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Evaluation of steam injection scheme applied to the well MFB-617, SW-SAGD first pilot in the Faja Petrolífera del Orinoco.

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Abstract

Petroleos de Venezuela SA, began operations completion of the first SW-SAGD pilot in the Faja Petrolífera del Orinoco (FPO), specifically in the sand TL reservoir MFB-15, Field Bare. This well was selected as a pilot, due to excellent petrophysical characteristics in the area and the mechanical conditions.

The first SW-SAGD pilot has a long period of implementation and evaluation, managing well production increase of 80 to 300 BNPD. Projections indicate that by 2012 will increase the recovery factor from 14 to 30% in the affected area by the steam injection.

The completion scheme used in this first pilot involves the use of two strings, a string of injection whose main objective is to bring steam to the site ,generating heat energy needed to heat the oil and reduce its viscosity. This string passes saturated steam at the end of the horizontal section of the well MFB-617, forming the steam chamber. The second string produced fluids heated by steam with the aid of artificial lift equipment, specifically, mechanical pumping.

Through numerical simulation were carried out new injection schemes, to optimize the recovery factor for the development of new SW-SAGD pilot projects. These new scenarios were visualized through the applying of sensitivities in the steam injection into the horizontal section of the well, considering the best choice channels to flow into the reservoir, the current existing field information and the efficiency of lifting equipment, preventing the steam lock phenomenon.

The results show that injecting steam into the middle and end of the horizontal section of SW-SAGD pilot increases the heated area by the steam chamber, translating these results on optimizing recovery factor. This paper presents a steam injection scheme to apply in future SW-SAGD wells Bare Field, Faja Petrolífera del Orinoco.

Introduction

The SW-SAGD process consists in to inject steam in the toe of the horizontal well, through the insulated injection tubing, and simultaneously the heated fluids are produce in surface with the help equipment of artificial lift, specifically rod pump. In the SW-SAGD, when start the steam injection, with the time, the steam chamber will develop, and the interface steam-oil will drain by gravirity effects.

The first pilot test SW-SAGD in the Faja Petrólifera del Orinoco was developed in the well MFB-617, the well is horizontal and it's completed in the sand TL reservoir MFB-15 in the Bare Field. It has 6000 feet of depth and the horizontal length is 1500 feet. The results obtained during the development of this pilot project demonstrated the increase of the recovery factor of 14% to 30% in the area of steam affectation. Further, three big zones were determined: heat zone, zone of transition and zone of temperature low. The length horizontal of 1500 was selected with the optimal length horizontal to control the loss of heat in the steam.

The Bare field started production in 1980, nowadays the produced reserves in this field are 680 MMBN, the primary recovery factor is 14%. The SW-SAGD technology will be one of the methods of thermal recovery to apply in the Faja Petrolífera del Orinoco, so is very important to do the evaluation of the scene of steam injection applied during the development the first pilot project SW-SAGD in the Orinoco oil belt, to determine the optimal injection scene and reduce the loss of heat, ensuring the efficient of the process.

Heat transfer mechanisms

The heat is defined as a form of energy that can be transferred from one system to another as a result of temperature difference. A thermodynamic analysis is concerned with the amount of heat transfer as a system that pass for a process, a steady state to another. The science that deals with the determination of the speeds of the transmission energy is the heat transfer. Heat can be transferred in three ways: conduction, convection and radiation. All methods of heat transfer require the existence of a temperature difference and they all occur in the medium which has the highest temperature to the lowest temperature.

During a thermal recovery process by injection of hot fluids, the heat has 2 ways to spread within the reservoir, the first apply to the steam injection stage, when the hot fluid is in transient regime (dynamic), there occurs transfer of heat by forced convection, after the injection step, usually starts soaking step, at this stage the heated fluid within the reservoir transfers its heat by conduction, due to the stationary regime.

During the generation of the termal energy in the reservoir, to reduce the viscosity of the oil, the heat is transfered by conduction through of rock matrix, in the same way occurs between the rock and the steam in stationary state, this also apply in the soaking step, when the well is injected by CCS. The heat has a flow speed proportional at the thermal conductivity of each of the components present in the system rock-fluid.

Injecting steam of water at the reservoir provides directly amount large of heat, this is transferred by forced convection in the rock saturated with oil.

