بسم الله الرحمن الرحيم

SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

College of petroleum engineering and technology

Department of petroleum engineering

دراسة تفصيلية لعمليات اختيار طرق الاستخلاص المحسن للنفط بحقل حديدة

Detailed study of Enhanced Oil Recovery screening for Hadida Oil Field

This dissertation is submitted as a partial requirement of B.Tech degree (honors) in petroleum engineering

This Project is a poperty of:

1- Abu Sofyan Ali Abd-Elrahman.

2- Ashraf Eldigair Elbuseiry

3- Ramy Abd El-Haleem Elhussain.

4- Yagoub Yousif Yagoub Mohamed.

Supervisor:

Dr. Elradi Abass Mohamed Nour

October 2017

بسم الله الرحمن الرحيم

SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

College of petroleum engineering and technology

Department of petroleum engineering

دراسة تفصيلية لعمليات اختيار طرق الاستخلاص المحسن للنفط بحقل حديدة

Detailed study of Enhanced Oil Recovery screening for Hadida Oil Field

This dissertation is submitted as a partial requirement of B.Tech degree (honors) in petroleum engineering

This Project is a poperty of:

1- Abu Sofyan Ali Abd-Elrahman.

2- Ashraf Eldigair Elbuseiry

3- Ramy Abd El-Haleem Elhussain.

4- Yagoub Yousif Yagoub Mohamed.

This project is accepted by college petroleum engineering and technology department of petroleum engineering

Project Supervisor: Dr. Elradi Abass

Signature:………………………………………………………………………………

Head of Department: .

Signature:………………………………………………………………………………

Dean of College: Dr. Tagwa Ahmed Musa.

Signature:………………………………………………………………………………

Date: / / 2017

الاستـــــهـــــلال

بسم الله الرحمن الرحيم

قال تعـــــالى:

(إِقْرَأْ بِاسْمِ رَبِّكَ الَّذِي

خَلَقَ (١) خَلَقَ الإنْسَانَ

مِنْ عَلَقٍ (٢) اقْرَأْ وَرَبُّكَ

الأَكْرَمُ (٣) الَّذِي عَلَّمَ بِالْقَلَمِ (٤)

عَلَّمَ الإنْسَانَ مَا لَمْ يَعْلَمْ(٥)

صدق الله العظيم

"سورة العلق"

DEDICATION

Our humble effort we dedicate it

to our beloved

Parents

Whose affection, love and encouragement make us

able to get much success and honor

Along with all hard working and respected

Teachers

Staff of College of petroleum Engineering &

technology

ACKNOWLEDGMENTS

We're immensely grateful to our advisor, **Dr. Elradi Abass**. who not only served us as our supervisor but also encouraged and challenged us throughout our accademic program. Without his constant support, encouragement and guidance, this work would not have been possible. We thank him for accepting us as one of his students, being so patient and pushing us to be a better future engineers.

We would also like to thank the staff of Petroleum Engineering & technology college, for their guidance and support in completing this work

Finally, we would like to acknowledge the trust and support of our **PARENTS** and our **FAMILY** members.

ABSTRACT

When the oil recovery comes to its lower level at which the production of oil is insufficient economically. The need for tertiary methods will be necessary. These techniques are referred to the ones that used after the implementation of the secondary recovery methods. Tertiary or well known as Enhanced oil recovery (EOR) is the recovery of oil from a reservoir by the injecting of materials that not normally present in reservoir. Usually these processes use miscible gases, chemicals, and/or thermal energy to recover additional oil.

Enhanced oil recovery (EOR) screening is considered as the first step in evaluating the Potential EOR techniques for candidate reservoirs. Therefore, as new technologies are developed, it is important to update the screening criteria.

In this study; the geological, reservoir and production data were collected for the screening process, the filtering process was done for wells that produce from Abu-Gabra and Bentiu formation. To reach the optimal accuracy in selecting process the data collected was analyzed and filtered well by well. Finally, the well pattern was ranked; the infill drilling wells was proposed in term of wells workover and wells modification.

Greater Hadida oil field is selected for the application of detailed (EOR) screening. From the screening processes were done, The most feasible methods are the immiscible gas injection and polymer flooding. The results show that a combination of conventional and detailed EOR screening represents a valuable approach to support reservoir development plans (RDPs).

تــجــريـــد

عندما ينخفض المعدل الأجمالى للنفط المستخلص فى مرحلة الانتاج الثانوى الى مستوى غير مجدى أقتصاديا يتم اللجوء الى أستخدام أساليب المرحلة الثالثة والتى يتم خلالها تبنى أساليب أكثر تقدما تأتى تحت مسمى الأستخلاص المحسن اوالمعزز للنفط والذى يهدف الى زيادة المعدل الاجمالى للنفط المستخلص من المكمن بأستخدام واحدة من تلك الطرق الحديثة والتى تشمل (المعالجات الكميائية والحرارية والغاز المحقون) مما يؤدى الى زيادة كفاء أستخلاص النفط من المكمن او الخزان النفطى .

تعتمد عملية أختيار طريقة الاستخلاص المحسن للنفط على عدة مراحل والتى تعتبر المرحلة الاولى فيها أجراء عملية الاختيار المثلى للمعايرالحقلية لكل طريقة من طرق الاستخلاص المحسن حيث تجرى عملية المقارنة او المقاربة لمعاير كل الطرق ومن ثم اختيار أكثر الطرق تطابقا اوتقاربا مع خصائص المكمن والمائع الموجود بالمكمن (النفط) المستهدف بتلك العمليات.

فى هذه الدراسة تم جمع المعلومات الجيولوجية والمكمنية ومعلومات الانتاج الخاصة بحقل حديدة لاجراء عملية الاختيار التفصيلية المثلى لإحدى طرق الاستخلاص المحسن للنفط مما يمكن من اسخدامها لاستخلاص النفط من طبقتى أبو جابرة وبانتيو وقد تم تحليل معلومات الآبار كل بئرعلى حدى، لاختيار أفضل الطرق التى يمكن تطبيقها بعد ان تم أختيار افضل ألانماط واجراء التغيرات اللآزمة والضروورية فى الآبار المستهدفة .

توصلت الدراسة الي اختيار افضل طريقتين من طرق الإستخلاص المحسن ، حيث وجد ان طريقة الحقن بالغاز غير القابل للإمتزاج هي الافضل لطبقة ابوجابرة و الغمر بالبوليمر هي الامثل للتطبيق بطبقة بانتيو . من النتائج ، فإن الدمج بين طرق الاختيار الاعتيادية والطرق التفصيلية تمثل منهجية قيمة لخطط تطوير المكامن النفطية.

TABLE OF CONTENTS

List of Tables

List of Figures

NOMENCLATURE

Symbol	Description
s	Saturation, fraction
ρ	Density of the fluid
ø	Porosity, percent
h	Formation thickness, ft
Pp	Pore pressure, psi
T	Temperature, oF
p	Reservoir pressure
μo	Oil viscosity, (cp)
μw	Water viscosity, (cp)
kw	Water relative permeability, fraction
ko	Oil relative permeability, fraction
D	Reservoir depth
md	Millidarcy
cp	Centipoise
ft	Foot
m	Meters
F	Fahrenheit
M	Mobility ratio, dimensionless
N	Original oil in place, STB
GOR	Gas Oil Ratio
EOR	Enhanced Oil Recovery
IOR	Improved Oil Recovery
OOIP	Original oil in place
ED	Displacement efficiency ES Sweep efficiency
RF	Recovery factor
API	American Petroleum Institut
SAGD	Steam Assisted Gravity Drainage

VAPEX	Vapor Assisted Petroleum Extraction
CHOPS	Cold Heavy Oil Products with Sand
AG	Abu Gabra
B	Bentiu
AD	Aradieba

CHAPTER ONE

1.Chapter One

1.1. INTRODUCTION

1.1.1. Enhanced Oil Recovery (EOR)

Enhanced oil recovery (EOR) has drawn great attention in the petroleum industry. A variety of supplemental recovery techniques have been developed to enhance the recovery factor obtained by utilizing the natural diving forces present in the reservoir.

The general mechanism of oil recovery is movement of hydrocarbons to production wells due to the pressure difference between the reservoir and the production wells. The recovery of oil reserves is divided into three main categories worldwide, figure 1 illustrates these categories:

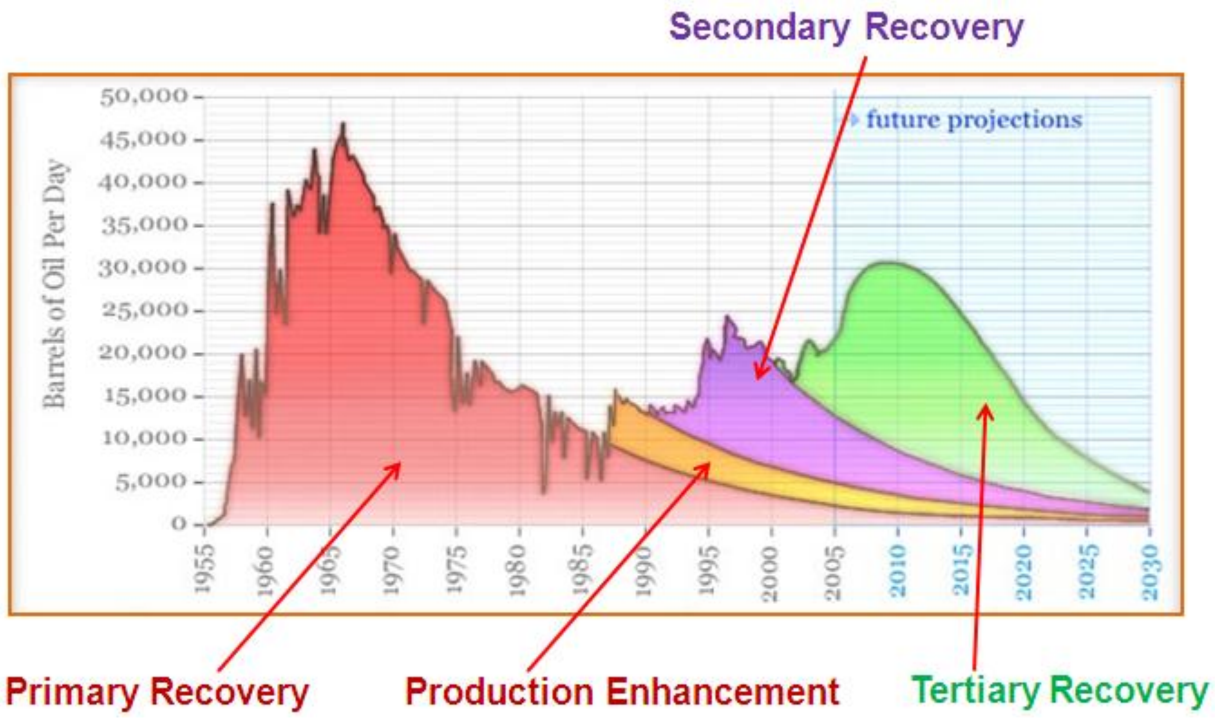


Figure 1 Recovery stages of a hydrocarbon reservoir through time (SPE ,JPT)

1.1.2. **Primary recovery techniques**

This implies the initial production stage, resulted from the displacement energy naturally existing in a reservoir. In the primary process, the oil is forced out of the petroleum reservoir by existing natural pressure of the trapped fluids in the reservoir. Primary oil recovery methods include solution-gas drive, gas-cap expansion, gravity drainage, rock expansion, water drive processes or their combination. With declining reservoir pressure, it becomes more difficult to get the hydrocarbons to the surface. Sometimes, artificial lift is required.

On average, only 5-10% of original oil in place can be recovered by primary techniques. Over a period of oil production, the reservoir energy will fall, and at some point there will be insufficient underground pressure to force the oil to the surface.

1.1.3. **Secondary recovery techniques**

Normally utilized when the primary production declines. Traditionally these techniques are water flooding, pressure maintenance, and gas injection. The recovery factor can rise up to 50%.

When a large part of the crude oil in a reservoir cannot be recovered by primary methods, a method for recovering more of the oil left behind must be chosen. Most often, secondary recovery is accomplished by injecting gas or water into the reservoir to replace produced fluids and maintain or increase the reservoir pressure. Conversion of some production wells to injection wells and subsequent injection of gas or water for pressure maintenance in the reservoir has been designated as secondary oil recovery.

1.1.4. **Tertiary recovery techniques**

The oil recovered by both primary and secondary processes ranges from 20 to 50% depending on the oil and reservoir properties (Speight, J. G. 2009).

These techniques are referred to the ones used after the implementation of the secondary recovery method. Usually these processes use miscible gases, chemicals, and/or thermal energy to displace additional oil after the secondary recovery process has become uneconomical. The recovery factor may arise up to 12% additionally to the RF obtained with the secondary recovery method. primary, secondary and tertiary recovery (enhanced oil recovery), as show in figure 1.

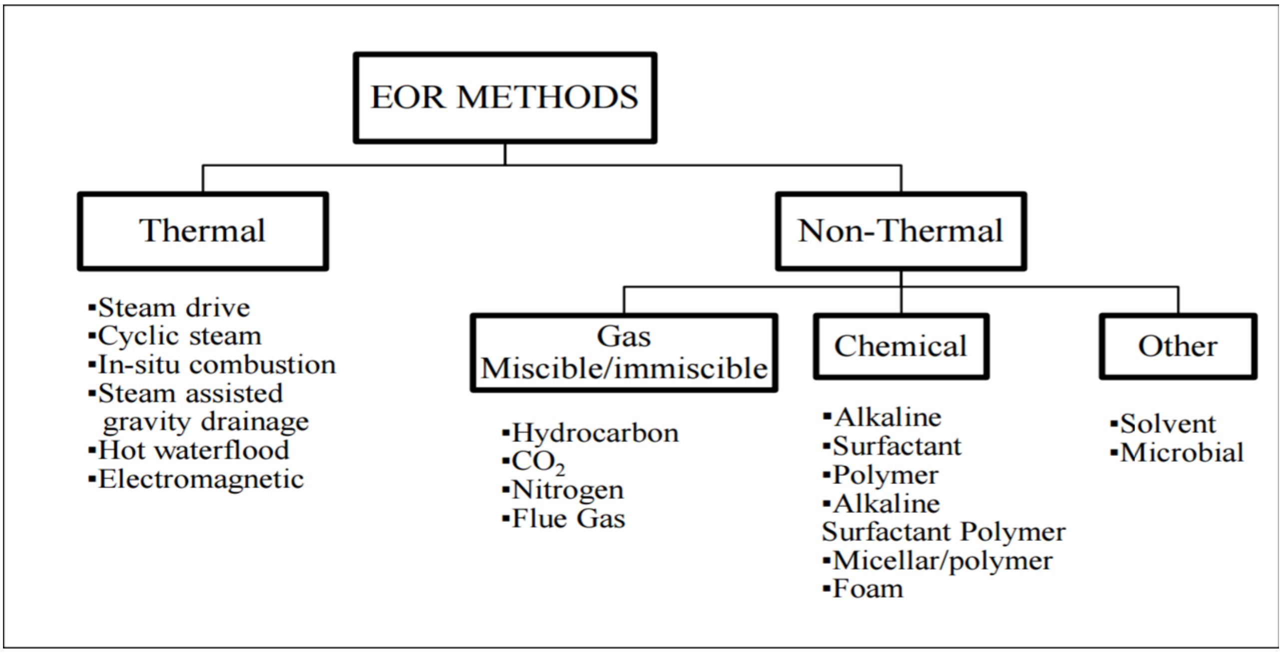


Figure 2 Enhanced oil recovery methods (Ali, S. M. F., & Thomas, S., 1989)

The biggest portion of oil left behind after conventional oil recovery exhausted.Therefore, enhanced oil recovery methods must be applied if further oil is to be recovered. Enhanced oil recovery (Tertiary recovery) methods have focused on recovering the remaining oil from a reservoir that has been depleted of energy during the application of primary and secondary recovery methods.

