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Analyses some sudanese reservoirs for water flooding and potential of EOR

تحليل بعض المكامن السودانية للغمر المائي وإمكانيتها للاستخلاص المحسن للنفط

This dissertation is submitted as partial requirement of B.Tech Degree (Honor) in Petroleum Engineering.

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الآيـــــــــة

قال الله تعالى في محكم تنزيله :

(قل لو كان البحرمداداً لكلمات ربي لنفد البحر قبل ان تنفد كلمات ربي ولو جئنا بمثله مددا)

سورة الكهف اية رقم (109).

Dedication

To our Parents father and mothers who lighting the Path for us to move forward, advising, and motivating us by their wide wisdom to reach this level of life without them we would not become the person who I am today. To our brothers and sisters who stand with us, allow us to use their purpose when we need it to complete this research. For Petroleum Student who will share and upgrade the oil industry Revolution in our great country Sudan. We are humble to offer this modest work and we hope that assisting to guide and understand some principle of an oil industry process. Thanks all for supporting and encouraging.

Acknowledge

Undertaking project of this size.We are deeply thankful to our supervisor Proff. Eng. Satti Marghani Mohammed Ahmed For his technical orientation, Motivation and good support .throughout this research. Our profound gratitude goes to engineer Hamza Ahmed for taking care about us and deducting from his working time to guide us. We greatly thanking him and wishing for him a nice future in oil industry. also we are appreciate to the department of Petroleum Engineering and Technology and all teaching staff for giving us huge information in oil industry and advance technology .

Abstract

In this research Rock prosperities and reservoir properties collected from Sudanese fformation and analyze carried out for these data by ranging method to select the suitable formation for water flooding method, and the formation which not applicable for water flooding, analyze carried out by using EOR gui software to select the suitable tertiary method, found that Just South alnagma field is suitable one in Bantiu and aradiba for water flooding method, and the EOR method for three fields (Bamboo, Tayeb and Azraq) in Bantiu and aradiba is Immiscible method .

التجـــــــــريد

في هذا البحث تم جمع معلومات من الحقول السودانية في طبقات بانتيو وعرديبة وهي صفات الصخور والصفات المكمنية وعمل تحليل لها لاختيار اي الحقول في الطبقات أنسب للاستخلاص الثانوي (الغمر المائي) بواسطة ال(.(ranging method

وجد أن حقل (South Annagma) ودفرة وكيبي هي أنسب الحقول لتطبيق الغمر المائي وتم عمل تحليل في الطبقات بانتيو وعرديبة للحقول الغير مناسبة للغمر المائي لاختيار أنسب طريقة للاستخلاص المحسن للنفط عن طريق برنامج (EOR gui) ووجد أن (immiscible gas) هي الامثل لثلاثه حقول وهي (بامبو, ازرق وحقل الطيب).

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Nomenclature

EOR : Enhanced Oil Recovery

GNPOC : Greater Nile Petroleum Operating Company

IFT : Interfacial Tension

ISC : In Situ Combustion

PV : Pore Volume

RF : Recovery Factor

SPE : Society Of Petroleum Engineering

S : Saturation, fraction

So : Oil saturation, fraction

M : Mobility ratio, general (displacing / displaced)

λ : Mobility (k/μ),md/cp

Pc : Capillary pressure.psi

EV : Volumetric efficiency

EA : Areal efficiency

Ev: Vertical efficiency

q : Production rate or flow rate, bbl/day

k : Absolute permeability, md

σ : Surface tension, interfacial, lbm/s2

g : Acceleration of gravity, ft/s2

ρ : Density, lbm/ft3

γo : Oil specific gravity

μo : Oil viscosity,

Ø : Porosity

h : Thickness (general and individual bed), ft.

D : Depth, ft.

T : Temperature, oF

CO2 : Carbon Dioxide

N2 : Nitrogen Gas

Chapter 1

Introduction

1.1Introduction:

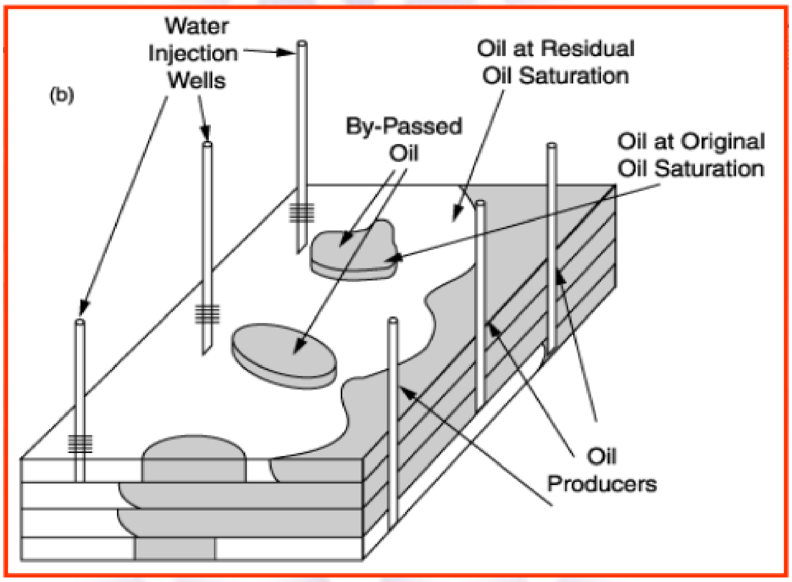
The general mechanism of oil recovery is movement of hydro carbon to production wells due to pressure difference between reservoir and the production wells The recovery of oil recovery is divided into three main categories worldwide:

1. Primary recovery Technique:

This implies the initial Production stage resulted from the displacement energy naturally existing in a reservoir

2. Secondary recovery Technique:

Normally utilized when the primary production declines, traditionally these technique are water flooding and gas Injection the recovery factor can raise up to 50% by using them.



(Fig 1:1) Water Oil Displacement at Reservoir

3. Tertiary recovery techniques:

These techniques refer to the ones used after the Implementation of the secondary recovery method, usually these processes use miscible gases chemical and or thermal energy to replace additional oil after the secondary recovery process has become Uneconomical the necessary factor may arise up 12C additionally to the RF obtained with the secondary recovery method.

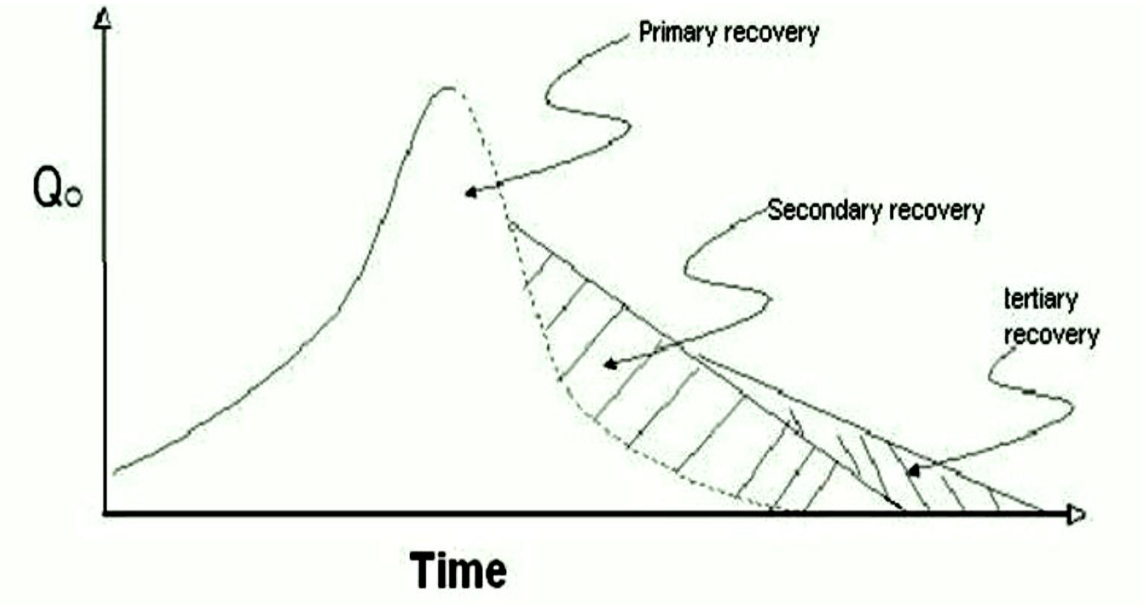


Fig.(1.2): Recovery Stages of a Hydrocarbon Reservoir Through Time (Sultan Pwage et al, 2010)

1.2.Problem Statement:

Sudanese oil Field has low recovery because of the decrease in the production, so that it need water flooding recovery process.

