Production logs in horizontal wells-case study of a developed field

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Abstract

Horizontal completions present a challenge in terms of the interpretation of their flow profile. This paper discusses production logging technology for horizontal wells whit and the results obtained using this technology in a well in a developed field, the deviation of which varied from 83 to 94° in the productive zone and where the contribution of the productive intervals of each fracturing cluster was identified and evaluated. The three fracturing techniques used (hybrid, slick water, and conventional) are compared to select the best technique for future wells. In this study, we observed that production is highly variable along the length of the wellbores, and that the number of clusters does not correspond to the number of fractures, that is to say, we could have seven clusters open but not all fractured and/or producing.

Keywords: Production logs, horizontal wells, mature field, developed field, horizontal wells.

Registros de producción en pozos horizontales - caso campo maduro

Resumen

La terminación horizontal representa un reto en la interpretación de su perfil de flujo. En este trabajo se presenta la tecnología de registros de producción para pozos horizontales y los resultados obtenidos con esta tecnología en un pozo de un campo maduro cuya desviación variaba entre 83° a 94° en la zona productora, donde se identificó y evaluó la aportación de los intervalos productores de cada clauster de fracturamiento y se compararon las tres técnicas de fracturamiento empleadas, (híbrida, slick water, convencional), para seleccionar la mejor técnica para futuros pozos. En este estudio, se observó que la producción es altamente variable a lo largo de la longitud del pozo, y que el número de clauster no corresponde al número de fracturas abiertas, es decir, podríamos tener siete clauster abiertos, pero no todos fracturados y/o productores.

Palabras clave: Desarrollo y optimización de la explotación de campos, campos maduros, registros de producción, pozos horizontales.

Introduction

At the present time, many producing wells have been completed in developed fields. These wells, despite being in fields that are in their final production phase, could possibly have remaining potential if their operability is optimized with the application of adequate technology. If these wells are not evaluated for production optimization, they are likely to be scheduled for abandonment. Therefore, to increase reserves, production, and profitability, and to take full advantage of the installed capacity of these developed fields, an effective evaluation of the wells drilled in those fields is necessary. To achieve this, adequate tools are required that will allow diagnosing the reasons for the low production of these wells to determine the best treatment and/or repair options available, and in so doing prolong their useful life.

In this paper, a horizontal well drilled in a developed field is discussed, for which it was possible to maintain a viable production cost even when the well was 75% depleted from its initial production phase. The flow of fluids was influenced by the deviation angle within the horizontal section, **Figure 1**, and the well was practically full of semi-static water, which caused the phenomenon of an apparent reverse flow, **Figure 2**, making evaluation difficult with the use of a production logging tool (PLT) string configured only with conventional sensors, (pressure, temperature, fullbore spinner, inline spinner, density, and capacitance), which perform measurements in the center of the well's transverse area.

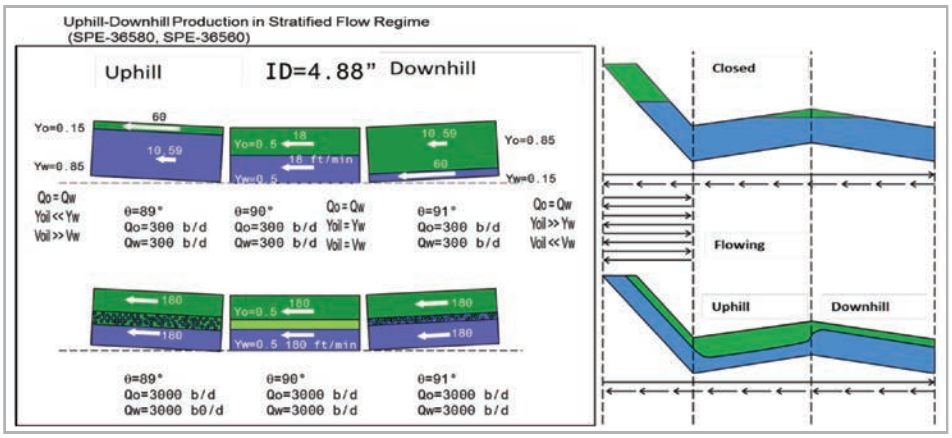

Figure 1. Deviation effect in horizontal wells, (from Theron and Unwin 1996).

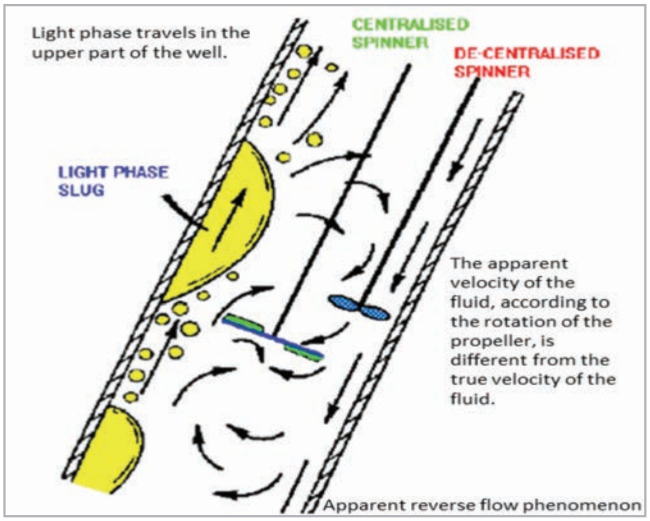

Figure 2. Apparent reverse flow phenomenon.

