A Novel Acquisition System for Production Logging in Multiphase Horizontal Wells

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Abstract:

Multiphase sub-horizontal wells have always been a challenge for interpreters as small changes in the well inclination, and the flow regime influence the flow profile. Conventional tools based on a center measurement are therefore unsuccessful in these environments.
This paper will present a new tool built specially for highly deviated and near horizontal wells. The tool is designed to specifically provide a recording of hold-up and velocity profiles along the vertical diameter of the borehole cross-section. Three sensor arrays consisting of six optical probes, six electrical probes and five spinners are deployed across the well bore on retractable arms that can be opened and closed with a hydraulic sub, so as to better locate hold-up interfaces. The optical probes use the fluid reflectance to derive the gas hold-up, while the electrical probes measure the fluid impedance to derive the water hold-up. The spatial location of the different sensors is accurately known through the use of an integrated relative-bearing sensor.
The direct measurement of the fluids velocity profiles and fluids hold-up profiles, allow a better description of the down hole fluid flow. This paper will illustrate through field examples, how this had been done successfully in different areas around the world.

Introduction:

Oil and water flows in horizontal and near horizontal wells are predominantly stratified, even for flow rates as high as 20,000 bpd in a 5” liner. For a constant flow rate, the holdup and velocity profiles of each phase vary with the well deviation. A tool string based on a centered measurement is thus unsuccessful under those circumstances. When gas is also present, depending on the well deviation, two major flow regimes are encountered. For well deviations above 90 degrees (downhill), the flow is still predominantly stratified, with different layers of water, oil and gas flowing over each other at different speeds. For deviations lower than 90 degrees (uphill), gas starts slugging. Understanding the nature of multiphase flow in producing wells has helped in designing the new tool string.

The FloScan Imager (FSI):

The FloScan Imager (FSI) was developed especially for highly deviated and near horizontal wells. It consists of two retractable arms that are equipped with sensors for deployment along the vertical diameter of the wellbore. On one arm are located 5 spinners designed to measure the well fluid velocity profile, while on the other are placed two arrays of six electrical and six optical probes for the measurement of the water and gas holdups. These probes are identical to those introduced previously on the DEFT and

GHOST tools. The electrical measurements are based on low frequency probes that measure the impedance of the fluid surrounding the probe. Since oil and gas are both resistive, the electrical probes can only discriminate between water and hydrocarbons (Fig.1). The electrical signal generated is somewhat binary with a large difference between water and hydrocarbon. A threshold is set to distinguish water from hydrocarbon (Signal > Threshold → Water). The optical probes are sensitive to the optical fluid index. Typically gas has an index close to 1, with 1.35 for water while that of crude oil is very near from 1.5. Since oil and water have similar fluid indices, the optical probes are used to distinguish gas from liquid (Fig. 2). Very similarly to the response of the electrical probes, that of the optical probes exhibits a large difference between gas and liquid. Again a threshold is used to discriminate gas from liquid (Signal > Threshold → Gas). A schematic of the tool along with its characteristics is given on Fig. 3. A caliper and a relative bearing sensor are also included in the tool to determine the exact position of the probes in the well cross section. If need be, the arms can be opened and closed with a hydraulic sub, so as to better locate the hold-up interfaces. The tool outside diameter is 1-11/16 ", and it is fully compatible with the PS Platform. It is run excentered lying on the low side of the well, with the arms deployed across the vertical diameter of the well bore. Field test results have indicated that the arm orientation will not depart from the vertical position by more than 10 degrees in the great majority of the cases. Special software was written to optimize and display the high volume of data sent up-hole. With data from 19 sensors, a simple LQC display will be very crowded and difficult to understand. Thus the specific software: the FSI Monitor Box was designed to display in a compact and intuitive way the major raw measurements from the different FloScan Imager sensors. It plots two views that are constantly updated during the real-time acquisition (Fig.4). The first view shows the fluid relative velocity as measured by the spinners array while the second view shows the phase repartition across the pipe section as measured by the probes arrays. For both views, the pipe is sliced horizontally into 5 layers. For each layer, is associated a combination of 1 spinner, 1 electrical probe and 1 optical probe (2 electrical probes and 2 optical probes for the top layer). In the spinner view, a rectangle is plotted with its width proportional to the rotational velocity of the corresponding spinner. This rectangle is then divided into three parts whose width is proportional to the 3 phase holdups seen by the electrical and optical probes. In the cross section view, each layer is color coded by the highest holdup seen by the probes. The 2 remaining phases are represented by bubbles whose numbers and sizes are computed to reflect their holdup values. In this view, the sensors exact positions are also shown, with circles representing the spinners array and the dots the probes positions.

