METHOD COMPARISON FOR WATER SATURATION ESTIMATION IN SHALY-SAND RESERVOIR FOR FIELD X

WAN AHMAD RAFAEL BIN WAN ZAIRUDIN

A project reportsubmitted in partial fulfilment of the
requirements for the award of the degree of
Master of Petroleum Engineering

School of Electrical Engineering
Razak Faculty of Technology and Informatics
Universiti Teknologi Malaysia

JULY 2020

ACKNOWLEDGEMENT

Alhamdulillah, all praise to God for His blessings and guidance which has allow me to complete this thesis. Special thanks I bid to my supervisor Prof Madya Dr. Muhammad Bin A. Manan who has been extremely supportive and understanding throughout the whole process of completing this thesis. I'm also deeply grateful to have a list of great lecturers who are always eager to assist in any way they possible could.

I would also like to express my deepest gratitude to my fellow classmates, Ismail, Syareena, Noorhashima, Fazdly and Aiman. They are my brainstorming buddies, problem solvers and most importantly, my number one moral supporter. I'm very proud to have them with me throughout this wonderful journey.

On top of that, I would also like to extend my appreciation to my family, friends and colleagues whom have been helping me either directly or indirectly during this whole experience.

Thank You.

ABSTRACT

The study is done to find out the impact that shale has upon the estimation of saturation in a clastic reservoir. It is widely acceptable that shaly sand saturation method must be used when dealing with clastic reservoir due to its consideration of shale content in its calculation. Despite knowing that, there are just so many shaly sand saturation methods available in the industry, hence this study is conducted to identify which method is best to represent Field X which located in Malay Basin, Malaysia. A controlled condition is developed to ensure consistency for each of the saturation methods. This was done by fixing a constant input parameter for each of the methods. Apart from that, a referenced saturation log that has been calibrated using core and actual field data is being used as the benchmark for comparison. All calculated saturation will be compared side by side with the referenced log and a complete discussion and analysis is done to identify which method would be best to represent Field X in estimating the water saturation.

ABSTRAK

Kajian ini dibuat untuk mengenalpasti kesan kehadiran syal terhadap pengiraan ketepuan air di dalam takungan klastik. Ia telah menjadi kata sepakat bahawa pengiraan ketepuan di takungan klastik mestilah dilakukan dengan menggunakan cara pengiraan yang mengambil kira kehadiran syal. Namun begitu, pada masa sekarang, terdapat begitu banyak cara pengiraan sedemikian di dalam industri minyak dan gas di seluruh dunia. Kajian ini dimulakan dengan niat untuk mengenalpasti cara pengiraan manakah yang terbaik untuk digunakan bagi mengira ketepuan di Lapangan X yang terletak di Lembangan Melayu, Malaysia. Suatu kondisi yang terkawal telah disediakan bagi memastikan keselarasan bagi setiap cara pengiraan yang dibuat. Ini dilakukan dengan memalarkan pembolehubah tertentu supaya semua cara pengiraan ketepuan yang dibuat dalam kajian ini didasarkan keatas keadaan yang sama. Selain itu, satu log ketepuan yang telah ditentu ukur dengan menggunakan data-data dari simulasi lapangan dan inti batuan sebagai kayu ukur untuk perbandingan. Semua ketepuan yang dikira berdasarkan pengiraan-pengiraan ini akan disusun sebelah-menyebelah bersama log ketepuan yang ditentu ukur tersebut. Perbincangan dan Analisa terhadap ketepuan-ketepuan ini seterusnya dilakukan bagi menentukan pengiraan yang mana satukah yang dapat digunakan sebaiknya bagi Lapangan X.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	**i**
	DEDICATION	**ii**
	ACKNOWLEDGEMENT	**iii**
	ABSTRACT	**iv**
	ABSTRAK	**v**
	TABLE OF CONTENTS	**vi**
	LIST OF TABLES	**viii**
	LIST OF FIGURES	**ix**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Problem Background	1
1.2	Problem Statement	2
1.3	Research Hypothesis	3
1.4	Research Objectives	3
1.5	Research Scope	3
1.6	Significance of Research	4
CHAPTER 2	**LITERATURE REVIEW**	**5**
2.1	Reservoir in Malay Basin	5
2.2	Shaly Sand Definition	6
2.3	Understanding Clay Behavior	7
2.4	Water Saturation Methods	12
2.4.1	Archie Water Saturation Method	12
2.4.2	Waxman-Smits Water Saturation Method	16
2.4.3	Dual Water Saturation Method	19
2.4.4	Simandoux Saturation Method and Its Modifications	22