The well also shows, as its principal flow scheme, a stratification of phases, which occurs in many wells, from highly directional to horizontal wells, including wells with little deviation, when flows are low; the lightest phase migrates to the high part of the well and the heaviest phase migrates to the low part of the well.

One of the characteristics of stratified flow is that the holdup and velocity of each phase can change drastically with small changes in the deviation of the well, (Lenn et al. 1996). The stratification of phases makes quantification of the produced flows difficult. For this reason, to establish the flow profile and more precisely determine the productive performance of the production intervals of horizontal wells, tools that allow for the viewing and calculation of the flow volume of each phase need to be used, with the holdups and velocities developed by each phase according to their distribution in the transverse section of the well and along its entire length (Figure 3). These types of tools are called "array tools," because they use sensors distributed around the periphery of the well to identify the type of fluids produced and measure their velocity. These tools include the following: spinner array tool (SAT), capacitance array tool (CAT), and resistance array tool, (RAT).

At this time, both flexible piping and tractors are used to lower the PLT tools into horizontal wells, (Al-Belowi et al. 2010).

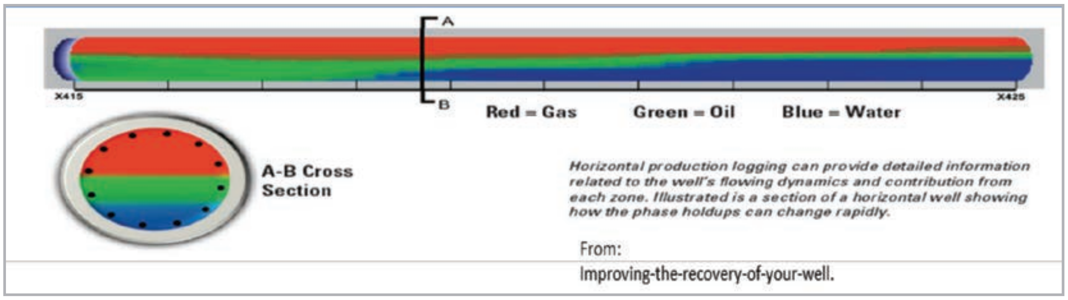

Figure 3. Distribution of phases in the horizontal section of a well.

Spinner Array Tool, (SAT)

This tool is designed to resolve the problem of measuring the velocity of fluid in horizontal or highly deviated wells. The tool has an array of six minispinners coupled in flexible centralizers. Each spinner measures the velocity of the fluid and the direction in which the phases are flowing, **Figure 4**.

Figure 4. Spinner array tool (SAT).

Capacitance Array Tool, (CAT)

This tool is designed to resolve problems involving the identification of phases in horizontal or highly deviated wells. Its measurement principle is based on the difference between the dielectric constants of oil, gas, and water. The tool has a radial array of 12 minicapacitors mounted in flexible folding centralizers, which monitor the distribution of the fluids in the well. Each sensor in the array measures the capacitance of the fluid in the well, **Figure 5**.

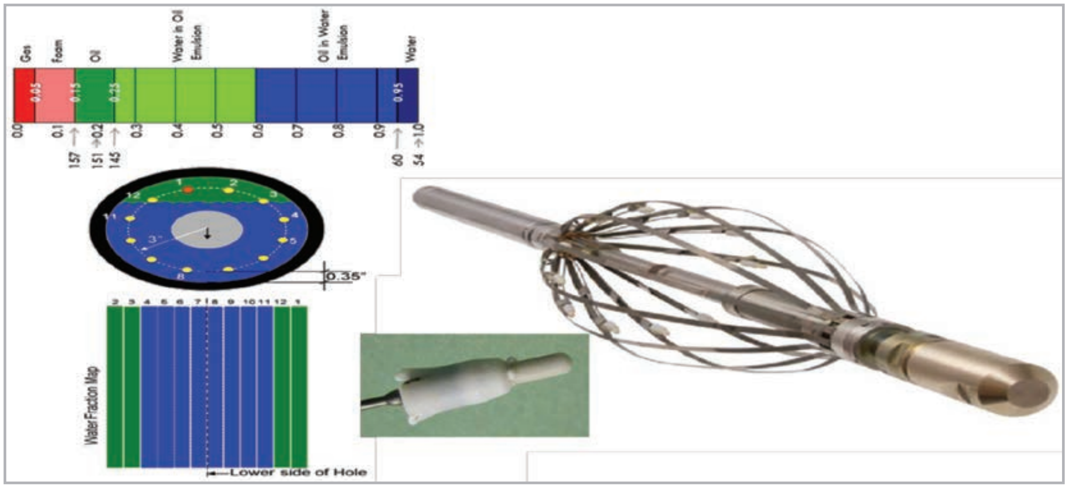

Figure 5. Capacitance array tool (CAT).

