PREDICTION MODEL OF FLUID FLOW BEHAVIOR IN THE NATURALLY FRACTURED RESERVOIRS BY MACHINE LEARNING

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A project report submitted in fulfilment of the
requirements for the award of the degree of
Master of Petroleum Engineering

School of Chemical and Energy Engineering
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Universiti Teknologi Malaysia

AUGUST 2022

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed toward my understanding and thoughts. In particular, I wish to express my sincere appreciation to my thesis supervisor, Dr. Abdul Rahim Bin Risal, for encouragement, guidance, critics and friendship. Without his continued support and interest, this thesis would not have been the same as presented here.

My fellow postgraduate student should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

The naturally fractured reservoirs are one of the products of the tectonic movements, which increases the permeability and conductivity of the fractures. The instability of the permeability and conductivity effect on the fluid's flow path causes problems during the transfer of the fluids from the matrix to the fractures and fluids losses during production. In addition, these complications made it difficult for engineers to estimate fluid flow during production. The fracture properties study is essential to model the fluids flow paths such as the fracture porosity, permeability, and the shape factor which are considered essential in the stability of fluids flow. To examine this, this research introduced new models called the Decision trees model (DT), Random Forest model (RF), Ridge regression model, LASSO regression model, and K-nearest regression model. The research studied the fracture properties in naturally fractured reservoirs like the fracture porosity and the shape factor. The datasets used in this study were collected from previous studies "i.eTexas oil and gas fields" to build a predictive intelligence model for fluid flow characteristics. The prediction process was conducted based on interporosity flow coefficient, storativity ratio, wellbore radius, matrix permeability, and fracture permeability as input data and shape factor (SF) and fracture porosity (FP) as output data. This study revealed a positive finding for the adopted machine learning models and was superior in using R2 of accuracy based on the quantitative metrics. The results of the test showed an increase in the readings of the fractured porosity and the shape factor compared to the actual data for oil and gas, which improved the fracture properties. For fluid flow, fluids are designed on the basis that the flow is radial. All models exhibited similar behavior of fluid flow, as the fluids were traveling parallel and radial, which changed the fluid properties except for the LASSO model. The research results of LASSO found that the accuracy of gas flow is less although gas flow is faster than oil flow in naturally fractured reservoirs. In conclusion, the radial flow model cannot be implemented for all fluids in the naturally fractured reservoirs that prefer to assume as flow is pseudo steady state. Overall, the research emphasized implementing computer aid models for naturally fractured reservoir analysis, which gives more details on the extensive executing techniques, such as injection or the creation of artificial cracks, to minimize hydrocarbon losses or leakage.

ABSTRAK

Takungan yang retak secara semula jadi adalah salah satu yang paling mencabar disebabkan oleh pergerakan tektonik yang menyebabkan peningkatan dalam kebolehtelapan dan kekonduksian patah. Ketidakstabilan kesan kebolehtelapan dan kekonduksian pada laluan aliran bendalir menyebabkan masalah semasa pemindahan bendalir dari matriks ke patah dan kehilangan cecair semasa pengeluaran. Selain itu, komplikasi ini menyukarkan jurutera untuk menganggar aliran bendalir semasa pengeluaran. Kajian sifat patah adalah penting untuk memodelkan laluan aliran bendalir seperti keliangan patah, kebolehtelapan, dan faktor bentuk yang dianggap penting dalam kestabilan aliran bendalir. Untuk meneliti perkara ini, penyelidikan ini memperkenalkan model baharu yang dipanggil model pokok keputusan (dt), model hutan rawak (rf), model regresi ridge, model regresi lasso, dan model regresi k-terdekat. Penyelidikan mengkaji sifat patah dalam takungan patah semula jadi seperti keliangan patah dan faktor bentuk. Set data yang digunakan dalam kajian ini dikumpulkan daripada kajian terdahulu "iaitu, medan minyak dan gas texas" untuk membina model ramalan pintar untuk ciri aliran bendalir. Proses ramalan dijalankan berdasarkan pekali aliran interporosity, nisbah storativiti, jejari lubang telaga, kebolehtelapan matriks, dan kebolehtelapan patah sebagai data input dan faktor bentuk (sf) dan keliangan patah (fp) sebagai data output. Kajian ini mendedahkan penemuan positif untuk model pembelajaran mesin yang diguna pakai dan lebih unggul dalam menggunakan r2 ketepatan berdasarkan metrik kuantitatif. Secara keseluruhannya, penyelidikan itu menekankan pelaksanaan model bantuan komputer untuk analisis takungan patah semula jadi yang memberikan butiran lanjut tentang teknik pelaksanaan yang meluas, seperti suntikan atau penciptaan rekahan buatan, untuk meminimumkan kehilangan atau kebocoran hidrokarbon.