1.1.4.1. EOR and IOR ,defferences and definition

Enhanced oil recovery is often synonymous to some extent with improved oil recovery **(IOR)**. Enhanced oil recovery **(EOR)** is the recovery of oil from a reservoir by the injecting of materials that not normally present in reservoir (Lake, 1989).The injected fluids interact with the reservoir rock and oil system to create conditions favorable for oil recovery. Improved oil recovery (IOR) refers to any process or practice that improves oil recovery. IOR includes EOR processes and other practices such as water flooding, pressure maintenance, infill drilling, and horizontal wells.

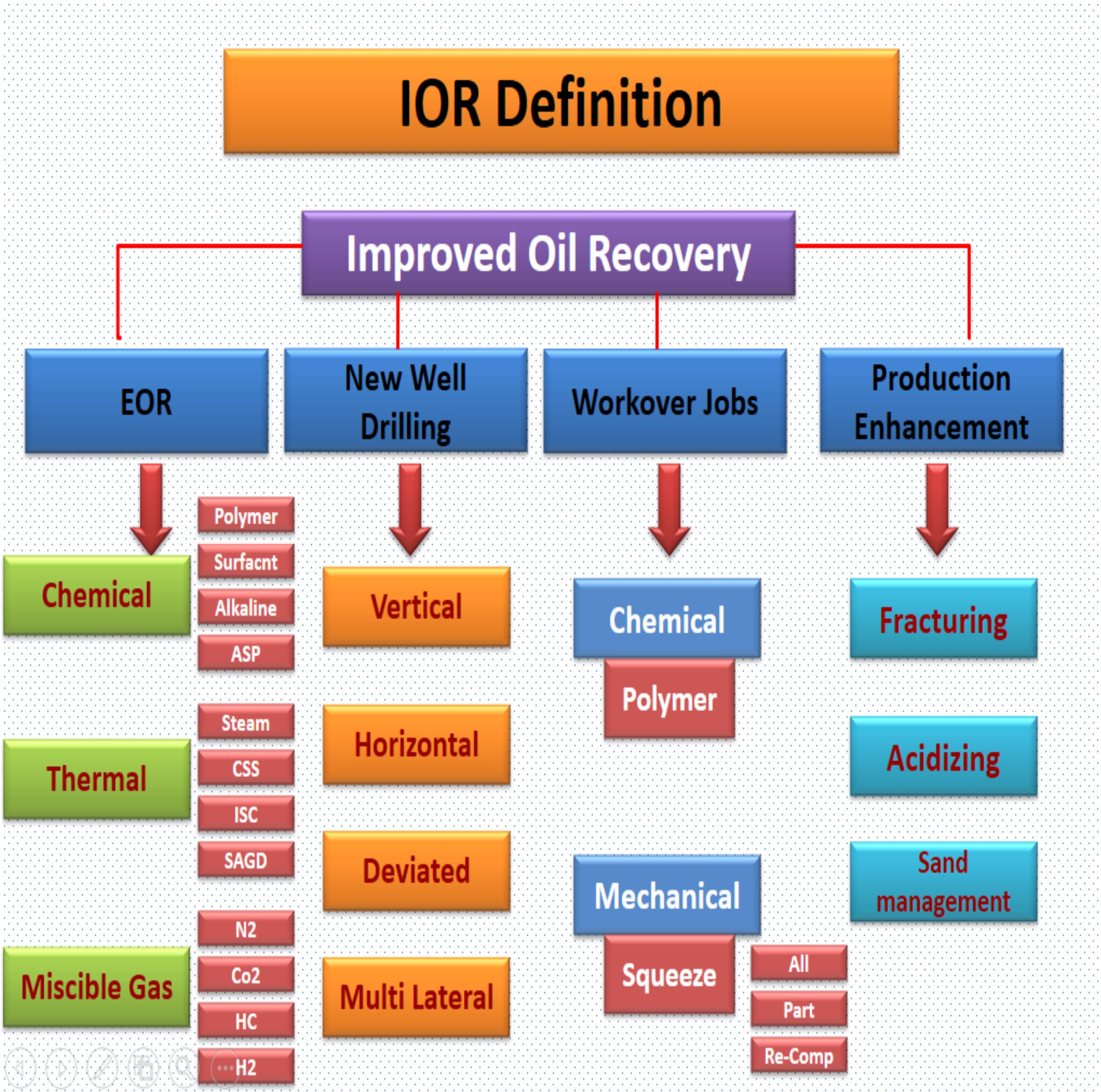


Figure 3 IOR Methods Identification

1.2. **INTRODUCTION TO THE ENHANCED OIL RECOVERY SCREENING CRITERIA**

Enhanced oil recovery (EOR) screening is considered as the first step in evaluating. Potential EOR techniques for candidate reservoirs. Therefore, as new technologies are developed, it is important to update the screening criteria.

Numerous enhanced recovery techniques exist today. These techniques and their applications and results have been translated into screening criteria (Iyoho 1978). Applying these screening criteria (or screening guides) is one of the first steps in determining whether the field in question can be produced by a certain recovery method
(Chu, 1985). Prospects that pass this screen are candidates for further engineering study.

The criteria include values for parameters such as oil gravity, oil viscosity, reservoir porosity, oil saturation start and end, reservoir permeability, reservoir depth, reservoir temperature, reservoir pressure and pay thickness. The criteria recommend minimum to maximum ranges for each parameter.

1.2.1. **Screening criteria for EOR methods**

The screening criteria are the most common, fast and easy tool to use to determine if a field and reservoir becomes a good candidate for implementing an EOR Process.

In the past, screening criteria or guides have been developed and employed to define the candidate reservoirs for each EOR method. Screening criteria are among the first items considered when a petroleum engineer evaluates a candidate reservoir for enhanced oil recovery (EOR). The screening criteria for a specific EOR process consist of a list of reservoir parameters and fluid properties such as oil gravity, oil viscosity, reservoir porosity, oil saturation start and end, reservoir permeability, reservoir depth, reservoir temperature, reservoir pressure and pay thickness and their ranges. The criteria recommend minimum to maximum ranges for each parameter, which are likely to lead to a success.

The nature of the reservoir will play a dominant role in the success or failure of any EOR process. Many of the failures with EOR have resulted because of unknown or unexpected reservoir problems. Therefore, geological study is usually warranted. Some EOR processes can be rejected quickly because of unfavorable reservoir or oil properties, so the use of preferred criteria can be helpful in selecting methods that may be commercially attractive (Taber 1997).

Where two processes are equally suited to any set of conditions, an economic study must be performed to determine which is cheaper or which will recover more oil.

Screening guides are provided to help engineers in deciding which particular recovery process might be most applicable for a given set of conditions (Iyoho, 1978).

Screening Criteria has been developed for EOR processes based on filed applications and laboratory tests. In addition to these conventional screening criteria, nowadays computer programming and machine learning are also employed to cover a wider range of data. The complexity of defining an oil reservoir's important parameters depends largely on the availability and quality of input data; therefore, these descriptions can result in a high degree of uncertainty.

Some software has been developed to perform screening based on a different number of EOR methods, among these softwares are: EORgui, Sword, SelectEORTM, PRIzeTM, Screening 2.0 and IORSys. Trujillo (2010) developed a software based on Screening 2.0, which executes screening criteria of nineteen EOR methods. Gharbi (2000) proposed an expert system for selecting and designing EOR processes. He applied an artificial intelligence (AI) technique to select and design the EOR processes. The expert system was able to select an appropriate EOR process on the basis of the reservoir characteristics.

The main problem for using these machine-learning methods is the lack of quality data. Sufficient number of data sets must be available so that the expert

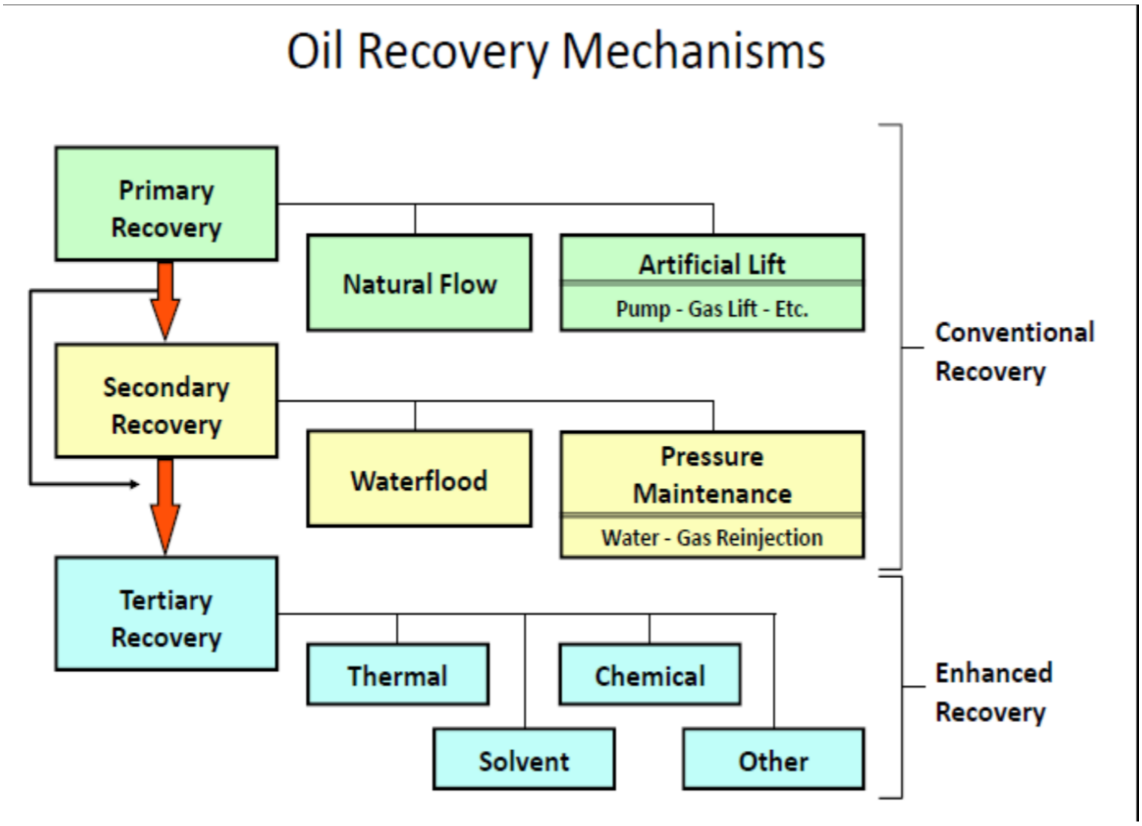


Figure 4 Oil Recovery Mechanisms (Oil and Gas Journal, 1990)

1.2.2. **A classification by Van Pollen and Associates (1981) of EOR methods has the following three categories:**

1. Thermal methods, which include steam stimulation (also known as “huff and puff”), steam flood (including hot water injection), and in situ combustion;

2. Chemical methods, which include surfactant-polymer injection, polymer flooding, and caustic flooding; and,

3. Miscible displacement methods, which include injection of hydrocarbon gas, CO2, or inert gas under high pressure.

Gas injection, the oldest EOR technique. The miscibility

mechanism is to solvent extraction to achieve miscibility. Most popular gas injection methods include nitrogen and flue-gas injection, hydrocarbon injection, CO2 flooding, *etc*. Taber et al. (1997) suggested a series of screening criteria for any EOR method. For applying nitrogen and flue-gas flooding method, most important parameters, *i.e.* depth and API degree, have been recommended more than 6000 ft and 35-48, respectively. For applying hydrocarbon injection method depth and API degree are >4000 ft and 23-41, respectively. The suggested depth for CO2 method and immiscible injection method are more than 2400 and 1400 ft, respectively. In addition, the recommended API degree are 22-36 and >12, respectively. Totally, gas injection methods have been implemented in the high depths and API degree.

A large number of variables are associated with a given oil reservoir, for instance pressure and temperature crude oil type and viscosity, and the nature of the rock matrix and connate water. Because of these variables, not every type of EOR process can be applied to every reservoir. An initial screening procedure would quickly eliminate some EOR processes from consideration in particular reservoir applications. This screening procedure involves the analysis of both crude oil and reservoir properties. This section presents screening criteria for each of the general types of processes previously discussed. It should be recognized that these screening criteria are only guidelines. If a particular reservoir–crude oil application appears to be on a borderline between two different processes, it may be necessary to consider both processes. Once the number of processes has been reduced to one or two, a detailed economic analysis will have to be conducted. Some general considerations can be discussed before the individual process screening criteria are presented. First, detailed geological study is usually desirable, since operators have found that unexpected reservoir heterogeneities have led to the failure of many EOR field projects. Reservoirs that are found to be highly faulted or fractured typically yield poor recoveries from EOR processes. Second, some general comments pertaining to economics can be made. When an operator is considering EOR in particular applications, candidate reservoirs should contain sufficient recoverable oil and be large enough for the project to be potentially profitable. Also, deep reservoirs could involve large drilling and completion expenses if new wells are to be drilled.

Screening Criteria Table in Figure 5 Screening Criteria Tablecontains the screening criteria that have been compiled from the literature for the miscible, chemical, and thermal techniques. The miscible process requirements are characterized by a low-viscosity crude oil and a thin reservoir. A low-viscosity oil will usually contain enough of the intermediate-range components for the multi-contact miscible process to be established. The requirement of a thin reservoir reduces the possibility that gravity override will occur and yields a more even sweep efficiency. In general, the chemical processes require reservoir temperatures of less than 200◦F, a sandstone reservoir, and enough permeability to allow sufficient injectivity. The chemical processes will work on oils that are more viscous than what the miscible processes require, but the oils cannot be so viscous that adverse mobility ratios are encountered. Limitations are set on temperature and rock type so that chemical consumption can be controlled to reasonable values. High temperatures will degrade most of the chemicals that are currently being used in the industry.

