Estimates of the Wetting-Phase Relative Permeabilities of a Typical Reservoir Rock in the Niger Delta Using Well Logs: Kolo Creek as Case Study

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Abstract **-Aimed at meeting the needs of reservoir simulation, estimates of the wetting phase relative permeability for a sandstone reservoir in the Niger Delta region were made by analysing variables obtained from well logs. Analysis was carried out for two reservoirs (RESERVOIR I and RESERVOIR II), one shallower than the other, within the study area by applying an empirical model (that related relative permeability to fractional water saturation and saturation exponent) to resistivity data obtained from the available well logs. The results showed that the wetting phase relative permeability had estimated values ranging from 0.000 to 0.113 and 0.000 to 0.202, for RESERVOIRS I and II respectively. Further analysis showed that the estimated wetting phase relative permeability was affected by the wettability and pore structure of the reservoirs of interest.**

Index Terms: **Wetting-Phase, Relative Permeability, Effective Permeability, Absolute Permeability, Pore Structure**

I. INTRODUCTION

One of the factors affecting permeability is the degree of saturation of the flowing fluid in the pore space [1]. Permeability can be described as absolute, effective or relative [2]. While the *absolute permeability* is a measure of the rock's ability to transmit fluid when saturated with a single fluid, *effective permeability* is a measure of the rock's ability to preferentially transmit a particular fluid when more than one fluid is present in its pore space. Practically, in a multi-phase flow, the individual effective permeabilities of the constituent fluids can be expressed as fraction of the absolute permeability of the rock relative to the constituent fluids at a 100% saturation. Such ratios are referred to as *relative permeabilities*. In other words, relative permeability (affected by fluid saturations, pore space geometry and pore size distribution, wettability and fluid saturation history) is unique for different rocks and fluids, affecting the flow characteristics of reservoir fluids.

Relative permeability is a dimensionless variable that comes in handy in applying Darcy's equation to multiphase flow scenarios [3]. As a vital parameter in the description of multiphase fluid flow in porous media, relative permeability has been conventionally measured in the laboratory either using recombined reservoir or laboratory oil at laboratory or simulated conditions. This process his however expensive and time-consuming [4]. Therefore, alternate methods have been developed to deduce the value of relative permeability of a reservoir rock from network modelling [5-8] or resistivity data [9, 10].

In this work, the methodology introduced by Li [9] will be adopted to estimate the relative permeability of the wetting-phase of a typical reservoir rock in the Niger Delta using data from resistivity logs.

II. THE KOLO CREEK

The Kolo Creek oil field, as shown in Fig. 1, is an onshore oil and gas field located in the Central Niger Delta [11, 12]. With an aerial extent of about 5 by 10 kilometer, the main reservoir is oil bearing, located at a depth range of 3580 to 3670 meters with thickness of about 50 to 60 meters.

With a sedimentary sequence described as mainly a deltaic depositional sub-environment [13], the Kolo Creek is made of lithofacies that are rich in palynodebris, black debris, wood fragments and amorphous organic matter. The reservoirs in the Kolo Creek, characterized by numerous predominantly E-W trending growth faults, are of the Middle Miocene and of the Agbada Formation [14].

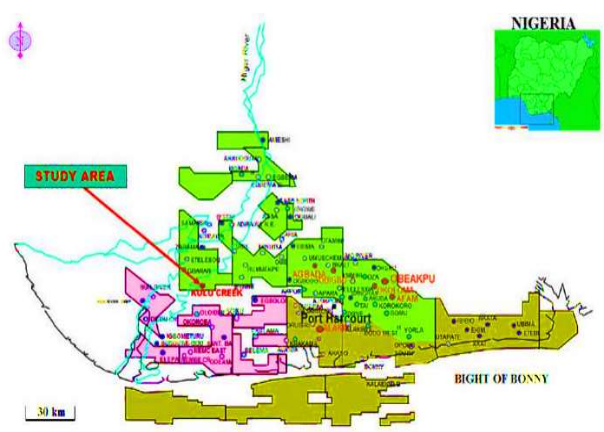

Fig.1: Location map of study area [12]

III. METHODOLOGY

To help in meeting with the desired objective of this work, five well logs, obtained from Shell Petroleum Development Company (SPDC), from the Kolo Creek were analysed. Digitized at a feet interval, resistivity data were extracted from the available well log to estimate the wetting-phase permeability of the delineated reservoirs.

