Sudan University of Science and Technology

College of Petroleum Engineering & Technology

Petroleum Engineering Department

Study the Sand Production Problem for Sudanese Oil Field (FNE Case Study)

دراسة مشكلة انتاج الرمل لحقل الفولة الشمالي الشرقي

This dissertation is submitted as a partial requirement of B-tech degree (honor) in petroleum engineering

Prepared by:

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iii. ***Hitham Omer MohamdAhmed***
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Supervisor:

Eng. Husham A. Ali

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Signature:

Date: / /2016

بسم الله الرحمن الرحيم

الاستهلال

قال تعالى:

{اللَّهُ لا إِلَهَ إِلَّا هُوَ الْحَيُّ الْقَيُّومُ لا تَأْخُذُهُ سِنَةٌ وَلا نَوْمٌ لَهُ مَا فِي السَّمَوَاتِ وَمَا فِي الأَرْضِ مَنْ ذَا الَّذِي يَشْفَعُ عِنْدَهُ إِلَّا بِإِذْنِهِ يَعْلَمُ مَا بَيْنَ أَيْدِيهِمْ وَمَا خَلْفَهُمْ وَلا يُحِيطُونَ بِشَيْءٍ مِنْ عِلْمِهِ إِلَّا بِمَا شَاءَ وَسِعَ كُرْسِيُّهُ السَّمَوَاتِ وَالأَرْضَ وَلا يَئُودُهُ حِفْظُهُمَا وَهُوَ الْعَلِيُّ الْعَظِيمُ }

(البقرة / 255)

{وَمَا مِنْ دَابَّةٍ فِي الأَرْضِ إِلَّا عَلَى اللَّهِ رِزْقُهَا وَيَعْلَمُ مُسْتَقَرَّهَا وَمُسْتَوْدَعَهَا كُلٌّ فِي كِتَابٍ مُبِينٍ}

(هود /6)

{وَلِيَعْلَمَ الَّذِينَ أُوتُوا الْعِلْمَ أَنَّهُ الْحَقُّ مِنْ رَبِّكَ فَيُؤْمِنُوا بِهِ فَتُخْبِتَ لَهُ قُلُوبُهُمْ وَإِنَّ اللَّهَ لَهَادِ الَّذِينَ آمَنُوا إِلَى صِرَاطٍ مُسْتَقِيمٍ}

(الحج/54)

ACKNOWLEDGEMENT

Everything that has a beginning must equally have an end. We appreciate Allah for the gift of life in good health and abundant grace throughout our stay in this great citadel. It's indeed a privilege and honor to pass through this college. We acknowledge the effort of every lecturer that has impacted knowledge into us, without your contributions we would not be who we are today.

We are grateful to our Supervisor, Eng. Husham A. Ali for accepting us at the time he did and his contributions from the start to finish of this work.

We appreciate the efforts of our parents. Their encouragements and prayers saw us through the time we did not even know how to begin. To our wives, we say thank you for not allowing us give up.

Thanks to all our friends and classmates, lastly special thanks go College of Petroleum Engineering& Technology Department of Petroleum Engineering

Dedication

Every challenging work, needs self -efforts as well as guidance of elders especially those who were very close to our heart

Our humble effort we dedicate to our sweet and loving Parents

Whose affection, love and encouragement make us able to get much success and honor. Along with all hard working and respected Teachers

ABSTRACT

The production of formation sand is a problem associated with most oil deposits in the world. Major Sand production effects affect safety, well or field economics and continuous production. This has prompted the continued search for solutions to mitigate sand production in the oil and gas industry over time. Fula North East(FNE) a Sudanese oil field is selected as case study, FNE Field is shallow heavy oil reservoir with good hydrocarbon concentrate in small area, which has three productive sand intervals, named “Bentiu”, “Aradeiba”, and “Abu Gabra”,. With normal Faults, and has clear oil/water contact (OWC) system in “Bentiu” formation, FNE oilfield produces high viscous crude oil from productive sand interval, (Bentiu) massive sand formation, sands in this formation had average initial oil saturation of 50%. Average porosity is 27% and permeability range from 1 to 10 Darcie’s, however the oil density of 10 to 17.9 degree API and viscosity of 3791.5 cp, combined with low initial reservoir temperature (44ºC) and (576psi) average reservoir pressure result in low primary recovery.

The study proposed to analyze high sand production wells it has been found that 42 wells suffering from sand production problem in this oil Field, Classification according to formation, location, pay zone and sand productivity has been done in this thesis. We used analytical method depending on data collected from workover program for mentioned wells and data from manual pigging and flushing for flow lines. The wells which produce from south location of FNE (Steam flooding Area) is highest sand production wells in FNE oil field. The Cold wells are producing higher sand compare to CSS wells.

مستخلص البحث

إن انتــاج الرمــل المصــاحب للــنفط يعتبــر مشــكلة مرتبطــة بمعظــم عمليــات انتــاج الــنفط فــى العــالم. كمــا و لهــذه المشــكلة تــأثيرات ســلبية مــن ناحيــة الســلامة و الانتاجيــة بصــورة اقتصــادية. ولمجابهــة هــذا التحــدي دأب البــاحثون علــى الاســتمرار فــي البحــث والتطــوير للوصــول لحلــول لتخفيــف وخامــة انتاجيــة الرمــل فــى صــناعة الــنفط والغــاز علــى مــر الزمن.

حقـل الفولــة الشــمالي الشــرقي موضــوع الدراســة هــو أحــد الحقــول الســودانية. وهــو مــن الحقــول الضــحلة الاعمــاق الغنيــة بخــام الــنفط الثقيــل علــى امتــداد مســاحة صــغيرة نســبيا تحتــوي علــى ثــلاث طبقــات رمليــة منتجــة هــي بــانتيو ، عرديبــا وابوجــابرة مــع وجــود فــالق طبيعــي وســطح فاصــل بــين الــنفط والمــاء فــي طبقــة بــانتيو. إن حقــل الفولــة الشــمالي الشــرقي ينــتج خــام الــنفط الثقيــل جــدا مــن الطبقــة الرمليــة بــانتيو وهــذه الطبقــة لهــا متوســط درجــة تشــبع 50% ومتوســط مســامية 27% و نفاذيــة تتــراوح بــين 1 إلــي 10 دارســي كمــا و لهــا كثافــة تتــراوح بــين 10 إلــي 17.9 مــن مقيــاس API و ذو لزوجــة3791.5 ســنتي بــواز وهــذه ســاهمت مــع درجــة حــرارة مكمــن منخفضــة(44 درجــة مئويــة) ومتوســط ضــغط ابتــدائي (576 رطــل لكــل بوصــة مربعــة)في انخفــاض معــدل الإســتخلاص الأولــي للمكمن.

إن هــذه الدراســة تهــدف إلــي تحليــل مشــكلة الآبــار ذات الإنتاجيةالعاليــة مــن الرمــل لهــذا الحقــل حيــث تمــت دراســة 42 بئــر مــن آبــار الحقــل .تــم التصــنيف فــي هــذه الدراســة اعتمــاداً علــى تموضــع الطبقــات الصــخرية و الطبقــات المنتجــة بالاضــافة الــى كميــة الرمــل المنــتج . لقــد اســتخدمت الطريقــة التحليليــة للمعلومــات المتــوفرة مــن برنــامج صيانة الآبار و المعلومات من النظافة اليدوية لخطوط الجريان من الآبار.

وجــد أن الآبــار التــي تنــتج مــن الناحيــة الجنوبيــة مــن الحقــل (الآبــار التــي يــتم فيهــا الإستخلاص بطريقــة (Steam Flooding) هــي الآبــار ذات أعلــى إنتاجيــة رمــل فــي الحقـل وأيضـا وجـد أن الآبـار التـي تنـتج بطريقـة (Cold Production Wells)أعلــى إنتاجية رمل من الآبار ذات طريقة الإنتاج (CSS).

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Nomenclature

API	American Petroleum Institute
B	Bentiu zone
B1a,b&c	Names of Bentiu layers
BBL	Barrel
BOPD	Barrel Oil Per Day
ºC	Degree centigrade
CHOP	Cold Heavy Oil Production
cp	Centipoise
Cum	Cumulative
FNE	Fula North East
Km	Kilometer
m	Meter
mD	Milli Darcy
mg	milligram
mKB	Meter Kelley Bushing
MRI	Magnetic Resonance Imaging
NA	Not Available
OGM	Oil Gathering Manifold
OWC	oil/water contact
PLT	Production Logging Tool
PPD	pour-point depressant
psi	Pond Per Square Inch
RF	Recover Factor

CHAPTER ONE

Introduction

1. 1 General Introduction

The production of formation sand is a major problem encountered during the production of oil and gas. Over 70 % of the world’s oil (heavy oil and extra heavy oil and bitumen) see figure 1.1 and gas reserves sit in sand formations where sand production is likely to become an issue during the life of the well (Osisanya, 2010). Sand production is typical of tertiary formations (with permeability of 0.5 to 8 Darcy) and older formations as they enter their mature stages of production due to poor completion and impact of depletion. Areas where severe sand production problems occur include Sudan, Nigeria, Trinidad, Indonesia, Egypt, Venezuela, Malaysia, Canada tar sands and Gulf of Mexico. The reservoirs in these formations lie between 3,500ft and 10,000ft (subsea). Generally, the effects of sand production ranges from economics and safety hazards to well productivity and therefore has been an issue of interest to tackle in the petroleum industry. Some of these effects include erosion of downhole and surface equipment, pipeline blockage and leakage, formation collapse, damage to casing/production liner due to formation subsidence, and increased downtime. These devastating effects lead to more frequent well intervention and workovers generating additional needs for sand disposal particularly in offshore and swamp locations. The effects of sand production are nearly always detrimental to the short and or long term productivity of the well (William and Joe, 2003). In order to mitigate problems related to sand production new strategies are being continuously investigated, from prediction to control and management. The ability to predict when a reservoir will fail and produce sand is fundamental to deciding whether to use downhole sand control or what type of sand control to use (Bellarby, 2009).

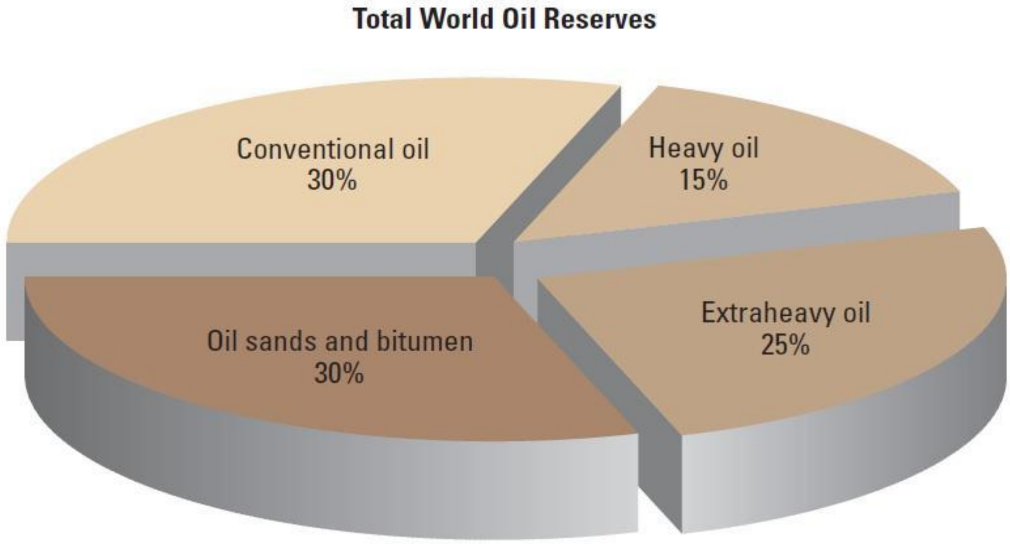

Figure 1.1 – Distribution of Total World Oil Reserves By Classification
(Schlumberger Oilfield Review,2006)

Sand production occurs normally as a result of drilling and reservoir management activities. Sand grains are disengaged from the rock matrix structure under physical (earth stress) and chemical action. The mechanism of sand production in terms of sand, volumes and sand producing patterns in the reservoir is needed to optimally develop a field. Mechanisms causing sand production are related to the formation strength, flow stability, viscous drag forces and pressure drop into the wellbore (Osisanya, 2010). The critical factors leading to accurate prediction of sand production potential and sand production are: formation strength, in-situ stress, and production rate. Other factors are reservoir depth, natural permeability, formation cementation, compressibility, surface exposed to flow, produced fluid types and phases, formation characteristics, pressure drawdown and reservoir pressure. Predicting sand production involves developing empirical and analytical techniques. Empirical techniques relate sand production to some single parameter or group of parameters such as porosity, flow or drawdown analytical techniques relates to rock stresses. Numerical analytical techniques are also sometimes used. They are models developed from finite element analysis. The techniques above use production data, well logs, laboratory testing, acoustic, intrusive sand monitoring devices, and analogy (Osisanya, 2010). At present, predicting whether a formation will or will not produce sand is not an exact science and needs more improvement.

Currently, there are two main classes of techniques available for sand management: sand prevention by passive method and sand control using mechanical exclusion (gravel packing); or screenless completion (sand stabilization by chemical consolidation or sandlock) (Osisanya, 2010). Chemically consolidating the formation around the wellbore with a plastic material is best applied to production intervals which are relatively free of clays and fines, have uniform permeability, are thin and have no prior history of sand production (Schechter, 1992). Preventing the production of sand using passive methods includes techniques to minimize or eradicate sand production to manageable levels. This includes perforation techniques and maximum sand-free drawdown rate. Limiting production rates to avoid sand production in some cases is the most cost-effective method of sand control. In most cases however, low production rates are uneconomical stressing the need for sand control. Sand control tools do not only serve the purpose of preventing the sand grain from entering the wellbore, but also to protect the rock matrix structure, preventing formation damage. At present, set standards to determine which type of control means to administer to a well does not exist. A lot of factors are considered to determine the method of control to use. Some of which are: the type of sand (fine or coarse), length of pay interval, variations in permeability, hole deviation, availability of rigs, and formation sand uniformity.

1.2 Oil Production challenges

The oil production faces numerous challenges as it addresses growing energy demand, the need for sustainable operations, and declining production reservoirs such as:

- High water cut wells production
- High wax oil content and high oil pour point:
- High oil viscosity production
- Sand Production

1.2.1High water cut wells production.

Most of oil companies produce an average of three barrels of water for each barrel of oil from their depleting reservoirs.

In many cases, innovative water-control technology can lead to significant cost reduction and improved oil production.

Water affects every stage of oilfield life from exploration the oil-water contact is a crucial factor for determining oil-in-place through development, production, and finally to abandonment.

A high water cut water flooded reservoir is one of the major economical, technical, and environmental problems associated with oil and gas production, it is always a challenging task for fieldoperators, the cost of handling and disposing produced water can significantly limit the economic producing life of the well, and can cause severe problems including tubular corrosion, fines migration, and hydrostatic pressure created by high fluid levels in the well.

ManySudanese reservoirs are adjacent to an active aquifer and are subject to bottom or edge water drive. Water is often injected into oil reservoirs for pressure maintenance or secondary recovery purposes; this injected water is one of sources of water production problem.

Excess water production represents difficult operational problems for all reservoirs producing by dominate mechanism of bottom water drive.

Too high production rate may result in quick water coning and fast water fingering, which lower down the efficiency of water displacement, hence reducing the cumulative oil production. (Elradi,2011)

1.2.1.1The Problems of Excess Water Production (High water Cut):

It is very important for engineers to identify exactly the problem which causes high water cut production.

- Reservoir Porous Media Problem.
- The water flooded reservoir development problem**.**
- High permeability streak problem.
- Unfavorable mobility ratio problem.
- Water Coning Problem.
- Well Problems (Casing/tubing leak, packer leak Problem, Cement channel Problem).

1.2.1.3 Methods of Diagnosing high water cut production:

Various tools and technologies are available in oil industry for controlling undesirable water production, each of these technologies has been developed for certain types of water production problems.

The methods of diagnosing problems are:

- MRI (Magnetic Resonance Imaging) Method:

The MRI is a powerful logging tools for providing conformance information also known as Production Logging Tool (PLT).

A preventive/proactive conformance process by using logging tools can delay or prevent excess water production. It can provide a higher hydrocarbon production without adventuring of early water breakthrough problems.

- Water Control Diagnostic Plots Method.

Conventionally, water cut vs. time linear plots were used to show the progress and severity of the excessive water production problems. which can be considered as the most appropriate methodology for identifying the source of the water production problems.