		Oil Properties			Reservoir Characteristics					
Detail Table in Ref. 16	EOR Method	Gravity (°API)	Viscosity (cp)	Composition	Oil Saturation (% PV)	Formation Type	Net Thickness (ft)	Average Permeability (md)	Depth (ft)	Temperature (°F)
Gas Injection Methods (Miscible)										
1	Nitrogen and flue gas	> 35 ↗ 48 ↗	< 0.4 ↘ 0.2 ↘	High percent of C_1 to c7	> 40 ↗ 75 ↗	Sandstone or carbonate	Thin unless dipping	NC	> 6,000	NC
2	Hydrocarbon	> 23 ↗ 41 ↗	< 3 ↘ 0.5 ↘	High percent of C_2 to C_7	> 30 ↗ 80 ↗	Sandstone or carbonate	Thin unless dipping	NC	> 4,000	NC
3	CO_2	> 22 ↗ 36 ↗ [a]	< 10 ↘ 1.5 ↘	High percent of C_5 to C_{12}	> 20 ↗ 55 ↗	Sandstone or carbonate	Wide range	NC	> 2,500[a]	NC
1–3	Immiscible gases	> 12	< 600	NC	> 35 ↗ 70 ↗	NC	NC if dipping and/or good vertical permeability	NC	> 1,800	NC
(Enhanced) Waterflooding										
4	Micellar/ Polymer, ASP, and Alkaline Flooding	> 20 ↗ 35 ↗	< 35 ↘ 13 ↘	Light, intermediate, some organic acids for alkaline floods	> 35 ↗ 53 ↗	Sandstone preferred	NC	> 10 ↗ 450 ↗	> 9,000 ↘ 3,250	> 200 ↘ 80
5	Polymer Flooding	> 15	< 150, > 10	NC	> 50 ↗ 80 ↗	Sandstone preferred	NC	> 10 ↗ 800 ↗ [b]	< 9,000	> 200 ↘ 140
Thermal/Mechanical										
6	Combustion	> 10 ↗ 16 → ?	< 5,000 ↓ 1,200	Some asphaltic components	> 50 ↗ 72 ↗	High-porosity sand/ sandstone	> 10	> 50 [c]	< 11,500 ↘ 3,500	> 100 ↗ 135
7	Steam	> 8 to 13.5 → ?	< 200,000 ↓ 4,700	NC	> 40 ↗ 66 ↗	High-porosity sand/ sandstone	> 20	> 200 ↗ 2,540 ↗ [d]	< 4,500 ↘ 1,500	NC
—	Surface mining	7 to 11	Zero cold flow	NC	> 8 wt% sand	Mineable tar sand	> 10 [e]	NC	> 3 : 1 overburden to sand ratio	NC

NC = not critical.
Underlined values represent the approximate mean or average for current field projects.
[a] See Table 3 of Ref. 16.
[b] > 3md from some carbonate reservoirs if the intent is to sweep only the fracture system.
[c] Transmissibility > 20 md-ft/cp
[d] Transmissibility > 50 md-ft/cp
[e] See depth.

Figure 5 Screening Criteria Table (J.J. Taber, SPE, F.D. Martin, SPE, and R.S. Seright, 1997).

1.3. **EOR SCREENING METHODS**

Three screening styles must usually be combined to paint a good picture of the enhanced oil recovery (EOR) decision problem and to make rational progress. The first one, conventional screening, is the one most engineers are familiar with, and it is usually carried out by comparing average reservoir properties with data in a look-up table that contains validity limits for each parameter considered important. Geologic screening is a way of looking at the reservoir type in terms of heterogeneity, connectivity, and other geologic characteristics that have been found to be important in managing risk or that correlate with process performance. Advanced screening helps when looking at possible combinations of variables and are sometimes referred to as multidimensional maps (to see more than three-dimensional projections). These projections are useful for finding proper reservoir analog.

1.3.1. **CONVENTIONAL SCREENING**

The most commonly used approach to selecting recovery processes for a reservoir is so-called conventional screening, which we refer to as “go–no go” screening. This strategy is based on look-up tables where intervals of validity are established on the basis of engineering considerations by collecting “expert opinions” or by analyzing data from successful field cases. A combination of all of these approaches is the most likely situation encountered. In this screening method, typically average representative fluid and reservoir properties of a particular field under evaluation are compared with intervals of the look-up table to decide whether the field or reservoir is suitable (which is why it is called go–no go) for a given recovery process. Screening methods of this sort are well documented in the literature (Taber et al., 1997) or are available in commercial analytical tools; for instance, PRIze implements a direct look-up table strategy, while Sword (IRIS, 2007) relaxes the look-up table, using fuzzy logic to generate an indicator between 0 and 1 and thus allowing hierarchical selection of the process type (water flooding, gas injection, thermal methods ,and chemical processes).

An important consideration of look-up tables is that biases frequently arise because engineering considerations or experts’ opinions are introduced in the process. For instance, PRIze was developed by the Petroleum Research Institute (formerly known as PRI; it is now part of the Alberta Research Center, or ARC; ARC integrated with Alberta Innovates, a new organization in Alberta), and as a result EOR applied to heavy oil substantially influenced expert opinions and sources of data.. The main goal of the screening analysis is to identify whether a specific EOR technology has been implemented under fluid and reservoir properties similar to those of to the field under evaluation.

1.3.2. **GEOLOGIC SCREENING**

Geologic characteristics, such as trap type, depositional environment, geologic age, lithology, type of structure, and digenesis, are used to establish a comparison basis between a field under evaluation and EOR projects recorded in a database or information documented in the literature. Several studies have demonstrated the use of reservoir geologic analogy to determine the technical feasibility or applicability of EOR in a particular field.

1.3.3. **ADVANCED EOR SCREENING**

Advanced EOR screening refers to more robust data mining strategies and artificial intelligence techniques that can lead to better screening criteria by considering simultaneous combinations of more than two reservoir and fluid properties.

The data mining process yields a new strategy for screening oil recovery methods (IOR and EOR). It is based first on space reduction techniques to simplify the representation of international experience on oil recovery methods, represented in a collated database of reservoirs and projected as 2-D cluster maps (“expert maps”).

The application of emerging expert-system technology to select EOR method is very important and useful. A reasonable solution has been conducted by matching all EOR methods and then arranging it by highest suitable match in which a major problem involved in the screening process, that is, a large number of EOR methods have applicable match to the oil field data concerned. The structure of an expert systems selection based on a new formulated screening criteria, Artificial Intelligence selection developed by a computer software called ($E^{K}OR^{A}$). The $E^{K}OR^{A}$ software is designed to accommodate new recommended parameter ranges of current and future implemented EOR Projects that helps to transfer the expert's knowledge to the users of the software. Moreover, estimations of additional field cases make it possible to continuously refine the screening procedure that may emerge and become available in the future. (Elradi Abass, Cheng Lin Song 2011).

1.4. CASE STUDY

The study area, Hadida oil field located in the South East Muglad Basin of Northern East Africa. Sedimentary development in the Central and Southern Sudan rift basins seem to have been affected by both local and global geological events.

Hadida field located in Nugara sub-basin in the western area of Block-6. Discovered by Hadida-1 in 2002.There're three discovered structures (Hadida Main, Hadida North & Hadida Central).

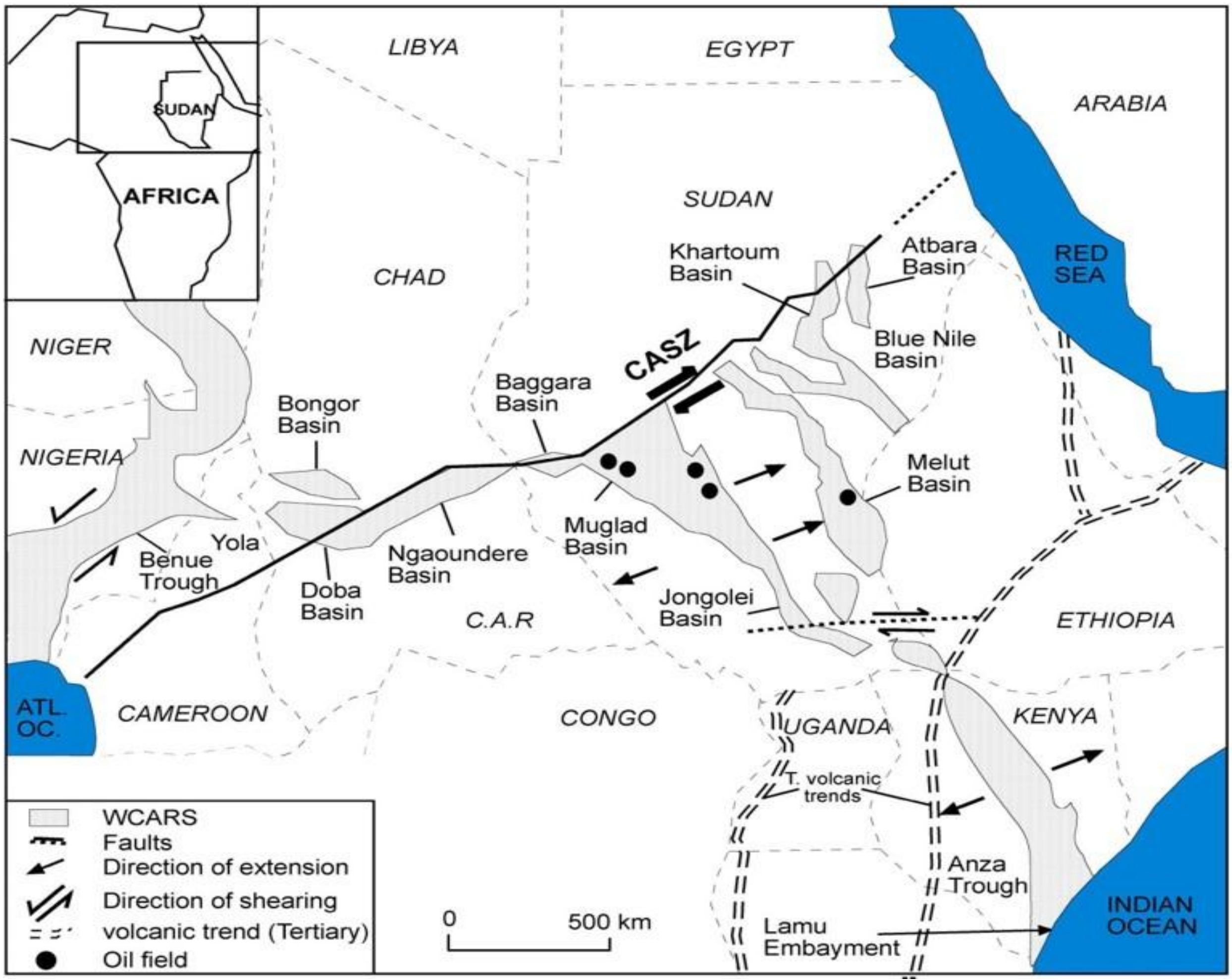


Figure 6 Hadida map

1.5. STATEMENT OF THE PROBLEM

Most of oil field in sudan have reached high water cut stage ,in order to meet the booming energy demanded ,oil production rate & optimal recovery factor must be enhanced & optimized using suitable EOR methods. In this study, Greater Hadida oil field is selected due to the following problems :

Case 1: Hadia main ,Bentiu reservoir problem is high water cut due to edge water incursion which lead to lowering the recovery factor & unfavorable mobiblity ratio between oil & water, casuing water coning & high water production during production life of wells (as shown in figure 7).

Case 2: Hadida North ,Abu Gabra formation bubble point pressure (3812 psi) is approxaimately equal to the initial reservoir pressure (4000 psi) , which caused a rapid decline in production rates as well as the recovery factor, so all wells in this formation stopped producing.

Due to the above problems, suitable EOR methods are needed urguntly to control the mobility ratio ,improving the recovery factor and sustain reservoir pressure high enough to aviod reaching bubble point at early production time. Detailed EOR screening will be held & applied to select the best applicable EOR methods.

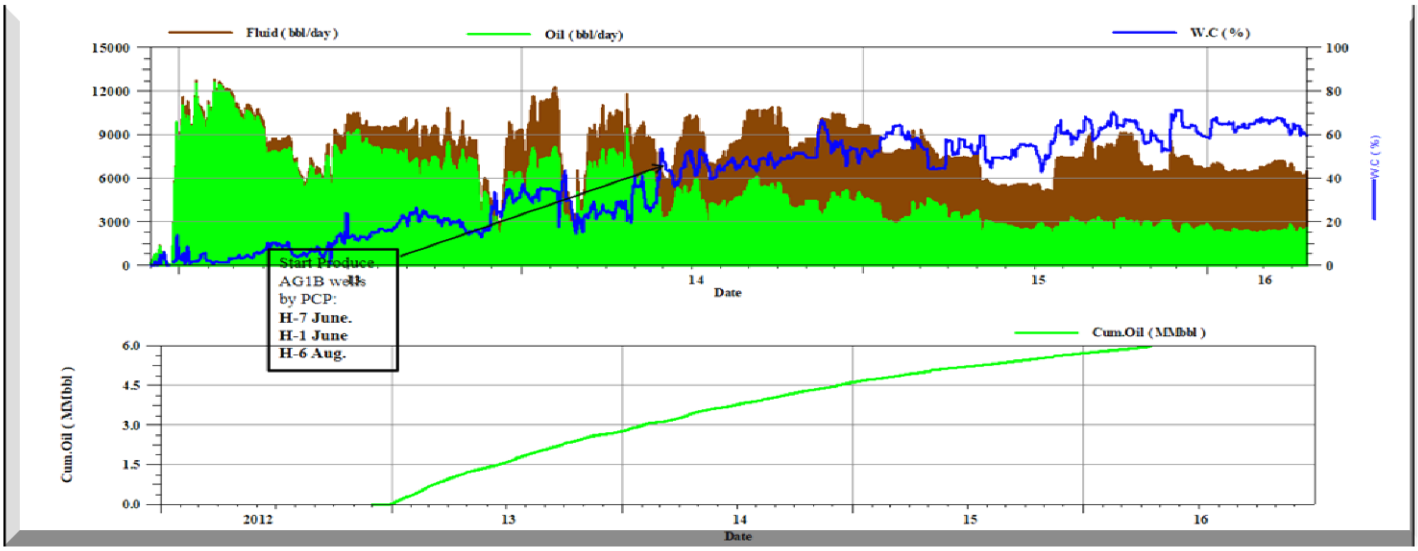


Figure 7 Hadida Production Performance

1.6. **OBJECTIVES**

The main objective of this screening study is to identify the most feasible recovery processes for the field under study,followed by the objectices below:

1. Detailed EOR screening for this area as pre-screening using EORGui computer software.
2. To select best options that proposed for this oil field in term of geological model ,well pairs conductivity ,wells patterns, faults location and production performance.
3. To select the best candidate well for injection or production in term of optimum production performance.
4. Propose infill drilling for development stage to increase the recovery factor depend on the obtained results.

CHAPTER TWO

2.Chapter Two

2.1. LITERATURE REVIEW

(Ahmed Al Adasani, Baojun Bai ,2011) Constructed an EOR database based on numerous reported EOR projects, illustrated the relationship of EOR project and presented depth analysis of EOR projects.from his analysis he supported EOR selection and implementation, updated EOR criteria and encouraged research advancements.

(J.J Taber, F.D. Martin, R.S. Seright, 1997) Presented brief description for screening criteria for the major EOR methods and describe relationship between them. They found that steam flooding was still the dominant EOR method, all chemical flooding had been declining, polymers and gels were being used successfully for sweep improvement and co2 flooding activity had increased continuously

(J.J Taber, F.D. Martin, R.S. Seright, 1997) estimated the total quantity of co2 that might be needed for the oil reservoirs and examined the impact of oil prices on EOR activities. They reached to that when only depth and oil gravity were considered 80% of the world's reservoirs could qualify for some type of co2 injection to also found EOR projects were based more on economic than screening criteria further oil prices were important.

(Mahendra K. Verma ,2015) Provided basic technical information regarding the CO2-EOR process, which is at the core of the assessment methodology, to estimate the technically recoverable oil within the fields of the identified sedimentary basins of the United States. Emphasis is on CO2-EOR because this is currently one technology being considered as an ultimate long-term geologic storage solution for CO2 owing to its economic profitability from incremental oil production offsetting the cost of carbon sequestration.

