Sudan University of Science and Technology

College of Petroleum Engineering and Technology

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The Influence of Steam Injection Volume on Sand and Oil Production in Cyclic Steam Stimulation (CSS) Wells-Case Study in FNE Field Sudan

تاثير حجم البخار المحقون على انتاج الرمل والنفط في ابار التنشيط الدوري بالبخار – دراسة حالة في حقل الفولة الشمالي الشرقي السودان

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

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الاستهلال

بسم الله الرحمن الرحيم

قال تعالى:

{لَا يُكَلِّفُ اللَّهُ نَفْسًا إِلَّا وُسْعَهَا لَهَا مَا كَسَبَتْ وَعَلَيْهَا مَا اكْتَسَبَتْ رَبَّنَا لَا تُؤَاخِذْنَا إِنْ نَسِينَا أَوْ أَخْطَأْنَا رَبَّنَا وَلَا تَحْمِلْ عَلَيْنَا إِصْرًا كَمَا حَمَلْتَهُ عَلَى الَّذِينَ مِنْ قَبْلِنَا رَبَّنَا وَلَا تُحَمِّلْنَا مَا لَا طَاقَةَ لَنَا بِهِ وَاعْفُ عَنَّا وَاغْفِرْ لَنَا وَارْحَمْنَا أَنْتَ مَوْلَانَا فَانْصُرْنَا عَلَى الْقَوْمِ الْكَافِرِينَ}

{البقرة : 286}

Dedication

To our parents who always inspiring and devising us, nothing of this could be done without them, may Allah saves them always

To our dears, all of our family members who always be there when we need them.

To our best friends & colleagues who are always with us step by step ,supports us to go forward.

To everyone who is an integral part of our support group, we dedicate this work.

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The greatest thanks always to Allah for completing this project. Most grateful and appreciation to our supervisor MR.Yahya sharfi …for their expertise support and endless valuable advices which guided us throughout this work and our engineering career life.

We also would like to thank all of our teachers in the school of electrical and nuclear engineering for all the help & knowledge that they gave to us.

Abstract

Sand production is one of the major challenges that petroleum industry faces in an oil field. It is one of the oldest problems plaguing the oil and gas industry, because of its adverse effects on well productivity and petroleum equipment.

Fula North East (FNE) a Sudanese oil field is selected as case study, to study the effect of steam volume variation through different cycles on the amounts of sand and oil been produced by the end of each cycle in cyclic steam stimulation(CSS) wells, trying to understand the production behavior of those wells and relate injected steam volume with those two major parameters .we found that, no relationship between steam volume and sand production, also Data analysis shows that when production period is about 50 days before shutting the well for workover then well will continue to produce for a very long period compared to prior workover operation. On the other hand, if the production period was more than 50 days, then it will operate for shorter periods after recovered from workover operation. In this case, well needs to start another cycle of steam injection instead of continuing production since sand production (especially for long production periods) is an essential indicator for the next steam cycle timing.

Also we found Sand production quantity in CSS wells basically depends on soaking period, more soaking time means formation temperature gets low, crude becomes colder, and more sand is expected to flow after well start up. Eventually, reduction of oil production and short operation period for these wells.

التجريد

انتاج الرمل من اكبر التحديات التي تواجهها صناعة النفط في الحقول النفطية , وهي من اقدم المشاكل التي تعاني منها صناعه النفط و الغاز لتاثيرها السلبي على انتاجية البئر والمعدات النفطيه .

حقل الفولة الشمالي الشرقي موضوع الدراسة احد الحقول السودانية التي تم اختياره لدراسة تاثير تغير حجم البخار المحقون من خلال دورات مختلفة على كميات النفط والرمل التي تم انتاجها في نهاية كل دورة في ابار التنشيط الدوري بالبخار ؛ محاولة لفهم سلوك الانتاج لهذه الابار وربط حجم البخار المحقون مع كميه الرمل والنفط المنتج . ولقد تم ايجاد انه لا يوجد علاقة بين حجم البخار المحقون وحجم الرمل المنتج , وبتحليل البيانات تبين عندنا بتوقف البئر بسبب انتاج الرمل بعد خمسين يوم فقط من تاريخ بداية الانتاج في الدوره يتم عمل عميلة نتظيف للبئر واستمرار الانتاج وسوف يستمر في الانتاج لفترة طويلة دون توقف . واذا كانت الفترة اكبر من خمسين يوم قد يتوقف بعد عملة التنظيف بفترة قصيرة , وفي هذه الحالة البئر يجب ان تبدا في دورة بخار جديدة بدلا من الاستمرار في الانتاج وان انتاج الرمل (خصوصا لفترات انتاج طويلة) مؤشر اساسي لبدء دورة بخار جديدة.

وايضا وجد ان كمية انتاج الرمل في الابار التي تستخدم فيها تقنية دورات التنشيط بالبخار تعتمد بصورة اساسية على فترة الامتصاص ,فترة امتصاص اكثر يعني انخفاض في درجة حرارة الطبقة والخام يصبح باردا , وبالتالي يتوقع في انتاج الرمل بعد تشغيل البئر, وهذا يسبب انخفاض في انتاج النفط و فترات انتاجية قليله لتلك الابار .

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Chapter one

Introduction

1.1. Heavy oil

Heavy oil or extra heavy crude oil is any type of crude oil which does not flow easily. It is referred to as "heavy" because its density or specific gravity is higher than that of light crude oil. Heavy crude oil has been defined as any liquid petroleum with API gravity less than 20 API .