The study examine Sudanese Reservoires to select the best reservoir for water Flooding.

1.3. Objective

1. Study Rock and fluid properties that effect selecting of water flooding methods.

2. analyze Sudanese reservoir to determine the best one for water flooding.

1.4 Methodology:

1- Collect Data from Sudanese wells (Rock proprieties and reservoir Prosperities)

2- Study successful Reservoire for water flooding Method.

3- Ranging for the successful prosperities.

4- Analyze for all Sudanese Reservoir for water Flooding Method.

5-Using EOR GUI Software for inapplicable Reservoires for water flooding.

Chapter 2

Literature Review and Theoretical background

2.1 Literature Review:

Taber et.al in 1996 developed EOR criteria in (EOR screening criteria revisited part1) paper. The criteria are based on oil displacement mechanisms, the results of EOR field projects application reported in oil and gas journal, and at various SPE, conferences and they mentioned that: The depth oil gravity and oil production from hundreds of projects are displayed in graph to show the wide distribution and relative importance of the methods. Steam flooding continues to be dominant method but hydrocarbon injection and CO_2 flooding are increasing and if only oil gravity is considered, the results show that there is a wide choice of effective methods that range from miscible recovery of the lightest oil by nitrogen injection to steam flooding and surface mining for heavy oil and tar sands. However, there is often a wide overlap in choice with low oil prices, there is less chemical flooding of the intermediate-gravity oils that are normally water flooding polymer flooding continues to show promise especially if projects are started at high oil saturation.

In 1996, Taber.et.al also has published EOR screening criteria revisited part 2. They have found that: The CO_2 screening criteria were used to estimate the capacity of the world's oil reservoir for the storage/disposal of CO_2 and the impact of oil prices on EOR production in the U.S was considered by comparing the recent EOR production to that predicted by the NPC reports for various oil prices

Ahmed Aladasani and BaojunBai in 2010 reviews recent development in enhanced oil recovery (EOR) techniques published in

SPE conference proceedings for 2007 to 2009. It also updates the EOR criteria developed by Taber et al.

GalalEldinYousif in 2010 has studied all Sudanese fields through screening criteria based on only five properties, which are permeability, oil viscosity, depth, pressure and API gravity by using SPE format, to select the suitable EOR method for each block to increase the recovery factor. He reviewed economic analysis for methods that applied in Sudanese fields also; he made road maps and wide picture for EOR in Sudan

Abd-AlrhmanSalih Ali et al in 2010 had proposed screening criteria for all enhance oil recovery methods based on geological description and reservoir properties from previous oil field experience besides economic evaluation and ranking of IOR/EOR opportunities. Data from AB field had been examined and the optimum. They had noted reservoir characteristics for successful field enhancing performance.

2.2History of Oil in Sudan:

Exploration activities in the Sudan began at the end of the 1950s in the coastal waters of the Red Sea and the Sudanese continental shelf by the Italian company (AGIP) at mid of 1970s to 1980s exploration activities were very active and shifted to the interior basins of the Sudan. Chevron drilled the first well in AbuGabra area in 1977 and Baraka-1 in 1978 providing the presence of source rock and made its first discovery of unity-1. Sudan has been producing its petroleum resource commercially since 1999 when Block 1/2/4 started production of reserve. This was the major achievement by its operator GNPOC when they commercialize and export crude to foreign buyers via 1500 km new pipeline to Port Sudan. Since then, its daily production has increase to maximum of 300 KBOPD in 2006 (before it started declining rapidly with increasing water production). Three more operators: Petro-Energy, PDOC and WNPOC started their oil production in 2006 (GalalEldin, 2010)

Total Sudan oil in place as of 1st January, 2009 was estimated to be 15.9 billion barrels, 39% of which (6.2 billion barrels) is in Block 3/7 operated by PDOC which contributes about 37% of total Sudan estimated ultimate oil recovery. GNPOC holds second biggest oil in place, which is about 5.5 billion barrels but the highest recoverable oil of 1.6 billion barrels, contributing about 45% of the national reserve. The remaining is possessed by WNPOC and Petro-Energy (GalalEldin, 2010).

The average recovery factor for Sudan is estimated at 23%, which is relatively low on international standard, and GNPOC's average recovery factor is the highest at 26%, followed by PDOC, Petro-Energy and WNPOC at 21.5%, 23% and 11.9% respectively according to (Sudapet, 2009). This is low recovery factor is attributed to amongst other qualities of the oil and also non-favorable reservoir properties, GNPOC's API is the highest at 33 API, followed by PDOC at 25 API, WNPOC at 21 API and Petro-Energy at 18 API. With declining production and the fact that 77% of the oil will remain in the ground at the end of field producing life, there is an urgent need to adopt new approach in order to enhance oil recovery to arrest the declining production. Most oil fields production is on natural depletion and assisted by artificial lift pumps. Only Unity and Talih fields in GNPOC are on water injection to provide pressure maintenance, while a pilot test was being implemented in PDOC. In the low API oil and viscous crude production environment, water injection is usually not favorable for application due to the poor mobility ratio which susceptible to water fingering. Early high water-cut and low oil production rate are expected in heavy oil production. Beside infill drilling, well stimulation and horizontal well drilling to produce the "low hanging fruits" a major step forward is needed to improve oil recovery. Suitable and cost effective enhanced oil recovery technique should be selected for implementation.

According to U.S Energy Information Administration report at September 2013, Sudan and South Sudan have 5 billion barrels of proved crude oil reserves of January 1, 2013. Approximately 1.5 billion barrels are in Sudan and 3.5 billion barrels in South Sudan. Currently, oil produced from Blocks 2, 4, 6 and 17 counted as Sudan's production, while oil from Blocks 1, 3 and 7 belongs to South Sudan. Total oil production in Sudan and South Sudan reached its peak of 486,000 bbl/d in 2010, but it declined to 453,000 bbl/d in 2011.

After the secession of the South (85% of total oil production come from it) Sudan’s, oil production declined to 120,000 bbl/d. At the end of 2012, Sudan brought two new fields: the Hadida field in Block 6 and al-Barasaya in Block 17. Sudan hope to increase production in the future by ramping up new fields and increasing oil recovery rates in existing fields from 23 % to 47 % (year 2012). The production forecast for Sudan and South Sudan and average recovery factor shown at figures (2.1 and 2.2).

There are many reasons for selecting EOR to increase the recovery factor in Sudan fields including low recovery factor, high water cut and high amount of remaining oil reserves. Availability of technology and good oil price also are important reasons for implementing EOR processes.

2.3 Summary factor used in the screening are:

1. Reservoir condition (Temp & Pressure)
2. Reservoir Fluid Propriety, Oil Viscosity, Density & formation water salinity.
3. Reservoir Geology, Rock type, depth ,permeability & porosity

There are some factor affecting Water Flooding

2.4 Factors that Affect Flooding Efficiency

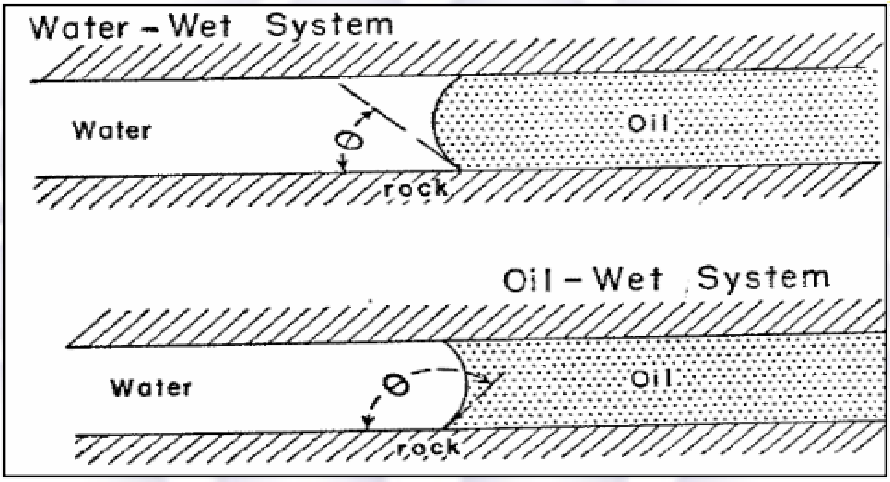
1. Wettability.
2. Capillary pressure.
3.Relative permeability.
4.Mobility Ratio.
5.Heterogeneity.
6. Gravity.

