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Thermal evaluation of nitrogen used as isolator in annulus during cycle steam stimulation (CSS). San Tomé District. Faja Petrolífera del Orinoco.

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ABSTRACT

San Tomé District located in Faja Petrolífera del Orinoco, applies technologies and methods to increasing extra and extra heavy oil production. One of these is CSS. This process consist in injection of defined volume of steam into the reservoir with purpose of reducing oil viscosity and improve its mobility.

One of the challenge in this steam injection scheme is to assure that the energy injected reaches the reservoir with minimum heat lost, reducing transfer of energy to other zone. The completion designs play a really important roll to achieved the objectives.

San Tomé District, is actually the area with more steam injection processes in Faja Petrolífera del Orinoco and with the mayor field data accumulated and evaluated. Different completions designs for steam injection have been performed and evaluated but completions with nitrogen in the annulus and conventional tubing have been used with more frequency. In this type of completion the steam processes is affected for changes in nitrogen volume and thermodynamic behavior, in some cases with high annular pressure, there is an increase in heat transfer affecting the steam saturation parameters.

The main objective of this paper was to evaluate thermal performance of nitrogen used as isolator during steam injection. The efficiency of the isolator is measured by evaluating the productivity of each well, additionally, it was reviewing the thermodynamic aspects of this fluid (gas), by analyzing its efficiency with real field data to prevent heat lost and optimizing the use of nitrogen as isolator.

INTRODUCTION

The Faja del Orinoco is a huge source of energy resources of heavy and extra-heavy crude. According to reservoir characteristics and availability of financial resources; these can be extracted via thermal recovery processes. The cyclic steam injection is used in an alternative strip for well stimulation, where steam injection allows the decrease of viscosity of the oil through heat energy transfer. The hot oil production requires special considerations in the completion. The components of the well should be chosen considering the high temperatures generated.

It is important to notice that stimulation efficiency is related to the amount of heat supplied to the oil sand. This is why it is important to take into account the parameters involved in the process of Cyclic Steam Stimulation (CSS), which it can be divided into two main groups: the controllable and uncontrollable parameters. The latters are associated with the well or reservoir and among the most decisive in the CSS are: reservoir pressure, thickness of the sand, formation permeability, viscosity and API gravity oil, size of the aquifer and reservoir, reservoir heterogeneity , volume of oil drain and wetting characteristics of the rock and its variation with temperature

Among the controllable parameters, they can be improved and must be monitored during the injection processes such as completion type, selected insulation, steam quality, soak time, frequency, number and duration of cycles and volume of steam to be injected.

In this study the use of nitrogen used as insulation in the annulus during cyclic steam injection was analyzed. Insulation used in operating steam injection plays an important role in the outcome. In San Tomé District Operations, 90% completions are performed with nitrogen in annulus space.

NITROGEN

In the Steam injection activities, nitrogen is used as insulation in the annulus. Below the main characteristics of nitrogen are described.

Nitrogen is an inert, odorless, colorless gas that makes up about 78% of atmospheric air. Chemical element symbol N, atomic number 7 atomic weight 14.0067; is a gas at standard conditions; its use varies, since it can be used in the food industry, medicine, electronics and Petroleum Industry in various fields, as well completion, production tests (induction wells), drilling pipe with N2, paraffin control , testing of pipes and connections, wells with acid stimulation and fracturing as well as insulation in the annulus of the well in the activities of Steam Injection.

Nitrogen is used in the oil industry for several reasons, among them are:

- It is an inert element, which eliminates the danger of combustion
- It is poorly soluble in water or oil
- Due to its low activity (It does not corroes the pipelines).
- The natural gaseous state does not damage the formations.
- Maintains its gaseous state at high pressures.
- It has a high yield of gas per volume of liquid.

Below you can see a table showing the main features of the Nitrogen gas.

Table 1. Properties of Nitrogen

Nitrogen	
Atomic number	7
Atomic mass	14.006 g/mol
Density at 20°C	1.25 g/L
Melting point	-210 °C
Boiling point	-195.8 °C
Isotopes	4
Electronic shell	[He] 2s22p3

DEVELOPMENT

Locación of Study.