One of the problems associated with oil production worldwide is the heavy oil production. In Sudanese oil fields there is a high production of low API gravity crudes (conventional heavy, extra heavy and super heavy crudes). Heavy oil has many problems specially its extraction from the reservoir since it cannot flow naturally which lead us to search for solutions like EOR, which is defined as that techniques applied in certain conditions to alter the fluid properties ensuring production of oil saturations

The crude oil is quite heavy with an API of 10 - 12. For any rod – lift system, it's quite challenging to lift such heavy oil without any operational failures. Special design considerations need to be evaluated which can overcome the challenges .other important aspects in the development of large scale sucker rod pumping wells are to accommodate uncertainties in terms of fluid characteristics, reservoir behavior ,and operational challenges to lift the heavy crude. The best method to produce heavy oil is cyclic steam stimulation (CSS).

1.2. Cyclic steam injection (CSS) :

Cyclic steam stimulation is a heat method considered one of the successful and most used methods in residue oil production and it increase the production of oil , heat methods forms 80% of the secondary production methods .steam injection into the reservoir heats the fluids and rocks of the reservoir ,warming the reservoir and reducing oil viscosity resulting in oil movement toward the well then to the surface . The process is comprised of three stages are: Injection stage ,Soaking stage ,Production stage.

1.3. 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:

•Sand Production

1.3.1. High 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 field operators, 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.

Many Sudanese 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)

1.3.2.High 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 flow lines. 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. Paraffin (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)

1.3.3.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.

1.3.3.1.causes of Sand Production

- Drag Force of Flowing Fluid
- Reduction in Formation Strength
- Reduced Relative Permeability
- Declining Reservoir Pressure

1.3.3.2. Sand production problems:

There are many problems when we have starting produce sand such as:

1.3.3.2.1. Accumulation Down hole:

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”.

1.3.3.2.2. 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 flow line. 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,

1.3.3.2.3. 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 down hole equipment may occur, resulting in critical safety and environmental problems as well as deferred production.

1.4. Problem statement:

For FNE oil field, the major problem is sand production that leads to Meany problems. Production of heavy oil today have many techniques and ways , cyclic steam stimulation (CSS) one of successful and suitable method in Sudan. Application of CSS technique in the wells followed large amount of sand production.

In this research we use some CSS parameters (steam injection volume, soaking period) to study its influence on sand and oil production.

1.5. Objectives:

The most important aspects to be considered for these wells are:-

1. The determination of the next cycle time according to sand production.
2. Studying the effect of soaking period during different CSS cycles .
3. Studying the effect of production period during different CSS cycles.
4. Monitoring the sand production.

Chapter two

Literature review and theoretical background

2.1. Literature review

2.1.1. 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 is extremely 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 months better 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 flows 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.

In 2015 in Kuwait, RQuttalnah, Ghazl AI Besan, and F Mehmood, Kuwait CII Company; MesbahHossam, and A Dange,
Weather lord.

In rod pump applications around the world heavy oil and sand production is believed to be a dangerous combination .This paper highlights a case study of a heavy oil well in the North Kuwait field where sand Production was monitored closely to avoid flow line choke and down hole failures .This case study was Used as a pilot for the neighboring wells producing from the same reservoir. In case of wells producing heavy oil with considerable sand production and that undergo cyclic steam stimulation the challenge is often at the end of the production cycle. While the oil is thin and has good viscosity the sand settles itself at the bottom .However, with time as the oil gets colder and thereby heavier, it carries the sand along with It to the surface causing plug in the flow line. This is due to the high viscosity of the oil. This is believed to be the end of production period beyond which it would have been impossible to produce any further Even after sand cleanup. Certain operational procedures were established to ensure the integrity of the down-hole equipment and to avoid the failures. It has been observed that by effective sand monitoring it was possible to determine the next injection cycle with more precision .

2.1.2. 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 with shale barriers. Successful CHOPS in this paper highlighted fine barriers (interbred/ intruded) 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, and analysis of sand problems commonly observed in field and explain some production technology with sand. In 2016sudanthe 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 work over 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) are highest sand production wells in FNE oil field. The Cold wells are producing higher sand compare to CSS wells.

2.2. C.S.S. history (LarryW.2014)

In this section some of the CSS projects and applications which had been accomplished recently worldwide and in Sudanese oil fields would be introduced.

First CSS or CSI "cyclic steam injection" jobs were incidentally applied in South America specifically in Venezuela in Lake Maracaibo area in 1959. As a result of one steam injector had blown out and started producing oil with higher rate than other adjacent wells, CSS technique has been applied in many fields all over the world such as Bolivar Coastal and Santa Barbara in Venezuela, Cold Lake oil Sands in Canada, Xinjiang and Liao he in China, San Joaquin Valley of California in USA and in other heavy oilfields around the world.

2.2.2.CSS cycles:

CSS technique simply using an injection and extraction process, it injects steam down hole and heated bitumen which facilitates the extraction process. This inclusive process contains a number of sub processes (injection, heating, flow and extraction) which combined together to make a cycle. Each cycle composes of three phases:

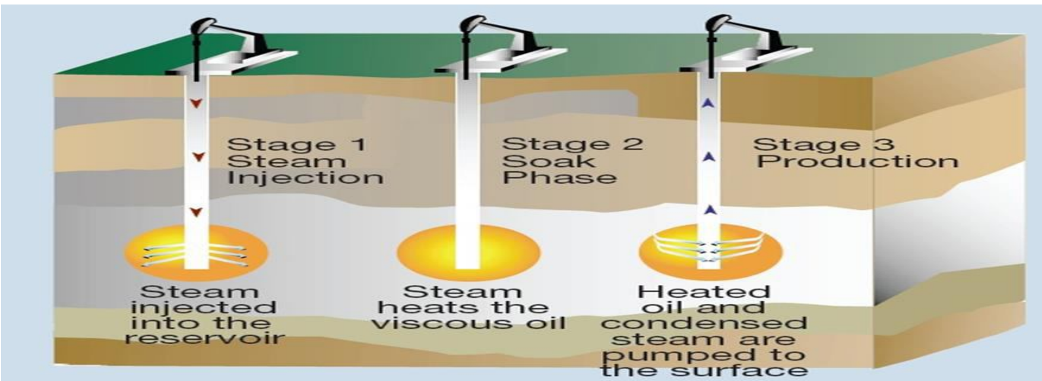

Figure 2.1. Cyclic steam injection cycles

2.2.2.1. Injection phase (injection period):

It’s the first step which by it a cycle of CSS begins to operate. So as previously noted, an amount of hot steam must be injected into a certain well (it doesn’t matter horizontal or vertical) for a small duration. Then a chamber is generated from that injected steam for pressure maintenance in the formation to make a pressure build-up facing the pressure of the injected steam.