The water coning and channeling can be clearly identified using of WOR derivative. (Elradi,2011)

1.2.2High wax oil content and high oil pour point:

Production of waxy crude oils normally is associated with such operational problems as wax deposition in the tubular and gelling of flowlines. Different methods are available to control wax deposition. Continuous addition of certain chemicals at low dosages to the well is popular because it reduces oil viscosity and other downstream problems. These chemicals, known as pour-point depressants (PPD's), remain in semisolid state at ambient temperatures. During winter, the chemical solution needs more expensive solvents or heating to maintain its fluidity. To avoid the costs involved in the surface setup and its maintenance and monitoring, the authors tried a simple method in a few pumping wells with satisfactory results. In this method, the oil column in the casing above the pump suction depth is replaced with a chemical solution. Density of the solution is maintained below that of the produced liquid. This prevents gravity swapping and ensures the presence of a chemical reservoir within the wellbore. When the pump is in operation, the temperature of the tubing's outer surface is a few degrees higher than that of the casing's inner surface. Natural convection currents occur in the liquid trapped between the two surfaces. The liquid rises along the tubing and moves in the opposite direction near the casing. Near the pump suction level, a constant exchange of mass between the crude entering the pump and the chemical reservoir takes place.

The temperature at which a fluid ceases to pour, in which the pour point is established as that temperature at which oil ceases to flow when the sample is held at 90 degrees to the upright for five seconds.

High pour points usually occur in crude oils that have significant paraffin content. Paraffins (or waxes) will start to precipitate as temperature decreases. At some point the precipitates accumulate to the point where the fluid can no longer flow. This phenomenon can occur with light oils as well as heavy oils. (Schlumberger , 2006).

1.2.3 High oil viscosity production

The viscosity of heavy crudes is strongly affected by temperature variations. For this reasons, thermal recovery methods are commonly used in heavy oil production.SeeFigure 1.2

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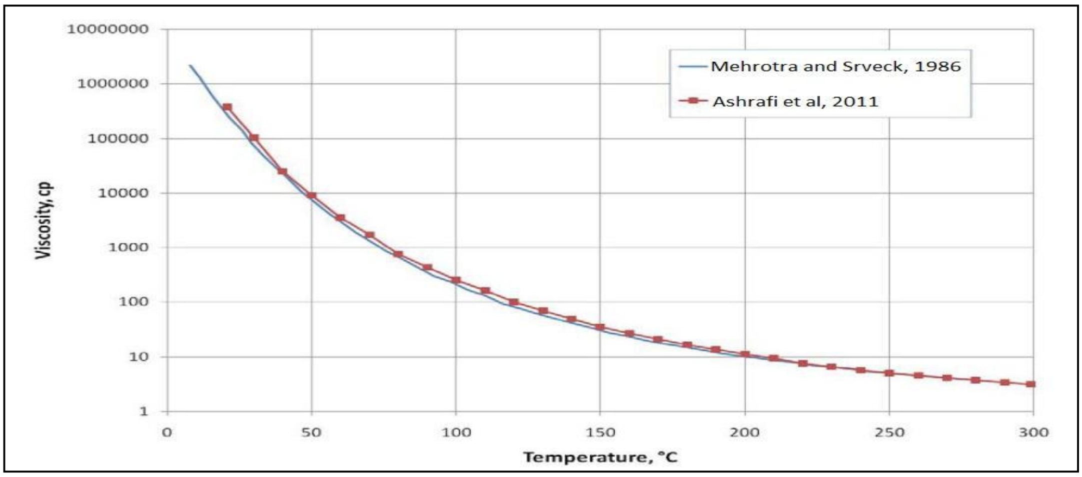

Figure 1.2 Viscosity – Temperature Relationship of an Athabasca Bitumen (Ashrafi et. al -2011)

No universal relationship between oil density and viscosity has been, though generally oils are found to be more viscous when density increases.

Density and viscosity are key properties in determining the economics of the oil field development. Heavy oil generally sells at a lesser price than lighter hydrocarbons, as it will have to go through an energy intensive upgrading process before use. On the other hand, high viscosity values lead to lower production and more expensive EOR investments(FabianBjornseth, 2013).

1.2.4 High sand production wells.

As reservoir rocks go, porous and permeable sand formations filled with large volumes of hydrocarbons that flow easily into an oil well are every petroleum engineer's dream.

When that sand formation turns out to be so poorly cemented together that sand grains flow into the well along with the oil, that dream can sometimes become a nightmare.

Sand problem is considered as one of the major problems in the petroleum industry. Every year, well cleaning and work-over operations, related to sand production and restricted production rates, cost the industry millions of dollars. Additional expenses associated with sand production include pump maintenance, well cleaning, disposal of dirty sands

Five sand problems commonly observed in the fields. These include sand problems induced by:

- ❖ Unconsolidated formations.
- ❖ Water breaks through for weak to intermediate strength formations.
- ❖ Reservoir pressure depletion in relatively strong formations.
- ❖ Abnormally high lateral tectonic force in relatively strong formations.
- ❖ Sudden change in flow rate or high flow rate.

1.2.6 Sand Production

Sand Production is the migration of the formation sand induced by the flow of reservoir fluids. It is initiated when the rocks around the perforations fail and the fluids thrust the loose grains into the borehole. It takes place when the reservoir fluid flow outpaces an assertive threshold which depends on factors like stress state, reservoir rock consistency and the way of completion which is used around the well.

The sand particles are first disintegrated from their parent rock before flowing with the reservoir fluids into the borehole. This can take place when the reservoir rocks have low formation strength and they fail under the conditions of in-situ and the imposed stress gets changed because of the hydrocarbon production, sand production is considered as one of the major problems in the petroleum industry. Every year, well cleaning and work-over operations, related to sand production and restricted production rates, cost the industry millions of dollars. Additional expenses associated with sand production include pump maintenance, well cleaning, disposal of dirty sands.

Sand production can cause a variety of problems with numerous technical, operational environmental and economic implications. Compressive and tensile

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5. Sudden change in flow rate or high flow rate.

Sand production occurs when the induced in-situ stresses exceed the formation in-situ Strength. The formation strength is derived mainly from the natural bond caused by the existing cementing materials that adheres grains together. According to this strength, the sandstone formations can be classified as competent weak or unconsolidated. In competent sandstone formations, sand production is due to shear failure, which occurs on the surface of the rock (borehole surface) due to high shear stress.

In weak and unconsolidated sandstone formations, sand is produced when the drag forces caused by the flowing reservoir fluids exceed the natural inherent cohesion of the formation. The movement of sand grains leads to the development of sand arches.

A significant proportion of the world oil and gas reserves is contained in weakly consolidated sandstone reservoirs and hence is prone to sand production. Material degradation is a key process leading to sanding. Drilling operations, cyclic effects of shut-in and start-up, operational conditions, reservoir pressure depletion, and strength-weakening effect of water may gradually lead to sandstone degradation around the perforations and boreholes. High pressure gradient due to fluid flow also facilitates the detachment of sand particles. In addition, fluid flow is responsible for the transport and production of cohesion less sand particles or detached sand clumps to the wellbore.

1.3 Cause of Production Sand

They are many factors lead to produce sand from reservoir as:

I. Unconsolidated shallow formation.
II. High oil viscosity.

1.3.1 Consequences of Sand Production

The consequences of sand production are always detrimental to the short-long-term productivity of the well.

1.3.2 Accumulation Downhole:

If the production velocity in well tubular is insufficient to transport sand to the surface, it will begin to fill the inside of the casing. Eventually, the producing interval may be completely covered with sand. In this case, the production rate will decline until the well becomes “sanded up” .

1.3.3 Accumulation in Surface Equipment

If the production velocity is sufficient to transport sand to the surface, the sand may still become trapped in the separator, heater treater, or production flowline. If enough sand becomes trapped in one of these areas, cleaning will be required to allow for efficient production of the well. To restore production,

1.3.4 Erosion of Downhole and Surface Equipment

If fluids are in turbulent flow, such sand-laden fluids are highly erosive section of eroded well screen exposed to a perforation that was producing sand.. If the erosion is severe or occurs long enough, complete failure of surface and/or downhole equipment may occur, resulting in critical safety and environmental problems as well as deferred production.

1.4Introduction to Case Study (FNE Field)

Fula North East (FNE) field is located in the East of Fula sub-basin, southwest of Sudan , 10 km north east from existing Fula North Field see figure 1.3 which established on October, 2010.

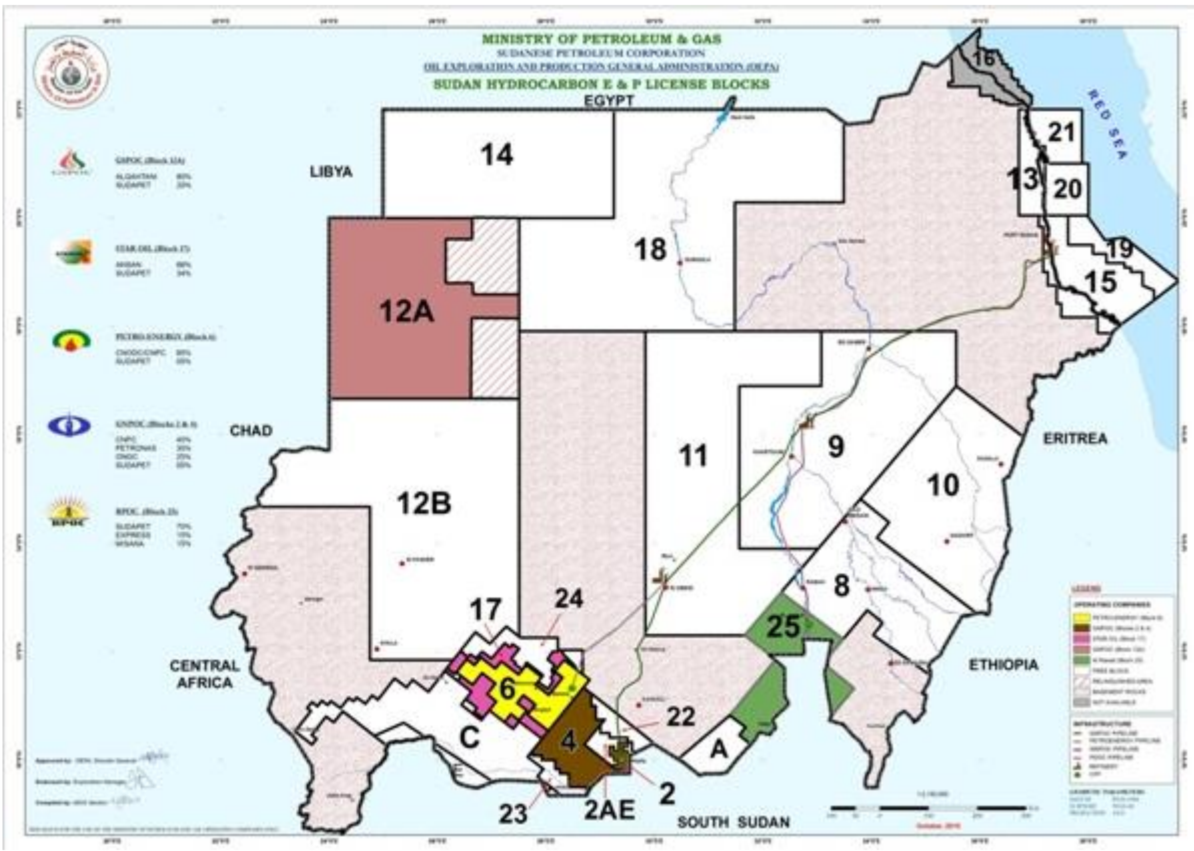

Figure 1.3 Sudan Hydrocarbon Exploration&Productionmap(Oil & Gas Magazine, 2015)

FNE Field is shallow heavy oil reservoir with good hydrocarbon concentrate in small area, which has three productive sand intervals, named “Bentiu”, “Aradeiba”, and

“Abu Gabra”,. With normal Faults, and has clear oil/water contact (OWC) system in “Bentiu” formation.

FNE oilfield produces high viscous crude oil from productive sand interval, (Bentiu) massive sand formation, sands in this formation had average initial oil saturation of 50%. Average porosity is 27% and permeability range from 1 to 10 Darcie’s, however the oil density of 10 to 17.9 degree API and viscosity of 3791.5 cp, combined with low initial reservoir temperature (44ºC) and (576psi) average reservoir pressure result in low primary recovery.

Estimated production as per Oct, 2016:

- ✓ Current production: about 9,000bbl/d
- ✓ Target production: up to 15,000bbl/d.

Total wells: 100 wells as distributed in figure 1.4.

Cold production wells: 18 wells.

Hot production wells: 78 wells.

Steam injector 4 wells

Figure 1.4 Strategy -Cold Production, CSS/SF, Vertical and Horizontal Wells. (13th DTR, 2016)

1.5 Problem Statement:

For FNE oil field, the major problem is sand production that leads to:

- ✓ Erosion of surface and down hole equipments.
- ✓ Blockage of Flow Lines, Accumulation of sand. Lowers the production, plugging flow lines. High amounts will block pipes leading to non- productive time.
- ✓ Separator Problems Separators work at certain production rate. Sand could take up a valuable volume, Reduction in the Separators efficiency, Reduction in oil flow rate, Helps in the formation of unwanted emulsions between oil and water.

1.6 Objectives:

- ✓ To study sand production problem as main challenge of heavy oil production from Sudanese oil field.
- ✓ To analysis for some wells of FNE with high sand production in term location, formation and production method.

1.7 Thesis Outline

The thesis is divided into five chapters. Chapter One gives a brief general introduction and Introduction to case study. It also states the objectives and defines the scope. Chapter Two talks about Theoretical background and literature review on the subject matter sand production effects, prediction, control, and management techniques. The methodology is discussed in Chapter Three. Chapter Four focuses on Results & Discussion. Chapter Five gives conclusions, and recommendations of the thesis.

CHAPTER TWO

Theoretical Background and Literature Review

2.1 Introduction

Sand production is a problem encountered during the production of oil and gas especially in formations relatively young in geologic age. These rocks are unconsolidated and accounts for majority of the world's reservoirs, therefore most formations are susceptible to sand production. It can be defined as the production of quantifiable amount of sand particles along with reservoir fluids. Sand production is a two-part decoupled phenomenon: sand must be separated from the perforation tunnel (failure), and the flowing fluid must transport the failed sand. Stress, controlled by drawdown and depletion does the first, and rate, also controlled by drawdown does the second (Venkitaraman et al., 2000). Depletion and drawdown fail the medium under either shear or tensile or volumetric failure mechanisms or a combination of them (Nouri et al., 2003). The production of formation sand might start during first flow or later in the life of the reservoir when pressure has fallen or water breaks through. Sand production can erode downhole equipment and surface facilities, production pipeline blockage and leakage, generate additional need for waste disposal which could be a problem in areas of stringent environmental regulations, lead to formation subsidence in severe cases and generate more frequent need for workovers and well intervention. These effects can be viewed as economic and of safety hazards in the oil and gas industry.

2.1.1 Sand Production Effects

The effects of sand production are often detrimental to the productivity of a well in the long run. Downhole equipment might be blocked or damaged and/or surface facilities disabled.

Erosion of downhole and surface equipment: sand produced with formation sand at high velocity can erode surface and downhole equipment leading to frequent maintenance to replace such equipment. Blast joints, tubing opposite perforations, screens or slotted liners not packed in the gravel pack installation are potential sites for downhole erosion. If the erosion is severe or occurs over a sufficient length of time, complete failure of surface and/or downhole equipment may occur, resulting in critical safety and environmental problems as well as deferred production. High-pressure gas containing sand particles expanding through the surface choke is the most hazardous situation. For some equipment failures see figure 2.1, a rig assisted workover may be required to repair the damage (William and Joe, 2003)

Figure. 2.1: Surface Choke Failure Due To Erosion ByFormation Sand (Completion Technology., 1995)

Formation subsidence: the cumulative effect of producing formation sand is collapse of the formation. Over time large volume of sand will be produced at the surface creating a void behind the casing. This void widens as more sand is produced. Formation sand or shale above the void may collapse into it as a result of lack of material for support. The sand grains rearrange to create a lower permeability than was originally especially in formations with high clay content or wide range of grain sizes. Complete loss of productivity is likely in situations where the overlying shale collapses. The collapse of the formation is particularly important if the formation material fills or partially fills the perforation tunnels. Even a small amount of formation material filling the perforation tunnels will lead to a significant increase in pressure drop across the formation near the well bore for a given flow rate (Completion technology., 1995)

Sand accumulation in surface equipment in situations where the production velocity of the reservoir fluid is sufficient to carry sand up the tubing to the surface. Sand particles often settle in surface facilities as separators, heaters, pumps, condensers. As the accumulation builds to appreciable volume in these facilities equipment cleanup becomes inevitable, this causesdeferred production (well is shut-in) and additional cost is inquired as a result of the cleanup activity. Production capacity of the separator is reduced if partially filled with sand. This is as a result of its reduced ability to handle gas, oil and water.

Subsurface accumulation: when the production flow velocity is not sufficient to carry the sand particles to the surface. The sand accumulates in the casing or bridges off in the tubing, with time the production interval might be filled with sand. This reduces the production rate for such wells which might eventually cease as the sand accumulation makes it impossible for production to continue. Work over actives is often required in such occurrences for the well to resume production. If sand production is continuous, well clean out operations may be required regularly. This causes increased maintenance cost and lost production which in turn reduces returns from the well.

Sand disposal: this constitutes a problem in formations producing sand especially in areas where there are stringent environmental constrains. Offshore processing systems that do not satisfy anti-pollution regulation the separated sand is to be transported onshore for disposal constituting additional production cost.