(M.trujillo, D.Mercado ,G.Maya, R.Castro,C.soto ,H.perez, V.Gomez and J.sandra , Ecopetrol S.A. 2010) This paper has a methodology to select the EOR method to apply a set of fields using the screening criteria, by help some of program. This study was applied in Colombian fields and most and the most of Colombian fields still primary recovery. It is one of the main reasons for the average recovery factor of oil, as indicated by the use the best investment option, and the technologies discussed in this analysis: water injection, lean and rich gas, nitrogen, wag, co2 (miscible and immiscible), polymer, surfactant polymer, steam(cyclic) and some other such as CHOPS, VAPEX, WET VAPEX and SAGD. In situ combustion and electromagnetic heating. The methodology presented in this study has enabled the identification of EOR technologies for applied in Colombian fields and has also helped to become an indicator for the development of a field development plan. This subject is important for companies either owning fields or having better characteristic of EOR projects in simple and easy ways that started developing any field.

(Eduardo Manrique, SPE, Mehdi Izadu ,Curtis Kitchen and Vladimir Alvarado 2008) This paper describes fully EOR decision-making on the use of expanded uranium using field case examples for Asia, Canada, Mexico, South America and the United States of America, including the type of assets assessed on several different reservoirs of oil sands and discussed the different stages with available information, Making decisions on uranium waste. The proposed methodology has proven to be useful for project screening and evaluation. The field case described in this paper shows that decisions can be made without the need for advanced technologies and time-consuming studies.

(Baghir A. Suleimanov, S. Ismayilov, Oleq A. Dyshin, Elchin F. Veliyev ,2016) Taber has given an overview of EOR's research history using its Taper Tables, and the authors propose an approach to selecting an EOR method based on fuzzy logic, potential Theory and Bayesian inference mechanism. The methodology was applied in the Alberta oil field as well as the marine field. Guneshli allowed the selection of the most effective method of uranium properties, confirming the accuracy and feasibility of the proposed approach.

(T.B. Jensen, K.J. Harpole, and A. Østhus, 2000) An investigation of alternative EOR processes having potential application in the giant Ekofisk chalk field is presented. Technical feasibility, process readiness, oil recovery potential, and related uncertainties and risks of five selected EOR processes, namely hydrocarbon (HC) WAG, nitrogen (N2) WAG, carbon dioxide (CO2) WAG, air injection and microbial EOR (MEOR), are assessed for possible application at Ekofisk. The objective of the screening study was to evaluate and rank the EOR alternatives and to select the most attractive process(es) on which to pursue further work toward possible field pilot testing. Estimates of potential EOR incremental oil recovery for the Ekofisk field can be quite significant. However, key project development and implementation issues and additional cost elements must be weighed equally with oil recovery forecasts in any EOR process ranking. Some of these issues (e.g. injection gas supply, facilities requirements, and the impact of EOR on chalk compaction, subsidence and wellbore integrity) may be significant enough to eliminate a process from further consideration.

(Elradi Abass, Cheng Lin Song 2011) This paper describes the application of an Artificial Intelligence (AI) technique to assist in the selection of an Enhanced Oil Recovery method (EOR). The structure of an expert systems selection based on a new formulated screening criteria, Artificial Intelligence selection developed by a computer software called (EKORA), with an easily and friendly user interface by using visual Basic-6 environment tools is presented. An additional capability provided by this software is the ability of changing and editing the parameters of EOR methods which emerged or tested in current implementation projects. Other commercial expert systems either offer limited or no capabilities for changing and editing the EOR parameters of screening rule.

(Ridha Gharbi, Abdullah Alajmi and Meshal Algharaib, 2012) An integrated full-field reservoir simulation study has been performed to determine the reservoir management and production strategies in a mature sandstone reservoir. The reservoir is a candidate for an enhanced oil recovery process or otherwise subject to abandonment. Based on its charateristics, the reservoir was found to be most suited for a surfactant/polymer (SP) flood. The study started with a large data gathering and the building of a full-field three-dimensional geological model. Subsequently, a full field simulation model was built and used to history match the water flood.The study resulted in the selection of surfactant and polymer concentrations and slug size that yielded the best economic returns when applied in this reservoir. The study shows that, in today's oil prices, surfactant/polymer flood when applied in this reservoir has increased the ultimate oil recovery and provide a significant financial returns.

CHAPTER THREE

3. Chapter Three

3.1. METHODOLOGY

In this study; the geological, reservoir and production, data were collected, using these data; the screening and filtering were done for wells that produce from Abu-Gabra & Bentiu.Then data collected were analyzed and filtered well by well to reach the optimal accuracy. Finally, the well pattern was ranked and well workover and modification as well as new wells was proposed.

Common decisions or questions that need to be answered from EOR screening studies can be exemplified with the following list*:*

1. Determine the most feasible EOR processes.
2. Justify data-gathering programs: drilling and logging wells, core and fluid samples recovery, and so on.
3. Justify more detailed engineering (Phase II) studies.
4. Generate preliminary Reservoir development plan (RDP) based on one or more EOR process, among others.

The steps involved in the implementation of any EOR project in a given reservoir are:

(1) selection of a suitable EOR process,

(2) performance prediction of the EOR process, and

(3) design optimization of the EOR process.

The selection of an EOR process for a given field can be made based on the reservoir characteristics. However, the process performance of a particular design and the costs associated with it should be estimated before a decision can be made to invest large amount of money to conduct such process in the field.

Here in this section, combination of the elements discussed in detail as shown in the preceding chapters and sections to integrate the strategy that is conducive to enhanced oil recovery (EOR) projects. You can think of the flowchart (see Figure 1) as a sequence of qualitatively different screening stages. Although the amount or type of data representation at each stage is different with each increased level of complexity, these stages do not necessarily represent a hierarchy; instead, different representations of the reservoir–field systems are adopted. The field cases described in this chapter illustrate the two types of decision-making problem. The steps in the proposed methodology were described in the previous sections.

To illustrate the different types of decisions, contexts, and constraints of the decision-making process, cases are divided according to the availability of data and the time constraints for the decision-making process. We divide the cases into two groups. Field case type I is characterized by a limited amount of data and a relatively short time frame for making decisions. This type of decision-making problem emphasizes the screening steps rather than the entire workflow because the decisions for this type of asset are often framed in terms of data gathering initiatives or they focus on aspects of feasibility. In contrast, type II field cases are not limited by the amount of necessary data but mostly by the time span allotted to the decision of necessary data but mostly by the time span allotted to the decision. This condition allows a focus on performance prediction, so the effective use of simulation tools is a must. (V. Alvarado and E. Manrique 2010).

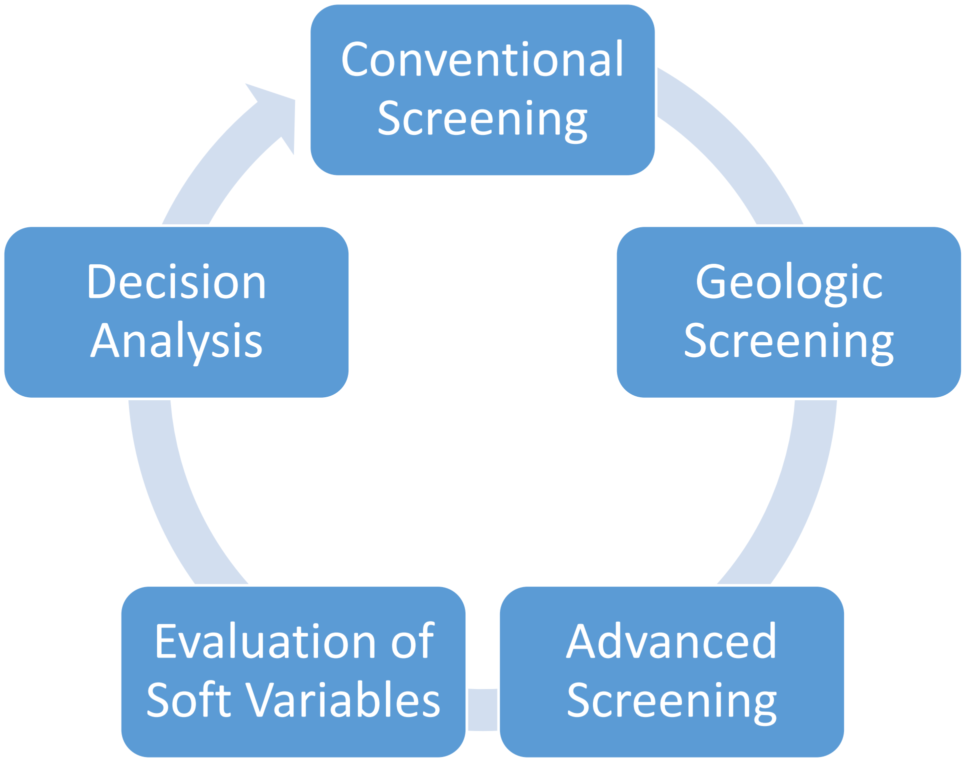
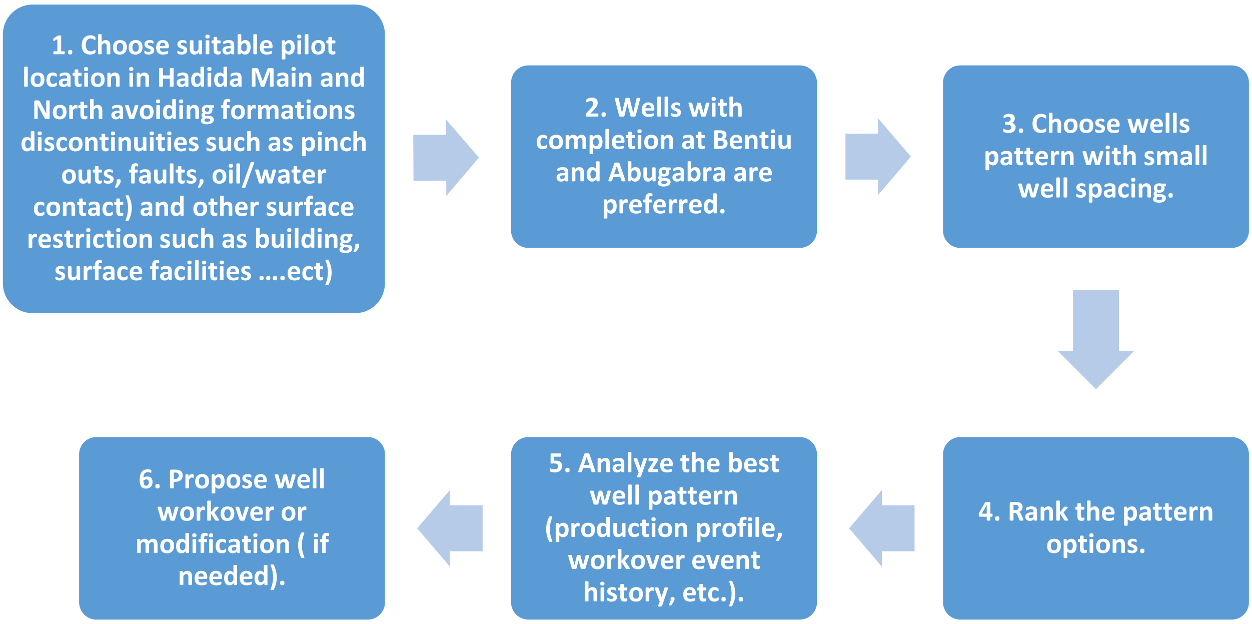


Figure 8: EOR decision-making workflow. Each field case type emphasizes a portion of the workflow.

Flow Chart 1:The below flowchart describes stages used to choose the sector Area:



3.2. DATA COLLECTION

1. Geological data. (subsurface structural maps to identify discontinuities such as pinch outs, faults, oil/water contact)
2. Reservoir data (rock and fluid properties)
3. Completion data (target formation)
4. Production data (daily production, WC …etc.)

3.2.1. Design

wells pattern /well Pair with small well spacing will be considered and applied.

3.2.2. Analysis

1. General Screening data
2. Detailed screening
3. Well by well review (Production profile, workover event, history........etc.*)*

3.3. PILOT WELL AREA SELECTION FOR POLYMER FLOODING & IMMISCIBLE GAS INJECTION IN HADIDA OILFIELD

In the first stage of the project, detailed EOR screening for Hadida oilfield was accomplished and specific wells were recommended as suitable wells for polymer & immiscible gas flooding and will be subjected to further studies to select the optimum pilot well area.

The screening process conducted in the first stage goes through several screening processes, starting by pre-screening which include collecting the data of Hadida oilfield then applying these field EORgui Software to select the proper EOR methods after that the fields were eliminated based on the basic polymer & immiscible gas flooding screening criteria (depth, temperature, viscosity, permeability, and pressure). Then in the second stage of the screening process the selected field was examined by formations plus additional screening criteria was also considered (STOIIP, numbers of wells, wells pattern, well spacing and locations). in addition to the result obtained from commercial EOR screening software (EORgui).

3.3.1. **Well Pattern Consideration Factors**

There are three main factors needed to be considered in selecting the pilot wells patterns and location, the first factor is lower the pilot cost by prioritize to use the existing producers as pilot wells and avoid drilling new well as injector, and also to utilize the existing surface facilities and minimize the requirement of any extra facility, the second factor is to have shorter pilot period by selecting wells with the spacing distance less than 350 m (1148 ft) to avoid the suffering from a lengthy period and higher operational cost, the last factor is to have Least Production Disturbance by selecting only wells with poor production performance (Ridha Gharbi ...et al. 2012).

3.4. DATA USED FOR EOR SCREENING

1. Reservoir & Rock properties.
2. Structure Maps.
3. Cross sections
4. Well spacing
5. Well location
6. Production data
7. Completion & Perforation Data

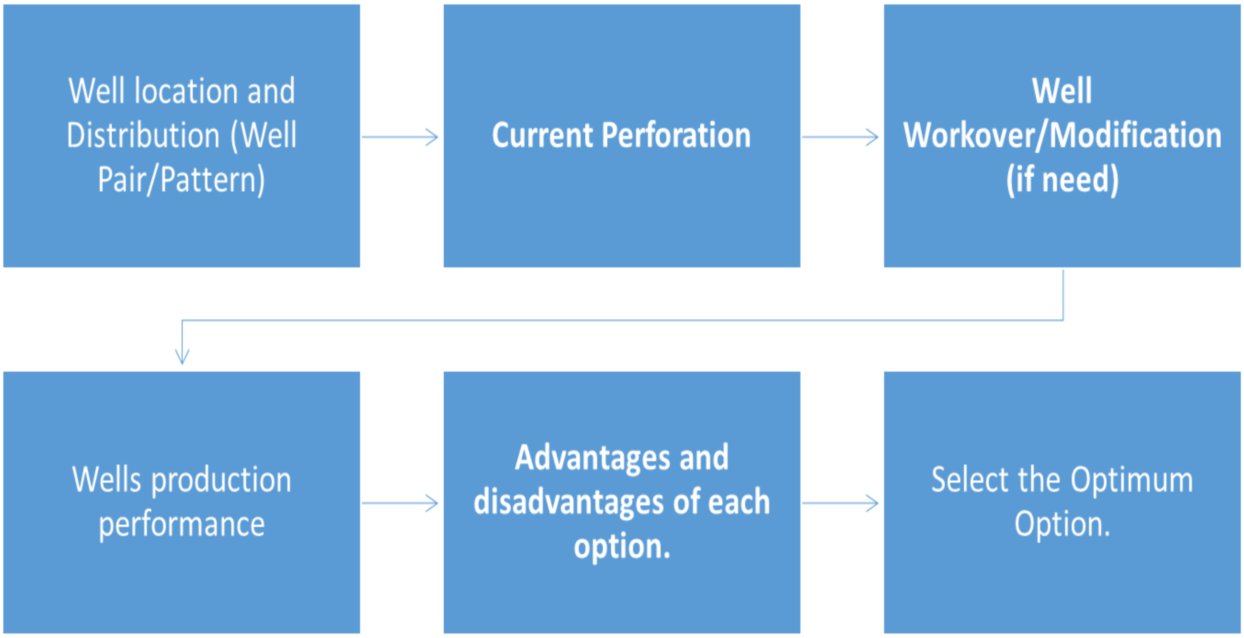


Figure 9 Detailed Screening Procedures

CHAPTER FOUR

4.Chapter Four

(RESULTS & DISCUSSION)

4.1. SUMMARY AND DATA COLLECTION

Hadida field located in Nugara sub-basin in the west are of (Block-6). 3 discovered structures (Hadida Main, Hadida North & Hadida Central). four reservoirs (Zarqa, Aradieba, Bentiu & AG) were discovered, meanwhile (Bentiu & AG) are main developed reservoirs. Field Development Studies:

Bentiu and Abu Gabra are the main target layers in this field. Reservoir lithology is predominantly fine to medium grained sandstones. Zarqa formation (Upper Cretaceous : 60-150m ; Bentiu formation (Lower Cretaceous) :1200-1300m.Abu Gabra formation (Lower Cretaceous) : 430-850m (Not drill through).

