DEVELOPMENT AND IDENTIFICATION OF PETROPHYSICAL ROCK TYPING FOR EFFECTIVE RESERVOIR CHARACTERIZATION

BIOR ATEM BIOR BARACH

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School of Chemical and Energy Engineering Faculty of Engineering
Universiti Teknologi Malaysia

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DEDICATION

This Thesis work is dedicated to my dear wife, for her unconditional love and support.

To my lovely sons and daughters, for the joy they gave me in overcoming the hard times.

To my beloved parents and siblings, for continuously encouraging me to explore new areas.

To my supportive parents-in-law, for their deep love and care of my family.

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ABSTRACT

Rock typing is an essential tool used to distribute reservoir rock and fluid properties in reservoir models. It provides more accurate estimates of oil reserves during field studies and prediction of reservoir performance. These properties are required inputs for static and dynamic models to populate porosity, permeability, and shale volume which influence reservoir productivity. During field development studies (FDP), the technical main aim is to design a fit for purpose project within budget to produce commercial volume of hydrocarbons in the field and reduce residual oil in the reservoirs. However, geomodellers frequently faced challenges in integrating geological facies with rock characteristics and fluid flow to predict petrophysical properties due to limited correlation between geological features and engineering concepts. This thesis examined Petrophysics rock types based rock classification scheme by comparing the approaches using rock samples. Among the trimmed approaches are Hydraulic Flow Unit(HFU), Global Hydraulic Elements(GHE), Winland R35, Pore Geometry Structure (PGS). Also presented is the use of electrical and nuclear log data obtained from the well Neutron-Density to produce relationships that tie pore geometric attributes, pore structures, and hydraulic flow characteristics. The study selected Hydraulic Units and GHE methods among others to be robust in Rock Typing based on consistencies observed between porosity and permeability relationships in typical clastics reservoirs. Thus, it reduces the uncertainties in reservoir models. Using capillary data to derive saturation height functions, the Hydraulic units demonstrated consistent results of rock types that integrates geological description with engineering hydraulic features.

ABSTRAK

Pengkelasan batuan adalah satu keperluan untuk mengagihkan jenis atau kelas batuan dalam model takungan. Ini akan membantu anggaran simpanan minyak dan ramalan pencapaian takungan dengan lebih tepat. Jenis batuan berkait rapat dengan sifat takungan seperti keliangan, keterlapan, jumlah shale dan semua ini mempengaruhi pengeluaran sesebuah takungan. Semasa kajian pembangunan takungan, tujuan utama ialah untuk membuat projek yang memenuhi kehendak optima ekonomi. Tetapi ahli model kajibumi sering berhadapan dengan masalah mengabung data geologi, sifat batu batuan, keboleh aliran, sifat petrofizik disebabkan kurang pemahaman di antara sifat geologi and konsep kejuruteraan. Thesis ini mengkaji skim pengkelasan batuan berlandaskan Petrofizik dengan membandingkan pendekatan yang menggunakan sampel batuan. Antara pendekatan yang dikaji ialah Unit Aliran Hidraulik, Elemen Hidraulik Sejagat, Kaedah Winland R35 dan Struktur Geomteri Liang. Turut dikajikan ialah pengunaan data berlandaskan elektrik dan nuklear yang didapati dari telaga, dan mengaitkan hubungan antara skim ini dengan tujuan memahami hubungan antara asas geometri, struktur keliangan dan sifat aliran hidraulik. Kajin ini memilih Unit Aliran Hidraulik, dan Elemen Hidraulik Sejagat sebagai skim pengkelasan yang sesuai digunakan dalam takungan jenis batuan klastik berdasarkan hubungan yang konsisten dianatara keliangan dan kebolehaliran. Oleh itu ia boleh menggurangkan ketidakpastian dalam model takungan. Menbanding keputusan ketepuan dari model kapilariti dan Unit Aliran Hidraulik, ia menunjukkan keputusan yang seragam atau konsisten, membolehkan teknik ini boleh dipercayai. Ini menunjukkan ia mampu menggabung asas geologi dan sifat kejuruteraan

