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What You Need to Know About Production Logging

Production logging is a critical component of developing optimum modeling, completion and stimulation practices. When measuring downhole flowing production profiles, identifying zonal contributions of water, oil and gas are critical to validate and calibrate reservoir modeling and completion and stimulation practices. It is important to remember zonal production rates should be consistent with predictions from reservoir models and will verify the effectiveness of the stimulation treatments.

Over the years, production logs have proved invaluable for identifying production and completion anomalies and problems. However, running production logs in horizontal wellbores presents unique challenges requiring modification not only to the tools but also in the delivery techniques. Since the wellbore is horizontal, conventional wireline delivery systems will not work. In horizontal wells, the three most common methods of delivery are:

► Using 1 ¼” coiled tubing run through 2 ⅜” production tubing (Figure 1).

► If production tubing is 2 ⅞”, the logging tool can be deployed with a tractor well (Figure 2).

► 2” coiled tubing can be used to insert the tool if production is up the casing (in low flow wells, the coil can be used to gas lift the well to provide flow.)

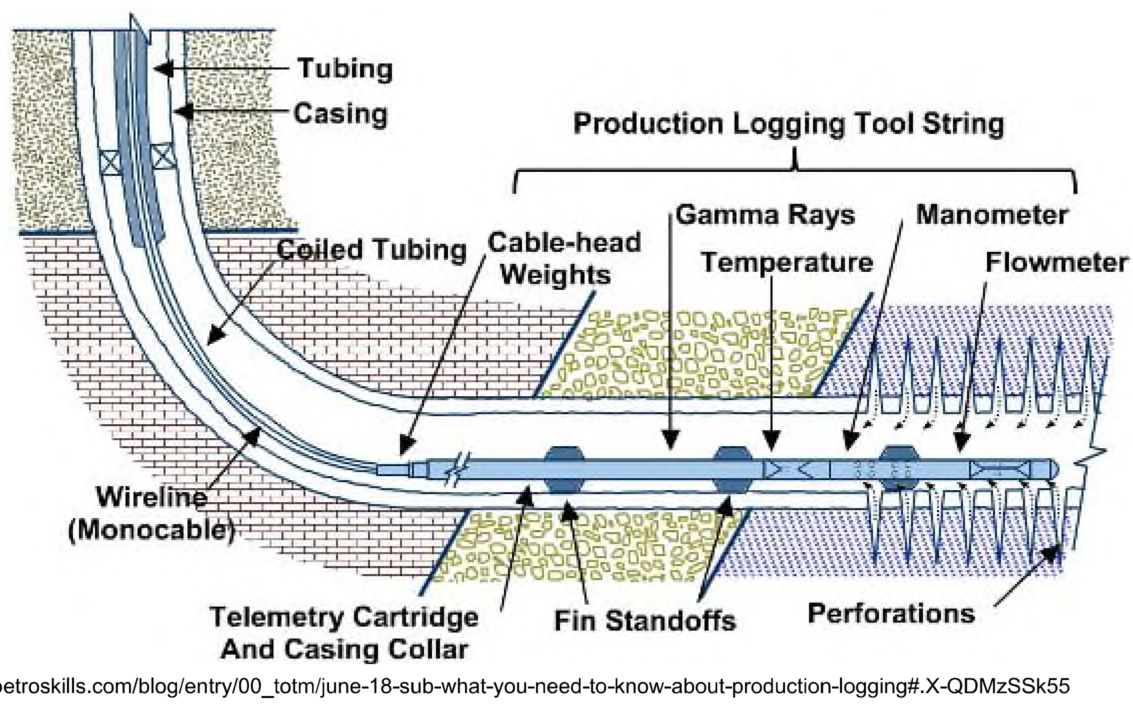


Figure 1. *Production logging tool run with 1 ¼" CT through 2 ⅜" production tubing.*