As everyone knows, it has become a truism that the Temperature is directly proportional with the viscosity especially in liquids. That means by the increment of the reservoir temperature, the viscosity of the crude is always decreases which helps in getting more initial oil rate. In addition, an augment in the oil velocity is noticed due to a rising in the reservoir pressure adjacent the wellbore. While this phase “injection phase”, the steam saturation degree of temperature is put equal to the average temperature of the chamber which is formed by the injected steam. After this degree is reached the injection period has been stopped and the soaking period is had to start by closing the well for a while until the chamber of the steam is created and the temperature is begun to rise.

2.2.2.2. Soaking phase:

This is the shut-in period in the CSS cycle for the preparing and fulfillment of the injection goals and objectives. During soaking, the well is closed for a certain short duration which is selected precisely making the chamber expands by extending of the steam and allowing the steam to reach to further possible point in the formation to heat a bigger possible area. Due to the gravity segregation the chamber of the steam and the crude oil after the heat distribution takes place to decrease crude viscosity. Surely the lighter component will rise upwards and another one will force to drop downwards because of its density. Therefore the heavier component “oil” will go downwards while the steam which is the lighter one floats up inside the reservoir due to gravity effect. When looking from the side of heat transfer study, it can be logically considered that this segregation happened by convection process between two fluids with different densities aiming in the enhancement of the whole process. The soaking time is a sensitive phase affected by the fluids properties and it’s an achievement step to the injection phase. As the soaking period decreases, the ratio of the produced oil to that oil in place increases.

2.2.2.3. Production phase (production period):

This phase is the last phase in a single CSS cycle. It comes directly after the small duration shut-in period “Soaking time”. As noted earlier, the oil which is heated by the hot injected steam is forced to go down in the reservoir according to the density differences and gravity segregation effect and due to the variety in the pressures inside the well which will produce. After that, the well will start to produce this oil.
By the injection of the hot steam many zones has been heated and its degree of temperature will be large affecting in the initial oil rate which will become higher. By passage of time, more oil will be produced and that high degrees of temperature in the heated zone will decrease leading to the decline of that initial rate. Then the injected steam will again continue heating the oil which its temperature decreased and it became in a cold area in the zones which previously heated. The increment of the temperature is followed by the decrement of viscosity of the crude oil which leads to a high enhancement in the oil producing rate when comparing with the production without CSS. The variety in pressures and the gravity segregation effect is combined together to represent the two essential mechanism in the cyclic steam injection to induce oil. In addition, the chamber of the steam which had been begun during the injection phase and completed in the Soaking period by the increment of the oil production continues expanding to compensate that produced oil and replaces it to conserve the reservoir energy.

2.2.3. CSS Parameters:

There are many CSS parameters such as:

2.2.3.1. Steam Injection Rate:

Defined as the volume (or mass) of steam injected into the well at specific period of time {unit (m3/day) }.

2.2.3.2. Steam Injection Volume:

Produced oil volume is directionally proportional to the volume of injected steam , When large steam volume injected more heat carried thus more utilization of steam and increased volume of cumulative oil .

Small volumes of steam do not provide sufficient heat. This will reduce the cycle oil production, then more volumes of steam needed but further steam increment will push the oil away from well bottom hole and the cumulative oil-steam ratio drops.

2.2.3.3. Steam Soak duration:

Soak period is a requirement for CSS to improve heat distribution to the reservoir, so short soak periods do not provide enough utilization of steam.
However very long periods not recommended too, because production is delayed, from previous experiences in some cases the cumulative oil first decrease at some periods then decrease due to heat losses to overburden and under-burden thus the bottom hole temperature decreases by increasing of soaking period.
Other cases concluded that any extension in soaking period will lead to decrement of cumulative oil production and cumulative water production, but due to viscosity differences the impact on oil production is relatively higher than on water, because oil viscosity is a function of temperature rather than water viscosity.

