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FEASIBILITY STUDY TO IMPLEMENT STEAM ASSISTED GRAVITY DRAINAGE (SAGD) FOR FULA NORTH EAST (FNE) SUDANESE OIL FIELD

دراسة استقصائية لامكانية تطبيق طريقة حقن البخار المدعوم بتأثير

الجاذبية (SAGD) في حقل الفولة " شمال شرق " السوداني

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

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October 2015

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

استهلال

قال الله تعالى :

﴿وَعَلَّمَ آدَمَ الْأَسْمَاءَ كُلَّهَا ثُمَّ عَرَضَهُمْ عَلَى الْمَلَائِكَةِ فَقَالَ

أَنْبِئُونِي بِأَسْمَاءِ هَؤُلَاءِ لَكُمْ صَادِقِينَ ﴿31﴾ قَالُوا

سُبْحَانَكَ لَا عِلْمَ إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ

﴿31﴾

صدق الله العظيم

سورة البقرة الايات (31 ، 32)

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

To the Sprit of Dr.Mohammed Naieem

Acknowledgment

Our first acknowledgment is to our supervisor Dr.Elradī Abass whose guidance, supervision, kindness and tolerance in this study made it possible for this work to assume its present form.

Our special thanks to Eng.Husham Awad ,Eng.Mhanned Mahgoub and everyone who directly or indirectly contributed to this research

Lastly but not least special thanks go to Sudan University for Science and Technology and petroleum engineering department staff

Abstract

When the oil recovery comes to its lower level at which production of oil in economical amount not possible; the need for tertiary methods will be necessary.

Steam Assisted Gravity Drainage (SAGD) one of the thermal enhanced oil recovery methods it increase the recovery by using horizontal wells; one for continued steam injection and the other for continued production.

This method frequently is used when the oil has very high viscosity and low API degree.

SAGD method depend on many factors; such as steam quality " for viscosity reduction", the horizontal wells to cover a large space for recovery as much as possible and the gravity to facilitate oil moving from injection well to production one.

Fula North East Sudanese oil field is selected as case study, the study proposed to investigate the SAGD method it can be used to increase the recovery in FNE oil field, which revealed low recovery rate.

Using simulator (CMG-STAR3) to estimate various values for certain factors such as steam quality, temperature and injection rate, then predict the results for five years starting from 1st Jan 2015.

The simulation model of SAGD has shown a promising implantation where a successful result is achieved in the FNE field, so that provide opportunities for more studies about other fields, if it has desired geological data are given for the future.

التجريد

عادة ما تأتي الحاجة لاستخدام احدى طرق الاستخلاص المحسن للنفط عندما تقل نسبة الاستخلاص الى ادنى معدلاتها، بحيث يكون من غير الممكن انتاج كمية اقتصادية من الهيدروكربونات تكفي لتغطية تكاليف الانتاج ومن ثم تعطي الارباح المرجوة منها.

الطريقة موضع الدراسة في هذا البحث هي احدى الطرق الحرارية للاستخلاص المحسن للنفط ، وتعتمد هذه الطريقة على زياده نسبة الاستخلاص بواسطة استخدام بئرين افقيتين ، احدهما للحقن باستخدام البخار ، والاخرى للانتاج ، وتستخدم هذه الطريقة عادة في انواع المكامن التي تحتوي على خام يمتاز بدرجات لزوجة وكثافة عالية جدا.

الطريقة تعتمد على عوامل البخار (لتقليل لزوجة الخام)، الابار الافقية (لتغطية أكبر مساحة للاستخلاص) وكذلك تأثير الجاذبية لنقل الخام المعالج الى بئر الانتاج.

تمت دراسة امكانية تطبيق هذه الطريقة في حقل سوداني (الغولة شمال شرق) والذي يمتاز خامه النفطي باللزوجة العالية.

تم فرض عدة قيم للعوامل التي تؤثر على نتائج الطريقة (كدرجة حرارة البخار المحقون وكفاءته ومعدل الحقن) ومن ثم التنبؤ بنتائج هذه الفرضيات لمدة خمس سنوات بدءاً من 2015\1\1م باستخدام برنامج محاكي لطبيعة المكمن "CMG-STARS" ، ومن ثم اختيار القيم التي تعطي افضل النتائج في الحقل موضع الدراسة.