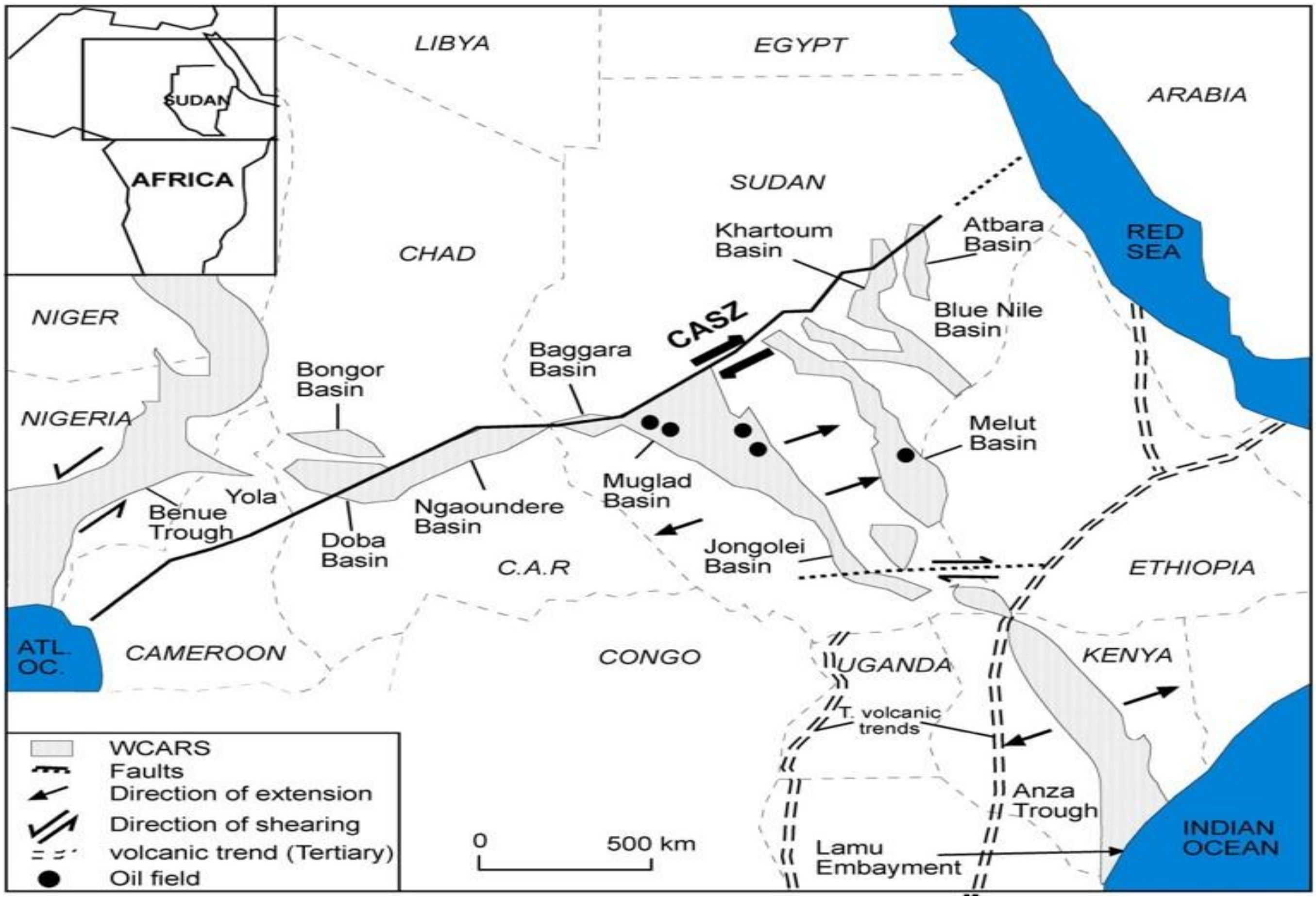


Figure 10 Hadida Map View

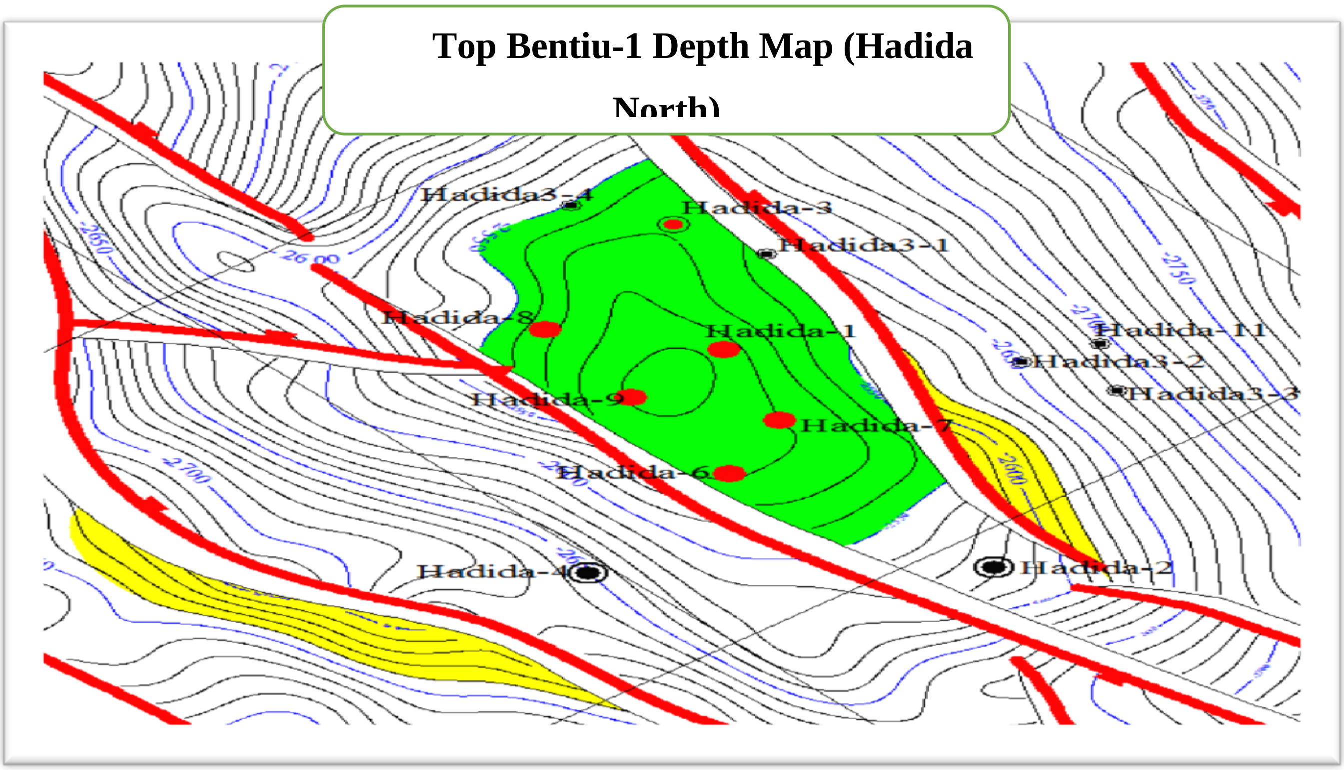


Figure 11 Top Bentiu-1 Depth Map (Hadida North)

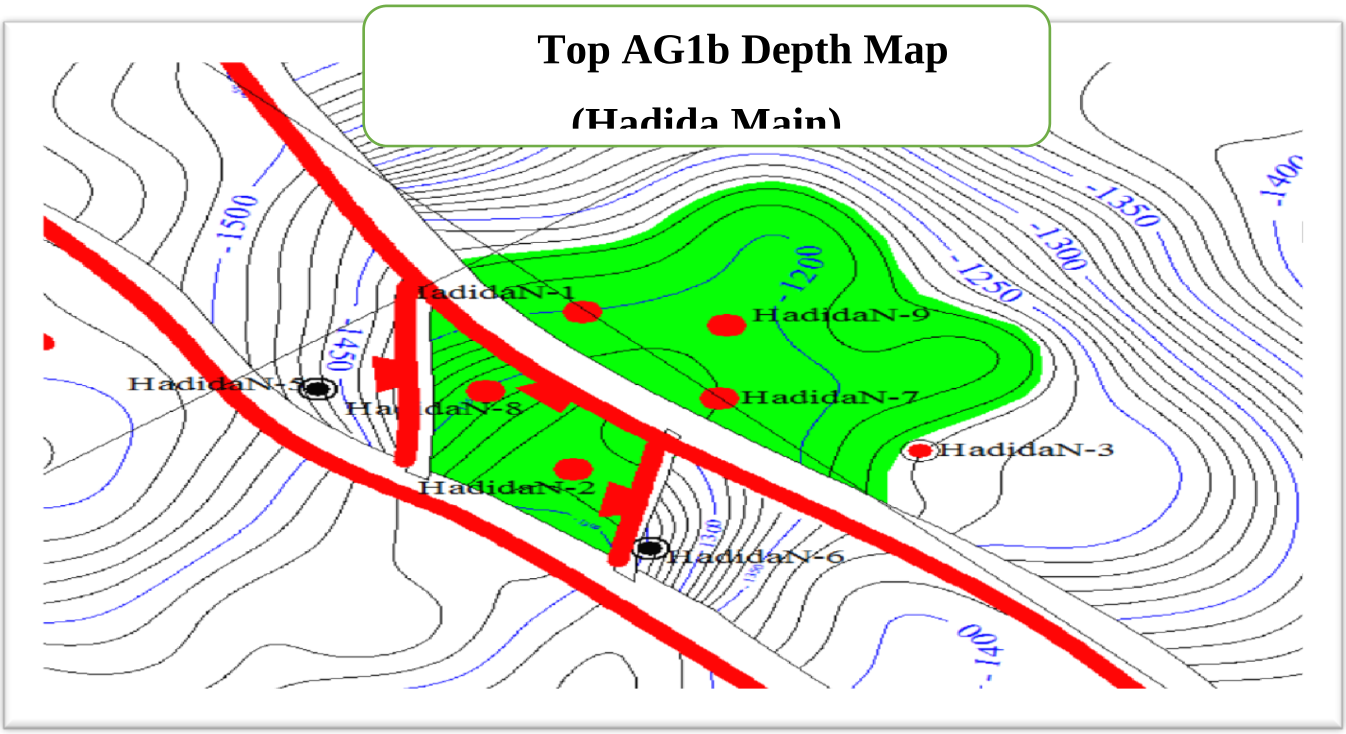


Figure 12 Top AG1b Depth map (Hadida Main)

Reservoir			H-1	H-3	H3-1	H3-2	H-3-3	H3-4	H-4	H-5	H5-1	H5-2	H-6	H-7	H-8	H-9	H-11	HN-1	HN-2	HN-6	HN-7	HN-8	HN-9	HC-1
Zarga									●															
Aradieba																	●							
Bentiu	B1	a				●	●	●		●	●	●					●				●		●	
		b		●	●														●			●		
		c																						
		d																		●				
		e																						
	B2																	●	●		●	●		
AG	AG1	a														●								
		b	●										●	●	●									●
		c																	⊘					
		d	⊘															⊘		⊘				
		e	⊘																			⊘		

Figure 13 Hadida Wells completion

Production Performance

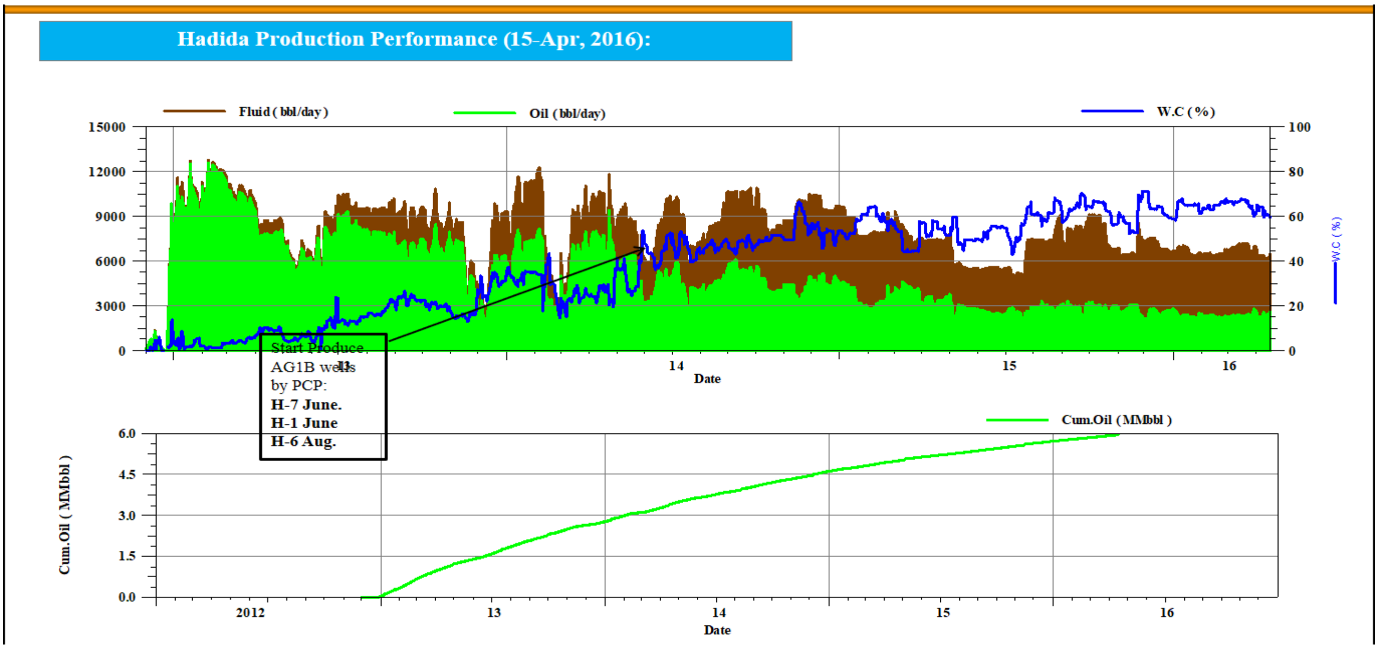


Figure 14 Production Performance

4.2. RESULTS FROM QUICK SCREENING

In this section, a quick screening of the collected data has been conducted using commercial EOR screening software (EORgui) for Hadida oil field. Results is illustrated in the next figures.