Resistance Array Tool, (RAT)

This tool, **Figure 6** is used to determine the holdup of water in a transverse section of piping in wells with any degree of deviation, from vertical to horizontal, and with any flow scheme. The tool has a radial array of 12 miniature resistive sensors that are mounted on flexible collapsible centralizers, which monitor the distribution of fluids in the well. The RAT differentiates between conductive water and hydrocarbons, which are not conductive. The sensor detects small and rapid bubbles of movement.

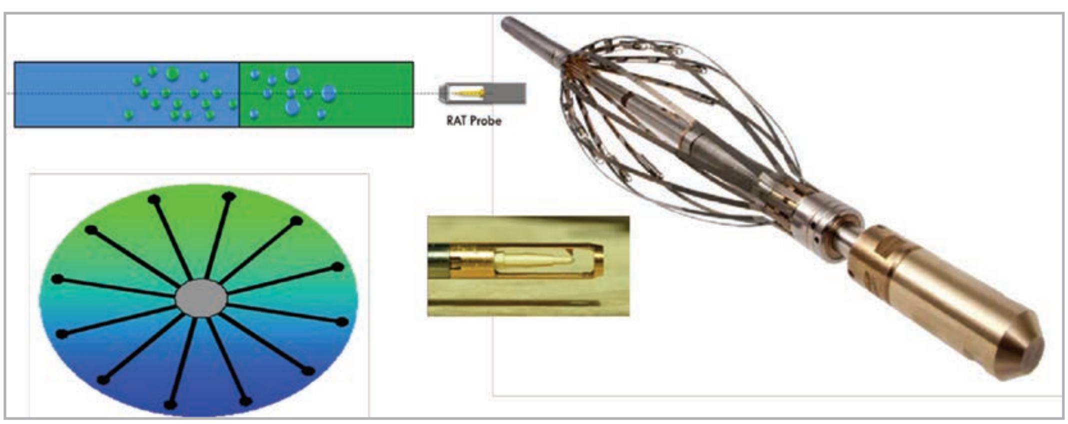

Figure 6. Resistance array tool, (RAT).

Production log—case study of a developed field

The well in this study was drilled horizontally. The well's deviation within the productive zones varies between 83 and 94°, according to the directional log. It is a gas and oil producer of the Paleocene and completed with a cemented 4 1/2-in, (monobore) liner. Seven fracturing phases were performed, and each had three intervals of 1 m, for a total of 21 fractures distributed along 690 m of a horizontal section, **Figures 7** and **8**.

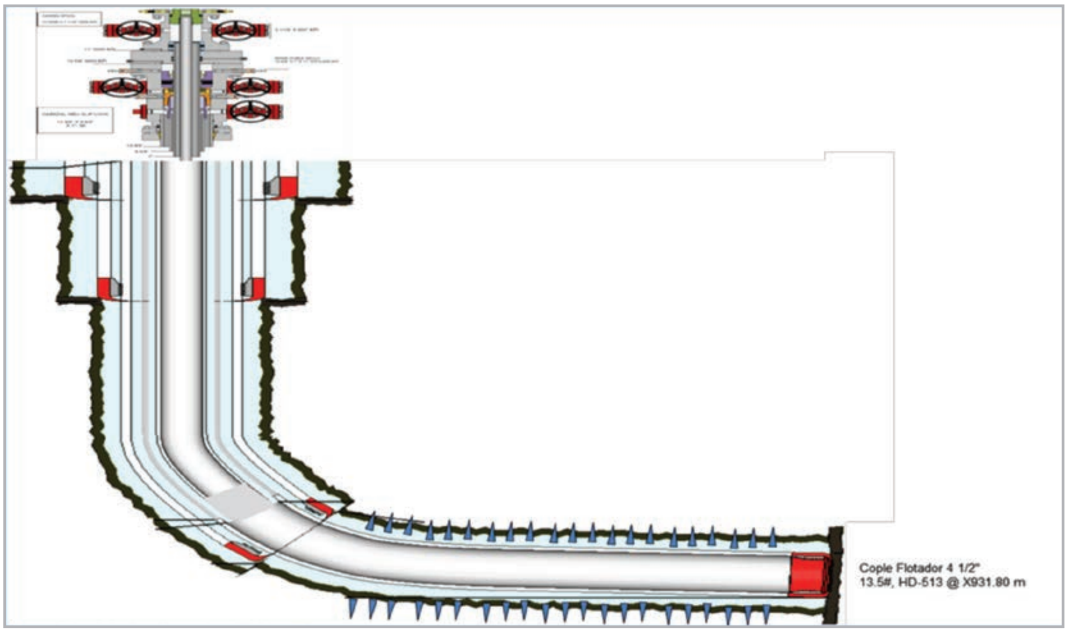

Figure 7. Mechanical state of the well.