Field Example 1:

Well A is located in Gabon (West Africa). In this example the FloScan Imager was used to locate the water and oil entries in a 3 phase well, where previously a conventional tool string had been run inconclusively. The well presents a 38-degree deviation from vertical. It produces fluids under the form of an emulsion which when centrifuged at surface gave a water cut of 40%. Fig.5 is a merge display of the electrical and optical probes during a down flowing pass @ 160 ft/min. On this display the difference between the probes minimum and maximum readings (shaded in yellow for the electrical probe and in pink for the optical probe) corresponds respectively to readings in hydrocarbon and in water for the electrical probes, and to readings in gas and in liquid for the optical probes. The tool performs flawlessly with a good signal dynamics of 3 Volts on all the sensors. In each track is displayed in blue the water holdup and in red the gas holdup. The first oil entry is clearly picked up by all the electrical probes at around XX45 m. The optical probes are also sensitive to this oil entry as shown by the shift to lower values in the readings that are due to the slight difference in optical index between oil and water. Gas coming out of solution is clearly picked up by the optical probes with the readings at high values. The shift in the water reading on all the electrical probes at around XY81 - 85 m is due to a fluid entry that is less conductive than water. The high gas entry @ XY81 m is seen on the electrical probes as a hydrocarbon continuous phase reading with the minimum and maximum waveform readings being less than 1 Volt, while the optical probes are at their best with high readings due to the big contrast in optical index between gas and liquid. Fig. 6 is the merge display of all the FSI sensors that are nearest to the sonde body, (Spinner #0, Electrical Probe #0, Electrical Probe #0 bubble count) along with the companion curves from the PSP (Pressure, Temperature and Fluid Density). Since the tool is run excentered, lying on the low side of the well, these inner most FloScan Imager sensors are seeing the heaviest produced fluid, due to fluid segregation. The color-coding used on this display is such that curves corresponding to the same pass would have the same color. Up going passes are coded dotted while down going passes are solid. Mini-spinner#0 displayed in track 1 clearly shows fluid recirculation. Even though fluid is re circulating down, the first oil and gas entries are still picked out by the inner most probes buried inside the sonde body. The different holdups measured by these inner-most optical and electrical probes are misleading due to the high amount of water falling down hole and thus their very low values. Fig. 7 is the merge display of the outer-most FloScan Imager sensors. This display clearly shows that no fluid recirculation is taking place on the high side of the casing where the produced fluid (oil and gas) is flowing up-hole. Fluid entries seen by the probes are also seen by conventional sensors like the gradio-manometer and the temperature sensor. Fig.8 is the multi-spinner calibration plot that clearly shows the fluid recirculation seen by the inner most spinners. A mixture fluid velocity profile derived from all the spinner measurements is shown in Fig 9. A color-coding is used on this figure to distinguish produced fluid (light green=>dark green) from the re-circulating fluid (yellow=>red). Fluid re-circulation is clearly seen by the spinners that are on the low side of the well with producing fluid on the high side. Surface flow-rates computed from the logged data compare well with surface production data gathered during the log (table1).

Field Example 2:

The second example comes from the North Sea, where the FloScan Imager was run in combination with the RST+ in a near horizontal well using coiled tubing conveyance. The maximum well deviation is 93 degrees with a 700-meter long horizontal section. The well produced 28 000 bpd of oil and water through a 4.5" liner with a 20% water cut during the logging. The well undulates around a deviation of 90 degrees, which makes it interesting to illustrate the change in flow characteristics associated with the well deviation. Indeed, undulations in the well trajectory can create "valleys" and "hills" where respectively the heavier and lighter phase fluids can accumulate as is shown on

