FORMULATION OF GENERAL RELATIVE PERMEABILITY CORRELATION OF FIELD A

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"My dearest late father, mom, wife, family, Assoc. Prof Zaidi and friends"

This is for all of you

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ABSTRAK

Data kebolehtelapan relatif amat penting untuk hampir semua pengiraan pengaliran bendalir dalam takungan dan digunakan secara meluas dalam banyak bidang kejuruteraan petroleum. Pengukuran kebolehtelapan relatif dilakukan pada sampel teras di makmal dan kedua-duanya memakan masa dan mahal untuk dihasilkan. Hasil daripada kesukaran dan kos yang terlibat dalam mengukur nilai kebolehtelapan relatif, kolerasi dan pengiraan empirik sering digunakan untuk menganggarkan nilai-nilai tersebut. Dalam bidang kajian yang merupakan Lapangan Minyak A, hanya terdapat satu data SCAL yang boleh didapati daripada satu takungan. Oleh itu, terdapat keperluan untuk merumuskan kolerasi am untuk digunakan dalam lapangan minyak yang dikaji atau lapangan minyak yang lain di lembangan melayu tanpa data SCAL. Penubuhan kolerasi tersebut telah menjadi matlamat utama penyelidikan ini. Tiga kolerasi yang diterbitkan telah dipilih untuk dianalisa dan dibandingkan untuk menentukan kolerasi yang paling sesuai untuk lapangan minyak yang dikaji. Penyelidikan bermula dengan pengumpulan data yang meliputi pemeriksaan kualiti data dan penapisan data. Analisi terperinci mengenai data dana rumusan kolerasi dijalankan. Tiga (3) kolerasi iaitu Corey, Chierici dan LET telah dibandingkan dan dianalisa. Dari semua kolerasi, kolerasi Corey dan Chierici tidak cukup fleksibel untuk menyelaraskan keseluruhan set pemerhatian eksperimen. Kolerasi LET mempamerkan fleksibiliti untuk menyelaraskan seluruh set data eksperimen dengan memuaskan. Tingkah laku s dimodelkan dengan baik menggunakan kolerasi LET. Kolerasi ini telah dipilih dan diuji dalam model dinamik untuk menguji kesahihannya. Keputusan menunjukkan bahawa pemadanan kadar minyak dan air boleh diterima. Oleh itu, kolerasi ini telah diterima dan telah digunakan untuk menghasilkan lengkung kebolehtelapan relatif untuk takungan minyak lain di Lapangan Minyak A.

ABSTRACT

Relative permeability data are essential for almost all fluid flow calculations in reservoirs and are utilized extensively in many areas of petroleum engineering. Relative permeability measurements are conducted on core samples in laboratory and are both time-consuming and expensive to produce. As a result of the difficulties and cost involved in measuring relative permeability values, empirical correlations and calculations are often employed in order to estimate the values. In the field of study which is Field A, there is only one SCAL data available from a reservoir. Hence there is a need to formulate a general correlation to be used in the field of study or other fields in Malay basin with no or limited SCAL data. The establishment of such correlation will be the main objective of this research. The available SCAL data were manipulated and analyzed to create a suitable correlation to be used for other reservoirs. Three published correlations were chosen to be analyzed and compared to determine the most suitable correlations for the field under study. The research started with data collection which includes data quality checking and screening. Six (6) core samples for kro-krw and six (6) core samples for krg-kro was were used in this research. Then detailed analysis of the data and correlation formulation was conducted. Three (3) correlations which are Corey, Chierici and LET were compared and analyzed. From all the correlations, Corey and Chierici correlations are not flexible enough to reconcile the entire set of experimental observations. LET correlation exhibits flexibility to satisfactorily reconcile the entire set of experimental data. The s-behaviour is well modeled by LET correlation. This correlation was chosen and tested in the dynamic model to test its validity. Results showed that acceptable matching of oil rate and water cut were obtained. Hence the correlations were accepted and will be used to generate pseudo-relative permeability curves for other hydrocarbon reservoirs in Field A.

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ABBREVIATIONS

SCAL	-	Special Core Analysis
RCA	-	Routine Core Analysis
RQI	-	Rock quality index

LIST OF SYMBOLS

k	-	Permeability
kro	-	Relative permeability of oil
krw	-	Relative permeability of water
krg	-	Relative permeability of gas
Swi	-	Irreducible water saturation
Sgc	-	Critical gas saturation
Sorw	-	Residual oil saturation
Sorg	-	Residual oil saturation to gas
Q	-	Fluid flowrate
A	-	Cross-sectional area
dp/dl	-	Pressure gradient
μ	-	Viscosity
cp	-	Centipoise
Nc	-	Capillary number
σ	-	Interfacial tension
θ	-	Rock porosity in fraction
Swn	-	Normalized water saturation
kair	-	Permeability to air
krin	-	Normalized relative permeability
kro-krw	-	Oil-water relative permeability
krg-kro	-	Gas-oil relative permeability

CHAPTER 1

INTRODUCTION

1.1 Background

Permeability is a property of the porous medium that measures the capacity and ability of the formation to transmit fluids (Ahmed, 2001). The rock absolute permeability, often given the symbol k is a very important rock property because it controls the directional movement and the flow rate of the reservoir fluids in the formation. If it takes a lot of pressure to squeeze fluid through a rock, that rock has low permeability. If fluid passes through the rock easily, it has high permeability.

