RESERVOIR ASSESSMENT FROM HORIZONTAL WELL LOG EVALUATION-DIFFERENT UNCERTAINTIES AND CHALLENGES.

S.K.Dhar , J. Basu
Oil and Natural Gas Corporation Ltd.

This paper was prepared for presentation at the SPWLA Conference held in Mumbai, India, March 19-20, 2007.

ABSTRACT

With the advancement in drilling technology, high angle and horizontal wells (HA/HZ) are very common today for better drainage of oil reservoirs. At the same time Logging data acquisition technology also got a transformation from normal wireline operation to pipe conveyed operation and ultimately into logging while drilling technology to log these tough wells. While the industry has developed technologies to log and acquire data from these wells, it has not yet developed the technology to interpret the data quantitatively on a routine basis.
Assessment of a reservoir is made on the basis of computing hydrocarbon pore volume (HPV) from the log. It depends on correct estimation of reservoir height (thickness), Porosity and fluid saturation. Uncertainty in estimating above values leads to a wrong interpretation. As the apparent wellbore deviation angle increases the uncertainty in the log derived properties also increases. Using currently available technology, the impact of increased uncertainty associated in reservoir assessment from log data of HA/HZ wells needs to be recognized and addressed.
In the present work, an attempt has been made to design a suitable workflow which can reduce the uncertainty in formation evaluation from HA/HZ wells.

INTRODUCTION

Drilling of HA/HZ wells are necessary to increase the reservoir producibility in a mature field. It requires exact well placement in the target reservoir section (sweet zone) by avoiding the gas cap above and active aquifer below. Real time log analysis is required in this case to geo steer the well in the desired profile as per objective. Logging while drilling (LWD) technology is normally been used in this type of designer well for monitoring the well course and selection of suitable completion option. Quantitative formation evaluation may not be always required in this type of situation. This is because in most of the cases a vertical appraisal offset well is available against the same pay section.
In the second case HA/HZ wells are drilled where surface facility or the environment does not support of drilling a vertical well. Such type of situation normally occurs (generally happens) in a coastal area where drilling is done by an onshore rig but the sub surface point lies under the water covered part, or environmentally difficult terrain. In this situation a detailed log analysis is required to identify and evaluate the reservoir quantitatively.

Third situation arises when original vertical well bore becomes sick after prolonged production and it is required to drill a sidetrack well by cutting a window from the old casing to reach in the part of the reservoir where oil is still left. This also requires a quantitative log evaluation to predict the well performance and further assessment of the reservoir producibility.
Therefore role of correct evaluation of log data is utmost important in HA/HZ wells for reservoir assessment like any other vertical wells. But it is still a very big challenge in the industry to the operating companies and as well as to the service companies to come out with the suitable methodology or the techniques to interpret the logging data acquired in a horizontal well.

Apparent Deviation Angle, θ (Relative angle between borehole axis & Axis to the bedding plane)	Well Type	Possible Logging Mode
$\theta \leq 30°$	Vertical or Near Vertical	Wire line
$30°<\theta \leq 60°$	Moderately Deviated	Drill Pipe Conveyed
$60°<\theta \leq 80°$	High Angle (HA)	LWD
$\theta > 80°$	Horizontal (HZ)	LWD

METHODOLOGY

The classification of HA/HZ well are based on the relative angle (?) between the borehole axis and the axis of the bedding plane.

On the basis of this definition if the well bore is vertical but the formation dip is higher than 30 degree then also the well will turn as a deviated one. Therefore formation dip is equally important with the direction and azimuth of the borehole to decide the well course. Continuous inclination and azimuth has to be recorded while drilling for accurate placement of the well and for true vertical depth measurement.

