WHOC12-215

# Quantification of the soaking time in a reservoir subjected to Cyclic Steam Stimulation, based on real data, Orinoco Oil Belt, Venezuela.

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## Abstract

*The Orinoco Oil Belt (OOB) is a huge reservoir of heavy-extra heavy oil locatet in easernt Venezuela, with reserves estimated at about 270 billion barrels.*

*The thermal recovery method used most often in the OOB has been Cyclic Steam Stimulation (CSS). This method is based on injecting a limited volume of steam, in order to supply heat to the reservoir to reduce the viscosity of the fluid and improve its mobility. After a closure (soaking time),to put the well back on production you must repeat this cycle according to the production profile obtained.*

*The determination of the soaking time is crucial.Iif we make an energy balance under the CCS scheme, the energy supplied could be produced, lost or used, all these pathways are related to time of soaking and heat dissipation within the reservoir.*

*According to the actual data analyzed, in the first days after injection has been stopped, the temperature drop is higher. The rock - fluid system decreases in temperature from 517 ° F (@ injection conditions) to 334 ° F in just 2 days, dissipating its energy very rapidly to reach a stabilization point. This dissipation is by heat flow to adjacent areas. The main objective of this paper is to demonstrate with real reservoir data what must be the optimal soaking time before opening the well back to production. The data used were obtained using fiber optisc and sensors on real steam operations done in the OOB.*

## Introduction

For many reasons in viscous oils thermal methods are used rather than other extraction methods. When using heat, reduced viscosity of the oil that accompanies the increase in temperature allows the oil to flow more easily. The primary assessment and monitoring of thermal recovery projects is the temperature, this being a relative measure of how hot or cold an object is.

In thermal processes, steam is the medium most commonly used to transmit heat to the formation, with the weakness that only part of the heat supplied reaches the target, giving rise to heat losses at the surface and downhole adjacent formations.

Steam injection has many years of application in the oil industry as a method of recovery. Due to the variable "High Temperatures" immersed in the process, this technique has leveraged many technological developments in both subsurface and surface, among which are new completion tools, geosteering methods, special cement slurry, casing with more resistant metals, more efficient steam generation equipment, computer software with variable heat, insulated surface lines, surface and subsurface sensors with greater reliability, amongst others.

The temperature data acquisition has benefited the oil industry since 1930, using these in its history for different calculations and technical support. Each engineering team works with the idea of finding new data-analysis that allows them to know and understand the operation of tools in real conditions.

Today technological advances have made of data acquisition a beneficial tool, giving the operating companies high performance and benefits with its use. From the beginning, the industry has conducted research to develop more modern sensors, kicking off with wireline logs and today using fiber optics.

## Steam Generation

The steam is a gas that is obtained by evaporation or boiling of liquid water. At a molecular level this is when the H2O molecules themselves are freed from the bonds that hold them together.

In liquid water, the H2O molecules are constantly moving together and separated. However, when heating the water molecules, the joints connecting the molecules begin to break down faster than they can be formed. Eventually, when enough heat is supplied, some molecules will break free. These free molecules are the transparent gas we know as steam.

There are two terms thermodynamically defined, the first is wet steam and applies when liquid water and gas coexist in a single volume, the dry steam applies when all the molecules are maintained in the gaseous state.

In the petroleum industry the Cyclic Steam Stimulation (CSS) arises from the need to stimulate the well to increase production rates and thus we have a faster recovery of reserves. This is one of the methods of stimulation that has demonstrated greater efficiency in the field. The following is the process of generating and injecting steam into San Tomé District reservoirs.

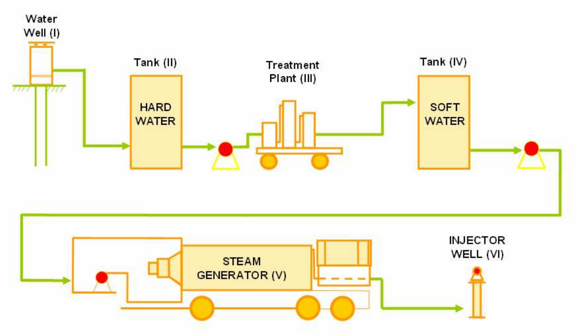


Figure # 1. Steam generation process

Initially, the water required for the production of steam is extracted from an aquifer through a water production well (I), drilled in the vicinity of the steam injector. The extracted water driven by a pump, is stored in a hard water tank (II) for the purpose of precipitating some entrained solids, to subsequently enter into the treatment unit.