1. Wet ability:

Tendency of one fluid to adhere to a solid surface in the presence of other immiscible fluidsl.

Imbibitions flow process in which the saturation of the wetting phase (water) increases
and the non-wetting phase saturation decreases.

Drainage - flow process in which the saturation of the non-wetting phase increases.



(Fig 2.1) Illustration of wet ability

2. Capillary Pressure:

The pressure difference between non-wetting phase and wetting phase caused by interfacial tension and curved surface when two immiscible fluids are in contact with each other.

Capillary pressure is a function of surface tension/IFT, pore size/geometry and wet ability.

P-c is a function of interfacial tension (if liquid-liquid system)

P-c is a function of surface tension (if gas-liquid system)

In porous medium, capillary pressure is the force necessary to squeeze a hydrocarbon droplet through a pore throat (works against the interfacial tension between oil and water phases) and is higher for smaller pore diameter.

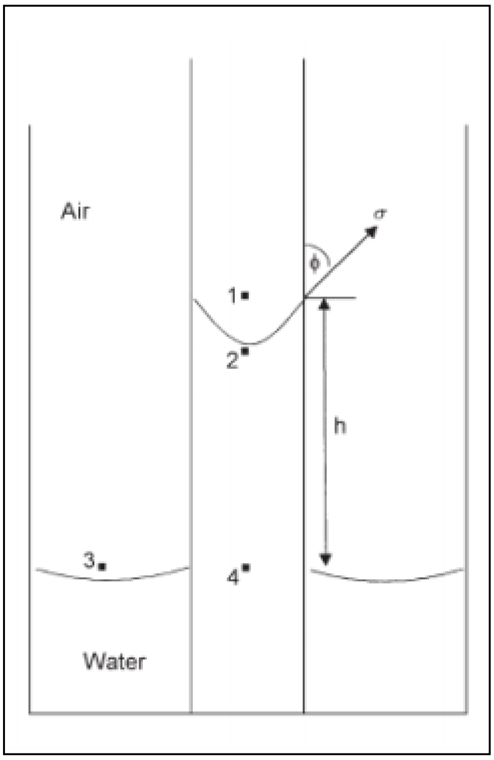


Fig 2.2 Pressure Relation in Capillary Tube (Tarek Ahmed, 2010)

3. Relative Permeability:

When a wetting and non-wetting phase flow together, the relativepermeability of each phase (at a specific saturation) is the ratio of theeffective permeability of the phase to the absolute permeability (of the rock)Relative permeability to fluid = Effective permeability of the fluidAbsolute permeability of the rock.

At connate Sw and residual So, the end point relative permeability are denoted as kro and krw

4. Mobility Ratio:

Mobility, k/μ, is defined as permeability of a porous material to a given phase divided by the viscosity of that phase.

Mobility ratio, M, is defined as mobility of the displacing phase divided by the mobility of the displaced phase as below equation :

$$\text{Mobility Ratio} = \frac{\text{Water mobility } (\frac{kw}{\mu w})}{\text{Oil mobility } (\frac{ko}{\mu o})}$$

5. Reservoir Heterogeneity:

Reservoir heterogeneity- aquifers, and *gas* caps- introduce large- uncertainties in- water flooding performance and consequently, the *economic* evaluation.

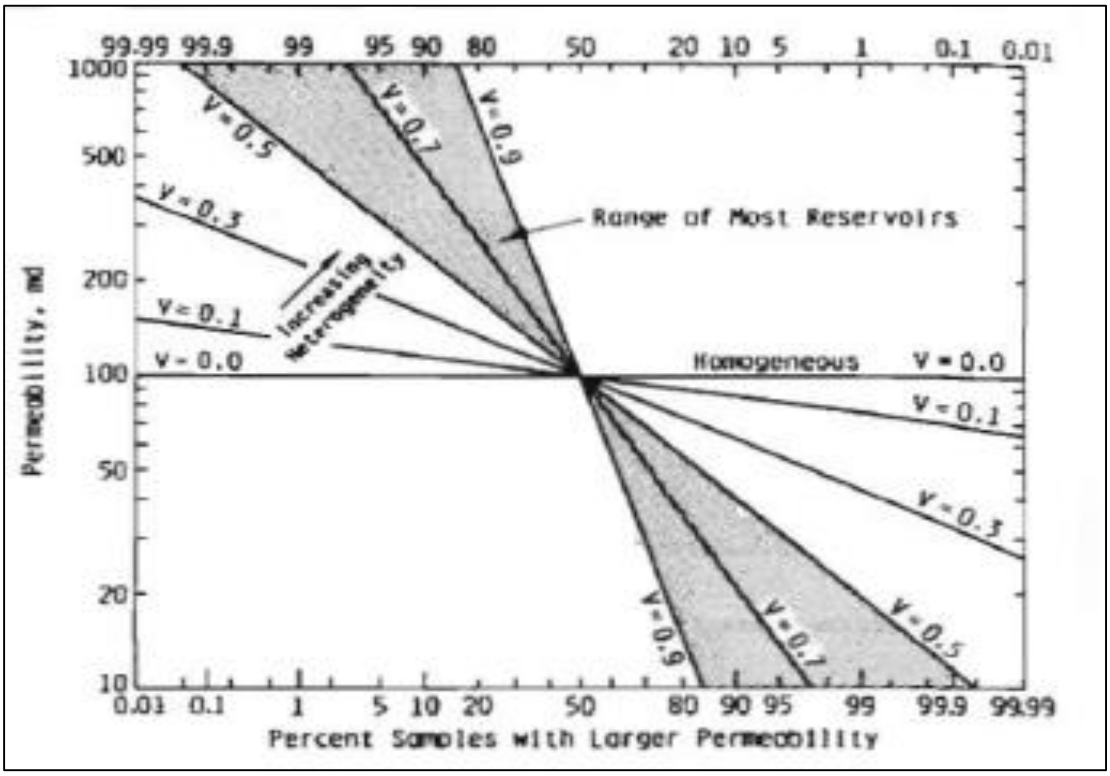


Fig 2.3Reservoir Heterogeneity change with permeability

Example shows reservoir heterogeneity changes with permeability variation

for a sample that has a log mean permeability of 100 md.

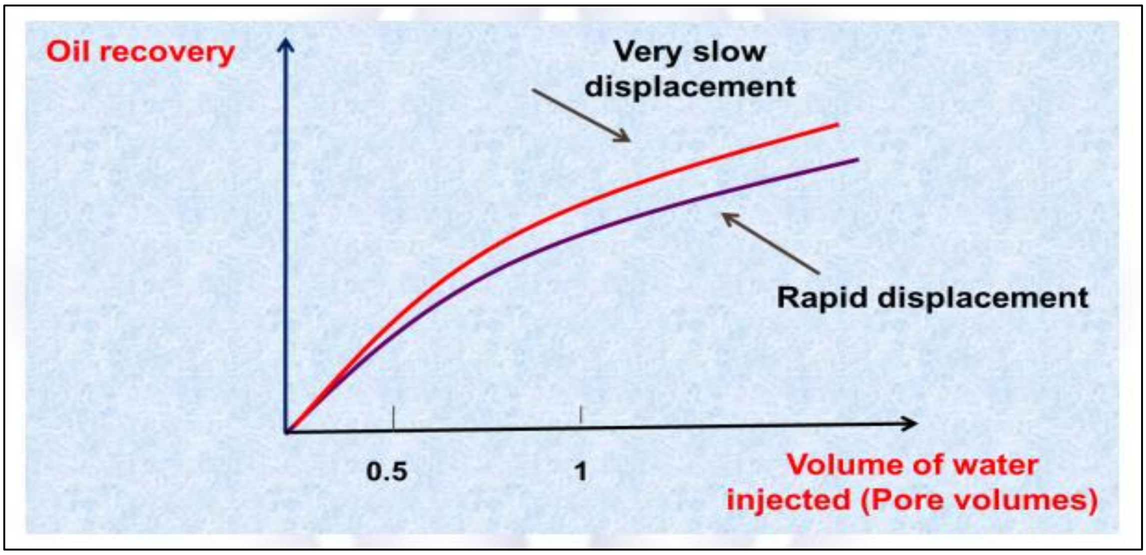


Fig (2.4) Effects of Heterogeneity

In general, reservoir heterogeneity probably has more influence than any other factor on the performance of secondary or tertiary injection project.