2.1.2 Causes of Sand Production

Factors influencing the tendency of a formation/ well to produce sand can be categorized into rock strength effects and fluid flow effects. Production of sand particles consists of formation fines and load bearing solids. The production of formation fines which is not considered as part of the formations mechanical framework is beneficiary as can they move freely through the formation instead of plugging it. Production rates are often kept to levels so as to avoid the production of the load bearing particles, in many cases however low production rates are uneconomical. These factors include:

Degree of consolidation: The ability to maintain open perforation tunnels is closely tied to how strongly the individual sand grains are bound together. The cementation of sandstone is typically a secondary geological process and as a general rule, older sediments tend to be more consolidated than newer sediments. This indicates that sand production is normally a problem when producing from shallow, geologically younger tertiary sedimentary formations. Such formations are located in the Gulf of Mexico, California, Nigeria, French West Africa, Venezuela, Trinidad, Egypt, Italy, China, Malaysia, Brunei, Indonesia and others. Young Tertiary formations often have little matrix material (cementation material) bonding the sand grains together and these formations are generally referred to as being "poorly consolidated" or "unconsolidated". A mechanical characteristic of rock that is related to the degree of consolidation is called "compressive strength". Poorly consolidated sandstone formations usually have a compressive strength that is less than 1,000 pounds per square inch (Completion technology., 1995).

Production rate: Increasing the well production rate creates large fluid pressure gradient near the wellbore (perforation) which tends to draw sand into the wellbore. Generally, production of the reservoir fluids creates pressure differential and frictional drag forces that can combine to exceed the formation compressive strength. This indicates that there is a critical flow rate for most wells below which pressure differential and frictional drag forces are not great enough to exceed the formation compressive strength and cause sand production. The critical flow rate of a well may be determined by slowly increasing the production rate until sand production is detected. One technique used to minimize the production of sand is to choke the flow rate down to the critical flow rate where sand production does not occur or has an acceptable level. In many cases, this flow rate is significantly below the acceptable production rate of the well. (Completion technology. 1995).

Pore pressure reduction: Reservoir fluid production overtime depletes the reservoir pressure resulting in pore pressure reduction. As the reservoir pressure is depleted throughout the producing life of a well, some of the support for the overlying rock is removed. Lowering the reservoir pressure creates an increasing amount of stress on the formation sand itself. (Completion technology., 1995) i.e. the effective overburden pressure increases. The formation sand particles may be crushed or break loose from its matrix at some time in reservoir life which could be produced along with the reservoir fluids. The formation might subside if the effective stress exceeds the formation strength due to compaction of reservoir rock from reduction in pore pressure.

Reservoir fluid velocity: The frictional drag force exerted on the formation sand grains is created by the flow of reservoir fluid. This frictional drag force is directly related to the velocity of fluid flow and the viscosity of the reservoir fluid being produced. High reservoir fluid viscosity will apply a greater frictional drag force to the formation sand grains than will a reservoir fluid with a low viscosity. The influence of viscous drag causes sand to be produced from heavy oil reservoirs which contain low gravity, high viscosity oils even at low flow velocities. (Completion technology., 1995)

Increasing water production: Increase in water cut increases sand production or as water production beings sand production beings too. These occurrences can be explained by two mechanisms. In a typical water-wet sandstone formation, some grain-to-grain cohesiveness is provided by the surface tension of the connate water surrounding each sand grain. At the onset of water production the connate water tends to adhere to the water produced, resulting in a reduction of the surface tension forces and subsequent reduction in the grain-to-grain cohesiveness. The stability of the sand arch around the perforation has been shown to be limited greatly by the production of water resulting in the production of sand. An arch is a hemispherical cap of interlocking sand grains that is table at constant drawdown and flow rate preventing sand production (Jon Carlson et al., 1992). A second mechanism by which water production affects sand production is related to the effects of relative permeability. As the water cut increases, the relative permeability to oil decreases. This result in an increasing pressure differential being required to produce oil at the same rate. An increase in pressure differential near the wellbore creates a greater shear force across the formation sand grains. Once again, the higher stresses can lead to instability of the sand arch around each perforation and subsequent sand production see figure 2.2 (Completion technology, 1995).

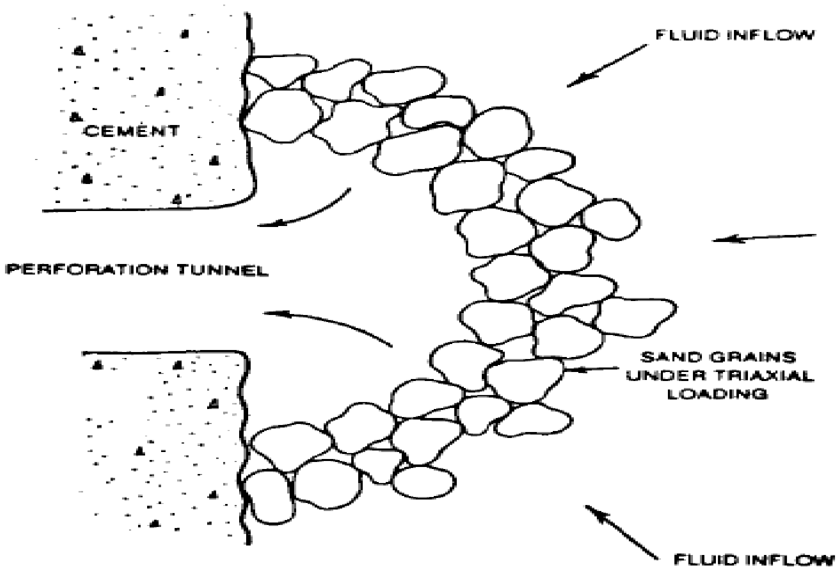

Figure.2.2: Geometry Of A Stable Arch Surrounding A Perforation (Source: Completion Technology.1995)

2.2 Literature Review

2.2.1 Cause study in the worldwide

In 1972 Spurlock, J. W,illustrate a new Approach to the Sand Control Problem A Multi-Layer, Wire-Wrapped Sand Screen that have been used to control unconsolidated oil-bearing sands since the early 1900's.The function of the multiple wraps of variously spaced wire is to bridge the larger sand grains at the outer layer of the screen, intermediate size grains in the successive layers, and the smaller size grains in the innermost layer. The multi-layer screen does not require a gravel pack It is applicable produced at high velocities. It is has been installed and tested in 33 wells onshore and 26 wells offshore with an overall success ratio of 80 percent. It can be used for multiple completions without gravel packing and offers simplified mechanical packing.

In 1989 Islam, M. R., Horizontal wells are of great interest to most oil companies operating in heavy oil fields. Unfortunately, likely candidates of horizontal wells are mostly "quicksand" type formations and the critical velocities of sand in a wellbore isextremely low. Consequently, sand is very likely to enter the horizontal wellbore if not preventive measure is taken. Problems of sand production in a horizontal well is more complicated than in a vertical well due to difficulty in cleaning sands in horizontal wellbores. The present study discusses the problems of sand production in a horizontal well and offers recommendation in controlling them. Physical simulation of the top part of the horizontal well showed that both gravitational and inertial forces help minimizing sand production. This will mean that increasing flow rates will decrease sand production.

In 1991 Morita.N,analyses of five typical sand problems commonly observed in the field. These include sand problems induced by (1) unconsolidated formations; (2) water break through for weak to intermediate strength formations; (3) reservoir pressure depletion in relatively strong formations; (4) abnormally high lateral tectonic force in relatively strong formations; and (5) sudden change in flow rate or high flow rate. The paper explains (using field data) how these sand problems occur and how they progress. In this paper that core-based selection of completion methods can be adopted as a routine field procedure to increase hydrocarbon production with minimum sand problems.

In 1995Dusseault, M. B., explain Cold production as a new primary production process can be used successfully in heavy oil unconsolidated sandstones. application of Cold Production to many other cases in other parts of the world must be investigated. Strategies to initiate sand production involve aggressive perforation and swabbing measures. Keeping sand production stable after initiation requires pumps to cope with large initial sand ratios in a foamy oil form for several weeks, and smaller amounts of sand and foamy fluid continuously for many monthsbetter controlled work-over approaches and new technologies are needed. Sand and "gorp" separation from oil at surface is necessary.

In 2003 Wong, R..ExplainSand production and foamy oil flow are the two key factors contributing to successes in cold flow production in Alberta and Saskatchewan. However, the two mechanisms have been studied and treated separately as geomechanics and multiphase flow problems, respectively. This paper describes special experiments that were designed to combine these two processes, The experiments involved flow of heavy oil with no dissolved gas (dead oil) and heavy oil with dissolved gas (live oil) in natural, intact heavy oil sand cores. It was found that gas nucleation in heavy oil is the major factor in causing the initiation of sand production in oil sand.

2.2.2 Case study in Sudan

In 2011 Wang, R demonstrates application of Cold Heavy Oil Production with Sand (CHOPS) in Sudan, which has been successfully applied in B heavy oil reservoir of FN field. B reservoir is a series of massive sandstones with strong bottom water drive, which are loosely consolidated and interbedded with shale barriers. Successful CHOPS in this paper highlighted fine barriers (interbed/ intrabed) characterization and optimized perforation strategy, infill well drilling, optimized borehole lifting and facilities design, giving a cost-effective staircase for CHOPS implementation.

Previous mentioned studies discussed sand control problem for unconsolidated oil-bearing sands, sand production in a horizontal and vertical wells, analysis of sand problems commonly observed in field and explain some production technology with sand.

In this research we will do analysis for some wells of FNE with high sand production and accordingly finds the suitable solution for this case.

Chapter Three

Methodology

3.1 Data Collection

FNE filed is producing heavy viscous oil associated with sand and consist of 100 wells drilled in 72000 m^2, these wells included steam flooding injector wells, steam flooding producer wells, cold productionwells and hot production wells.

We chose 42 from wells which produced high sand according to:

1. Laboratory test.
2. Workover histories.
3. Surface cleaning and sand removal from well flow lines and OGMs.

We have focus in our research on the data from workover because it's more accurate and each well has many workover from start-up, and the accumulation sand has been calculated from the period from well commissioned until last workover program for each selected well.

Data from lab shows less amount of sand comparing with the actual amount of sand removed manually from flow lines, data collected from Surface cleaning and sand removal from well flow lines and OGMs by pigging or flushing gives actual witness of the wells with high sand production.

3.2 Data Analysis

FNE wells producing from Bentiu formation, this formation has three layers (B1A, B1B and B1C), and the high production wells of FNE had been classified based on:

- Wells formation.
- Pay zones.
- Location.
- Production methods, Cyclic Steam Stimulation (CSS) & Cold Heavy Oil Production (CHOP).

Also analysis consists of comparing between thickness, production period and accumulative production with sand production amount.

3.3 Field Selection

Sand Production is the initiative of various problems related to the oil and gas industry sand production still make challenge and affect to oil production in FNE Field Blockage of flow lines& process piping due to sand deposition occurred, therefore FNE field has been selected to study the sand problem which cause trouble for smooth production, FNE is good field for sand study because it has shallow reservoir and has viscous oil all these factors caused to producing sand with oil.

3.4 Process Chart

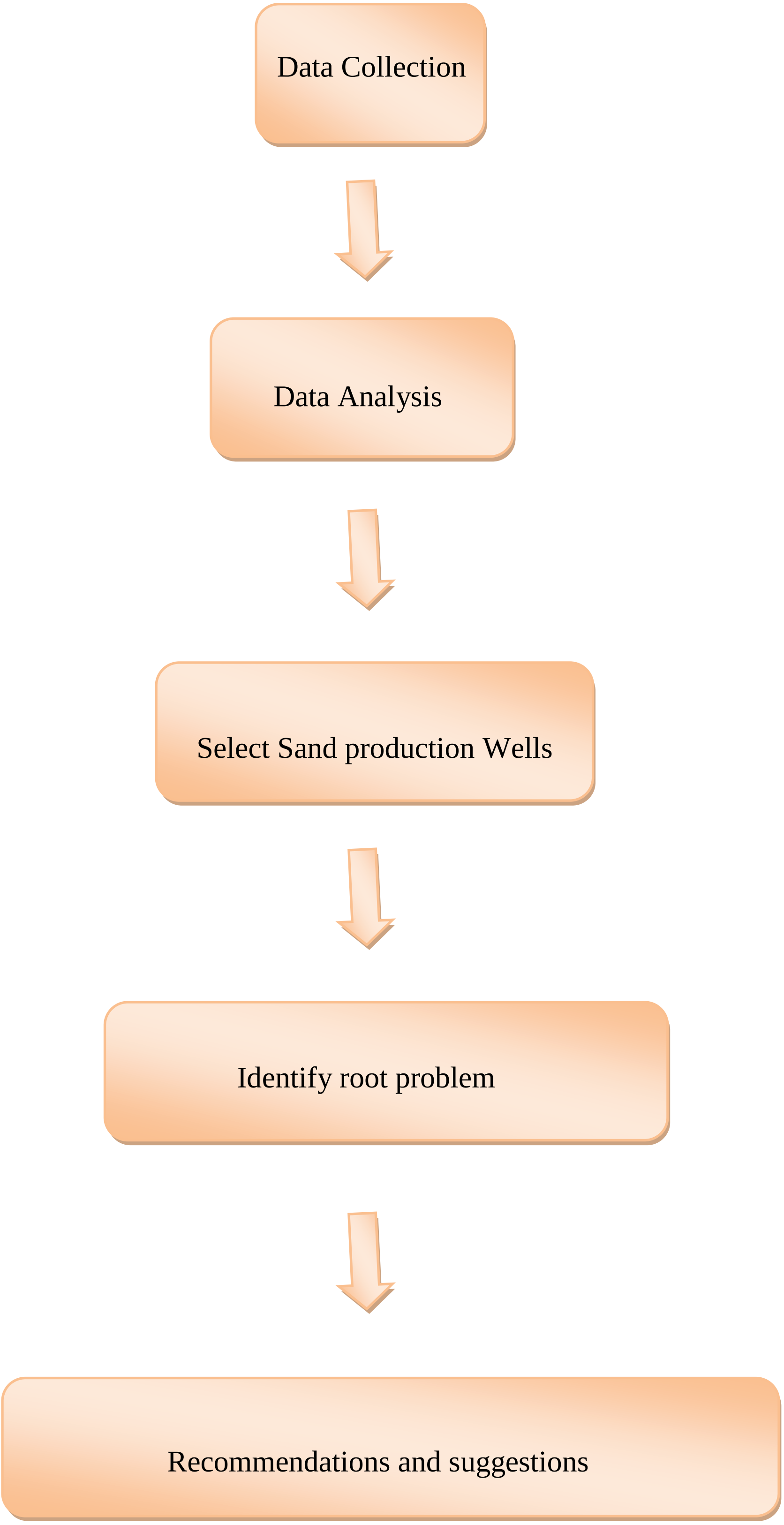

Figure 3.1 Flow Chart of Case Study Process

Chapter Four

Result and Discussion

4.1 FNE Oil Properties

FNE Oilfield is geographically located in the southwest of Sudan, about 700 km from the capital, Khartoum; structurally located in the northeast of Fula sub-basin of Muglad basin and in the southwest of the Moga Oilfield, and has a long narrow structure from northwest to southeast, the biggest length of northwest-southeast is about 10 km, the average width of northeast-south is about 1.5 Km. The field oil bearing area is around 12 Km^2. The overall terrain in FNE Field is higher in the southwest and lower in the northeast.

FNE Oilfield exploration began in 1989, the first well FNE-01 has been drilled in 2005, and then immediately the development and research began. The oilfield development Case was completed by Beijing Research Institute of Petroleum Exploration and Development in May 2008.

FNE heavy crude oil belongs to high carbon naphthenic acid value crude oil. Crude, the following is the summary of crude oil analysis:

Density 0.9241 g/cm^3

Pour point 0 ^{O}C

Asphaltene 0.2 %

Wax 4.8 %

Acid number 6.83 mgKOH/g

GOR of wells 1.0 sm^3/m^3

Formation water: $NaHCO_3$ type.

FNE reservoirs are highly porous (~30%), permeable (1000-2000 mD and unconsolidated in nature. the fluid properties include viscous crude with 15 to 17.7

API. Corresponding viscosities are in the range of 250 cp and 500 cp at reservoir conditions.

4.2 High sand production wells

The below table (4.1) contains all the high sand production wells (42) in FNE field which has been selected from entire wellsdepending on data from workover and manual sand cleaning job by pigging and flushing.