The water obtained from nature, has unwanted features such as suspended solids, dissolved and hardness, which must be eliminated through physical-chemical processes, so it is transported to a portabl processing unit (III), this treatment unit consists of a filter and two softeners.

Since the hard water is pumped through pipes to the fluid treatment unit starting in the filter. These filters are a activated charcoal natural material with millions of microscopic holes to capture and break molecules of contaminants present, this adsorbs the greatest amount of solids in the water.

After the filter unit, it is brought to water softeners which are responsible for reducing water hardness through ion exchange resins. These resins, in the form of zeolites, allows the removal of calcium and magnesium present in the water which and replaced by sodium ions contained in the zeolites.

The water, now free of Hardness is sent to the soft water tanks (IV) used to store water without the presence of hardness. From there we send the water to the steam generator (V) where the fluid, originally in liquid state, is heated and changes state.

The generated steam has the following characteristics:

- Maximum discharge pressure of 1200 to 1600 psi.
- Maximum discharge temperature of 500 to 580 ° F.
- Volume of steam produced by each unit is 250 Ton / Day.
- Steam Quality 80%.

Finally the generated steam is sent to the wellhead (VI) which is internally completed as an injector.

## Cyclic Steam Stimulation

There are two ways to perform injection of steam into oil fields, cyclical and continuously, the main differences between both methods lies in the volume of steam injected, the exposure time to heat the oil and the impact area. In the cyclic steam stimulation (CSS) the steam is injected by the same production well. The continuous steam injection (CSI) involves the use of one or two wells, one injector / producer (eg SW-SAGD) or an injection well and another producer (eg SAGD). Here are some variables and their impact on the CSS CSI processes.

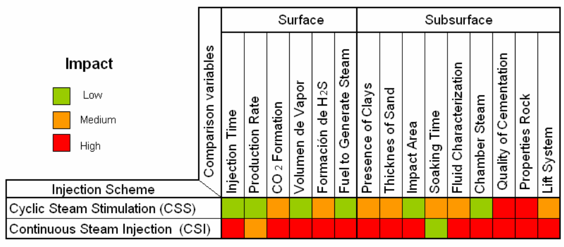


Figure # 2. Impact of variables in CSS and CSI.

The cyclic steam stimulation divides its process into 3 stages: first the steam injection, second the soaking time and last the Production. Annexd is a schematic of the process.

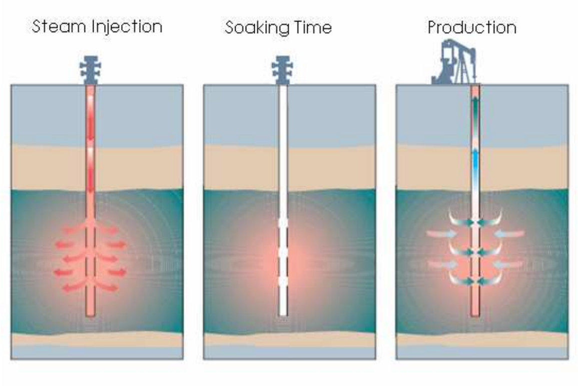


Figure # 3. Stages of cyclic steam stimulation.

In the injection phase ( Fig. 4) is when it deposits a small volume of steam (wet or dry), with some key parameters for evaluation:

- Steam injection rate per day.
- Total injection volume.
- Amount of heat to be supplied.
- Pressure and Temperature of Injection.
- Mechanical configuration of the well.
- Completion of injection well.
- Mechanical elongation
- Reliability of generation equipment.

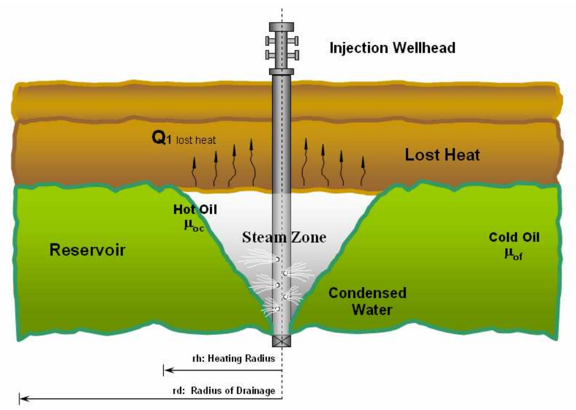


Figure # 4. Steam injection stage. Vertical well.