This study was developed in San Tomé District of Ayacucho Division in the Orinoco Oil Belt. Limited to the north with traditional heavy oil fields, the south with the Mix Company Petropiar at the East with Carabobo Division and the West with Junín Division. The location of the study area is indicated in Figure 1.

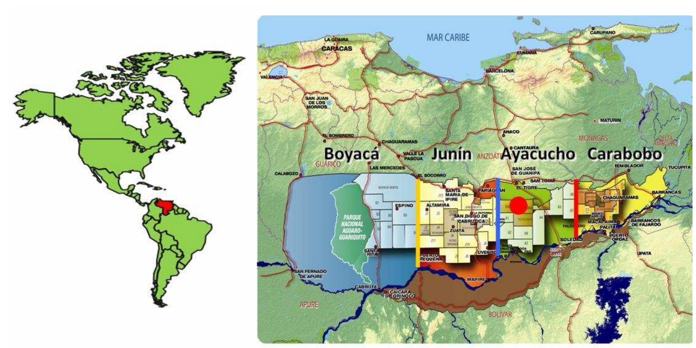

Figure 1. Study area.

Steam injection has been used in San Tomé District since the 80s, in fields of extra-heavy oil with good volumetric results. This activity has an annual commitment of petroleum generation.

The amount of oil recovered from the reservoir by applying thermal processes is closely related to the completion used in the injection process; which is responsible for the energy supplied and ensures to reach the area of interest

The well is the element that provides the mechanical connection between the reservoir and the surface, the medium through which hydrocarbon extraction is performed. Productivity and longevity of a well is affected by the type of completion and the type of work done on it.

The selection of completion has as main objective to achieve maximum production in the most efficient scenary and therefore should be carefully studied. The factors that determine the design of completion are described:

- Production rate.
- Volume of reserves
- Production mechanisms.
- Sand control
- Need for stimulation.
- Type of artificial lift.
- EOR projects.
- Insulation type used.
- Costs involved.
- Mechanical state of the well

The efficiency and feasibility of the connection between the reservoir and the surface depend on the proper use of all the parameters which conform it, so it can be inferred well productivity in terms of completion. This includes an analysis of their mechanical status and economic returns to justify their application.

Thermal completions Nitrogen in the annulus

In San Tomé District is often used two types of well completion for cyclic steam injection. The first and frequently used is conventional pipe with nitrogen in the annulus where this study is focused; the second considered the use of pre-insulated pipe. Both completions are designed to slow down the flow of heat to the vicinity of the well that may affect its mechanical condition; and ensure that all the energy supplied reaches the reservoir with minimal losses. A schematic drawing is presented below using conventional completion with nitrogen:

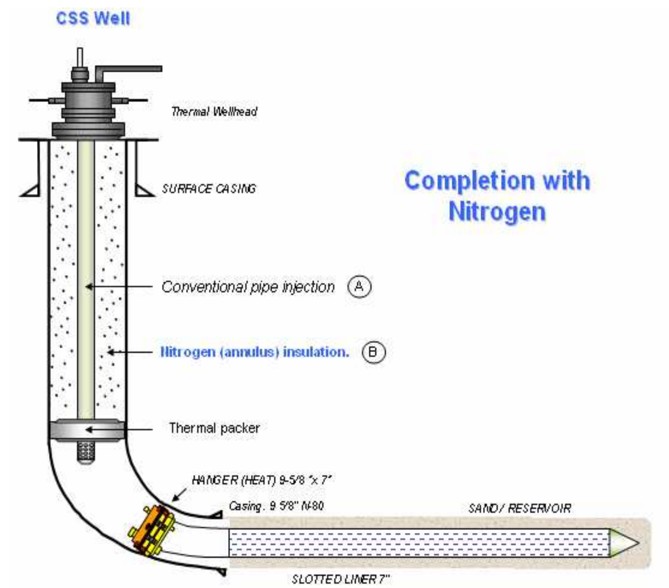

Figure 2. Conventional completion using nitrogen as insulation.

