

# Dedication

## Dear father

The Role models in my life , the person who were always learn me how can I deal with the life , solving my problems , be patient on the bad time , sharing me my enjoying times ...

**It's for you**

## Dear mother

My angel , you always been with me in my bad times before the best , afraid for me , caring of me and loving me ...

**It's for you**

## Dear brothers and sisters

Who always be with me , helping me , give me some advices when I need it , corrected me when I make some mistakes ...

**It's for you**

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## Nomenclature

### Symbols

<b>A</b>	Cross-sectional area of a block,
$V$	Oil formation volume factor (dimension less)
$c$	Oil compressibility, $\text{psi}^{-1}$
$c_f$	Fluid compressibility, $\text{psi}^{-1}$
$c_g$	Gas compressibility, $\text{psi}^{-1}$
$c_o$	Oil compressibility, $\text{psi}^{-1}$
$c_w$	Water compressibility, $\text{psi}^{-1}$
$c_r$	Rock compressibility, $\text{psi}^{-1}$
<b>Cum oil</b>	Cumulative oil production, million of stock tank barrel (STB)
$f$	An arbitrary function
$g$	Gravitational acceleration, $\frac{\text{cm}}{\text{sec}^2}$
$h$	Reservoir Thickness or distance, $\text{ft}$
$k$	Permeability, mD
$k_o$	Oil Relative Permeability (dimension less)
$k_w$	Water Relative Permeability (dimension less)
$k_{rog}$	Oil Relative Permeability in the oil-gas system (dimension less)
$k_{row}$	Oil Relative Permeability in the oil-water system (dimension less)
$l$	Length, $\text{ft}$
<b>M</b>	Molecular weight
$M = Q_w/Q_o$	Mobility Ratio (dimension less)
$p_c$	Capillary Pressure, psi
$p_{cg}$	Oil-gas capillary Pressure, psi
$p_{cw}$	Oil-water capillary Pressure, psi
$p$	Pressure, psi
$p_b$	Bubble point pressure, psi

$P$	Reservoir pressure, psi
$P_s$	Static pressure, psi
$P_{wf}$	Flowing well pressure, psi
$Q_o$	Oil Production Rate, STB/D
$R$	Universal gas constant (dimension less)
$R_{so}$	Solution gas-oil ration (dimension less)
$r_e$	External radius, ft
$r_w$	Wellbore radius, ft
$S_g$	Gas saturation, fraction
$S_w$	Water saturation, fraction
$S_o$	Oil saturation, fraction
$S_{wc}$	Connate Water saturation, fraction
$S_{oc}$	Critical oil saturation, fraction
$T$	Temperature, °C, °F
$t$	Time, Sec
$\Delta t$	Time increment, Sec
$u$	Superficial or Darcy velocity, $\frac{m}{d}$
$V$	Volume, m <sup>3</sup>
$x, y, z$	Distance, ft
$\rho$	Density in term of pressure/ distance
$\mu$	Viscosity, centipoises (cP)
$\rho_f$	Fluid Density, $\frac{m}{d}$
$\theta$	Angle, degree
$\phi$	Porosity, fraction

## **Abbreviations**

AIME	the American Institute of Mining, Metallurgical and Petroleum Engineers
AOFP	Absolute Open Flow Potential
API	American Petroleum Institute
GNPOC	Greater Nile Petroleum Operating Company
GOR	Gas-Oil Ratio
ECLIPSE	Simulation Software (2005)
ESP	Electric Submersible Pumps
EUR	Estimated Ultimate Recovery
FWCT	field water cut
FWCTH	field water cut history
FVF	Formation Volume Factor
HA	A Sudanese Oil Field in Block 2A which is studied in this thesis
IMPES	Implicit Pressure-Explicit Saturation
IPR	Inflow performance relationship
IPTC	International Petroleum Technology Conference
MMSTB	Millions of Stock Tank Barrel
NTG	Net To Gross Ration
OOIP	Original Oil in Place
OTC	Offshore Technology Conference
OWC	Oil-Water Contact
PCOSB	Petronas Carigali Overseas Sdn. Bhd
PCP	progressive cavity pump
PDE	Partial Differential Equation
PERF	Perforation
PI	Productivity Index
PLT	Production Logging Tool
PVT	Pressure-Volume-Temperature
QC	Quality Check
RF	Recovery Factor
RUNSPEC	Run specification
SCAL	Special Core Analysis