Title	AG Main				
API Gravity	39.74	Formation	Sandstone	Depth [feet]	9806
Oil viscosity [cP]	19.11	Thickness	< 20 ft	Temperature [deg F]	210
Oil Saturation, fraction	67.3	Composition	High % C1-C7	Permeability [mD]	1.8

Summary Screening | Detail

Properties	Nitrogen and flue gas	Hydrocarbon	Carbon Dioxide	Immiscible Gases	Miscellar/polymer, ASP, and alkaline flooding	Polymer flooding	Combustion	Steam
Oil API Gravity	> 35 Average 48	> 23 Average 41	> 22 Average 36	> 12	> 20 Average 35	> 15, < 40	> 10 Average 16	> 8 to 13.5 Average 13.5
Oil Viscosity (cp)	< 0.4 Average 0.2	< 3 Average 0.5	< 10 Average 1.5	< 600	< 35 Average 13	>10, <150	< 5,000 Average 1200	< 200,000 Average 4,700
Composition	High % C1-C7	High % C2-C7	High % C5-C12	Not critical	Light, intermediate. Some organic acids for alkaline floods	Not critical	Some asphaltic components	Not critical
Oil Saturation (%PV)	> 40 Average 75	> 30 Average 80	> 20 Average 55	> 35 Average 70	> 35 Average 53	> 70 Average 80	> 50 Average 72	> 40 Average 66
Formation Type	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate	Not critical	Sandstone preferred	Sandstone preferred	High porosity sandstone	High porosity sandstone
Net Thickness (ft)	Thin unless dipping	Thin unless dipping	Wide range	Not critical if dipping	Not critical	Not critical	> 10 feet	> 20 feet
Average Permeability (md)	Not critical	Not critical	Not critical	Not critical	> 10 md Average 450 md	> 10 md Average 800 md	> 50 md	> 200 md
Depth (ft)	> 6000	> 4000	> 2500	> 1800	< 9000 Average 3250	< 9000	< 11500 Average 3500	< 4500
Temperature (deg F)	Not critical	Not critical	Not critical	Not critical	< 200	< 200	> 100	Not critical

Figure 15 shows a detailed information for data analyzed using screening software for Abu Gabra main

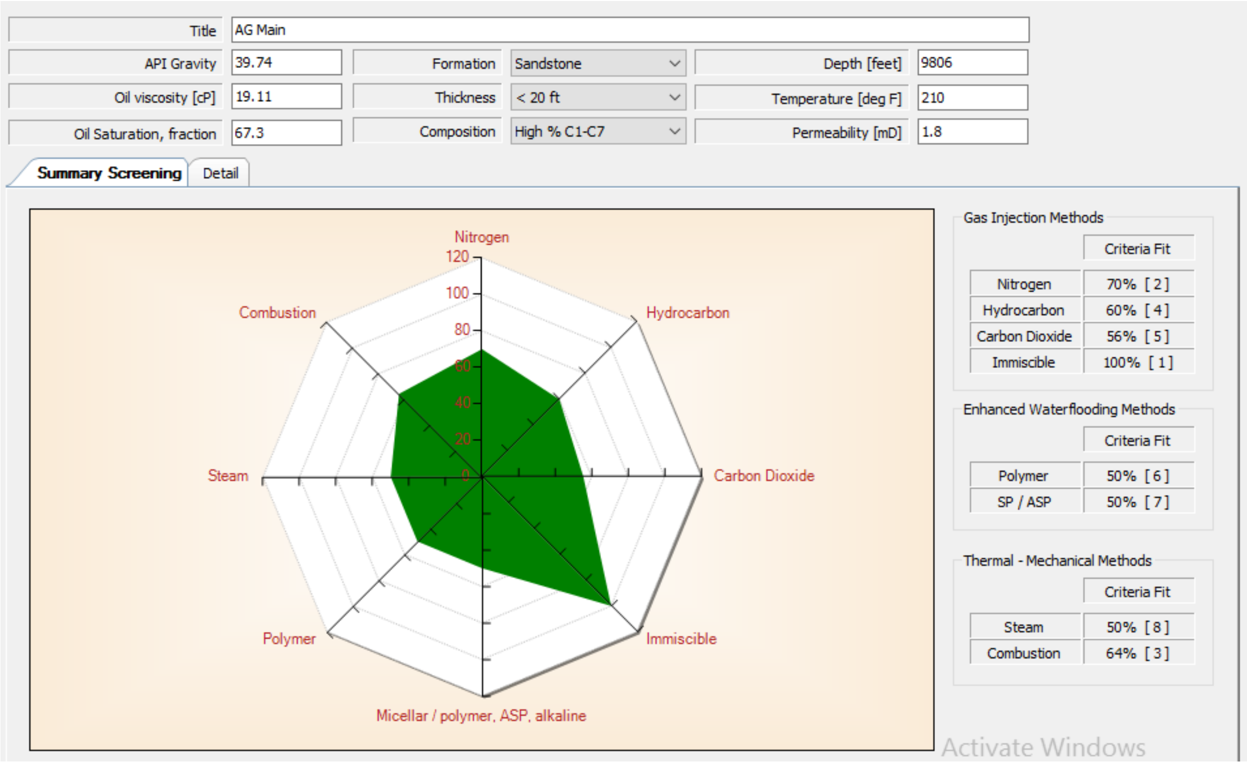


Figure 16 Graphical results of screened EOR methods for Abu Gabra

Figure above summarized the results of the quick screening. This Table shows that the immiscible is placed on the first rank in terms of accuracy with 100% and Nitrogen method is placed on the second rank in terms of accuracy with 70%. The accuracy of Hydrocarbon & CO2 miscible flooding method is 60% & 56% respectively. Moreover, the accuracy of chemical-based (micellar/polymer, ASP and alkaline) and polymer flooding are reported 50% and 50%, respectively. For Thermal and mechanical methods, it shows 50% & 64% for steam flooding & in-situ combustion respectively.

Title	Bentio Main Summmary				
API Gravity	24.3	Formation	Sandstone	Depth [feet]	5715
Oil viscosity [cP]	110.5	Thickness	< 20 ft	Temperature [deg F]	158
Oil Saturation, fraction	59.1	Composition	High % C1-C7	Permeability [mD]	1.8

Summary Screening | Detail

Properties	Nitrogen and flue gas	Hydrocarbon	Carbon Dioxide	Immiscible Gases	Miscellar/polymer, ASP, and alkaline flooding	Polymer flooding	Combustion	Steam
Oil API Gravity	> 35 Average 48	> 23 Average 41	> 22 Average 36	> 12	> 20 Average 35	> 15, < 40	> 10 Average 16	> 8 to 13.5 Average 13.5
Oil Viscosity (cp)	< 0.4 Average 0.2	< 3 Average 0.5	< 10 Average 1.5	< 600	< 35 Average 13	>10, <150	< 5,000 Average 1200	< 200,000 Average 4,700
Composition	High % C1-C7	High % C2-C7	High % C5-C12	Not critical	Light, intermediate. Some organic acids for alkaline floods	Not critical	Some asphaltic components	Not critical
Oil Saturation (%PV)	> 40 Average 75	> 30 Average 80	> 20 Average 55	> 35 Average 70	> 35 Average 53	> 70 Average 80	> 50 Average 72	> 40 Average 66
Formation Type	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate	Not critical	Sandstone preferred	Sandstone preferred	High porosity sandstone	High porosity sandstone
Net Thickness (ft)	Thin unless dipping	Thin unless dipping	Wide range	Not critical if dipping	Not critical	Not critical	> 10 feet	> 20 feet
Average Permeability (md)	Not critical	Not critical	Not critical	Not critical	> 10 md Average 450 md	> 10 md Average 800 md	> 50 md	> 200 md
Depth (ft)	> 6000	> 4000	> 2500	> 1800	< 9000 Average 3250	< 9000	< 11500 Average 3500	< 4500
Temperature (deg F)	Not critical	Not critical	Not critical	Not critical	< 200	< 200	> 100	Not critical

Figure 17 shows a detailed information for data analyzed using screening software for Bentiu Main

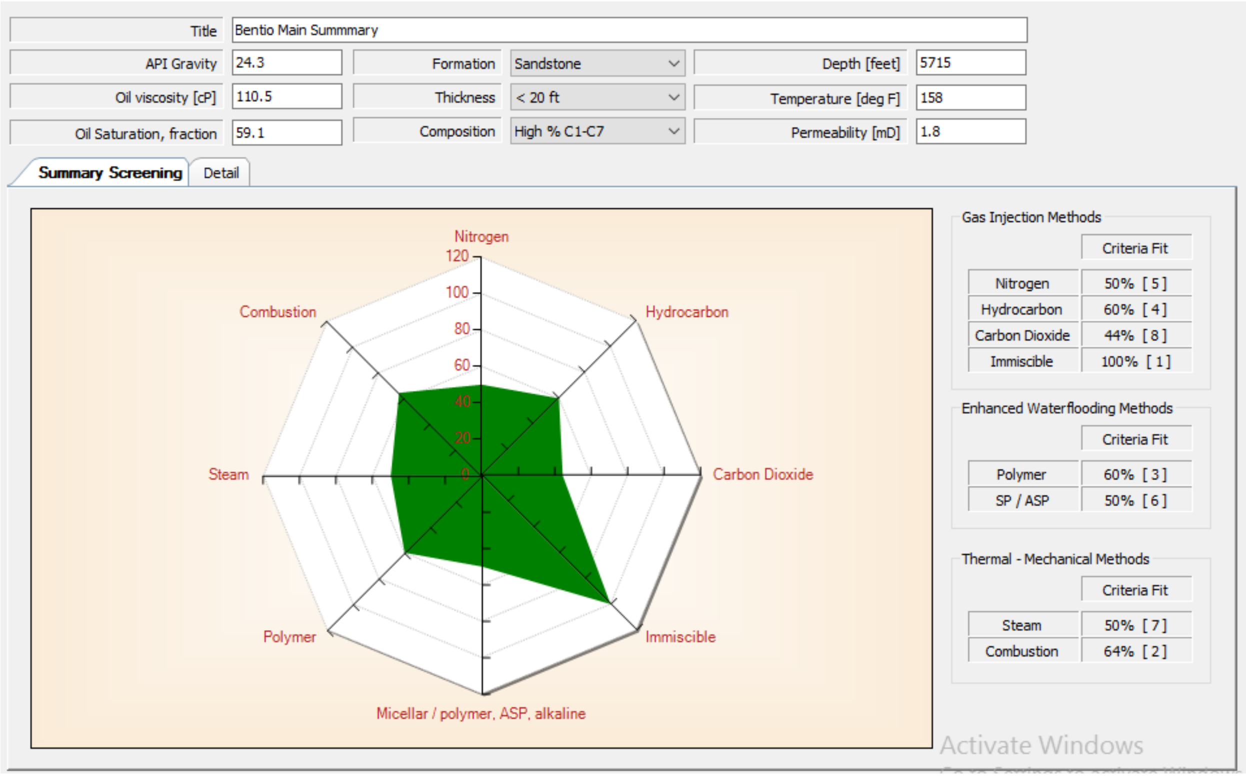


Figure 18 Graphical results of screened EOR methods for Bentio main

Figure above summarized the results of the quick screening. This Table shows that the immiscible is placed on the first rank in terms of accuracy with 100% and Hydrocarbon method is placed on the second rank in terms of accuracy with 60%. The accuracy of Nitrogen & CO2 miscible flooding method is 60% & 44% respectively. Moreover, the accuracy of chemical-based (micellar/polymer, ASP and alkaline) and polymer flooding are reported 60% and 50%, respectively. As previously mentioned, chemical flooding methods are recommended for oils higher than 15 API degree and viscosity in range of 15-35cp and greater depths. For Thermal and mechanical methods, it shows 50% & 64% for steam flooding & in-situ combustion respectively.

the study of conventional EOR screening resulted in:

1. Immiscible gas injection for AbuGabra formation.
2. Polymer flooding for Bentiu formation.

4.3. **HADIDA MAIN (ABU GABRA & BENTIU)**

Hadida Main area is sub- structure in Greater Hadida field. 1.5 Km² total area of the structure with 14 production wells till date as per below summary:

AG is primary target ,it Sub-structure allocated as follow (H-1,H-6, H-8, H-7 & H-9). while Bentiu in secondary target allocated as the following blocks:

1. Block 3 has Hadida (3,3-1, and 3-4)
2. Block 3-3 has Hadida (11,3-2 and 3-3)
3. Block 5 has Hadida (5,5-1 and 5-2)

additional screening criteria will be considered for Greater Hadida Field including Hadida main (Bentiu-1 & Abugabra) formations:

1. Well Pattern /Pairs
2. Well spacing

Wells at Hadida main oil field Total Wells at the field 22 single wells

Table 1 Hadida Field well Production data

Wells	Production zone Targeted	Production zone	Oil Rate	Water cut	Total fluid	Remarks
Hadida-3	Aradieba **D** ,B1a,B1b	B1b	76	83	449	Perforated Thickness 8m/2 zones
Hadida 3-1	B1a,B1b	B1b	34	82	188	Perforated Thickness 13.5m/2zones
Hadida 3-3	Aradieba D ,B1a	B1a	190	72	678	Perforated Thickness 11m/1zone
Hadida 3-4	B1b	B1b	214	69	690	Perforated Thickness 11m/1zone
Hadida- 5	B1,Aradieba E	B1	24	85	160	Perforated Thickness: 16m/4zones
Hadida 5-1	B1	Bentiu-light oil	20	88	164	Perforated Thickness: 16m/4zones
Hadida 5-2	B1	Bentiu-light oil	51	78	232	Perforated Thickness 34m/3zones
Hadida 3-2	B1a ,B1b	B1a	54	80	270	Perforated Thickness: 4.5m/1z
Hadida -11	Aradieba	Aradieba	22	86	157	Perforated Thickness 4m/1zone
Hadida-1	AG1b,AG1d,AG1e	AG1b	77	55	171	Perforated Thickness 7m/2zones
Hadida -6	AG1b	AG1b	550	58	1311	Perforated Thickness 11m/2zones

Hadida-7	AG1b	AG1b	115	75	461	Perforated Thickness 2m/1z
Hadida -8	AG1b, B2	AG1b	6	81	31	Perforated Thickness 6m/1z
Hadida-9	AG1a	AG1a	732	37	1162	Perforated Thickness 17.5m/6z