Table 4.1 FNE High Sand Production Wells

FNE High Sand Wells										
No.	Name	Start-up Date	Reservoir	Perforated Thickness (m)	Mid-Depth(mKB)	Formation	Cum. Sand Production(bbl)	Production days	Connected to	Well location
1	FNE-05	Jun.19,2010	Bentiu	21.2/3zones	515.5	B1a,B1b(2 Zones)	15.7	704	OGM-01	North
2	FNE-07	Aug.25,2010	Bentiu	14.0/2zones	528.5	B1a(2 Zones), B1b	25.91	1388	OGM-03	South
3	FNE-08	Aug.15,2010	Bentiu	15.0/3zones	524.5	B1a (3 Zones)	105.2	901	FNE-FPF	East
4	FNE-09	Sep.13,2010	Bentiu	21.9/3 zones	513.85	B1a (2 Zones),B1b	16.36	247	OGM-01	North
5	FNE-11	Sep.07,2010	Bentiu	19.0/2zones	537.5	B1a	15.3	294	OGM-01	North
6	FNE-13	Sep.22.2010	Bentiu	17.7/5zones	514.2	B1a,B1b	21.09	186	OGM-01	North
7	FNE-15	Jun.18,2010	Bentiu	10.9/3zones	558.05	B1a(3 zone)	6.9	2087	OGM-01	West
8	FNE-16	Mar.12,2010	Bentiu	17.3/3zones	535.55	B1a(2 zone) & B1b(1 zone)	41	1523	OGM-01	North
9	FNE-18	Jun.23,2010	Bentiu	16.0/2zones	544.5	B1a & B1b	7.7	525	OGM-02	North
10	FNE-19	Jul,07.2010	Bentiu	14.7/3zones	572.5	B1a (3 Zones)	51.2	678	OGM-02	West
11	FNE-22	Jun.24, 2010	Bentiu	13.5/1zone	542.5	B1a	24	532	FNE-FPF	West
12	FNE-24	Jun.24,2010	Bentiu	9/1zone	568.5	B1a	3.8	1894	FNE-FPF	West
13	FNE-25	Jun.24,2010	Bentiu	14.50/4zones	553	B1a	23.12	1471	FNE-FPF	West
14	FNE-26	Sep.05,2010	Bentiu	23.5/2zones	520.25	B1a,B1b	18.59	817	OGM-02	North
15	FNE-27	Aug,29.2010	Bentiu	9.5/2zones	539	B1a (2 Zones)	19.67	1590	OGM-02	North

Table 4.1 High Sand Production Wells (Cont'd)

No	Name	Start-up Date	Reservoir	Perforated Thickness (m)	Mid-Depth(mKB)	Formation	Cum. Sand Production(bbl)	Production days	Connected to	Well location
16	FNE-28	Aug.13,2010	Bentiu	12/1zone	534	B1a	21.34	1737	OGM-02	North
17	FNE-29	Jun,16.2010	Bentiu	10/2zones	553	B1a (2 Zones)	17.89	896	FNE-FPF	North
18	FNE-30	Jun, 24.2010	Bentiu	32.3/1zone	532.15	B1a,B1b(2 Zones)	19.7	650	FNE-FPF	North
19	FNE-31	Aug,18.2010	Bentiu	12.6/1Zone	547.1	B1a	20.5	1235	FNE-FPF	North
20	FNE-33	Oct.21,2010	Bentiu	9.5/2zones	539.25	B1a	N/A	N/A	OGM-03	North
21	FNE-34	Oct.07,2010	Bentiu	15.8/3 Zones	533	B1a & B1b	48	1702	OGM-03	South
22	FNE-35	Dec.03,2010	Bentiu	16.5/4zones	520.75	B1a(2 zone) & B1b(2 zone)	15	1192	OGM-06	south
23	FNE-36	Aug.16,2011	Bentiu	15/3zones	518	B1a(2 zone) & B1b(1 zone)	11.1	971	OGM-04	South
24	FNE-37	Nov.14,2009	Bentiu	14.5/2zones	528.6	B1a & B1b	11	1315	OGM-06	South
25	FNE-38	Sep, 30.2009	Bentiu	14/2zones	528	B1a & B1b	9	1987	OGM-03	South
26	FNE-39	Jul.28,2011	Bentiu	13.25/2zones	528.5	B1a & B1b	90.5	1219	OGM-04	South
27	FNE-40	Jul.16,2011	Bentiu	15/1Z	529.5	B1a	N/A	N/A	OGM-04	South
28	FNE-41	Aug.18,2011	Bentiu	18/2Zones	523.25	B1a & B1b	29.14	1767	OGM-04	South
29	FNE-45	May.08,2013	Bentiu	22/4Zones	530.5	B1a,B1b & B1c(2 Zone)	104.5	489	OGM-06	South
30	FNE-47	Apr. 5.2013	Bentiu	21/4Zones	494	B1a (2 Zones),B1b(3zones)	22.27	534	OGM-06	South

Table 4.1 FNE High Sand Production Wells(Cont'd)

No	Name	Start-up Date	Reservoir	Perforated Thickness (m)	Mid-Depth(mKB)	Formation	Cum. Sand Production(bbl)	Production days	Connected to	Well location
31	FNE-48	Mar.29.2013	Bentiu	19/3Zones	521.5	B1a,B1b(2 Zones)	9.18	567	OGM-06	South
32	FNE-49	Feb.10.2013	Bentiu	18/3zones	529	B1a,B1b,B1c	16.52	654	OGM-06	South
33	FNE-50	Feb.25,2013	Bentiu	18/3Zones	523.25	B1a,B1b & B1c	N/A	N/A	SF injector	South
34	FNE-51	Mar.12.2013	Bentiu	16/3zones	533.5	B1a (2 Zones),B1b(3zones)	14.03	N/A	SF.injector	South
35	FNE-52	Apr.21.2013	Bentiu	16/3zones	525	B1a,B1b(3zones),B1c	19.7	N/A	SF.injector	South
36	FNE-53	Apr.30.2013	Bentiu	17/4zones	529.5	B1a,B1b(3zones),B1c	18.2	N/A	SF.injector	South
37	FNE-55	May.9,2015	Bentiu	8/3Zones	556	N/A	21.87	N/A	OGM-07	West
38	FNE-58	Jun.26,2015	Bentiu	10/2zones	557	B1a	16.46	N/A	OGM-02	West
39	FNE-59	Jun.26,2015	Bentiu	10/2zones	557	N/A	22.01	N/A	OGM-07	West
40	FNE-61	Jun.17,2015	Bentiu	9.5/2Zones	558.5	B1a & B1b	N/A	N/A	OGM-07	West
41	FNE-103	July, 27.2015.	Bentiu	10/3Zones	539	B1a , B1b & B1c	N/A	N/A	FN-FPF	North
42	FNE-104	July, 26.2015.	Bentiu	10/3Zones	539	B1a , B1b & B1c	N/A	N/A	FN-FPF	North

They are 15 wells were eliminated from table (4-1) due to different reason such as diverting to steam flooding injector, gravel packing technic implemented and lack of some information ,as illustrated in below table (4-2).

Table 4.2 FNE High Sand Production WellsAfter 15 Wells Eliminated

No.	Name	Perforated Thickness (m)	Formation	Cum. Sand Production(bbl)	Production days	Well location
1	FNE-05	21.2/3zones	B1a,B1b(2 Zones)	15.7	704	North
2	FNE-08	15.0/3zones	B1a (3 Zones)	105.21	901	East
3	FNE-16	17.3/3zones	B1a(2 zone) & B1b(1 zone)	41	1523	North
4	FNE-18	16.0/2zones	B1a & B1b	7.7	525	North
5	FNE-19	14.7/3zones	B1a (3 Zones)	51.2	678	North
6	FNE-22	13.5/1zone	B1a	24	532	west
7	FNE-25	14.50/4zones	B1a	23.12	1471	west
8	FNE-26	23.5/2zones	B1a,B1b	18.59	817	North
9	FNE-27	9.5/2zones	B1a (2 Zones)	19.67	1590	North
10	FNE-28	12/1zone	B1a	21.34	1737	North
11	FNE-29	10/2zones	B1a (2 Zones)	17.89	896	North
12	FNE-30	32.3/1zone	B1a,B1b(2 Zones)	19.7	650	North
13	FNE-31	12.6/1Zone	B1a	20.5	1235	North
14	FNE-34	15.8/3 Zones	B1a & B1b	48	1702	South
15	FNE-35	16.5/4zones	B1a(2 zone) & B1b(2 zone)	15	1192	South
16	FNE-36	15/3zones	B1a(2 zone) & B1b(1 zone)	11.1	971	South
17	FNE-37	14.5/2zones	B1a & B1b	11	1315	South
18	FNE-38	14/2zones	B1a & B1b	9	1978	South
19	FNE-39	13.25/2zones	B1a & B1b	90.5	1219	South
20	FNE-41	18/2Zones	B1a & B1b	29.14	1767	South
21	FNE-45	22/4Zones	B1a,B1b & B1c(2 Zone)	104.5	489	South
22	FNE-47	21/4Zones	B1a (2 Zones),B1b(3zones)	22.27	534	South
23	FNE-48	19/3Zones	B1a,B1b(2 Zones)	9.18	567	South
24	FNE-49	18/3zones	B1a,B1b,B1c	16.52	654	South
25	FNE-58	10/2zones	B1a	16.46	N/A	West
26	FNE-103	10/3Zones	B1a,B1b & B1c	N/A	N/A	North
27	FNE-104	10/3Zones	B1a,B1b & B1c	N/A	N/A	North

4.3Sand ProductionAnalysis

From table (4-2) the data analysis and classification of high sand wells has been done according to:

- Wells formation&Pay zones.
- Production methods, Cyclic Steam Stimulation (CSS) & Cold Heavy Oil Production (CHOP).
- Location.
- Sand Productivity (bbl/d & bbl/m)

4.3.1 According to wells formation

In FNE field they are three pay zones in Bentiu formation B1a, B1b and B1c accordingly the wells were categorized as below.

4.3.1.1 Bentiu (B1a) Formation

There are 14 wells producing from B1a formation, 05 wells (FNE-15, 24, 33, 40&11) were eliminated see table (4-3) below, FNE-15 and FNE-24 due to low amount of sand comparing with the other wells in its group location, FNE-33 & FNE-40 shows too much sand from the data in manual cleaning sand and pigging but from workover we didn't got enough information and FNE-11 gravel packing implemented.

The rest 9 wells they have high sand production with average sand production 33bbl see table (4-3) and figure 4-2 which show individual well sand production, this wells represented 33% from total high sand production wells (27) which mentioned in table (4-2).

Table 4.3Bentin B1aWells

No	Name	Start-up Date	Reservoir	Perforated Thickness (m)	Mid-Depth(mKB)	Formation	Cum. Sand Production(bbl)	Production sand period
1	FNE-08	Aug.15,2010	Bentiu	15.0/3zones	524.5	B1a (3 Zones)	105.21	901
2	FNE-19	Jul,07.2010	Bentiu	14.7/3zones	572.5	B1a (3 Zones)	51.2	678
3	FNE-22	Jun.24, 2010	Bentiu	13.5/1zone	542.5	B1a	24	532
4	FNE-25	Jun.24,2010	Bentiu	14.50/4zones	553	B1a	23.12	1471
5	FNE-27	Aug,29.2010	Bentiu	9.5/2zones	539	B1a (2 Zones)	19.67	N/A
6	FNE-28	Aug.13,2010	Bentiu	12/1zone	534	B1a	21.34	1737
7	FNE-29	Jun,16.2010	Bentiu	10/2zones	553	B1a (2 Zones)	17.89	N/A
8	FNE-31	Aug,18.2010	Bentiu	12.6/1Zone	547.1	B1a	20.5	N/A
9	FNE-58	Jun.26,2015	Bentiu	10/2zones	557	B1a	16.46	N/A
Average sand production							33	
Accumulation sand production							299	

The below figure 4.1 show the location of B1a wells in structure map which highlighted by red circle.

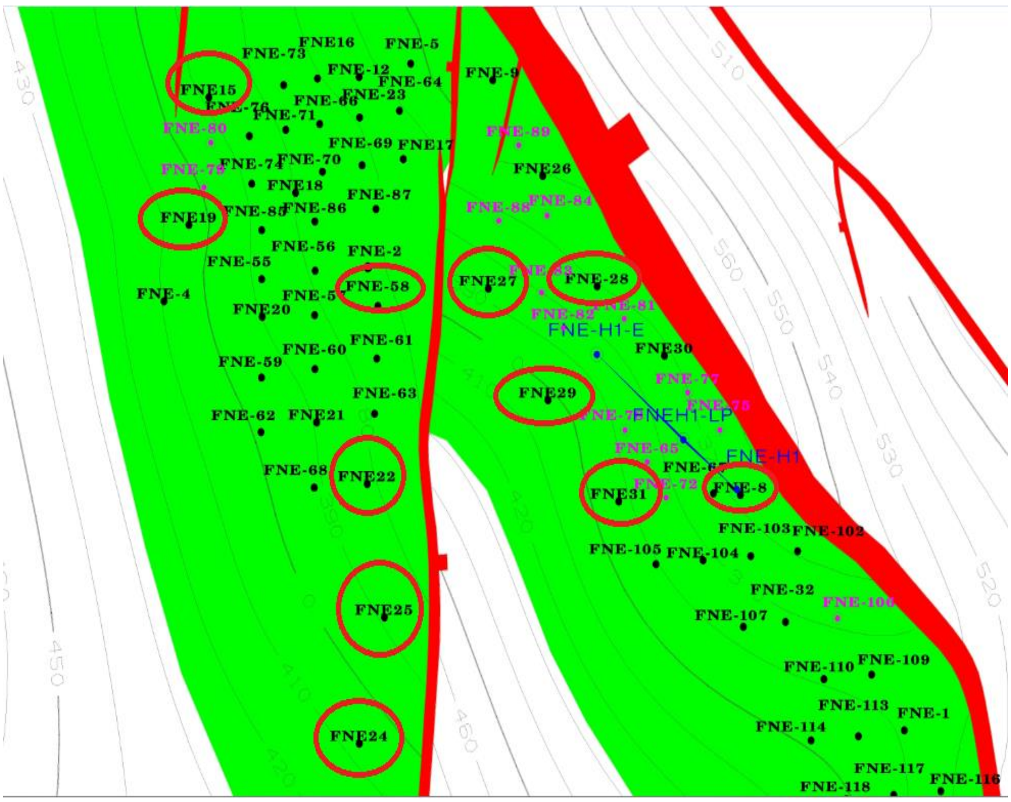

Figure4.1StructureMap of Formation B1a and Location of High Sand Wells.

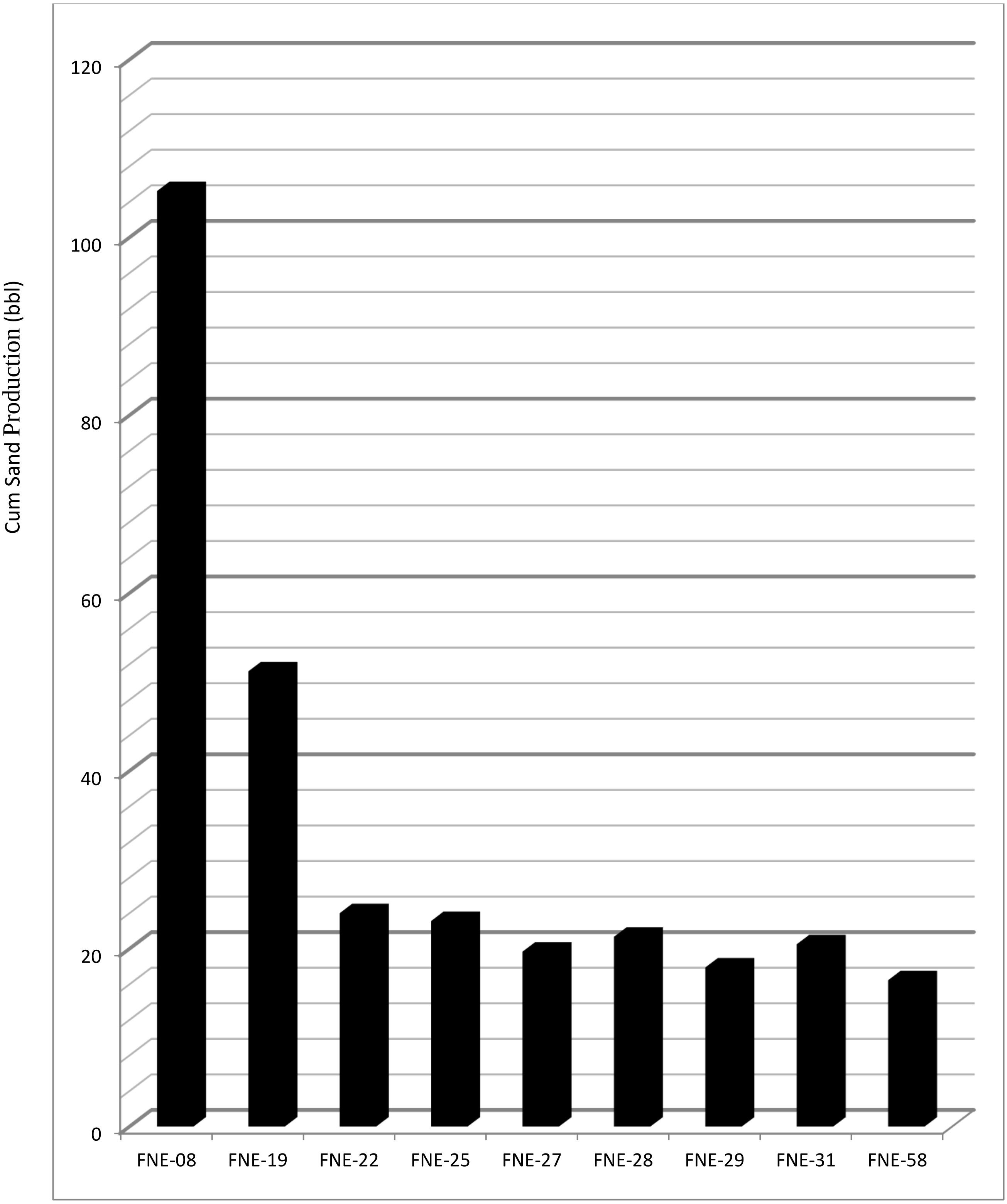

Figure4.2 B1a Sand Production

4.3.1.2Bentiu (B1a & B1b) Formation

There are 19 wells producing fromBentiu (B1a and B1b) which have high sand record, FNE-51eliminated because has been converted to injector for steam flooding project and FNE-61 due to no enough data, also FNE-07, FNE-09 and FNE-13 because gravel packing were implemented, the rest are 14 wells with average sand production 25bbl,and figure 4-3 show individual well sand production which represented 52% from total high sand production wells (27) which mentioned in table (4-2).