SPE	Society of Petroleum Engineers
STB	Stock Tank Barrel
SUDAPET	Petroleum Company
Thick	Reservoir Thickness
VCL	Volume of Clay
WCT	Water Cut
WOR	Water-Oil Ratio
3-D	Three Dimensional

## **Abstract**

The main objective of this research is to study and evaluate the water injection in sandstone reservoir to provide pressure support and sweep oil out of the pore space to improve oil production. The work focuses on several important issues of reservoir characterization and data integration for water flooding in sand stone reservoir.

In determining the suitability of a given reservoir for water flooding or pressure maintenance many factors are important, these factors considered: reservoir geometry, lithology, reservoir depth, porosity, permeability (magnitude and degree of variation), continuity of reservoir rock properties, magnitude and distribution of fluid saturations, fluid properties, relative permeability relationships, and primary reservoir driving mechanisms. Optimization of reservoir development requires a comprehensive evaluation of many decision variables, such as the reservoir properties, well locations and production scheduling parameters, to obtain the best economical strategies.

Reservoir simulation studies for East Unity oil field, Muglad Basin, Sudan used to

know the best field water injection method. Reservoirs in Unity oil field are resulted of fluvial and lacustrine deposition. The field is a highly complex anticline with major flanking faults to the west and east. Oil is trapped in separated compartments with varying degrees of dip faults closures. On flanking faults the oil-bearing formations are Aradeiba and Bentiu.

East Unity oil field sandstone reservoirs is young reservoir started production at 1999.

Reservoir is highly heterogeneous, characterized by mid to high porosity and mid to high permeability.

The purpose of this simulation study is to determine the suitable water injection method for high cumulative oil production. The simulation model was developed using two-phase, 3D black oil options in ECLIPSE. A good history matching was achieved for the field as general and for the wells one by one. The bottom formation (Bentiu) did not considered or perforated through this study because there are many previous studies suggested to produce from this formation later because water cut will increase by 60% if this zone perforated at the same time with Aradeiba zone.

The field now has 9 producers and 4 injectors. The study of the optimum future performance was evaluated through several water injection cases.

Cumulative water injection for ten years later for the base case (the actual case) was used as the main control for all the cases. Several cases were tested included cyclic water injection which is a process that improves waterflooding efficiency in heterogeneous reservoirs. Several cyclic water injection scenarios by "injection/no injection" time ratios such as 2:1, 1:1, and 1:2 also were simulated and evaluated using numerical simulation. The cases compared together with the actual case. The keys criteria; cumulative oil production, water cut, and recovery; were used as qualitative indicator to determine the quality of the comparison matches.

Simulation shows the optimum water injection rate is about 2835 Sm<sup>3</sup>/day for every well, using this amount oil recovery will increase by 3.63 %. The study shows adding new injection well has no positive effects in the area although cyclic water injection was failed in East Unity field since water cut from all producers are more than 90 %.



## التجريد

ان الهدف الاساسى من هذه الدراسة هو دراسة وتقييم حقن الماء فى المكامن الرملية لدعم الضغط للحصول على زيادة المستخلص الاقصادى. يركز العمل على عدة عوامل هامة كتركيب المكمن وتكامل البيانات للحقن المائى فى المكامن الرملية.

لتحديد ملائمة مكمن معين للغمر المائى أو المحافظة على الضغط فيه، هناك عدة عوامل توضع فى الاعتبار وهي: هندسة وليثولوجيا المكمن، عمق المكمن ومساميته ونفاذيته (الحجم ودرجة الاختلاف)، إضافة الى استمرارية خصائص الصخور المكمنية وآليات الدفع الابتدائية لدى المكمن. تطوير المكمن الامثل يحتاج الى تقييم شامل لعدة قرارات مختلفة مثل خصائص المكمن، مواقع الابار ومعدلات الانتاج للحصول على استراتيجية اقتصادية.