اثبتت هذه الدراسة نجاح الطريقة في هذا الحقل مما يفتح الباب لإمكانية تطبيقها مستقبلياً في حقول اخرى تكون اكثر ملاءمه و حوجه لها وذلك اذا ما توفرت الدراسات الجيولوجيه الدقيقه .

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Nomenclature

SAGD	Steam Assisted Gravity Drainage
FNE	Fula North East
EOR	Enhanced Oil Recovery
API	American Petroleum Institute
AOSTRA	Alberta Oil Sands Technology and Research Authority
GOR	Gas Oil Ratio
OOIP	Original Oil In Place
ASP	Alkaline Surfactant Polymer
UTF	Underground test facility
C-FER	a significant portion of the current expertise
ERCB	Alberta Energy Resources Conservation Board
STARS	Steam, Thermal, and Advanced Processes Reservoir Simulator
GEM	Generalized Equation-of-State Model Compositional Reservoir Simulator
IMEX	Implicit-Explicit Black Oil Simulator
WINPROP	phase behavior and property program
CMG	Computer Modeling Group
SC	Standard Conditions
MD	Mill Darce
MPA	Mega Pascal
K_v	Vertical Permeability
K_H	Horizontal Permeability
FT	Feat
M	Meter
BBL	Barrel

Chapter one: Introduction

Oil is found in subterranean formations or reservoirs in which it has accumulated, and recovery is initially accomplished by pumping or permitting the oil to flow to the surface of the earth through wells drilled into the oil-bearing stratum. Oil can be recovered from such producing zones only if certain conditions exist. There must be adequate permeability or interconnected flow channels through the pore network of the oil-bearing stratum or "pay zone" to permit the flow of fluids there through and recovery efficiency.

1.1 Statement of the problem:

According to the field under study " FNE Sudanese oil field"; which characterized with high viscous crude oil and very low API, therefore must be way to increase the oil recovery efficiency, and as fact of other thermal recovery methods efficiency decrease gradually with time, that create an idea to use the steam assisted gravity drainage (SAGD) method to give better results in recovery rate.

1.2 Objectives:

- a) Study the possibility of implementation "SAGD" method in a Sudanese "FNE" oil field which had large quantities of heavy oil must be recovered by suitable method to increase the recovery rates.
- b) To study the effect of well configuration in determining SAGD performance.
- c) To develop a suitable method to pass the limitations of other thermal methods at preheating issues.
- d) Propose several scenarios to achieve the optimum parameter which gives the best recovery rate results.

1.3 Development sequence:

In the **primary oil recovery** stage, the RE is influenced by the natural energy or drive mechanisms present, such as water drive, gas cap drive, gravity, drainage, and liquid expansion, relative permeability of reservoir formation and combinations thereof within the formation and this natural energy is utilized to recover petroleum. In this primary phase of oil recovery, the oil reservoir natural energy drives the oil through the pore network toward the producing wells. When the natural energy source is depleted or in the instance of those formations which do not originally contain sufficient natural energy to permit primary recovery operations, some form of supplemental or artificial drive energy must be added to the reservoir to continue RE. Supplemental recovery of enhanced recovery is frequently referred to as secondary recovery, although in fact it may be primary, secondary or tertiary in sequence of employment. Enhanced recovery usually encompasses water flooding or gas injection with or without additives, and other processes involving fluid or energy injection whether for secondary or tertiary oil recovery such as the use of steam or heated water

Secondary recovery is a term utilized to mean any enhanced recovery first undertaken in any particular underground formation. Usually it follows primary recovery but can be conducted concurrently therewith to expedite production. Water flooding is the most common method of secondary recovery.

Tertiary recovery refers to any **enhanced recovery** undertaken following secondary recovery. Broadly, tertiary recovery encompasses such procedures as miscible displacement, thermal recovery, or chemical flooding.

All of these procedures have been and, as noted, are being utilized to try to recover as much oil as possible from any given formation, but none is completely satisfactory. Many are expensive procedures not only in terms of equipment to be able to enhance the recovery, but also in terms of the chemicals and techniques utilized.

Perhaps most importantly it has been found that in many cases the particular technique used is extremely limited in terms of type of oil reservoir in which the recovery technique can be utilized and that a broad procedure for universal use has not been found.

