A New Method of Acquiring Open Hole Logs In Unconventional Wells

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Abstract

Open hole logging of highly deviated and horizontal wells is now becoming more accepted due to a recently developed conveyance and acquisition system that can greatly reduce the cost and risk associated with running logs in these types of wells. Conventional log measurements including resistivity and porosity, which in many cases may not have been previously economical to obtain in lateral wells, can now be used to delineate the needed basic reservoir properties for planning completions and future drilling designs.

The method employs a newly engineered ultra slim toolstring that is designed to pass through the drill pipe and a specially designed hollow PDC bit into open hole. Data can then be obtained beyond the bit in memory while tripping out with the tools on pipe. Lost in hole risk and the higher cost of using other more expensive methods, such as LWD, can be minimized by using the drill pipe and bit to safely acquire the data and retrieve the tools if necessary. Circulation of the well fluids and pressure control can still be maintained throughout this process. A brief overview of the conveyance method and acquisition tools will be presented along with log examples from some of the common unconventional plays that outline the applications of this data.

Introduction

A relatively large percentage of horizontal wells currently being drilled have very little open hole log information from which the operator can plan the completion. In many cases, only a gamma ray from the MWD is available. As drilling of horizontal wells has become more prevalent, the technology of acquiring open hole logs in this challenging environment has steadily progressed. Logging while drilling, tractoring logs into open hole, and different variations of pipe conveyed logging are some of the options currently available. One system now in use delivers a set of slim hole tools through the drill string and a hollow bit to gather data in lateral wellbores. The associated equipment and technique offer some unique advantages over other pipe conveyed logging approaches. Being able to condition the well with the hollow bit prior to logging, rotating the pipe and circulating the mud during logging and down logging through the drill string in real time are some examples. Log examples obtained using this conveyance method will be shown from three areas that illustrate the added value of having the log data that can be provided by this system.

Slim Holes Tools and Through Bore Bit

A new set of slim hole logging and conveyance tools having a maximum outer diameter of 2-1/8” have been developed that are capable of passing through a drill string and hollow bit with a minimum internal diameter of 2-1/2”(2-3/8” drift). The schematic in Figure 1 shows the tools in their typical configuration to log a horizontal well. The measurements include an array induction with 10”, 20”, 30”, 60” and 90” depths of investigation, bulk density with photo electric factor (PEF), thermal neutron, caliper and gamma ray. Other auxiliary sensors measure temperature, tool orientation and casing collars. A monopole sonic tool with a six receiver array has also recently been built. A mechanical no-go device is located near the top of the tool to enable the string to be hung off in a special sub above the bit. The sensors are then extended beyond the bit in the final stage of deployment. Figure 2 is a photo of the through bore bit. This special bit is available in sizes ranging from 6” to 12-1/4”.
Deployment

The through bore bit and Hang-Off sub are installed in the BHA prior to a conditioning trip. Once the lateral wellbore is ready for logging, the bit is positioned just short of the maximum depth that logs are needed. This allows room enough for the logging sensors to extend beyond the bit. The slim tool assembly is lowered on wireline into the drill pipe at the surface. Pressure gear including a pack-off and swivel are installed to allow for pressure control, circulation and pipe rotation during logging. The tools then descend through the drill pipe while recording a real time down log of casing collars, gamma ray, and neutron porosity. This down log also serves as a depth reference for the final up log that will be recorded in tool memory. After the tools have gone as far down as gravity will take them through the vertical section of the well and into the curve, the rig mud pumps are engaged to pump the tools through the horizontal section to the end of the drill string. Gradual pump pressure forces the logging string through the hollow bit into open hole. The tools stop and are suspended when the no-go device reaches the Hang-Off sub. At that point, only the logging sensors are in open hole. The wireline, which is still attached to the head of the tool, and a Wired Drop-off/Retrieval tool remain inside the drill pipe. One final check of the tool is made and the caliper is opened. Accelerometers inside the tool give verification of the tool’s position, indicating that the density skid is on the low side of the hole. Signals are then sent through the wireline from the surface unit to switch the tool over to battery power and release the wireline at the Wired Drop-off/Retrieval tool. The wireline and the upper part of the drop-off tool are subsequently removed from the drillstring leaving a fishing neck exposed at the upper end of the logging string. This enables retrieval of the logging tool and nuclear sources from the well at any time. This deployment method, along with other optional procedures for the logging through a hollow bit, and a more detailed description of the equipment, have been previously documented.\(^{(2)}\)