The soaking time is the second stage of CSS and starts once the required volume of steam is injected to the reservoir completely. The fundamental reason of this parameter is to define the heat transfer between the energy supplied and the location. Annexd is an illustrative picture of the process:

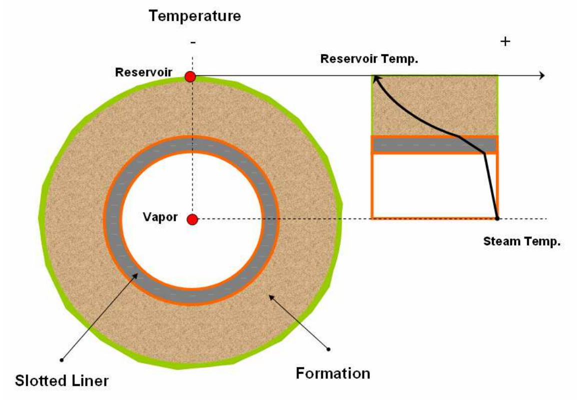


Figure # 5. Soaking time in a horizontal well

Using appropriate well completion materials the steam at the sand face may reach temperatures above 500 ° F. This large amount of energy that carries the steam must be transmitted to the reservoir by ways of conduction and convection, to fulfill its function of increasing temperature in the vicinity. One of the parameters that distinguish CSS is "low volume of steam injected", which is why we must take into account the optimal soaking time in order to give the command to put the well into production.

The last is the production stage, starting when the well changes its status from closed to open. At this stage must consider these key parameters:

- Bottom hole pressure control when completing the well as a producer.
- Lift system (high temperature).
- Monitoring of water and sand production.
- Formation of $CO_2$ and $H_2S$.
- GOR.

## Heat Transfer

Heat is the energy transfer process between different bodies or different areas of the same body that are at different temperatures. This flow always occurs from the body of higher temperature to lower body temperature, occurring transfer until both bodies are in thermal equilibrium.

Energy can be transferred by different mechanisms, among which include radiation, conduction and convection, although in the majority all real processes are present in greater or lesser degree.

The phenomenon of radiation is the propagation of energy as electromagnetic waves or subatomic particles through a vacuum or a material medium. This energy transfer is not significant in the injection of steam, there is not enough empty space for electromagnetic propagation.

Convection is the transport of thermal energy through a fluid to a region with different temperatures. Forced convection occurs when the fluid motion is induced by external forces. Natural convection takes place when the temperature gradient in the fluid causes differences in densities.

For most cases in thermal recovery the forced convection is the dominant form of transfer, however natural convection may be important in some wells heat load.

Conduction is given through solid bodies at different temperatures, in the case of steam injection this is responsible for heat losses in the underlying layers. According to the flow velocity, driving may be important in the dissipation of heat within the reservoir.

In the steam injection process there are several mechanisms of production, all with different degrees of importance. The dominant mechanism in the case of heavy oils is the reduction in viscosity, this due to the rise in temperature. Below is a graph of change in viscosity as a function of temperature.

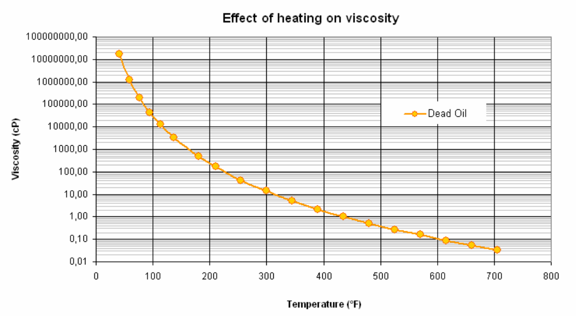


Figure # 6. Effect of temperature on viscosity.

We can observe in the graph above that with a higher magnitude of viscosity the impact of temperature is more significant (higher slope), once the viscosities decreass the effect is smaller.

## Soaking Time.

Once the production stage has started, the energy supplied to the reservoir involves 3 stages, in the first the heat is in the wellbore and the energy supplied is produced, another scenario occurs when placing the well under production with a high soak time, due to the low volume of steam this could be lost in the reservoir, and finally opening production at the optimum time, using the energy supplied to the maximum.

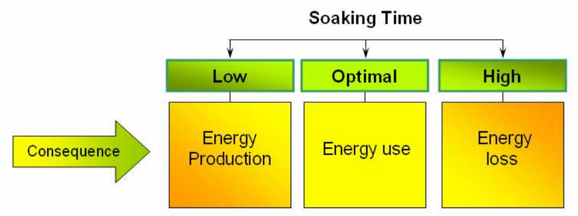


Figure # 7. Scenarios with the soaking time.

