WHOC12-216

Thermal analysis of completions for Cyclic Steam Injection used in San Tomé District. Orinoco Oil Belt.

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Abstract

The San Tome District, located in the Orinoco Oil Belt, has used cyclic steam injection for a long time. This method is based on injecting a limited volume of steam, in order to heat up the reservoir to reduce the fluid's viscosity and improve its mobility.

One of the key challenges in this recovery scheme is to make the heat injected reach the site with minimal loss, avoiding the transfer of energy to areas without interest, having the right type of completion used in the injection process vitaly important.

In San Tomé District various techniques of thermal completion desing have been evaluated in steam injection, two of them are currently being employed, the first lowering conventional steam injection tubing using nitrogen in the annular space, the second using insulated tubing (IT). Both types of completion based their efficiency in the use of insulation, indicating its effectiveness in reducing heat losses.

The main objective of this paper is to compare the thermal performance of the two completions, and describe with field data which is the most efficient. Also this paper will discuss the point of heating fluid by thermodynamic reasons occurred in a rod pumping well completed and how this effect can increase the temperature over 20 ° F to activation of the pump.

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 most commonly used method 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.

The surface heat loss is related to the generator and the pipes that carry the steam to the injector well, even when isolated. Inside the Well, these losses are related to the injection pipe and the casing, as the steam moves through the well there is heat loss due to the geothermal gradient and the injected fluid. Adjacent formations losses arise due to the high mobility of vapor and contact with the same formations above and below adjacent, supplying energy to zones without interest.

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 time condition.

Steam Injection

Steam injection has been used in the San Tomé District for over 20 years, the Bare field of extra-heavy oil is where this activity has grown more strongly, following is the location of the study area.

Figure N° 1. Study area.

The amount of oil recovered from the reservoir at which the Steam injection process is applied is closely related to the completion used in the injector, because it is responsible for the energy delivered to formation of interest . The choice and the proper design of the schemes completion of the wells drilled, are decisive part in the operational performance and production of a Field.

The well is the element that gives us the mechanical connection between the reservoir and the surface, being the medium through which performs the extraction of hydrocarbons, their depth, diameter and type of materials will be designed according to different parameters. The productivity of a well and its future productive life is affected by the type of completion and the work done during it. The selection of the completion has as main objective to get the maximum production in the most efficient scenario and therefore, should be carefully studied. The factors that determine the selection, such as:

- Production rate.
- Volume of reserves to development
- Production mechanisms.
- Need for stimulation.
- Sand Control
- Future repairs.
- Type of artificial lift.
- Projects enhanced oil recovery.
- Costs involved.

The efficiency and reliability of the link between the reservoir and the surface depend on the correct use of all the parameters that comprise, so one could speak of well productivity in terms of completion, which includes an analysis of its mechanical condition and economic returns to justify their existence.

About the completion well for cyclic steam injection, the San Tomé District have used most often two (2) types, the first mentioned below is using conventional injection pipe using nitrogen in the annular as an insulator:

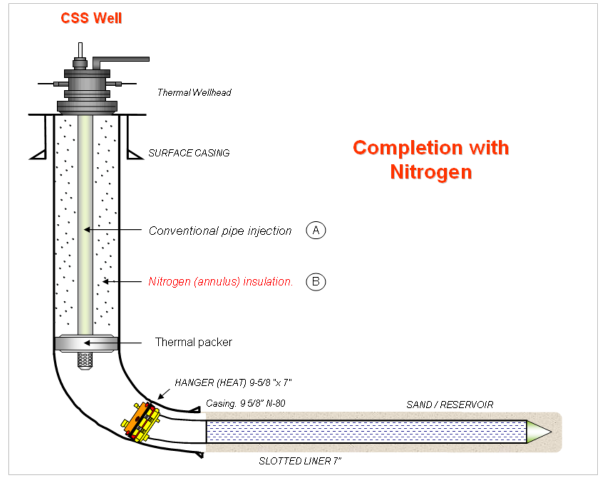

Figure N° 2. Completion using nitrogen as an insulator

As shown in the completion diagram, at point "A" is located conventional injection pipe, its diameter varies according to the restrictions in the well, in the annular "B" will inject more nitrogen as insulation to prevent heat losses through the walls of the injection pipe. The second configuration completion shown below:

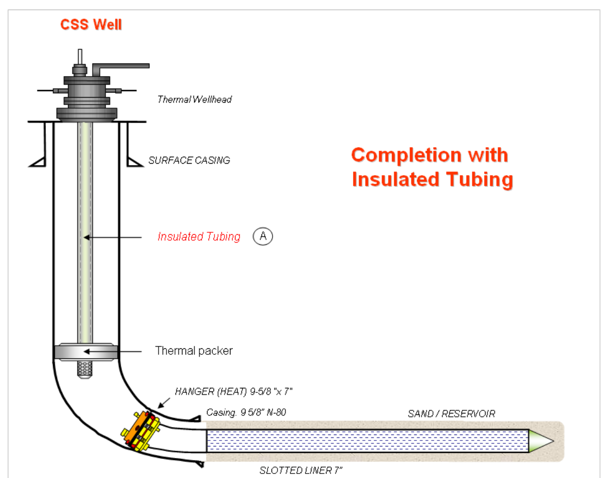

Figure N° 3. Typical IT Completion for Bare Field.

In this latter configuration is using insulated tubing "A", which consists of different layers of insulation, forming a ring which is under vacuum, thereby reducing heat transfer with other zones.

Heat Transfer

Heat flow 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. 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 transfer.

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 transfer, in the annular space in one of the completions has nitrogen as an insulator, and the other alternating Completion for cyclic steam injection have insulated tubing, giving two (2) mechanical schemes of injection which are presented below:

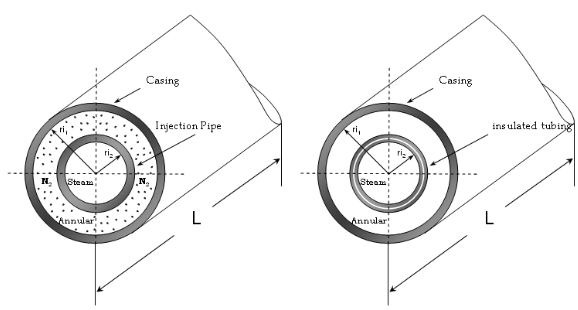

Figure N° 4. Mechanical schemes of steam injection.

Steam Properties

Thermodynamics is the branch of natural science concerned with heat and its relation to other forms of energy and work. It defines macroscopic variables (such as temperature, entropy, and pressure) that describe average properties of material bodies and radiation, and explains how they are related and by what laws they change with time. Thermodynamics does not describe the microscopic constituents of matter, and its laws can be derived from statistical mechanics.

Thermodynamics can be applied to a wide variety of topics in science and engineering, such as engines, phase transitions, chemical reactions, transport phenomena, and even black holes.

As the temperature increases and the water approaches its boiling condition, some molecules attain enough kinetic energy to reach velocities that allow them to momentarily escape from the liquid into the space above the surface, before falling back into the liquid. Further heating causes greater excitation and the number of molecules with enough energy to leave the liquid increases. As the water is heated to its boiling point, bubbles of steam form within it and rise to break through the surface.

Considering the molecular arrangement of liquids and vapours, it is logical that the density of steam is much less than that of water, because the steam molecules are further apart from one another. The space immediately above the water surface thus becomes filled with less dense steam molecules. When the number of molecules leaving the liquid surface is more than those re-entering, the water freely evaporates. At this point it has reached boiling point or its saturation temperature, as it is saturated with heat energy. If the pressure remains constant, adding more heat does not cause the temperature to rise any further but causes the water to form saturated steam. The temperature of the boiling water and saturated steam within the same system is the same, but the heat energy per unit mass is much greater in the steam.

At atmospheric pressure the saturation temperature is about 100°C. However, if the pressure is increased, this will allow the addition of more heat and an increase in temperature without a change of phase.

Therefore, increasing the pressure effectively increases both the enthalpy of water, and the saturation temperature. The relationship between the saturation temperature and the pressure is known as the steam saturation curve (see Figure 5).

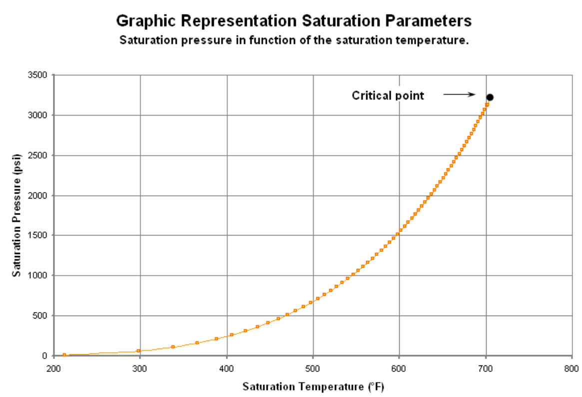

Figure N° 5. Saturation pressure vs saturation Temperature for Water.

