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Pressure dynamics controlling crude oil migration for reservoir management and exploration in Niger Delta, Nigeria

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ABSTRACT

Pressure conditions are required in reservoir operations management. This is essential in the adjustment of migration and production strategies. The study investigates the relationship between fluid flux and static pressure across multiple wells in a Niger Delta reservoir using well log and pressure data. Fluid flux and pressure gradients were obtained from modified Darcy's Law, and these were used to generate plots for oil, gas, and oil/water phases. A threshold pressure of approximately 4,899 psi was identified beyond which fluid flux increased sharply, reaching a maximum of 1,400 ft^3/day. Below this threshold pressure, fluid mobility was minimal, which indicates an insufficient energy to overcome capillary barriers. The optimal pressure suggests enhanced bulk fluid transmissibility, where both metrics exhibited a sharp decline, stabilizing at lower positive values until approximately 4800 psi. A critical pressure range of 4800 psi to 5050 psi was identified as a pressure range for optimal fluid flux. The major fluid encountered across the entire pressure spectrum was identified as oil, with isolated occurrences of gas and oil/water mixtures. In the present work, we observed that there is existence of a pressure-controlled migration regime and emphasize the importance of maintaining reservoir pressure above threshold values to enhance the oil production. The results obtained would provide insights for designing enhanced oil recovery (EOR) strategies and maintaining long-term reservoir performance above the present traditional concepts of oil production.

Keywords: Threshold Pressure Gradient (TPG), Crude oil migration, Darcy's Law, Seepage velocity, Reservoir management, Niger Delta basin

Nomenclature

Symbol	Description	Units
q	fluid flowing velocity	cm/s
$\emptyset$	Porosity	Fraction or %
k	Permeability	mD
μ	viscosity of the flowing fluid	centipoise
dp/dx	pressure gradient in the direction of flow	atm/cm
x	distance in the direction of flow	Cm
ΔP	total pressure drops	Psi
P_a	initial pressure	Psi
P_b	final pressure	Psi
l_a	initial depth	Ft
l_b	final depth	Ft
q	fluid flux	ft^3/day
v_s	seepage velocity	m/s

INTRODUCTION

Petrophysics integrates geological, physical, and chemical properties of reservoir rocks to evaluate parameters such as porosity, permeability, volume of shale, and fluid saturation for assessing reservoir productivity (Shah et al., 2021; Shalaby et al., 2023). The well log interpretation, core analysis, and pressure monitoring help petrophysical evaluation to provide critical inputs for reservoir management. When accurate and timely data are provided, petrophysics enables operators to make useful decisions that optimize production rates, reduce operational risks, and improve total reservoir management (Okoro et al., 2022; Esiri et al., 2024; Iriogbe et al., 2024). The significance of enhanced reservoir management lies in its ability to firstly, improve reservoir understanding and characterization, thereby enabling more accurate estimation of reservoir properties and production potential. This is crucial in mature fields where remaining reservoirs may be complex to quantify using conventional methods. Secondly, advanced monitoring techniques enable real time monitoring of reservoir performance, allowing operators to promptly detect and respond to changes in reservoir situations. This can help to identify issues such as gas coning, water breakthrough, or production anomalies, thus modifying potential production losses and extending the reservoirs life (Satter and Iqbal, 2016; Wu et al., 2023).