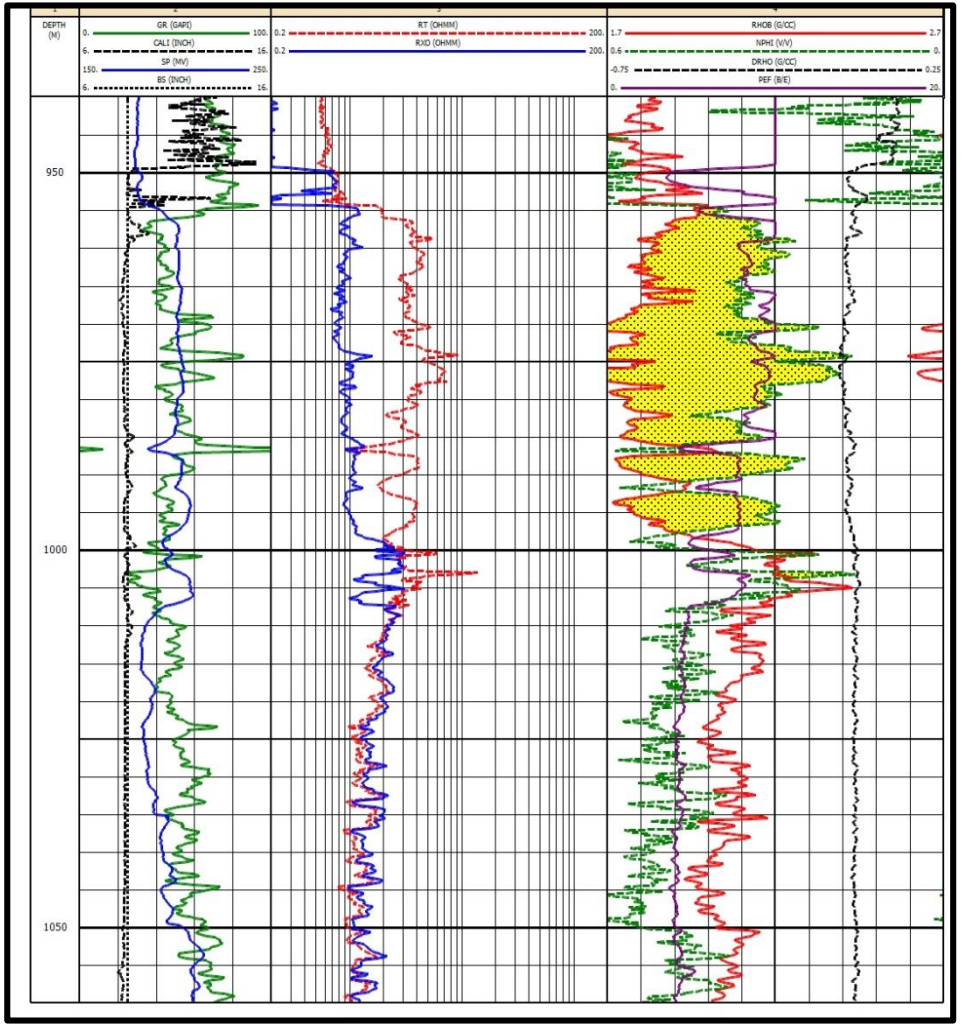
Water Saturation Computation Using Resistivity Ratio Method