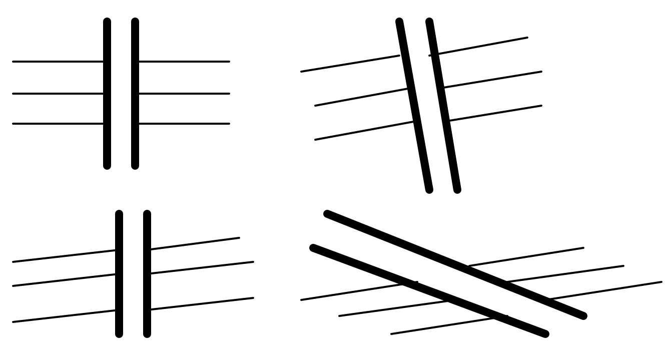

Fig. 1: Different borehole and bedding geometry.

Now let us work out what are the possible changes occur when we switch over from vertical depth frame to horizontal depth frame. So far, in a vertical depth frame we were thinking about a vertical borehole cutting across horizontal beds/stratas (? =0 degree) or a very low angular deviation (?) in a near vertical case. Normal wireline conveyed logging tools can measure the reservoir properties here and we are familiar to this type of situation. If the relative angle (?) goes beyond 30 degree then it is becoming exceedingly difficult to convey the tool through wireline. In this case a drill pipe conveyed mode is preferred with the same set of tools used earlier in wireline with hardly any additional modification. As soon as we enter in a deviated borehole, determination of exact borehole geometry becomes utmost important for accurate depth control and suitable well placement. It is often found that TVD computation becoming erroneous due to measurement inefficiency in azimuth and inclination data and actual depth of marker tops differs with the earlier estimated values. This will also introduce an error in computation of true vertical thickness (TVT) of the pay section and hence in computation of hydrocarbon pore volume (HPV). To overcome this situation a continuous measurement of borehole inclination and azimuth is preferred over discreet measurement in every 9 meters interval during pipe connection.
Once depth control is accurately done then we will come into other log measurements. Prior to that, objective of Logging the horizontal well has to be clear. We have to plan the logging jobs at the predrilling stage based on our objective of drilling the HA/HZ well . Basically there are three kinds of objective behind drilling a HA/HZ well and accordingly logging is planned.

1. Geo steer the well correctly within the sweet zone (designer well).
2. Quantitative formation evaluation from a well drilled in environmentally difficult terrain where drilling of vertical well is not possible.
3. Assessment of reservoir producibility for undrained/ bypassed oil when a side track high angle well is drilled after old vertical well became sick.

Objective 1:

Proper Well Placement

In this case the data of vertical appraisal well and the control of suitable marker is available before drilling horizontal section.
Based on the offset vertical well data expected reservoir properties are modeled for the horizontal well and desired well course are planned. It is also possible to prepare a synthetic gamma ray and resistivity log curve for the planned horizontal well from the vertical offset well log data. With the advancement of drilling the deviation between the actual log with the modeled logs are constantly monitored to place the well suitably.
It is well known from various case study analysis that log derived properties of HA/HZ well will vary appreciably from its vertical well counterpart. This can be due to mainly three reasons –

1. Logging tool design of the different service companies are suitable for near vertical well log measurement. They have different depth of investigations around the well bore based on their instrument geometry and response function. Tool response is not exactly known in the case of HA/HZ well .
2. All the logging tool response are affected by the borehole environment and the drilling fluid invasion. Invasion geometry is not clear for HA/HZ well to use suitable correction.
3. Formation anisotropy also play a role since log derived properties may vary laterally and vertically as well.

Continuous R & D has been done by the operating company and the service company jointly in last two years to overcome this challenge with a feasible solution. Logging While Drilling (LWD) technology is used in this case for real time data analysis and constant monitoring of well trajectory. Logging companies has improved their LWD tool designing in recent years to give a better solution. Now Gamma Ray sensor is available in drill collar to identify the lithology and Resistivity sensor is available above the drill bit for better identification of reservoir in real time. Continuous inclination and azimuth measuring is also available to update the well geometry in real time and accurate depth control. LWD tools are not affected by borehole invasion because measurement is carried out immediately after drilling. Formation anisotropy effect can be very well minimized by circumferential measurement around the borehole instead of directional measurement. As logging service companies are geared up to the industry demand operator companies have also refined their modeling technique by applying inversion and neural network.
Therefore designer well is no more a dream. A major operator company has drilled 144 HA/HZ wells successfully in year 2006. A major logging service company has logged 21,793 m of horizontal section in 58 wells which shows 21,275m section are logged within the reservoir and only a small portion has missed the desired target. So time has come, we are able to design a well and place it as per our choice and complete it in desired target.