Table 4.4 (B1a& B1b) Formation Wells

No	Name	Perforated Thickness (m)	Formation	Cum. Sand Production(bbl)	Production sand period	Well location
1	FNE-05	21.2/3zones	B1a,B1b(2 Zones)	15.7	704	North
2	FNE-16	17.3/3zones	B1a(2 zone) & B1b(1 zone)	41	1523	North
3	FNE-18	16.0/2zones	B1a & B1b	7.7	525	North
4	FNE-26	23.5/2zones	B1a,B1b	18.59	N/A	North
5	FNE-30	32.3/1zone	B1a,B1b(2 Zones)	19.7	N/A	North
6	FNE-34	15.8/3 Zones	B1a & B1b	48	1702	South
7	FNE-35	16.5/4zones	B1a(2 zone) & B1b(2 zone)	15	1192	south
8	FNE-36	15/3zones	B1a(2 zone) & B1b(1 zone)	11.1	971	South
9	FNE-37	14.5/2zones	B1a & B1b	11	1315	South
10	FNE-38	14/2zones	B1a & B1b	9	1978	South
11	FNE-39	13.25/2zones	B1a & B1b	90.5	1219	South
12	FNE-41	18/2Zones	B1a & B1b	29.14	1767	South
13	FNE-47	21/4Zones	B1a (2 Zones),B1b(3zones)	22.27	534	South
14	FNE-48	19/3Zones	B1a,B1b(2 Zones)	9.18	567	South
	Average sand production			25		
	Accumulation sand production			348		

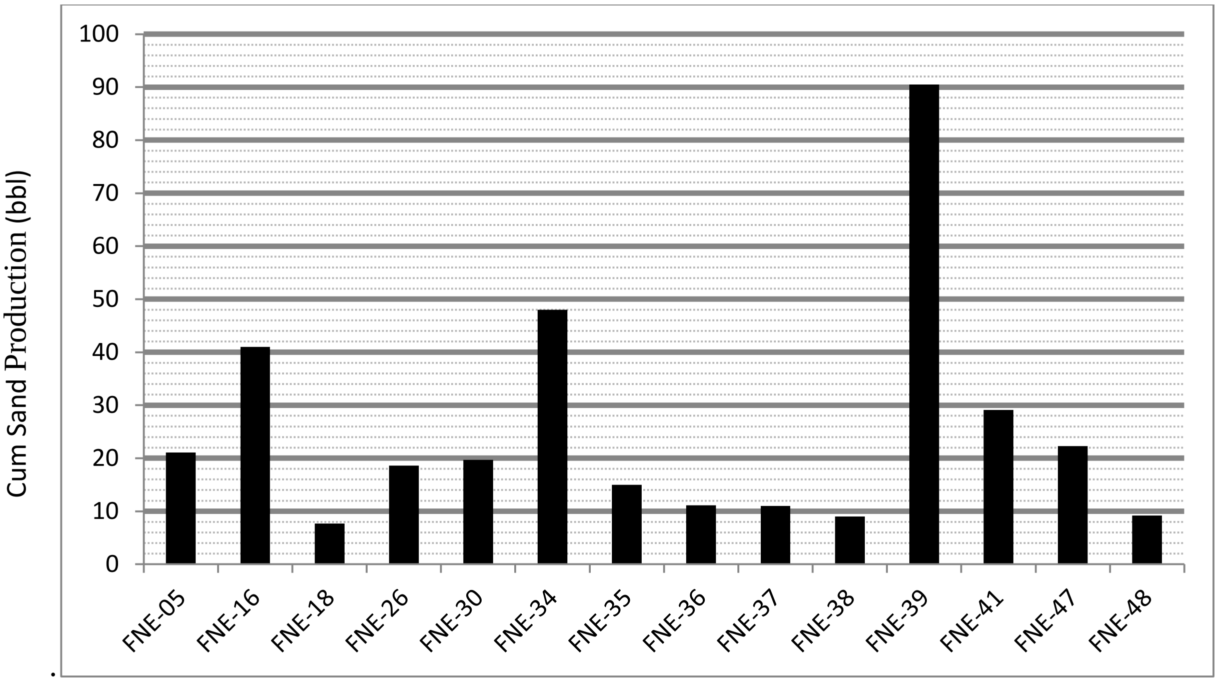

Figure- 4.3B1a&B1bWells

The below figure 4.4 and figure 4.5 show the location of wells B1a&B1b in structure map which highlighted by white circle

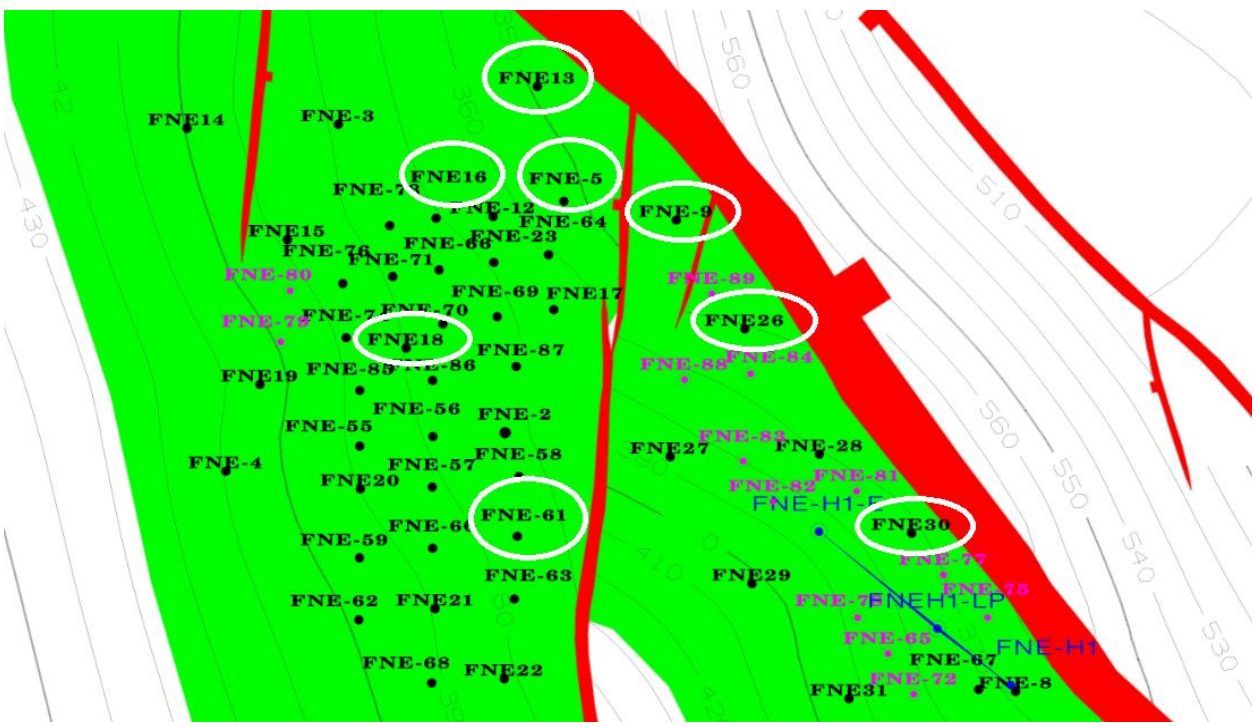

Figure 4.4 Structure Map of Formation B1a&B1bWells

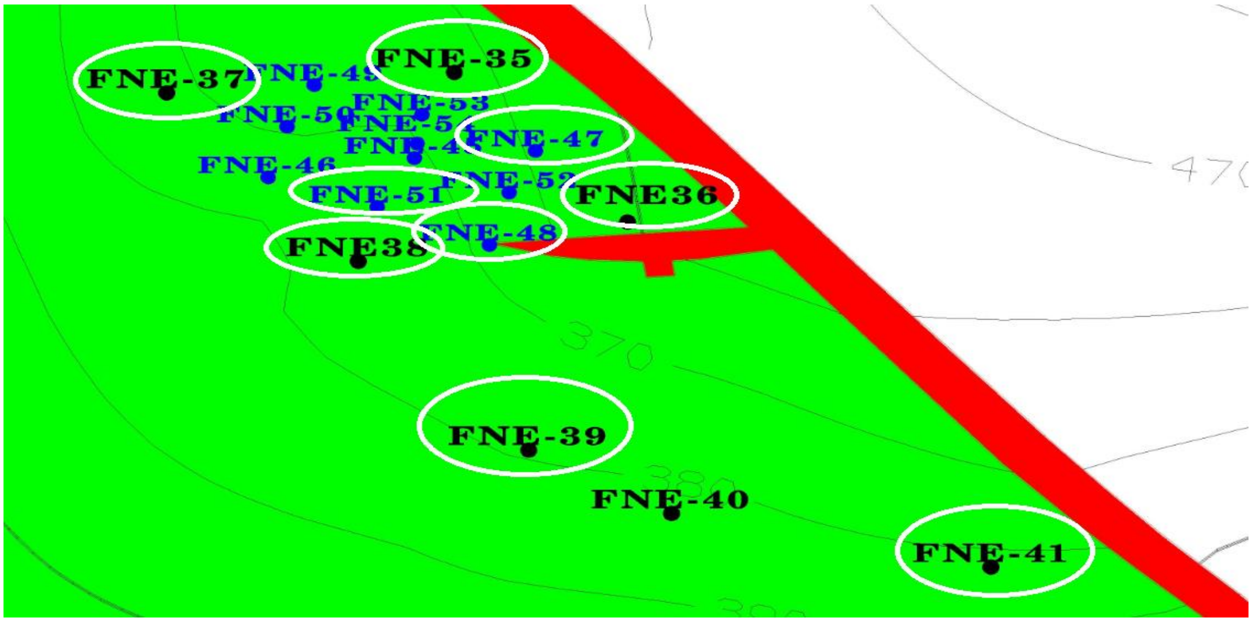

Figure4.5Structure Mapof Formation B1a&B1bWells

4.3.1.3 Bentiu (B1a, B1b & B1c) Formation

This formation contain 7 wells three of them FNE-50, FNE-52 and FNE-53 were converted to injectors for steam flooding project the below table illustrated the 4 remaining wells. With average sand production 60.5 bbl,and figure 4.6 show individual well sand productionwhichrepresented15% from total high sand production wells (27) which mentioned in table (4-2).

Table 4.5 B1a, B1b& B1c Formation Wells

No	Name	Perforated Thickness (m)	Mid-Depth (mKB)	Formation	Cum. Sand Production(bbl)	Production sand period	Well location
1	FNE-45	22/4Zones	530.5	B1a,B1b & B1c(2 Zone)	104.5	489	South
2	FNE-49	18/3zones	529	B1a,B1b,B1c	16.52	654	South
3	FNE-103	10/3Zones	539	Bentiu	N/A	N/A	North
4	FNE-104	10/3Zones	539	Bentiu	N/A	N/A	North
	Average sand production				60.5		
	Accumulation sand production				121		

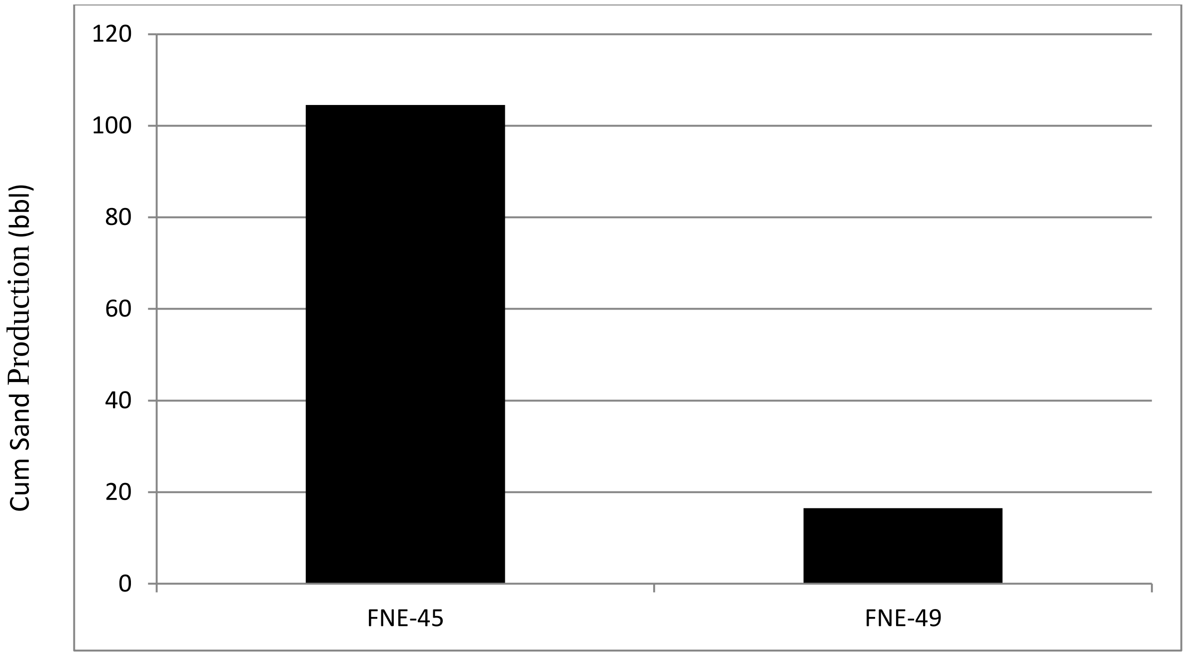

Figure 4.6 B1a, B1b&B1c Wells

The below figure 4.7 show the location of wells B1a, B1b & B1c in structure map which highlighted by red circle.

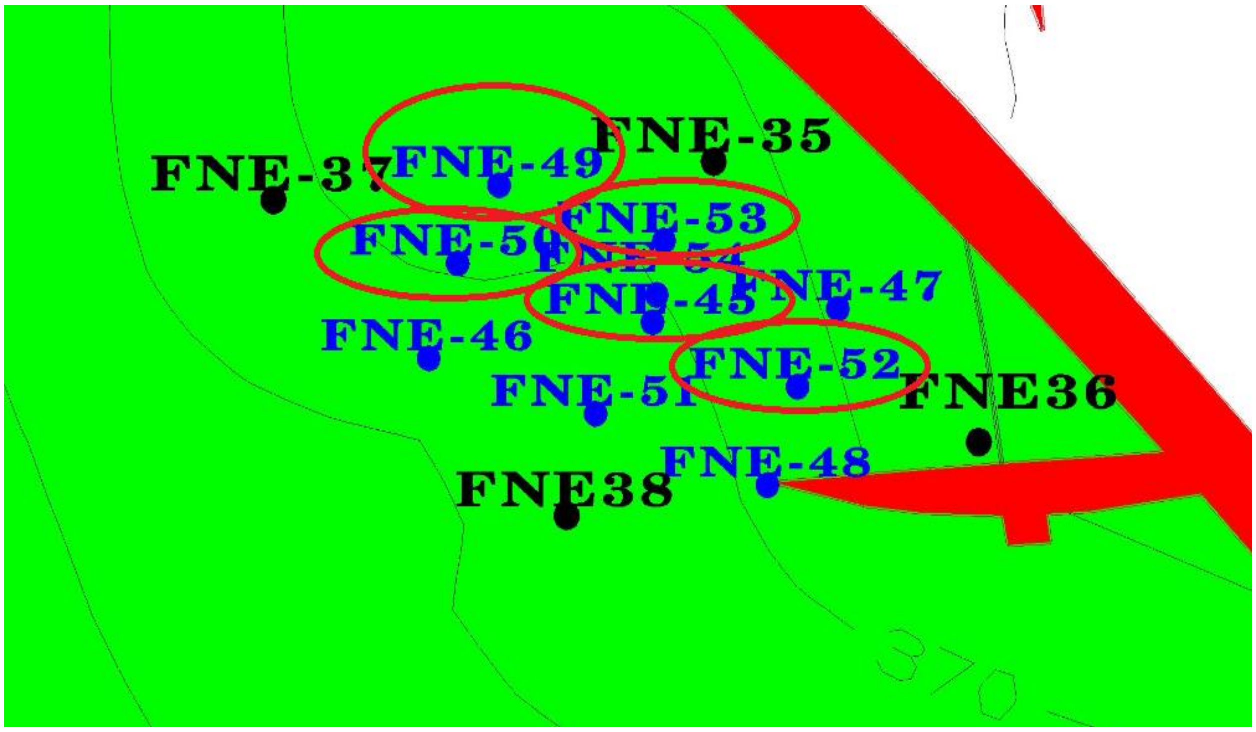

Figure 4.7 Wells Location of B1a, B1b & B1c

Comparing between average sand productions for three pay zone of Bentiu formations has been conducted and shows that wells producing from combination zones (B1a B1b and B1c) are highest sand production as below figure 4.8.