	FRACTURE GEOMETRIES																				
Cluster	1			2			3			4			5			6			7		
Fracturing Techniques	Hibrid						Slick Water						Conventional								
No Fractures	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Interval	x899-x900	x864-x865	x828-x829	x790-x791	x755-x756	x721-x722	x668-x669	x639-x640	x611-x612	x584-x585	x552-x553	x511-x512	x479-x480	x443-x444	x409-x410	x378-x379	x342-x343	x306-x307	x275-x276	x241-x242	x213-x214
Propped Length (m)	113	123	118	131	159	159	138	166	161	163	163	162	79	93	121	81	92	76	78	75	81
Propped Height (m)	34	30	31	32	28	28	39	35	36	38	36	40	25	25	23	27	29	29	34	33	34
Conductivity (mD-ft)	1747	1946	1945	797	844	842	404	386	370	522	477	489	1931	1600	1416	1630	1208	1364	1533	1356	1098

Figure 8. Fracturing geometries.

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The optimization of the number of fractures in an initial stage (before the execution) is decided through the study of the reservoir with some software (for our case Quicklook). Reservoir properties (production of neighboring zones, PVT information, etc.) are taken into account, the simulation is loaded by performing iterations to different numbers of fractures. During this analysis, the type of termination, (vertical well, diverted well, horizontal well), and the number of fracture stages are selected, in order to finally select the best economic technical option.

The reason why it was decided to make a design of this type in this well was to prove that treatment would be more effective. The most fragile zones were designed with Slick water fluid (brine + friction reducer), those of medium fragility were hybrid (linear + activated) and the less fragile (more ductile) were conventional (activated fluid).

Operative challenge

The operator required identifying and evaluating the contribution of the productive zones of each fracturing cluster, as well as a comparison of the three fracturing techniques used (hybrid, slickwater and conventional), to establish the best plan of action for the present condition of the well and determine the best technique for future wells.

Solution and analysis procedure

To identify and evaluate the production of the 21 fractures distributed along the 690 m of the horizontal section of the horizontal well being studied and to assess the fracturing techniques employed, the solution proposed to the operator was to lower a PLT string of flexible piping, fitted with conventional sensors and the SAT, CAT, and RAT, to measure the parameters at different locations, thereby identifying the distribution of the phases and their velocities inside the horizontal pipe, **Figure 9**.

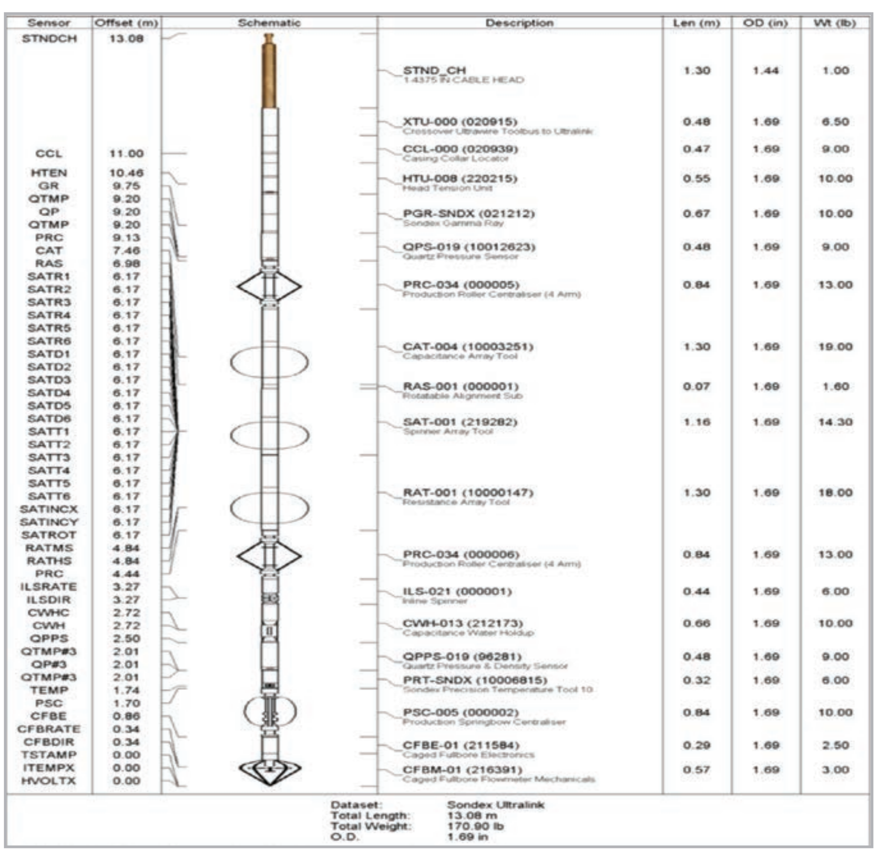


Figure 9. Diagram of the PLT string used.

Initially, from the temperature log and SAT spinner, it was determined which of the 21 fractures distributed along the horizontal section were apparently contributing fluids. Also, toward the end of the well's horizontal section, **Figure 10**, point I, a high capacitance reading was observed, indicating the presence of hydrocarbons.