Those phenomena occur by the scheme of steam injection used. The heat flow in the reservoir occurs in transient regime and the flow speed is function by the characteristic of system rock- fluid.

Steam injection scheme SW-SAGD.

The well MFB-617 was drilled in November 2002, it is horizontal and presents 1500 ft of length horizontal. Before of the application of the SW-SAGD technology, this well had an oil rate 100 BNPD, with an oil accumulative 500 MSB, starting the project, the oil rate of the well increased 300 BNPD, obtaining an extra per SW-SAGD of 200 BNSB. At The oil accumulative at the moment is 834 MSB.

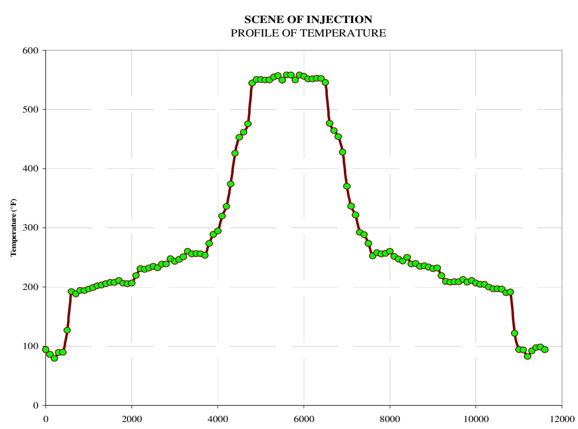
In This well was applied the SW-SAGD technology using the scheme of conceptual steam injection, where the steam was transferred to reservoir considerated one point of steam injection, specifically in the toe of horizontal section. The transfer of heat was made using insulated tubing with thermal conductivity 0,002 BTU/(Hr.*ft*°F), the insulated tubing provided excellent result in the reduction of losses of heat in the steam in the way to the reservoir. The hot fluids were transported to surface through of one tubing of production, with help artificial lift rop pump.

To make the evaluation of scheme of steam injection in the well MFB-617, it made one studies in the variables most important produced during the performance of the pilot project. Capturing of Information in real time, specifically profiles of temperature by optical fiber, behavior of the steam quality from wellhead to heel, production of the fluids and evaluation of the recovery factor were analyzed.

1) Capturing of Information

In the insulated tubing were placed sensors of temperature type thermocouples and optical fiber, these provided to determine the behavior of the steam in the heel of the well, monitoring the formation of the steam chamber and the optimization of the injection process.

Through optical fiber, before to start the pre-heating step (t=0), the temperature in the reservoir was 140 °F. Starting the pre-heating step (t=10 days), it was observed 1000 ft horizontal length with 500 °F, this indicated that this zone was 100% saturated with steam. Finishing the first step of the project, the behavior described above is maintained, because it were created the conditions necessary to form the steam chamber. Later, for the injection-production step (t=40 days), it observed a increase in the temperature of the well, the length horizontal saturated with steam increased about 1100 feet with temperature 450°F (figure #1).



Figure# 1. Profile of temperature SW-SAGD.

2) Behavior steam quality

In the saturation temperature, the water can exist in liquid or gas phase. It depending of content of heat. The mixture steam-water exist in the saturation temperature, it is called wet steam and is characterized by contain steam in the mixture, called as a fraction of total weight by the quality.

The dry-saturated steam has a quality 100%, because there isn't exist water in liquid state. While the saturated water can be considerate as wet steam with quality zero. Steam quality between this two extreme is called wet steam.

The enthalpy or heat contain of wet steam depends strongly of the quality, specially to low pressures. Where the enthalpy of the saturated water is low. The enthalpy of wet steam is intermediate between of the saturate water and dry-saturate steam, this is the equation.

$$H= hw+X*L$$

In the figure #2 can observe the behavior of the quality in the way to downhole, during the steam injection process applied in the well MFB-617. The steam quality in wellhead was 80%, due the excellent insulated generated by the insulated tubing (Kt= 0,002 BTU/(Hr.*ft*°F)), the heat loss in the well were reduced, obtained quality in downhole 75%, indicating the efficient of the process. According to the above injected steam largely maintained downhole conditions for generating the effect assisted gravity drainage with steam..