Water and steam can coexist at any pressure on this curve, both being at the saturation temperature. Steam at a condition above the saturation curve is known as superheated steam:

• Temperature above saturation temperature is called the degree of superheat of the steam.

• Water at a condition below the curve is called sub-saturated water.

If the steam is able to flow from the boiler at the same rate that it is produced, the addition of further heat simply increases the rate of production. If the steam is restrained from leaving the boiler, and the heat input rate is maintained, the energy flowing into the boiler will be greater than the energy flowing out. This excess energy raises the pressure, in turn allowing the saturation temperature to rise, as the temperature of saturated steam correlates to its pressure.

Enthalpy of evaporation or latent heat (hfg): This is the amount of heat required to change the state of water at its boiling temperature, into steam. It involves no change in the temperature of the steam/water mixture, and all the energy is used to change the state from liquid (water) to vapour (saturated steam).

The old term latent heat is based on the fact that although heat was added, there was no change in temperature. However, the accepted term is now enthalpy of evaporation.

Like the phase change from ice to water, the process of evaporation is also reversible. The same amount of heat that produced the steam is released back to its surroundings during condensation, when steam meets any surface at a lower temperature. This may be considered as the useful portion of heat in the steam for heating purposes, as it is that portion of the total heat in the steam that is extracted when the steam condenses back to water.

Enthalpy of saturated steam, or total heat of saturated steam: At the saturation temperature the water can coexist in liquid and in vapor state, depending on their heat content, their enthalpy. The mixture of steam and water coexist at the saturation temperature, is called wet steam and characterized by vapor content in the mixture, expressed as a fraction of the total weight of the quality. Thus the dry and saturated steam is 100% quality since there is no liquid water, whereas water can be regarded as saturated with moisture vapor quality equal to zero. Vapor qualities between these extremes is called simply wet steam.

The enthalpy or heat content of the wet steam depends heavily on the quality, particularly at low pressures, where the enthalpy of saturated water is low. Since the moisture vapor enthalpy is intermediate between that of water vapor saturated and dry and saturated, this is given by:

$$hg = hf + hfg \qquad \text{Equation 1}$$

Where:
hg = Total enthalpy of saturated steam (Total heat) (kJ/kg)
hf = Liquid enthalpy (Sensible heat) (kJ/kg)
hfg = Enthalpy of evaporation (Latent heat) (kJ/kg)

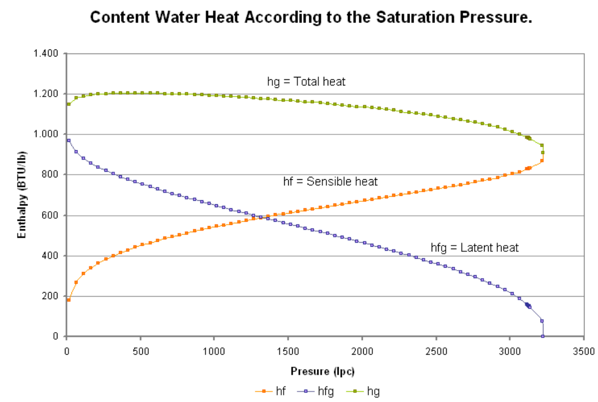

Figure N° 6. Saturated Water Heat Content.

the above figure shows the variation of the total heat (sensible+latent) in the water with respect to the saturation pressure, as relevant point while the saturation pressure increases, decreases latent heat and increases sensitive heat, this is because at high pressures the spacing between the molecules is reduced.

Steam quality plays a relevant point in energy efficiency, since this determines the fraction of total enthalpy of mixing. In San Tome District injected steam quality is 80%, this indicates that the vapor contains 20% saturated liquid water, thereby maintaining solid impurities in solution which can be harmful to the steam generation system and provides hydrostatic head as well.

Once generated the steam, one of the objectives of the completion of the injection well is to preserve the energy and transport to the reservoir minimizing heat losses by using insulating materials or low thermal conductivity. Here are presented some thermodynamic calculations taking into account energy loss and its impact on the quality of the steam:

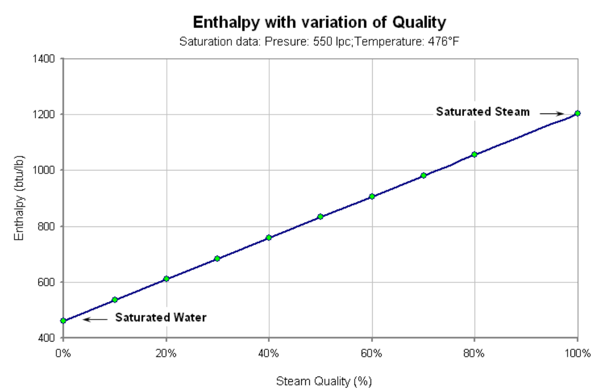

Figure N° 7. Enthalpy with variation of the steam quality.