Relative permeability, a dimensionless quantity, is the ratio of effective permeability to absolute permeability. Relative permeability is a crucial empirical parameter in describing the flow of multiple immiscible fluids within a porous medium (Honarpour and Mahmood, 1988).

$$Relative\ Permeability, kro/krw/krg = \frac{Effective\ Permeability, ko/kw/kg}{Absolute\ Permeability, k}$$

The relative permeability to one phase changes with the relative saturation of that phase. It is equal to one at 100% saturation of the phase and gradually decreases to reach zero at the critical or irreducible saturation of that phase. Figure 1.1 shows the general oil water relative permeability curve.

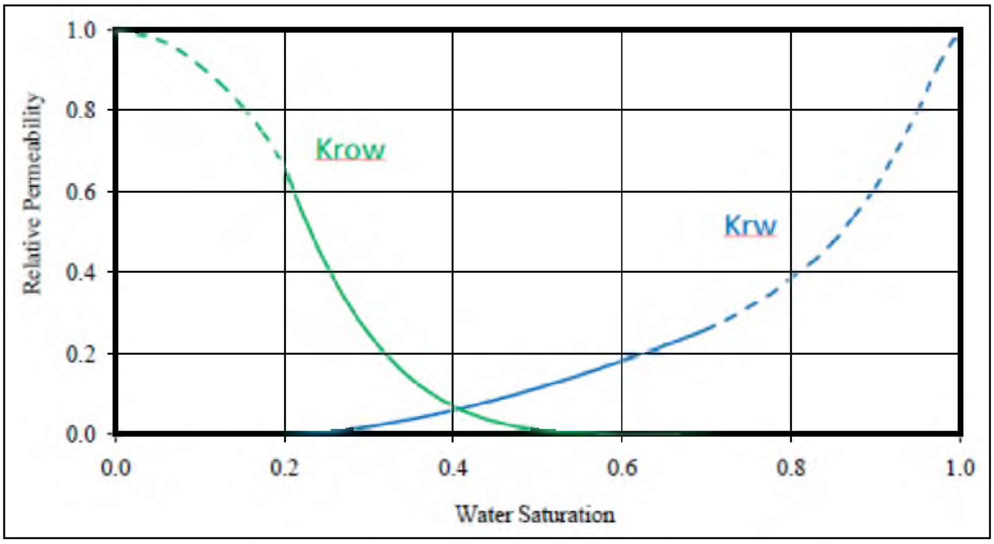

Figure 1-1: Example of Oil-Water Relative Permeability Curve

In hydrocarbon reservoirs, no one phase can reach the saturation of 100%. Consequently, in a multiphase system, the relative permeability of any phase cannot reach the value of one. However, most core analysis laboratories evaluate the relative permeability as referenced to the maximum effective permeability of the oil phase rather than referencing to the porous medium’s absolute permeability. This leads to reporting the value of one for the maximum relative permeability to the oil phase. In any reservoir study, this should be noticed and all relative permeability values should be adjusted before further proceeding. In two-phase system, the fluids consists of oil and water, oil and gas or gas and water, while in three-phase system, the fluids consists of oil, water and gas. An example of an oil-water system is shown in Figure 1-2.

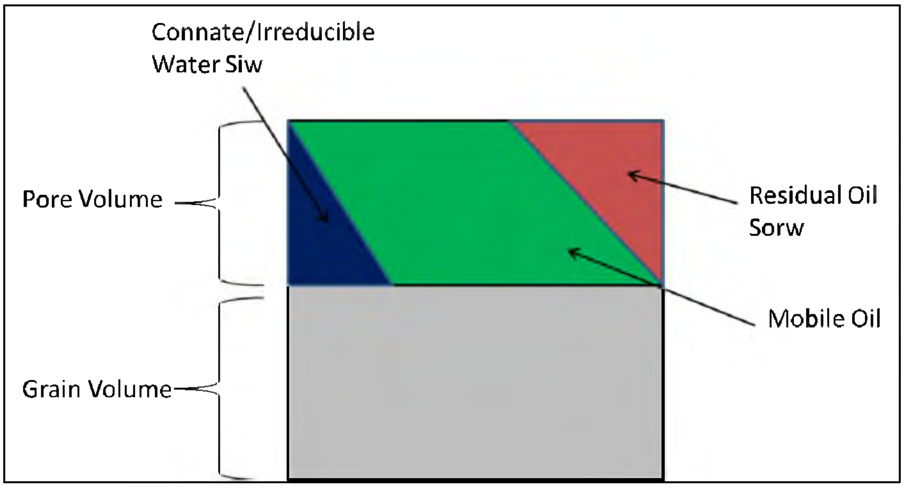

Figure 1-2: Illustration of two-phase reservoir system

Relative permeability data are essential for almost all fluid flow calculations in reservoirs and is utilized extensively in many areas of petroleum engineering such as determining the residual fluid saturations, calculating the fractional flow and frontal advance and making engineering estimates of productivity, injectivity and ultimate recovery. The data are more particularly used for matching, predicting and optimizing oil and gas reservoir performances through numerical simulations.