Chapter three

METHODOLOGY

3.1 Introduction to Case Study (FULA North East (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.

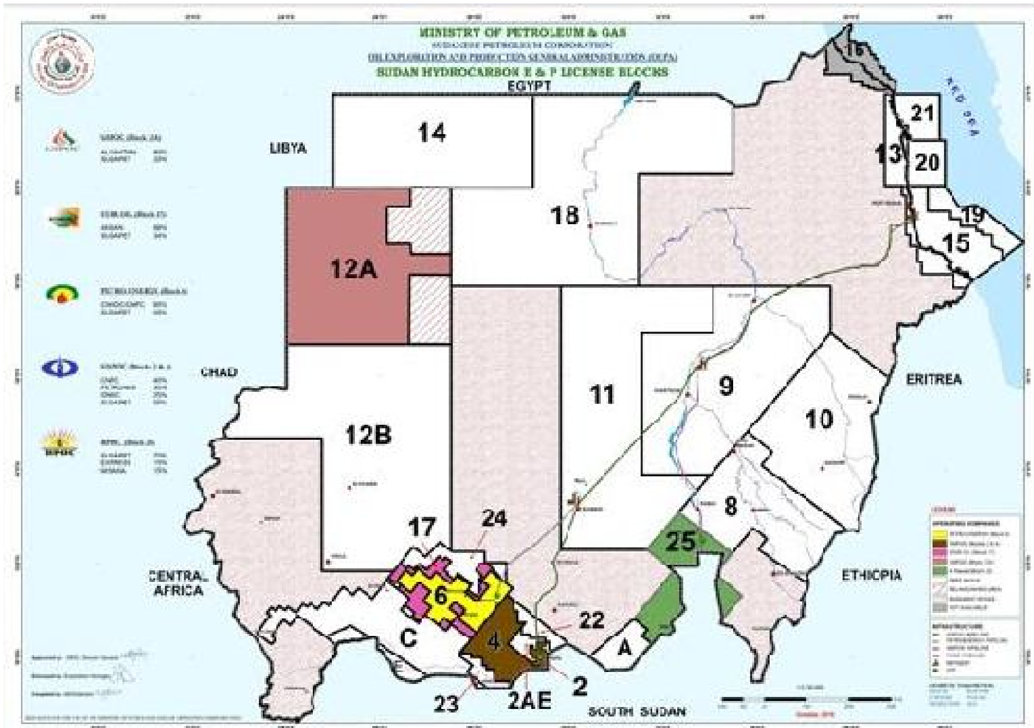

Figure 3.1 Sudan Hydrocarbon Exploration & Production map (Oil & Gas Magazine, 2015)

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

3.2. Mean properties of FULA North East (FNE) field:

FULA North East field is a medium size heavy oil field at shallow depth of 550-600 m. Bentiu sand is the main oil bearing formation which holds more than 90% of STOIIP. 3-Dimensional numerical simulation modeling has been carried out to generate the various scenarios for selecting the optimum primary exploitation scheme. Despite all precautions and suitable drilling, completion and well placement, with drawl rates, perforations strategies in field development plan expected ultimate recovery factor of 19%. Envisaged recovery factor in cold heavy oil production with sands (CHOPS) is moderate one.

Oil fields like FULA North East where oil gravity is low or viscosity is more than 3000 cp at reservoir conditions and is unfavorable for conventional methods of recovery, thermal recovery is the best technique for maximum ultimate oil recovery.

Screening study was carried out which suggest that reservoir and fluid characteristics of FULA North East field are most suitable and favorable for steam based enhanced oil recovery processes (J.J. Tabcr, 1997; Jasper I.Dickson, 2010). The viscosity of oil will decrease with increased temperature and reduce the drag force in the formation and make fluid flow easy in the formation. Oil mobility also improves with heating, resulting into increase in oil rate. A thermal process also reduces the residual oil saturation thus increases the moveable oil volumes and better sweep efficiency is obtained at higher temperature.FNE filed is producing heavy viscous oil associated with sand and consist of 100 wells drilled in 72000 square meter, these wells included steam flooding injector wells, steam flooding producer wells, cold production wells and hot production wells.

3.3. Data analysis method:

Also known as analysis of data or data analytics is a process of inspecting, cleansing, transforming, and modeling data with the goal of discovering useful information, suggesting conclusions, and supporting decision-making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, in different business, science, and social science domains. in this research we use data analysis method , depending on effective and practical data and field reports for all wells history founded in FNE (FULA North East) field and identified some wells which have problems in sand production and used in it CSS technology .

3.4. Data Collection:

i. The injection and soaking and production periods.

ii. The sand production records in every single day during steam injection cycles application.

(We used the tag sand level and flushing sand level to find sand height –produced sand-)

iii. Steam injection rates.

iv. Oil production records in every single day during steam injection cycles application.

v. Work over histories.

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

3.5. Analysis procedures:-

3.5.1. Production period

The production period was found in each cycle and wells separately, on the basis of the first day of the actual production to the day that production had stopped in order to equip the well to start the next cycle, this depends on the field data of the production obtained in advance as in the following table (3.1).

	First Cycle				Second Cycle			
Well No.	Boiler	start inj.	end inj.	start prod.	Boiler	start inj.	end inj.	start prod.
FNE-12	GWCSS2	29-Sep-2014	7-Oct-2014	1-Dec-2014	GWCSS2	22-Sep-2016	29-Sep-2016	
FNE-15	GWCSS1	3-May-2011	10-May-2011	12-Jun-2011	GWCSS 1	19-Jul-2012	27-Jul-2012	27-Aug-2012

Table 3.1 production period

3.5.2. Produced oil volume

It had been found the volume of oil produced during the period between the beginning and end of the specified cycle by using the function (sum (C11:C1n)) in Excel program and found from table 3.2.

ALIAS	Date	UpTime	DownTim	singPressu	bingPress	wLineTe	lowLinePr	Current	Speed	Freq	Fluid	Oil	Water
FNE-15	18/06/10	7		0	30.45	20	27.55	27	25	5	0	0	
FNE-15	19/06/10	24		0	31.9	21	29	29	25	5	67.932	65.89404	2.03796
FNE-15	20/06/10	23		0	31.9	21	29	29	25	5	65.0364	64.38538	.651015
FNE-15	21/06/10	24		0	31.9	21	29	29	25	5	67.932	67.25268	0.67932

Table 3.2 produced oil volume

We can find the cumulative oil produced by take summation of all oil produced in very day at production period of the specific cycle.