Objective: 2

Quantitative formation evaluation :

It is a known fact that Logs from HA/HZ wells vary from the vertical well logs due to various reasons already discussed. With the increase in relative angle (?), log character is changed phenomenally and most of the logs are adversely affected. Quantitative formation evaluation from such unusual log response is an uphill task and a big challenge in front of the industry now. For correct reservoir assessment and to predict about the reservoir producibility(,) petrophysicists mainly depend on correct determination of formation porosity and resistivity from the available logging tools in the industry. Any uncertainty in determining either of the two parameters introduces an error in computation of saturation. As the relative angle (?) increases, it is noticed in various case studies that conventional logging sensors yields too high porosity and also too high resistivity (Rendeiro etal 2005). This is primarily because our nuclear porosity device is padded type and have a very low depth of investigation. As the relative angle increases the pad faces lower side of the borehole which is normally filled up with mud and formation cutting sample. This generates a high optimistic porosity value which may not relatable with actual formation porosity.

Resistivity measuring devices are laterally focused and having varying depth of investigation. Resistivity measurement is mostly affected by the borehole geometry or HA/HZ effect, borehole fluid invasion and formation anisotropy. In near vertical borehole resistivity computation is done by considering the resistance of each layer (strata) as a parallel electric circuit. Tool response is the equivalent resistance of all the layers in parallel coming in front of the tool. As relative angle (?) increases, the tool does not see the layer (strata) as a parallel electric circuit like in earlier case. Instead of it the stacks of the layers become the source of different electrical resistances acting is in series. Due to this fact the equivalent resistance becomes higher in the second case justifies the high resistivity with high relative angle (?). Borehole invasion play a least role in LWD resistivity measurement because log is measured immediately after drilling and prior to any invasion. However the nature of invasion in case of HA/HZ well is not very well understood. As invasion took place due to the difference in density between the borehole fluid and the formation fluid and distributed almost radially around the borehole in near vertical well situation. But in case of HA/HZ well it is controlled by the gravity and the permeability anisotropy around the borehole and does not have a regular spherical distribution. Moreover due to formation resistivity anisotropy, sometimes resistivity value in the vertical direction i.e. perpendicular to the bedding plane (Rv) is higher than the corresponding value in the horizontal direction i.e. parallel to the bedding plane (Rh). These are the reasons behind the apparent high resistivity value in HA/HZ well. High value of porosity and resistivity read by the logging tool in HA/HZ well instead of the actual (real) value made the fluid saturation (Sw) computation highly subjective.

Uncertainty in porosity measurement may be reduced by applying image tools instead of single padded device. Azimuthal density image tool used with LWD string is a possible solution for reducing porosity uncertainty. Even porosity can be computed quite accurately from resistivity image data generated by buttoned resistivity device run along with drillpipe or LWD. In the resistivity image the conductive fraction with darker shade in the log is considered as porous part of the rock volume as compare to the lighter shade i.e. high resistivity rock matrix.

Uncertainty in resistivity measurement is a serious point of concern. It is often ambiguous to differentiate the resistivity increase is due to the HA/HZ effect or due to formation anisotropy. Study of impact of formation resistivity anisotropy over Sw computation (Passey, etal , 2005) shows that with Rv/Rh =5, a change in ? from 45 degree to 85 degree introduce an error of 25 s.u in Sw computation from 5 s.u when other parameters like porosity and Rw are kept same in both the cases. For any interpretation to be successful , it is very essential to extract true resistivity value of the formation from the logs because ultimately resistivity differentiates between a hydrocarbon saturated reservoir and a brine saturated one.

