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## **Shale Gas Horizontal Production Logging Measurements and Challenges**

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### **Abstract**

Traditional shale formations are presently being produced via horizontal well completions. These horizontal wells consist of numerous selectively stimulated stages containing as many as 20 stages spread out across 2000 ft to 9000 ft interval.

The well completions have been stimulated using low technology methods such as high volume water / slick water & sand. The initial production of the well requires a short period of flowback of the injected load water prior to the wells being kicked off with hydrocarbon production. The load water flowback can range from as little as 2% load return as high as 70% returns. Since these types of formations are far from being homogeneous, these horizontal laterals can intersect existing natural fractures or faults in the formation or an aggressive stimulation could induce fractures into existing natural fracture or faulting network.

This paper will showcase horizontal well production logging measurements ideal for this flowing environment in order to deliver a high confidence, representative flow profile.

In addition, deployment techniques & the logging challenges will be discussed to establish the best possible representative flowing environment for measuring these types of well completions.

### **Introduction**

The recent trend of exploiting hydrocarbon bearing shale formations now being produced via horizontal well completion has now made deployment, measuring and understanding the flow contributions across a producing lateral more complex than the traditional vertical well environment. Many of these new style horizontal completions consist of numerous perforated intervals containing as many as 20 stages ranging from 2000 ft to 9000 ft interval. Stimulations using sand & water are required to energize the formation across the lateral and a flowback period of the injected load water is needed prior to the wells producing hydrocarbon. Shale formations across a horizontal plane can consist of natural fractures and a faulting network. The horizontal laterals can intersect these existing natural fractures or faults in the formation which lead to unproductive intervals across the lateral. (D. Heddleston, 2009)

In some areas the completion and stimulation of a shale horizontal well can be close to 60% of the total well cost; therefore, operators are experimenting with lower cost stimulation techniques to utilize less resources in the hope of creating efficient production.

In order to properly understand the efficiency of the well completion (frac) and the deliverability of flow across the lateral a production log is required to measure and monitor contributions of water and hydrocarbons. However, due to the completion and flow environment there are many challenges to overcome in order to gather representative flow results from a production log in a horizontal well.

## Horizontal Well Completions

An unconventional shale horizontal well completion consists of numerous perforated intervals containing up to or more than 20 stages ranging from 2000 ft to 9000 ft long interval.

Stimulations using sand & water are required to energize the formation across the lateral and a flowback period of the injected load water is needed prior to the wells producing hydrocarbon. Shale formations across a horizontal plane can consist of natural fractures and a faulting network.

The perforated intervals are normally chosen by the operators based on seismic information & formation characteristics such as quartz content & thickness of formation.

Approximately 4 to 5 intervals per stage are stimulated with a large volume of slick water, for example ~ 20,000 bbl of water per stage & 200,000 lbs of 100 mesh sand. A typical frac gradient in certain areas can be ~ 0.8-.9 psi/ft.

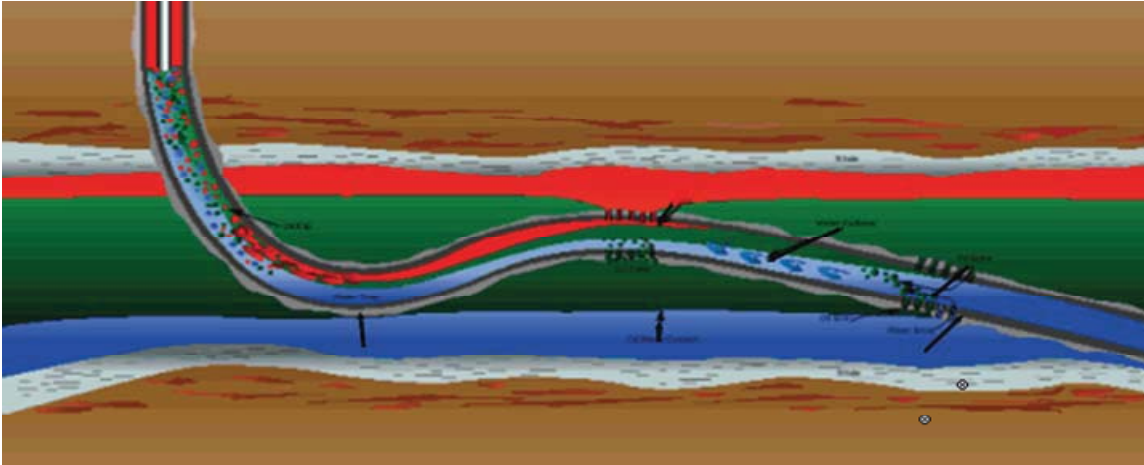


Fig 1. Horizontal Well Production illustration.