Relative permeability measurements are conducted on core samples in laboratory and are both time-consuming and expensive to produce. Consequently, relative permeability measurements are mainly requested for projects where secondary and/or tertiary recovery is being considered. As a result of the difficulties and cost involved in measuring relative permeability values, empirical correlations and calculations are often employed in order to estimate the values. In the past decades, several correlations have been developed to predict relative permeability of oil reservoirs. In 1954, Corey introduced a correlation to estimate relative permeability of water-oil and gas-oil systems, based on relative permeability measurements on a large number of cores from several formations. Honarpour, Koederitz and Harvey (2000) utilized the relative permeability data obtained from oil and gas fields in various parts of the world, to develop a new correlation for prediction of relative permeabilities. Chierici (1984) suggested a two-parameter exponential relationship to predict relative permeabilites of water-oil and gas-oil systems. In the current study, these three correlations are used and compared. Fine tuning of the correlation might be done to fit the field of study.

Analysis done by Cocco (2002) concluded that each depositional environment has its distinct relative permeability correlations. There are differences in the average values and variances, as well as in the strength of the correlations between the variable. Hence it is necessary to sample core plugs in the reservoir under study. Relative permeability also depends on a combined effect of pore geometry, fluid distribution, wettability, and fluid saturation (Okasha, Funk and Balobaid, 2001). Hence relative permeability is unique to the field or regions. This study was conducted to formulate the most suitable correlations for the field of study.

1.2 Problem Statement

Relative permeability is one of the most essential parameters in reservoir engineering studies. In reservoir simulation, relative permeability is the parameter used by reservoir simulators to define the relative movements of different reservoir fluids. The concept of relative permeability is quite simple. However, proper evaluation is not an easy task. Relative permeability is evaluated in laboratory as part of the SCAL (Special Core Analysis) program. Both steady and unsteady state displacement are used to evaluate relative permeability at different saturation values. These measurements are being carried out on small core plugs obtained from the available whole cores. In addition to lab work uncertainties, core coverage is an important factor that affects the reliability of the evaluated relative permeability. Due to operation concerns, it is very difficult to have adequate core coverage for any reservoir. Strict precautions and high costs make it even more difficult to obtain adequate coverage of SCAL. These factors raise the importance of careful and effective handling of the available SCAL data to obtain reasonably representative relative permeability data for any reservoir study.

Since obtaining relative permeability data from laboratory experiments is rather delicate, time consuming, and costly, a series of empirical models has been developed in literature to estimate them when experimental data from core samples is not available. The empirical correlations are also employed to reproduce experimentally determined relative permeability curves as verification. These methods were based on experimental data and mathematical derivations or heuristic concepts to predict relative permeability.

In the field of study, there is only one SCAL data available from a reservoir. Hence there is a need to formulate a general correlation for other reservoirs in the field. The available SCAL data can be manipulated and analysed to create a suitable correlations to be used for other reservoirs. Since relative permeability is such a strong controlling factor in determining reservoir performance, accurate determination of water-oil and gas-oil relative permeability character for a formation matrix is essential for accurate prediction and optimization purposes. Although a variety of correlations to predict relative permeability are available, considerable variance can be present in the predicted results, and experimental measurements still provide the most accurate method of determination. Three published correlations were chosen to be analysed and compared to determine the most suitable correlations for the field of study. Fine tuning of the correlations might be done if none of the correlations satisfy the criteria. There is also no general workflow of formulating the relative permeability correlation available. Hence a general workflow will be generated in the study for the use of other users.

1.3 Objectives

The main objectives of this study are:

i) To develop a general relative permeability correlation to be used in the field of study or other fields in Malay Basin with no or limited SCAL data.

ii) To establish a workflow in order to guide users on proper way of formulating relative permeability correlations.

iii) To perform a case study whereby the correlation formulated is applied in a specific field.

1.4 Scope of Study

i) Data collection and quality checking

a. Six (6) core samples for kro-krw (labelled as 21A/25A/35A/43A/47A/51A).

b. Six (6) core samples for krg-kro (labelled as 21D/25D/35D/43D/51D).

ii) Detailed analysis and correlation formulation

a. Finding a trend using few properties to find endpoints general formula to be used in the correlation.

b. Three correlations were generated and analysed based on the published papers.

c. Fine tuning the generated correlations to fit the field of study.

iii) Correlation workflow generation

a. Detail workflow was generated for formulating general relative permeability correlation.

iv) Field application

a. Formulated correlation was applied and tested in a reservoir in the field of study to prove concept.

1.5 Significance of Study

i) Relative permeability is essential for dynamic simulation to forecast the reservoir performance more effectively.

ii) The formulated relative permeability correlation can be used in other reservoirs in the field having limited or no SCAL data.

iii) The generated workflow can be used as a guide for other users in formulating the correlations in other regions.

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