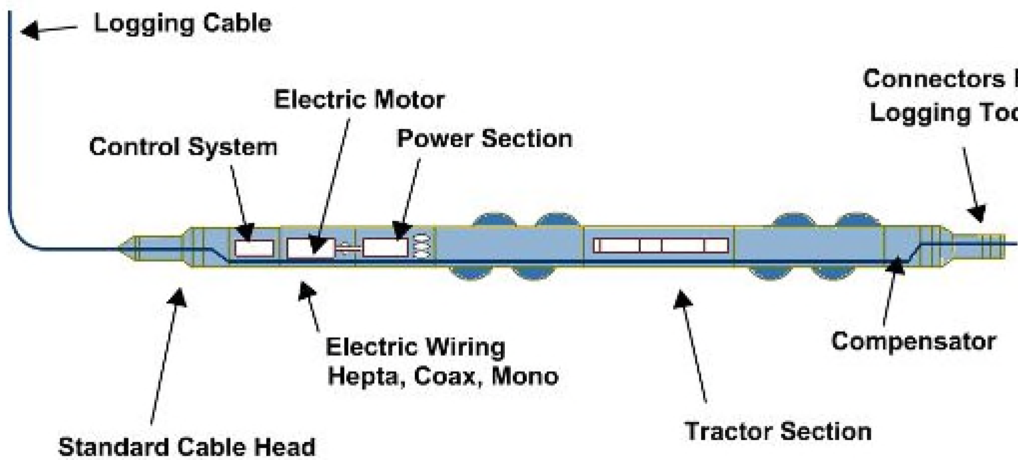
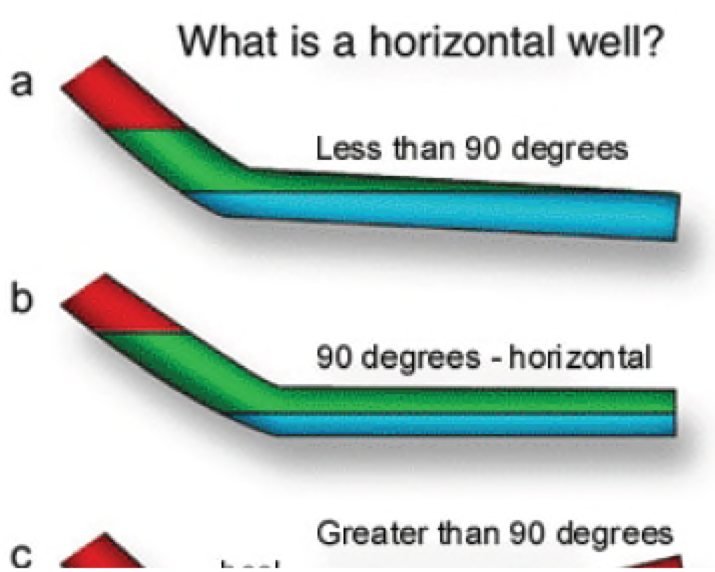


Figure 2. *Production logging tool being deployed with a downhole Well Tractor Tool.*

Well flowing conditions in a horizontal well are considerably different than a vertical hole requiring modifications to the instruments and making the interpretation more difficult. As seen in the figure below, the term horizontal well is loosely defined in the industry and all the listed definitions are accepted. In horizontal wells, there is rapid phase segregation and fluid stratification creating a multiphase flow situation in which production logging tool responses become sporadic or unpredictable. Undulations in the wellbore (uphill and downhill) create flow conditions that can't be properly measured by the tools.



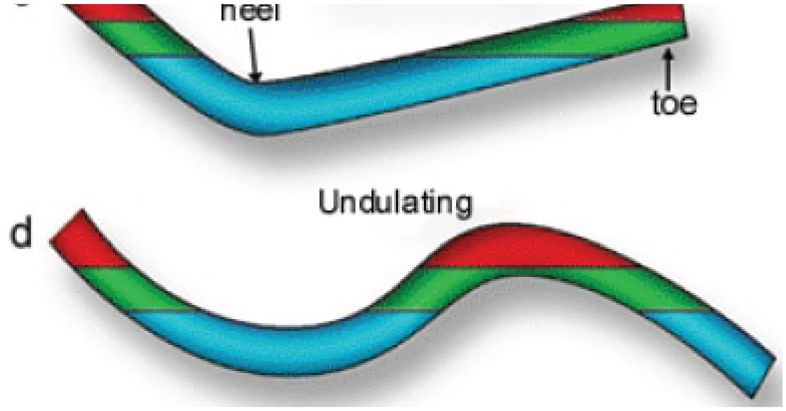


Figure 3. *Phase segregation in a horizontal well and horizontal well defined (from http://www.industrimigas.com/2013/06/production-logging-of-multiphase-flow.html)*

Figure 4 illustrates that the tool must be centered to ensure the proper measure of the segregated fluid flow. Conventional sensors work well in a vertical well where the fluids have relatively uniform mixing. However, in a horizontal well with stratified flow, special sensors are required to properly measure fluid flow and distribution across the wellbore (Holdup).