Based on the theory behind the similarity between fluid flow in a porous media and electricity flow in a conductive body, Li [9], the specific water saturation (S_w), residual or irreducible water saturation (S_{wr}) and resistivity index (I) of a formation to its wetting-phase relative permeability, k_{rw}, described as;

$$k_{rw} = \left(\frac{S_w - S_{wr}}{1 - S_{wr}}\right)\frac{1}{I} \quad \mathbf{1}$$

The minimum water saturation in each delineated reservoir unit will be used as the residual water saturation for that unit. The specific water saturation will be estimated by adopting the mathematical description introduced by Archie [15] relating formation water resistivity (R_w), formation resistivity (R_t), cementation factor (m), saturation exponent (n) and tortuosity factor (a) to water saturation;

$$S_w = \left(\frac{a \times R_w}{R_t \times \Phi^m}\right)^{\frac{1}{n}} \quad \mathbf{2}$$

The porosity will be estimated from density logs as described by Krygowski [16]. For the cementation factor, a value of 1.65[17]will be adopted, while a value of2[18], 1.45[19] and 9.80 $ohm - m$[20] will be adopted for the saturation exponent, tortuosity factor and the formation water resistivity respectively.

Archie [15] also showed that the resistivity index, I, is related to the water saturation (n) and the saturation exponent (n) of formation in such a way that;

$$I = \frac{1}{S_w^n} \quad \mathbf{3}$$

Therefore, the mathematical description for the wetting-phase relative permeability, as described by equation ***1***, can be re-written as;

$$k_{rw} = \left(\frac{S_w - S_{wr}}{1 - S_{wr}}\right)S_w^n \quad \mathbf{4}$$

IV. RESULTS AND DISCUSSION

A.Results

The results obtained from our analysis are shown below;

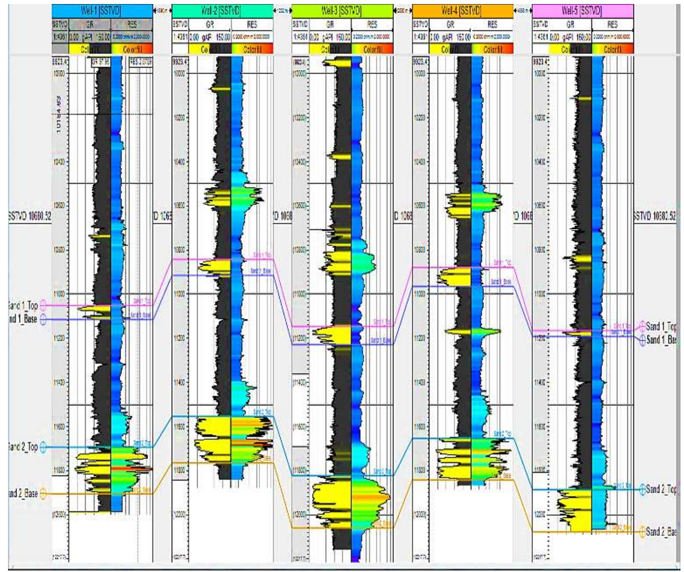

Fig.2: Delineated reservoirs from well logs

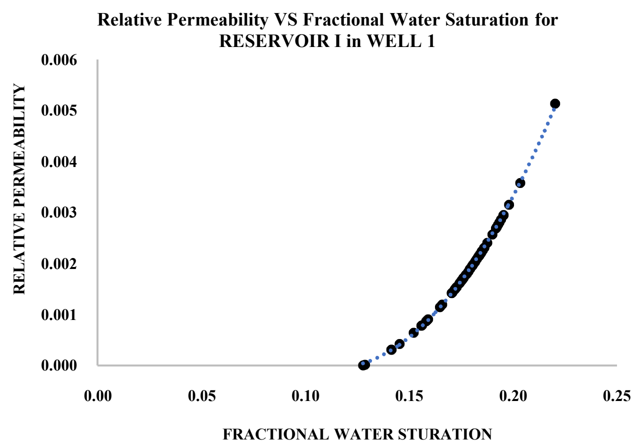

Fig. 3: Relationship between relative permeability and fractional water saturation for RESERVOIR I in WELL 1