Considering different stages of soaking time, subsurface data acquired were reviewed in various steam operations in the Orinoco Oil Belt. The first data is referenced to a cyclic steam stimulation in Bare field, annex is its graphical representation:

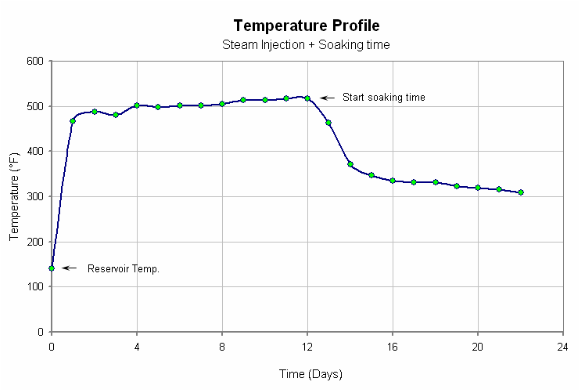


Figure # 8. Temperature profile cyclic steam stimulation.

The data from the previous figure was provided by temperature sensors located in the horizontal section near the point of steam injection, in this graph displaying multiple relevant sections, the first denotes the reservoir temperature, this point was compared with logg data temperature obtained before. After initial injection of steam is displayed an increase in temperature due to heat supplied (500 ° F av.). The injection was stopped at the twelfth day (12) starting the soaking time at this point.

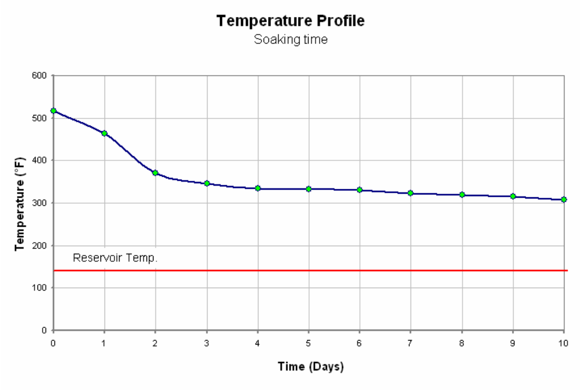


Figure # 9. Temperature Profile only Soaking Time.

Fig # 9 shows the temperature profile of the soaking phase from time zero (0). In this range it can be viewed that there is a sharp drop in temperature in the first 3 days, implying that energy transfer is fast to the reservoir and then we can see a stabilized trend, with heat transfer but in lower quantities. Below are data only for the soaking phase:

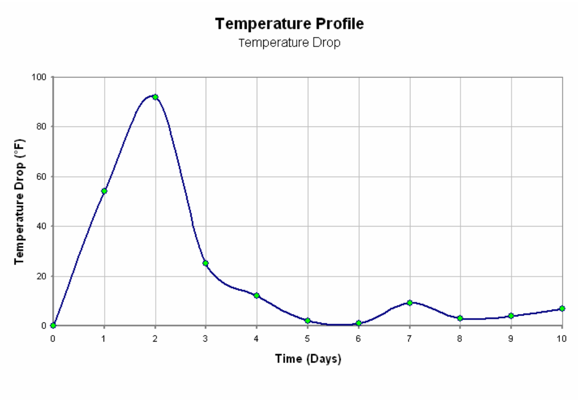


Figure # 10. Temperature Drop Profile only Soaking Time.

Over 80% of the temperature drop occurs in the first 3 days of initiation of the soaking time (Fig. 10), this delivery of energy to the vicinity of the reservoir is given in terms of several parameters which are listed below:

- The amount of energy injected.
- Heat capacity.
- Thermal conductivity.
- Porosity.
- Heat transfer coefficient.
- Saturations
- Heat transfer area.
- Differences in temperature.
- Density of the rock.
- Volume of clay.