• The most important two types of heterogeneity affecting sweep efficiencies, EA and EV, are the reservoir vertical heterogeneity and areal heterogeneity

6. Gravity:

Gravity is the factor that affects the vertical efficiency not only on heterogeneous Reservoirs but also but also in homogeneous

Gravity segregation occurred when injected fluid is more dense than the displaced fluid for water flood .

Gravity segregation leads to early breakthrough of injected fluid and reduced vertical sweep efficiency.

2-5Water drive Theory:

• In water-oil displacement we are dealing with a process which takes place at arrange of scales.

• Pore or microscopic scale.

• Isolation and movement of fluids is dependent on,IFT, wet ability, viscosity, pore size and shape.

• Larger, macroscopic scale.

• Behavior at laboratory level scale, e.g. core plug scale. Permeability, relative permeability and capillary pressure.

• Field Scale, or behavioral scale.

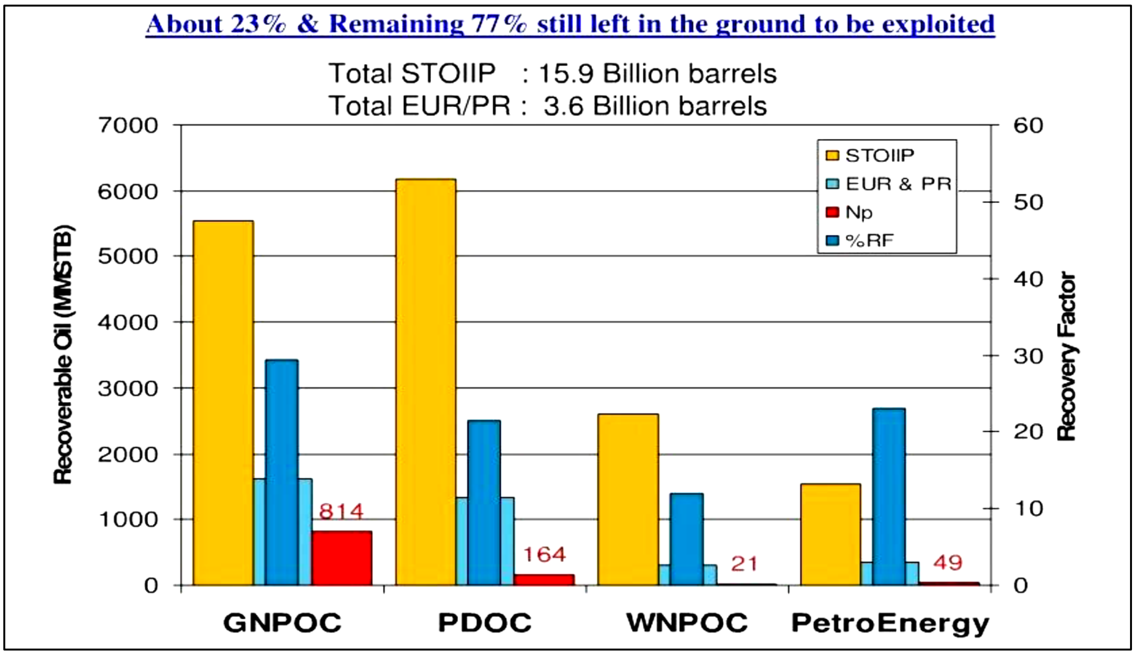
• Quantum leap of scale. Heterogeneous formations.

• Vertical segregation over large thickness.

2.6 Screening Concepts:

means a large number of variables are associated with a given oil reservoir such as pressure, Temp, crude oil type and viscosity and the nature of the rock matrix and connate water, because of variables not every type of water flooding recovery can be applied to every reservoir.

An initial screening procedure would quickly element some water flooding process from consideration in particular reservoir application



Fig(2.5) Production Forecast for Sudan & South Sudan (Sudapet, 2009)

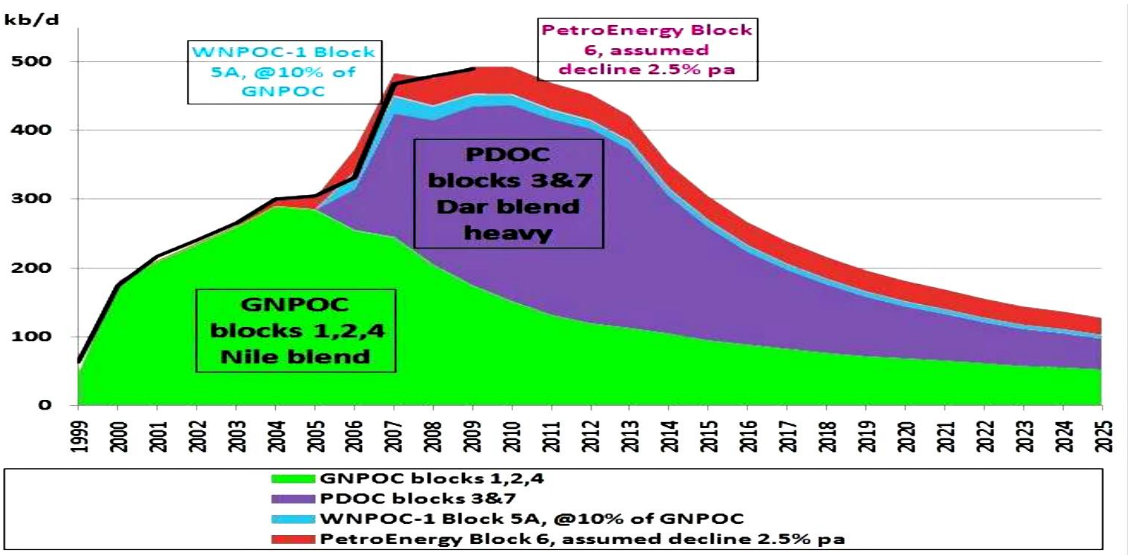


Fig. (2.6): Average RF for Sudan & South (Sudapet, 2009)

Chapter 3

Methodology

This chapter will use some method to select the most technically applicable for Water Flooding, which they are: ranging of successful field and not applicable field we use Manual method using SPE format, EOR gui allows to apply EOR screening criteria to two field to apply EOR screening criteria.

3.1 Analyze using ranging Method:

Arrange the successful Field for water flooding to select the suitable Reservoire applicable for water flooding.

3.2. Analyze using EOR gui:

3.2.1 EOR gui Description:

E OR gui is a Graphical User Interface for the United States of America ,Department of Energy, National Energy Technology Laboratory, Publically Available EOR
Software.

With this software the user can quickly screen oil fields and quantify incremental production for potentially applicable EOR techniques **(**Petroleum Solutions, 2010).

3.2.2. Applications of EOR gui:

1. Quickly screen and rank appropriate EOR methods for a given set of summary reservoir and fluid properties.
2. Prepares the input files required for the technical analysis portion of the publically available FORTRAN application.
3. The GUI runs the FORTRAN applications and imports the result back

into the application.

