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The Relevance of Porosity in the Evaluation of Hydrocarbon Reservoirs

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Summary

This work is intended to encourage the direct computation of porosity (Φ) in the equations for the permeability (K), fluid flow index (FFI), reservoir quality index (RQI) and flow zone indicator (FZI). These parameters are always determined with aid of other expressions that are initially calculated based on one or two other factors and porosity. Porosity is a very important parameter, it is advisable to avoid approximating it over a range of equations before it is indirectly engaged. This could help to minimise underestimation/overestimation errors. Porosity was optimised by using it as the only variable among other inputs in the modified FFI, K, RQI and FZI expressions to help evaluate the hydrocarbon potential and flow units of two reservoirs. The equations for relative water permeability (Kwr) and relative oil permeability (Kor) were modified and used to predict the water cut (Cw) of another reservoir. A sensitivity analysis shows that the change in tortuosity factor does not have a significant effect on the results. Therefore, alternative equations were presented for these parameters for use mainly in sandstone units. The curves were generated based on these expressions and are recommendable for use as quick-look models.

Introduction

Porosity is an influential parameter in the petrophysical and volumetric evaluation and the majority of the reservoirs physical characteristics are not completely expressed without the use of porosity. The relationship between porosity and reservoir's flow units is very effective for explaining reservoirs' geological attributes such as grain sizes and sorting, shale content, cementation, consolidation of rocks, pore sizes and interconnectivity among others [Schlumbeger 1989; Asquith and Krygowski. 2004; Tiab and Donaldson 2012]. The predictability of the occurrence of hydrocarbon in the reservoirs and recoverability of hydrocarbon from the reservoirs are dependent on these attributes. Free fluid index (FFI), permeability (K), reservoir quality index (RQI) and flow zone indicator (FZI) are the parameters with which the stated attributes are evaluated. These parameters are directly or indirectly dependent upon porosity and one another.

Porosity plays a major role in formation evaluation and when it is well calculated and harnessed, it could present a way of reducing risk. This work suggests a way of optimising porosity for formation evaluation by presenting equations (FFI, K, RQI and FZI) that have the porosity as the only variable. The relevance of the optimisation of porosity for formation evaluation cannot be overemphasised. In volumetric estimations, for instance, every other parameter been all right, 0.05 to 0.1 (5 – 10%) increase or decrease in porosity value could result in a notable increase or decrease in the computed volumes of hydrocarbons in place. Similarly, in qualitative evaluations the expression for FZI is dependent upon RQI, which is dependent upon K. In the same vein, K is dependent upon S_{wirr} and/or FFI, both S_{wirr} and FFI are dependent upon F while F is dependent upon Φ. If one must follow the computation in steps from the determination of F, Φ will be approximated over a range of equations, because most of these equations never give their results in whole figures. Errors due to estimation are always undesirable, especially when it comes to volumetric analysis and other decision dependent calculations, where overestimation or underestimation error as low as ±0.05 can result in a notable difference. This can bring about risk and uncertainty. As such, traditional expressions (FFI, K, RQI and FZI) were modified for use in sandstone hydrocarbon reservoirs unit. Similarly, the equations for water relative permeability (K_{wr}) and oil relative permeability (K_{or}) were modified and used to predict the anticipated volumes of water-cut (C_w), which will be produced with the hydrocarbon in the reservoir. Two other factors associated with these equations are the exponent of porosity (m) and the factor of tortuosity (a). Usually, the exponent of porosity is taken as 2 in sandstones and the factor of tortuosity has a range of 0.6 to 1.0. This evaluation looks at presenting equations and models involving porosity as the only variable input. Therefore a sensitivity analysis to investigate the change in tortuosity factor was carried out. It showed that the change does not have a significant effect on the results. Hence, alternative equations with porosity as the only variable input were presented for these parameters for use mainly in sandstone units. Curves were generated based on these expressions and are recommendable for use as quick-look models for the estimation of these parameters.