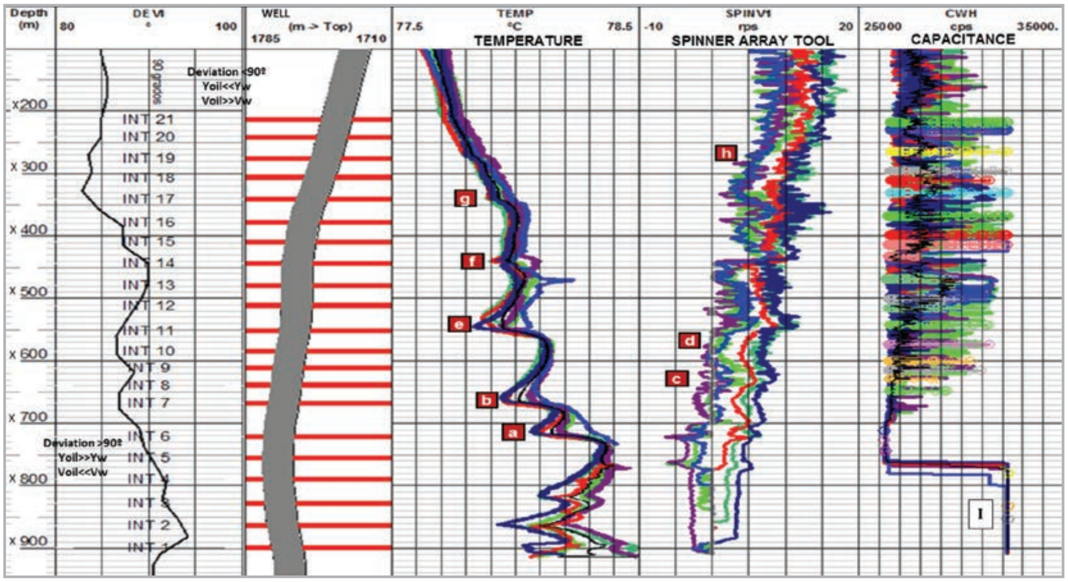


Figure 10. Conventional profile curves.

After performing a qualitative evaluation of the curves, the information was processed and images were obtained, **Figure 11**, showing the holdup and velocity of the fluid.

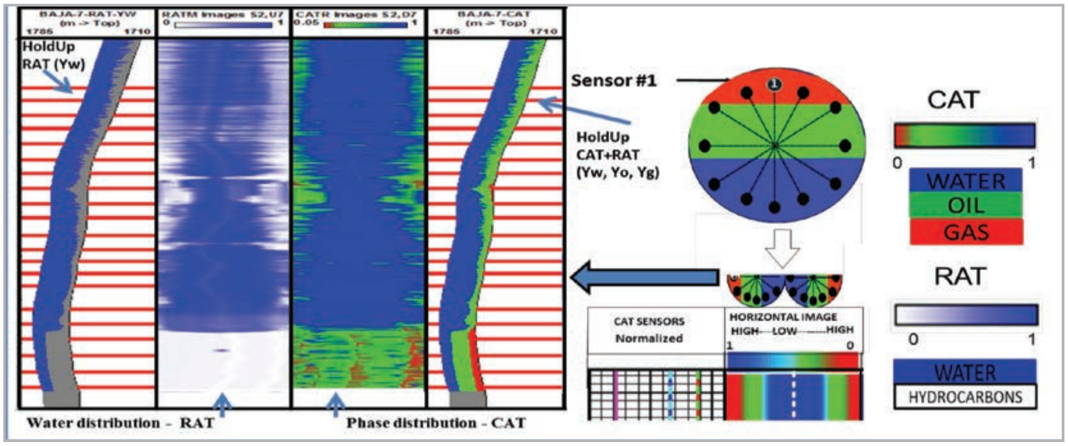


Figure 11. Horizontal format: CAT and RAT images.

VOL. 57 No. 5, SEPTIEMBRE-OCTUBRE 2017 · ISSN 0185-3899

The images are shown in horizontal format, (Figure 11), representing the low side of the piping in the center of the image and the high part of the piping at the ends. To the right, a view of the well is shown. These views only represent the percentage of the piping that is occupied by each of the phases, (hangup or holdup).

The CAT image is based on normalized data, in which the water is represented in blue, oil in green, and gas in red. The RAT uses blue to indicate water and green to indicate hydrocarbons, (Frisch et al. 2009).

The RAT and CAT array sensors used for the identification of phases, **Figure 12**, detected the presence of a high volume of water in the 4 1/2-in, liner pipe, (point A). They also identified an accumulation of hydrocarbons toward the end of the horizontal section, (point B).