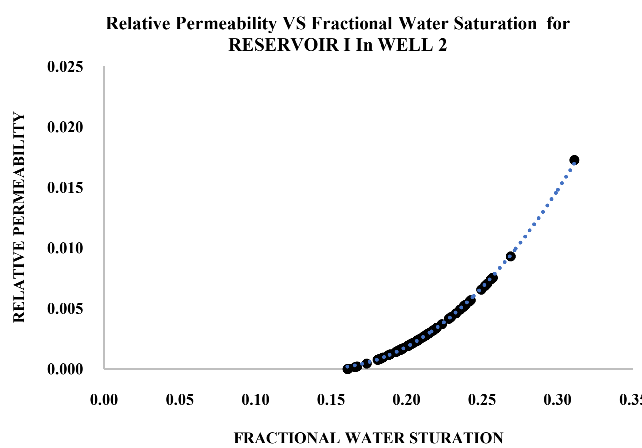

Fig. 5: Relationship between relative permeability and fractional water saturation for RESERVOIR I in WELL 2

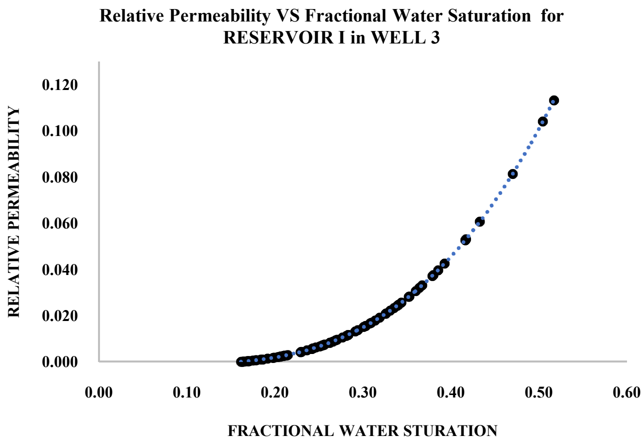

Fig. 7: Relationship between relative permeability and fractional water saturation for RESERVOIR I in WELL 3

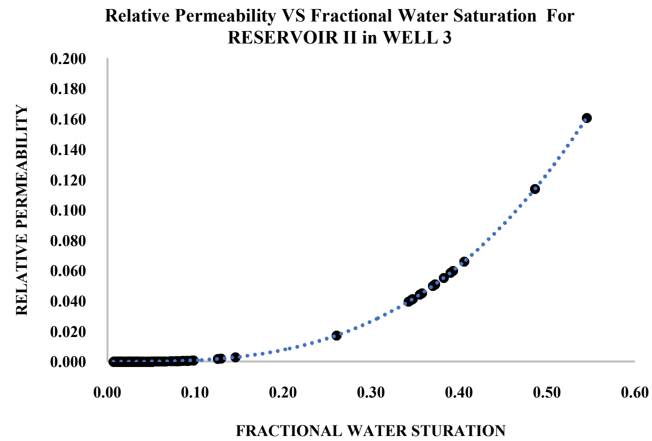

Fig. 8: Relationship between relative permeability and fractional water saturation for RESERVOIR II in WELL 3

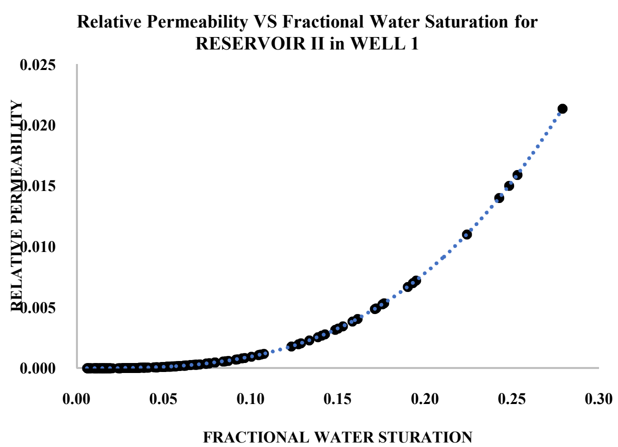

Fig. 4: Relationship between relative permeability and fractional water saturation for RESERVOIR II in WELL 1