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LIST OF ABBREVIATIONS

$\emptyset_f$	-	Fracture Porosity
K_f	-	Fracture Permeability
ω	-	The Storativity Ratio
σ	-	The Shape Factor
r_w	-	Wellbore Radius
C_m	-	Matrix Compressibility
NFR	-	Naturally Fractured Reservoir
ML	-	Machine Learning
K_m	-	Matrix Permeability
$\emptyset_m$	-	Matrix Porosity
λ	-	Interporosity Flow Coefficient
C_f	-	Fracture Compressibility

LIST OF SYMBOLS

Y, X	-	Input Index
β	-	Coefficient vector
T	-	Transpose
TPR	-	True Positive Rate
TP	-	True Positive
FP	-	False Positive
B	-	Unfastened parameter
F	-	Bootstrap
t	-	Prespecified free parameter
N	-	Size
C	-	Classifier of data
LRM	-	Linear Regression Model
DTRM	-	Decision Trees Regression Model
KNNM	-	K-Nearest Regression Model
RFRM	-	Random Forest Regression Model
LRM	-	Lasso Regression Model
$£_i$	-	Error Variables
TNR	-	True Negative Rate
FDR	-	False Discovery Rate
FOR	-	False Omission Rate
TN	-	True Negative
FN	-	False Negative
U	-	Uncertainty of the Prediction
B_o	-	Constant coefficient
W	-	Weights
B1, B2	-	Constants
R	-	Conversion Factor

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CHAPTER 1

INTRODUCTION

1.1 Research Background

A naturally fractured reservoir (NFR) is one in which natural processes such as diastrophism and volume shrinkage have caused fractures that have been dispersed as a consistently linked network across the reservoir. Where tectonic processes have evolved in the reservoir, fractured reservoirs are frequently found in a weak reservoir rock with poor porosity. Due to that, the fracture is extended and large and often referred to as the large fracture. If the granular porosity is high but the rocks are fragile, the fracture is relatively small and limited in quantity, often referred to as microfractures.(Ordonez, Peñuela, Idrobo, & Medina, 2001)

Naturally fractured reservoirs are mostly found in igneous rocks, sandstones and carbonates, as well as in igneous rocks.(Jaffré, Mnejja, & Roberts, 2011). Fractured reservoirs represent an important percentage of world reserves such as the Campos and Santos Basins in Brazil and the Kwanza Basin in Angola. Fractured carbonate reservoirs represent an important percentage of world reserves such as the Campos and Santos Basins in Brazil and the Kwanza Basin in Angola. (Lima & De Ros, 2019; Lima et al., 2020)

Naturally fractured reservoirs cover 20% of the world's oil reserves, which makes fractured reservoirs one of the most complex in terms of production efficiency. Naturally broken reservoirs are distributed in the oil fields of Ain Zala and Jambour, as well as Khazaz located in Iraq. (Lima & De Ros, 2019; Lima et al., 2020)