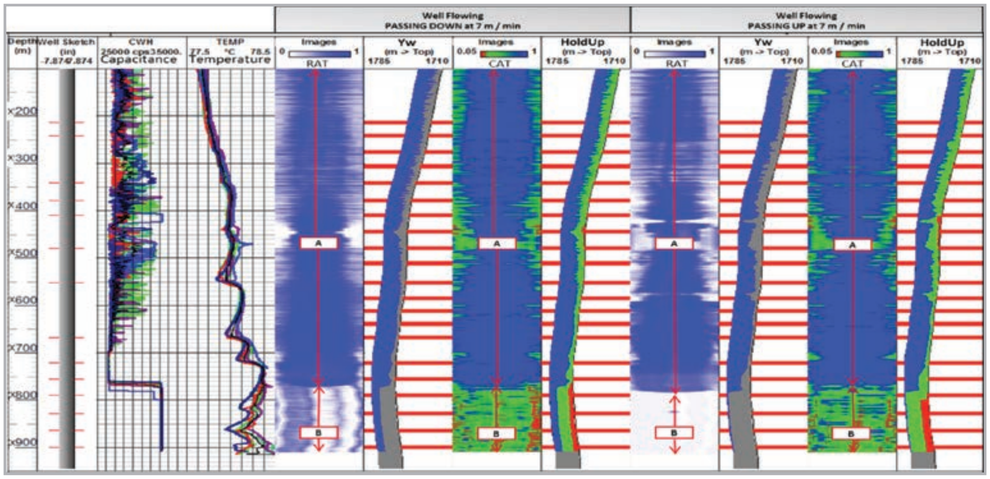


Figure 12. CAT and RAT phase identification maps.

Figure 13 shows the SAT velocities map, in which the different colors indicate direction and velocity. The colors from white to black indicate descending flow, with black indicating the maximum negative velocity and white indicating zero movement. The colors from yellow to magenta indicate ascending flow with positive velocity, (Frisch et al. 2009).

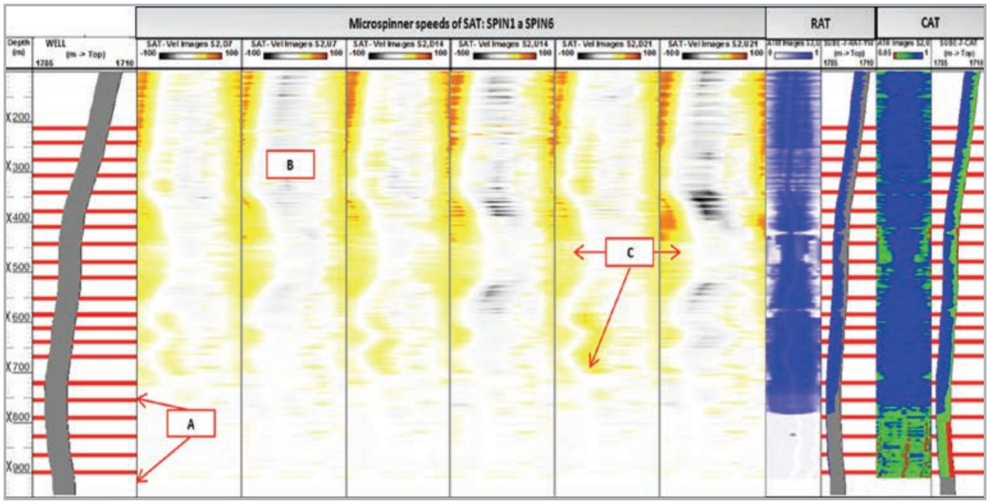


Figure 13. SAT velocities map.

When the SAT information was integrated with the information from the CAT and RAT, it could be observed, in point A, that the zone comprised between <X900 to X722> m measured depth (MD) has practically no fluid velocity, and that there should, therefore, be a deposit of semi-static hydrocarbons toward the end of the horizontal section. In Point B, it can be observed that the water found in the low part of the liner pipe develops velocities that are between negative (black) and zero (white) along the entire length of the logged zone, showing that a part of the water found in the 4 1/2-in. liner pipe is developing a descending flow and that another part of the water volume—possibly the greater part—would be in a semi-static condition. In Point C, it can be observed that, beginning at X722 m MD, the hydrocarbons traveling in the high part of the liner pipe do have a fluid velocity (yellow-magenta).

In point A of **Figure 14**, the trajectory of the well in the depths between X900 m MD and X760 m MD is greater than 90°, which favors the holdup of light fluids, (hydrocarbons). In effect, a bank of apparently semi-static hydrocarbons can be observed. This bank of hydrocarbons does not have sufficient force to displace the water accumulating in the liner pipe, beginning at X760 m MD, because of the alteration in holdup caused when the well trajectory changes to less than 90°, which favors the holdup of water, (point B).