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LIST OF ABBREVIATIONS

PRT	Petrophysical Rock Typing
PTR	Pore Throat Radius
RCA	Routine Core Analysis
SEM	Scanning Electron Micrograph
SCAL	Special Core Analysis
HFU	Hydraulic Flow unit
RQI	Reservoir quality index
Φz	normalized porosity
FZI	Flow Zone Indicator
MICP	Mercury Injection Capillary Pressure
SHF	Saturation Height Function
GHE	Global Hydraulic Elements
PGS	Pore Geometry Structure
K	permeability
core perm	core permeability
PHID	density porosity
Sgv	surface area per grain volume
φ	porosity

CHAPTER 1

1. INTRODUCTION

1.1. Background

Reservoir characterization has always been a challenging domain in oil and gas industry for a long time. There are many approaches and methodologies that are applied with the aim of establishing statistically significant correlations between reservoir storage and fluid flow characteristics. Ranking of obtained correlations and their optimized clustering are used for rock typing that aims to derive representative model equations for static modelling. However, selection and validation of these methods of clustering the similarities still face hurdles due to complexities in pore-space conditions and reservoir geometry. Petrophysicists need to adequately understand these complexities in order to derive representative models for accurate predictions of petrophysical characteristics, mainly, between fluid flow (permeability) and reservoir storage (porosity) across the field.

It has become Industry standard to come up with Petrophysical Rock Types that are used as inputs in saturation height models and in three dimensional (3D) reservoir characterization models. The ultimate goal is for accurate initial water saturation distribution, hydrocarbon volumes determination, fluid contacts determination (hydrocarbon-water contacts), free water level confirmation and evaluation of various uncertainties.

Integration of routine core analysis data, mineralogical studies such as XRD, petrographical studies as thin-sections, SEM, CT-Scan, and pore geometry information from SEM analysis are used to determine Petrophysical Rock Types (PRTs). Other important information is obtained by incorporating Special Core

Analysis (SCAL) mercury injection capillary pressure (MICP or HPMI) data. In complex lithologies, such as carbonate formation, NMR T2 distributions on water saturated samples are valuable in detecting connected vugs, that will reveal large pore body sizes in the absence of large pore throats on MICP. On the other hand, mercury injection experiments are carried out on core samples, and the results are used to determine pore-size-distributions for subject rocks. As for confirmation, the pore size distributions obtained from RFT and core analyses are compared. The information on pore-throat-size distribution, can only be used for rock typing when comparison indicates appreciable agreement.

The most well-known petrophysical rock type characterization based on pore throat radius indicators (PTRi) are: Winland, Pittman, Leverett k-PHI Ratio, Lucia Rock Fabric Number (RFN), Flow Zone Indictors (FZI), Reservoir Quality Index (RQI), and Aguilera. In this characterization, four rock properties to be studied are Permeability, Lithology, Porosity and Lithofacies. It is imperative to note that none of the standard Pore Throat Radius indicators (PTRi) directly account for multi-modal pore geometries leading to poor representation and typing for complex reservoir rocks.

Static and dynamic models are mostly depending on reservoir energy through facies classification that are driven by shape and pore geometry. The objective is to distribute porosity, permeability, thickness and net-to-gross in three dimensions using various mapping techniques provided that the similarity grouping (i.e. rock typing) is done appropriately. However, distributing initial and irreducible water saturation remains extremely challenging for reservoir engineers because of several factors such as diagenesis that often affect flow characteristics which is therefore the cause of volumetric reduction.

The ultimate goal of PRTs is to provide users with transforms for flow characteristics and volumetric parameters that are important inputs for three dimensional dynamic reservoir simulators and reservoir characterization software. This thesis aims to study effects pore-throat-size-distribution in defining Petrophysical Rock Typing by using both core and log data and enhance the relationship between capillary properties, permeability and porosity correlations and hydraulic flow units.

1.2. Problem Statement

Clastic formations often have variation in rock properties as a function of location. This rock character is termed as reservoir rock heterogeneity. It's a property of the reservoir rocks that has a huge impact on petroleum system modeling, formation evaluation and reservoir simulations which are critical in maximizing production from shaley reservoir sands. Static and dynamic models are incapable of modelling volume of shale (silt and clay) due to this heterogeneity. In order to build a robust static and dynamic reservoir models, it therefore becomes essential to come up with Petrophysical Rock Types. These Petrophysical Rock Types act as the bases of relating permeability and porosity to execute a successful drilling, production, injection, reservoir studies and simulation models.