These parameters affect the transmission of energy from the wellhead to the reservoir, and are responsibal for the magnitudes in the conduction or convection of heat in the affected area. In the case being analyzed (Fig. # 8) the energy injection at reservoir conditions was on the order of 83 BTU/L, taking into account the heat losses occurring in the well. This was calculated by using a regression model when you reach the original terms of reservoir, taking into account the energy loss time, annexed are the results:

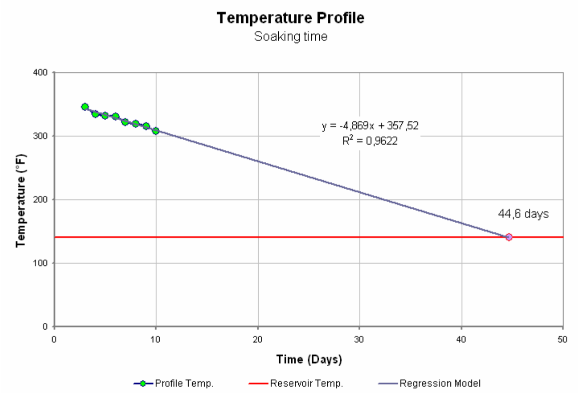


Figure # 11. Regression Model Soaking time

Points were used from the 3rd day of soaking time, which shows a better trend. We used mathematical models and they were evaluated according to their representative measure with the determination coefficient (R2). The linear regression resulted as the best fit , indicating that in 44.6 days (as correlation) we could decrease the temperature inside the well to the original magnitude. This confirms the comment that the energy dissipation occurs quickly from the well to the reservoir.

One of the key parameters for the transfer of heat to the reservoir, is the amount of energy injected, this was evaluated by phase locking the energy supply 2 additional cases with similar characteristics of rock and fluid, the first a project of continuous steam injection (CSI) with a volume of daily injection energy on the order of 51 BTU/L and the second using a heating cable (HC), in these 2 projects the well data were obtained using bottom hole sensors. Below is the graph with the CSS analyzed plus the 2 additional cases:

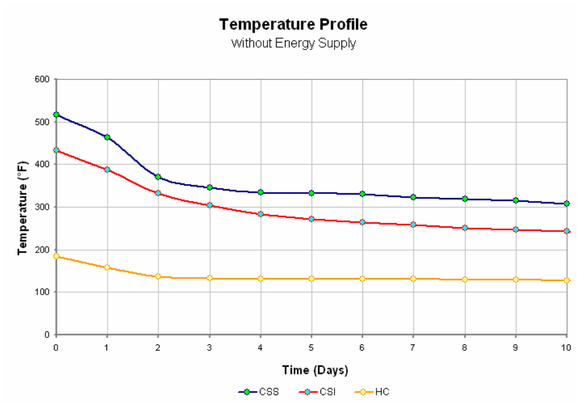


Figure # 12. Actual temperature profiles in 3 cases without energy supply.

Because the process definition is different in each case of Figure # 12, we took the time zero (0) profile in the closure of energy with the idea of revising the behavior in the temperature drop; this demonstrates that despite being injected at different rates of heat with different energy accumulated in each well, the sudden drop in temperature in the early days without supply of energy is clear in all cases, later there is a less tendency decrease. Below is the graph of temperature decline of the cases presented:

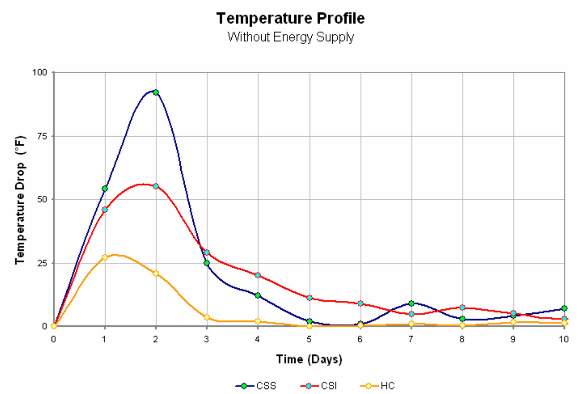


Figure # 13. Temperature drop profiles in 3 cases without energy supply.

The start of Figure # 13, shows the highest temperature drop in the closing of energy supply phase in the cases presented. Of the first 10 days, 80% in average of the temperature drop occurs until third day, as shown in the following chart:

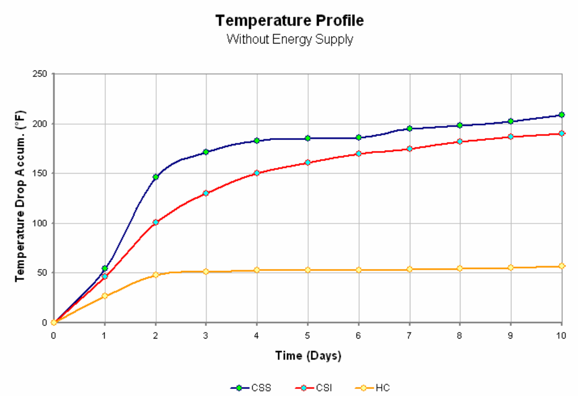


Figure # 14. Temperature drop Accumulated in 3 cases without energy supply.