Nitrogen is used in the annulus of the well primarily as thermal insulation, the annular space is formed between the outer diameter of the injection pipe and the inside diameter of the casing, highlighting that the annular space in such completions is saturated with nitrogen whith a constant volume, This is used in order to conserve heat in the injection completion. The Energy as heat that is transmitted in the operations of steam injections must reach the reservoir with few losses.

Heat transfer is the process where the thermal energy passes from a higher body temperature to a lower temperature. For example, a solid object or fluid is at a different temperature than its surroundings, the transfer of thermal energy also known as heat transfer occurs so that the body and its surroundings reach thermal equilibrium.

When there is a temperature difference between two objects in proximity to each other, the heat transfer can not be stopped; it can only be slowed. For conventional completion tubing and nitrogen in the annulus, its principle is based on the low thermal conductivity that develops in the annulus by the presence of nitrogen.

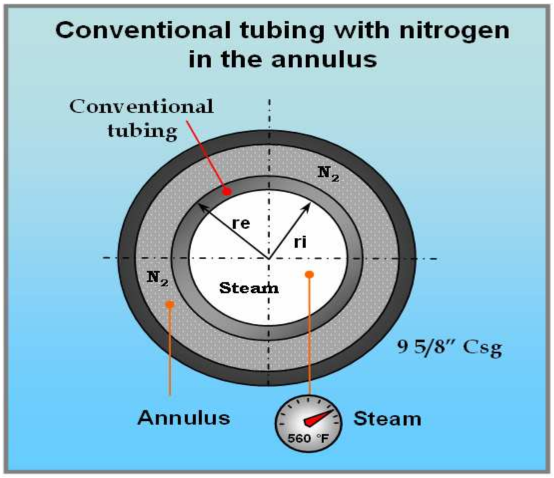

Figure 3. Mechanical scheme of steam injection with N2 in the annulus.

The previous figure showed a cross section of completion with a conventional pipe with N2 within a casing 9 5/8 ". The annulus temperature is kept low due to nitrogen thermodynamic properties

Operational Procedure by Nitrogen Displacement.

Operational aspects for the injection of nitrogen in the annulare:

1- Select the well to perform the steam injection.
2- Check that the well meets the minimum requirements in terms of thermal materials in its completion
3- Place down into the well one thermal packer with expansion joint and a conventional pipe for injection.
4- Check the seating of the thermal packer and sealing of pipe. Proceed to call the Nitrogen injection team work.
5- Calculate the volume of the annular space.
6- Place the N2 injection equipment in the well.
7- Place equipment in wearing position, following the standards procedure used for this type of activity (in upwind, watching sunrise and away as possible from engines in operating work, storage tanks and equipments that are in the process of working were high risk is involved.
8- Dressing pumping lines according to the instructions corresponding work, described in the quality control operations manual.
9- Try out Lines for injection.
10- Open well, register wellhead pressure and start up pumping at maximum N2 rate and design pressure indicated; always take preventing the formation fluid. Avoiding as possible the intake fluid
11- Constantly check out that the return fluid is reaching the tank intended for that purpose.
12- Ensure that the adjustable gearbox or manifold of the drill, always be operated by the person responsible for it. The operator must be present during operation
13- It should be noted the response of the well and verify that fluid volume correspond to the barrels of nitrogen pumped has been displaced
14- The average operating pressures handled are around 600 to 1200 psi and the nitrogen used for an average volume is 800 to 2000 gallons.
15- Undressed equipments.
16- The well is ready to connect the lines of steam injection.
17- Ready to Start up well Injection

Cyclic Steam Stimulation. (CSS)

There are two ways to perform the steam injection to oil reservoir , cyclically and continuously, the main differences between the two methods lies in the volume of steam injected, the time of exposure to heat the oil and the impact area . In the cyclic steam injection (CSS) fluid is injected by the same producer well. Continuous steam injection involves the use of one or more wells, if modalities as Single Well-Steam Assisted Gravity Drainage (SW-SAGD) one completed well is used as an injector / producer, otherwise the Steam mode Assisted Gravity Drainage (SAGD) where it is necessary to use two wells, one injector and one producer positioned one above the other. This paper only takes into account the cyclic steam injection (CCS) process.