Rock Types give crucial insights on how pore size and pore throat size distribution relates to saturation height models that helps in calculating saturation away from well location in a 3D sense based on the established physics of buoyancy and capillary pressure in a rock-fluid system. Also, a correlation between permeability and porosity can be established to distinguish reservoirs based on rock quality. In such correlations, we expect to see small pore-throat size represents poorer rocks and large pore-throat-size indicates better rock quality. Armed with these valuable informations, the team can characterize formations that may contain large amount of hydrocarbons but not commercial due to low permeability across the field. This study will provide essential tools to recommend suitable approach to recover these hydrocarbons.

1.3. Objectives

The main of this thesis is to integrate core data and well logs to enhance reservoir characterization through reservoir rocks classification in a geologically and petrophysically consistent manner. The main objective is to investigate scientific approaches of utilizing rock data at different time and length scales to describe reservoir rock-fluid systems consistent.

a. To determine Petrophysical Rock Types through quantitative methods that derive pore-sized distribution functions from MICP data to characterize complex pore system.
b. To integrate multiple pore system attributes defined in (a) to detect petrophysical variation between pore systems that improves petrophysical ranking of rock types.
c. To recommend the best petrophysical rock typing approach that reflects coherency in saturation height functions (consistency in J-Function).

1.4. Hypotheses

a. Pore Throat Size distribution relate pore geometry to reservoir properties (Controls of conduit size for effective fluid flow). Small Pore Throat Radius indicates poor quality rock.
b. Petrophysical Rock Typing provides more accurate reservoir characterization to minimize errors in reserves estimation.
c. Provide important insights to recommend proper development strategies to produce economical amount of hydrocarbons in particular formations to reduce residual oil.

1.5. Research Scope

Conventional and Special Core analysis data will be used to calibrate well log data. Capillary pressure curves(from MICP data) will be used to distinguish

Petrophysical Rock Types into poor and good quality rock as a function of Pore Throat Radius.

Scope 1: Characterizing PRTs using core description

a. Petrographic analysis (Mineralogical study such as XRD, thin section, SEM and CT-scan)
b. Establishing relationship between pore geometry and pore size distribution using core description and analysis (lab measurement- MICP)
    i. Using RQI/FZI equations
    ii. Poro-perm transform to predict permeability away from well location.

Scope 2: Integrating lithofacies from core data with log characters to group rocks into:

a. Rocks with similar flow behavior and rocks with same reservoir storage
b. Selecting rock with similar geological attributes to relate rocks-fluid interactions

Scope 3: Using Special Core Analysis to construct Cap Pressure curves and construct SHF according to:

a. Cluster rocks that exhibit similar fluid flow behavior
b. Determine consistency in J-Function curves for a given saturation (Sw) for any height above free water level in reservoir
c. Comparing the permeability generated from other empirical equations with log derived permeability to recommend a suitable approach for clastic formations in Sabah fields.

1.6. Significance of Study

Modern volumetric estimation approach requires petrophysical rock typing which are controlled by porosity and permeability. Each rock type represents distinctive pore geometry/morphology that signifies specific pore throat size distributions. For a particular rock type there is a single saturation height function that exhibits a certain set porosity and permeability is constructed.

Although pore throat radius is not the only thing, but one of the controls of permeability since it shapes up the conduit size for the flow. Permeability has no direct downhole measurement other than complex and lengthy pressure testing and flow measurements because it is a dynamic reservoir property. Permeability controls fluid flow because it is a function of the rock's microscopic properties such as pore size, grain sorting, tortuosity, cementation, and compaction. If pore throat radius distributions derived from mercury injection are similar, the rock pore geometry shows similar trends. These trends are characteristics of permeability which is intrinsic hydraulic property that control fluid flow. High permeability rocks result in high production rate as a function of pressure drop during drawdown.

Thus, it would be of great advantage if the most of reservoirs parameters can be predicted within great certainty. This project will therefore, assist in:

a. Providing accurate reservoir characterisation by assigning representative Petrophysical parameters for hydrocarbons volumetric calculations.
b. Establishing appropriate correlation to predict fluid flow characteristics far away from well location in a field wide.
c. Recommend proper development strategies to produce economical amount of hydrocarbons in these particular formations to reduce residual oil.

1.7. Thesis Summary

This project will be organized by covering the sections summarized below:

a. Sufficient, for data acquisition and analysis on each procedures & compilation
b. No equipment or lab experiment needed

c. Using Capillary Pressure data to established the relationship between PRTs and PTR

d. Sufficient research SPE papers/journals: One petro website

e. Reference from industry standards, books & manual available.

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