Pulsed Neutron Gas Detection and Possible Quantification Techniques

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Abstract

Pulsed neutron techniques have been widely used to monitor movements of formation fluids within the reservoir as well as production from the wells. Recent developments in this type of tools allowed both carbon-oxygen water saturation capabilities with pulsed neutron capture measurements such as formation sigma, porosity and borehole salinity. Along with the improved accuracy and precision, the advance in tool characterization, has also allowed the possibility of gas detection and in some cases, gas quantification from these measurements.

Recently, the new RST- Reservoir Saturation Tool, has made available measurements in both IC (inelastic-capture) and Sigma modes. The new tool, in two different diameters, allows for measurements to be taken either within single completion wells as well as complex (one or dual tubing, gravel pack) completions.

This paper concentrates on one of the multiple applications of the RST – the detection and (when possible) quantification of gas in cased hole wells. It describes the different techniques mainly from Sigma mode to determining corrected presence of gas, and show some local examples where these techniques were applied.

Introduction

Two new through-tubing carbon-oxygen (C/O) tools, the 1 11/16-in. RST tool (“RST-A/C”) and the 2 1/2-in. RST tool (“RST-B/D”), were introduced a few years ago. In addition to C/O – water saturation - capability, these tools can also provide pulsed neutron capture “sigma” logging. Sigma logging can determine formation oil saturation *indirectly* by measuring the lack of salinity presence in the formation (Albertin et al., 1996). This measurement is based on the macroscopic thermal neutron capture cross section (Σ) of the formation, a quantity which is highly influenced by the salinity of the formation water. When the formation water has low salinity, an anomalously low sigma signal provides the hydrocarbon signature. Unfortunately, the ability of Sigma logs to detect liquid hydrocarbons breaks down in fresh or low-salinity (generally below 50 ppk) environments, since fresh water and hydrocarbons have nearly the same capture cross section.

One advantage is that Sigma logs can be run at reasonable fast speeds (above 1800 ft/hr) with enough precision to detect changes in the reservoir. In IC mode, the logging speed is generally very low and strongly influenced by environmental characteristics of the well. Another important application of the Sigma logs, and using the same physical properties as the Sigma logs, is the detection of gas. Neutron based porosity tools respond mainly to the hydrogen index of the fluid filling the porosity. A drop in porosity signifies the presence of gas. Different techniques can be used to determine the presence of gas, and that’s what it is shown later in this paper.

The RST Tool

The RST tools – 1 11/16-in. RST tool (“RST-A/C”) and the 2 1/2-in. RST tool (“RST-B/D”), were introduced a few years ago (figure 1). These tools were developed to offer pulsed neutron logging with the last generation of Sigma (Σ) – capture cross-section –techniques, as well as inelastic and capture spectroscopy and other activation measurements. These tools were designed and are characterized to operate in either single or complex completions (including multiple tubing and gravel pack configurations).

The tools include considerable shielding in order to focus the detectors away from the source and the borehole signal (Plasek et al., 1995). In RST-B, this focus is more effective as a physical shielding is present between the far detector and the borehole side of the tool as well as the near detector and the formation side of the tool (figure 1). During logging, the tool is compressed against the borehole wall. The detector spacing related to the source is also a must in these tools, improving their vertical resolution. Gadolinium oxyorthosilicate (GSO) crystals and precise regulation are used to provide very high-count rates and gain stabilized near-to-far porosity ratios. The deuterium-tritium electronically ignited neutron generator allows for high and precise neutron burst.

The tool operates mainly in two different modes (figure 2). The IC – inelastic-capture – mode gives one neutron burst, and measure both inelastic and capture energy spectrum. From these spectrums, both C/O ratio (inelastic) as well as a lithological (capture) analysis can be made (Albertin et al., 1996). During the sigma mode, two neutron bursts are given separately. Both borehole as well as formation signals are measured, between the bursts and after the second burst respectively. These measurements enable mainly Sigma and Porosity to be measured in the formation, however, as it will be shown later in this paper, other important ratio can be obtained, specially regarding gas detection. Other modes can also be used with the RST tool, but they are out of the scope of this work.