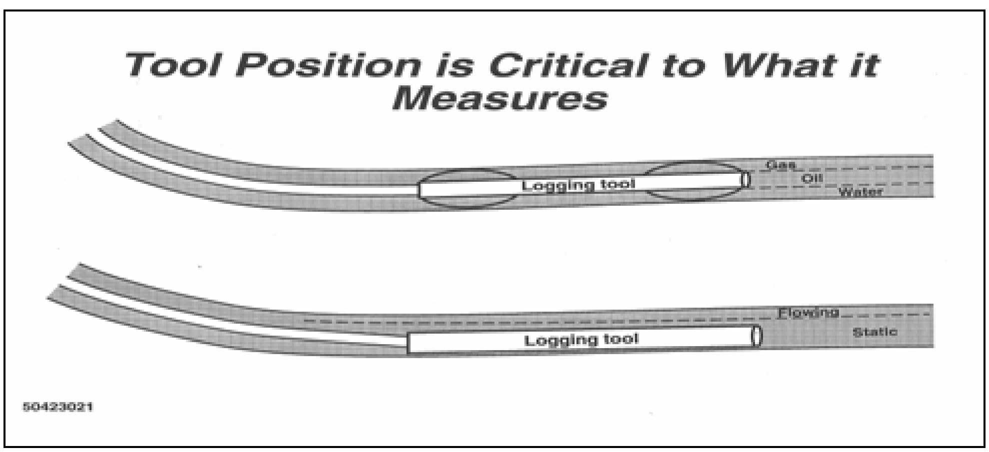


Figure 4. *With phase segregation in a horizontal well, it is critical the tool is centered.*

A production log is usually run by the operator in a flowing wellbore to measure to the zonal contribution of water or hydrocarbons to evaluate the flow performance model and stimulation effectiveness. Also, the survey can identify problem areas such as channeling, leaks, cross flow and thief zones.

A typical horizontal well production logging sensor package consists of a (Figure 5):

► Gamma Ray – for depth correlation

► Collar Correlation Log – for depth correlation

► Pressure – determine downhole flowing pressure

► Temperature – measure fluid or gas inflow or channeling behind pipe

► Flowmeter – measures the rate of flow from each interval

► Fluid identification sensors are used in 2 or 3 phase flow flowing conditions

• Fluid capacitance – measures the difference between water & hydrocarbons

• Fluid density – measures the difference between water, hydrocarbon liquid and hydrocarbon gas

• Holdup (YG) – is a direct measurement occupying the cross-section of the wellbore

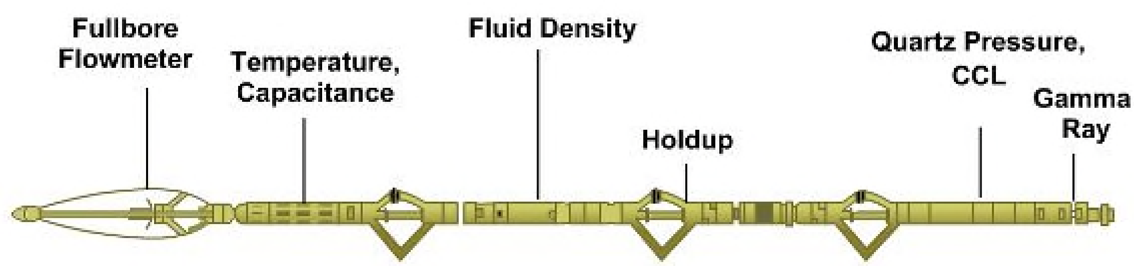


Figure 5. *Horizontal well Production Logging sensor package (Heddleston, 2009).*

The fluid density and capacitance measurements are used to calculate a Holdup – gas to liquid occupancy in the pipe. The Holdup measurement is critical for measuring 2 or 3 phase flow in a horizontal well.

Horizontal Flow Regime - in a horizontal well, the lateral leg is very seldom perfectly horizontal. Most laterals have undulations, either by plan or simply as an artifact of the drilling operation. Many horizontal shale gas wells are drilled with the lateral in a toe up position to promote gravity drainage of produced water to the heel section, allowing gas velocity and gas lifting mechanisms to produce the water more effectively.