CHAPTER 3 RESEARCH METHODOLOGY 25

3.1 Introduction 25

3.2 Proposed Methodology 25

3.2.1 Data Gathering 26

3.2.2 Evaluating Input Parameters 26

3.2.3 Establishing Referenced Saturation Log 27

3.2.4 Estimating Water Saturation using Shaly-sand Methods 27

3.2.5 Technical Comparison 27

CHAPTER 4 RESULTS AND DISCUSSIONS 29

4.1 Input Parameters 29

4.2 Results 31

4.3 Discussion 35

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 37

5.1 Conclusion 37

5.2 Recommendation 38

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 4.1	Constants values used as input parameters	29
Table 4.2	Error analysis summary between shaly sand saturation methods versus referenced log	35

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Modes of shale distribution, after Schlumberger	5
Figure 2.2	Diagram depicting the geometry of a silica where silicon is in the middle surrounded by 4 oxygen. Source: Karla Panchuk (2018) CC BY 4.0, modified after Steven Earle (2015) CC BY 4.0	7
Figure 2.3	Plan view of silica molecule forming a hexagonal shape structure as they grow. Notice that the oxygen is shared between each silica molecules. Source: Karla Panchuk (2018) CC BY 4.0, modified after Steven Earle (2015) CC BY 4.0	8
Figure 2.4	Diagram depicting the geometry of an alumina octahedron where the aluminium is in the middle surrounded by 6 hydroxide molecules. Source: Zi Newsletter Issue 06/2014	8
Figure 2.5	Diagram showing how alumina crystal grows laterally leaving no gaps in between each molecule. Source: Clay structure by Linda Bloomfield	9
Figure 2.6	Clay layering and its bonding (Thomas, 2018).	9
Figure 2.7	Layering of 1:1 and 2:1 clay structure	10
Figure 2.8	The chemical structure of the common clay minerals found in clastic reservoir (Thomas, 2018).	11
Figure 2.9	Porosity and permeability relationship against formation resistivity factor using core samples from Consolidated Sandstone cores from the Gulf Coast (Archie, 2003).	13
Figure 2.10	Porosity and permeability relationship towards formation resistivity factor using core samples from Nacatoch Sand, Bellevue, LA. (Archie, 2003)	14
Figure 2.11	Water Saturation Relationship to Resistivity Ratio	15
Figure 2.12	"B" as a function of water resistivity and temperature.	17
Figure 2.13	Comparison of estimated water saturation between Archie and Waxman-Smits equation (Onovughe and Sofolabo, 2016).	19
Figure 2.14	Porosity model for a shaly sand reservoir (Al-Ruwaili et al).	20