Gas Detection (and Quantification) Techniques

Traditionally, gas detection has always been obtained based on the hydrogen index of this fluid and the changes in formation density it gives when present within the reservoir. The main characteristic in open hole logs is the cross-over observed with low porosity and low density values. In cased wells and using pulsed neutron capture techniques, the fundamentals are not much different. Porosity measurements tend to show low values in the presence of gas. Sigma also decreases because of the “absence” of hydrogen. In this case, the presence of gas reduces the amount of water, thus producing an anomalously low sigma signal. However, along with these primary measurements described above, The RST operating in sigma mode can also provide numerous auxiliary measurements that can indicate and even quantify the presence of gas.

One of the techniques used to identify gas is the comparison between open hole and RST porosities (TPHI-NPHI). Neutron based porosity tools respond to the hydrogen index of the fluid filling the porosity. A drop in porosity signifies the presence of gas. Overlaying the TPHI porosity from the RST with the NPHI porosity from the original open hole logging should produce a good match except for zones where gas has replaced oil or water. This technique only responds to changes in gas saturation. If the gas was already present when the well was drilled, then this technique will not reveal the gas as the curves should match.

Among the main techniques are the use of count-rates and count-rate ratios. These are formed using short-burst inelastic counts and late-decay capture counts from both detectors. The far-to-near inelastic ratio (IRAT) is defined as the ratio between the inelastic far detector count rate and the inelastic near detector count rate. Soon after the end of the neutron burst the gamma rays detected are chiefly a function of inelastic collisions. The near detector count rate will be much higher than the far detector due to the attenuation caused by the fluid filled matrix and well bore fluid. If the fluid in the matrix is replaced by gas, then the attenuation of the neutrons and gamma rays will be much less and the ratio defined above tend to increase. Along with IRAT and based on that is the WINR. This curved is computed from Sigma and IRAT and can be defined as below:

WINR = (IRAT-a)*(b/SIGMA),

where, IRAT is the inelastic ratio discussed previously, SIGMA is the formation sigma and “a” and “b” are tuning parameters, which in shale zones are chosen to bring the expressions IRAT-a close to zero and b/SIGMA close to unit. In the presence of gas, WINR tends to increase and it is commonly shown in the plots against IRAT and with opposite scales. An example showing both techniques is presented at the end of this paper.

Another important measurement used for detecting gas are the ratios of capture and the capture to inelastic ratios. These are computed separately for each detector and when properly scaled in the logs, can show overlays that are gas indicators. The main ratios are RSCN and RSCF and CIRN and CIRN respectively. For one of detector ratio, a scale is usually chosen to nicely cover the track. The other ratio scale is then iteratively adjusted to give an overlay between the curves in shales and filled fluid porosity zones. When separation between curves is observed, they usually indicate the presence of gas. This technique tends to work better for RSCN and RSCF then to CIRN and CIRF.

In order to quantify the presence of gas, or determine its saturation, a couple of empirical techniques are available (Schnorr, 1996). The most common technique is based on Sigma values for fluids and matrix and the effective porosity as below.

$$\Sigma = \Sigma_m (1 - \phi) + \Sigma_{liq} \phi (1 - S_{gas}) + \Sigma_{gas} \phi S_{gas} ,$$

where Σ is the measured Sigma, Σ_m is the matriz Sigma, Σ_{liq} is the formation fluid sigma, Σ_{gas} is the sigma value for gas, ϕ is the effective porosity and S_{gas} is the formation gas saturation one wants to compute.