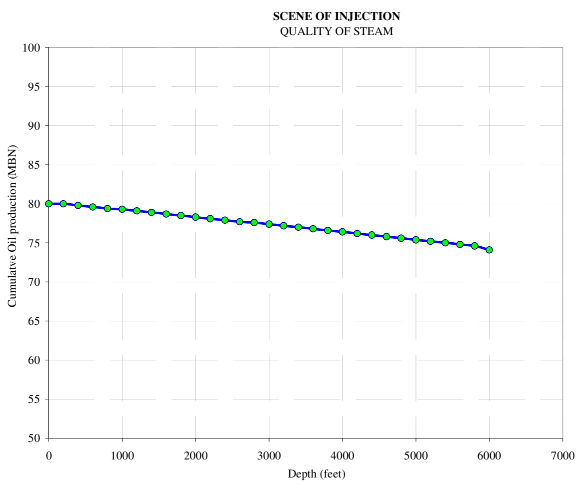


Figure # 2. Behavior steam quality MFB-617.

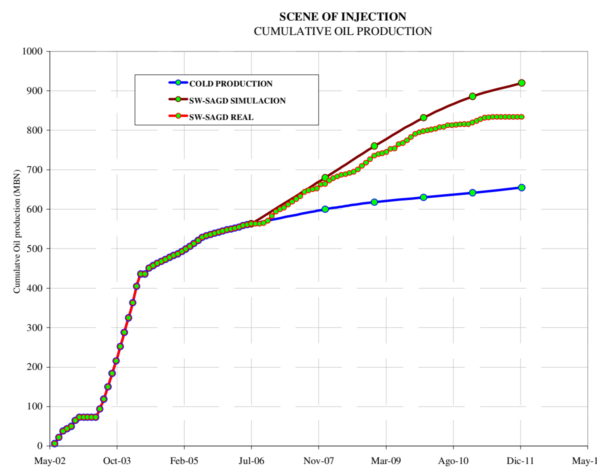
3) Production of fluids

The reservoir engineering always has been the fundamental objective of estimating the likely behavior of exploitation processes of reservoir. Currently, the purpose remains the same, however, the manner of carrying it out has decisively changed over time, thus: decline curves, analytical prediction methods, physical models and even analogies with other processes, have been used to reach the numerical simulation of fields, thanks to technological advances in the areas of information technology and oil.

The reservoir simulation has to do with the construction and operation of a model which integrates all the results generated by geology, petrophysics and engineering, capable of reproducing the actual behavior of the reservoir. They are simply a set of partial differential equations, which are subject to certain assumptions, describe the physical processes active in the field, such as mass transfer and fluid motion in porous media.

From evaluate the behavior of the fluids productions of the pilot SW-SAGD, in the planning step was built a simulation model of the reservoir, used Cartesian grip, this had 80 cells of 70 feet in the 80 cells of 70 feet in the "X" axis and 70 cells of 30 feet at the "Y" axis, and 4 layers in the axis "Z" 10,5,10 and 10 feet respectively.

The planned information capture during execution of the pilot was introduced to the initial numerical simulation model, in order to study the behavior of the well MFB-617. Figure # 3 shows the actual behavior of the well, compared with the simulated behavior through field data obtained during the project. In the figure above shows similarity between real and simulated behavior of the well during the first years of production, however this behavior experiment a significant change from 2010, due the start of production of H2S in the well, the undesirable fluid impossible to perform the evaluation and design optimization. The results indicate the increase in recovery factor from 14% to 20% in 5 years of operation, forecast an increase in recovery factor to 30% on completion of the project.



Figur3 # . Cumulative oil produced MFB-617.

The following figure shows the behavior of water production SW-SAGD pilot, the water cut average in the well was 50 %, this value represented the estimate water cut during project planning. Make an estimate of the water production very in important to recovery thermal projects, to determine the efficiency of the injection and calculate the necessary infrastructure to avoid problems of management of water in surface.