In addition, the tectonic movements affected on the behaviour of the fracture during transfer and production of the fluids flow due to the high conductivity and permeability of the natural fractures (D. Li, Jiao, Yue, Xiang, & Pan, 2015)The conductivity and permeability of the fractures factor minimize the fracture porosity of the fluids that cause low storage capacity (Beckner, 1990). In contrast, the conductivity of the matrix increases storage capacity with low permeability which causes an increase in the matrix porosity (Beckner, 1990). According to previous studies, matrix porosity is higher than fracture porosity in the naturally fractures reservoirs which the fluids store in the matrix (Frey et al., 2022)

The fractured reservoirs are divided according to storage capacities or porosity, matrix permeability, and fractions into different types. According to Aguilera. (Aguilera, 1974) the fractured reservoirs were classified into A, B, and C. Type A reservoirs, most fluids stored in the matrix while the storage capacity of the fluids is low in the fractures. As for type B reservoirs, the storage of the fluids is divided between the matrix and the fractures, where half of the fluids are in the fracture but the other half in the matrix. While the type C reservoirs, these reservoirs do not need the matrix contribution in storage, as the fractures provide them with the storage capacity. (Aguilera, 1974)

Based on Nelson, fractured reservoirs have been classified according to the percentage of the total porosity and permeability. In the first type of fractures reservoirs, the porosity and permeability are controlled by the fractures. The second type of fractures reservoir, the fractures control the basic permeability. The third type of fractures reservoir, fractures are permeable. Finally, the fourth type of fractured reservoirs, fractures adopt anisotropic barriers which do not provide additional porosity or permeability. (Nelson, 2001)

The naturally fractured reservoirs are different from the conventional reservoir. The naturally fractured reservoirs separate the matrix blocks from the fractures system as presented in (Figure 1.1). The matrix has been characterized in the permeability Km and porosity m while the fractures have been characterized in porosity f and permeability Kf.

The naturally fractured reservoirs have presented as double-porosity and double-permeability reservoirs. (Guo, Nie, & Jia, 2012)

Naturally fractured reservoirs are one of the distinct challenges in extracting hydrocarbons. Naturally fractured reservoirs are considered to have a positive or negative impact on the hydrocarbon flow pattern. The matrix has high storage capacity and low flow capacity while fractions have high flow capacity and low storage capacity. The characterization of naturally fractured reservoirs has faced many challenges in the engineering and geological character of naturally fractured reservoirs. (Beckner, 1990)

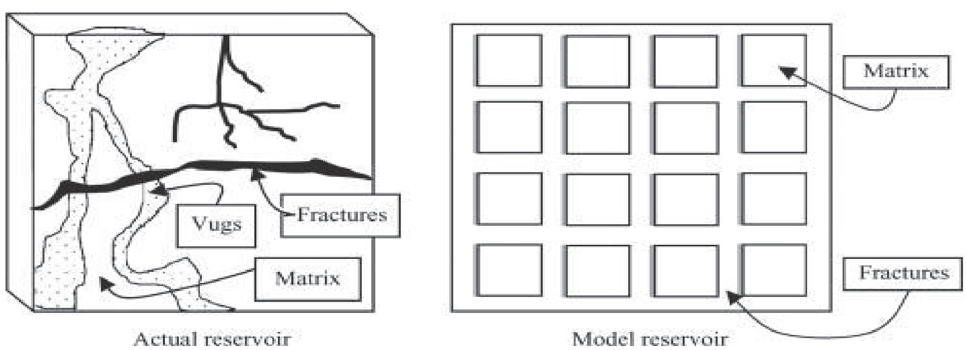

Figure 1.1 The distribution of blocks within matrix system and fracture system

The multiphase flow modeling in naturally fractured reservoirs has been considered an issue for petroleum reservoirs engineers. The modeling of the reservoir has become more complex due to the existence of fractures that impact the capacity of hydrocarbons flow. Many researchers have presented models of fractured reservoirs and developed them in different approaches but some of the results were not accurate due to a large contrast of permeability values between fracture and porous matrix. Many researchers have presented models of fractured reservoirs and developed them in different approaches but some of the results were not accurate due to a large contrast of permeability values between fracture and porous matrix. (Hawez, Sanaee, & Faisal, 2021)