Fig. 10. Due to the high fluid velocities encountered in this well, one spinner was broken during the job, however thanks to the sensor redundancy, this had no impact on the quality of the data set as a whole, and a reliable interpretation could still be carried out. During the flowing pass and even with the well choked back to 40%, the dependency on deviation of the holdup and velocity profiles of each fluid is minor as at such high fluid velocities, the frictional forces against the pipe wall and those at the fluid interface increase to become predominant compared to the influence of gravity. On Fig.11, is displayed along side the flow profile obtained through a traditional approach. Contrarily to the existing PL interpretation algorithms, which provide a 0-dimensional description (one value) of the flow per depth, a new approach has been adopted for the FloScan Imager with the FSI Inflow Profiler (FSIIP) to provide a 1-dimensional description (one profile) of the flow per depth. This drastically improves the understanding of the complex multi-phase flows that take place in deviated and near horizontal wells. The FSIIP is a mono-pass-based algorithm that outputs profiles along the vertical diameter of the well bore cross-section for the fluids velocities and for the hold-ups (Fig. 12). Down-hole volumetric phase flow-rates are also computed along the well trajectory, as well as cross-sectional average velocities and hold-ups for the 3 phases. FSIIP is a forward model based on simple interpolations and surface integrations, which makes it fast in processing time. In particular, real time FSIIP processing while logging is possible with the MAXIS acquisition system providing thus a powerful real-time LQC that is complementary with the FSI Monitor Box (the latter provides a user friendly display of the FSI raw data).

Figure 1 Electrical Probe Principles

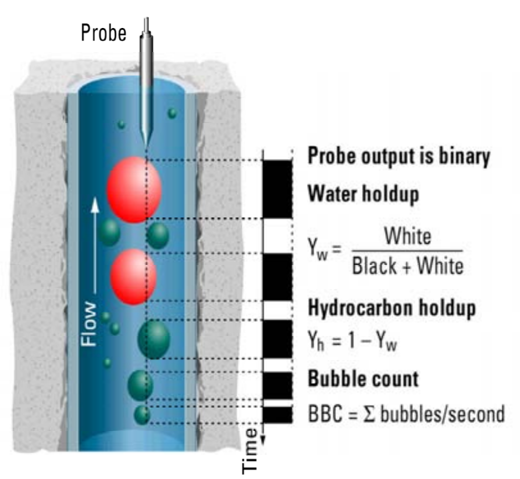


Figure 2 Optical Refractive Index

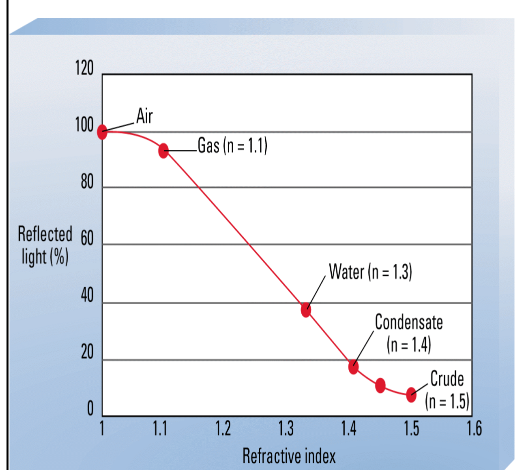


Figure 3 FSI Tool String (Length=16 ft Max. Temp=300 F Max. Pressure=15 000 psi)