With pressure data at 550 psi and a saturation temperature of 476 °F were calculated enthalpies using tables and thermodynamic equations, as evidenced by the graph No. 6, at the same conditions of pressure and temperature, the total heat of the mixture varies significantly from 1204 Btu / lb (saturated steam) to 460 Btu / lb (water saturated), only varying the quality of 100% to 0%. Below is the graph with the energy lost by each level of quality of steam:

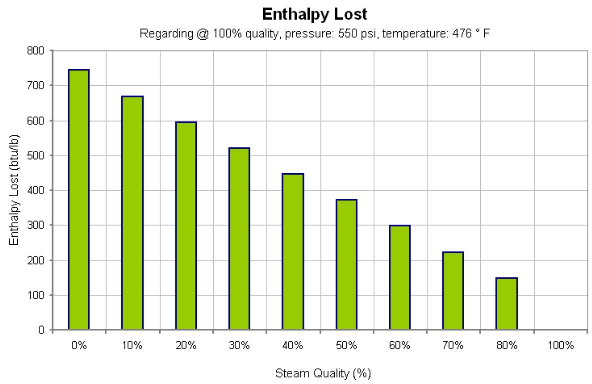

Figure N° 8. Total enthalpy loss with variation of the steam quality.

In the above figure we observe the behavior proportional between the loss of enthalpy and the decrease of the steam quality , note that this assessment was made with respect to 100% quality, that is why at that point the losses are zero (0). At the point of 0% is shown as the largest energy loss on the order of 744Btu/lb (1204 Btu / lb - 460Btu/lb), representing almost 60% this loss of energy of the mixture.

As heat losses (with quality) are comparable for different injection rates, the higher the injection rate, higher the downhole quality considering similar wellbore heat losses

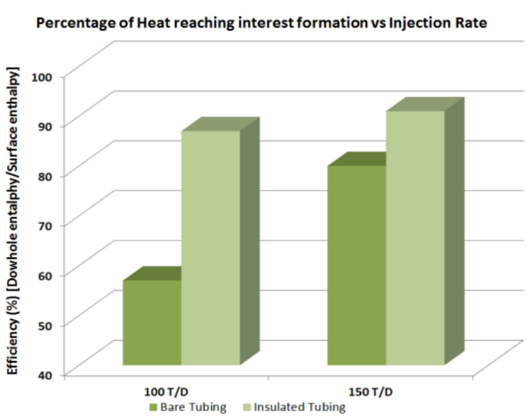

Figure N° 9. Heat Losses, 30 Days, Conventional Tubing and IT 100 and 150 T/D

The energy generated must be preserved and delivered to the pay zones, preventing its dissipation in areas of no interest, since this would represent an equivalent volume of fuel used to generate heat that will not reach zones of interest and with negative impact into the overall process efficiency, and its ultimate impact on the recovery factor. There might be as well mechanical problems caused in downhole raise in temperature in unsuitable areas (casing / cement).

The data the heat losses were converted to equivalent barrels of oil per year per each 100 TON/day of injected steam. This value is also related to the tons of CO2 (equivalent) that could have been saved.

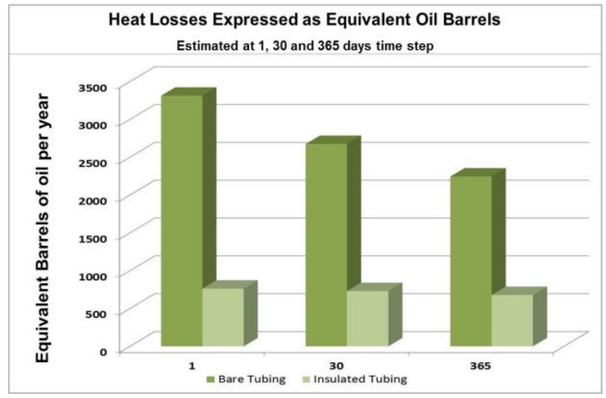

Figure N° 10. Heat losses in equivalent BOPD Vs Time

Each fraction of energy transported to the reservoir will have its impact on oil production, which is why the preservation of this energy must be carefully analyzed and studied by the engineers in charge of the steam injection projects.