4. The results are input into convent data tables, and plotted in charts for export into other applications.

3.2.3. EOR gui sections:

1- Quick Screening

2- CO2 Miscible Flooding Predictive Model

3- Chemical Flood Predictive Model

4- Polymer Predictive Model

5- In-situ Combustion Predictive Model

6- Steam flood Predictive Model

7- Infill Drilling Predictive Model

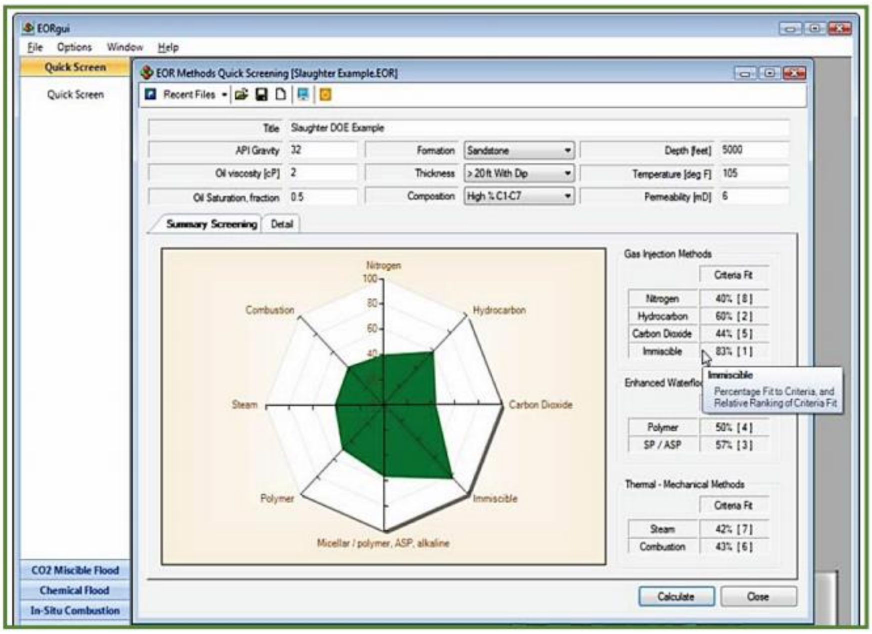


Fig. 3.1: EORgui Enhanced Oil Recovery Software (Petroleum Solutions, 2010)

3.2.4. EOR Method Quick Screening:

This routine based on the 1996 Society of Petroleum Engineers Paper entitled "EOR Screening Criteria Revisited" by Taber, Martin, and Sleight.

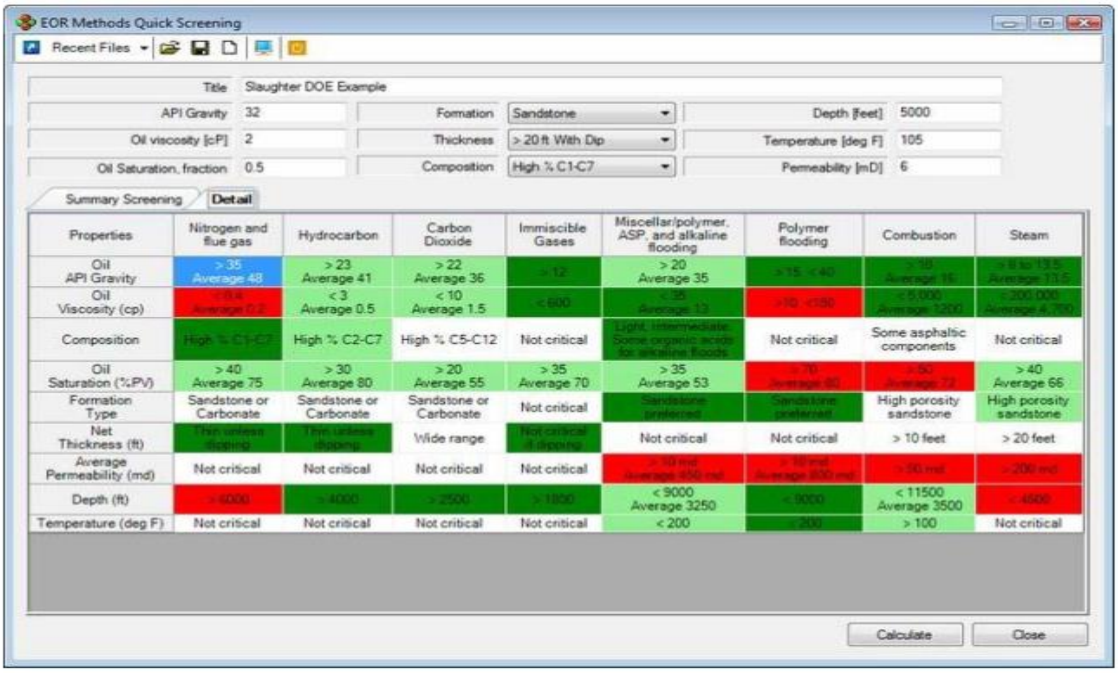


Fig. 3.2: EOR Method Quick Screening (Petroleum Solutions, 2010)

Chapter 4

Result and Discussion

In this chapter, data presented in table (4.1) was processed by using collecting data and ranging methods table (4.2) and analyzing using EOR gui.

4.1Data collection:

Collect data from all fields (Aradiba and Bantiu formation) coring sample result as below table (Table 4.1, 4.2):

Table 4.1 Aradiba formation data

Field	Depth	So	k	Poros	Temp	viscosty	API
Heglig	1426.8-1437.8	31.46	13.07	22.75	82	15.66	28.76
Taiyeb	1389.7-1394.3	-	-	-	54	474	21.51
Hammra	1551.7-1562.3	26.92	58.32	24.65	69	13.95	34.19
Bamboo	1294.1-1299.8	37.15	1370.1	31.67	80	78.32	22.25
Toma	1629.4-1639.18	25.02	725.29	28.88	77	44	24.9
Keyi	1514.5-1537.8	34.06	487.4	26.97	67.2	26	24
South Alnajma	1458.57-1597.10	14.01	115.67	23.38	80	3.3	38

Table 4.2 Bentiu formation data

Field	Depth	So	k	Poros	Temp	viscosty	API
Heglig	1631.3-1634.5	42.03	13.07	22.75	82	15.66	28.76
Taiyeb	1650-1656.3	28.4	15.83	21.46	54	474	21.51
Hammra	1668-1740.4	39.8	129.15	22.72	69	13.95	34.19
Azraq	1945-1954.6	23.32	19.81	19.7	87	78	21.89
Bamboo	1300.1-1490.8	39.38	350.09	30.73	80	78.32	22.25
Difra	2740-3171	12.13	19.22	11.25	116	13	26
Simbir	2745-2750.5	18.43	9.08	18.99	89	3.72	33.23