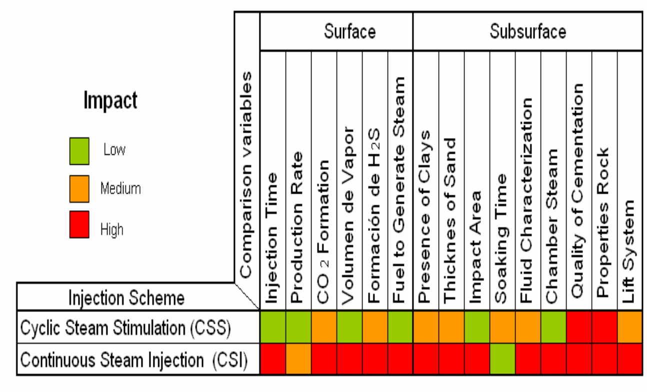

Figure 4. Impact of Variables in CSS and CSI.

Cyclic Steam Stimulation process is divided into 3 stages: first Steam Injection, second time Soaking and third Production. Figure 5 shows the schematic of the process.

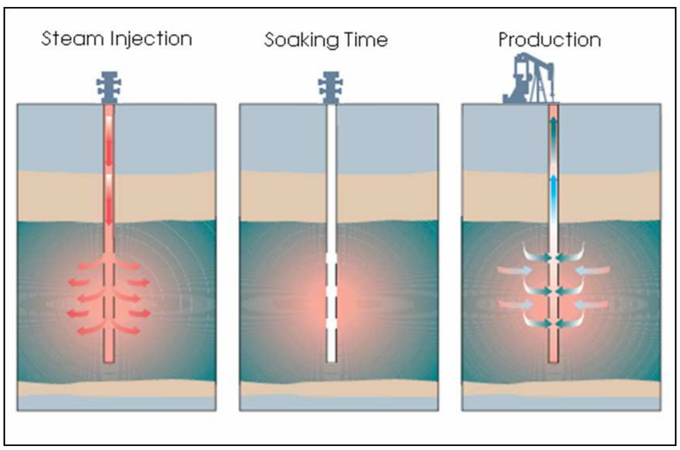

Figure 5. Stages of cyclic steam injection.

The steam injection phase is the moment in which thermal energy is supplied to the reservoir. Data such as daily rate, total volume and injection saturation parameters vary with reservoir properties. Soak time starts after steam injection in order to wait for the optimal energy dissipation in the reservoir, usually about 5 days are used (Armas & Mago 2012) . The last phase is the production. It is when the well is reactivated to production, thus initiating the transport of hydrocarbons to the surface through a type of completion and artificial lift system suitable for high bottom temperatures.

Study Data

A total of 25 wells that were subjected to cyclic steam injection and completed with conventional tubing and nitrogen in the annulus were analyzed. These were completed during the period 2010 and 2014 in the Bare field. Injection operational data was collected such as wellhead pressures and casing, wellhead and casing temperatures, injected volume , injection time, wellhead elongation, statistics from operational failures, among others. The studied wells are shown in table 2
.

Table 2. Study wells.

WELLS				
MFB-616	MFB-225	MFB-644	MFB-724	MFB-722
MFB-578	MFB-519	MFB-511	MFB-448	MFB-723
MFB-485	MFB-566	MFB-456	MFB-717	MFB-824
MFB-720	MFB-687	MFB-825	MFB-859	MFB-645
MFB-806	MFB-718	MFB-632	MFB-827	MFB-860

To analyze the behavior of operational variables, it is important to know the average magnitudes (p-50) of the injection conditions, see details in table 3:

Table 3. Variables averages Steam injection.