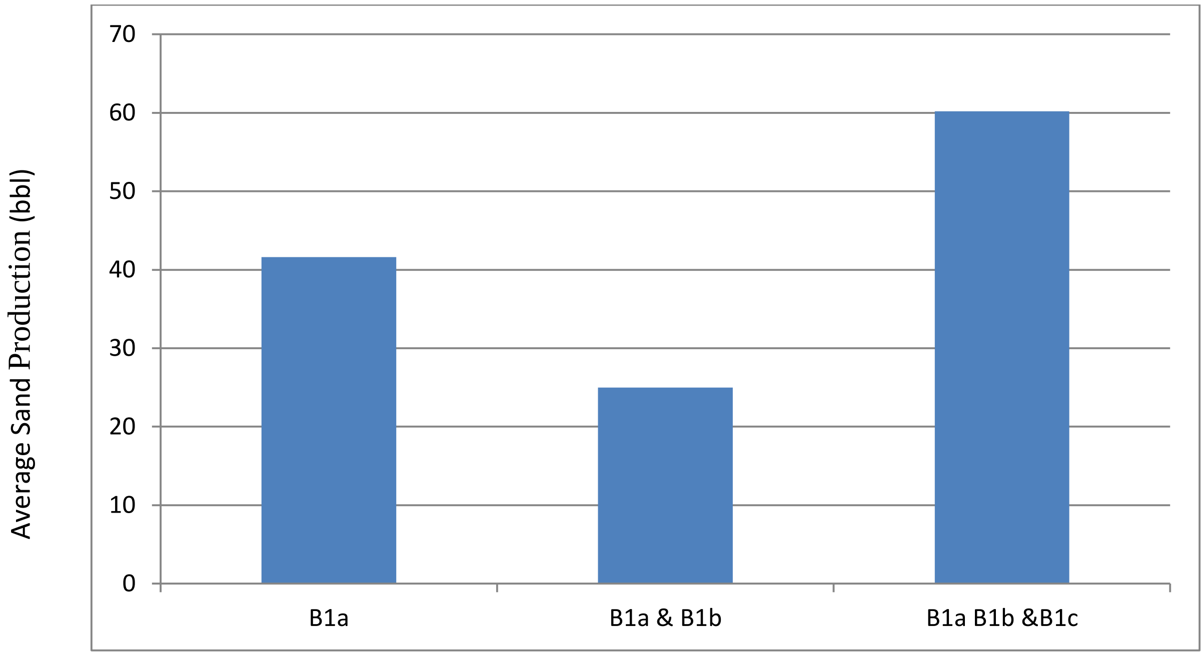

Figure 4.8 Average Sand Production bbl of Bentiu Formation

4.3.2 According to Production methods (CSS & (CHOP)

The analysis according to production method (cyclic steam stimulation and cold production wells show that the average sand production from cold wells (60bbl) higher than cyclic steam stimulation wells (32bbl) see the below tables (4.6 & 4.7) CSS well and cold production wells and figure 4.9 show the average sand production Of CSS & Cold.

Table 4.6 Cold Production Wells

No	Name	Reservoir	Formation	Cum. Sand Production(bbl)	Production method
1	FNE-08	Bentiu	B1a (3 Zones)	105.2	**Cold**
2	FNE-22	Bentiu	B1a	24	**Cold**
3	FNE-19	Bentiu	B1a (3 Zones)	51.2	**Cold**
Average sand production				60	
Accumulation sand production				180	

Table 4.7 CSS Wells

No	Name	Reservoir	Formation	Cum. Sand Production(bbl)	Production method
1	FNE-05	21.2/3zones	B1a,B1b(2 Zones)	15.7	704
2	FNE-16	Bentiu	B1a(2 zone) & B1b(1 zone)	41	CSS
3	FNE-45	Bentiu	B1a,B1b & B1c(2 Zone)	104.5	CSS
4	FNE-39	Bentiu	B1a & B1b	90.5	CSS
5	FNE-34	Bentiu	B1a & B1b	48	CSS
6	FNE-41	Bentiu	B1a & B1b	29.14	CSS
7	FNE-25	Bentiu	B1a	23.12	CSS
8	FNE-47	Bentiu	B1a (2 Zones),B1b(3zones)	22.27	CSS
9	FNE-28	Bentiu	B1a	21.34	CSS
10	FNE-31	Bentiu	B1a	20.5	CSS
11	FNE-30	Bentiu	B1a,B1b(2 Zones)	19.7	CSS
12	FNE-27	Bentiu	B1a (2 Zones)	19.67	CSS
13	FNE-26	Bentiu	B1a,B1b	18.59	CSS
14	FNE-29	Bentiu	B1a (2 Zones)	17.89	CSS
15	FNE-49	Bentiu	B1a,B1b,B1c	16.52	CSS
16	FNE-58	Bentiu	B1a	16.46	CSS
17	FNE-35	Bentiu	B1a(2 zone) & B1b(2 zone)	15	CSS
18	FNE-36	Bentiu	B1a(2 zone) & B1b(1 zone)	11.1	CSS
19	FNE-37	Bentiu	B1a & B1b	11	CSS
20	FNE-48	Bentiu	B1a,B1b(2 Zones)	9.18	CSS
21	FNE-38	Bentiu	B1a & B1b	9	CSS
22	FNE-18	Bentiu	B1a & B1b	7.7	CSS
23	FNE-103	Bentiu	B1a B1b& B1c	0	CSS
24	FNE-104	Bentiu	B1a B1b& B1c	0	CSS
Average sand production				27	
Accumulation sand production				572	

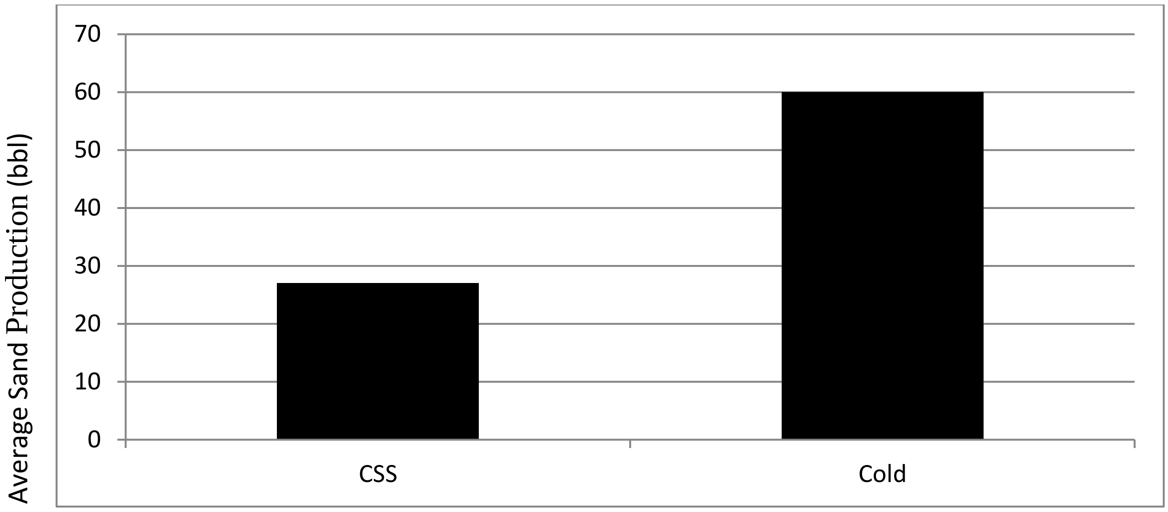

Figure 4.9 Average Sand Production of CSS & Cold Wells

4.3.3 According to wells location:

Another classification for high sand production wells has been applied according to well location (North, South & West area).

4.3.3.1 North location

There are 07 high sand production wells located on north area of FNE see table (4-10). With average sand production 21.0bblwhichrepresented26% from total high sand production wells (27) which mentioned in table (4-2).

Table 4.8North Area Wells.

No	Name	Formation	Cum. Sand Production(bbl)	Well location
1	FNE-16	B1a(2 zone) & B1b(1 zone)	41	North
2	FNE-18	B1a & B1b	7.7	North
3	FNE-28	B1a	21.34	North
4	FNE-27	B1a (2 Zones)	19.67	North
5	FNE-29	B1a (2 Zones)	17.89	North
6	FNE-31	B1a	20.5	North
7	FNE-33	B1a	N/A	North
Average sand production			21	
Accumulation sand production			128	

4.3.3.2 Southlocation

There are 10 wells at south areaof FNE field they have high sand production,see table (4.11).With average sand production 27.0bblthis wells represented 37% from total high sand production wells (27) in table (4-2).

Table 4.9South Area Wells.

No	Name	Formation	Cum. Sand Production(bbl)	Well location
1	FNE-34	B1a & B1b	48	South
2	FNE-35	B1a(2 zone) & B1b(2 zone)	15	South
3	FNE-36	B1a(2 zone) & B1b(1 zone)	11.1	South
4	FNE-37	B1a & B1b	11	South
5	FNE-38	B1a & B1b	9	South
6	FNE-39	B1a & B1b	90.5	South
7	FNE-40	B1a	N/A	South
8	FNE-41	B1a & B1b	29.14	South
9	FNE-47	B1a (2 Zones),B1b(3zones)	22.27	South
10	FNE-48	B1a,B1b(2 Zones)	9.18	South
Average sand production			27	
Accumulation sand production			245	

4.3.3.3 West location

There are 06 high sand production wells located on west area of FNE field which represented 22% from high sand production wells.

Table 4.10 West Area Wells.

No	Name	Formation	Cum. Sand Production(bbl)	Well location
1	FNE-22	B1a	24	West
2	FNE-24	B1a	3.8	West
3	FNE-25	B1a	23.12	West
4	FNE-58	B1a	16.46	West
5	FNE-15	B1a(3 zone)	6.9	West
6	FNE-19	B1a (3 Zones)	51.2	West
Average sand production			21	
Accumulation sand production			125	

From above analysis of sand production according to location show that south area has highest sand production as illustrated in below figure 4.10.

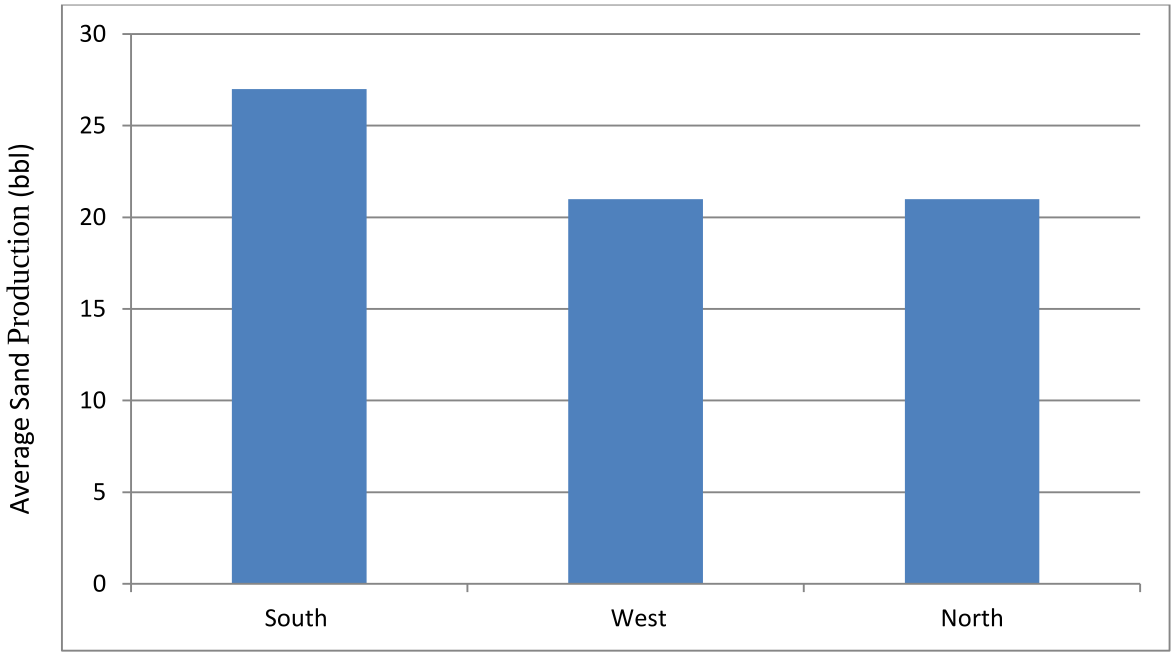

Figure 4.10 Average Sand Production According to Location.

4.3.4According to wells Productivity

Analysis for high sand well production 27 wells has been conducted according to sand productivity (bbl/day) show that the south area has highest productivity see table 4.11.

Table 4.11 Rate of Production Sand

No.	Name	Formation	Cum. Sand Production(bbl)	Production days	Well location	Sand productivity bbl/day
1	FNE-19	B1a (3 Zones)	51.2	678	North	0.08
2	FNE-45	B1a,B1b & B1c(2 Zone)	104.5	489	South	0.21
3	FNE-22	B1a	24	532	west	0.19
4	FNE-08	B1a (3 Zones)	105.2	901	East	0.12
5	FNE-16	B1a(2 zone) & B1b(1 zone)	141	1523	North	0.09
6	FNE-39	B1a & B1b	90.5	1219	South	0.07
7	FNE-30	B1a,B1b(2 Zones)	19.7	650	North	0.03
8	FNE-34	B1a & B1b	48	1702	North	0.03
9	FNE-05	B1a,B1b(2 Zones)	15.7	704	North	0.02
10	FNE-26	B1a,B1b	18.59	817	North	0.02
11	FNE-29	B1a (2 Zones)	17.89	896	North	0.02
12	FNE-31	B1a	20.5	1235	North	0.02
13	FNE-41	B1a & B1b	29.14	1767	South	0.02
14	FNE-25	B1a	23.12	1471	west	0.02
15	FNE-18	B1a & B1b	7.7	525	North	0.01
16	FNE-35	B1a(2 zone) & B1b(2 zone)	15	1192	South	0.01
17	FNE-28	B1a	21.34	1737	North	0.01
18	FNE-36	B1a(2 zone) & B1b(1 zone)	11.1	971	south	0.01
19	FNE-27	B1a (2 Zones)	19.67	1590	North	0.01
20	FNE-37	B1a & B1b	11	1315	South	0.01
21	FNE-38	B1a & B1b	9	1978	South	0.00
22	FNE-47	B1a (2 Zones),B1b(3zones)	22.27	534	South	0.04
23	FNE-48	B1a,B1b(2 Zones)	9.18	567	South	0.02
24	FNE-49	B1a,B1b,B1c	16.52	654	South	0.03
25	FNE-58	B1a	16.46		South	0.00
26	FNE-103	B1a,B1b,B1c			west	N/A
27	FNE-104	B1a,B1b,B1c			North	N/A
Sum of north area Sand productivity bbl/day						0.34
Sum of south area Sand productivity bbl/day						0.42
Sum of west area Sand productivity bbl/day						0.21

After analysis according to sand productivity and location of wells show that south area has highest sand productivity with summation 0.42bbl/day while north and west have summation 0.34bbl/day and 0.21bbl/day respectively see figure 4.11.