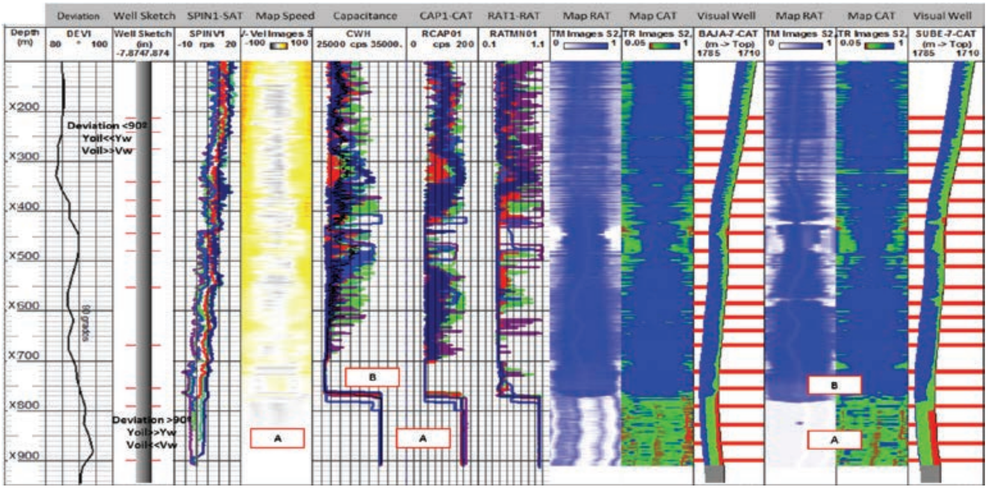


Figure 14. Influence of the deviation angle in the horizontal section of the well.

Interpretation of data and discussion of the results

Based on the premises of the qualitative evaluation, a calculation of the total production was conducted, as well as a calculation of each interval, based on the holdups determined with the CAT and RAT and the velocities determined with the SAT minispinners.

The results of the process show that, according to the PLT, along with the pressure-volume-temperature, (PVT) data used, the well was producing, at the time of the logging, an estimated 283.26 stb/D of oil, 0.27 MMscf/D of gas, and 77.45 stb/D of water, which equates to a water flow of 21.5%, **Figure 15**.

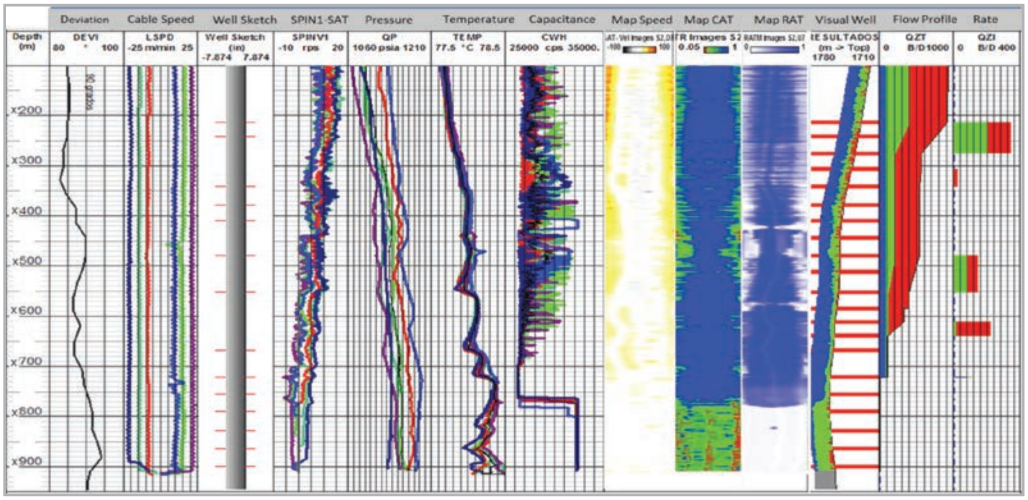


Figure 15. Processed contribution profile.

The PLT log determined which of the 21 fractures distributed along the length of the 690 m of the horizontal section were producing, and with this information, it was possible to evaluate the fracturing techniques used, **Figures 16** and **17**.

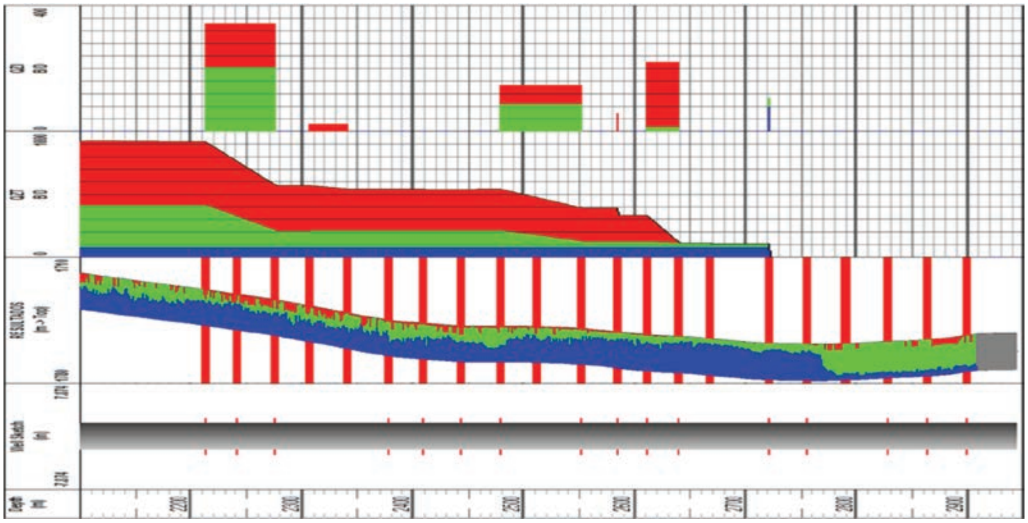
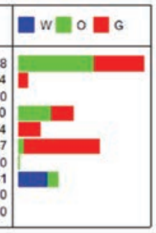


Figure 16. Contributing zones in the horizontal section of the well.