Materials and Methods

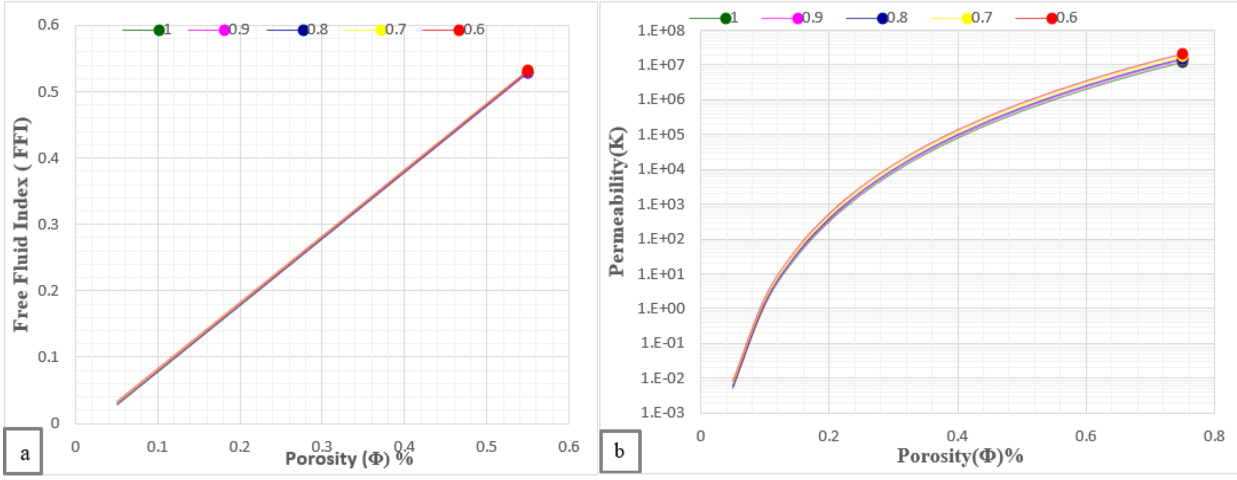
Gamma-ray log (GR), deep laterolog (LLD), water saturation log (SW), neutron porosity log (NPHI) and density tool (ROHB) were engaged in this work. The evaluated parameters are; free fluid index (FFI), permeability (K), reservoir quality index (RQI), flow zone indicator (FZI), water relative permeability (K_{wr}) and oil relative permeability (K_{or}).The basic methods herein are:

(a) modification of traditional equations for the relevant parameters to help provide alternative expressions in sandstone units;
(b) sensitivity analysis on the expressions in (a) above using different values of tortuosity factor to help verify the influence of its change on parameters;
(c) redefinition of the equations using the idea derived from (b) above;
(d) determination of porosity from well logs to aid the computation of parameters across of the selected reservoirs with the aid of the equations as in (c) above;
(e) generation of curves showing permeability/porosity, reservoir quality index/porosity and flow zone indicator/porosity relationships based on the results as in (d) above and

(f) determination of $RQI_{average}$ and $FZI_{average}$ based on the three expressions for each of them, to help generate a combined model for the estimation of the reservoirs flow units.

The traditional equations (Schlumbeger 1989; Tiab and Donaldson 2012) for FFI, K, RQI, FZI, and relative fluids permeability (K_{wr} and K_{or}), were modified such that, expressions having tortuosity factor (a) and porosity (Φ) were initially presented for each of them. Three alternative expressions were presented for each of RQI and FZI based on Tixier, Timur and Coates permeability equations

Sensitivity analysis on FFI and K (K_{mtm}, K_{mtx} and K_{mc}) considering the possible range (0.6 to 1.0) of tortuosity factor (a). This analysis shows that the change in the factor tortuosity has no significant influence on FFI and K values as shown in Figures 1a and 1b**.**



Figures 1 (a): The influence of the change in the factor of tortuosity on FFI
(b): The influence of the change in the factor of tortuosity on K.

The results of the sensitivity analysis coupled with the fact that the reservoirs present some shale influences at regular intervals, the average (0.8) of the range (0.6 to 1) of tortuosity factor was used to redefine the equations for the reservoirs, such that only porosity dependent expressions were presented as shown in equations 1 to 10.

Free fluid index (FFI); FFI = Φ – 0.02 (1)

Permeability (K); $(K_{mtx})^{0.5} = \frac{11180\Phi^4}{0.894}$ (Based on Tixier's idea) (2)

$(K_{mtm})^{0.5} = \frac{4472\Phi^{3.25}}{0.894}$ (Based on Timur's idea) (3)

$(K_{mc})^{0.5} = \frac{3130.4\Phi^3 - 62.58\Phi^2}{0.894}$ (Based on Coates'idea) (4)

Reservoir quality index (RQI); $RQI_{aa} = \frac{351\Phi^4}{0.894\Phi^{0.5}}$ (Based on Tiab and Donaldson idea) (5)

$RQI_{ab} = \frac{140.4\Phi^{3.25}}{0.894\Phi^{0.5}}$ (6)

$RQI_{ac} = \frac{98.29\Phi^3 - 1.965\Phi^2}{0.894\Phi^{0.5}}$ (7)

[RQI_{aa}, RQI_{ab} and RQI_{ac} are alternative expressions for RQI, modified with K_{mtx}, K_{mtm} and K_{mc}]

Flow zone indicator (FZI); $FZI_{aa} = \frac{351\Phi^4}{(0.894\Phi^{0.5})\Phi_r}$ (Based on Tiab and Donaldson idea) (8)