Evaluation of injection wells completions

Insulated Tubing: In a steam injection well, completed with this type of configuration, optical fiber was employed for data acquisition of temperature to which was recorded continuously every 5 minutes generating a temperature profile with 3600 data points. Each temperature reading may be performed by meter (3.28 feet) along the wellbore. The fiber had an additional protection provided by a metal control line of 0.63 cm (1/4 inch) diameter, inside which is housed. See Figure N ° 11.

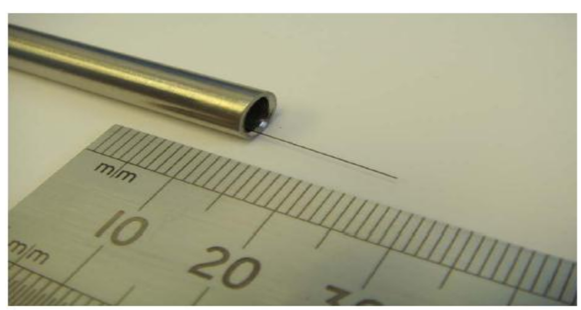

Figure N° 11. Photo of Fiber Optics and its control line.

This continued measurement allowed obtaining accurate data for the study of the efficiency of this type of completion, allowing controls and diagnosis in real time. At the completion of the injection well was employed a double ended fiber, in this case the fiber is pumped hydraulically by the control line ¼ inch, about a U-shaped tube and back to the surface, providing this increased flexibility and accuracy. This was done to measure the actual temperature at different times, Annex graph:

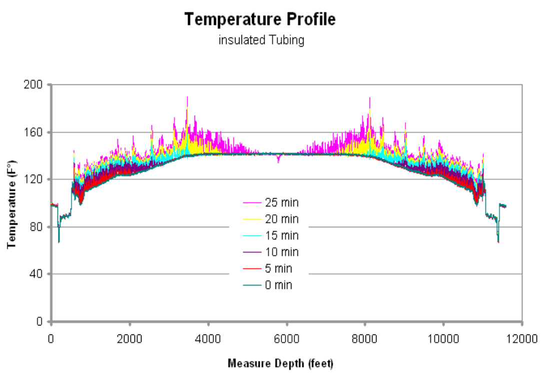

Figure N° 12. Temperature Profile Insulated Tubing.

Figure 13 represents temperature variation respect to the initial temperature. For the early stage of injection it exhibits a small rise of temperature. A few lost of enthalpy is then estimated to occur throughout the section of pipe

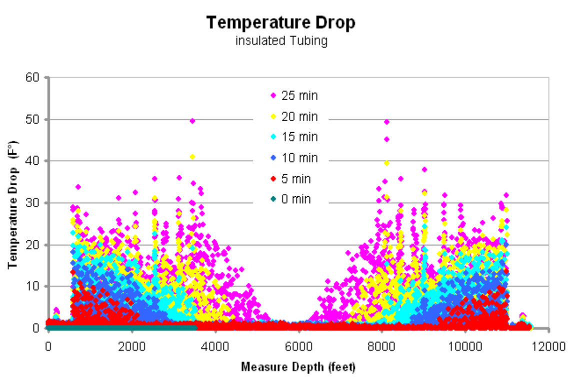

Figure N° 13. Temperature Profile Insulated Tubing.

With the data obtained, we note that the early stage og the injection that the temperature increase was about 30 ° F, which seems to validate that this type of completions (IT) is very efficient. This low loss will cause the injected fluid arrives with more enthalpy at the area of interest.

Conventional completion and Insulated Tubing: This section assessed various indicators between the two (2) types of completions that are used in the District San Tome, the idea is to review and describe the differences in the use of each, annex the indicators used:.

- Steam quality: was calculated the behavior of the steam quality and its relation with time (1, 30 and 365 days), according to each type of completion (conventional and insulated).
- Enthalpy Total: With Equation 1, which involves the latent heat, sensible heat and steam quality was calculated total enthalpy taking into account each completion and its effect over time.
- Drop enthalpy: This indicator was calculated with the difference of the original enthalpy and enthalpy with losses at each depth, representing the energy lost steam in the injection phase.
- Lost Heat: according to the enthalpy drop was calculated how much represents this in heat lost per day, which is proportional to the volume of oil without heating.
- Energy Efficiency: This section will compare the transport efficiency of steam (high temperature) for each completion, resulting in which will lose more or less energy.