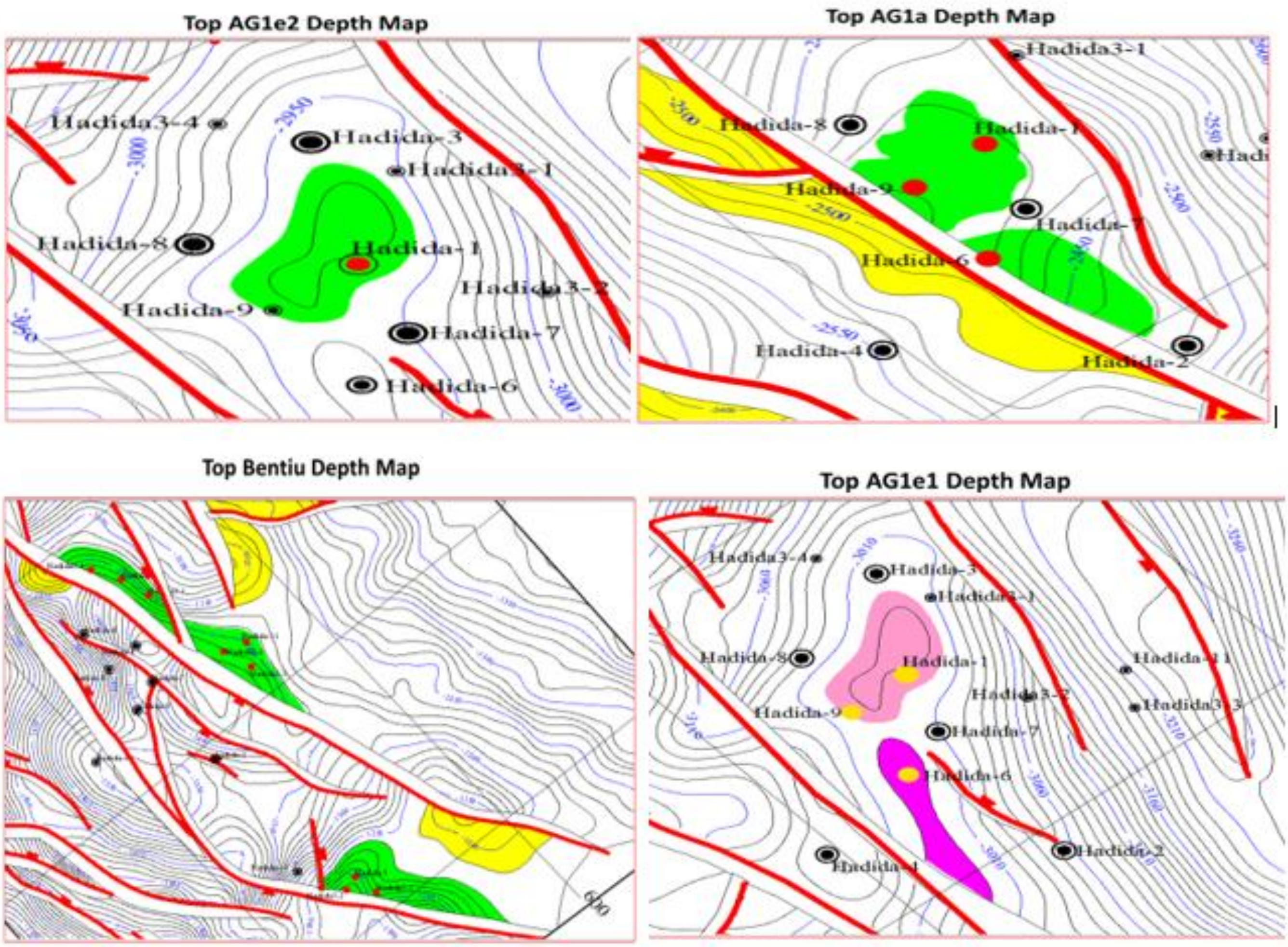


Figure 19 depth maps for Abu Gabra & Bentiu formations

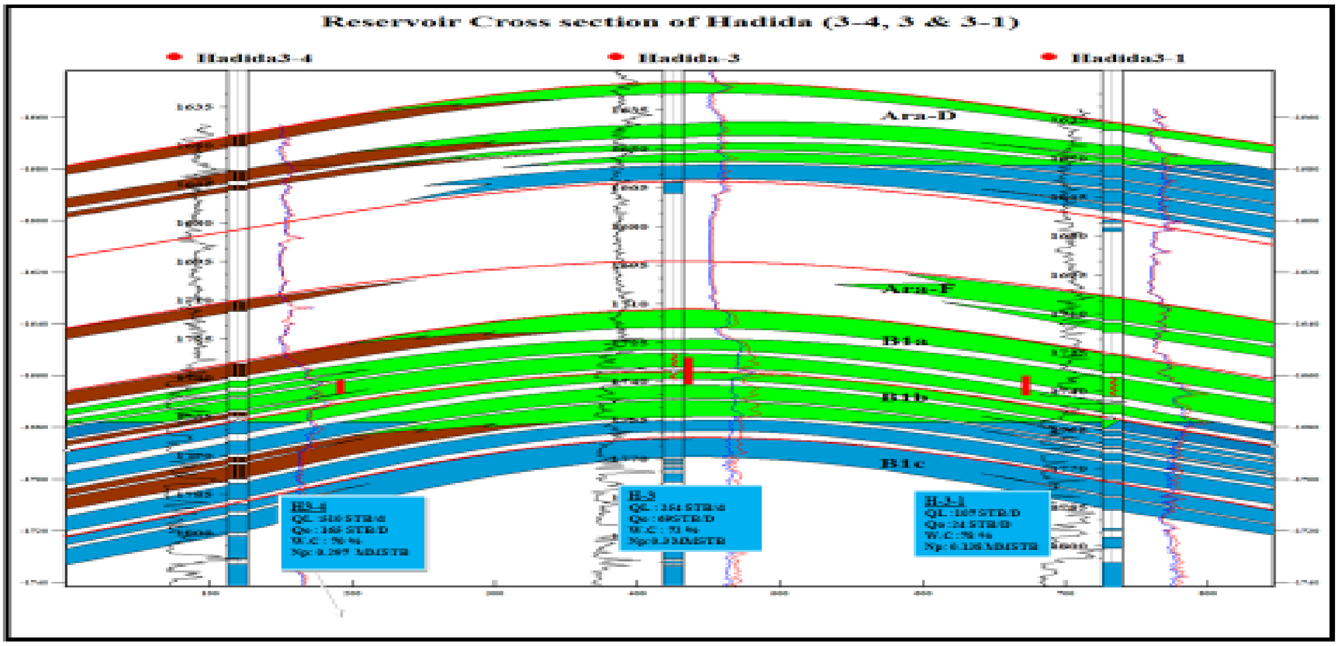


Figure 20 reservoir cross section of Hadida (3-4, 3, 3-1)

4.3.1. **Proposed patterns options**

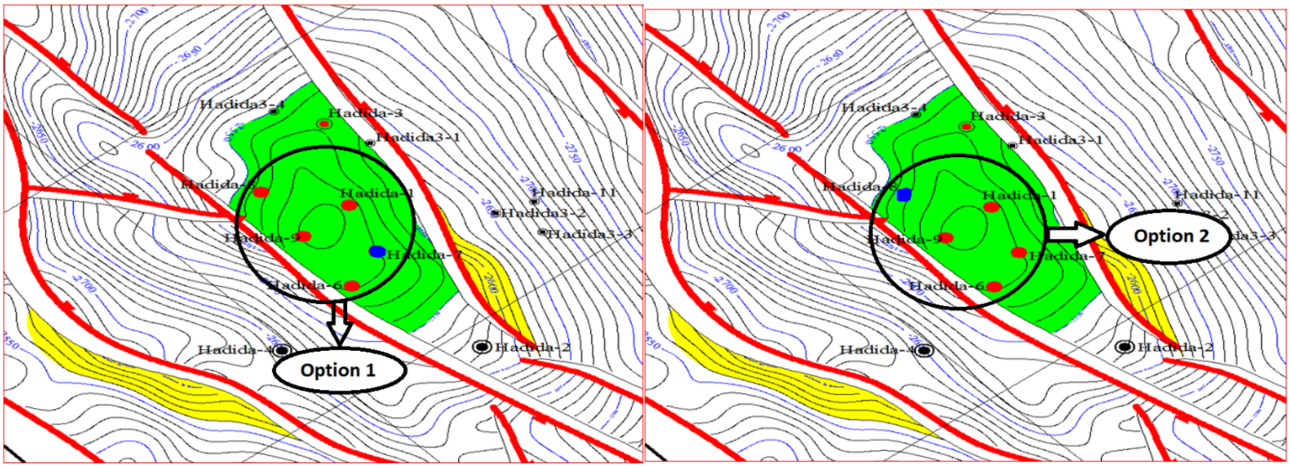


Figure 21 well patern options (1 and 2)

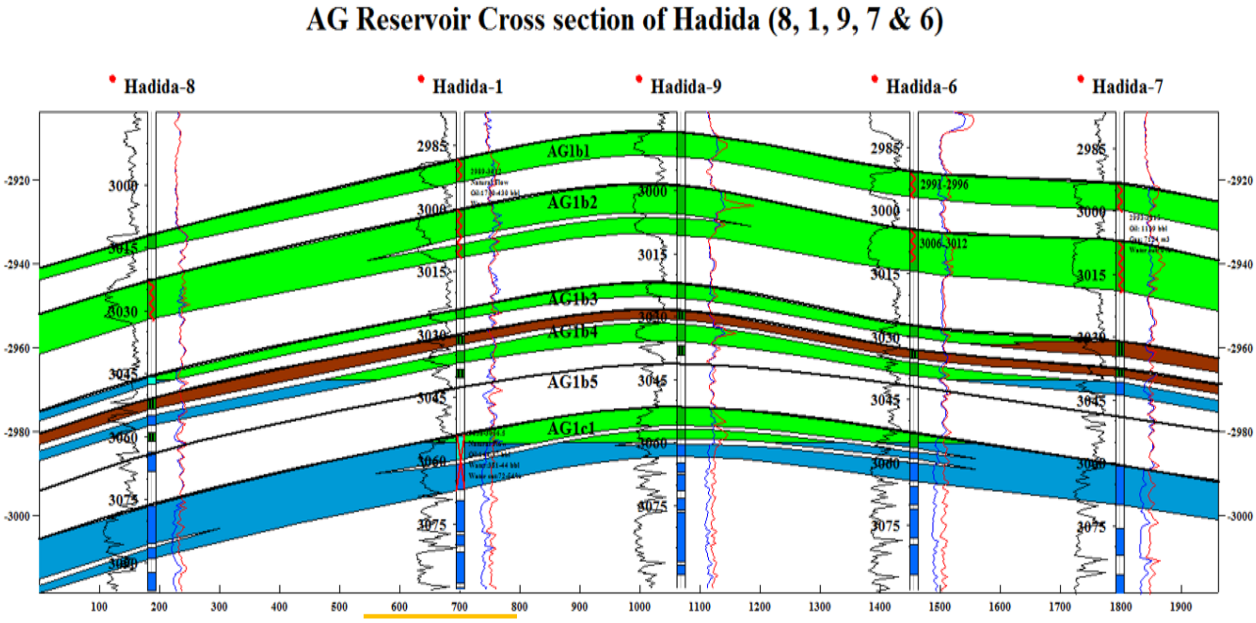


Figure 22 Gabra reservoir cross section (8,1,9,7 & 6)