In many shale gas wells, low production rates along the lateral (less than 1 MMSCFPD & less than 1000 BPD) result in a low energy condition in the lateral creating stratified 2 less than 1000 BPD) result in a low energy condition in the lateral creating stratified 2 phase (gas and water) flow.

Measurement in the stratified 2 phase flow regime is compounded by the problem of slippage. When flowing uphill, gas tends to move faster than the liquids, usually in the slug regime. In downhill sections, the liquids tend to flow faster than the gas, often resulting in a change in flow regime to stratified or annular flow. Producing the well at maximum rates can achieve better logging results because the higher velocities reduce the importance of slippage.

Unlike flow in a vertical well, in a horizontal well, wellbore production does not mix well, therefore, special sensors are required to properly measure the holdup across the lateral section. The ideal sensors provide full cross-section wellbore Holdup and Temperature measurements. The holdup measurement provides a true image of the fluid distribution in the wellbore. Figure 6 is an example of a production log showing the changing holdup in the wellbore as water or gas are enter the wellbore and occupy more of the pipe volume.

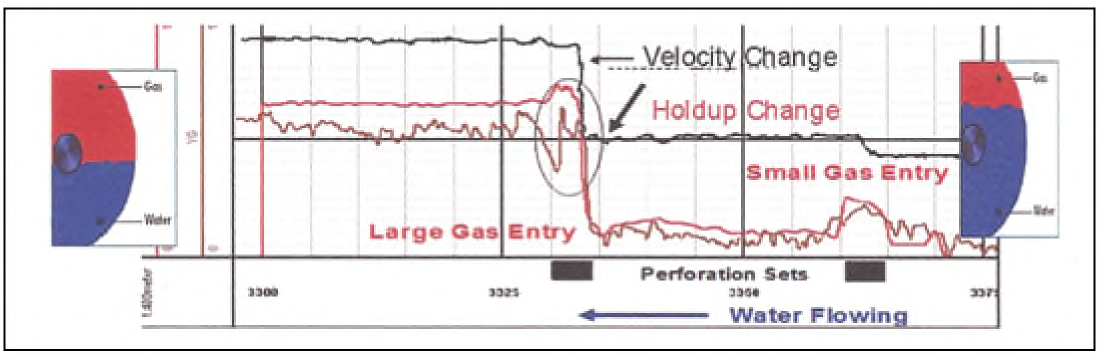
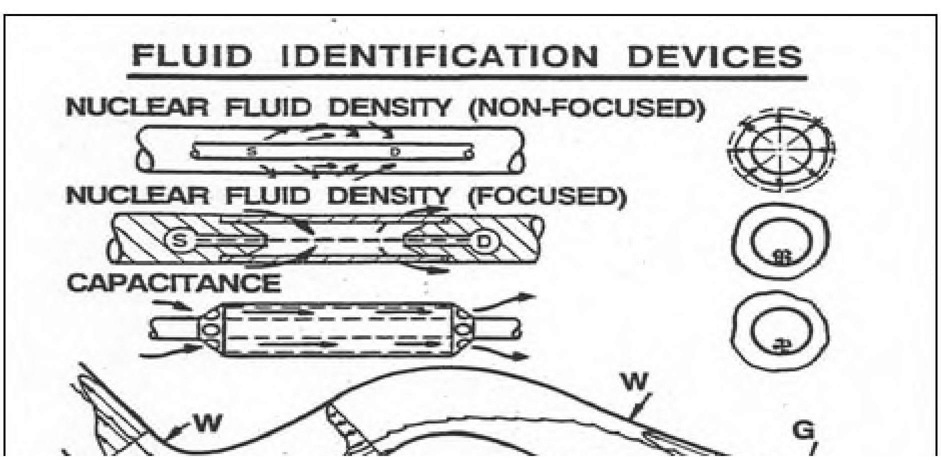


Figure 6. *Horizontal wellbore phase fraction holdup measurement (Heddleston, 2009).*

Figure 7 shows how the unfocused density measurements identify phase holdup changes in the wellbore.