According to this behavior the time with the well shut in the process of soaking in a cyclic steam stimulation should not be too high, considering that the delivery of energy from the wellbore to the reservoir is effective. Considering the data analyzed we could say that a good average would be 5 days of soaking, this will be sufficient to dissipate the energy supplied and to open the well. The suggested time is also sufficient so that the wellhead can be in conditions to be manipulated by staff to change the completion status of the well (injector to producer).

## Dynamic Simulation.

Dynamic Reservoir Simulation refers to the construction and operation of a model that incorporates all available information resulting from the implementation of integrated reservoir studies. To represent the production mechanisms active in the reservoir, and major geological features that allow adequately to reproduce the movement of fluids in the reservoir.

In the study we created a conceptual model which incorporates the average properties of the area under application of CSS. There are many variables that can be analyzed in a dynamic simulation, this paper was used in order to have computer references on the affects of soaking time in the cumulative production from a well, and if the variation in size can affect it. Annexed is steam injection data used in dynamic simulation:

| Soaking Time (days) * | Injection Rate (ton./day) | Injection Time (days) | Total Injection Volume (ton.) |
|---|---|---|---|
| 5 | 250 | 20 | 5000 |
| 10 | 250 | 20 | 5000 |
| 20 | 250 | 20 | 5000 |
| 30 | 250 | 20 | 5000 |
| 40 | 250 | 20 | 5000 |
| 50 | 250 | 20 | 5000 |

* Only varies the soaking time , the other elements remain constant

Figure # 15. Injection steam input data of the simulator.

The data shown above were selected by analyzing the operational statistics of steam injection in the Orinoco oil belt. Six simulation runs were conducted with the conceptual model in the STARS simulator of the Computer Modelling Group (CMG), yielding the following results:

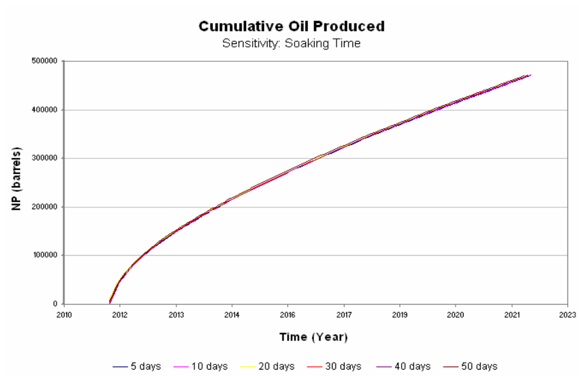


Figure # 16. Graphical representation of the simulation results.

The sensitivity analysis helps decision making substantially in specific situations, this is to evaluate the response of an indicator to the modification of a variable. Thus, taking the new behaviors, we can calculate or improve our estimates.

Sensitivities made with the soaking time (variable) show that the cumulative production (indicator) do not vary significantly, presented in full similar magnitudes. The idea for these simulation runs was to understand the impact of soaking time in the flow of fluids in the reservoir, and whether the increase of this magnitude would impact greatly on this.

## Conclusion

The activity of Cyclic Steam Stimulation has been widely used in the Orinoco Oil Belt. One of the parameters discussed was the time that the well had to stay shut in after a CSS, seeking where possible, to maximize the heat transfer to the reservoir and avoid the deferred volume or closure of production. With the definitions given and the actual data presented it is recommended to wait a period of 5 days of soaking time in such activities, considering the rapid spread of energy from the wellbore to the reservoir. This period is also long enough for safe manipulation at the wellhead by the completion technicians. The sensitivity on the conceptual model with the soaking time, clarified that it does not affect the cumulative production indicator, which is proportional to potential output and the recovery estimated by CSS.

## Acknowledgement

The authors would like to express their gratitude to PDVSA for permission to publish the data included in this paper. Also to engineers: Gleydis Rodriguez, Joanna Infante, Teofilo Villarroel and Carlos Herrera for their valuable assistance.

## Nomenclature

Psi = Pound per square inch
°F = Fahrenheit degree.
Ton. = Tons
CSS= Cyclic steam stimulation.
CSI= Continuous steam injection.
HC = Heating cable
BTU/L = British Thermal Unit / Volume (liter)
BTU/día = British Thermal Unit / Time (day).

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