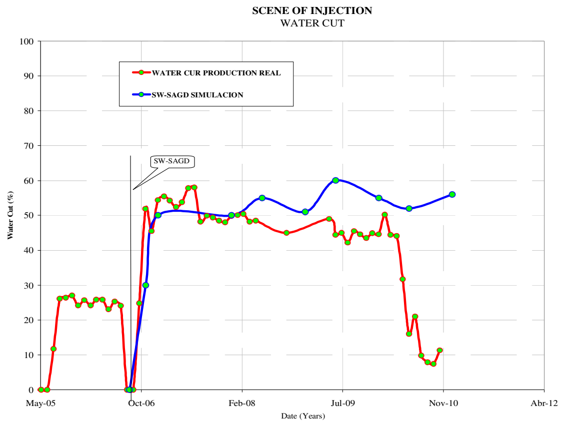


Figure # 4. Water cut MFB-617.

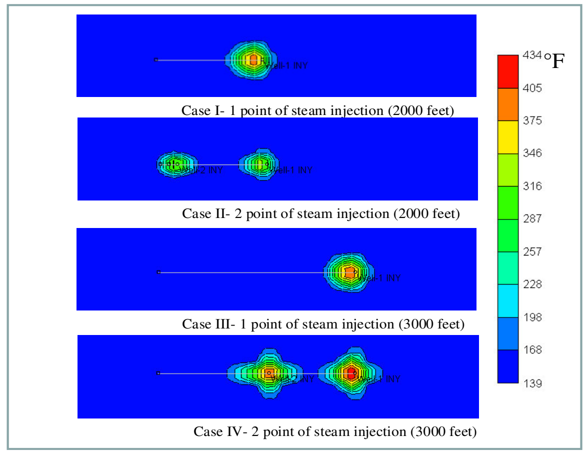


Figure # 5. Scenery numerical simulation.

Optimal scheme steam injection per horizontal lenght

Bare field began production in 1983, initially the plan of the production in the field was oriented to the drilling of vertical wells and thermal stimulation by CCS, managing to reach a daily production of 30 MBSBDD. In 1998, it was born directional drilling and thus the horizontal drilling, the production of the field increased to 120 MSBD. Currently this area has more than 600 horizontal wells drilled with horizontal sections ranging from 2000 to 3000 feet. The SW-SAGD technology is viewed as one of the thermal recovery methods to be applied in the Faja Petrolífera del Orinoco, them it is necessary determine the optimal scheme of steam injection, given the great diversity of horizontal lenght in the wells drilled in the field .

To determine the optimal scheme of steam injection with reference to the horizontal length, were made four scenarios based in the diversity of existing length horizontal in the wells of the Bare field. Through numerical simulation conceptual model were constructed wells with horizontal sections 2000 and 3000 feet. Was initially established a well of 2000 feet with one steam injection at the end of the horizontal section, we performed a new scenary applying two steam injection in the same well (heel and toe). Subsequently we constructed a second well with a horizontal section of 3000 feet using a steam injection point at the end of the horizontal section, and finally the same well by placing an additional point of injection in the middle of the horizontal section (see figure # 5 .)

The cases described were simulated using a steam injection rate of 100 TON/D, the quality of steam was 80% in the wellhead.

1) **Evaluation of recovery factor.**

Based on the above scenarios posed, We determined the volumes of oil drained for a period of 5 years. The base case represents continue operating the Well in cold production, showed cumulative oil of 450 MSB, equivalent to a recovery factor of 13%. For the case-I, which refers to the construction of a horizontal section 2000 feet, using an injection point at the end of the horizontal section, the cumulative oil was 930 MSB, resulted in a recovery factor of 29%. In connection with the case-II, where same the horizontal well described above is applied to the SW-SAGD technology using two injection sites at the end and heel of the well, the reserves were 650 MBSB with a recovery factor of 20%. As regards the construction of a horizontal well section 3000 feet, the case-IV where the equivalent steam injection scheme is two injection points at the end and heel of the well, showing the best results 1.5 MMSB, expressing a recovery factor of 46% (see figure # 6).

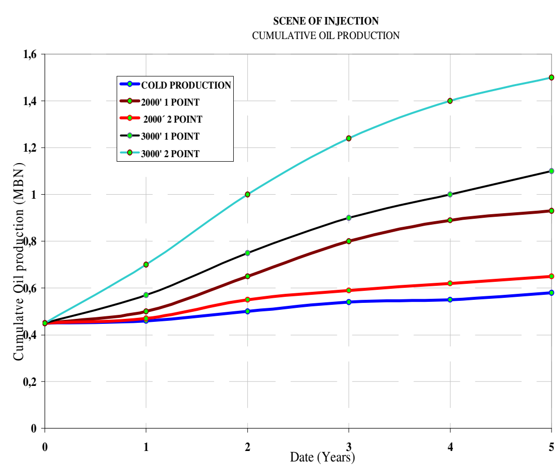


Figure # 6. Cumulative oil produced, scheme of injection.