PROPERTIES AVERAGES	
Steam Injection Rate	240 ton./Day
Injection cycle time	25 Days
Tons per cycle	5000 ton.
Injection Pressure	880 Psi
Saturatión Temperature	530 °F
Target depth	2800 Pies TVD

It was not within the scope of this study to evaluate the operational parameters used in the process of thermal stimulation. It was limited solely to take the field data to develop analysis comparative and to review the operational behavior of completions with nitrogen in the annulus.

STATISTICS OF OPERATIONALS PARAMETERS

All operationals parameters evaluated from the 25 wells were taken from surface data. The well head readings represent the magnitudes of steam saturation. The data read in the casing represent conditions of the annular. The annulus space is formed between the outer diameter of the injection pipe and the inside diameter of the casing which would be saturated with nitrogen. Is showed the data acquired in field

-Wellhead temperature and annulus temperature (Nitrogen)

Temperature is an important factor during steam injection activities, this governs the amount of energy supplied to the reservoir, playing an important role in the transfer of heat to the mechanical configuration of the well. Temperature data taken from casing and wellhead was analyzed from 25 wells in study during the injection cycle. The magnitudes of temperatures (P50) with respect to the days of injection are showed.

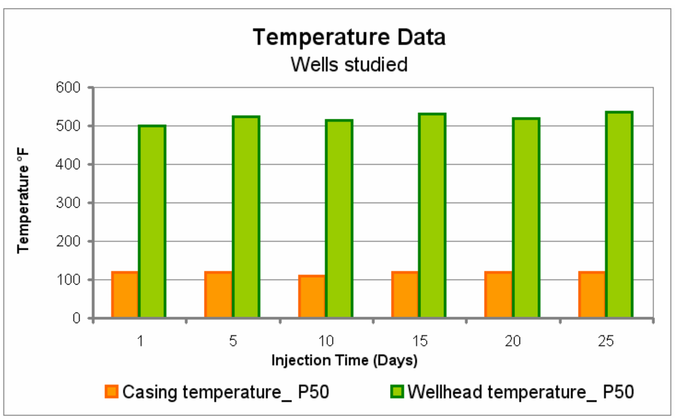

Figure 6. Behavior of Temperature on the annulus and wellhead

Figure 6 shows the temperature behavior during the injection phase, observing temperature levels from wellhead and casing in a the order of 120 ° F and 520 ° F respectively. According to the completion model and data analysis the casing is subjected to moderate deformation temperature, since the starting temperature of the plastic regime for N80Q steel casing is in the order of 330 ° F.

- Wellhead Pressure and Casing Pressure (Annular)

Another aspect studied was the wellhead and casing pressure. Since the annular well is saturated with gas (nitrogen), these values should be known due to variation in the kinetic energy of the fluid with respect to heat exchange from steam. The behavior of these parameters (P50) in function of the injection time, are shown in Figure 7. Data From the 25 wells in study:

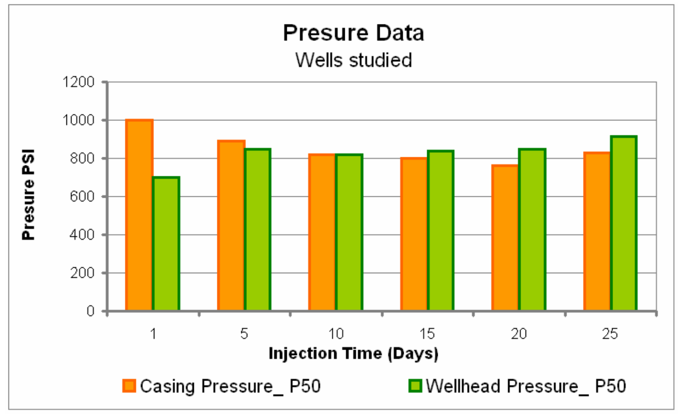

Figure 7. Behavior of the pressure in the annular and wellhead.

- Elongation of the wellhead.