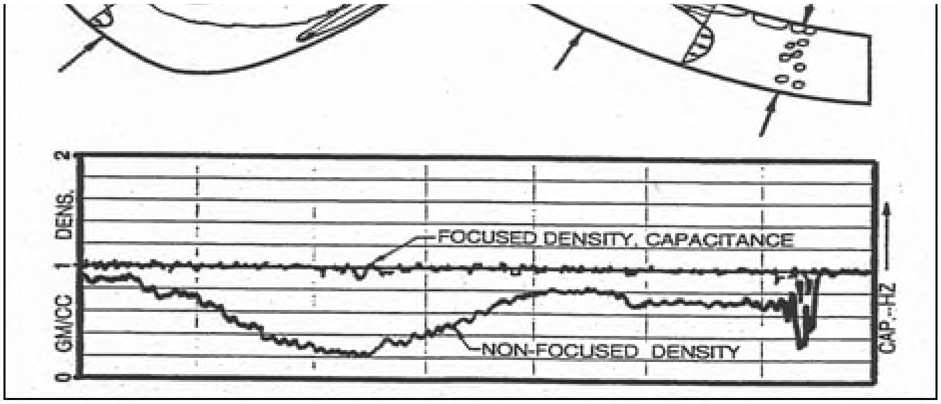


Figure 7. *Fluid identification tool response in horizontal environment.*

The temperature measurement is ideal for correlating the changes in the holdup as water is usually a warmer event and gas is a cooler event.

Flowmeter single point or an array of spinners are not always reliable enough (Figure 8) to correlate the truer readings such as holdup and temperature. Laterals often contain a high concentration of frac sand and plug debris that can cause anomalies in spinner velocities. Flowmeters are more reliable in higher production rate (<1000 BPD) conditions.

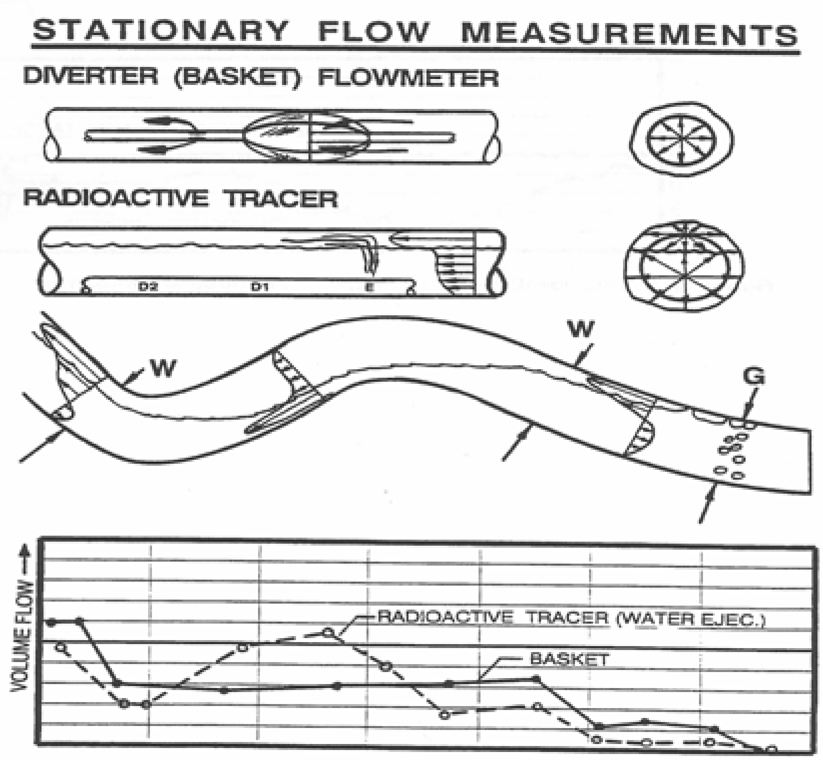


Figure 8. *Stationary flow measurements techniques in horizontal wells.*

The most popular completion style for unconventional shale wells is a horizontal well with a lateral section between 2,000 and 5,000 ft. (current wells are trying even longer laterals). Casing sizes are either 4 ½" or 5 ½", and production tubing is run at some point to allow a longer flow life. In low rate wells, gas lift is used to assist in flowing back frac water and lift produced formation water.

Stimulation of the horizontal wells incorporates 6 to 12 staged fracture treatments for shorter laterals (+ 2,000') and stage consists of 4 to 5, 1 to 2' perforated intervals. Perforated intervals are normally selected based on seismic information, which identifies faults and fractures.