The first indicator evaluated was the steam quality, considering a quality of 80% in surface was calculated its variation by each completion, the conventional completion at depths greater than 5000 feet (MD) this decreased at 0% quality the first day of injection, clear evidence that could be injecting hot water instead of steam (Fig. No. 19). Using the insulated tubing we have an energy conservation because the quality drops in values close to 60%. And this does not change much over time.

Starting with an enthalpy of about 1060 BTU/lb at the surface (80% quality) the evaluation of this parameter was that using insulated tubing we will have greater magnitud to reservoir condition., injecting about 946 BTU/lb, Unlike using completion conventional, since it only reaches the area of interest 506 BTU/lb (saturated water) the first day and 685 Btu/lb about one year after injection starts (see Fig. 20).

According to the enthalpy drop, we have that with conventional completion losses exceeded 553 Btu/ lb in the early days of injection, this will decrease as time passes (see Fig. # 21). As regards the pre-insulated pipes this drop is low, around 127Btu/lb, representing a good level of operation. This enthalpy loss is proportional to the heat that is not injected, having that with conventional completion heat losses are high compared with insulated tubing (see fig. # 22).

As a last indicator we have the energy efficiency, with is conventional completion of the order of 45%, leaving only sensible heat, can get 65% a year after starting the injection. With insulated tubing, this type of completion has efficiency in the order of 85-90%, which does not vary significantly with time (see fig. # 23).

Adiabatic Compression Heating

One point we wanted to describe in this paper is the effect of heating for adiabatic compression observed in a lift system by mechanical pumping. This was observed in a well completed with optical fiber, with the same description as the previous case. Below is the temperature profile obtained by the optical fiber before activation of pump.

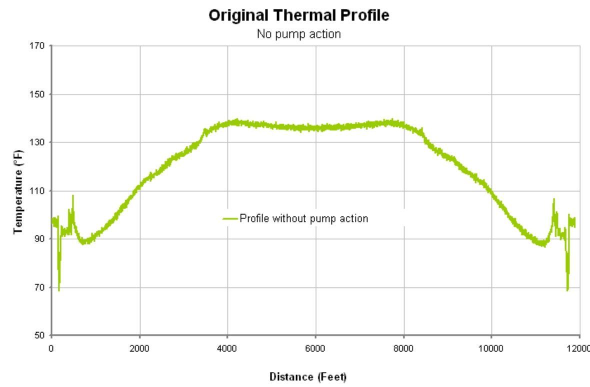

Figure N° 14. Original Thermal profile.

The profile above is repeated on each side (butterfly graph), with a well end close to 5940 feet. After completing the well and the different sensors calibrated, was activated the pump, observing the following:

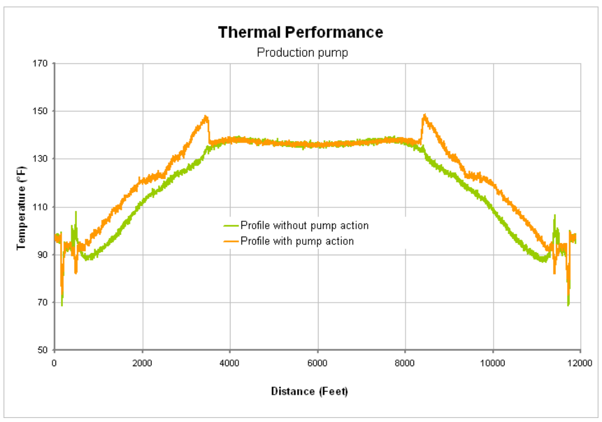

Figure N° 15. Thermal profile (pump action)

The previous figure (N° 15.) shows two curves, the green being the original temperature profile without pumping action and the orange was obtained upon commissioning the pump, The differences represents the incremental temperature between the seating of the pump (3504 feet) to the wellhead (630 feet).

This temperature variation was calculated according to the stabilization point resulting the following:

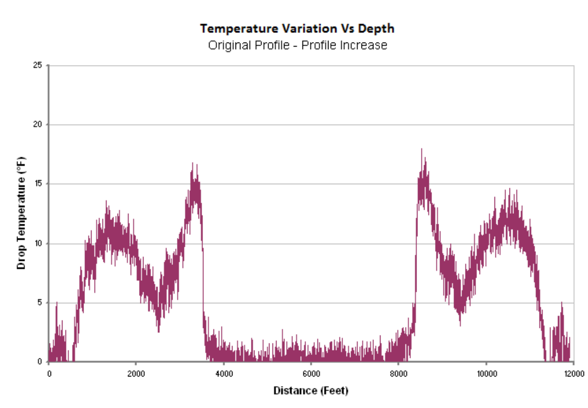

Figure N° 16. Temperature drop between original profile and the profile with pump action.