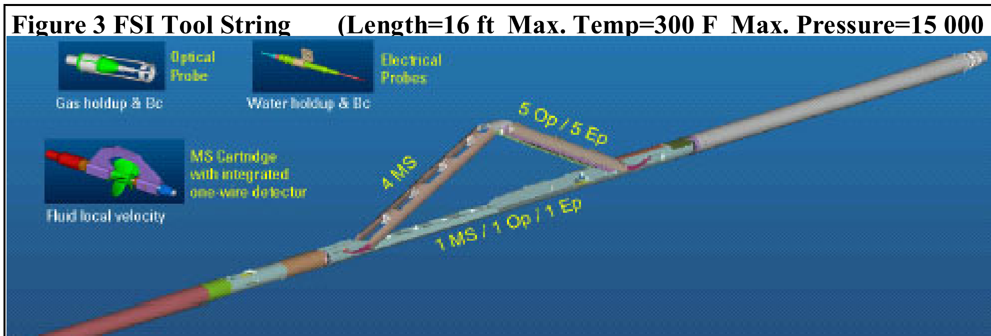


Figure 4 FSI Monitor Box Real Time display

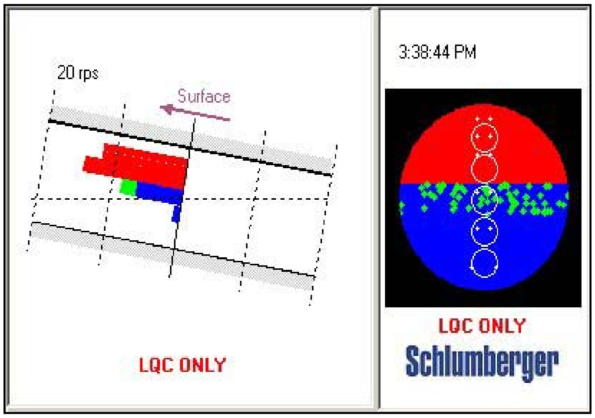


Figure 8 Spinner Calibration Plot

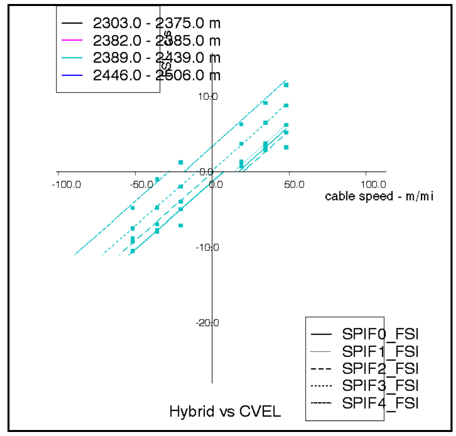


Figure 5 Electrical and Optical probe response