2) Behavior water production.

Regarding the behavior of water production, the scenario of higher water cut was represented by the case-II with 70%, reducing oil production to 650 MSB. It's noteworthy that the largest drawdown pressure in horizontal wells are located in regions to the heel of the well, so that by applying SW-SAGD technology these pressure drops will remain due to the operation of artificial lift equipment, causing high water production and impossibility of forming the steam chamber that produce the gravity effect between the oil and steam (see figure # 7).

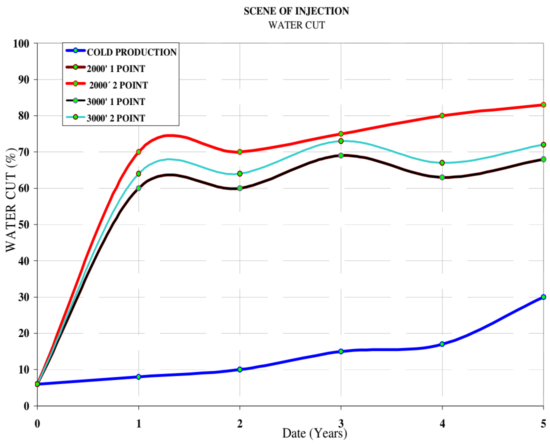


Figure # 7. Water cut, scheme of injection.

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3) Length heated area

In recovery thermal project is very important determine the heated area for the steam, this variable provide amount of hot hydrocarbons and the efficiency of the steam injection. The result indicated that the best effect is producing by case IV. Placing an additional point in the middle of the horizontal section for this length wells permits the development of an additional steam chamber more than twice the area heated by steam compared to the traditional scheme of injection. It is important to select the optimum point of injection due to pressure drops in the well could decrease the length of heating, increasing the volumes of surface water (see figure 8).

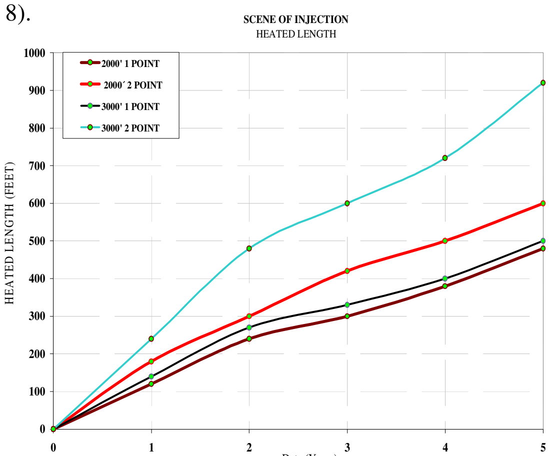

Figure # 8. Length heated area, scheme of injection

The results indicate that in wells with horizontals length equal to 2000 feet, place an injection point at the end of the horizontal section ensures the formation of the steam chamber in an area of approximately 400 feet radio, waiting for the recovery factor is about 29 %. For the second scenario on the application of SW-SAGD technology in existing wells 3000 feet of horizontal section, the most efficient scenario is to place two steam injection points, the expected recovery factor is 46%.

Conclusion

- The projection of the recovery factor increase in the well MFB-617 is 14 to 30% in the area affected by steam injection.

- The steam injection scheme applied in the well MFB-617 was optimal, achieving inject steam in downhole with quality 75%, so that much of the injected steam made gravitational segregation in the reservoir.

- According to the results of the sensitivity of the effect of the horizontal section in wells subjected to SW-SAGD, it is necessary to propose the use of a steam injection point at the toe of the horizontal length for wells with 2000 ft and two injection points in the final half of horizontal section to existing wells with horizontal sections above 3000 feet.

Acknowledgement

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Nomenclature

STB = Standard Barrels
H= enthalpy
X= Quality of steam.

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