A sensitive parameter to study for steam injection is the elongation at the well head, representing the level of deformation of materials that conform it; ignoring the control of this variable could cause mechanical failures. Considering changes in temperature between the injected fluid and the geothermal gradient, the flow of energy moves from the center of the injection pipe to the formation; traveling across the mechanical structure of the well, originating all mechanisms of heat transfer.

By increasing the energy level in the materials that make up the well inside a plastic regime, the original mechanical condition is affected avoiding the materials to return to its original conditions, once the acting forces are diminished. This behavior, causes fatigue and premature failure of materials. Figure 8 shows the average elongation magnitudes as function of time of injection using a conventional completion tubing with nitrogen in the annulus:

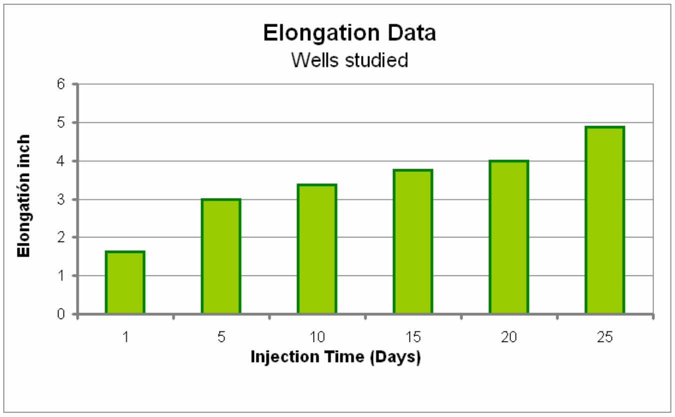

Figure 8. Behavior 50 percentile elongation in conventional completions.

Wellhead elongation is important information, which can be easily monitored in surface, giving this magnitude estimate of well conditions after the implementation of steam injection.

In Figure 8, you can see the elongations recorded during CSS activities with these completions; the elongation is in the order of 5 inches (end time). The statistical mechanical failure in wells undergoing cyclic steam injection is low, keeping the operation there after the injection process is completed.

VARIABLES DURING STEAM INJECTION PHASE.

The variable terminus is defined as any characteristic or quality that identifies a reality and you can measure, monitor and study through a research process. The evaluation of variables in nitrogen use as an insulator in the annulus allowed for analysis of operational parameters, achieving identify scenarios in order to develop analytical models

Graphics were made incorporating the operational parameters obtained from 25 wells in study, identifying the behavior of variables and viewing trends presented Next; the behavior of one of the wells is showed, displaying the actual changes and trends during steam injection

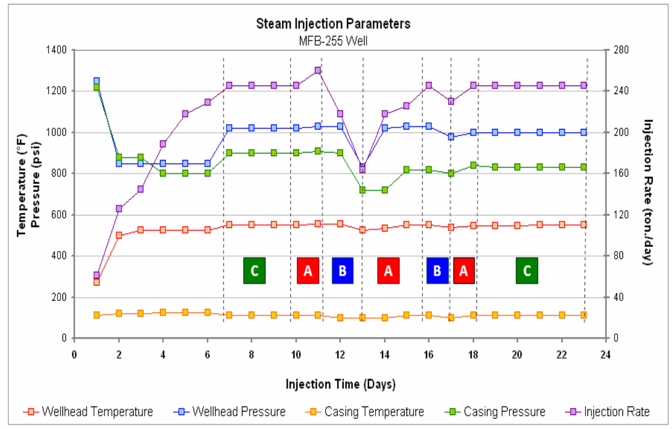

Figure 9. Model of Type variables.