## Production Logging Measurements

Production logs are quite often required by operators to help identify the deliverability and rate contributions across a flowing wellbore. The measurements are used for analyzing dynamic well performance of different zones, diagnosing problem wells, or used in the monitoring process as the results stimulation of a completion.

The production log consists of a suite of sensors each required to better identify downhole fluids, pressure, temperature & rates, in order to convert the measurements from the downhole in-situ conditions to represent surface values.

A compact horizontal well production logging sensor package consists of a (Fig 2);

Depth Correlation	– GR/CCL
PTA & PVT info	– Pressure & Temperature
HC & Water Inflows	– Temperature / Holdup / Flowmeter
HC & Water Identification	– Capacitance / Density / Holdup
Gas & Liquid Ratio	– Holdup
Rate Measurement	– Flowmeter

In regards to a higher confidence - direct measurement of Holdup, a very low energy GRs encounter Compton scattering & this backscatter of GRs into the detector is proportional to the electron density of the borehole fluid, since liquids are heavier than gas there is more scattering back to the detector when liquids are in the wellbore. (Kessler & Finch, 1995)

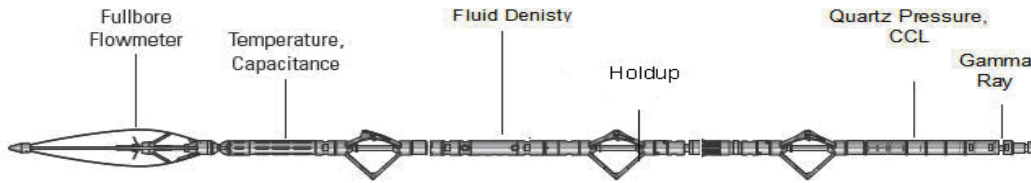


Fig 2. Horizontal well Production Logging sensor package

### Horizontal Shale Flow Regime

Most shale horizontal wells, after ~ 5 - 30 days of flowback usually contribute at a high gas to liquid rate. On average 2 MMscfd and very little water production < 200 bbl/day, however in some areas rates can be > 10 MMscfd of gas and still contribute low water production.

Rates such as these in 4 ½ - 5 ½ Casing are considered to be single phase production, meaning with these low water rates with high gas rates the phase ratio can be less than 10% water occupying the cross section of the well.

With little water phase occupancy in the cross section of the wellbore, the flow regime is stratified flow as shown in figure 3. Since the rates are considered to be relatively low, well below critical velocity of the pipe size and the laterals are usual long, the production moves across the lateral as a stratified flow regime.

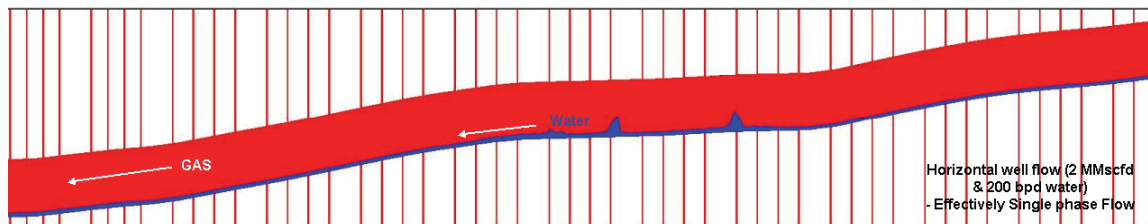


Fig 3. Horizontal wellbore with 2 phase Holdup Fullbore Image ~ 2 MMscfd & <200 bbl/d.