The area with drop 0° F (from 3820 feet to 5940 feet approx), is the reservoir interval, because the pump is operated above this level, the reservoir is not affected by this increase of heat. In the setpoint of the pump is observed highest temperature by the order of 15 ° F, oscillating in this value until wellhead.

In order to better analyze the real behavior of the temperature, was done a graph leaving to constant depth the pump. and thus represent the behavior of the temperature with respect to time. Getting the following:.

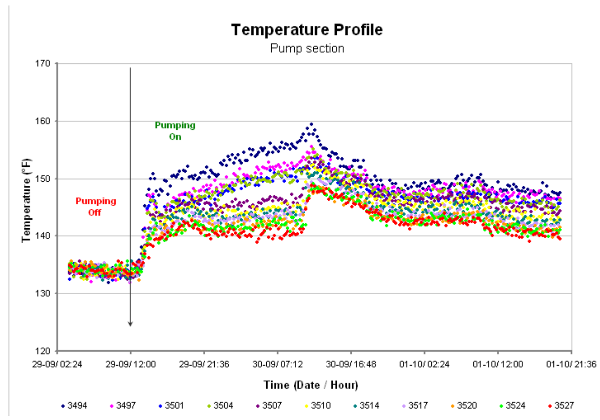

Figure N° 17. Temperature Profile interval pump (constant depth)

The top of the graph corresponds to the top of the pump (blue dots) and the lower part corresponds to the pump base (red dots). Analyzing the chart above we have that less depth profiles have a slope greater of increase of temperature, considering under pump the fluid has original condition and that as the piston rises loaded with fluid the adiabatic compression effect and the mechanical friction have generated heat, increasing their temperature more easily.

Some arithmetic calculations were performed with the idea of establishing a pattern of overall effect of the lift system with respect to temperature yielding the following:

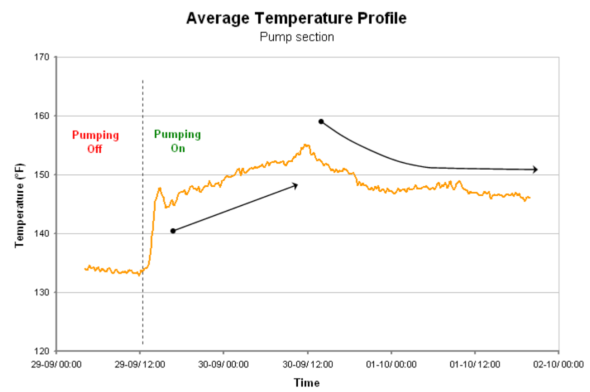

Figure N° 18. Average temperature profile above and below Sucker Rod Pump.

Figure 18 represents the temperature increase after the pumping action begins. It raises sharp its peak value within 1 day and then becomes stable. This profile is assumed to be related with the fluids been pumped (completion fluids, gas, crude oil). Further investigation is in progress to determine whether these values plus other parameters can be used to estimate a synthetic multiphase test .

Conclusion

In the San Tome District are commonly used two types of well completions, which have a significant difference in terms of energy efficiency. According to the calculations shown the insulated tubing is the one with the best properties as they have less heat loss, which affects quality, enthalpy and, energy efficiency among others.

Conventional completion has low efficiency when used in short times, and for low injection rates since the lost heat is very high, affecting largely the thermodynamic parameters of the vapor and ultimate efficiency and project economics.

Extra Heat Losses when comparing conventional completion to IT can represent a significant amount of oil used as additional fuel. Additional to that the overall project efficiency will be reduced and potential reservoir problems may arise when injecting hot water instead of saturated steam.

Reduced casing temperature due to the effect of IT allows operator to inject into wells with non-thermal cement or lower grade casing with some completion considerations.

Adiabatic compression effect was evident a temperature rise in a well in the order of 10-15 ° F, is an energy that is generated as a result of the use of mechanical pumping unit. Further analysis is required to establish a pattern that can be used to estimate fluid production.

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 and Hector San Martin for their valuable assistance.