3.5.3. Soaking period:

The soaking period was found in each cycle which applied in all wells separately by calculate the period between end injection to start production by using the information that shown in the table (3.3):

	First Cycle				Second Cycle			
Well No.	Boiler	start inj.	end inj.	start prod.	Boiler	start inj.	end inj.	start prod.
FNE-12	GWCSS2	29-Sep-2014	7-Oct-2014	1-Dec-2014	GWCSS2	22-Sep-2016	29-Sep-2016	
FNE-15	GWCSS1	3-May-2011	10-May-2011	12-Jun-2011	GWCSS 1	19-Jul-2012	27-Jul-2012	27-Aug-2012

Table 3.3 soaking period

3.5.4. Injection period:

The injection period calculated from start and end of injection date. And we take the data from table (3.4):

	First Cycle			
Well No.	Boiler	start inj.	end inj.	start prod.
FNE-12	GWCSS2	29-Sep-2014	7-Oct-2014	1-Dec-2014

Table 3.4 injection period

3.5.5. Volume of injected steam:

It had been found the volume of steam (in BBL) which injected in each cycle and in all wells by the following equation:

$$\text{Steam volume} = \text{injection rate} * \text{injection period}$$

3.5.6. Sand calculation:

It was studied the process of work over which was conducted on the wells, the sand level is determined before the flushing process (TSL) and the level of sand in the well after the flushing process (FSL). After that we will find the sand height in the casing to find the volume of sand in it after that .taking into consideration that any work over process contains the flushing process and also FSL be usually at PBTD (bottom hole casing plug)finally, we find the sand height in the casing by meters. The unit of length is converted to volume by using the cylinder volume equation

r =0.5 D (D=internal diameter of casing)

V=volume of sand in casing (m^3)

l = *the hieght of*

Then it had been found the summation of the produced sand in every cycle separately, depending on date of the beginning of cycle of injecting steam to the date of beginning of the next cycle. All sand production sets in tables for etch well alone.

The table below explains how we set the values:

well	WO No	date	PRIOD	TSL	FSL	CYCLE	sand height (m)	sand pro Volume BY M3	SP VOLUME BY BBL	sand production	
FNE-15	1	21/04/11	4	613.4						19.0	1st cycle
	2	25/05/11	6	557.56	679.4		55.8	1.1	6.8		
	3	02/08/11	5	625	0	1	54.4	1.1	6.6		
	4	19/06/12	6	579	679.41		46.0	0.9	5.6		
							156.2	3.0	19.0		
	5	13\8\2012	8	647.26	678.42	2	32.2	0.6	3.9	41.0	2nd cycle
	6	23\12\2012	11	548.46	678.42		130.0	2.5	15.8		
	7	7\2\2013	4	647.26	678.42		31.2	0.6	3.8		
	8	2\6\2013	6	535.78	678.42		142.6	2.8	17.4		
							335.9	106.2	41.0		
	9	٠٦-يوليه-١٣		675.84			2.6	0.1	0.3	9.2	3rd cycle
	10	٠٧-فبراير-١٤		602.63		3	73.2	1.4	8.9		
							75.8	1.5	9.2		
	11	٢٠-مارس-١٤								7.3	4th cycle
	12	٢٦-سبتمبر-١٤		554.72	678.38	4	47.91	0.9	5.8		
	13	١٣-يوليه-١٥		666.45			11.93	0.2	1.5		
							59.8	1.2	7.3		

Table 3.5 sand calculation

3.5.7.Steam Influence study:

It had been gathered all data in one diagram and it had been taken the injected steam volume as a reference and ascending arranged and observation the effect of steam volume on sand and oil production in all wells together.

3.5.7.1. Steam Influence on sand production:

It had been compared the production of sand in all wells and in all cycles and compared between them depended on steam injection volume and dividing to zones based on increase and decrease in sand produced volume after that described the influence of steam injected volume in sand production at every zone . Taking into consideration the soaking period to every cycle and it had been found best of injected steam soaking period to avoid produce large quantity of sands during oil production.

3.5.7.2. Steam Influence in oil production:

It had been compared the production of oil in all wells and in all cycles and compared between them depended on steam injection volume and dividing to zones based on increase and decrease in oil produced volume after that described the influence of steam injected volume in oil production at every zone . Taking into consideration the soaking period to every cycle and it had been found best of injected steam soaking period to avoid produce large quantity of sands during oil production

3.5.6. Relationship between date of well stuck because sand production and production period and it indicator to start new steam cycle or continue in production:

From field data of workover reports and pump stuck history in specific wells , we found first workover operation and compared with next production period.

Chapter four

The Results and discussions

4.1.Introduction

As mentioned we used in this research the data analysis method to analyzing the steam injection volume and sand and oil production data,after that we discuss the influence of steam injection volume on sand and oil production then determine the best injection volume and suckingperiod.

We select some wells to study it, based on the bad history in producing a large quantity of sand and not good in oil amounts production.

The wells which identified from FNE field and have problems in sand production are:

FNE-15 , FNE-16 , FNE-17 , FNE-23 , FNE-29 , FNE-41 , FNE-61 , FNE- 66 , FNE-33 , FNE-34, FNE-39

4.2. The calculations:

The flowing calculations have been calculated from field data

4.2.1.The CSS periods and steam volume and oil production:

From FNE field data we calculate the CSS periods and steam volume and oil production in the table below:

well	Cycles	Injection period (days)	Soaking period (days)	Production period (days)	injection rate (BBL/day)	steam volume (BBL)	oil production (BBL)
15	1	7	33	332	1175.33	8227.31	75000.79
	2	8	31	280	1179.38	9435.04	41484.68
	3	9	21	206	1085.03	9765.27	31953.22
	4	9	12	467	1207.68	10869.12	64712.19