1.4 Enhanced oil recovery (EOR):

Enhanced oil recovery (EOR) is the process of obtaining stranded oil not recovered from an oil reservoir through certain extraction processes. EOR uses methods including thermal recovery, gas injection, chemical injection and low-salinity water flooding. Although these techniques are expensive and not always effective, scientists are particularly interested in EOR's potential to increase domestic oil production.

A method of recovering petroleum from an underground source thereof comprising injecting into said underground source a petroleum displacement agent comprising a fluid and a modified liposome, said liposome being present in an amount sufficient to lower the interfacial tension between said fluid and said petroleum to below about 10 mill dynes and the displacement agent

Improved recovery technology includes traditional secondary recovery processes such as water flooding and immiscible gas injection, as well as enhanced oil recovery (EOR) processes. EOR processes are usually classified as follows: chemical, miscible gas, thermal and microbial.

A brief description of each of these processes is presented below. The success of an EOR project depends on good planning. (White, 2005) recommend the following steps for planning an EOR project:

- 1- Identify the appropriate EOR process
- 2- Characterize the reservoir
- 3Determine engineering design parameter
- 4- Conduct pilot or field tests as needed
- 5- Finish with a plan to manage the project

1.4.1 Enhanced oil recovery Methods Classification:

After the completion of the primary processes and secondary to extract oil from the place remaining large amounts estimated at about 65% need the remaining quantity to pressure very high, so that is it has to be reduced interfacial tension between oil and fluids can reach it either heat treated to convert oil and water to the situation steam or by chemical injection solutions.

Use thermal methods in the same high-viscosity oils cases roads while using chemical methods for oils with viscosity medium or low

Chemical:

Chemical flooding methods include polymer flooding .micelle-polymer flooding or surfactant-polymer flooding, and alkaline or caustic flooding.

Miscible:

Miscible flooding methods include carbon dioxide injection, natural gas injection, and nitrogen injection . Miscible gas injection must be performed at a high enough pressure to ensure miscibility between the injected gas and in situ oil.

Microbial:

Microbial EOR uses the injection of microorganisms and nutrients in a carrier medium to increase oil recovery, reduce water production in petroleum reservoirs, or both

Thermal:

Thermal flooding methods include hot water injection, steam drive steam soak, and in situ combustion. The injection or generation of heat in a reservoir is designed to reduce the viscosity of in situ oil and improve the mobility ratio of the displacement process. Electrical methods can also be used to heat fluids in relatively shallow reservoirs containing high viscosity oil, but electrical methods are not as common as hot fluid injection methods. The in situ combustion method requires compressed air injection after in situ oil has been ignited. Steam injection methods require the injection of steam into a reservoir, steam and hot water injection processes are the most common thermal methods because of the relative ease of generation hot water and steam. The in situ combustion process is more difficult to control than steam injection processes and it requires in situ oil that can be set on fire. Hot gases and heat advance through the formation and displace the heated oil to production

well.