Warren and Root have shown a dual-porosity model which presented the multiphase behavior in fractured reservoirs. The dual-porosity model has explained the fractures as the naturally fractured reservoirs that are inclusive of two kinds of pores, one of them in the matrix while another is in the fracture. The natural fractures permeability is higher than the matrix permeability in a dual-porosity system, where it allows the hydrocarbons to produce through fractures while the matrix stores the hydrocarbons. The hydrocarbons flow from the matrix to the fractures by transport method. Warren and Root's model depended on two parameters, the storage ratio (ω) that measure the percentage of hydrocarbons storage to the total hydrocarbons in the reservoir and the flow coefficient between the porosity (λ) to characterize the flow behavior in naturally fractured reservoirs. (Gilman, Bowzer, & Rothkopf, 1995)

The dual-porosity affected the hydrocarbons movement in the naturally fractured reservoirs can result in fractures that produce holes causing a leak of hydrocarbons in the fractured reservoir. Dissolution of the reservoir can form a hole in the porosity systems and it has shown in Ellenberger Pegasus field and Canyon Reef field, Texas. The production strategy of oil recovery in fractured reservoirs is considered a crucial factor for obtaining economic production. The fractured reservoirs represented many challenges to their rock properties estimations. The fluid flow is lower between the fractures and matrix due to low matrix permeability and low storage capacity of the fractures which leads to residual oil saturation. The fractured reservoirs, in general, are not good enough which has a large impact on the fluids flow. It can leak in the hydrocarbons flow which exists difficulty of hydrocarbons recovery that impact on creating a suitable model able to represent the fluids flow behavior. (Mesbah, Vatani, & Siavashi, 2018)

The research has resolved a number of challenges by developing an Artificial Intelligence-based prediction model that can explain hydrocarbon flow behavior in fractured reservoirs. The machine learning program is an Artificial Intelligence approach that displays several Algorithms. These algorithms are used in reservoir modeling which is more important in the oil and gas industry in the United States. Machine learning is a simple, trustworthy method that considers all reservoir conditions, assumptions, and limits. It may also generate many models for a single database, allowing engineers to conduct reliable analyses and find additional answers to their reservoir problems.

Multiphase flow modeling in naturally fractured reservoirs has been considered an issue for petroleum reservoirs engineers (H. Hawez, R. Sanaee, & N. Faisal, 2021; H. K. Hawez, R. Sanaee, & N. H. Faisal, 2021). Warren and Root have shown a dual-porosity model which presents multiphase behavior in fractured reservoirs (Warren, 1963). In the dual-porosity model, there are two characteristics regions, matrix and fracture (Gilman, Bowzer, & Rothkopf, 1995). The naturally fractured reservoir present one of the difficult reservoirs in the petroleum industry due to the fractures properties like permeability and porosity where natural fractures permeability is higher than the matrix permeability in a dual-porosity system (Gilman et al., 1995). The hydrocarbons flow from the matrix to the fractures and from these to the wellbore where the fractures cannot store these fluids which cause fluid flow losses and obstacle of the fluids flow can see in Figure.1(Gilman et al., 1995; Rangel-German & Kovscek, 2005).

The importance of this project has represented an analytical study on the hydrocarbons flow behavior in the naturally fractured reservoir and the impact of fractures on the transportation of hydrocarbons flow from matrix to the fracture and production too. This analytical study can clarify the behavior of the fractures and their impact on fluids flow more widely accurately than previous studies through depending on the smart technology that its Machine learning.