Production at bottom conditions

Zones m	Qw res. B/D	Qo res. B/D	Qg res. B/D
Interval 19	0.00	204.92	139.38
Interval 17	0.00	0.00	24.54
Interval 14	0.00	0.00	0.00
Interval 11	0.00	86.26	62.70
Interval 10	0.00	0.00	58.74
Interval 8	0.00	14.36	207.57
Interval 7	0.00	2.64	0.00
Interval 6	79.28	27.71	0.31
Interval 5	0.00	0.00	0.00
Interval 1,2,3 y 4	0.00	0.00	0.00



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Conductivity (mD-ft)	1747	1946	1945	797	844	842	404	386	370	522	477	489	1931	1600	1416	1630	1208	1364	1533	1356	1098
% Of total fluid distribution per clauster	Incipiente			8.25% Aceite, 0.06% Gas, 100% Agua			5.07% Aceite, 42.08% Gas			25.68% Aceite, 24.62% Gas			Incipiente			4.98% Gas			61% Aceite, 28.26% Gas		
% Production by Fracture Technique	8.25% Aceite, 0.06% Gas, 100% Agua						30.75% Aceite, 66.7% Gas						61% Aceite, 33.24% Gas								

Figure 17. Expense itemization per fracturing, cluster, and fracturing technique.

According to the data obtained the clauster 1, has an incipient production, the clauster 2 produces 100% of the total water of the well, 8.25% of the total production of oil and 0.06% of the total production of gas. Cluster 3 produces 5.07% of total oil production and 42.08% of total gas production. Cluster 4 produces 25.68% of total oil production and 24.62% of total gas production. The clauster 5, has an incipient production. The clauster 6 produces 4.98% of total gas production and clauster 7 produces 61% of total oil production and 28.26% of total gas production.

That production is highly variable along the length of the wellbores. It is observed that the number of clusters does not correspond to the number of fractures, that is to say, we could have seven clusters open but not all fractured and/or producing.

Currently the techniques used to increase the efficiency of clusters are based on the use of divergent that allows greater fracture efficiency (greater volume of stimulated reservoir). This is independent of the type of termination (fracture liners, jeteo or cemented csg).

Conclusions

The following conclusions are a result of this work:

- For a better evaluation of the effectiveness of the fracture techniques employed, it would have been more convenient to run the PLT at the beginning of well production and it was in original condition. At this time, a differential depletion by the previous history of flow of the zones, could be affecting the distribution of the production.

- That production is highly variable along the length of the wellbores. It is observed that the number of clusters does not correspond to the number of fractures, that is to say, we could have 7 clusters open but not all fractured and/or producing.

- Completion parameters such as the number of perforation cluster per frac stage, the perforation cluster spacing and the staging of stimulation treatments, can all impact the productivity of an individual perforation cluster.

- In complicated flow schemes, especially in horizontal wells where the phenomenon of phase segregation occurs almost naturally and combined with the effect of the deviation angle in the horizontal section, it is recommended to use the new generation of multi-sensor production tools to determine the flow profile and thereby permit a more accurate diagnosis of the performance of productive intervals.

- In the case of the horizontal well studied, using the PLT log with array sensors met the objective of evaluating the fracturing phases and the three fracturing techniques applied. Moreover, based on the results obtained with the PLT, required optimization work was performed to improve its production.

- Determining flow behavior for current horizontal wells can serve as the basis for planning future drilling programs and the completion of future wells.

Nomenclature

CWH =	Capacitance water holdup
CAT =	Capacitance array tool
CAP1…12 =	Minicapacitors of CAT
cps =	Accounts per second
q =	Flow rate
Yw =	Water holdup
MAP CAT =	Map CAT Holdup
MAP RAT =	Map RAT Holdup
PLT =	Production logging testing
Rps =	Round per second
SAT =	Spinner array tool
Spin1…6 =	Minispinner of SAT
RAT =	Resistivity array tool
RAT1…12 =	Resistive sensor of RAT

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Appendix

- Slip velocity, Vslip: Vslip = Vlight – Vheavy

- Holdup, Y: Yw +Yo+Yg = 1

- Holdup from density: YH = (ρM - ρL)/(ρH - ρL); ρL = light phase density,

  ρH = heavy phase density, ρM = mixture density

- Total rates: Qt = qw + qo + qg

- Qt = 1.4x [0.83xVapp] x D^2; (Units - Q [bbl/d]; Vapp, Vm [ft/min]; D [inch])

- Water Cut = Qwater/Qtotal

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