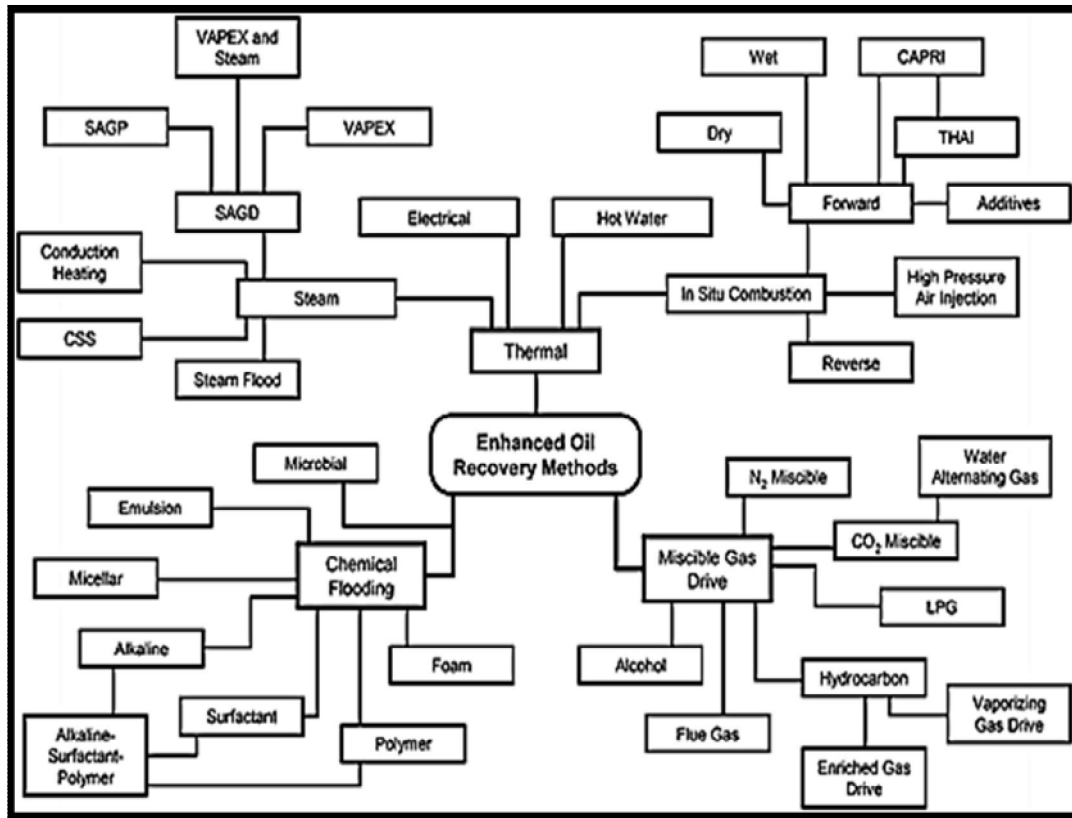


Figure 1-1: Explain Enhanced Oil Recovery Methods& Techniques Classifications

1.5 Thermal enhanced oil recovery method and apparatus:

A thermally-enhanced oil recovery method and apparatus for exploiting deep well reservoirs utilizes electric down hole steam generators to provide supplemental heat to generate high quality steam from hot pressurized water which is heated at the surface. A down hole electric heater placed within a well bore for local heating of the pressurized liquid water into steam is powered by electricity from the above-ground gas turbine-driven electric generators fueled by any clean fuel such as natural gas, distillate or some crude oils, or may come from the field being stimulated. Heat recovered from the turbine exhaust is used to provide the hot pressurized water. Electrical power may be cogenerated and sold to an electric utility to provide immediate cash flow and improved economics. During the cogeneration period (no electrical power to some or all of the down hole units), the oil field can continue to be stimulated by injecting hot pressurized water, which will flash into lower quality steam at reservoir conditions. The heater includes electrical heating elements supplied

with three-phase alternating current or direct current. The injection fluid flows through the heater elements to generate high quality steam to exit at the bottom of the heater assembly into the reservoir. The injection tube is closed at the bottom and has radial orifices for expanding the injection fluid to reservoir pressure.

1.6 Steam-Assisted Gravity Drainage (SAGD):

Steam Assisted Gravity Drainage (SAGD) is an Enhanced oil recovery technology for producing heavy crude oil and bitumen. It is an advanced form of steam stimulation in which pair of horizontal wells is drilled into the oil reservoir, one a few meters above the other. High pressure steam is continuously injected into the upper wellbore to heat the oil and reduce its viscosity, causing the heated oil to drain into the lower wellbore, where it is pumped out.(Butler 2012)

Although the steam-assisted gravity drainage (SAGD) process has application in the recovery of conventional heavy oil, it was originally conceived for the recovery of bitumen where the in-situ viscosity is so high that conventional production methods are impractical.

In the Steam-assisted Gravity Drainage (SAGD) process, heated oil drains from around growing steam chambers, driven by gravity, to lower horizontal wells. As the oil drains, the steam chamber advances into the reservoir. The process has several features:

- The displacement of the oil is systematic and high recoveries can be obtained.
- In suitable applications, oil to steam ratios higher than those found for conventional steam-flooding can be achieved.
- The process can be used in even the heaviest of bitumen reservoirs without extensive preheating. The feature which makes this possible is that once the oil is heated, it remains hot as it drains to the production well; this is unlike conventional steam-flooding where oil which is displaced from the steam chamber tends to cool on its way to production.