### Horizontal Production Logging

In a low flow energy environment, such as a horizontal wellbore with stratified flow, consisting of a high gas to liquid ratio, this flow environment is considered to be single phase flow. Therefore, the ideal and most practical sensor measurements that delivers the best representation of horizontal flow is a full cross section wellbore Holdup, Fast Response Temperature & a bulk flowrate measurement.

A full-bore holdup measurement measures the entire cross section of the pipe, delivering a true image of the holdup changes as water or gas is starting to enter the wellbore & occupy more of the pipe volume. The Temperature measurement is ideal for correlating to the changes in the holdup as water is usually a warmer event and gas (due to Joule Thompson expansion) is a cooler event. (D. Heddleston, 2009)

In a high gas/liquid ratio flow in horizontal wells, the wellbore gas/liquid holdup can be ~ 70% 99%. Therefore, using a bulk flowrate measurement is the most practical & reliable method to measure velocity as seen in Figure 4, demonstrating repeatable / consistent velocity passes is shown.

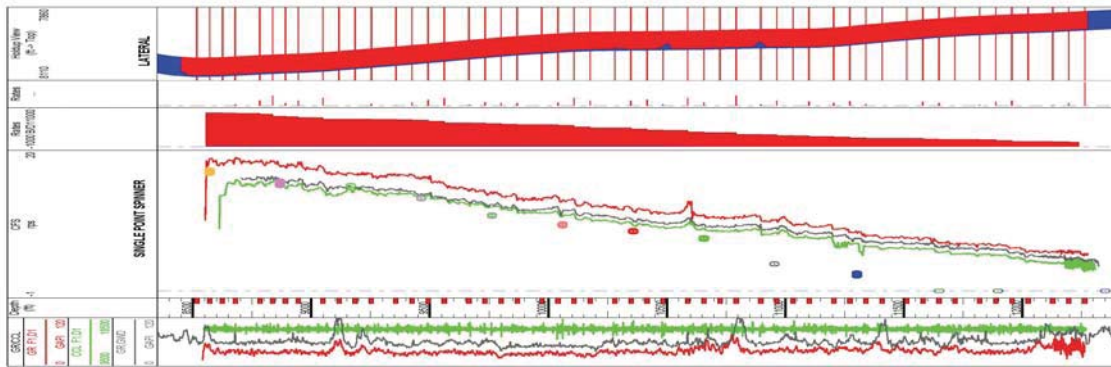


Fig 4. Example of a bulk flowrate measurement with repeatability.

### Horizontal Production Logging Challenges

The challenges for production logging deployment and measurements is how to ensure the survey is measuring representative horizontal lateral contribution that is consistent with its every day flow pattern.

The majority of the horizontal wells are logged using coiled tubing (CT) as the conveyance method. A pre-logging CT run is used to clear the well of obstructions such as sand and plug debris in order to lessen the debris entering the production log, most E & P operators migrate to the use of CT for this reason. A second method for conveyance is the use of Well Tractor. A well tractor uses E-Line to convey a tractor through tubing or down casing and motors the logging string on the end of the tractor. Both conveyance methods have delivered good results in regards to production logging surveys.

Shale formations are normally stimulated with low cost resources such as sand and water, over the flowback period the sand normally collects in the wellbore and coarser material such as stage plug material also can settle out in the heel sections, approximately 70 degree deviation.

All of these conditions can affect the performance of the logging measurements if not properly addressed. Therefore, this flow environment required robust production logging systems capable of deploying through sand and plug material in order to measure effectively across the rest of the flowing lateral.

### Production Logging Challenges using Coiled Tubing Deployment

Coiled tubing (CT) can be deployed using 1 ¼" & 1 ½" through tubing sizes or deployed down casing with 1 ¾" & 2", is used in order to reach the end of a long lateral section.

Normally with CT the shallower the TVD and the longer the lateral, the bigger the CT is required to reach the end of the lateral due to friction lockup.

Even though CT is reliable to perform a cleanout trip and deploy the logging tools, the issues that arise when using CT can be the perturbation of well flow across the lateral section while performing the production log. In some cases the choking effects by the CT can range from 10%-40%. In 4 ½" 15.1 # casing, with a pipe ID of 3.826" and CT pipe OD 2" is ~ 52% pipe occupancy. In 5 ½" 20# casing, with a pipe ID of 4.778" and CT pipe OD 2" ~ 42% pipe occupancy.

