Introduction

Permeability is one of the key parameters that characterizes the reservoir quality and flow capacity in any subsurface studies. It is widely used in 3D reservoir model for saturation distributions using the Saturation Height Functions (SHF), to describe flow behaviours and to predict productivity. Despite that, quantification of permeability at well remains challenging, even more challenging to populate it in 3D reservoir model.

The common approach to predict permeability and subsequently water saturation in 3D reservoir model is by first establishing porosity-permeability relationship with respect to rock typing from the poro-perm plot. The permeability will then distributed into the 3D model with regards to its respective porosity and rock types models. Then, SHF is utilized to distribute water saturation throughout the whole field. This approach will require comprehensive core samples from all ranges of rock qualities to improve correlation. Although commonly used, the approach of predicting permeability and SHFs based on core date often over-simplifying the predictions as the cloud of dataset are only represented with a best regression line for each rock type. In determining the representative SHFs often only limited number of capillary pressure data utilized. In addition, the upscaling of core and log data to the reservoir model posing it’s challenges that often not addressed accordingly as discussed by Delfiner (2007) & Worthington (2017).

An alternative approach was developed for clastic reservoir to establish robust petrophysical properties into 3D reservoir models within significantly enhanced pace.

Permeability Model at Core and Log Scale

Choo, C.F. (2010) has introduced permeability prediction based on grain size (Rg), porosity (Phit) and lithology distribution by incorporating Kozen-Carman equation, Kozeny Carman capillaric model. Choo’s equation addresses the permeability using dual-rock model with dividing rock into load-bearing and not load bearing rock. Numerous wells have been evaluated using Sand-Silt-Clay (SSC) model and Choo’s permeability equations in Malaysia and world-wide. The model has been proven robust with verification of core data from various fields, reservoir and geological setting in clastic environment.

Below is one of the many examples where the Choo’s permeability equation has been used to predict permeability. The predicted permeability match well with core permeability and Choo’s permeability is comparable with other industry approaches using rock types and core poro-perm relationships.

![Figure 1](image-url)

**Figure 1** Permeability from various approaches compared with core data. Track 3 shows regression permeability from single core porosity-permeability relationship (blue) which is consistent with geometrical average permeability (orange) using binning approach. Track 4 consists of Choo’s permeability (Red) and Permeability from Rock Type using Flow Zone Indicator (Green).
Permeability Distribution at Reservoir Model

Rock typing has been used widely in distributing permeability using poro-perm relationship that established using core data. Various approaches from simple Vshale cutoff to more sophisticated Artificial Neural Network (ANN) or Self Organizing Maps (SOM) being used to establish the rock types. Using rock type approach the core data will be divided into few groups and regression line will be established to represent the poro-perm relationship in each rock types. Hence, the permeability at each 3D model cells can be computed when the rock type and porosity available.

Figure 2 highlights poro-perm data with single relationship (a) and with 5 Rock Types (b) using Hydraulic Unit approach (Amaefule, J.O). Analysis of regression lines below shows that, permeability computed with five rock types provides better match with core data compared to single rock type relationship. The matching or accuracy of prediction improve with number of rock types. However, due to the practical reasons, the 3D reservoir model often limited to 3-5 rock types.

Permeability Modelling of Infinite Rock Types

In clastics reservoirs, it is common to use Volume of Shale (Vsh) and PHIT to establish rock types as both these properties are directly related to the reservoir quality. Equation (1) shows that Choo’s permeability model has incorporated the effect of various rocktype through Volume of Clay (Vcl) and Volume of Silt (Vsi) input, which considered as non-load bearing rocks. At certain depth, the combination of Vcl and Vsi will determine the degradation of permeability from the clean sands (Choo,C.F.2010).

\[ k = 0.125 \frac{\phi \left( \frac{V_{cl}}{c} \right)^{2} + 1}{10^{6(V_{cl} + 3V_{si} + 1)}} \]  

As highlighted earlier at well control where the SSC evaluation available, Choo’s equation can be used establish permeability that matches well with core data. However, it is challenging to apply the same equation at the reservoir model as the Vcl and Vsi usually not distributed by geomodeller as there are significantly geological uncertainties related to this properties. In current practice, porosity, rocktype/lithofacies and in some cases Vsh distributed in reservoir models.

Hence, by exploiting the relationship between Vsh-Vcl-Vsi from SSC model at well control, latter can be distributed into the 3D static model. With all input parameters set in-place, the permeability model can be calculated using the Choo’s permeability. Figure 3 shows the validation done by comparing the reservoir properties from logs (black colour) and from 3D reservoir properties (Red color) at well control. Once permeability has been established using Choo’s Saturation Height Functions (Choo,C.F.2010), the water saturation (Sw) can been calculated, and the volumetric can be estimated.
Proposed Workflow

Based on the above mentioned methodology workflow established to distribute permeability and Sw as mentioned in Figure 4. This alternative workflow would only require Vsh and PHIT models as input. Using these input permeability will be calculated and with incorporation of Free Water Level (FWL) and Saturation Height Function the Sw will be distributed.

Results and Value Creations

This alternate new approach has successfully been applied in multiple fields in Malaysia. Below are the volumetric results of Field A & Field B compared against conventional volumetric estimations:

<table>
<thead>
<tr>
<th></th>
<th>Field A</th>
<th>Field B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Type Model, MMSTB</td>
<td>350</td>
<td>300</td>
</tr>
<tr>
<td>Proposed approach, MMSTB</td>
<td>358</td>
<td>310</td>
</tr>
</tbody>
</table>

Table 1 Volume comparisons
The results in term of the volumetric are within the range of uncertainties. However, they are significant value creations established through this new approach:

1. **Pace:** Reduction in the 3D Reservoir modelling process by 3-5 months. As there is no additional rock typing required during the petrophysical evaluation and static model development, significant time saving established. This eventually resulted in faster FDP/FFR.

2. **Robust:**
   a) As the model using Vsh that derived from geological concept, depo and lithofacies modeling, it maintain geological imprint thought the process as highlighted in Figure 4.
   b) The workflow is using regionally well-established method at well control hence it has eliminated the averaging/upscaleing issue resulted by the poro-perm regression lines.

3. **Audit trail and QC:** The input required for permeability and Sw modelling are same as the input used at the petrophysical evaluation at well control. Hence, any changes or amend would require systemic and consistent approach which simplify auditing process.

4. **Uncertainties analysis:** As the modelling workflow is simplified with significant reduction in time, detailed uncertainty analysis can be carried with different 3D model addressing different geological concept.

### Conclusion and Way Forward

The proposed new approach is “game changer” in petrophysical property modelling as robust model can be built within significantly short duration. The approach allows the geomodeller to establish numerous static models to capture the geological uncertainties accordingly. In addition, it can be used for quick resource assessment and as a quality check for existing model.

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### References