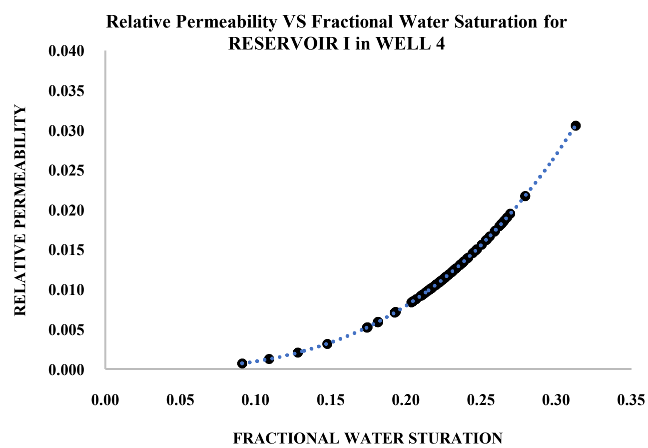

Fig. 9: Relationship between relative permeability and fractional water saturation for RESERVOIR I in WELL 4

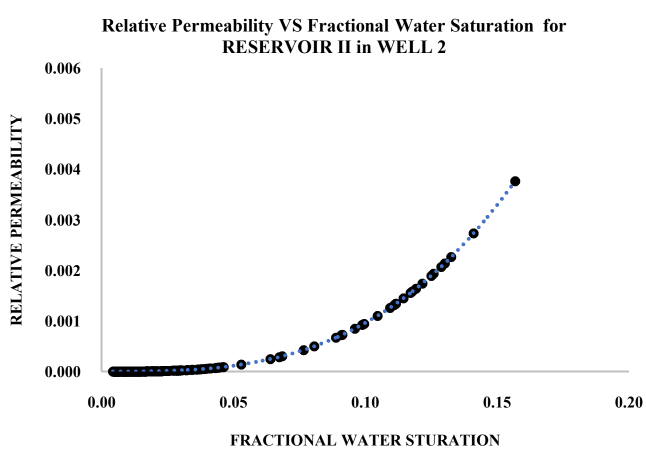

Fig. 6: Relationship between relative permeability and fractional water saturation for RESERVOIR II in WELL 2

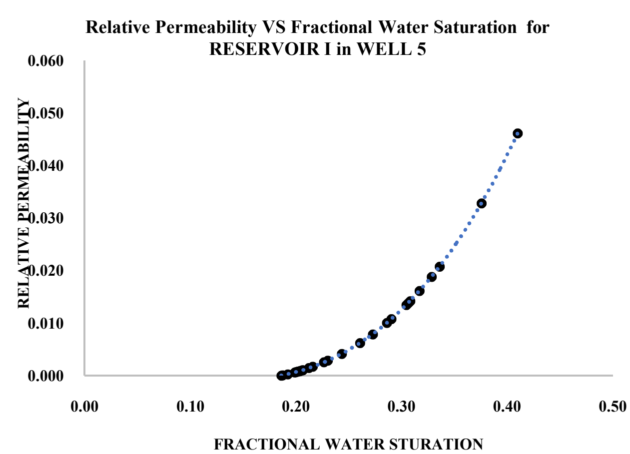

Fig. 11: Relationship between relative permeability and fractional water saturation for RESERVOIR I in WELL 5

B.Discussion

Relative to density and resistivity responses and reservoir continuity, as seen on the analysed well logs, two reservoirs (RESERVOIR I and II) were delineated, as seen in Figure 1. RERVOIR I and II had mean thicknesses of 20 and 64 metersthick, respectively. From the data extracted, values of fractional water saturation were estimated, which was used to make estimates of relative permeability, whose mean values are shown in Table 1, for both reservoirs.