### Case History 1

The case history shown in figure 5 & 6, this shale well horizontal lateral flows ~ 1 MMscfd gas and very little water production. During the production logging survey the flow performance was ~ 700 Mscfd. Therefore, by deploying 1 ¾" CT with the horizontal production logs through 4" ID casing ~ 43.75% pipe occupancy allowed for 56.25% flow area allowed for drop a 30% of production during the production logging survey.

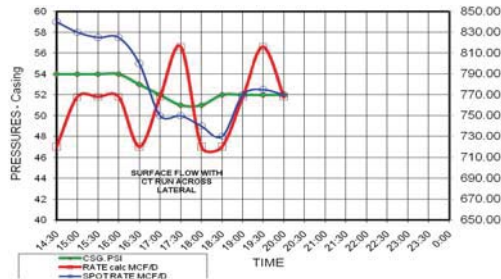


Fig 5. Flowback results during PLT deployment (RECON 2009).

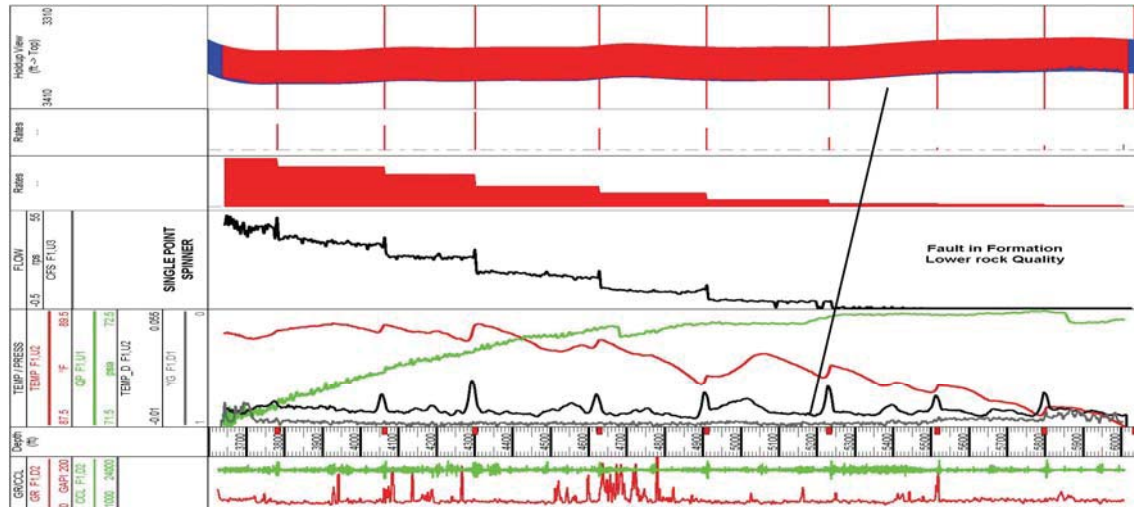


Fig 6. CT deployed Horizontal PLT Results.

In regards to this Case History, even though there was ~ 1/3<sup>rd</sup> choking effect during the production logging survey, the measurements showed < 5% water occupancy (cross sectional holdup) in the lateral, the bulk flowrate measurement is very reliable across the lateral & the temperature changes from interval to interval correlate to the flowmeter. The data was deemed to be representative of flow as the operators knowledge of the toe section having a less quality formation is confirmed with the horizontal production log showing very little contributions coming from the final 1/3<sup>rd</sup> of the lateral.

**Case History 2**

The case history shown in figure 7 & 8, this shale well horizontal lateral flows ~ 3.8 MMscfd gas and 200 bbl/d of water production. During the initial clean out trip a large amount of sand was tagged at the heel & N2 was used to circulate out the sand & debris. During the production logging survey the flow performance was ~ 2.5 MMscfd; therefore, by deploying 2" CT with the horizontal production logs through 4.778" ID casing ~ 42% pipe occupancy allowed for 56.25%, a 2 7/8" BHA was used by the operator further reducing the flow area to 39.8 %. The decrease inflow area allowed for a drop of 34% of production during the production logging survey. Also take into account the sand bridge occupying the heel section, causes not only debris issues with the logging strings but also lowers the flow area.