Figure 3.1 Project Methodology Workflow 25

Figure 4.1 Saturation plot comparison for depth interval 1 32

Figure 4.2 Saturation plot comparison for depth interval 2 33

Figure 4.3 Saturation plot comparison for depth interval 3 34

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Oil and gas subsurface's studies primarily consist of an understanding of the structure, connectivity, and properties of the reservoir. When evaluating the value of a reservoir, one can't resist asking how much hydrocarbon they can produce from it. To answer that, a thorough understanding of the water saturation, estimated pore volume, and formation volume factor are required as input to calculate the hydrocarbon initially in-place (HCIIP). The general breakdown of the calculation is based on the formation volume factor, hydrocarbon saturation, and reservoir pore volume. Evaluating each of these parameters is far from easy and requires huge efforts from various subsurface disciplines, mainly; reservoir engineers, geologists, and petrophysicists. Reservoir engineers are expected to deliver the formation volume factor, petrophysicist should provide the estimated water saturation and average reservoir porosity, while the geologist will come up with the most representative pore volume of the targeted reservoir based on their geological understanding of the reservoir's facies distribution. Each discipline would have their fair share of hardship in coming up with all these deliverables. It is such a broad topic to discuss all of these deliverables in one seating, hence for this dissertation, the focus will be on how the water saturation is being estimated.

One could argue that the estimation of water saturation is probably the trickiest one out of the lots. That is particularly due to the fact that there are so many water saturation methodologies available, and all of them are being used widely in the industry. Each of the saturation methods was initially developed based on the same fundamental, ie: Archie's Equation (Archie, 2003), however, they were often modified to cater to the varying subsurface parameters of the respective regional environment. Using the right water saturation method with the right parameters has always been a

challenge to petrophysicists, in coming up with the best water saturation estimation to be used by geologists and reservoir engineers in developing their static and dynamic reservoir models.

Figuring out which water saturation models to be used often highly dependent on the type of lithology the reservoir is located at. A comprehensive understanding of the basin can give an overview of the expected characteristic that the reservoir could have such as its structural geology and petroleum system. In order to be specific on the topic of discussion, this report will be focusing on the Malay basin.

Malay basin is located offshore of Peninsula Malaysia and it has been a very prolific basin for Malaysia. Most of the reservoirs in the Malay basin are made up of clastic; which are often characterized based on its sand and shale lamination. This layered reservoir was studied to be the result of multiple cycles of sand deposition from different variances of sedimentary rock.

This lamination of sand and shale, and sometimes clay, give a huge impact on the actual value of water saturation. The presence of fine-grained shales and clay minerals is known to give an impact on the interaction of rock and fluids in the reservoir. Many theories were crafted to cater to this interaction and to find the proper relationship to assist in acquiring a better and more accurate saturation estimation. Hence this study is brought forth to evaluate the best approach and to understand which reservoir parameters or how rock properties contribute towards getting the best estimation of reservoir saturation.

1.2 Problem Statement

In Malaysia, specifically in Malay basin, PETRONAS has adopted Waxman & Smits's equation (Waxman and Smits, 1968) as the standard methodology in estimating its reservoir's water saturation. There is no official documentation from PETRONAS which explains the reason behind the adaptation of the approach that they have taken. There was however some hearsay which says that PETRONAS has actually conducted a thorough study based on the vast available core data that they

have at their disposal, but there is also no official documentation to support this statement. Hence this study will look into the various water saturation methodologies and apply them to a selected field in the Malay basin and compare the results and observation on which methods are more representative for water saturation estimation in Malay Basin.

1.3 Research Hypothesis

i. A representative water saturation estimation for the shaly-sand reservoir is highly impacted by the presence of clay mineral within the formation.
ii. The types of clay, its distribution and the way the clay is dispersed in the formation could change how the water reacted to its surroundings.
iii. Classification of sedimentary rocks such as grain size, sorting, and angularity would impact the estimation of water saturation.

1.4 Research Objectives

i. To identify if the presence of clay in the reservoir impacts the water saturation estimation, and if it does, what could be the main contributing factor to it.
ii. To evaluate the effects of different clay types towards the reservoir's initial water saturation.
iii. To analyse the relationship of sedimentary rock's classifications with the reservoir rock properties and how it impacted water saturation estimation.

1.5 Research Scope

This study focuses on the factors that impact the water saturation estimation of clastic reservoirs in Malay basin. The breakdown of the scopes is as follows.

i. Analyzing how clay minerals give impacts towards water saturation by looking into different types of clay minerals and matches it to the clay types presence in Malay basin.