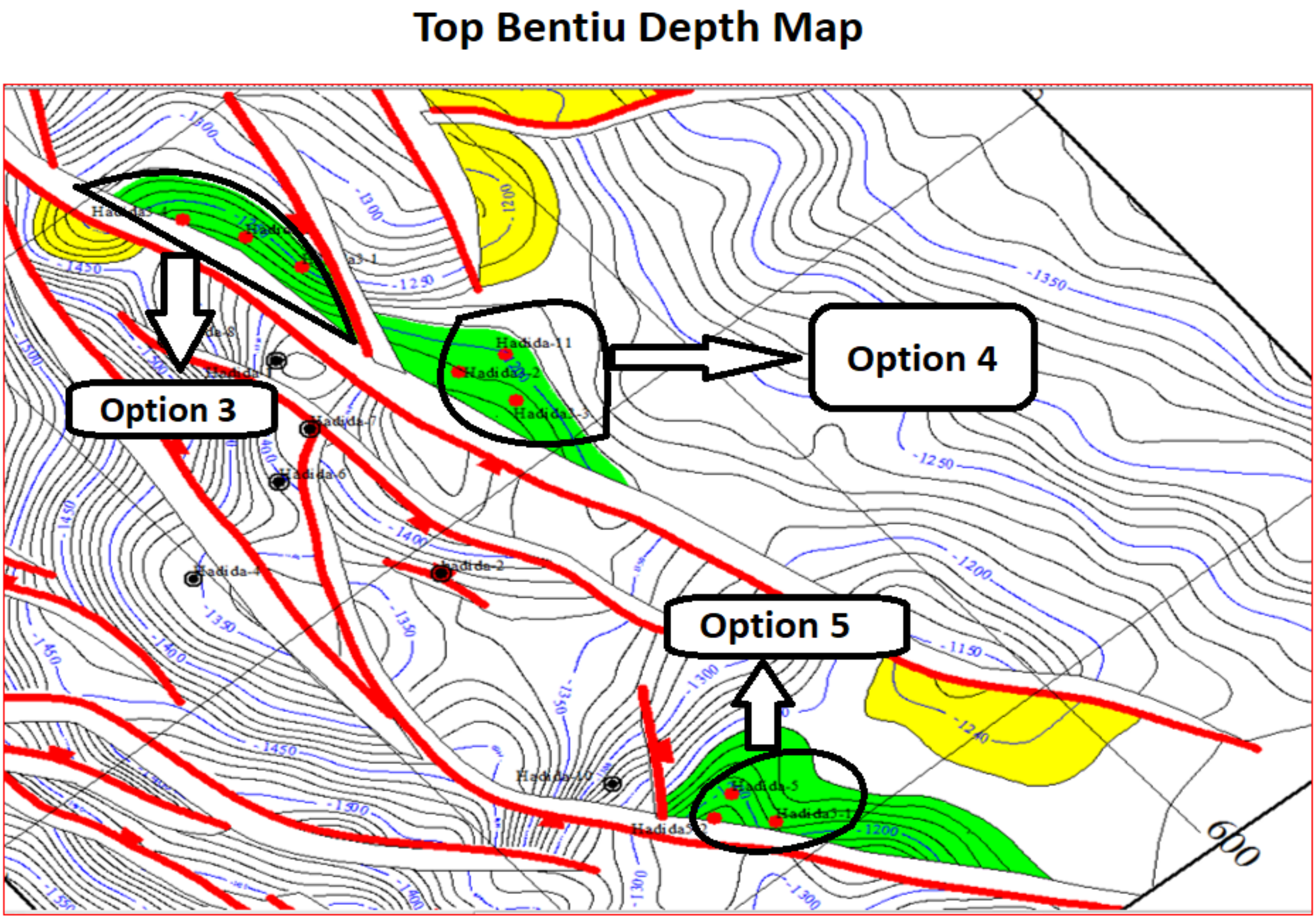


Figure 23 Well patter options

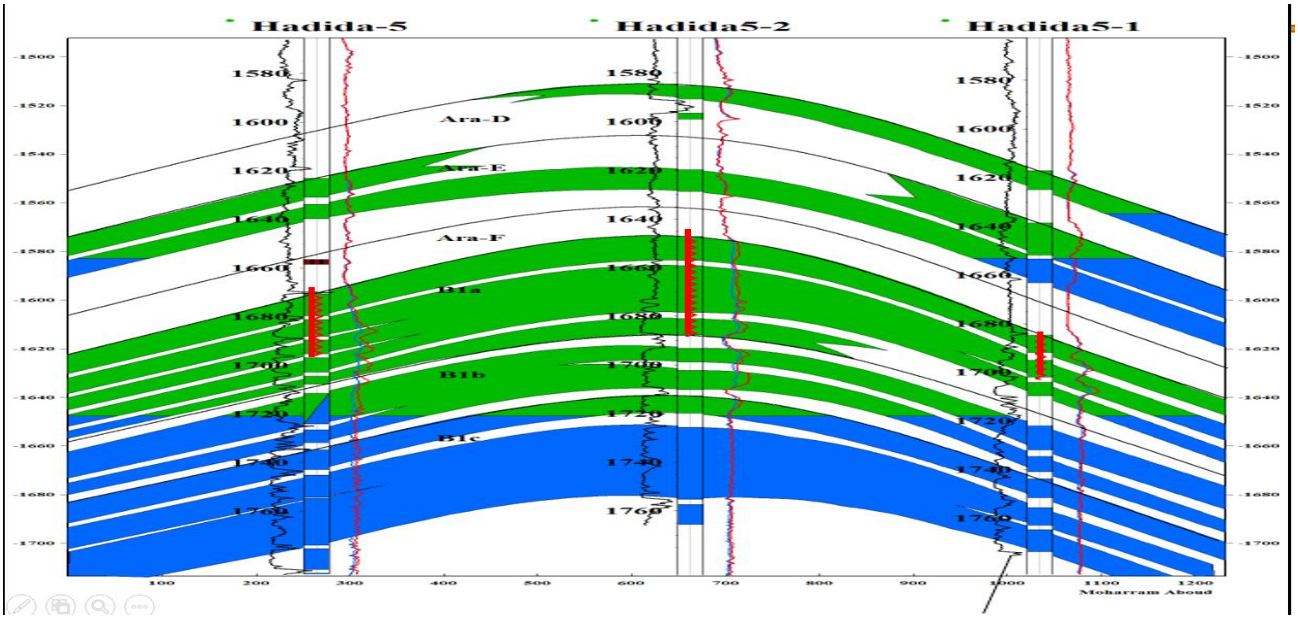


Figure 24 Bentiu reservoir cross section of hadida (5,5-2 & 5-1)

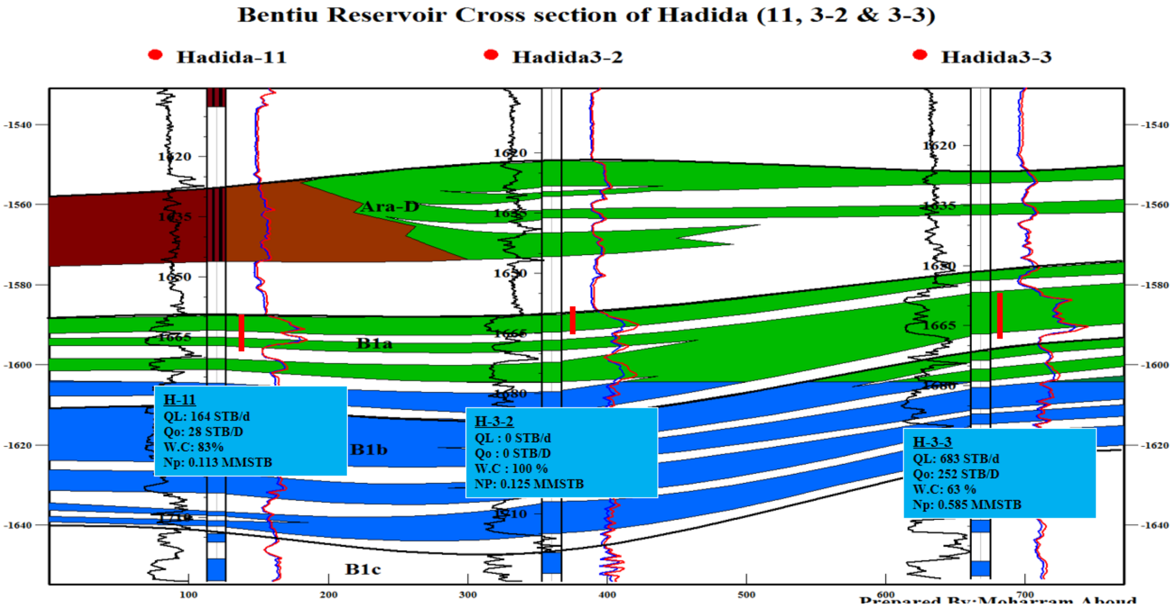


Figure 25 Bentiu reservoir cross section of hadida (11,3-2 & 3-3)

4.3.2. **Well spacing for Hadida Main**

Option 1

Table 2 : well pattern options – choosing N-07 as injector :

*

From	To	Distance (m)
H-07	H -06	340
H-07	H-09	730
H-07	H-01	1100
H-07	H-08	1620

Option 2

Table 3 well pattern options choosing N-08 As injector :

From	To	Distance(m)
H-08	H-07	1620
H-08	H-06	1280
H -08	H-09	890
H-08	H-01	520

Option 3

Table 4 : well pattern options choosing H 3-1 As injector :

From	To	Distance(m)
H 3-1	H 3	300
H 3-1	H 3-4	620

Option 4

The well H-11 proposed to be converted to an injector, it's currently produced in a low rate (22 bbl/day) and a high water cut 86%. Furthermore, it has a good spacing 240m from producer H 3-2 .It needs workover jobs (Squeeze H-9 AG1a and perforate AG1b).

Table 5 : well pattern options choosing H-11 As injector :

From	To	Distance(m)
H- 11	H 3-3	540
H -11	H 3-2	240

Option 5

For this option, we recommend to drill a new well as an injector, for a reason that the well spacing doesn't meet the minimum requirement (the shortest distance is 410m > 350m)

Table 6 well pattern options choosing H-5 As injector :

From	To	Distance(m)
H- 5	H 5-2	410
H -5	H 5-1	780

4.3.3. **Production Disturbance Tables**

Options	Injector	Producer	Oil rate (bbl /d)	Water Cut (%)
Option 1	**Convert –H-07 (Oil rate = 157 bbl/d WC = 75 %)**	**H-01**	**93**	**44**
		H-06	**550**	**58**
		H-09	**732**	**37**
	Average Oil Rate and Water Cut		**458.33**	**46.3**
Option 2	**Convert –H-08 (Oil rate = 6 bbl/d WC = 81%)**	**H-01**	**93**	**44**
		H-06	**550**	**58**
		H-07	**157**	**75**
	Average Oil Rate and Water Cut		**266.66**	**59**

Table 7 Production Disturbance for Abu Gabra

Table 8 Production Disturbance for Benetiu

Option 3	**Convert –H 3-1 (Oil rate = 34bbl/d WC =82 %)**	**H-03**	**76**	**83**
		H 3-4	**214**	**69**
	Average Oil Rate and Water Cut		**145**	**76**
Option 4	**Convert H-11 (Oil rate = 22 bbl/d WC = 86%)**	**H 3-2**	**54**	**80**
		H3-3	**190**	**72**
	Average Oil Rate and Water Cut		**122**	**76**
Option 5	**Drill new well**	**H -05**	**24**	**85**
		H5-1	20	88
		H 5-2	51	78
	Average Oil Rate and Water Cut		**35.5**	**83**

4.3.4. **Work over Proposals for the Pilot Wells**

Table 9 Workover proposal for Abu Gabra

Options	injectors	Current Perforation	Producer	Current Perforation	Required Work over
Option 1	Convert H-07	AG1b	H-01	AG1b,AG1d, AG1e	Squeeze H-1 AG1d and AG1e
			H-06	AG1b	
			H-09	AG1a	Squeeze H-9 AG1a and perforate AG1b
Option 2	Convert H-08	AG1b	H-01	AG1b,AG1d, AG1e	Squeeze H-1AG1d and AG1e
			H-06	AG1b	
			H-07	AG1b	

Table 10 Workover proposal for Bentiu

Option 3	**Convert H 3-1**	**B1a,B1b**	**H-03**	**Aradieba** D **,B1a,B1b**	**Squeeze H-3 (Aradieba D and B1a) and drill new well as producer at B1b**
			H 3-4	B1b	
			H-07	AG1b	
Option 4	infill drilling	B1a	H 11	Aradieba	Squeeze formation (Aradieba)& add new perforate B1a for well (H-11).
			H 3-2	B1a	
			H 3-3	B1a	
Option 5	infill well drilling	B1	H 5-1	B1	
			H-05		
			H5-2	B1	

-

Table 11 Advantages & disadvantages of considered options

Options	Advantages	Disadvantages
Option 1	Three producers are vertical wells	Required workover (1 Perforation and 3 squeeze job)
Option 2	Low cost than option 1 & option 3	• Requires workover (2 squeeze jobs)
Option 3	- Good Spacing -Low average production	• Requires new well drilling • Requires workover (2 squeeze job)
Option 4	Good spacing	• Requires new well drilling
Option 5	Low cost than option 1 & option 3 (only one well proposed for new drilling)	Requires new producer

4.3.5. **Well spacing for best proposed Candidates for well pair for Hadida main (Abu Gabra and Bentiu)**

Table 12 Well pairs options for Abu Gabra

Option	Formation	From	To	Distance (m)
1	Abu Gabra	H-07	H-06	340

Table 13 :Well pairs options for Bentiu

Option	Formation	From	To	Distance (m)
2	Bentiu	H-11	H3-2	240
3	Bentiu	H 3-1	H 3	300

4.4. **FINAL RESULTS & DISCUSSION**

- Pre-screening (quick sqreening) using EORGui commercial software has been conducted followed by a detailed screening to select the most feasible EOR method.
- From the conventional and Detailed screening processed ,the results shows that the most feasible recovery processes for Hadida field (Abu Gabra & Bentiu) is:

  i. The immiscible gas flooding for Abu Gabra main as convetional screening only due to the lack of sufficient data.

  ii. Polymer flooding is recommended due to high water production in Bentiu formation ,hence polymer is used to obtain favorable mobility ratio and because of the availability of the polymer compared to other methods.

- Best options that propposed for this oil field in term of geological model ,well pairs conductivity ,wells paterns, faults location and production performance has been selected as follow :
  1. Option 1 (H-7,H-9,H-1 and H-6)
  2. Option 2 (H-8,H-7,,H-1 and H-6)
  3. Option 3 (H 3-1 , H 3 and H 3-4)
  4. Option 4 (H 11, H 3-2, and H 3-3)
  5. Option 5 (H-5 ,H 5-1 and H 5-2)
- To select the best candidate well for injection or production in, the study shows that option 3 which include (H 3-1 , H 3 and H 3-4) is most likely to be the optimum pilot sector, that’s because:

a) The production disturbance in this option is average comparing to other options.

b) The well proposed to be converted to an injector (H 3-1) produces in a low rate and high water cut (Oil rate = 34bbl/d WC =82 %).

c) It has good well spacing and good sand continuity.

d) It requires workover squeeze job.

Option 3 has a good well spacing but it requires more workover jobs (squeeze and perforation) and new well drilling for the injection. Moreover, Option 5 has been eliminated because it doesn’t qualify to the well spacing criteria.

CHAPTER FIVE

5.Chapter Five

CONCLUSION AND RECOMMENDATIONS

5.1. SUMMARY

In this chapter, combination of the elements discussed in detail in the preceding chapters to integrate the strategy that is conducive to enhanced oil recovery (EOR) projects. Published results show that a combination of conventional and detailed EOR screening represents a valuable approach to support reservoir development plans (RDPs).

5.2. CONCLUSION

- The application of detailed EOR screening is very useful to select the best and most feasible EOR method.
- In this study the screening processes result for Hadida oil field show that the immiscible gas injection and polymer flooding are the most feasible EOR methods to be implemented in this area.
- The study proposes to apply irregular well patterns and fully use of the current existing wells.
- Drilling new infill wells are proposed in option 3 as injectors.

5.3. RECOMMENDATIONS

There are some recommended factors to be taken into *consideration* are resulting from the study

- Take into Consideration the economical evaluation before any stage of implementations of the process, profits from produced oil can be estimated and compared to overall production cost.
- Liquid production optimization is needed to control the massive water production, because Hadida Main (Bentiu formation) has a problem of high water cut due to edge water attack.
- The Wells are recommended to produce in a commingled way due to the limited distribution of pay zones and relatively thin net pay.

References

1. **Ahmed Al Adasani, Baojun Bai 2011 analysis of EOR project and updated screen criteria and enhanced oil recovery field project, Kuwait oil company, petroleum engineering department Missouri university of science and technology united states.**

2. **Baghir A. Suleimanov, S. Ismayilov, OleqA. Dyshin, Elchin F. Veliyev , Selection Methodology for Screening Evaluation of EOR Methods (2016) ,'oil gas scientific Research project'' Institute, SOCAR, Baku, Azerbaijan.**

3. **Eduardo Manrique, Mehdi Izadu Curtis Kitchen, Norwest-Questa Engineering and Vadimir Alvarado, Effective EOR Decision Strategies with Limited Data: field Cases Demonstration, University of Wyoming. Presentation at 2008.**

4. **Elradi Abass,Cheng Lin Song ,2011,Artificial Intelligence selection with capabilityof editing a new parameter for EOR screening criteria. Faculty of Petroleum Engineering, China University of Petroleum-Beijing (CUPB), China. Journal of Engineering Science and Technology, School of Engineering, Taylor's University 6:628---638.**

5. **J.J Taber, F.D. Martin, R.S. Seright, 1983,technical screening guides for the enhanced oil recovery of oil, In: Proceeding of the 58th annual technical conference and exhibition. San Francisco, California, USA.**

6. **J.J Taber, F.D. Martin, R.S. Seright, 1997, EOR screening criteria revisited. Part 1: introduction to screening criteria and enhanced recovery field projects. New Mexico petroleum recovery research center, Oklahoma.**

7. **J.J Taber, F.D. Martin, R.S. Seright, 1997, EOR screening criteria revisited. Part 2: introduction to screening criteria and enhanced recovery field projects. New Mexico petroleum recovery research center, Oklahoma.**

8. **Mahendra K. Verma ,2015, Fundamentals of Carbon Dioxide-Enhanced Oil Recovery (CO2-EOR)—A Supporting Document of the Assessment Methodology for Hydrocarbon Recovery Using CO2-EOR Associated with Carbon Sequestration, U.S. Geological Survey, Reston, Virginia.**
9. **M.trujillo, D.Mercado ,G.Maya, R.Castro,C.soto ,H.perez, V.Gomez and J.sandra 2010, Ecopetrol S.A. prepared for presentation at the SPE latin American& Caribbean petroleum Engineering conference held in Lima , peru.**
10. **Ridha Gharbi , Abdullah Alajmi and Meshal Algharaib 2012 , The Potential of a Surfactant/Polymer Flood in a Middle Eastern Reservoir, Department of Petroleum Engineering, Kuwait Universit.**
11. **T.B. Jensen, K.J. Harpole, and A. Østhus 2000, EOR Screening for Ekofisk .Phillips Petroleum Company, This paper was prepared for presentation at the SPE European Petroleum Conference held in Paris, France.**