Logging data is recorded versus time in the tool’s memory as pipe is tripped from the well. After the desired amount of logging is complete, a retrieval tool can be lowered through the drillstring on wireline to retrieve the tool. Early retrieval allows the data to be downloaded, verified and sent out while the pipe trip to surface is being completed. Alternatively, the tool can be tripped all the way to surface on the end of pipe. Once it is downloaded from the tool, the time indexed log data is merged with the depth-time data recorded at the surface to obtain the log data versus depth in a similar fashion to the way that LWD data is processed.

The attributes of this deployment method and associated equipment that make it unique compared to pipe conveyed logging systems are:

1) The through bore bit allows the well to be conditioned prior to logging. Along with the drill string it acts as a protective conduit through which the slim tools can pass into open hole after the well is known to be in satisfactory condition.
2) The wireline connection is used to convey the tools and record a down log through the pipe. This technique provides verification that the tools are functioning properly from the time they leave the surface until they are switched to memory acquisition mode. The wireline is always inside the drillstring and never exposed to open hole.
3) The 2-1/8” tools and their nuclear sources can be retrieved during the procedure if well conditions deteriorate and there is an increased risk of sticking pipe.
4) When reaming is required, the logging can be performed on the same trip. This can potentially save the additional rig time required for another trip.

These features enhance the reliability of the 2-1/8” logging tools since they are not deployed until the bit is in position near TD, thus resulting in less exposure to shock, vibration, and temperature. Risk is minimized since the tools are retrievable and the system allows for full well control capability. The rig time to acquire logs is reduced because the deployment and acquisition can take place during the conditioning or reaming trip.

Log Examples

Logs successfully obtained using the method and tools described above are shown below for some of the common horizontal targets currently being drilled.

Bakken Example

Figure 3 is a log from the Bakken formation in North Dakota. The 2-1/8” tools reached a total measured depth of over 20,000’. The TVD depth curve from a third party survey is presented as a solid black line in the depth track. It portrays a 2D representation of the well trajectory showing that the deviation is slowly building towards TD to around 90 degrees. The porosity shows variation throughout the interval and is lower than average in Zone B. The lithology track shows a three
mineral computation using the neutron porosity, bulk density and photoelectric factor curves. Yellow area coding in the lithology track indicates quartz, the blue shading indicates limestone and the green represents a mixture of dolomite and shale. This simplified lithology model shows a slightly different mineralogy in Zone A when compared to the other zones. Even though the gamma ray is fairly uniform throughout the interval, there are significant variations in porosity and lithology in this Bakken section. Zones A and C would be the more attractive intervals to focus on for the completion based on their higher porosity readings. The caliper curve shows evidence of some hole enlargements in Zone A and the upper part of Zone B. Caliper data is useful for the cement job design and could possibly affect the placement of packers.

**Eagle Ford Example**

A log section from an Eagle Ford well in South Texas is shown in Figure 4. Even though the wellbore is horizontal over this interval, porosity fluctuates between zero and 18%. When interpreting horizontal data one must consider the possibility of anisotropic effects of the surrounding geology on the various logging sensors having differing depths of investigation. For instance, the neutron, density and gamma ray all have an investigation radius of less than one foot, whereas the induction has multiple readings from 10" to 90" away from the wellbore. When changes in the shallow reading porosity and gamma ray curves have depth offsets with the deeper reading resistivity responses, or there is no direct correlation of changes in resistivity with changes in porosity, then the tools are most likely sensing different volumes of rock for one reason or another. Possible reasons for this include horizontal and vertical variations in properties and thickness of the rock layers surrounding the borehole, and their relative angles to wellbore. The response of the induction resistivity can be more complicated due to the varying thicknesses and high apparent dip of layers surrounding the borehole. Higher resistivity readings are normally associated with lower porosities if both the resistivity and porosity tools are sensing the same rock. In Zone B there are several intervals of low porosity that have no correlateable increases in resistivity. These types of tool responses imply that the lower porosity streaks sensed by the shallower reading porosity tools could be thin tight layers in close proximity to the borehole. Given that there is not much of a notable increase in the resistivities in those same intervals, the deeper reading resistivity is probably more representative of the higher porosity reservoir rock beyond the tight layers.