Other gas saturation technique convert the separation between the RSCN and RSCF curves into a volume of gas and subsequently a gas saturation (Whittaker). It is done as using the scaling parameters of the separation and correction factor which is used to control the amplitude of the answer (e.g. Sgas should range from 0 to 1). Below an example on how to cumpute Sg from RSCN and RSCF.

normalised_RSCF = (RSCF_RST - rscf_right_edge) / (rscf_left_edge - rscf_right_edge)
normalised_RSCN = (RSCN_RST - rscn_right_edge) / (rscn_left_edge - rscn_right_edge)
Vuga = (normalised_RSCF - normalised_RSCN) * factor - volume of gas formation
Sgas = Vuga/PHIE - gas saturation

Figures 3, 4 and 5 show three examples of gas detection and quantification using the techniques described above. In figure 3, track 3 shows a cross-over between IRAT (RST) and open hole density (RHOB). Track 4 shows the open hole NPHI-RHOB and track 5 shows the RSCF and RSCN from RST. For the three tracks a cross-over (red shadow) is obtained for the same interval, indicating the presence of gas. Tracks 6, 7 and 8 show gas saturation and volume computed from the Sigma technique. Figure 4 shows an example where open hole NPHI is compared with TPHI from RST (track 4). In this example it can be seen that gas saturation has increased from open hole analysis as TPHI reads lower than NPHI. Also in track 5, IRAT shows an increase in its value over the same interval where a difference is observed between TPHI and NPHI. In tracks 6 and 7, oil saturation from C/O shows low So for the gas zones and an increase in So for the bottom part of the reservoir, as IRAT decreases and TPHI increases. Figure 5 shows an example where IRAT and WINR clearly indicates the presence of gas (track 4), where SIGMA and TPHI also show low values (track 3). Note the decrease in SIGMA and TPHI as IRAT and WINR change the cross-over and then get more separated in gas-oil and oil-water contacts respectively.

Conclusion

There are different techniques for detecting and sometimes quantifying gas using the RST, but none are universally successful. Some will work in a specific field, some others will not. They generally show good results but different factors such as high clay content, very low water salinity can sometimes lead to misinterpretation. A good suggestion is to start off with the RSCN-RSCF overlay technique which has been proved very successful, before moving on to the IRAT-WINR method. CIRN-CIRF and TPHI-NPHI techniques can also be very helpful, specially when trying to see changes in gas saturation.

References

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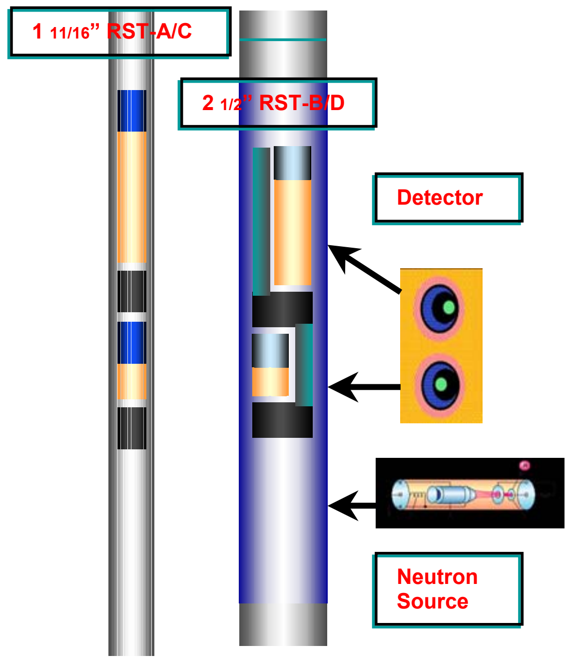

Figure 1 – RST-A/C and RST-B/D tool schematics.