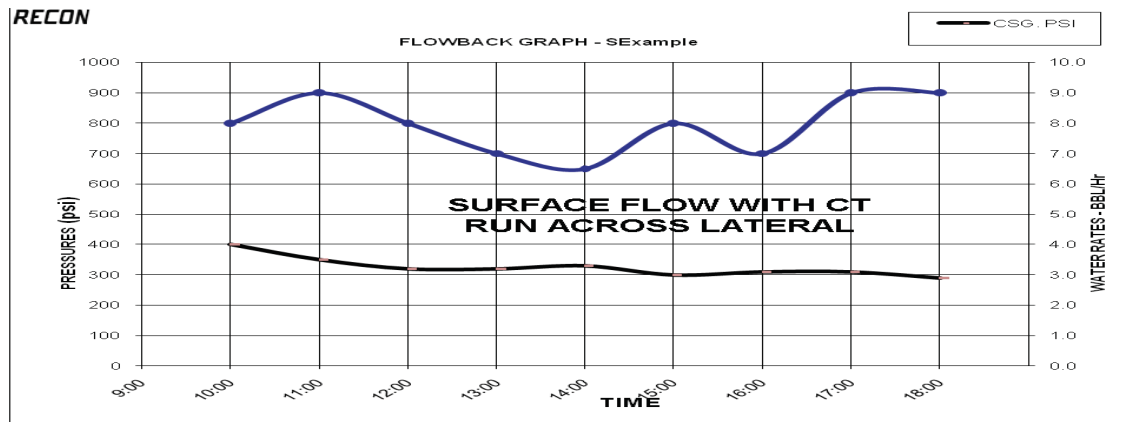


Fig 7. Flowback results during PLT deployment.

In regards to Case History 2, even though the CT does create a choking effect the flow results across the lateral are representative using this production logging technology & procedures.

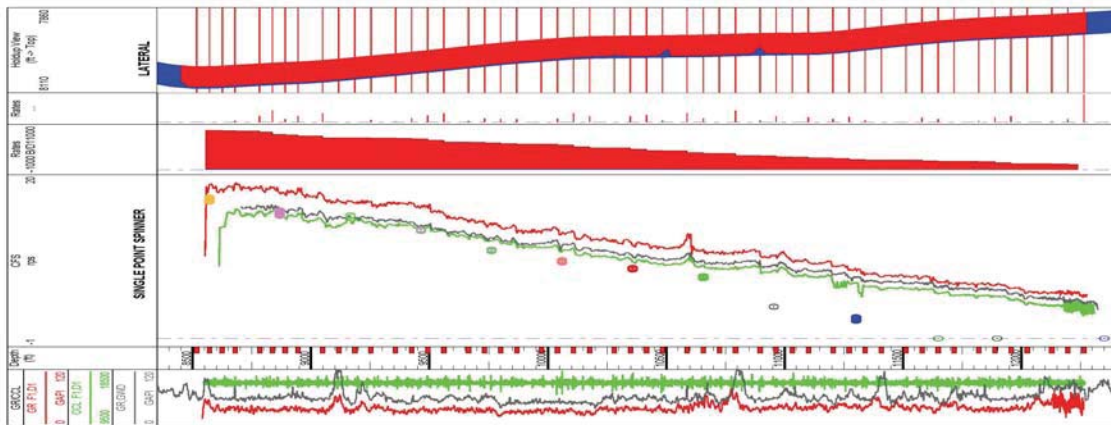


Fig 8. CT deployed Horizontal PLT Results

## New Technology

It has been determined that majority of shale horizontal wells contain sand and debris. Therefore, the best solution found to get the most representative data is to use a robust production logging platform, in order to acquire fullbore holdup, temperature & a bulk flowmeter measurement.

New technology platforms using array type probes & sensors is a complex method in determining a fullbore / cross section flow measurements. In the right conditions such as "a high rate oil/gas well with deviation approximately 45 degrees" (Frisch, Dorffer, Jung, 2009), is the window for success with delicate array sensor technology. Unfortunately, after test runs in the US shale horizontal well environment, tool setup reliability & sensor sensitivity were unable to deliver consistent measurement repeatability. Therefore, presently tool manufacturers are still in the field trial phase with production logging array technology to better understand their capabilities.