تمت دراسات تمثيل المكامن لحقن شرق الوحدة السودانى والذى يقع فى حوض المجلد لمعرفة افضل طريقة لحقن الماء بهذا المكمن. تكونت المكامن بهذا الحقن نتيجة للتوديع النهري والقارى. تكون المكمن نتيجة لطية محدبة معقدة مع فوالق محيطة من الغرب والشرق. تكون النفط فى عدة مصائد مع اختلاف درجة اغلاق الفوالق. تعتبر الطبقات التى تحتوى على النفط فى الفوالق المحيطة هى طبقتى عردية وبانتيو.

حقن شرق الوحدة النفطى حقل جديد نوعا بدأ الانتاج فى العام 1999. والمكمن شديد التباين ذو مسامية ونفاذية متوسطة الى عالية.

الغرض من هذه الدراسة هو الحصول على افضل طريقة لحقن الماء بواسطتها يمكن انتاج اكبر قدر ممكن من النفط. تم الحصول على نموذج محاكاة باستخدام طورين وثلاثة ابعاد مع خيار BLACK OIL فى برنامج ECLIPSE. تم الحصول على تطابق جيد لبيانات النموذج مع البيانات الحقيقية وذلك للحقن الكلى وللبار واحد الاخر. طبقة بانتيو السفلى لم تخضع للدراسة فى هذا البحث وذلك بسبب ان هناك مجموعة كبيرة من الدراسات السابقة والتى اثبتت ان افضل وسيلة لانتاج هذه الطبقة هى بعد توقف الانتاج من طبقة عردية اذ ان المياه المنتجة مع النفط تزيد بنسبة 60% فى حال تم الانتاج من هذه الطبقة مع طبقة عردية فى نفس الوقت.

هنالك 4 ابار حقل و 9 ابار انتاج بحقن شرق الوحدة حاليا. تمت دراسة الوضع المستقبلى للحقن بعدد من سيناريوهات الحقن المائى وقد كان المتحكم الاساسى لجميع السيناريوهات هو الكمية الكلية التى سيتم حقنها لعشرة سنوات قادمة باستخدام طريقة الحقن المستخدمة حاليا بالحقن. تتم تجربة عدة سيناريوهات بما فى ذلك سيناريو الحقن الدورى للماء والتى هى طريقة مستخدمة لتطوير فعالية الحقن المائى فى المكامن المتباينة. استخدمت عدة طرق للحقن الدورى منها 2:1، 1:1، 1:2 والتى تعنى نسبة زمن الحقن "حقل/عدم حقل" وذلك باستخدام التمثيل العدى. تمت مقارنة

كمية الانتاج التراكمى، نسبة المياه المنتجة، ومعامل الاستخلاص لجميع السيناريوهات معا ومع السيناريو الحالى المستخدم بالحقن.

اوضحت الدراسة ان معدل الحقن الامثل هو 2835 متر<sup>3</sup>/اليوم لكل بئر من ابار الحقن الاربعة، باستخدام هذه الكمية ستزيد نسبة معامل الاستخلاص ب 3.63%. ايضا اوضحت الدراسة ان اضافة ابار حقن جديد لا تعطى نتائج ايجابية بينما فشلت طريقة الحقن الدورى فى زيادة الانتاج وتقليل المياه المنتجة وذلك بسبب ان نسبة المياه المنتجة بهذا الحقن ومن جميع الابار قد تجاوزت 90%.