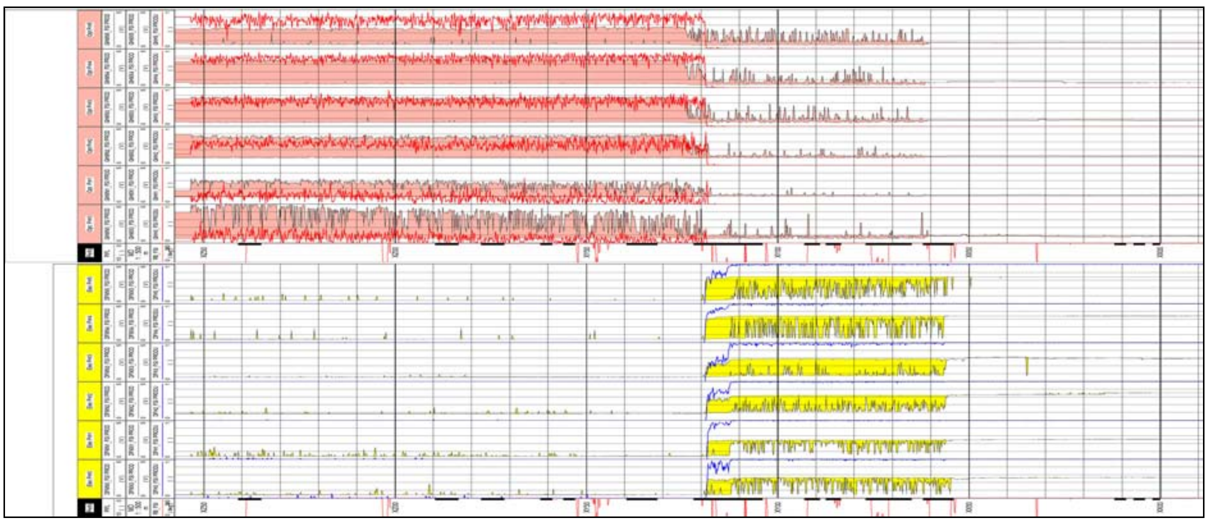


Figure 6 FSI Inner Most Sensor Response

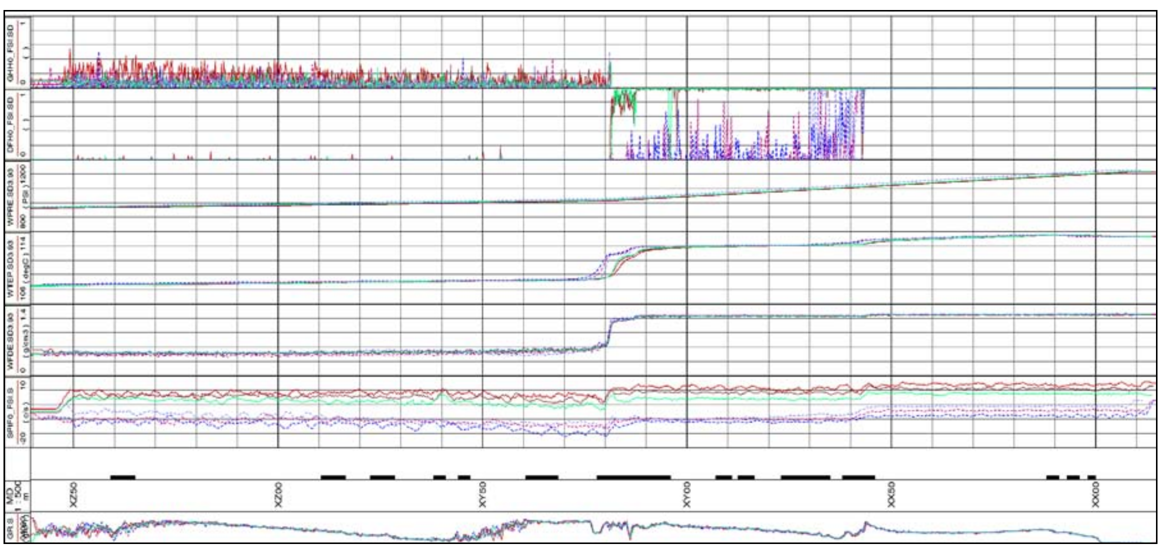


Figure 7 FSI Outer Most Sensor Response

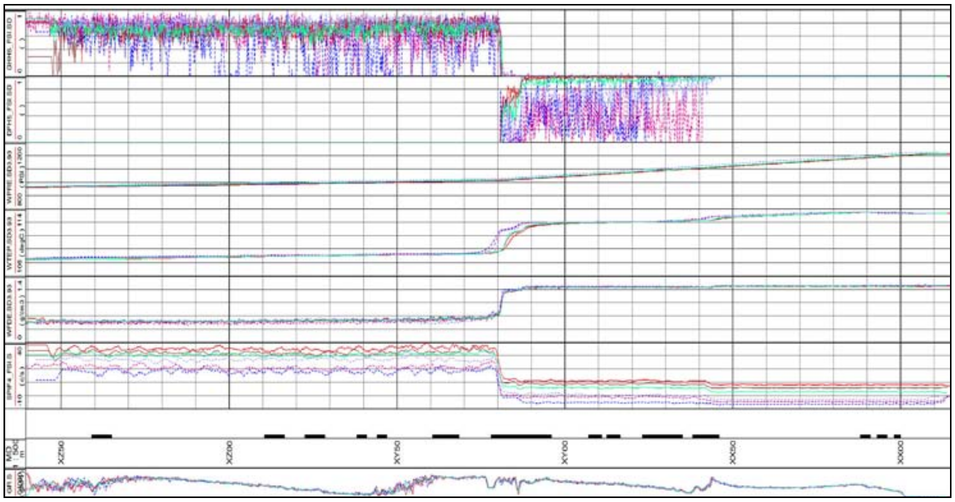
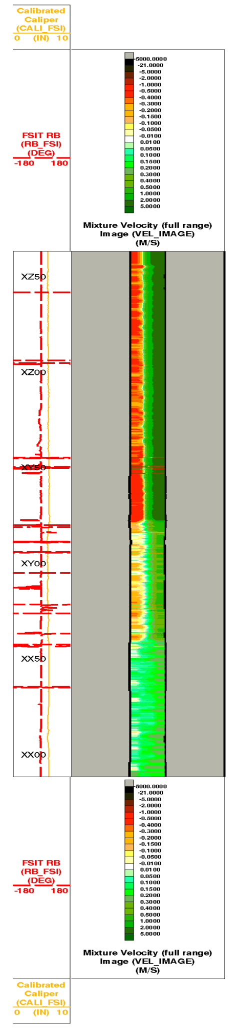