Due to the wellbore environment and delicate design of array type sensors, the tool design are expand in size (occupying the fullbore of the casing), this can cause additional choking effects. The tool set hardware architecture in fact occupies the full cross section of the flow area, or the sand & debris filling the casing can affect the sensors readings. Examples of a typical shale horizontal well logging survey using array type tools figure 9 & figure 10 show the results of debris and sensor reliability issues.



Fig 9 & Fig 10 array tool issues.

A comparison of a fullbore holdup measurement versus multi-sensors probe type measurements are represented in figure 11. The full-bore holdup measurement matches the multi-probe results, yet it was found that the full-bore holdup measurement setup was far more robust over the array sensor package and demonstrated better repeat data on the subsequent passes.

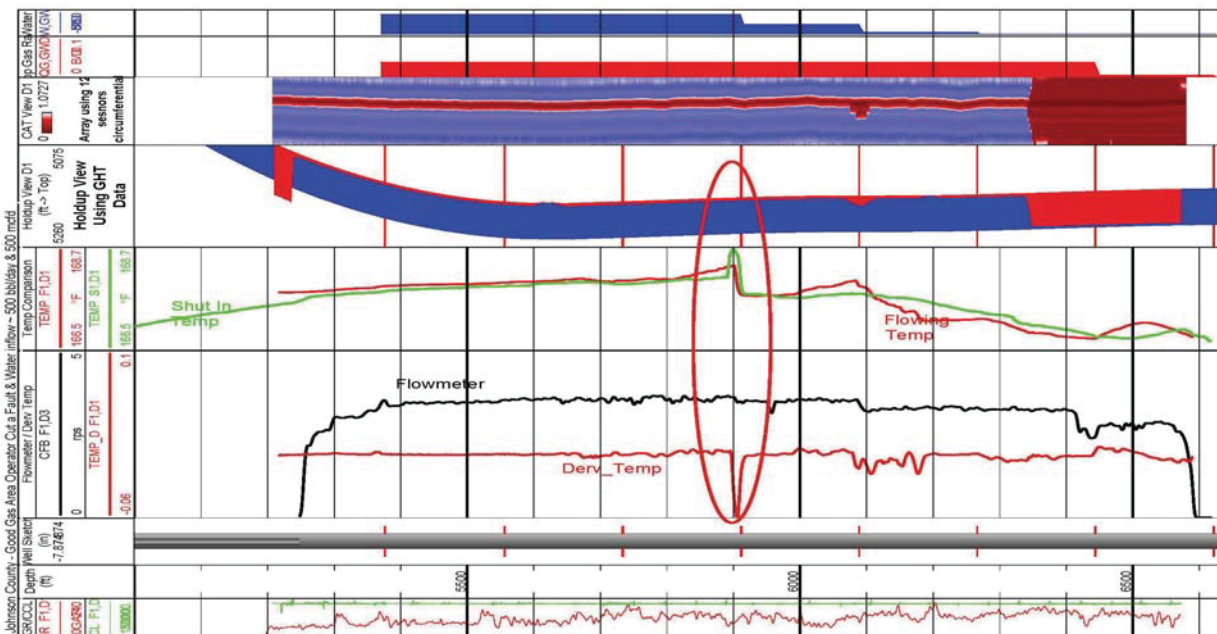


Fig 11. Array sensors compared to fullbore holdup measurements.

**Conclusion**

In order to acquire representative production log data in US shale horizontal completions, addressing deployment, flowback and well debris issues are important factors. With over 200 hundred trial runs in the US shale horizontal well environment with a proven production logging platform that is dependable, robust measurement setup is a solution to ensure representative data is acquired. The use of 3 fluid identification sensors technology with a full-bore holdup measurements, temperature & bulk flow measurements is an ideal platform in the majority of US shale horizontal environments.

With proper project management of setting up a horizontal production logging survey ensuring flowback, deployment, robust reliable measurements and experienced log analysis improves the success of delivering representative results.

**Reference**

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