To overcome this challenge there are some possible ways. First of all to understand the effect of HA/HZ well on resistivity curve, we have to know the relationship of the wellbore with the bedding for better resistivity modeling. This is now possible by running a borehole electrical image log in LWD string. It delivers continuous borehole inclination and azimuth to fix the borehole geometry as well as the dip of the formation (bed) can be picked up from the electrical image by applying available software. Once the borehole geometry is confirmed from above data , accurate TVD computation is possible and since formation dip uncertainty is also overcome hence true vertical thickness (TVT) of the strata will be known. Instead of focusing laterally, the resistivity in an electric image log is measured circumferential to the borehole and it helps to locate the directional variation of resistivity. Another important advantage of running an electrical image log in a HA/HZ well is that due to its low depth of investigation (around 3 inches) its measurement does not affected by shoulder beds. Therefore borehole electrical image tool can help to reduce uncertainty in resistivity measurement in some extent in a HA/HZ well.

Nowadays some of the logging service companies has designed a Phasor induction tool which can directly give Rv and Rh. By seeing the overlay of these two curves we will have an answer of the formation anisotropy. Determination of true resistivity (Rt) is comparatively easier if there is a vertical appraisal well. But in all the cases to compute Rt from LWD log modeling is necessary. Since exact modeling of nature is an inverse process and it has no unique answer, we have to provide as many inputs as possible to realize a better solution from a fine tuned model.

In case of a side track well from an existing casing (Case – III), normally original vertical well resistivity is available. It helps to compute Rt from the HA/HZ (sidetrack) well data by inversion of model. But areas where no vertical appraisal well is available , determination of Rt from HA/HZ well log data is still a challenge.

Conclusion:

- With the increase of relative angle ?, between the borehole and the formation the log response significantly changes with the borehole geometry effect.
- Based on LWD log analysis, it is possible to drill a *designer* well and its proper placement within the target and completes suitably.
- Accurate depth control is possible in HA/HZ wells after introduction of continuous measurement of inclination and azimuth while drilling.
- Better understanding of borehole geometry and bedding geometry (formation dip) is possible by running a borehole image log. It is helpful to build a more accurate reservoir model.
- Wellbore imaging is becoming important in HA/HZ wells to reduce the porosity and resistivity uncertainty. It is helping towards abetter reservoir assessment and prediction of reservoir producibility by doing quantitative formation evaluation.

- Determination of accurate Rt is very critical by using suitable modeling and inversion technique. Phasor resistivity tool which measure resistivity component Rv & Rh may help better in delineating formation anisotropy along with borehole electrical image.
- Invasion of drilling fluid is not affecting the LWD logs but still invasion phenomena in HA/HZ wells is not very well understood. Logs of HA/HZ wells are very much affected by tool rotation, doglegs, washouts & other borehole environments as compared to near vertical well logs. This is a need of concern of the petrophysicist to apply suitable environment correction on the log data. Though there is no correction chart currently available in the industry in this respect or neither any service companies till now has come out with any such environmental correction chart on their tool response.

Acknowledgement:

The authors wish to thank Well Logging Services, Ankleshwar Asset, ONGC Ltd, India, for encouraging to write this technical paper on such a burning issue. The authors are also thankful to Head Logging Services Corporate Mumbai, ONGC Ltd, India, for his constant motivation and guiding.

References:

Passey, Q. R., Yin, H., Renderio, C.M., Fitz, D.E., Overview of High-angle and Horizontal Well Formation Evaluation Issues, Learning And Future Ddirections, SPWLA 46th Annual Logging Symposium, June 26-29, 2005.

Renderio, C., Passey, Q., Yin, H.,2005, The Conundrum of Formation in High-Angle /Horizontal Wells Observations and Recommendations, SPE 96898, Oct. 2005.

Hu, G., Bitter, M., Hou, J., evaluation of Horizontal Wells Using LWD propagation Resistivity and Laterolog – types Resistivity logs, SPE 103150-MS, SPE Annual Technical Conference & Exhibition, San Antonio, Texas, 2006.

Johnston, J., Down and Out in Logging, Middle East Well Evaluation Review, Schlumberger, No:- 11, 1991.

Adolph, B., Stoller, C., Archer, M., et al., No More Waiting: Formation Evaluation While Drilling, Oilfield Review, Schlumberger, Autumn 2005.