From the analysis in Figure 9, the injection rate could be defined as an independent variable, since it has the ability to influence or affect the other variables in the system. According to this, it can be precised how the magnitudes of temperatures and pressures in the wellhead and casing vary with respect to the increase, decrease or maintenance of the injection rate. In this evaluation, it was possible to establish the scenario which was repeated in each of the studied wells, using as independent variable the rate of steam injection; this scenario will support the activities of monitoring and controlling the injection in the operational areas. The following table presents the observed behavior:

Table 4. Summary of Behavior Variables

SCENARIO		VARIABLES
A	Q INJ (↑)	Pressure (increases)
		Temperature wellhead (increases)
		Temperature casing (increases)
B	Q INJ (↓)	Pressure (decreases)
		Temperature wellhead (decreases)
		Temperature casing (decreases)
C	Q INJ (Ctte.)	Pressure (constant)
		Temperature wellhead (constant)
		Temperature casing (constant)

According to the 25 wells tested using a completion with conventional tubing and nitrogen in the annulus, a correlation analysis of variables was performed considering a systematic shift between them when the values of one with variable respect to the values counterparts of the other, vary; such that the relationship of one variable against the other could be observed. Below the designed relations are presented.

- Relationship between casing (annulus) temperature and pressure with respect to wellhead temperature.

Casing temperature and pressure are dependent variables and their monitoring is important in steam operations, these being proportional to the heat transfer to the casing of the well. These variables were plotted to identify trends.

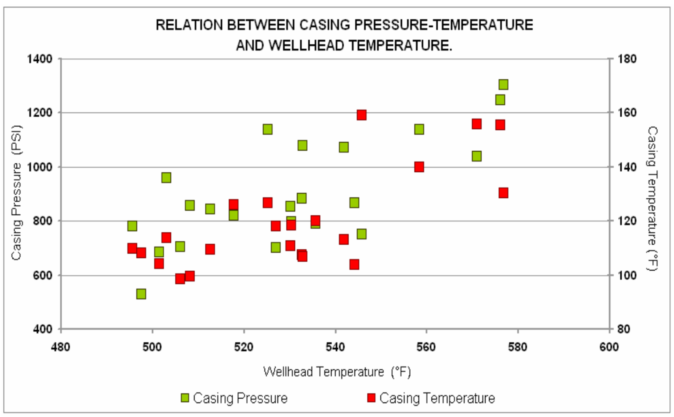

Figure 10. Behavior of Casing Pressure and temperature in function of Steam Injection temperature.

It can be observed from the Figure 10; that at higher injection temperature; conditions in the annular increase (pressure, temperature); indicating that there is a greater amount of energy dissipated in the mechanical structure of the well.

The gas pressure is directly proportional to its temperature, if the temperature of the system is increased, the pressure will increased. For this reason in the activities of CSS, it must be maintained a low pressure casing with a moderate injection temperature to avoid high temperatures in the casing.

- Relation between the casing pressure (annulus) and wellhead pressure (injection pressure)

In order to analyze and confirm the behavior of the variables of pressure in the casing as funtion of the injection pressure both variables were plotted, showing the results below.

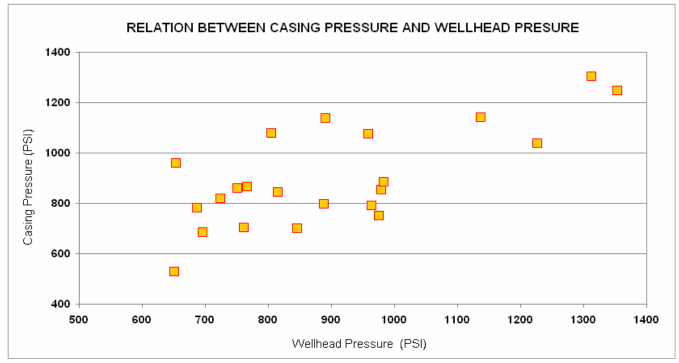

Figure 11. Relationship between the casing pressure and the injection pressure.

It was observed that the casing pressure is directly proportional to the injection pressure. The increasing of the injection pressure is related to temperature rise of the steam injection, thus increasing the injection pressure increases the casing pressure ; This is because the gas is a fluid without form and own volume, the molecules tend to separate from each other when a gas is heated; developing a distortion or collision among them, in turn colliding with the walls of the casing and injection tubing causing an increased of pressure as the storage space remains constant (fixed) and its volume can not change, implying that the variables studied are directly proportional.