16	1	11	30	910	1018.98	11208.78	216698.3
	2	10	21	203	1322.84	12328.4	47527.38
	3	11	14	555	1232.84	13561.24	110907.5
17	1	9	16	466	1034.36	9309.24	99693.68
	2	9	24	326	1196.5	10768.5	75700.49
	3	10	18	242	1088.74	10887.4	50110.72
	4	10	11	495	1197.62	11976.2	63317.64
	5	11	16	326	1197.39	13171.29	31192.68
28	1	9	12	982	1076.29	9686.61	206705.6
	2	9	21	238	1112.63	10013.67	41048.57
	3	9	11	235	1224.45	11020.5	49383.21
	4	10	22	148	1211.45	12114.5	24298.31
29	1	14	25	163	1258	17612	40336.26
	2	6	16	280	1213.07	2778.42	49385.45
	3	8	15	559	1171.51	9372.5	36478.1
	4	8	14	471	1176.23	9409.84	64199.37
41	1	11	23	237	1132.2	12454.2	28842.9
	2	12	21	194	1142.68	13712.16	32442.83
	3	13	15	347	1192.2	15498.6	47438.2
66	1	6	30	486	1174.13	7044.78	54150.8

33	1	6	11	940	1198.83	7193	204347
	2	7	11	173	1217.57	8523	38027
	3	8	15	192	1094.5	8756	23846
	4	8	11	478	1091.37	8731	77732
34	1	11	13	758	1085.27	11938	174898
	2	11	24	212	1195.09	13146	33666
	3	12	20	202	1205.58	14467	27353
	4	11	10	374	1198.54	13184	62522
39	1	15	14	243	568.2	8523	24513
	2	10	8	209	1314.6	13146	18593
	3	11	8	572	1196.27	13159	78705

Table 4.1 the CSS Periods and Steam Volume and Oil Production Calculation

4.2.2. Produced sand volume

From the field data and work over data we find the produced sand volume in table below:

Taking into consideration that the diameter of all the wells used in the field FNE is 0.157 m.

well	Cycle No	WO No	TSL	FSL	sand height (m)	Volume by m^3	Volume by BBL	sand production
FNE-15	1st cycle	1	613.4					19.0
		2	557.56	679.4	55.8	1.1	6.8	
		3	625	0	54.4	1.1	6.6	
		4	579	679.41	46.0	0.9	5.6	
					156.2	3.0	19.0	
	2nd cycle	5	647.26	678.42	32.2	0.6	3.9	41.0
		6	548.46	678.42	130.0	2.5	15.8	
		7	647.26	678.42	31.2	0.6	3.8	
		8	535.78	678.42	142.6	2.8	17.4	
					335.9	106.2	41.0	
	3rd cycle	9	675.84		2.6	0.1	0.3	9.2
		10	602.63		73.2	1.4	8.9	
					75.8	1.5	9.2	
	4th cycle	11						7.3
		12	554.72	678.38	47.91	0.9	5.8	
		13	666.45		11.93	0.2	1.5	
					59.8	1.2	7.3	
FNE-16		1	676.5	0				
	1st	2	624.1	680	55.9	1.083562732	6.815609581	38.91969114
		3	549.69	680	130.31	2.525922353	15.8880516	
		4	549	680	131	2.539297278	15.97217988	
		5	678	680	2	0.038767897	0.243850074	
					319.21	6.18755026	38.91969114	
	2nd	6	566.6	680	113.4	2.198139781	13.82629922	13.82629922
		7	0	680	NO tag sand level			
						2.198139781	13.82629922	
	3rd	8	0	680	NO tag sand level			7.230154708
		9	620.7	680	59.3	1.149468157	7.230154708	
						1.149468157	7.230154708	
	4th	10	0	0	no data			

[redacted]								
FNE-17		1	619.37					
		2	608.8					
	1st	3	540	681.33	141.33	2.739533468	17.23166551	17.23532326
		4	681.3	681.33	0.03	0.000581518	0.003657751	
					141.36	2.740114986	17.23532326	
	2nd	5	669.36	681.33	11.97	0.232025866	1.459442696	3.162735466
		6	667.36	681.33	13.97	0.270793763	1.70329277	
					25.94	0.502819629	3.162735466	
	3rd	7	662.31	681.33	19.02	0.368682704	2.319014208	4.102777503
		8	666.7	681.33	14.63	0.283587169	1.783763295	
					33.65	0.652269873	4.102777503	
	4th	9	653.37	681.33	27.96	0.541975205	3.409024041	3.409024041
					27.96	0.541975205	3.409024041	
	5th	10	651.8	681.33	29.53	0.572408005	3.60044635	3.60044635
					29.53	0.572408005	3.60044635	
	6th	11	0	0	/	L	L	
[redacted]								
FNE-23	1st	1	699	0	0			
		2	617.6	699	81.4	1.577853423	9.924698031	9.924698031
[redacted]								
FNE-28	1st	1	0	0				16.95367643
		2	0	0				
		3	545.3	684.35	139.05	2.695338065	16.95367643	
					139.05	2.695338065	16.95367643	
	2nd	4	680	684.35	4.35	0.084320177	0.530373912	8.132399984
		5	622	684.35	62.35	1.208589201	7.602026072	
					66.7	1.292909377	8.132399984	
	3rd	6	621.3	684.35	63.05	1.222157965	7.687373598	16.75250012
		7	610	684.35	74.35	1.441196585	9.065126518	
					137.4	2.663354549	16.75250012	
	4th	8	0	0	//	/	/	18.39483037
		9	522.21	673.08	150.87	2.924456338	18.39483037	
					150.87	2.924456338	18.39483037	
[redacted]								
FNE-29		1	659.17	0				
		2	636.9	0				
		3	618	0				
	1st	4	559	673.8	114.8	2.225277309	13.99699427	13.99699427
					114.8	2.225277309	13.99699427	
	2nd	5	635	674	39	0.755973999	4.755076452	6.169406884