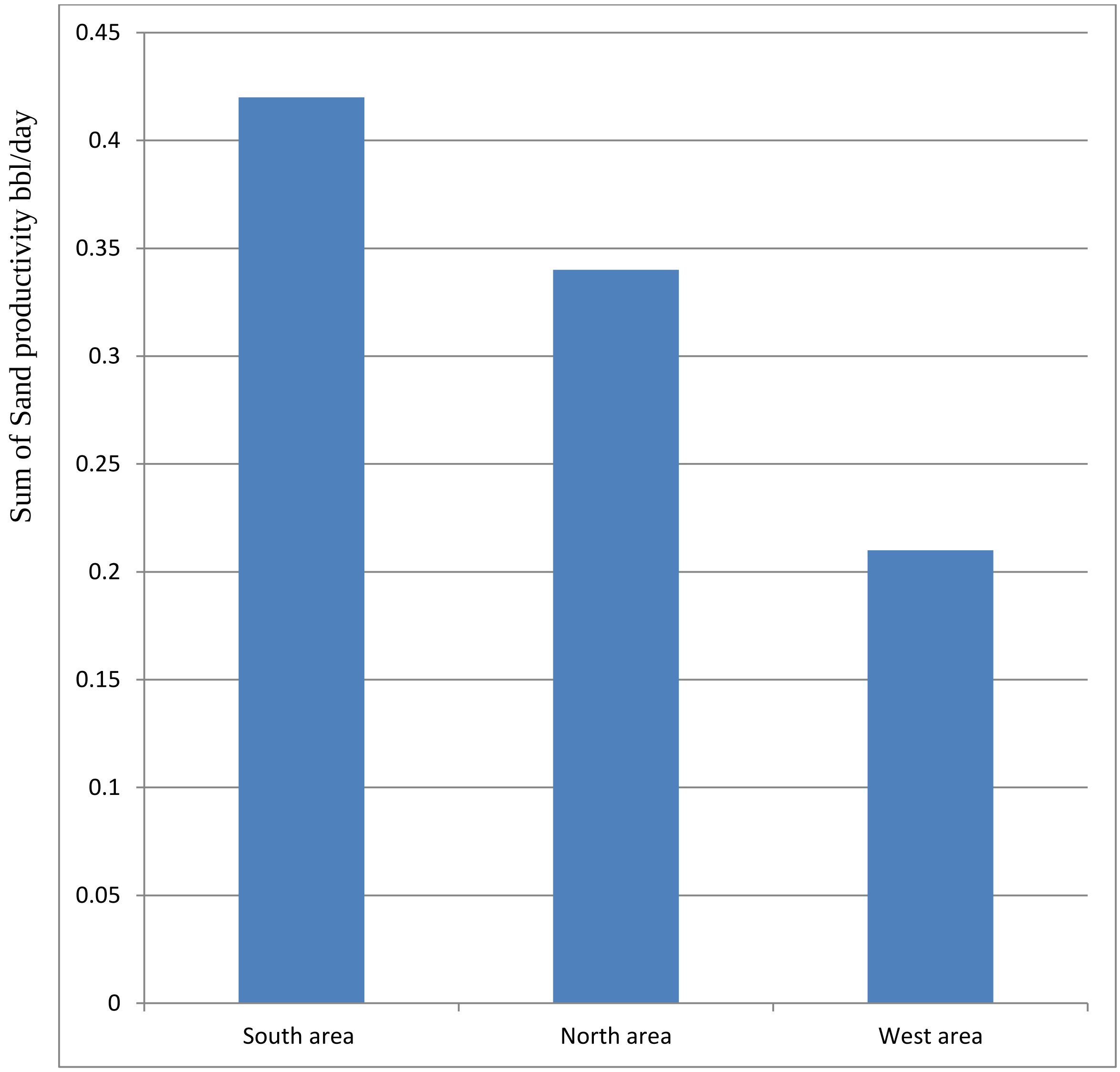

Figure 4-11Sand Productivity bbl/Day

Analysis for high sand well production 27 wells has been conducted according to sand productivity (bbl/m) show that the south area has highest productivity see table 4.12.

Table 4.12 Productivity Of Sand

No.	Name	Perforated Thickness (m)	Formation	Cum. Sand Production(bbl)	Well location	sand productivity bbl/m
1	FNE-22	13.5	B1a	98.7	west	7.31
2	FNE-08	15	B1a (3 Zones)	105.2	East	7.01
3	FNE-39	13.25	B1a & B1b	90.5	South	6.83
4	FNE-45	22	B1a,B1b & B1c(2 Zone)	104.5	South	4.75
5	FNE-19	14.7	B1a (3 Zones)	51.2	North	3.48
6	FNE-34	15.8	B1a & B1b	48	South	3.04
7	FNE-16	17.3	B1a(2 zone) & B1b(1 zone)	41	North	2.37
8	FNE-27	9.5	B1a (2 Zones)	19.67	North	2.07
9	FNE-29	10	B1a (2 Zones)	17.89	North	1.79
10	FNE-28	12	B1a	21.34	North	1.78
11	FNE-58	10	B1a	16.46	west	1.65
12	FNE-31	12.6	B1a	20.5	North	1.63
13	FNE-41	18	B1a & B1b	29.14	South	1.62
14	FNE-25	14.5	B1a	23.12	west	1.59
15	FNE-47	21	B1a (2 Zones),B1b(3zones)	22.27	South	1.06
16	FNE-49	18	B1a,B1b,B1c	16.52	South	0.92
17	FNE-35	16.5	B1a(2 zone) & B1b(2 zone)	15	south	0.91
18	FNE-26	23.5	B1a,B1b	18.59	North	0.79
19	FNE-37	14.5	B1a & B1b	11	South	0.76
20	FNE-36	15	B1a(2 zone) & B1b(1 zone)	11.1	South	0.74
21	FNE-05	21.3	B1a,B1b(2 Zones)	15.7	North	0.74
22	FNE-38	14	B1a & B1b	9	South	0.64
23	FNE-30	32.3	B1a,B1b(2 Zones)	19.7	North	0.61
24	FNE-48	19	B1a,B1b(2 Zones)	9.18	South	0.48
25	FNE-18	16	B1a & B1b	7.7	North	0.48
26	FNE-103	10	B1a,B1b,B1c	N/A	North	N/A
27	FNE-104	10	B1a,B1b,B1c	N/A	North	N/A
Sum of north area Sand productivity bbl/m						15.74
Sum of South area Sand productivity bbl/m						21.75
Sum of West area Sand productivity bbl/m						10.55

After analysis according to sand productivity bbl/m and location of wells show that south area has highest sand productivity with summation 21.75 bbl/m while north and west have summation 15.74 and 10.55 respectively see figure 4.12.

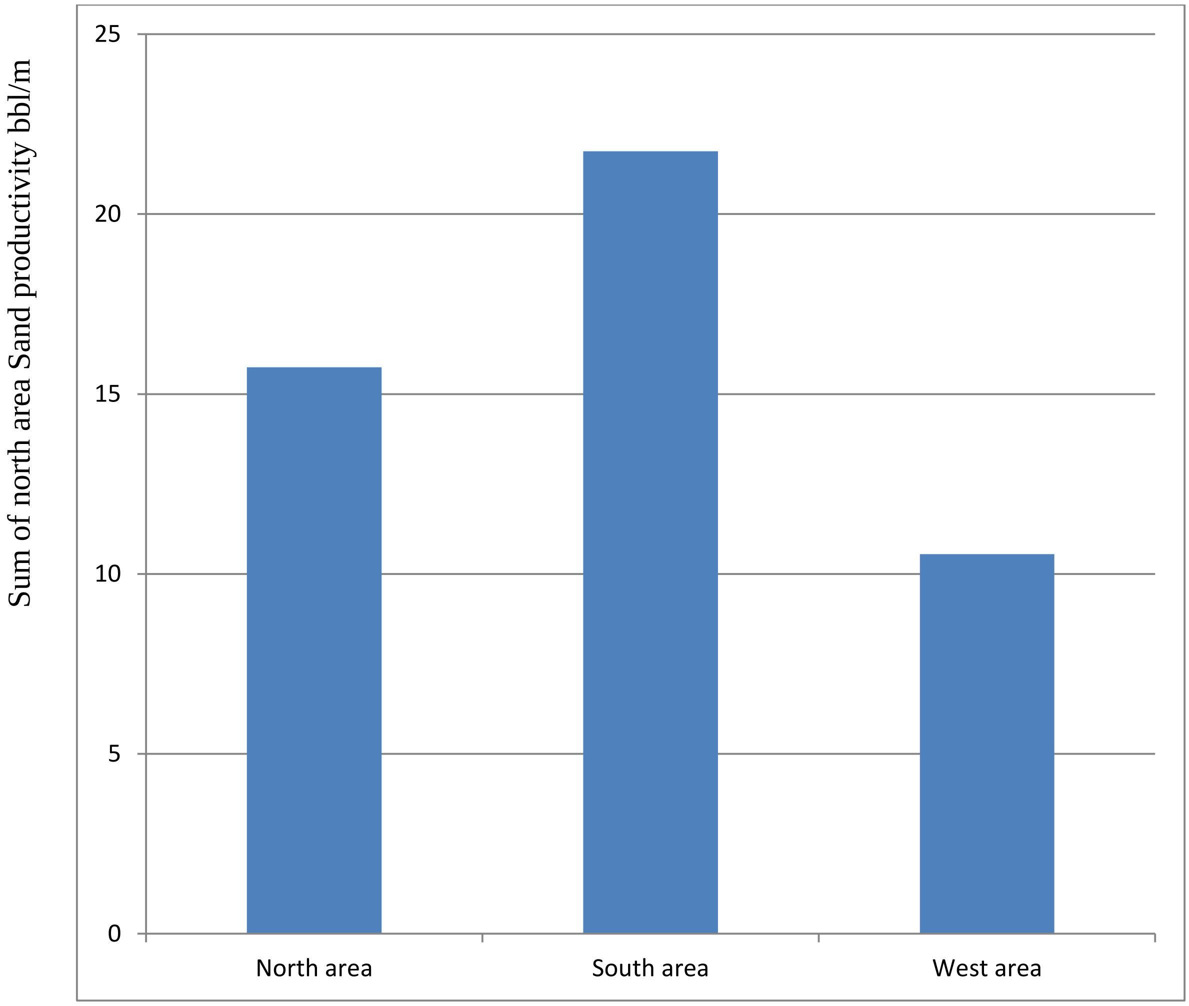

Figure 4-12 Sand Productivity bbl/m

4.4 Cross section of focusing area

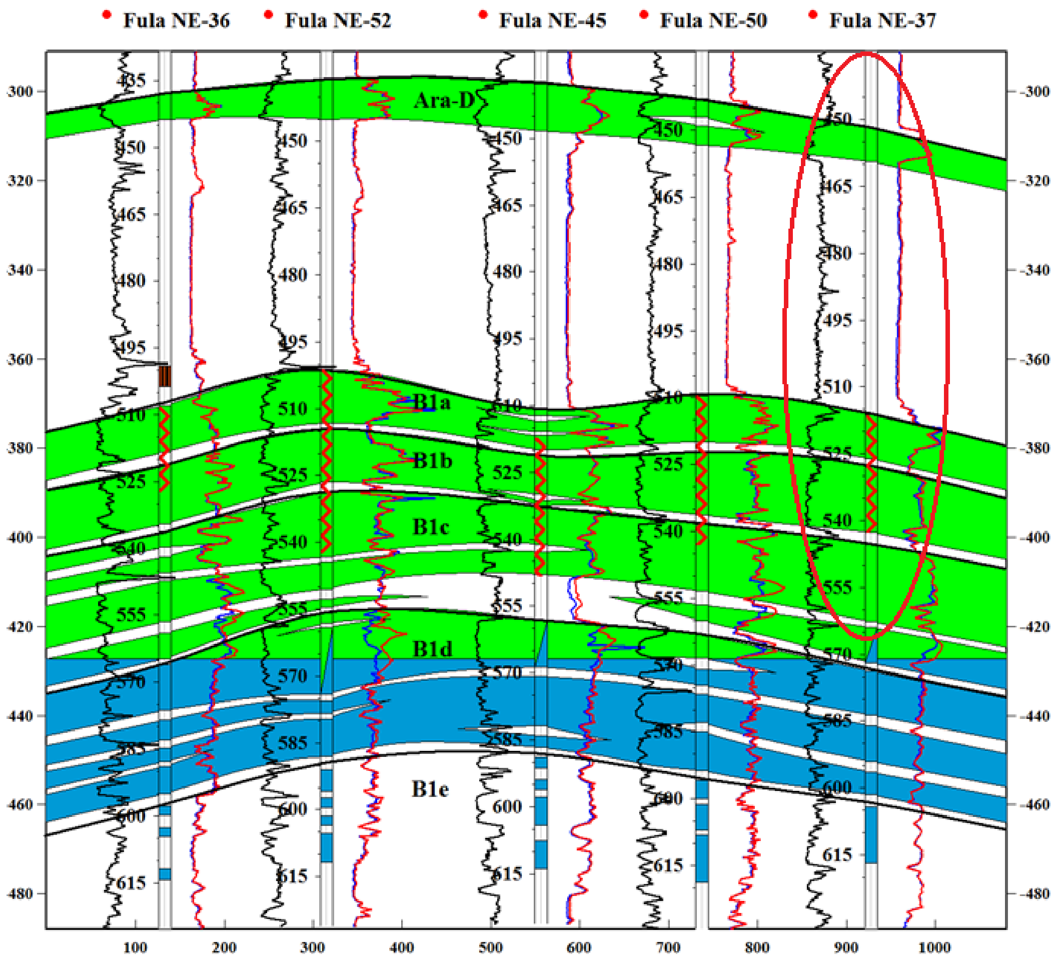

Figure 4.13 Reservoir Cross Section of FNE (36, 52, 45, 50 & 37)

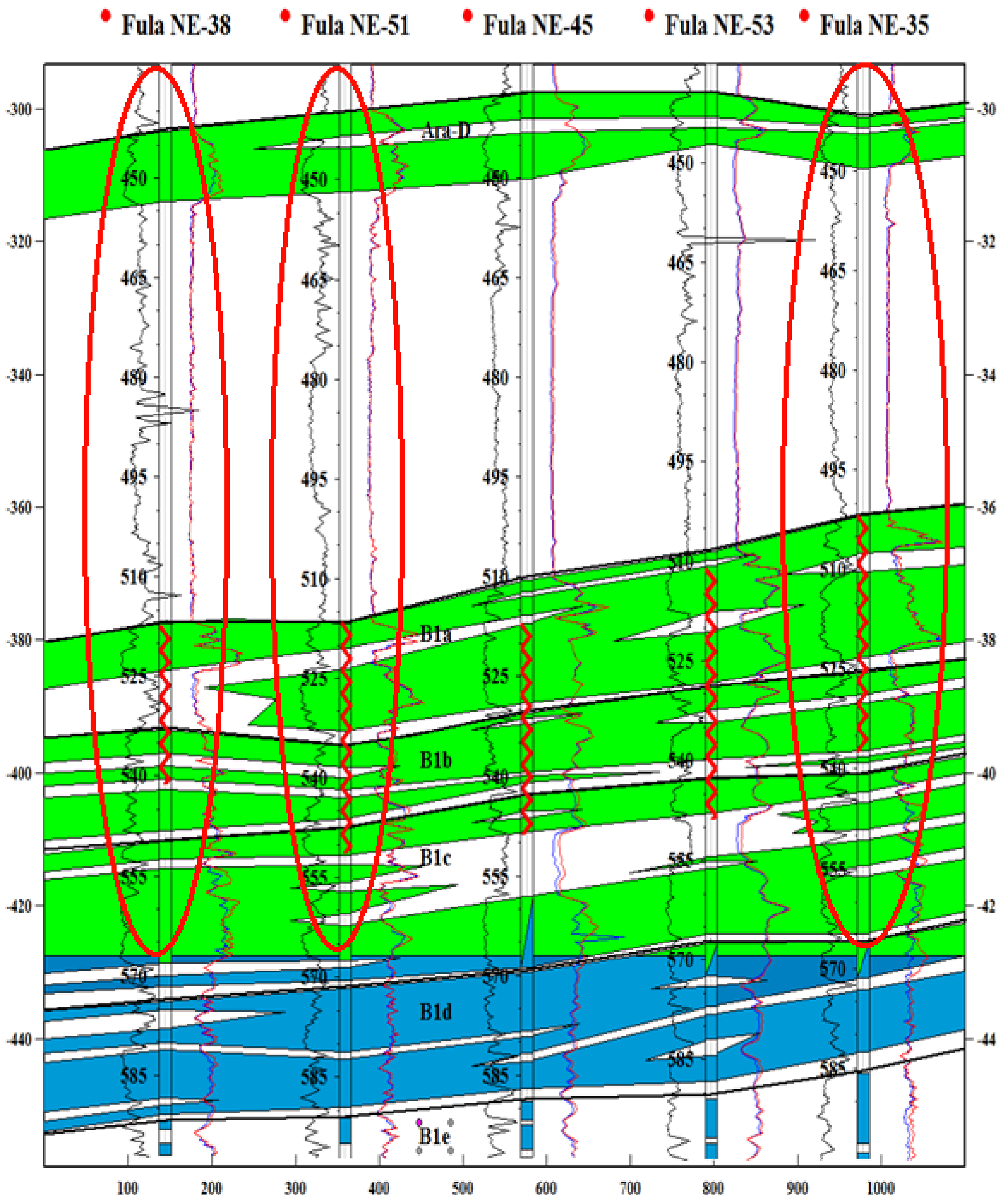

Figure 4.14 Reservoir Cross Section of FNE (38, 51, 45, 53 & 35)

