High Resolution Modelling for EOR Screening in Nigerian Reservoirs

The Niger delta is a prolific hydrocarbon province with total reserves estimated to be 28 billion barrels of crude oil and 165 Tcf of gas. These resources are produced by various fields across Niger delta (Figure 1), many of which are now mature and have been subject to change of operatorship.

As the new operators consider options to extend field life and maximise the value of these assets, the option of converting the production mechanism from water injection or natural water drive to Enhanced Oil Recovery (EOR) emerges. The question is whether the incremental investment can be justified. This study develops a workflow for EOR screening using non-standard, high resolution ‘truth’ modelling, and applying it to Niger delta archetype models such that the results can be applied generically across the basin.

Defining the archetypes

The Niger Delta reservoirs lend themselves well to archetype definition because of the similarity of depositional environments across the region within contracting realms of terrestrial, transition and marine environments. The terrestrial realm is represented by floodplain environment. The transition realm includes mangrove swamp, beach with beaches ridges and an estuarine environment. The marine realm consists of river mouth bars, delta platforms, prodelta slope, open shelf, continental slope and non-depositional environments.

Figure 1 Study location showing Niger delta fields (Iwegbu & Arochukwu, 2003)

Figure 2 Schematic representation of the diachronous nature of major Niger Delta lithofacies (Mode, Anyiam & John, 2017)
Within these environments, three diachronous formations have been defined (Figure 2):

1. The Akata Formation, a marine prodelta lithofacies consisting mostly of shales and clays with occasional turbiditic sandstones and siltstones (Omoboriowo, Chiadikobi and Chiaghanam, 2012), (Doust and Omatsola, 1989);
2. The Agbada Formation, a paralic clastic interval consisting mostly of alternating sandstones, siltstones and claystones, and

Reservoir and Simulation Model Set-up

The initial models take the form of high resolution ‘truth’ models, as defined by Bentley & Stephens (2017). ‘Truth’ models are defined as full-physics models which are resolved at the scale of the data but sized at the scale of the development question at hand. Model cell size is therefore at the scale of the core plugs used for SCAL analysis and the size of the model is governed by the well spacing which, in this case, is the scale required to evaluate the EOR decision (Figure 3). Although any EOR project will inevitably be executed at a full-field scale, the scheme will involve a repeating well pattern and its incremental benefits will depend on the interaction between injection and production wells, hence the focus on the well spacing.

There is no scale-up from the static to the dynamic models, and all models are Total Property Models (TPM, Ringrose, 2008) with all cells given reservoir properties and no cut-offs are applied, even for the very poor quality elements.

The simulation models, although 2D, are typically large (several million cells) but capture full heterogeneity and full physics, without compromise.

Properties from the models were typical for the region, based on well logs and core data obtained from the study area. The average porosity ranges from 10% to 35% and permeability 50 to 18000 mD. The high quality is typical of the region and is attributed to good sediment sorting and limited diagenesis. The studied reservoirs are characterised in terms of seven lithofacies types, distinguished based on sedimentological characteristics seen in core: very fine shelly sandstones, very fine grained with clay laminae, fine grained sandstones, fine-medium cross-laminated sandstones, medium to coarse grained sandstones, very coarse-grained sandstones and bioturbated sandy mudstones. These are grouped into
four modelling elements, namely: very fine sandstones, fine sandstones, fine-medium sandstones and medium-coarse sandstones.

**Model Results**

The models give an ultra-fine depiction of the displacement process, at a resolution not achievable without the benefit of recent computing power.

Two examples are illustrated. In Figure 4, a depiction is given of remaining oil after water flood (from Bentley et al., 2018), illustrating the habitat of oil remaining behind the flood front. It is clear that poorer quality elements within the better quality layers are bypassed, as expected. It is also clear, however, that as no reservoir elements are cut-off from model and as full physics is employed, the very poor quality units are also contributing to production, mostly by capillary imbibition of injected water in the better quality units.

**Figure 4** Waterflood model showing the location of remaining oil behind a flood front (Bentley et al., 2018, Ringrose & Bentley 2021)

The current work involves the application of EOR to the models (Figure 5). This shows an immiscible WAG process where the interplay between the different phases and the strongly contrasting underlying reservoir characteristics reveals a pattern of highly heterogeneous fluid flow, the ultimate productivity from which can be compared with the water flood case.

**Figure 5** WAG EOR applied to the ‘truth’ models: explicit multiphase flow patterns in a single heterogeneous bed, 400x4m in size with grid cells at the core plug scale (as per Figure 3).
Application

The current work involves the development of the Niger delta archetypes and their performance under EOR processes appropriate of these light oil reservoirs: WAG and Alkali Surfactant Polymer flood at the bed scale. These have been conducted as 2D models such that the potential incremental benefits of the EOR process can be quantified at the scale of the question, using realistic production rates and timescales.

The next is to step is to quantify these outcomes in larger-scale models for full reservoir intervals, calibrated against the ultra-fine ‘truth’ models, to yield a general recommendation as to which reservoir sub-types in the delta region are the most likely candidates to benefit from an EOR pilot, and by how much.

References