By

Ko Ko Kyi
Retired Principal Petrophysicist
September 2020

Introduction

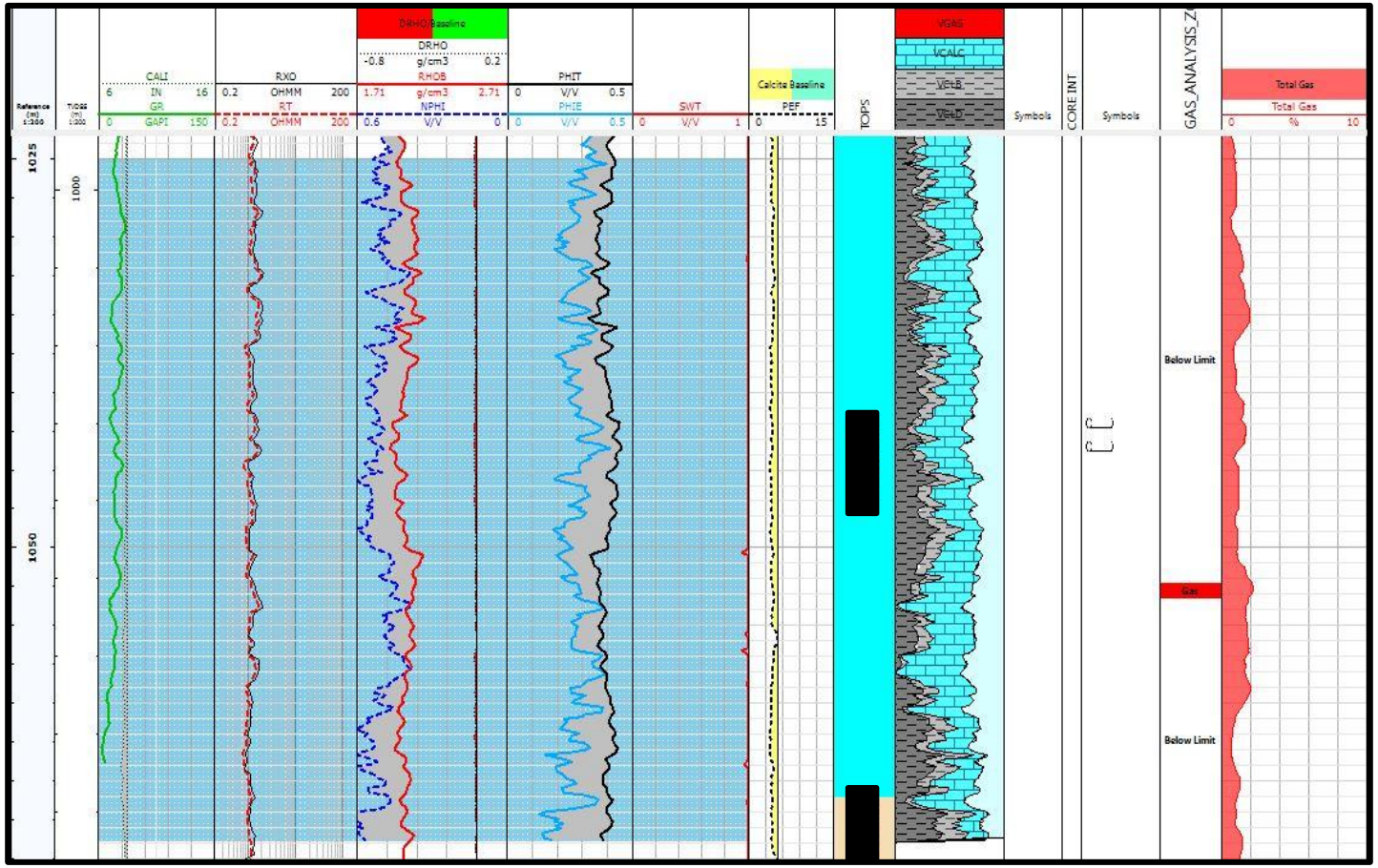
- In the following slide, the triple-combo logs clearly indicate the gas and water bearing intervals in this well.
- The well was drilled to evaluate the potential of a gas-bearing reservoir encountered in nearby blocks.
- It penetrated the target gas-bearing, shaly carbonate reservoir.
- The challenge was to evaluate the well log data and compute reasonable water saturation values for gas volume estimation.
- Mud log, formation fluid samples and well test data were available to help with the log analysis.
- At a glance, it looks like this is a straight forward and easy job.
- Core analysis not available at the time of this evaluation.



Wireline logs clearly indicate the gas and water bearing intervals.

Initial Computation of S_W

- Water bearing interval was identified where the R_{xo} and R_t logs were reading around 1 – 2 ohm-m and overlaying each other.
- Formation water resistivity R_w was computed using Archie's equation with standard cementation exponent m value of 2.
- With this R_w and a constant m of 2, water saturation S_W was computed for the gas bearing interval using Archie's equation.
- The resulting S_W was very high and unrealistic for the gas zones which were tested and produced water-free gas.
- Mud log indicated that the texture of the carbonate rock was different in the gas bearing and water bearing intervals.
- This suggests that these intervals have different cementation exponent m, which is quite common in carbonate reservoirs.



Rxo and Rt almost overlaying together at values between 1-2 ohm-m.
Possibly water bearing interval