Horizontal Well Logging Tool Deployment – Unconventional producing wells require various techniques and expertise to be able to deploy horizontal logging sensors while controlling the well to flow an effective rate to allow for quality measurements.

Here are some tool standards and recommendations:

► If the wells are producing at a low production rate (low flow velocity), tools must be run into the well with an understanding of the impact the tools can have on the flow. In some instances, the tools create enough interference that flow may be significantly reduced and in some cases killed.

► In low flow rate wells, using 2 ⅜" tubing and gas lift to unload produced water, the tools can be deployed through the production tubing using 1 ¼" CT.

► Deploying with CT will usually overcome problems associated with running tools in wellbores having unexpected sand and proppant blockages in the deviated sections. Fluid or nitrified fluid can be pumped down through the coil to wash out the solids, allowing for movement to continue in the wellbore. Care should be taken in choosing the cleanout fluid, as displacing fluids can impact well performance and compromise measurements. Nitrogen is a good fluid to use.

► The biggest obstacle to getting the tools to TD when using CT is buckling caused by sticking resulting from friction drag and/or debris. Worse case is when the buckling forces are so great the CT can't be run any further regardless of tubing movement at the surface known as Friction Lock. Worst case is large diameter hole and small diameter pipe. Service companies can provide a deployment simulation run to determine how far the tool can be run with a specific wellbore geometry.

► For best results, well should be flowed at least 3 days prior to logging and equipment should be available at the well site to accurately measure gas and water rates before and during the survey.

Figure 9 illustrates a survey run using 1 ¼” CT deployed through 2 ⅜” tubing while the well flowed up the annulus. The well was producing 300 MCFPD with 960 BWPD. The operator had no idea where the water was coming from. The survey shows the water and gas are coming from the toe shown by the increase in the flowmeter at 11,000’ MD. The holdup image shows the wellbore phase fraction of water occupies 80% of the lateral. The temperature survey shows a warming trend with water inflow and a cooling spike where gas entry occurs. Note no other production along the lateral.

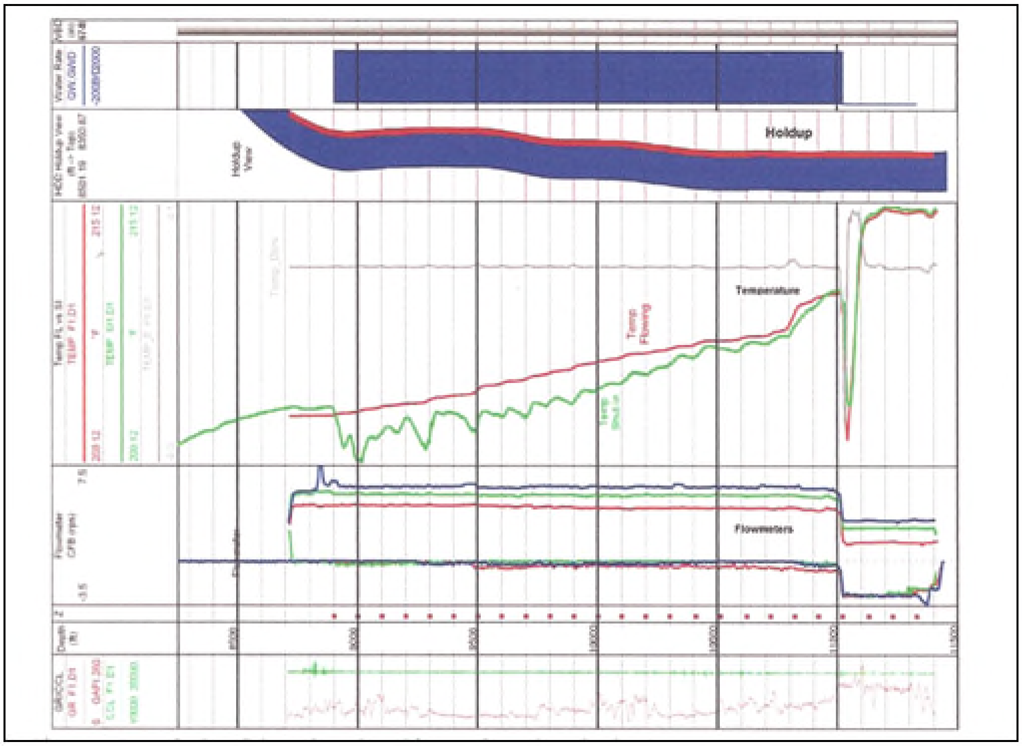


Figure 9. *1 ¼” CT deployed through 2 ⅜” tubing horizontal production log (Heddleston, 2009).*