$FZI_{ab} = \frac{140.4\Phi^{3.25}}{(0.894\Phi^{0.5})\Phi_r}$ (9)

$$FZI_{ac} = \frac{(98.29\Phi^3 - 1.965\Phi^2)}{(0.894\Phi^{0.5})\Phi_r} \quad (10)$$

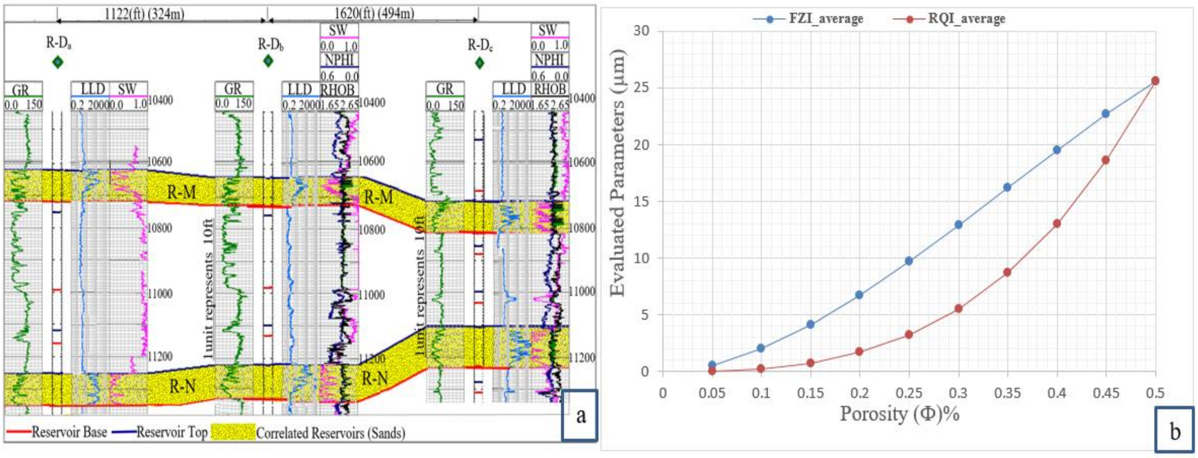
[FZI_{aa}, FZI_{ab} and FZI_{ac} are alternative expressions for FZI, modified with RQI_{aa}, RQI_{ab} and RQI_{ac}]
Where; a = the factor of tortuosity, Φ = porosity, Φ_r = ratio of the derived porosity and the difference between the maximum derivable value (100%) of porosity and the derived porosity.

These modified expressions herein were tested and compared with the results computed using the traditional equations and similar values were obtained.

Estimation of porosity (Φ), free fluid index (FFI) Permeability (K), reservoir quality index (RQI) and flow zone indicator (FZI).
The objective of this aspect is to predict the flow units of Reservoirs (R-M and R-N) mapped across Wells R-D_a, R-D_b and R-D_c (Fig. 2a) via the evaluation of FFI, K, RQI and FZI. Φ values were obtained from density log (RHOB) at intervals of 10ft and corrected for the influence of shale using equation 11.

$$\Phi_D = \frac{\rho_{ma}-\rho_b}{\rho_{ma}-\rho_f} - V_{sh}\left[\frac{\rho_{ma}-\rho_{sh}}{\rho_{ma}-\rho_f}\right] \quad (11)$$

A range of values from 0 to 50% (0 to 0.50) was used for porosity to compute FFI, K, RQI and FZI, such that the values of these parameters across the selected reservoirs were extracted from the results. The values of RQI_{aa}, RQI_{ab} and RQI_{ac} were averaged with the corresponding values FZI_{aa}, FZI_{ab} and FZI_{ac}. $RQI_{average}$ and $FZI_{average}$ were plotted against porosity to help generate curves (combined model) for RQI and FZI estimations of the wells (Fig. 2b).



$RQI_{average}$ = Average of the values of RQI_{aa}, RQI_{ab} and RQI_{ac}
$FZI_{average}$ = Average of the values of FZI_{aa}, FZI_{ab} and FZI_{ac}
Figure 2 (a): Correlated reservoirs across the wells.
(b): Combined quick-look model for the prediction of RQI and FZI

Results; Φ = 0.24, FFI = 0.22, K = 1721mD, 2343mD, and 1969mD for K_{mtx}, K_{mtm} and K_{mc} respectively, RQI =2.95µm and FZI = 9.00µm.