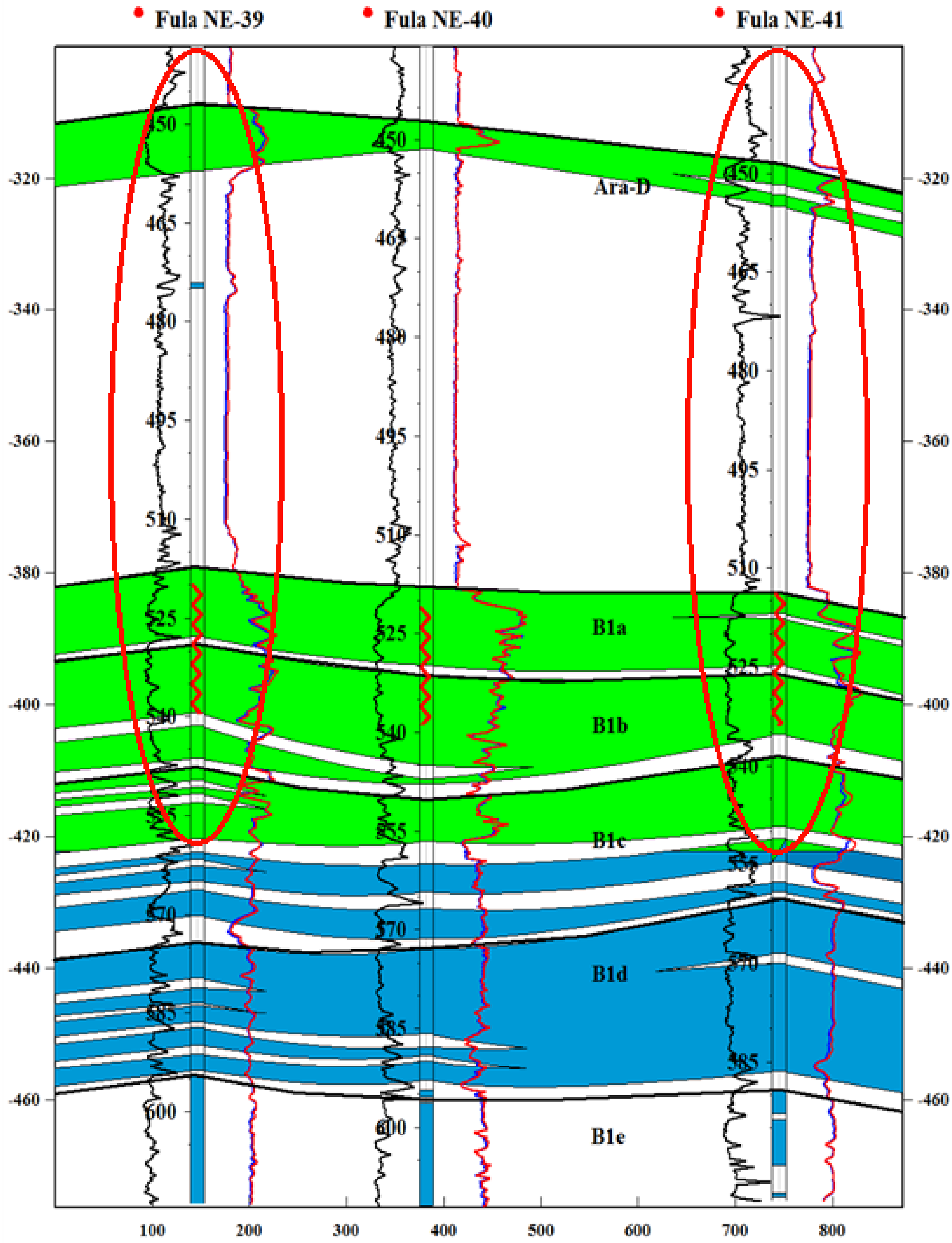

Figure 4.15 Reservoir Cross Section of FNE (39, 40 & 41)

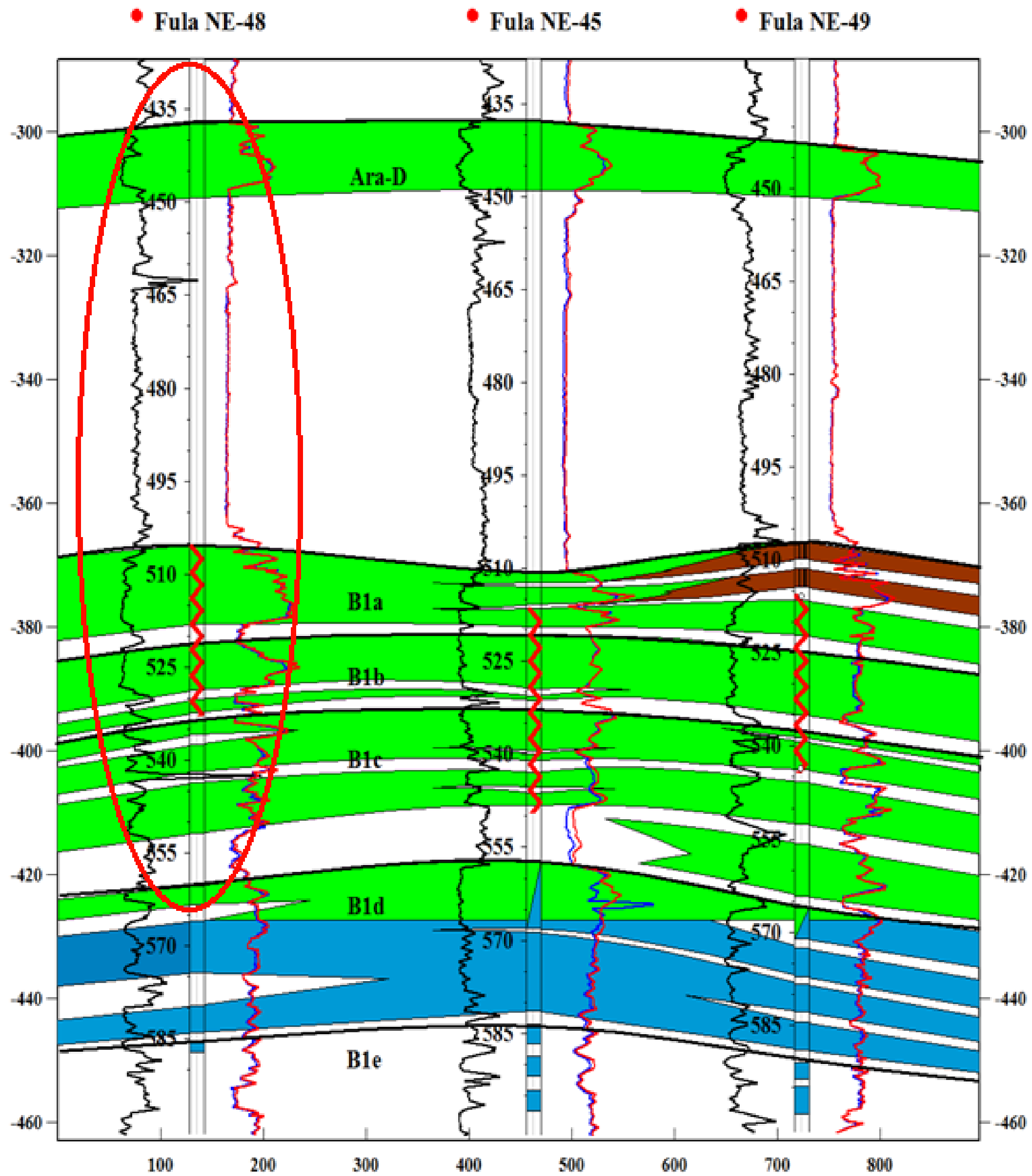

Figure 4.16 Reservoir Cross Section of FNE (48, 45 & 49)

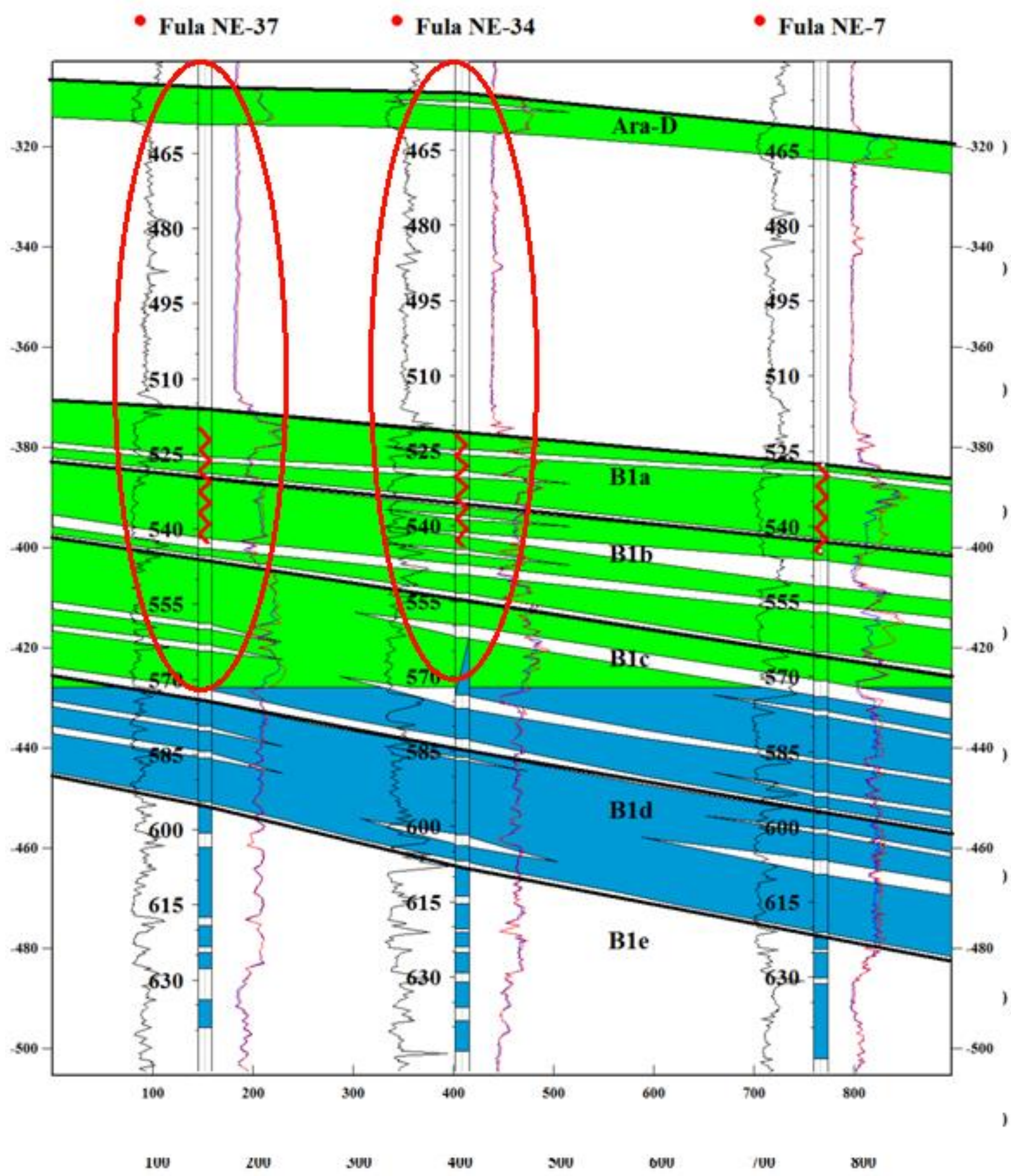

Figure 4.17 Reservoir Cross Section of FNE (37, 34 & 07)

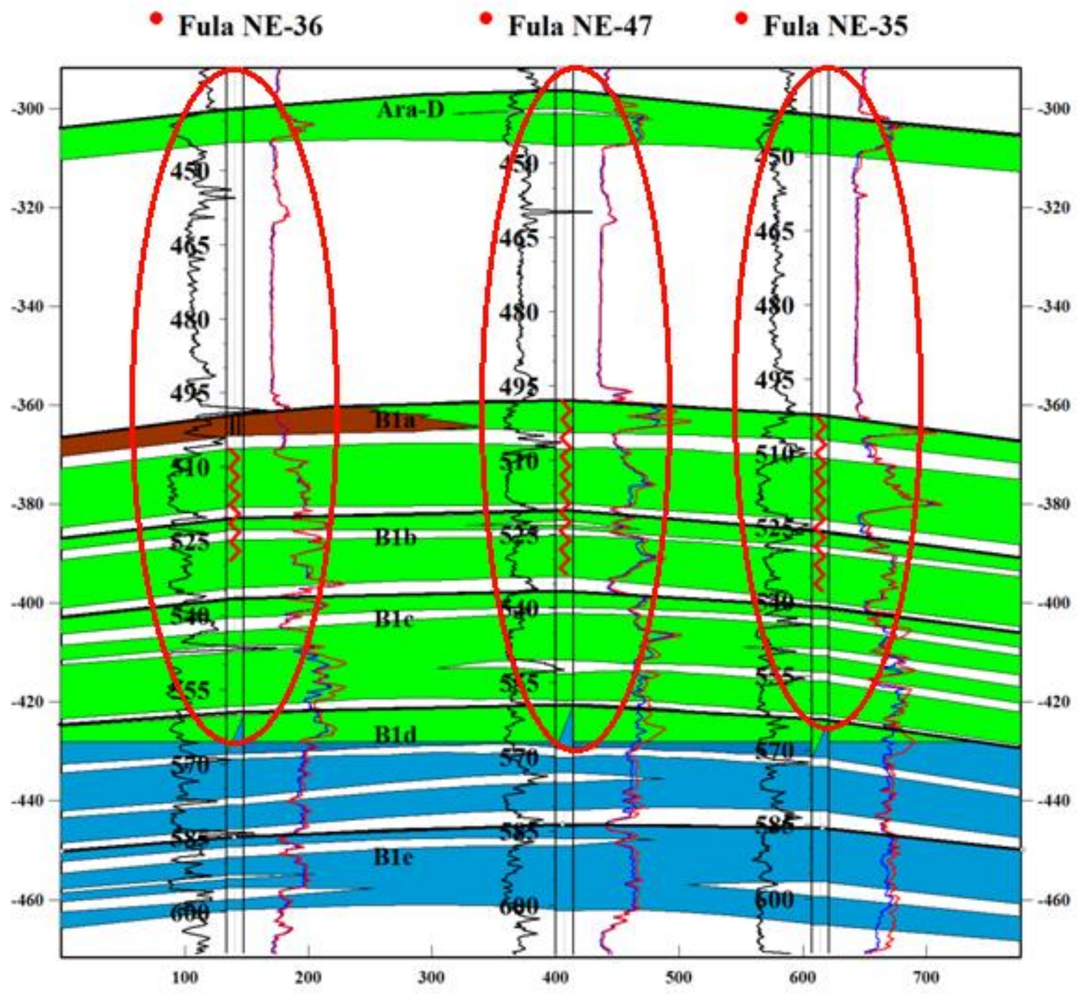

Figure 4.18 Reservoir Cross Section of FNE (36, 47 & 35)

4.5 Final Result

After data analysis of 42 wells, the high sand productionwellsare 27 wells distributed as B1a 09 wells, (B1a &B1b) 14 wells, and (B1a-B1b-B1c) 04 wells in FNE field. 15 of them has been eliminated due to (4 wells converted to steam flooding injectors, 4 wells gravel packing implemented, 7 wells due to lack in data collection)

Then according to formation and pay zone it has been found that the wells which producing from combining zones (B1a, B1b, B1c) has highest sand production.

And according to production method The Cold wells are producing higher sand compare to CSS wells.

Depending on location the south area well has high sand production which located steam flooding project.

The result from productivity (bbl/d &bbl/m) support that south area is the highest sand production in FNE field.

Figure 4.19Sand Cleaning of FNE OGM-1

4.6 Economic Overview

According to sand cleaning schedule which implemented for high sand production wells, each well will be shut in one time per month for flushing and pigging or workover ,Some wells will shut in for a few days andtheother wells shut in for many dayswhile in normal cleaning spend 4 hours per month, That means the average downtimefor each wellestimated around 10 hoursper month for removing sand from down hole or flow line.

Average production 100 bbl/day for each well, total production lost per year due to workover, flushing and pigging job calculation as below:

42 wells* 10/24*12 month *100 bbl =21000 bbl/year

Oil price approximately 50$ for one barrel.

21000* 50 =1050000$ per year

The total lost per year equal toone millions and fifty thousand dollars beside the cost of equipment operation such as rig , sand truck, pump truck and water tanker.

Above calculation illustrated just economic overview not reflect economic study in detail.

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

- Data collection and Analysis has been done to determine the high sand wells in FNE oil Field.
- It has been found that 42 wells suffering from sand production problem in FNE oil Field.
- Classification according to formation, location, pay zone and sand productivity has been done in this thesis.
- 27 wells have been selected from 42 because their data is satisfactory for this case study.
- The wells which produce from combination zone in south location of FNE block 1-Steam flooding Area is highest sand production wells in FNE oil Field.
- The Cold wells are producing higher sand compare to CSS wells.

5.2 Recommendation

- It's highly recommended to conduct detail study for Sand Problem in FNE oil Field.
- Sand control techniques such as Gravel pack should be used in FNE oil Field for both CSS and Cold wells.
- Economic evaluation should be done before implementation.
- Laboratory study for sand production and sand control techniques should be done before implementation.
- Cycle steam stimulation to be applied for cold production wells in order to reduce sand production.

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