91	24.34	45.77
Annual production ratio (%)	0.43	0.52	0.67	2.28	0.76	1.14	2.40

6. Conclusion

Girasol is a heavy oilfield with high porosity and permeability, it is in the middle stage of CSS, but the recovery factor of 5 % is considered to be low compared to similar reservoirs, the reason is attributed to poor initial plan for the field.

Mansarovar then proposed a project to enhance the production and recovery factor by first implementing horizontal wells all over the field after the success of the pilot test that they conducted.

Well spacing was not effective in the field, it was much larger than the heating radius of the steam, therefore infill wells had to be implemented to increase the recovery.

Sector model analysis showed that increasing the amount and rate of steam to two times of its current value will result in much higher production, decreasing the lateral length to 400 m result in higher production as well.

The promising potential for this field is converting CSS to steam flooding under current well pattern will result in recovery up to 44 %.

7. Recommendation

Girasol was compared to another field of the same type called XZ South3, it was found that the cumulative production in Girasol is 65% less than XZ South due to low amount and intensity of steam in Girasol, this shows the poor initial development of the field and such problems could have been detected earlier before the field has reached its 6th steam cycle.

Well spacing is known to be a concern in any flooding process, but in Girasol the well pattern was designed such that large amount of oil is left (unswept) between the wells, steam flooding is also known for its higher sweeping efficiency and recovery so it could have been applied to the field since the first or second cycle.

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