Nomenclature

Psi = Pound per square inch
°F = Fahrenheit degree.
Ton. = Tons
MMBtu = Million British Thermal Unit

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Appendix

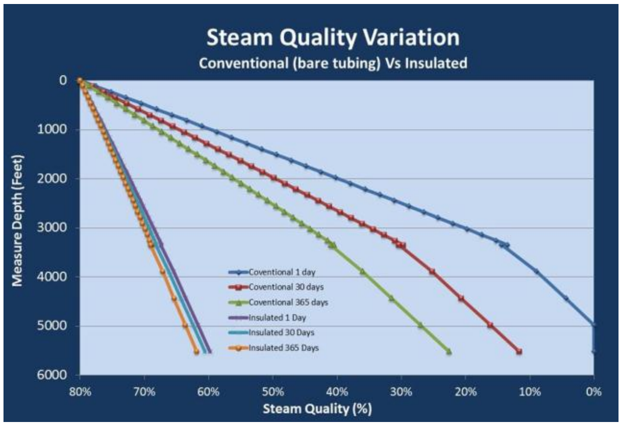

Figure N° 19. Steam Quality Variation

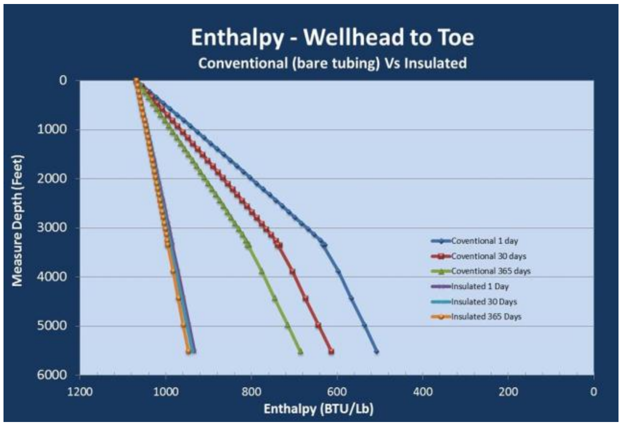

Figure N° 20. Enthalpy Variation

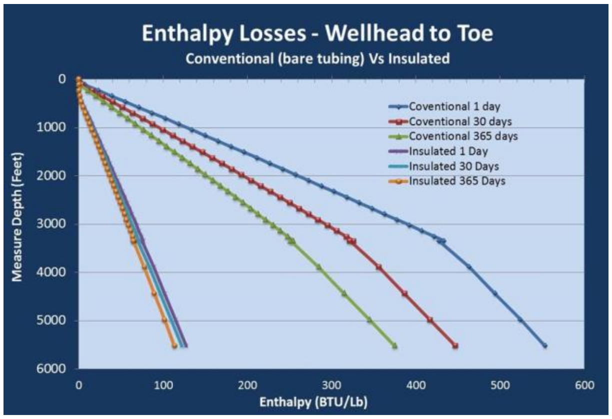

Figure N° 21. Enthalpy Losses. IT compared to standard tubing

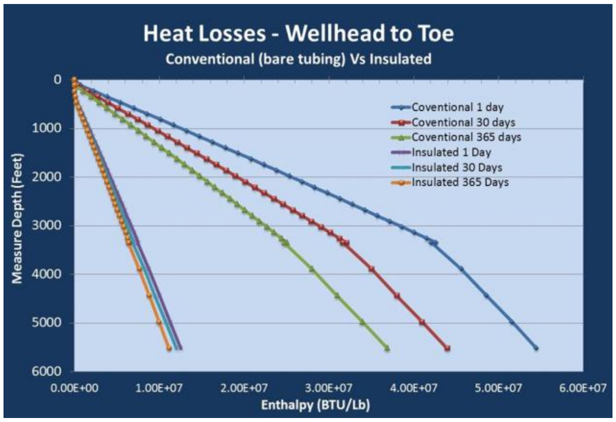

Figure N° 22. Comparison of heat losses using conventional completion vs IT.

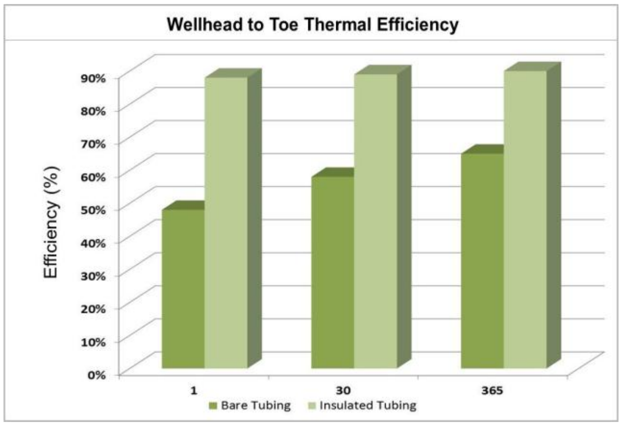

Figure N° 23. Wellhead to Toe (5521’) Energy Efficiency