Figure 9 Fluid Recirculation



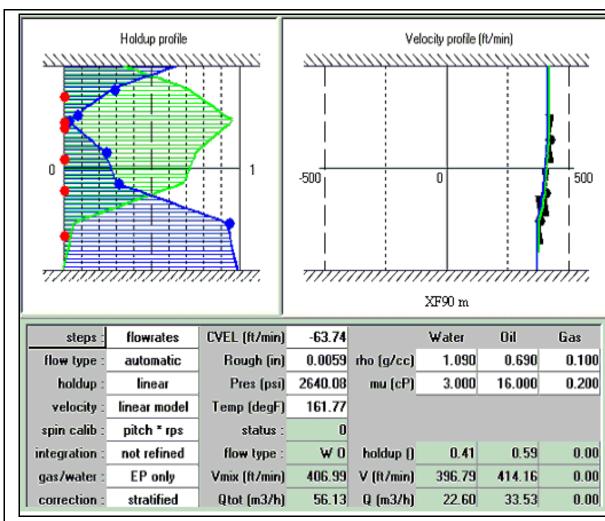


Figure 10 Fluid segregation in valleys and hills during shut-in

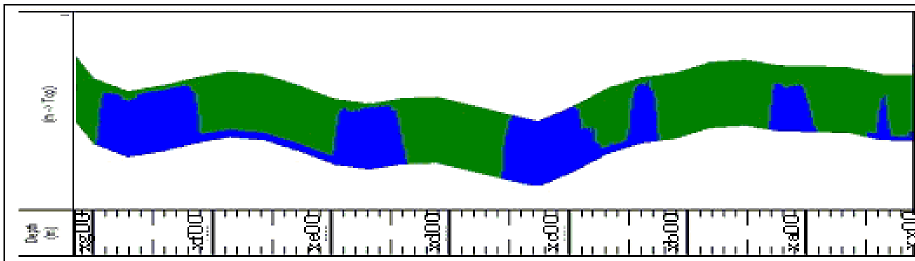


Figure 11 Influence of fluid velocity on holdup profile

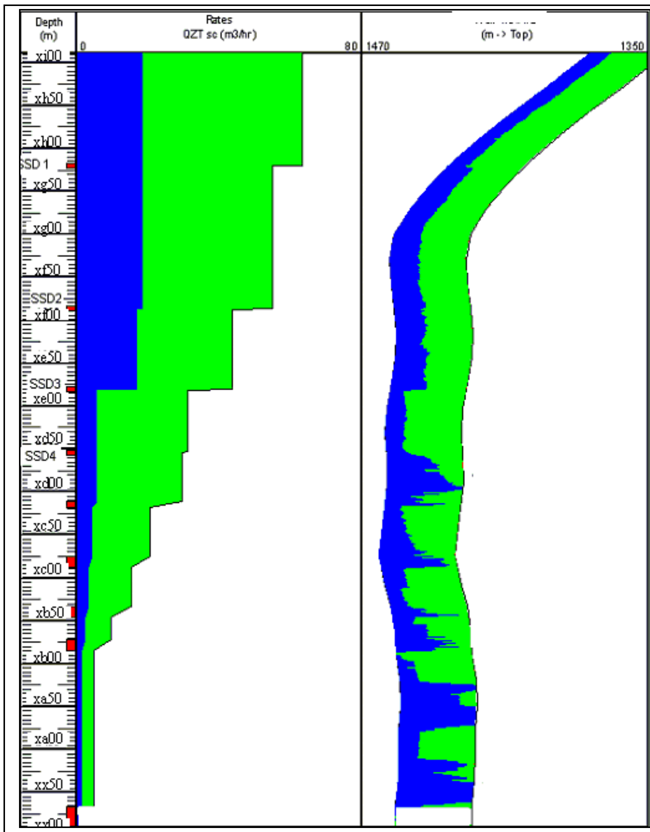


Figure 12 FSI InFlow Profiler Display