The interpreter must use all of the data available along with their understanding of the local geology to make best use of the log information. Based solely on the log observations above, the prime area for completion consideration in this well is all the rock in Zone B. Most of the lower porosites in Zone B are probably not major barriers that would impede the stimulation or producibility of the reservoir.

**Granite Wash Example**

The Granite Wash formation in the Texas Panhandle is made up of a mixture of clays, radioactive feldspars, quartz and carbonate components. Its deposition is also known to be stratigraphically complex with considerable lateral changes in reservoir continuity. Figure 5 is a horizontal log from a Granite Wash well. The wellbore traverses alternating sections of cleaner rock, as observed by the cross-over on the neutron-density (yellow shading), and shale deposits in between. There is a fair degree of correlation between the changes in lithology and resistivity response which implies that the tools are seeing lateral changes in rock type along the horizontal section. Clay rich intervals on the nuclear data show higher gamma ray and lower resistivity readings. The gamma ray is of little use by itself for correlation. Some of the cleaner intervals with neutron-density cross-over have elevated gamma ray responses due to increased feldspar content. The information obtained from this log is useful for making specific choices of which intervals to complete based on the presence or absence of reservoir rock, and how to best group the various intervals for stimulation design. Stimulation costs can be minimized by not completing intervals with non-reservoir quality rock.

**Conclusions**

The new 2-1/8" tools and through bore bit along with the deployment method described herein allow for the successful acquisition of basic logging data in horizontal wells. The reliability of this acquisition system is enhanced due to the fact that the tools are not deployed until the well is in satisfactory condition for logging, thus reducing the exposure time of this equipment to down hole conditions. Use of the wireline inside the drill pipe to position and retrieve the tools further enhances the dependability of this method when compared to other pipe conveyed logging systems since the tool’s operation can be continuously monitored during the down logging. Lost in hole risk is minimized since the wireline is not exposed to the open hole and the tools can be retrieved at any time during the logging procedure. Market pricing of the data acquisition using this through bore method and tools is typically much less than LWD and some of the other pipe conveyed methods which can provide equivalent data. Significant rig time savings can also be realized since logs can be obtained with in the same run as a conditioning or reaming trip.

The logging data made available using the 2-1/8" tools and through bore bit is revealing when compared to the sole use of an MWD Gamma Ray for selecting completion intervals. One should consider the possible effects of anisotropy and complex
bedding geometry near the wellbore when interpreting the porosity and resistivity logs in horizontal wells. Knowledge of the local geology and all other available data should be factored into the interpretation. The use of this data allows completions to be optimized by targeting the best intervals for perforation and packer placement. Stimulation costs can be reduced by not treating sections of low reservoir quality.

Acknowledgements

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References

1) Kuchinski, Stayton, “Mitigating the Risks Associated With the Acquisition of Formation Evaluation Data”, AADE National Technical Conference and Exhibition, Houston, Texas 2007
Figures

**Figure 1:** Tool string configuration for horizontal logging operation. The No-go has a slightly larger diameter than the other tools and is used to hang the tools off inside a hang-off sub just above the bit. The Wired Drop-off/Retrieval tool and the wireline remain inside the BHA and drill string until they are removed just prior to the log data being recorded in memory while the pipe is being tripped from the well.

**Figure 2** – End and side views of a 6-3/4" PDC through-bore bit. The 2-1/8" logging tool string with all associated accessories can easily pass though the middle in both directions.
Figure 3 – Bakken well from North Dakota showing changes in porosity lithology. Note the washouts on the caliper in the upper part of the hole. (Horizontal Scale = 1000’/major division; TVD Scale=130’)

Figure 4 – Eagle Ford horizontal section from a South Texas well showing variations in porosity, some of which are due to thin tight layers near the borehole. (Horizontal Scale = 1000’/major division; TVD Scale=70’).
Figure 5 – Granite Wash horizontal section from the Mid Continent area showing lateral variations in porosity and lithology. These are stratigraphic changes due to the complex depositional environment of the Granite Wash. The better quality reservoir intervals are those shown with yellow shading where the neutron and density porosities cross-over. The areas in between with higher neutron porosity (blue curve) are primarily shale. Using the gamma ray curve by itself to identify the prospective completion intervals would be misleading. (Horizontal Scale = 500'/major division)