- Analysis of the casing temperature (annulus) according to the days of steam injection.

From the analysis of behavior of both variables of temperature (casing and injection) during the activities of steam injection, a graph was built with the average temperature data in the annulus of wells; as a function of injection days. These are key variables during CSS activities see figure 12.

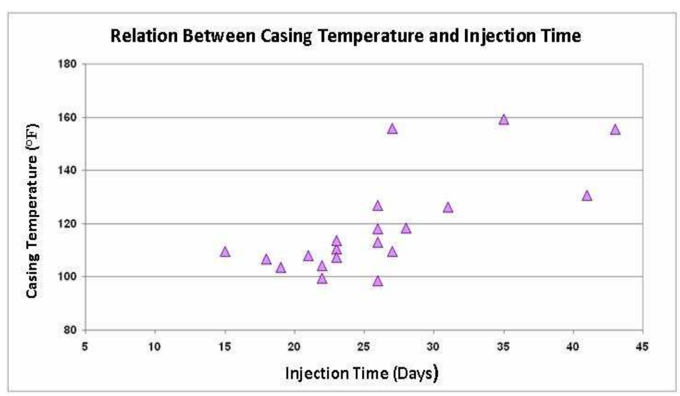

Figure 12. Behavior casing temperature (annulus) as a function of injection days.

It is observed that as the days of injection increased the temperature in the casing is increased, this is due to the extended time that the well completion is exposed to heat , allowing an increase of heat transfer to the annulus of the well, which is negative for the well and the injection results.

A value of 25 days of injection time was taken from operational statistics. It is advisable to keep this value and thus handle temperatures in the annular well around 110 ° F. A steam injection times over 25 days temperatures increase up to high values.

OIL PRODUCTION

For the analysis of volumetric success of the 25 wells in study, their production results were analyzed. Cold oil rate was collected after thermal stimulation, showing a beneficial for the project of 3141 STBPD of oil and an increase of 125 STBPD average per well due to the injection

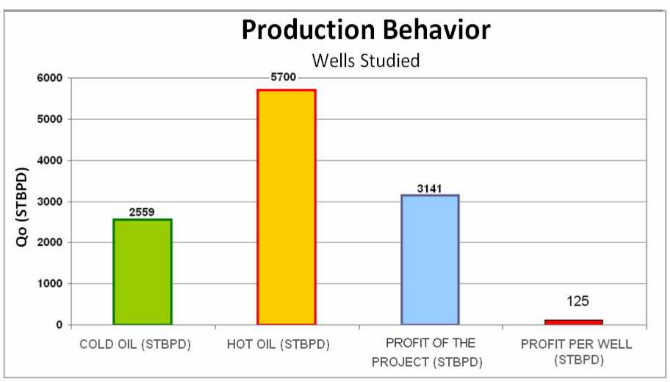

Figure 13. Behavior of Production of the CSS Project executed in the Bare field; San Tome District.

The presented results strength the strategy of thermal steam injection activity with completions using nitrogen as an alternative of thermal insulation, with a beneficial production above 120% of the original production. All wells tested were subjected to a single cycle of steam injection.

CONCLUSIONS

The temperature in the annulus; measured at surface level in the most extreme case (P50), do not exceed 120 ° F; therefore the casing is not subjected to high temperatures. this magnitude is directly proportional to the depth.

The elongation registered during the thermal stimulation process with conventional completion and nitrogen in the annulus was around 5 inches. The statistic of mechanical failures in the 25 wells evaluated was negligible, therefore maintaining the wells in full operation.

The steam injection rate is an independent variable in the thermal stimulation process, because it has the capability to influence or affect the other system variables.

At higher steam injection times, the temperature in casing increases, due to the prolonged time of well completion to heat.

When the annular pressure increases due to the thermal expansion of nitrogen, heat losses are increased as a result of increase of convection heat transfer coefficient

The total increment of oil production in the wells evaluated was 120 %. The oil average increase per well was 125 Bls/day.

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