## Table of content

Topic	Pages
Dedication	I
Acknowledgement	II
Nomenclature	III
Abstract (English)	XII
Abstract (Arabic)	VII
Table of Contents	VIII
List of Tables	XI
List of Figures	XIII
<b>CHAPTER (1) : INTRODUCTION</b>	
1.1 Reservoir Simulation	2
1.1.1 Meaning of Reservoir Simulation	3
1.1.2 Why Reservoir Simulation	4
1.1.3 General Idea about Simulation	4
1.1.4 Reservoir Simulation Classification	5
1.2 Methods of Oil Production	5
1.3 Study Objectives and Outlines	7
1.3.1 Study general and specific objectives	7
1.3.2 Thesis outlines	7
<b>CHAPTER (2) : LITERATURE REVIEW AND GEOLOGY</b>	
<b>BACKGROUND OF UNITY OIL FIELD</b>	
2.1 Literature Review.	8
2.1.1 Reservoir Simulation.	8
2.1.2 History of Water Flooding in Sudan.	9
2.1.3 Previous Studies in Unity Area.	11
2.2 Regional Geology Background.	14
2-2-1 Muglad Basin.	14
2-2-2 Regional Tectono-Stratigraphy.	17
2-2-3 Basin Stratigraphy.	19
2-2-4 Basin Evaluation.	19
2-2-5 Geo-Seismic Section.	22
<b>CHAPTER (3) : PRINCIPLES OF WATER INJECTION</b>	
3.1 Basic Information Required for Planning the Process of Water Injection.	25
3.2 Select of Patterns.	26
3-2-1 Irregular injection Patterns.	27
3-2-2 Regular injection Patterns.	27
3-2-3 Peripheral injection Patterns.	30
3.3 Important Factors in the Process of Injecting water and Maintain Pressure.	30
3-3-1 Reservoir Geometry.	31
3-3-2 Litho logy.	31
3-3-3 Reservoir Depth.	31
3-3-4 Porosity.	31

<b>CHAPTER (3) :PRINCIPLES OF WATER INJECTION</b>	
3-3-5 Permeability.	32
3-3-6 Fluid Saturations.	32
3-3-7 Relative permeability of fluid miscible and immiscible.	32
3-4 Optimum time to water injection.	32
3-5 Water used for water injection.	33
3-6 Water treatment systems.	34
3-7 Water sources.	36
3-8 Areal sweep efficiency.	37
3-9 Economic factors are taken into Compiled design process of water injection.	38
<b>CHAPTER (4) : DATA CLASSIFICATION AND PETROPHYSICAL MODEL</b>	
4-1 Eclipse Simulator.	39
4-1-1 Introduction.	39
4-1-2 How ECLIPSE Work.	40
4-2 Data Classification.	41
4-2-1 Run Specification Section (Runspec).	41
4-2-2 GRID SECTION (GRID).	44
4-2-3 PVT SECTION.	45
4-2-4 SCAL SECTION.	46
4-2-5 INTIAILIZATION SECTION.	48
4-2-6 REGION SECTION.	48
4-2-7 SCHUDLE SECTION.	48
4-2-8 Summary Section.	49
4-3 Petrophysical Model.	49
4-3-1 Porosity.	49
4-3-2 Permeability.	50
4-3-3 Net to Gross Ratio.	52
<b>CHAPTER (5) : HISTORY MATCHING AND VALIDATION OF SIMULATION MODEL</b>	
5-1 Introduction.	54
5-2 Initial oil in place and oil saturation.	55
5-3 History matching of field production.	57
5-4 History Matching of Single Well Production.	61
5-5 The Field Oil Saturation at the End of History Matching.	64
<b>CHAPTER (6) : OPTIMIZATION OF WATER INJECTION SCHEDULE</b>	
6-1 Introduction.	66
6-2 East Unity Water Injection History.	67
6-3 Prediction Cases.	70
6-3-1 The Base Case (do nothing case).	71

6-3-2 Case 1.	75
6-3-3 Case 2.	77
6-3-4 Case 3.	78
6-3-5 Case 4.	78
6-4 Comparison Between the All Cases.	84
6-4-1 Cumulative Oil Production.	85
6-4-2 Water Cut.	85
6-4-3 Recovery.	86
6-5 Residual Oil Distribution.	89
<b>CHAPTER (7) : CONCLUSION AND RECOMMENDATIONS</b>	
7-1 Conclusion.	92
7-2 Recommendations.	93
<b>REFERENCES</b>	
	94