S_W Computation Using Ratio Method

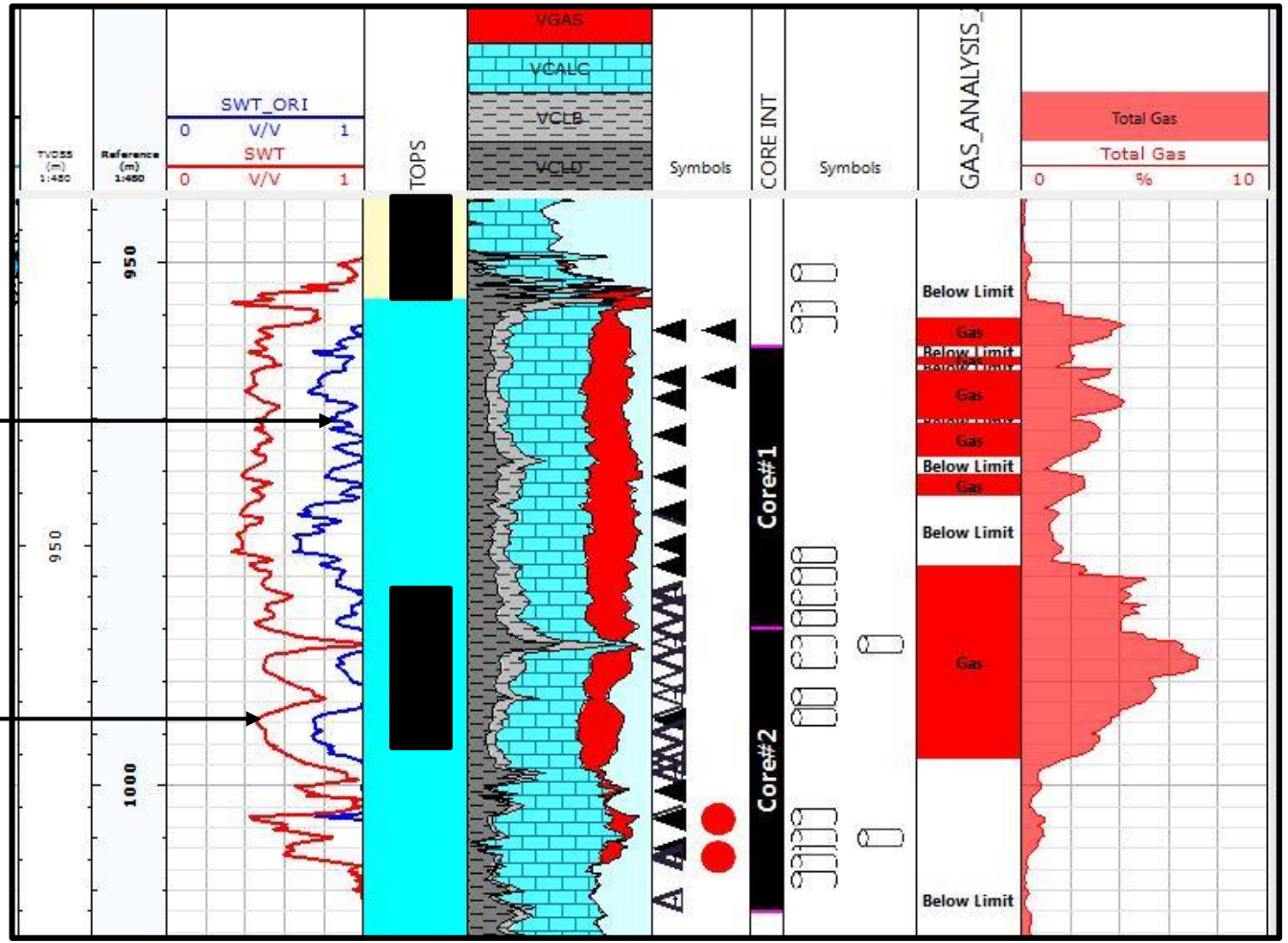
- An alternate method of computing water saturation using the resistivity ratio was tested.
- This method does not require the cementation exponent m.
- In the water bearing zone: $S_W = S_{XO} = 1$
- Therefore, dividing the S_W equation by the S_{XO} equation, we get the relationship $R_w/R_t = R_{mf}/R_{xo}$.
- This allows the estimation of R_w without using formation porosity Φ and the cementation exponent m.
- Using the values of R_t, R_{xo} and R_{mf} at downhole temperature, the formation water resistivity R_w was computed.

S_W Computation Using Ratio Method

- For the gas bearing interval: $S_W^n = [R_w/(\Phi^m \times R_t)]$ in the virgin zone and $S_{XO}^n = [R_{mf}/(\Phi^m \times R_{xo})]$ for the invaded zone.
- Dividing the S_W equation by the S_{XO} equation, the porosity Φ and cementation exponent m terms are eliminated.
- The resulting equation is $(S_W/S_{XO})^n = (R_w \times R_{xo})/(R_{mf} \times R_t)$
- Assuming n = 2 and $S_{XO} = 0.95$, S_W is computed.
- The resulting S_{WT} (red colour) is plotted together with the previously computed S_{W_ORI} (blue colour) in the next slide.
- It can be seen that the S_{WT} computed using the resistivity ratio method is more realistic than the S_{W_ORI} computed with a constant value of cementation exponent m.

S_W computed using Archie's equation with constant value of m

Reduced S_W and improved S_{hc} using ratio method



Conclusions

- **In evaluating carbonate reservoirs, where the cementation exponent m is variable, due to variations in rock texture, it is not feasible to use a constant value of m to compute water saturation using Archie's equation.**
- **A reasonable or acceptable solution can be obtained by using the resistivity ratio method to compute water saturation.**
- **For this method, deep and micro-resistivity logs are required.**
- **The cementation exponent m is not required in this method.**
- **This method is mentioned in some books on petrophysics.**
- **The results of the evaluation should be validated with other data such as mud log, fluid samples, core analysis, well tests.**