Volumetric estimations
Volumetric estimations were carried out in another reservoir (X) selected across the two wells (D_1 and D_2). The seismic data and a recovery factor of 32% of these wells were provided by the data source. The objective of this aspect is to calculate the water-cut (C_w) anticipated to be produced with the oil in Reservoir X. Equations 12 and 13 were used for the estimation of recoverable volumes of oil and gas.

$$V_{Ro} = \frac{OIP}{FVF} \times R.f \quad (12)$$

$$(V_{Rg}) = \frac{GIP}{FVF} \times R.f \times \frac{0.43 \times depth}{15} \quad (13)$$

[OIP = Oil in place, GIP = Gas in place, FVF = Formation volume factor and RF = Recovery factor]
The modified relative water and oil permeability (K_{wr} and K_{or}) equations (14 and 15) were used as inputs in a simplified water cut (C_w) equation (16) to help predict the associated water production.

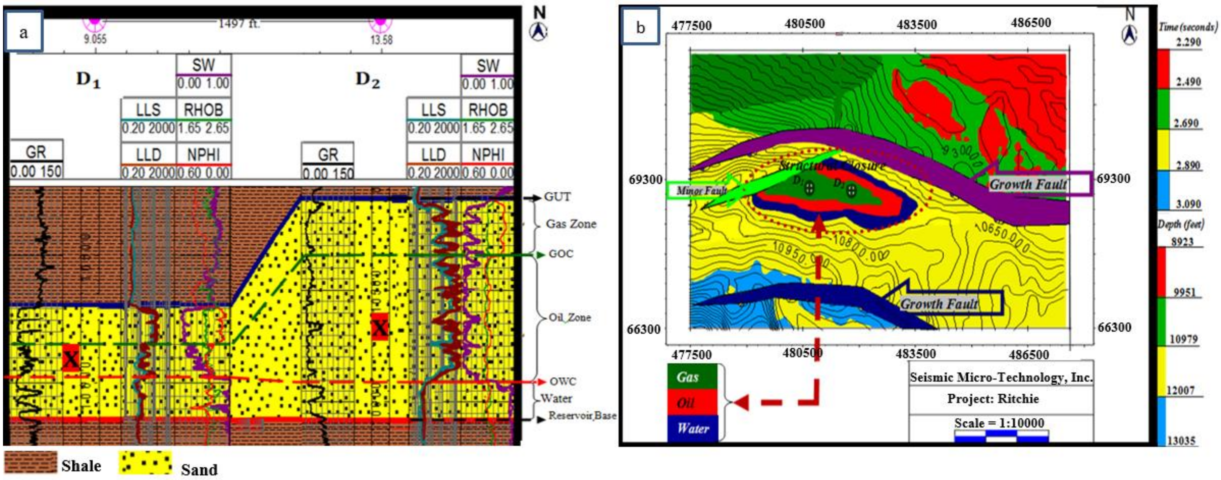
Fluids relative permeability; $$K_{wr} = \left[\frac{44.72\Phi S_w - a^{0.5}}{44.72\Phi - 0.8^{0.5}}\right]^3 \quad (14)$$

$$K_{or} = \frac{2000\Phi^2 S_h{}^{2.1}}{2000\Phi^2 - 0.8} \quad (15)$$

Water-cut; $$c_w = \frac{K_{rw}\mu_o}{K_{rw}\mu_o + K_{or}\mu_w} \quad (16)$$

[μ_w = water viscosity and μ_o = oil viscosity]

Volumes of recoverable oil and gas (V_{Ro} and V_{Rg}) were estimated in another reservoir (X) that was selected across two wells (D_1 and D_2) as shown in Figures 3a and 3b.



Figures 3 (a); Correlated wells showing suites of wire-line logs, reservoir thickness and fluids contact (b); Depth structural map showing reservoir area extent, fluids contact and trapping mechanism.

Results;

Reservoirs	V_{Ro} *bbl*	V_{wc} *bbl*
XD_1	1,984,835.73	372,740.20
XD_2	7,391,073.53	127,873.00
Total	**9,375,909.26**	**499,513.20**

Reservoirs	V_{Rg} *cu.ft*
XD_1	**2,298,936,564.00**
XD_2	**5,393,942,368.00**

Conclusion

It is believed that this work has presented a way of optimising porosity to aid the qualitative and volumetric estimations herein. The estimation of FFI, K, RQI and FZI were all computed involving the use of porosity as the only variable. This has helped to avoid the approximation of porosity over a range of equations. Possible errors of underestimations and/or overestimations of porosity with the use of traditional equations are presumed to have been avoided. The results suggested that the reservoirs (R-M and R-M) across wells (R-D_a, R-D_b and R-D_c) show significant values for the evaluated parameters. Therefore, the flow units are expected to be good and significant recovery rates are anticipated within the reservoirs. The volumes of water-cuts in Reservoir X across Well D_1 and Well D_2 are within the acceptable range.

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