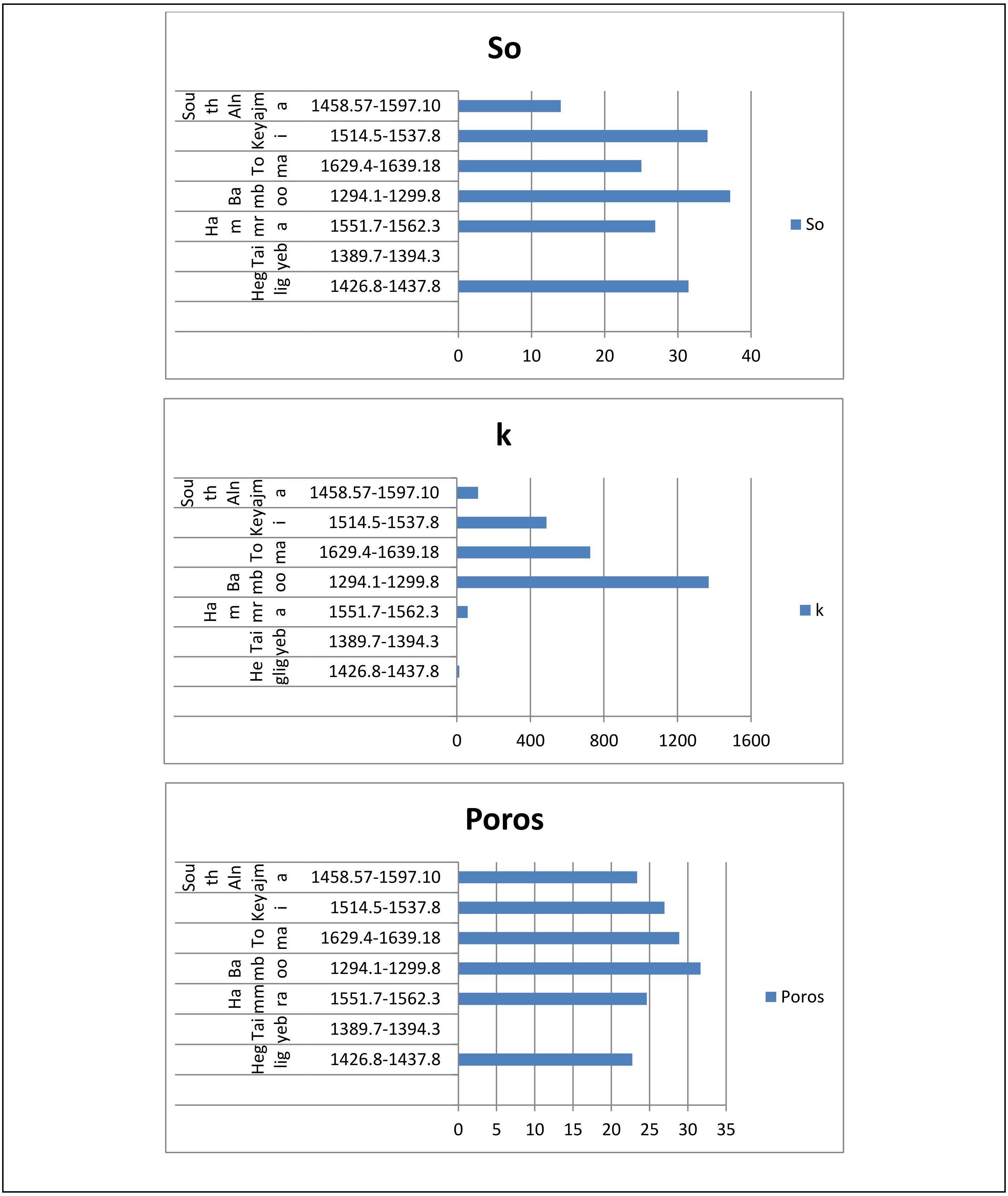


Fig.4.1. Oil saturation, permeability and porosity Aradiba formation sudanese fields