## List of Tables

<b>Table</b>	<b>Title</b>	<b>Page</b>
Table 2-1	Stratigraphic Units of the Muglad Rift Basin lithology and Depositions.	20
Table 4-1	Dimensions of the grid.	41
Table 4-2	Dimensions for aquifer data.	42
Table 4-3	Dimensions for region data.	42
Table 4-4	Dimensions of equilibration tables.	43
Table 4-5	Set tables dimensions.	43
Table 4-6	Well and group dimensions.	43
Table 4-7	Grid properties (this table is just contain the value of the first layer).	44
Table 4-8	Grid geometry.	44
Table 4-9	Water properties.	45
Table 4-10	Rock compressibility.	45
Table 4-11	Fluid density.	46
Table 4-12	Dead oil properties.	46
Table 4-13	Solubility of gas in oil.	46
Table 4-14	Relative permeability against water saturation.	47
Table 4-15	Equilibration data.	48
Table 4-16	Numbers of grids in regions.	48
Table 4-17	Production information.	49
Table 5-1	Hydrocarbon in Place in East Field.	56
Table 5-2	Comparison between Field Actual Water cut and Simulation Results.	61
Table 5-3	Situation at the end of history matching.	65

<b>Table</b>	<b>Title</b>	<b>Page</b>
Table 6-1	The production summary of the injection wells before it shut down.	67
Table 6-2	Water injection summary of injection wells.	67
Table 6-3	Connection Data.	71
Table 6-4	Cumulative water injection for injection wells under the base case.	80
Table 6-5	Cyclic Water Injection Scenarios.	83
Table 6-6	Comparison between cyclic injection scenarios and the base case.	88

## List of Figures

<b>Figure</b>	<b>Caption</b>	<b>Page</b>
Fig. 1-1	.Oil Recovery Methods	6
Fig. 2-1	.Main and East Unity Production and Injection Historical Performance	11
Fig. 2-2	.Sudan in the heart of Africa	15
Fig. 2-3	Generalized map of Central Africa showing Central Africa rift system, associated riftBasins, Muglad basin, Sudan, with location of Unity field .((from Giedt, 1990	16
Fig. 2-4	Geographic Information System (GIS) package A GIS viewing.	17
Fig. 2-5	Tectonic model of the West and Central African Rift System from Fairhead .((1988	18
Fig. 2-6	Generalized stratigraphic column for the Muglad Basin ((Modified from .(Schull, 1988; Giedt, 1990; Mohamed <i>et al.</i> A.Y, 2000	21
Fig. 2-7	Tectonic evolution of Muglad Basin (Modified from Almond, 1986; Schull, 1988).	22
Fig. 2-8	.Geoseismic section through Unity field	23
Fig. 2-9	.(Structural section of Unity field (CNPC	24
Fig. 3-1	.Direct Line Drive	27
Fig. 3-2	.Staggered Line Drive	28
Fig. 3-3	.five spot	28
Fig. 3-4	.seven spot	29
Fig. 3-5	.Nine spot	29
Fig. 3-6	Peripheral injection Patterns.	30
Fig. 3-7	.Simplified diagram of the open-water treatment system	34
Fig. 3-8	.Simplified diagram of the open-water treatment system	35
Fig. 3-9	Simplified diagram of the water treatment system, semi-closed.	35
Fig. 4-1	.Sketch showing how Eclipse works	40
Fig. 4-2	.(Relative permeability ( $K_{ro}$ , $K_{rw}$ ) vs. water saturation ( $S_w$	47
Fig. 4-3	.(distribution of the porosity in top (Ab	50
Fig. 4-4	.(distribution of the porosity in bottom of (Ab	50
<b>Figure</b>	<b>Caption</b>	<b>Page</b>