Deploying Tool Through 2 ⅞” Tubing - If production tubing is 2 ⅞”, the logging tool can be run using a wireline well tractor (minimum tractor OD is 2 ⅛”). The tractor is deployed and activated through an electric wireline and will carry the tool to the end of the lateral without the need to push as with CT.

Well tractors provide an advantage over CT in that the tractor causes little to no choking or perturbation effects on the well flow resulting in more representative measurements of the well producing rate.

Well tractors are deployed with electric line, 5/16” OD, with the logging sensors installed below the tractor (Figure 2). It is typically run at 40 to 60 ft./min. by controlling the voltage applied to the tractor.

applied to the tractor.

Debris in the hole, and, in some instances, a steep inclination in the toe up configuration can prevent the tractor from reaching the end of the lateral.

Heddleston, 2009, describes an application where low gas flow and high water rates prevented deploying the logging tool with 1 ¼” CT through 2 ⅜” tubing because the choking effect caused the well to die. To obtain a log, it was necessary to pull the production tubing, then run the logging tool on 2” CT. The first pass was with the well static to allow the tools to measure the entire lateral as a baseline measurement. The sensors were then pulled back to the near vertical section and N2 was pumped down the CT, through a specially designed nozzle, to unload the well and initiate flow. After 2 to 3 hrs. of production with stable water flow rates, in the case described – 600 BWPD and 600 MCFPD, the N2 is shut off and the logging passes were made. As Figure 10 illustrates, the log identified the zones of gas (toe) and water entry (2 faults documented by seismic).

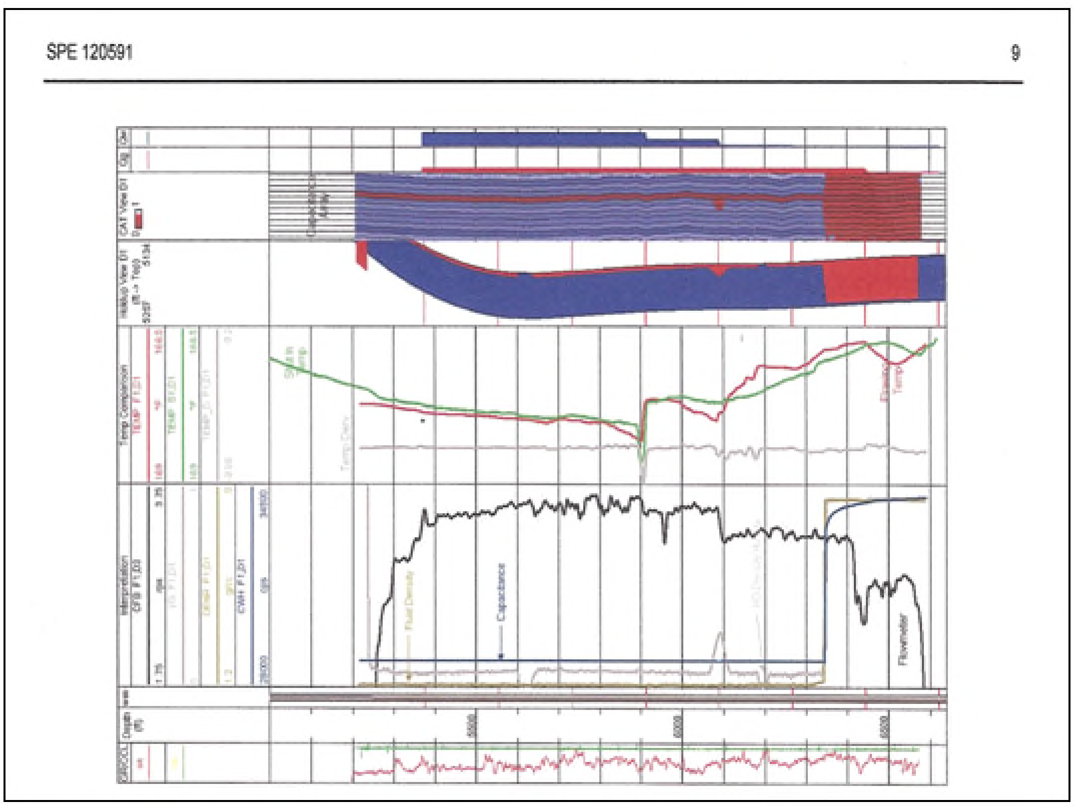


Figure 10. *2 ”CT deployed down casing production log (Heddleston, 2009).*

Another application for production logs is to quantify the contribution of each interval completed in the lateral.