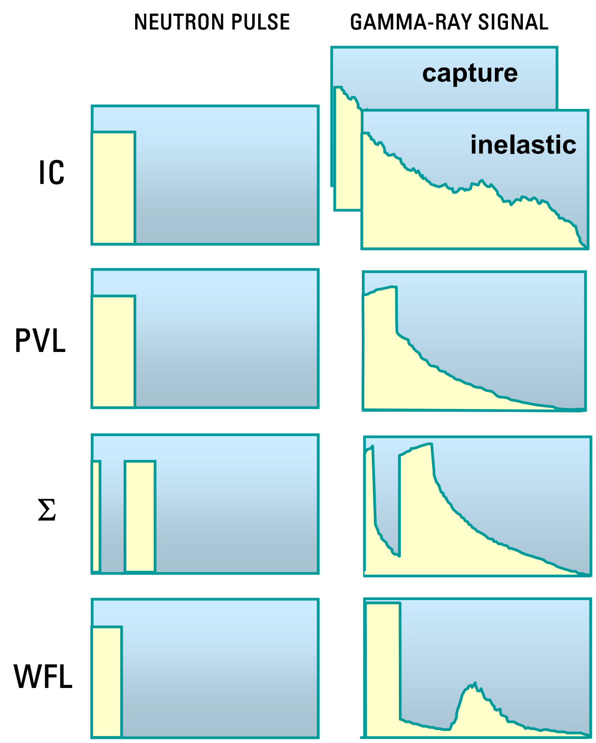

Figure 2 – RST tool modes and source/detector spectral.

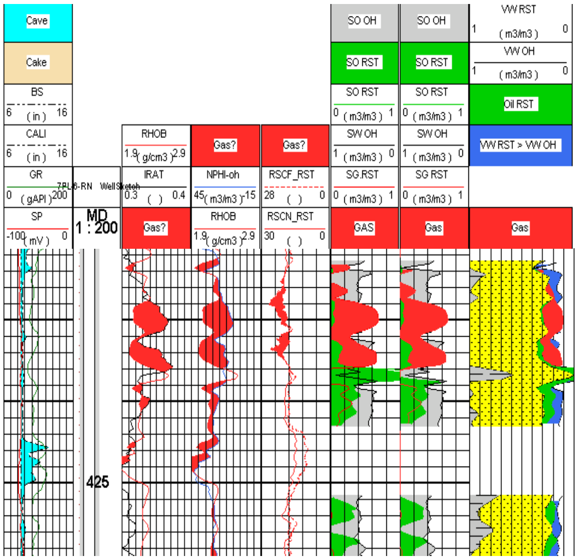

Figure 3 – Example 1 showing the IRAT, open hole and RSCF and RSCN gas detection techniques. Note gas saturation computed from SIGMA.

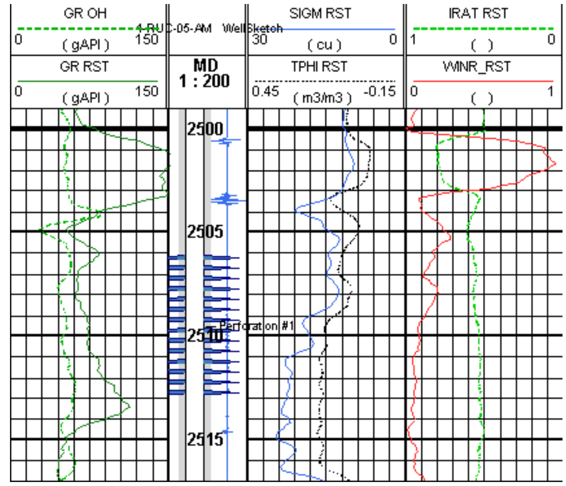

Figure 5 – Example 3 showing SIGMA, IRAT-WINR gas detection techniques.

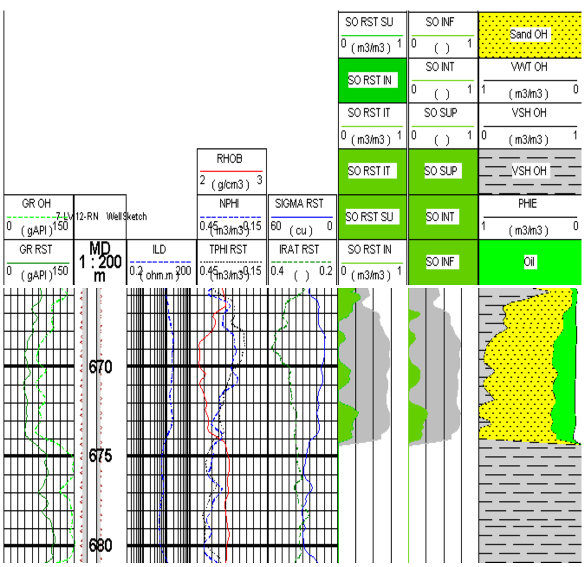

Figure 4 – Example 2 showing TPHI-NPHI and IRAT gas detection techniques.