Fig. 4-5	Permeability in x direction at bottom of (Ab) .	51
Fig. 4-6	.(Permeability in y direction at top of (Ab	51
Fig. 4-7	Permeability in direction at middle of (Ab).	52
Fig. 4-8	The net to gross ratio in Top of (Ab).	52
Fig. 4-9	.(The net to gross ratio in Bottom of ( Ab	53
Fig. 5-1	.Top Virgin Aa Oil Saturation	55
Fig. 5-2	.Top Virgin Ab Oil Saturation	55
Fig. 5-3	.Top Virgin Ac Oil Saturation	56
Fig. 5-4	.(Initial oil saturation (1.jan.2019	56
Fig. 5-5	.(Distribution oil saturation (1.jan.2009	57
Fig. 5-6	.(Field liquid production rate vs. Time (History data and simulation results	58
Fig. 5-7	Field liquid production total vs. Time (History data and simulation results).	58
Fig. 5-8	.(Field oil production rate (History data and simulation results	59
Fig. 5-9	Field oil production total vs. Time (History data and simulation results).	59
Fig. 5-10	Field water cut total vs. Time (History data and simulation results).	60
Fig. 5-11	Field water production rate vs. Time (History data and simulation results).	60
Fig. 5-12	.(Field water production total vs. Time (History data and simulation results	61
Fig. 5-13	Well liquid production rate vs. time (History data and simulation results for .(well 53	62
Fig. 5-14	Well liquid production total vs. Time (History data and simulation results .(for well 53	63
Fig. 5-15	Well oil production rate vs. Time (History data and simulation results for .(well 53	63
Fig. 5-16	Well water cut total vs. Time (History data and simulation results for well .(53	64
Fig. 5-17	.(Distribution oil saturation Aa layer at (1. jan. 2009	64
Fig. 5-18	Distribution oil saturation Ab layer at (1. jan. 2009).	65
Fig. 5-19	.(Distribution oil saturation Ac layer at (1. jan. 2009	65
Fig. 6-1	.(Well UN11 water injection rate (from Dec 2001– Dec 2008	68
Fig. 6-2	.(Well UN32 water injection rate (from Dec 2001– Dec 2008	68
Fig. 6-3	.(Well UN33 water injection rate (from Dec 2001– Dec 2008	69
Fig. 6-4	.(Well UN105 water injection rate (from June 2008– Dec 2008	69
<b>Figure</b>	<b>Caption</b>	<b>Page</b>
Fig. 6-5	Cumulative Water Injection of the Four Injection Wells (from Dec 2001–	70

	.(Dec 2008	
Fig. 6-6	.(Field Oil Production Rate vs. Time (the base case	72
Fig. 6-7	.(Field Cumulative Oil Production vs. Time (the base case	72
Fig. 6-8	.(Field Cumulative Water Production vs. time (the base case	73
Fig. 6-9	.(Field Cumulative Water Injection vs. Time (the base case	73
Fig. 6-10	.(Field Pressure vs. Time (the base case	74
Fig. 6-11	.(Distribution of Oil Saturation for Layer Aa at 2019	74
Fig. 6-12	.(Distribution of Oil Saturation for Layer Ab at 2019	75
Fig. 6-13	.(Distribution of Oil Saturation for Layer Ac at 2019	75
Fig. 6-14	.(Field Oil Production Rate vs. Time (Case 1	76
Fig. 6-15	.(Field Oil Production Total vs. Time (Case 1	77
Fig. 6-16	.(Distribution of Oil Saturation for Layer Aa at 2019 (Case 1	77
Fig. 6-17	Well Un11 water injection Rate (from 1157 to 7185 days).	80
Fig. 6-18	.(Well Un32 water injection Rate (from 945 to 7185 days	81
Fig. 6-19	.(Well Un33 water injection Rate (from 945 to 7185 days	81
Fig. 6-20	.(Well Un105 water injection Rate (from 3349 to 7185 days	82
Fig. 6-21	.(Cumulative water injection of the injection wells (from 945 -7185 days	82
Fig. 6-22	.(Field Oil Production Total vs. Time (Comparison for the Six Schemes	85
Fig. 6-23	.(Field water production total vs. time (compare for six schemes	86
Fig. 6-24	.(Layer Aa Residual Oil Distribution (The First Case	89
Fig. 6-25	.(Layer Ab Residual Oil Distribution (The First Case	90
Fig. 6-26	.(layer Ac residual oil distribution (the first case	90