		6	662.4	674	11.6	0.224853805	1.414330432	
					50.6	0.980827804	6.169406884	
	3rd	7	597.8	674	76.2	1.47705689	9.290687837	9.290687837
		8	0	674	NO tag sand level			
					76.2	1.47705689	9.290687837	
	4th	9	553	654.2	101.2	1.961655607	12.33881377	12.33881377
					101.2	1.961655607	12.33881377	
FNE-41		1	647.63	0				
		2	624.13	0				
	1st	3	528.2	694.95	166.75	3.232273443	20.33099996	19.39347772
		4	0	0	NO tag sand level			
		5	652.82	694	41.18	0.798231007	5.020873033	
					207.93	4.03050445	25.35187299	
	2nd	6	628.87	694	65.13	1.262476578	7.940977675	3.743450322
		7	0	0	NO tag sand level			
					65.13	1.262476578	7.940977675	
	3rd	8	520	637.1	117.1	2.269860391	14.27742186	21.22850239
		9	609	694	85	1.647635638	10.36362816	
		10	0	609.46	NO tag sand level			
					202.1	3.917496029	24.64105003	
FNE-61		1	580	0				
	1st	2	555.8	690.5				
					134.7	2.611017888	16.42330252	
FNE-66		1	0	0				
	1st	2	541.57	641.72				25.86639665
		3	560	672	100.15	1.941302461	12.21079248	
					112	2.171002253	13.65560417	
	2nd	4	523	672	212.15	4.112304714	25.86639665	18.16683055
					149	2.888208354	18.16683055	
FNE-33	1							10
	2							1
	3							2
	4							49
FNE-34	1							22
	2							2
	3							2

	4							30
FNE-39	1							4
	2							1
	3							18

Table 4-2 the produced sand volume

4.3. The steam volumes and soaking period compared to sand production:

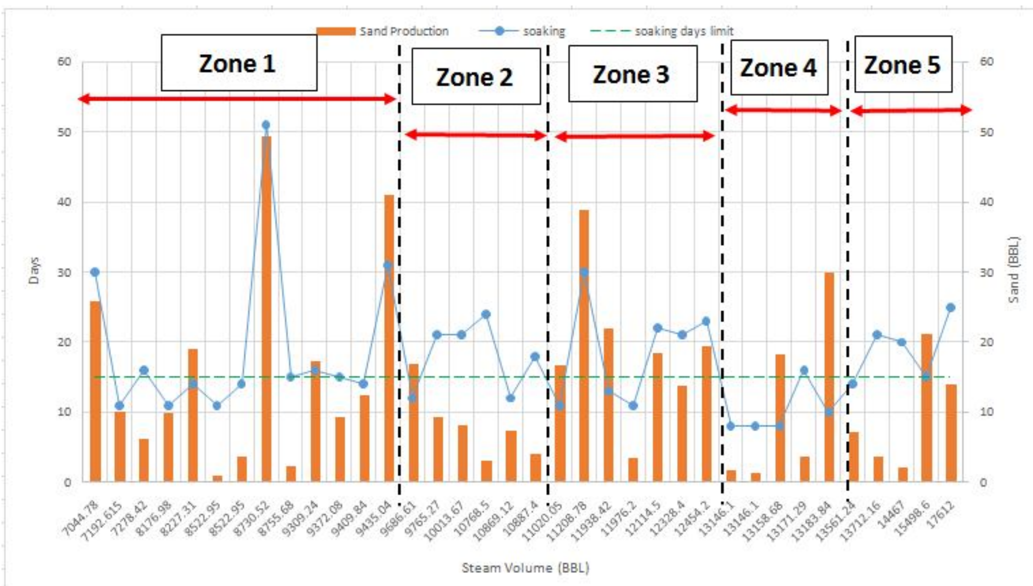

Figure4.1. Steam volume and soaking period compared to sand production

4.3.1. The discussions of the above figure:

● Zone 1:

Low steam volumes (7,000 - 9,700) BBL

High sand production is associated with long soaking period (>15 days)

● Zone 2:

Medium steam volumes (9,700 - 11,000) BBL

Low sand production is associated with long soaking period (>15 days)

● Zone 3:

Large steam volumes (11,000 - 13,000) BBL

High sand production is associated with long soaking period (>15 days)

● Zone 4:

Extra large steam volumes (13,000 - 13,500) BBL

Same scenario in zone 1

● Zone 5:

Extra large steam volumes (>13,500) BBL

Same scenario in zone 2

4.4. The steam volumes and production period compared to oil production:

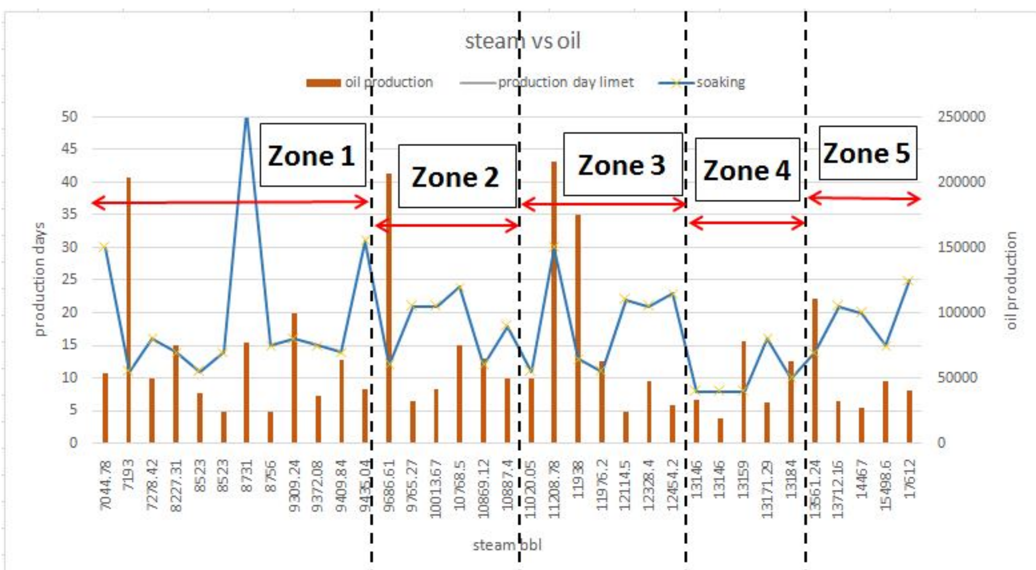

Figure 4.2 Steam volume and soaking period compared to oil production

4.4.1. The discussions of the above figure:

- Zone 1:

Low steam volumes (7,000 - 9,700) BBL

Normally that value used at first’s cycles.