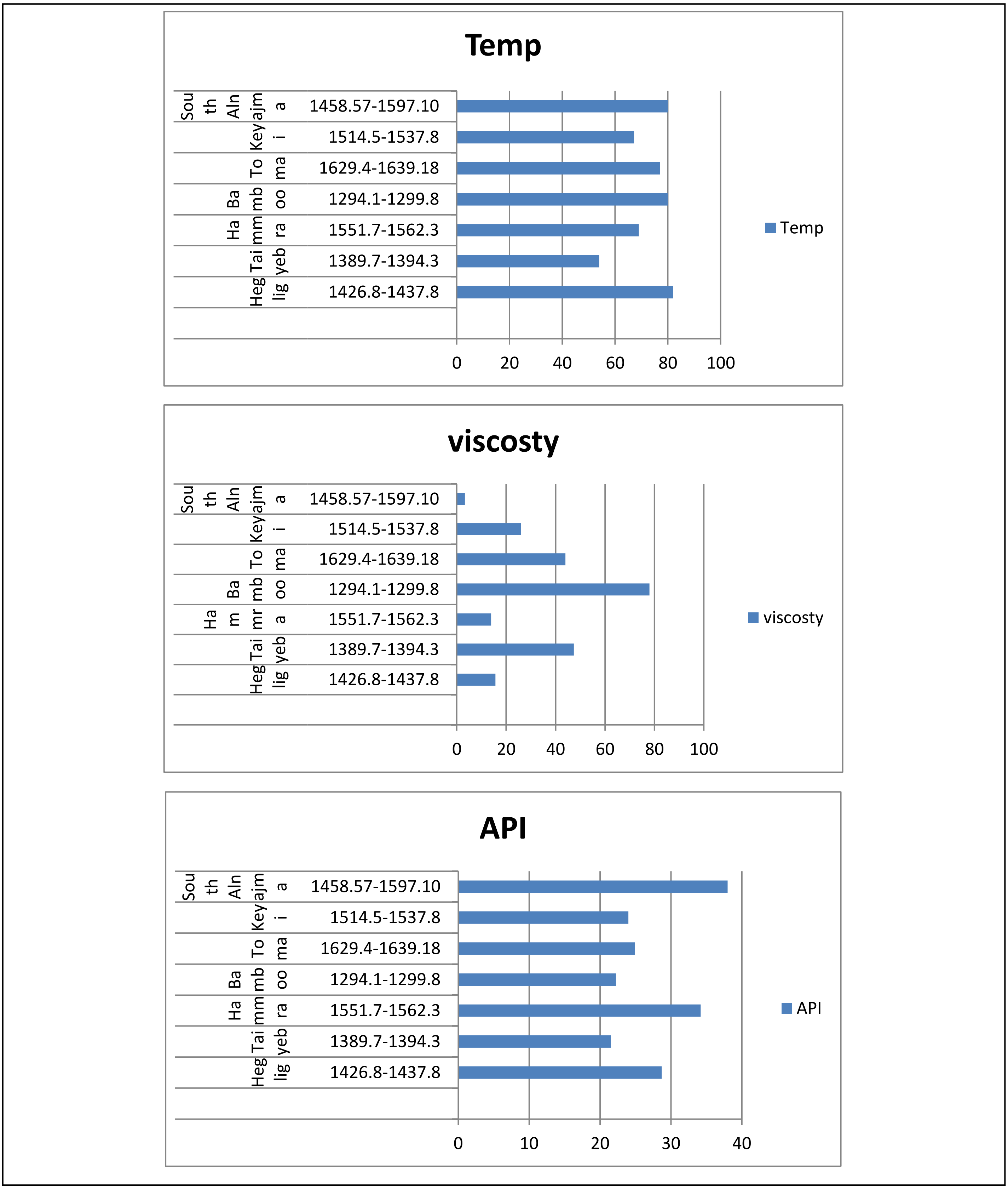


Fig.4.2. Tempreture, viscosity and API Aradiba formation sudanese fields

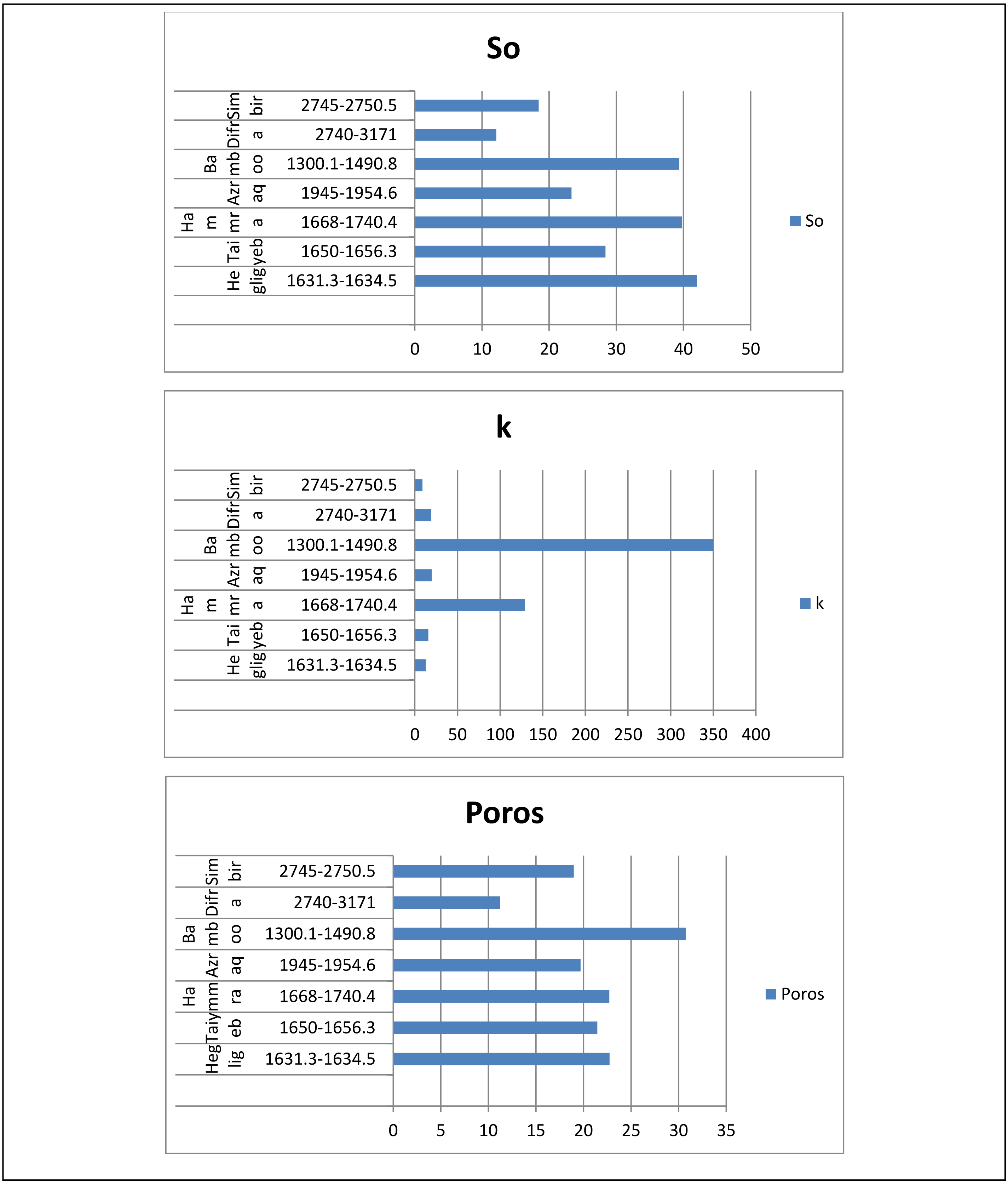


Fig.4.3. Oil saturation, permeability and porosity Bantiu formation sudanese fields

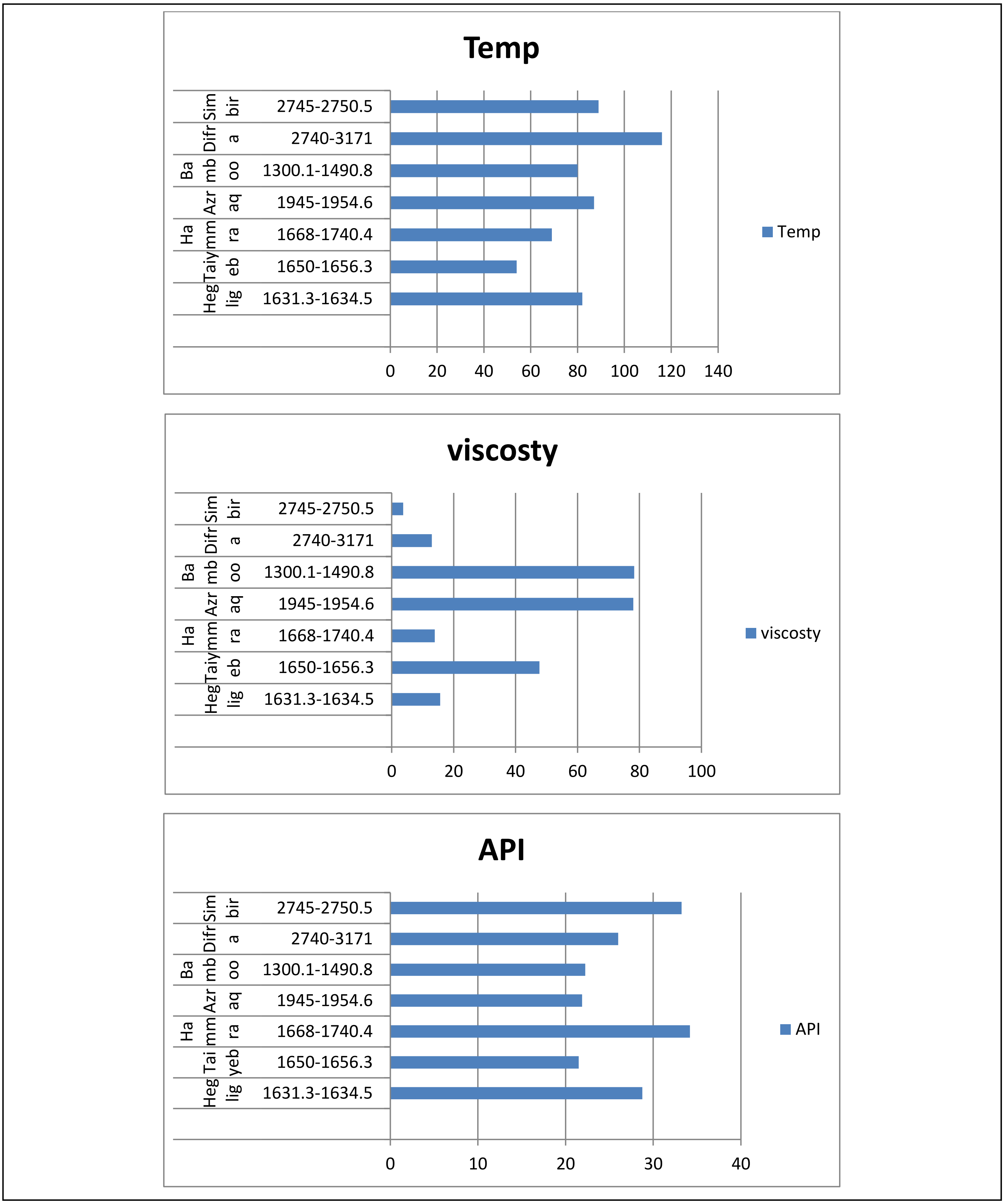


Fig.4.4. Tempreture, viscosity and API Bantiu formation sudanese fields

4.2 Ranging for successful field proerities:

Table 4.3 Illstrate ranging for successful field data

Properity	So	Depth	Permeability	Porosity	Temp	Viscosity	API
Range	18-99	1426-2750	3.6- 638	18- 29	69-89	4-26	25-38

Table 4-4 screening for aradiba formation

Field	Depth	So	k	Poros	Temp	viscosty	API
Heglig	1426.8-1437.8	ok	ok	ok	ok	ok	ok
Taiyeb	1389.7-1394.3	ok	-	-	below	high	low
Hammra	1551.7-1562.3	ok	ok	ok	ok	ok	ok
Bamboo	1294.1-1299.8	ok	ok	ok	ok	high	low
Toma	1629.4-1639.18	ok	high	ok	ok	high	low
Keyi	1514.5-1537.8	ok	ok	ok	low	ok	ok
South Alnajma	1458.57-1597.10	ok	ok	ok	ok	ok	ok

Table 4-5 screening for Bentiu formation

Field	Depth	So	k	Poros	Temp	viscosty	API
Heglig	1631.3-1634.5	ok	ok	ok	ok	ok	ok
Taiyeb	1650-1656.3	ok	ok	ok	low	high	Low
Hammra	1668-1740.4	0k	ok	ok	ok	ok	ok
Azraq	1945-1954.6	ok	ok	ok	ok	high	low
Bamboo	1300.1-1490.8	ok	ok	ok	ok	high	low
Difra	2740-3171	ok	ok	low	Ok	ok	ok
Simbir	2745-2750.5	ok	ok	ok	Ok	ok	ok

4.2.1: Aradiba formation :

Aradiba formation heglig field already implemented for water flooding.

Aradiba formation Tayeb field low temp of high viscosity low API cant apply for watre flooding.

Aradiba formation Hamra field already implemented for water flooding.

Aradiba formation Bamboo field cant apply for watre flooding due to high viscosity and low API.

Aradiba formation Toma field high permeability can't apply for watre flooding due to high viscosity and low API.

Aradiba formation Keyi field can apply for watre flooding.