The estimated relative permeability for RESERVOIR I had values ranging from 0.000 to 0.113 while those for RESERVOIR II had values ranging from 0.000 to 0.202. Plots of relative permeability against fractional water saturation for both reservoirs from the five well logs analysed are shown from Figs 3 to 12, for which a third order polynomial curve provided the best fit to the data points on the graph.

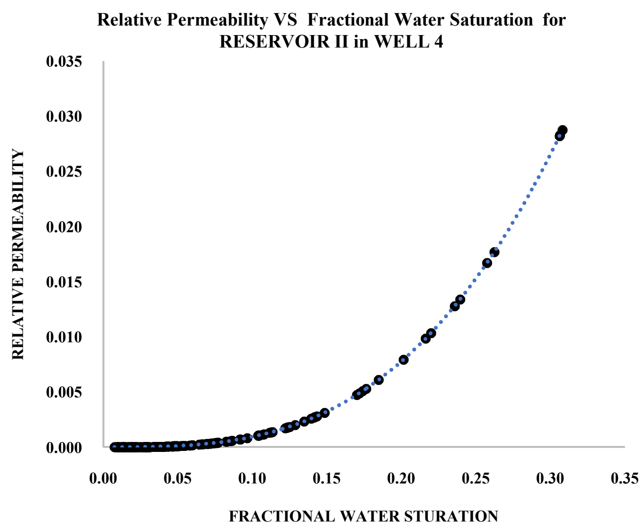

Fig. 10: Relationship between relative permeability and fractional water saturation for RESERVOIR II in WELL 4

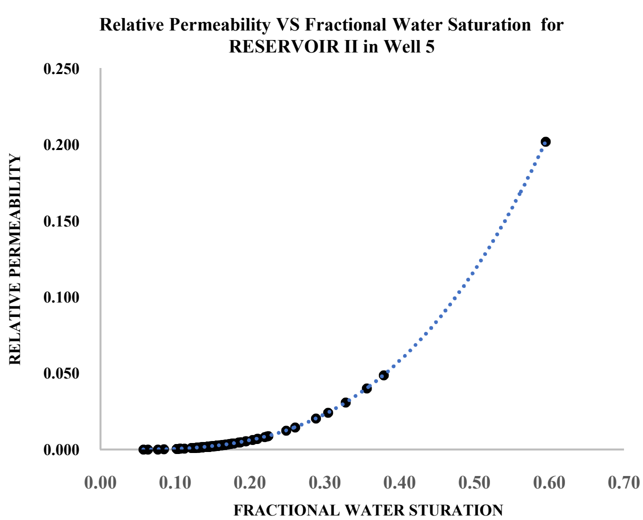

Fig. 10: Relationship between relative permeability and fractional water saturation for RESERVOIR II in WELL 5

Table 1: Average Values of estimated relative permeability for both reservoirs from the five well logs

RESERVOIRS	RELATIVE PERMEABILITY				
	Well 1	Well 2	Well 3	Well 4	Well 5
I	0.002	0.003	0.016	0.012	0.008
II	0.001	0.000	0.004	0.001	0.004

Evidently, these curves show that with small changes in large values of fractional water saturation, relative to similar changes in smaller values of fractional water saturation, there are more aggressive changes in relative permeability, which could be attributed to the effect of wettability on relative permeability [21, 22]. Also, the curves for RESERVOIR II, which is located deeper in the formation, have a different trend for those of RESERVOIR I, located shallower in the formation, even though the curves for each of the reservoirs from the different well logs have similar trends. These could be attributed to the fact that relative permeability is affected by pore structure [23-25].

V. CONCLUSIONS

In view of estimating the wetting phase relative permeability from well logs of a sandstone reservoir located in the Niger Delta region of Nigeria, five well logs were analysed. Two reservoirs, RESERVOIR I and RESERVOIR II, were delineated from the analysed wells, with mean thicknesses of 66ft and 201ft respectively. The following conclusions were reached after our analysis;

- The estimated relative permeability for RESERVOIR I had values ranging from 0.000 to 0.113 while those for RESERVOIR II had values ranging from 0.000 to 0.202.
- Wettability of the reservoir rock had an effect on the estimated wetting phase relative permeability.
- The estimated relative permeability was also found to be influenced by the pore geometry of the reservoir rock.

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