When the soaking time is long the oil production will be low.

If we want work in zone 1 we should reduce the soaking period below 15 days.

- Zone 2:

Medium steam volumes (9,700 - 11,000) BBL

Normally that value used after second cycle.

Regardless of soaking period there is an increasing in oil production.

- Zone 3 and zone 4

Large steam volumes (11000 - 13500) BBL

When the soaking time is long the oil production will be low.

- Zone 5

Extra-large steam volumes (>13,500) BBL

When the soaking time is long the oil production will be low

4.5 workover date Vs production period and next steam cycle time:

- production days according to workover in table 4-3 :
  - ✓ in table 4-3 yellow color indicate to around 50 days and red color more than 50 days .

well	cycle	W/O	Prod. Days Before W/O
15	1	1	51
		2	276
	2	1	101
		2	33
	4	1	184
		2	93
33	4	1	42
		2	142
		3	269
34	4	1	47
		2	315
39	1	1	50
		2	588
	3	1	91
		2	102
41	1	1	150
		2	62
	3	1	231
		2	102

table 4-3

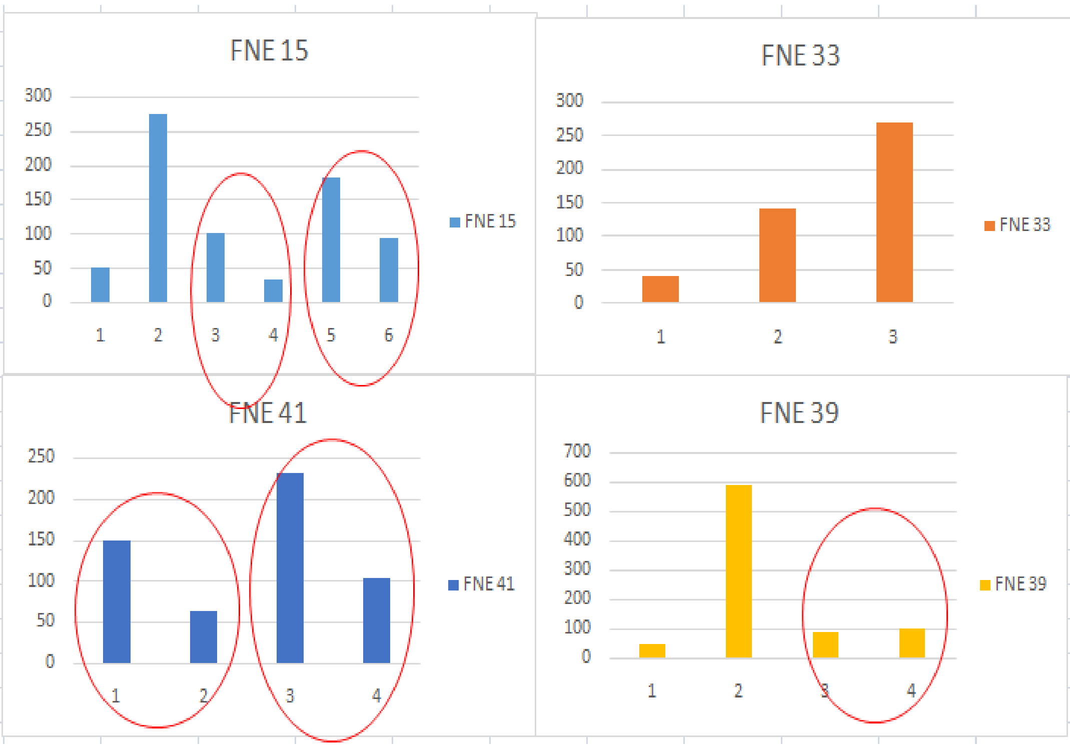

figure 4-3

Chapter five

Conclusion and Recommendation

5.1. Conclusion

From previous results and discussion held in this research, the following conclusions can be written:

- Sand production quantity in CSS wells basically depends on soaking period, more soaking time means formation temperature gets low, crude becomes colder, and more sand is expected to flow after well start up. Eventually, loss of oil production and short operation period for these wells.
- There are no stable trend in increasing or decreasing oil and sand production when increasing steam volume .
- There Generally, all wells are shut due to pump stuck caused by sand production after been operated for a period of time. Data analysis shows that when production period is about 50 days before shutting the well for workover then well will continue to produce for a very long period compared to prior workover operation. On the other hand, if the production period was more than 50 days, then it will operate for shorter periods after recovered from workover operation. In this case, well needs to start another cycle of steam injection instead of continuing production since sand production (especially for long production periods) is an essential indicator for the next steam cycle timing.

5.2. Recommendation

- Soaking period must be less than 15 days especially for CSS application at early cycles with low steam volumes.
- In the early days of production if the well stopped (pump stuck) after 50 days doing flushing work and continuous in production without do any steam work , if the well stopped after much more than 50 days that indicates to we should do new steam cycle .
- Data limitation is a constraint; if more data is available this work would be more accurate and widely expanded to cover different areas in this field.

Chapter six

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