1.2 Problem Statement

i) Drops of the fracture porosity and shape factor during production period which are considered key parameters of fluids flow losses.

ii) Difficulty of controlling fluids flow movements in the naturally fractured reservoirs which cause difficult in the analysis of fluids transfer in the fractured reservoirs can be seen in (Figure 1.2)

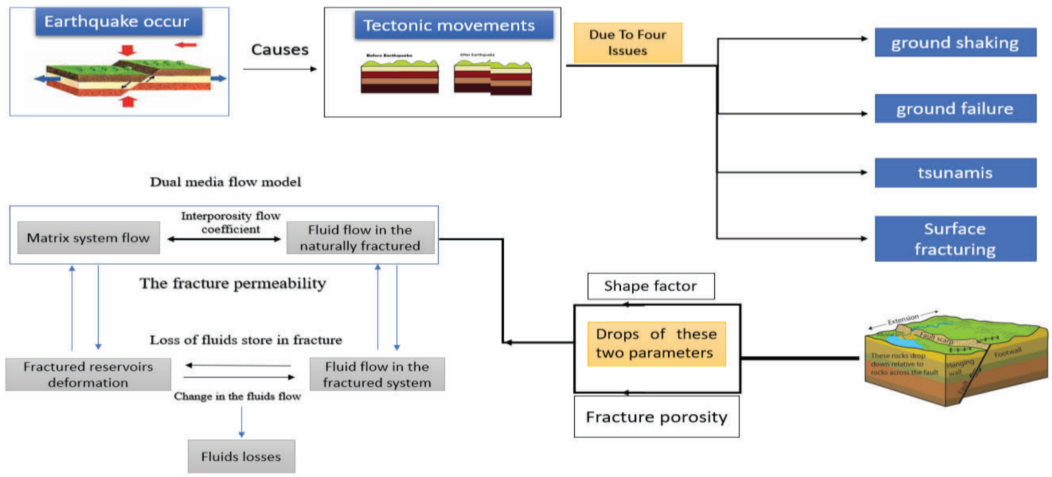

Figure 1.2 The distribution of blocks within matrix system and fracture system.

1.3 Research Objectives

Modelling of the fluids flow in the naturally fractured reservoirs using well-test analysis data through machine learning.

Specific objectives are:

a) To estimate of the fracture porosity and shape factor predictably.
b) To analyze fluids flow behavior in the naturally fractured reservoirs.

1.4 Scope of Work

This project is specialized in the study of analysis of well test data for dual-porosity in fractured reservoirs.

1. The well test has been applied in limestone rocks under conditions of the reservoir like pressure 3626 psi and temperature 120 F.

2. The reservoir thickness of oil or gas is limited to 100 ft, matrix porosity 22% as assumption of Werbung well-test data, and matrix compressibility $6.8\times10^{-7} psi^{-1}$.
3. The project assumptions have been established to radial flow, no Darcy equations, no skin factor, and matrix porosity equals 22%
4. New data have been collected from oil and gas databases by using equations followed by (Perez Garcia, 2006) and model (He, Chen, Zhang, & Yu, 2017) which are interporosity flow coefficient, storage capacity, shape factor, and fracture porosity.

   These elements are applied by using Excel program:

   i. The interposition flow coefficient indicates the dynamics of the fluid exchange between matrix and the fractures.
   ii. Storage capacity measures the flow capacitance of the fluids in the fractures.
   iii. The shape factor is a parameter how smoothly fluid flows between matrix and fractures.
   iv. Fracture porosity is a type of secondary porosity produced by the tectonic fracturing of the rock.
5. Finally, these two sets of data have been established by using a machine learning program to create a prediction model. This prediction model analysis the hydrocarbons flow accurately and has taken into account the existence of a fracture during the transfer of hydrocarbons This technique has worked to develop our oil and gas industries correctly allowing us to present our suggestions and ideas for preventing these issues occur in the fractured reservoirs.

1.5 The Significant of Research

The scopes of the research are listed as follow:

a) This research contributes to solve many problems that related with fluids flow occur in fractured reservoirs.

b) Moreover, this research could do analysis the fluids flow behavior deeply through comparison the actual data of fluids flow keys with predicted data of fluids flow keys such as the fracture porosity and the shape factor.

c) Machine learning can assist and enhance the modelling process for research's data through do hybrid and optimized models that results high improving of the research's data in the future.

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