If the well can be flowed with at least 2 different flow rates, the flowing pressures and production rates for each interval can allow the construction of an inflow production curve for each zone and a composite curve for the well which can provide the basis for forecasting production, evaluating stimulation effectiveness and estimating the effective reservoir pressure for each interval.

Another tool that can be used to better predict performance is to plot % flow (from the production log) to one or more log characteristics. For example, Pucknell, et. al.,1993, plotted % flow for each interval in a horizontal well in Prudhoe Bay versus Gamma Ray measurements (Figure 11) and found all production was coming from intervals with GR less than 20 (note: these were conventional sandstone reservoirs). A similar approach could be applied using several different logging parameters to attempt to establish a correlation that could be used to identify the relative potential of the intervals contacted by the lateral.

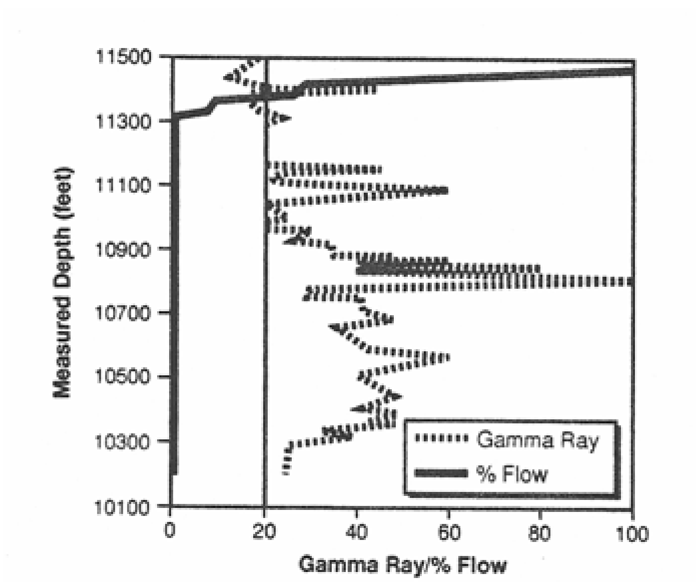


Figure 11. *Flowmeter superimposed on GR log indicates all production is from intervals with GR less than 20 (Pucknell,et. al., 1993).*

SUMMARY

Production logging is a critical component to developing optimum modeling and processes. This is why it is important to understand the tools and techniques that comprise it. Production logging has also proven invaluable for identifying production and completion anomalies and problems.

Key Points:

► When measuring downhole flowing production profiles, identifying zonal contributions of water, oil and gas are critical to validate and calibrate reservoir modeling and completion and stimulation practices.

► Running production logs in horizontal wellbores presents unique challenges requiring modification not only to the tools but also in the delivery techniques.

► A production log is usually run by the operator in a flowing wellbore to measure to the zonal contribution of water or hydrocarbons to evaluate the flow performance model and stimulation effectiveness.

► Unlike flow in a vertical well, in a horizontal well, wellbore production does not mix well, therefore, special sensors are required to properly measure the holdup across the lateral section.

To learn more about this topic we suggest enrolling in the upcoming session of Evaluating and Developing Shale Resources(SRE) (https://www.petroskills.com/course/evaluating-and-developing-shale-resources-sre). Related courses include Unconventional Resources Completion and Stimulation(URCS) (https://www.petroskills.com/course/unconventional-resources-completion-and-stimulation-urcs), Petrophysics of Unconventional Reservoirs(PUR) (https://www.petroskills.com/course/petrophysics-of-unconventional-reservoirs-pur) and Reservoir Management for Unconventional Reservoirs(RMUR) (https://www.petroskills.com/course/reservoir-management-for-unconventional-reservoirs-rmur).

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