Aradiba formation South Alnajma field can apply for watre flooding.

4.2.2: Bantiu formation :

Bantiu formation heglig field already implemented for water flooding.

Bantiu formation Tayeb field cant apply for watre flooding due to high viscosity low API.

Bantiu formation Hamra field already implemented for water flooding.

Bantiu formation Bamboo field cant apply for watre flooding due to high viscosity and low API.

Bantiu formation Diffra field can apply for watre flooding.

Bantiu formation Simber field already implemented for water flooding.

4.3 Screening using EOR gui for unapplicable fields for water Flooding method:

1. **Bentiu formation Azraq Field:**

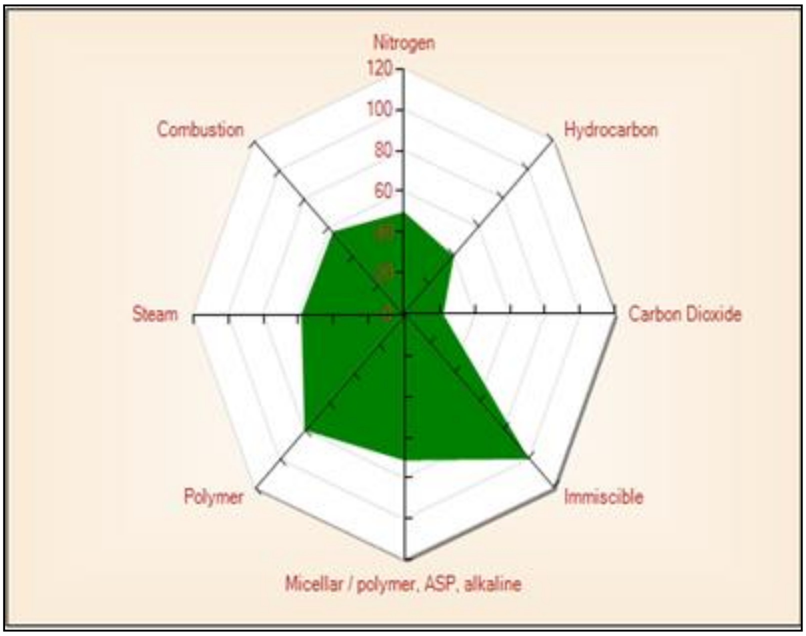


Fig. 4.5: Screening Using EORgui for Bantiu formation Azraq Field

Suitable EOR methods are:

1- Immiisible method (100%)
2- Nitrogen Injection as asecond method (90%)
3- Polymer in third order with (80%)
4- Chemical methods group(Micellar/Polymer,ASP,Alkaline) in fourth method(71%)

2. Bantiu formation Bamboo Field:

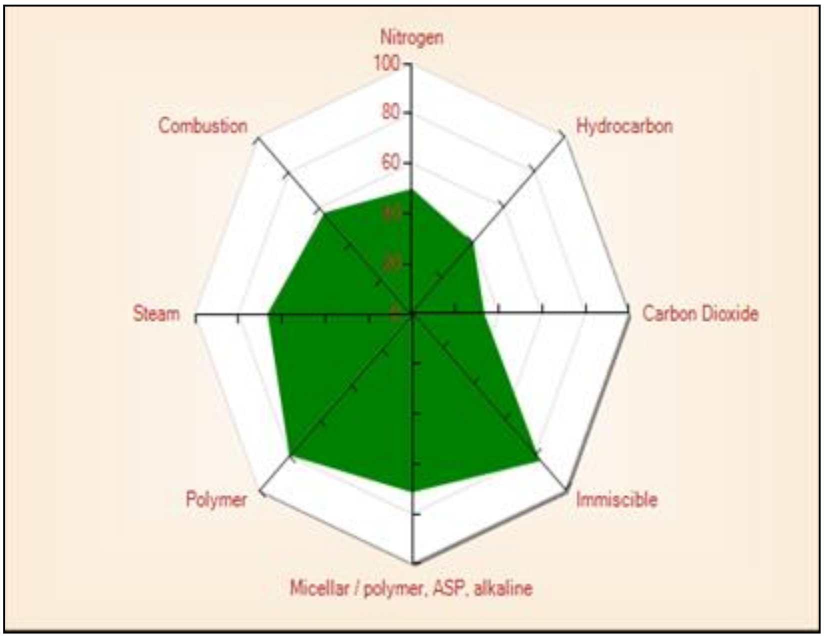


Fig. 4.6. Screening Using EORgui for Bantiu formation Bamboo Field

Suitable EOR methods are:

1- Immiscible method (83%)
2- Polymer injection as a second method (80%)
3- Chemical methods group (Micellar/Polymer,ASP,Alkaline) in fourth method(71%)
4- Steam injection in fourth method (67%)

3. Bantiu formation Tayeb Field:

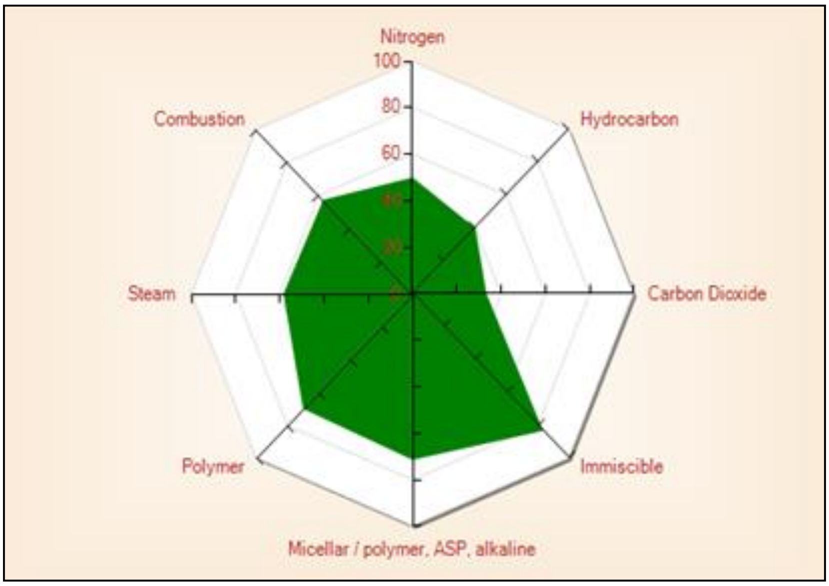


Fig. 4.7. Screening Using EORgui for Bantiu formation Tayeb Field

Suitable EOR methods are:

1- Immiscible method (83%)
2- Chemical methods group (Micellar/Polymer, ASP, Alkaline) in second method (71%)
3- Polymer injection in third method (70%)

Chapter 5

Conclusion and Recommendation

5.1Conclusion:

1. There are successful fields in Bantue and Aradieba Formation already implemented in Sudanese field for water flooding method:
   A. Heglig Fieldl.
   B. Hamra Field.
   C. Simber Field.
2. There are unapplicale fields in Bentue and aradieba formation for water flooding:
   A. Tayeb Field.
   B. Bamboo field.
   C. Toma field.
   D. Azraq Field.

3. There is three fields in Aradieba and Bentue formation applicable for water Flooding method (South Naggma Field, Diffra Field and Kezi field).
4. EOR gui Software applied for un applicable in Bantiu formation in 3fields found that the suitable EOR method are:
   A. Bamboo field (Immiscible and Polymer Method).
   B. Azraq Field (Immiscible and Nitrogen method).
   C. Tayeb Field (Immiscible and ASP method).

5.2 Recommendation :

By results obtained in this research, the following recommendations have been signed:

1. Laboratory analyses must be carried out for successful field for water injection.
2. Water flooding can be done by using one injection well or more and there are many factors must be studied carefully before selecting well/s location including: reservoir uniformity and pay continuity, reservoir geometry and depth, fluid properties and saturations, litho logy and rock properties and reservoir driving mechanisms.
3. Water injection source preferred to be from the same field (water source well Dry well or suspended well to reduce the cost.
4. EOR method technical screening must be followed by economical screening to come up with the most cost effective method. This process should include; availability of injected fluid, cost of equipment, remaining oil and recovery factor by the method…etc.

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