

UNIVERSITI TEKNOLOGI MARA

**INVESTIGATION OF WATER
INJECTION RATE AND OIL
VISCOSITY PARAMETER IN THE
SAND COLUMN (ARTIFICIAL OIL
RESERVOIR) DURING
WATERFLOODING**

ABDUL AFIQ BIN ABDUL AZIZ

Thesis submitted in fulfillment
of the requirements for the degree of
Master of Science
(Chemical Engineering)

Faculty of Engineering

May 2023

ABSTRACT

Waterflooding is a secondary oil recovery process that commonly utilized. However, there are several factors affecting the efficiency of water-flooding. Current research focused on the effects of injection rate and oil viscosity on the sweep efficiency where it is key factor on determining waterflooding efficiency. Computational Fluid Dynamics simulation is utilized to predict the effect of the injection rate and oil viscosity towards waterflooding. Computational Fluid Dynamics simulation is utilized to overcome the disadvantages of radiotracer commonly used to determine waterflooding efficiency. Volume of fluid and Realizable $k-\epsilon$ models are utilized in this research. Ergun's equation is also utilized in this research for estimation of permeability and inertial loss within the porous medium. Species transport model is used for Residence Time Distribution simulation to predict the flow behaviour within the porous medium. Further analysis of Residence Time Distribution reactor model determination is done using software from International Atomic Energy Agency. Validation between the simulation and experimental studies is done to validate the accuracy of the simulation results. The validations show the simulation has similar result with the experimental studies thus simulation can be utilized for further study. The research found as injection rate and viscosity ratio increase; viscous fingering predominantly seen within the porous medium. Viscous fingering occurred when the mobility ratio is more than unity and instability number more than 1000. The phenomenon of viscous fingering is directly affected by injection rate and viscosity ratio. The phenomenon directly affects sweep efficiency during waterflooding process thus affecting oil recovery process. Research also found injection rate of 1.0 ml/min is the best injection rates for various viscosity ratio due to no or minimal occurrence of viscous fingering within the porous medium. Based on the Residence Time Distribution simulation, perfect mixers in parallel is selected as the best Residence Time Distribution model based on the sum of square of error value to interpret the waterflooding process occurred within the porous medium.

ACKNOWLEDGEMENT

Firstly, I would like to thank God for giving me the opportunity to embark on my postgraduate and for completing this long and challenging journey successfully. My gratitude and thanks go to my supervisors Assoc Prof Ir. Dr. Nadiyahnor Md Yusop and Dr. Noraishah Othman. My gratitude also goes to Universiti Teknologi MARA (UiTM) and Agensi Nuklear Malaysia for the support. I would also want to thank Ministry of Science, Technology, and Innovation of Malaysia (MOSTI) for support under FGRS Grant No: FRGS/1/2018/TK07/MOSTI/02/3.

Finally, this thesis is dedicated to my loving family for supporting and motivating me to complete my study especially to my wife and daughter. Alhamdulillah.

TABLE OF CONTENTS

	Page
CONFIRMATION BY PANEL OF EXAMINERS	ii
AUTHOR'S DECLARATION	iii
ABSTRACT	iv
ACKNOWLEDGEMENT	v
TABLE OF CONTENTS	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xiii
LIST OF SYMBOLS	xiv
CHAPTER ONE INTRODUCTION	1
1.1 Research Background	1
1.2 Problem Statement	2
1.3 Objectives	3
1.4 Research Scope	3
1.5 Significance of Study	4
CHAPTER TWO LITERATURE REVIEW	5
2.1 Literature Review	5
2.1.1 Oil Recovery Method	5
2.1.1.1 Surfactant Flooding Method	6
2.1.1.2 Polymer Flooding Method	7
2.1.1.3 Alkaline Flooding Method	8
2.1.1.4 Low Salinity Waterflooding Method	8
2.1.2 Waterflooding Method	9
2.1.3 Sweep Efficiency	11
2.1.4 Relative Permeability	12
2.1.5 Capillary Number	14
2.1.5.1 Effect of Fluid Viscosity	16

2.1.5.2	Effect of Injection Rate	16
2.1.6	Sandstone Reservoir	17
2.1.7	Residence Time Distribution Modelling	18
2.1.7.1	Radioisotope Tracer	21
2.1.8	Computational Simulation	23
2.2	Literature Review Summary	25
 CHAPTER THREE RESEARCH METHODOLOGY		26
3.1	Methodology Framework	26
3.2	Mathematical Model	28
3.2.1	Mass, Momentum, and Energy Conservation Model	28
3.2.2	Turbulence Realizable k-epsilon (k- ϵ) Model	29
3.2.3	Multiphase Volume of Fluid (VOF) Model	30
3.2.4	Species Transport Model	31
3.2.5	Ergun's Equation for Porous Medium	32
3.2.6	Residence Time Distribution Model	32
3.2.6.1	Axial Dispersed Plug Flow with Exchange Model	33
3.2.6.2	Perfect mixers in series model	34
3.2.6.3	Perfect mixers in parallel	34
3.3	Computational Methodology	35
3.3.1	Computational Boundary Condition	35
3.3.2	Mesh Independent Test	37
3.4	Computational Simulation	38
3.5	Data Analysis	40
 CHAPTER FOUR RESULTS AND DISCUSSION		41
4.1	Simulation Validation with Previous Studies	41
4.2	Waterflooding Simulation	46
4.2.1	Viscous Fingering Effect	47
4.2.2	Effect of Injection Rate, Viscosity Ratio, and Relative Permeability Ratio on Mobility Ratio	53
4.2.3	Effect of Mobility Ratio on Sweep Efficiency	56
4.3	Residence Time Distribution (RTD) Simulation	58