REFERENCE

Aboudi Mana, S. C., Hanafiah, M. M. and Chowdhury, A. J. K. (2017) 'Environmental characteristics of clay and clay-based minerals', *Geology, Ecology, and Landscapes*. Taylor & Francis, 1(3), pp. 155–161.

Archie, G. E. (2003) 'The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics', *SPE Reprint Series*, pp. 9–16.

Bardon, C. and Pied, B. (1969) 'Formation water saturation in shaly sands', *SPWLA TENTH ANNUAL LOGGING SYMPOSIUM*.

Clavier, C., Coates, G. and Dumanoir, J. (1984) *Theoretical and Experimental Bases for the Dual-Water Model for Interpretation of Shaly Sands*. Schlumberger Well Services.

Hill, H. J. and Milburn, J. D. (1955) 'Effect of Clay and Water Salinity on Electrochemical Behaviour of Reservoir Rocks', 207.

Jakosky, J. J. and Hopper, k. H. (1937) 'The Effect Of Moisture On The Direct Current Resistivities Of Oil Sands And Rocks', *GEOPHYSICS*, 2(1), pp. 54–55.

Jürgen H. Schön (2015) *Well Production Performance Analysis for Shale Gas Reservoirs*.

Kriaa, A., Hajji, M., Jamoussi, F. and Hamzaoui, A. H. (2014) 'Electrical conductivity of 1: 1 and 2: 1 clay minerals', *Surface Engineering and Applied Electrochemistry*, 50(1), pp. 84–94.

M. C. Leverett (1938) 'Flow of Oil-water Mixtures through Unconsolidated Sands', *Transactions of the AIME*, 127(01), pp. 226–239.

Martin, M., Murray, G. H. and Gillingham, W. J. (1938) 'Determination Of The Potential Productivity Of Oil-Bearing Formations By Resistivity Measurements', *GEOPHYSICS*, 3(3), pp. 258–272.

Mbaga, D. E. and Mwendenusu, G. (2019) 'Effect of Shale Volume on the Porosity of Clastic Reservoirs. Case-Study From Mkuki-1 Reservoir, Offshore Tanzania', in. European Association of Geoscientists & Engineers, pp. 1–5.

Mortland, M. M. and Mellor, J. L. (1954) 'Conductometric Titration of Soils for Cation-Exchange Capacity', *Soil Science Society of America Journal*, 18(4), p. 363.

Onovughe, E. and Sofolabo, A. (2016) 'Saturation Modelling: Using The Waxman-Smits Model/Equation In Saturation Determination In Dispersed Shaly Sands', *Journal of Multidisciplinary Engineering Science and Technology (JMEST)*, 3(6),

pp. 2458–9403.
Tessier, D. (1990) ‘Behaviour and Microstructure of Clay Minerals’, in De Boodt, M. F., Hayes, M. H. B., Herbillon, A., De Strooper, E. B. A., and Tuck, J. J. (eds) *Soil Colloids and Their Associations in Aggregates*. Boston, MA: Springer US, pp. 387–415.
Thomas, E. C. (2018) ‘What is it about shaly sands? Shaly sand tutorial’, *Petrophysics*, 59(3), pp. 276–287.
Waxman, M. H. and Smits, L. J. M. (1968) ‘Electrical Conductivities in Oil-Bearing Shaly Sands’, *SPE Reprint Series*, (55), pp. 107–122.
Wildenschild, D., Roberts, J. J., Carlberg, E. D., Group, E. G. and Livermore, L. (1999) ‘Influence of microstructural properties on geophysical measurements in sand-clay mixtures Introduction : SEG 1999 Expanded Abstracts SEG 1999 Expanded Abstracts’.
Wyckoff, R. D. and Botset, H. G. (1936) ‘The flow of gas-liquid mixtures through unconsolidated sands’, *Journal of Applied Physics*, 7(921), pp. 325–345.