Steam-assisted Gravity Drainage allows steam-flooding at economic rates without the bypass of steam. It gives high recoveries in both bitumen and heavy oil reservoirs. It

has been demonstrated in Canadian field trials with results which are in reasonable agreement with prior theoretical and scaled model studies.(Butler 2012)

1.6.1 The Initial Concept of (SAGD) Process:

The mechanism by which process proceeds and general nature of the flows within the reservoir are indicated by the diagram in the Figure 1 below .This shows the process in fairly early phase. Steam is being injected from a well, either a horizontal well, or sometimes one or more vertical wells. The steam flows to the perimeter of steam chamber and conduction. The heat transferred by thermal conduction into the surrounding reservoir. The water condensate from the steam and the oil heated flow, driven by gravity. To the production well below. As the oil flows away and is produced. The steam chamber expands. It can expand both upwards and sideways.(S.M Farouq Ali 1997)

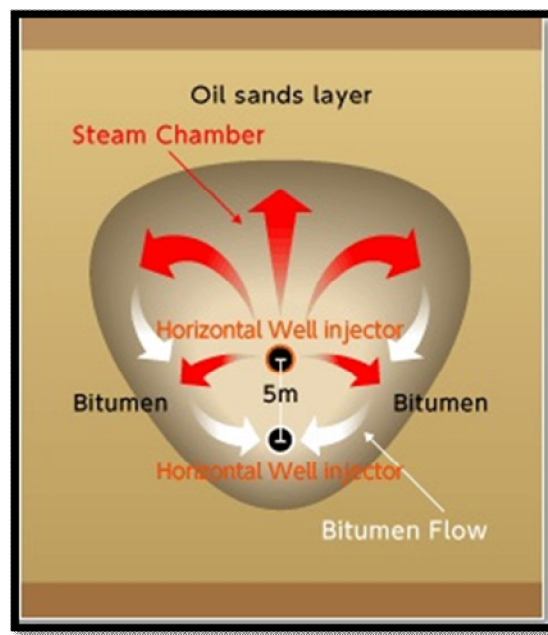
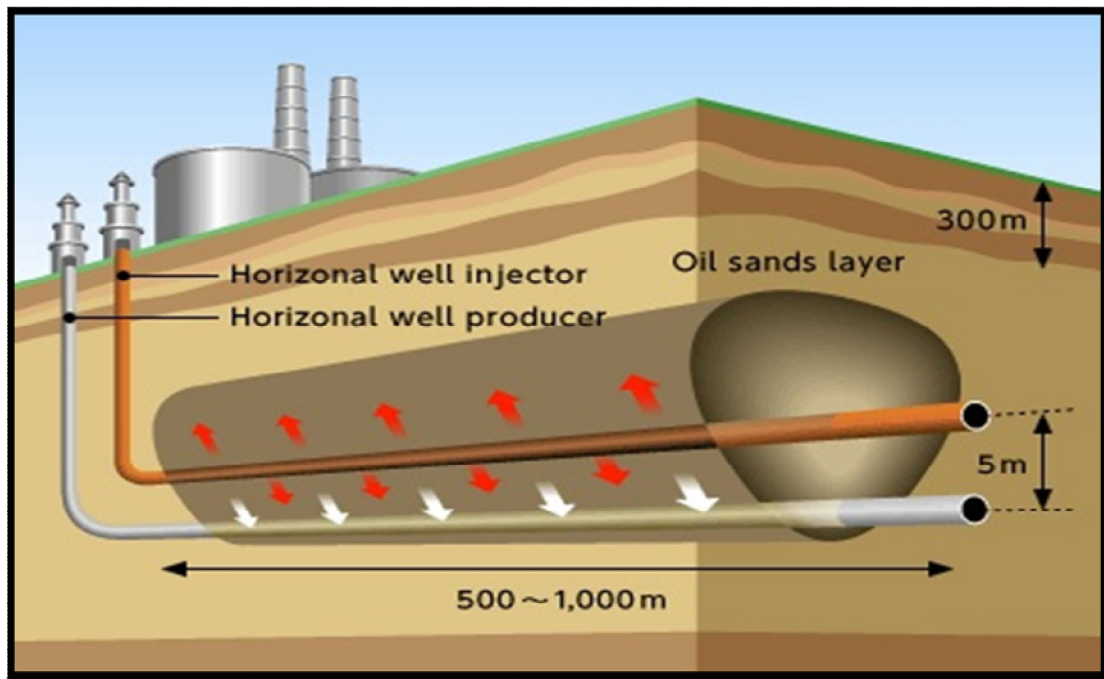


Figure 1-2:Conceptual diagram of the steam-assisted gravity drainage process



Figure(1-2):Cross-sectional diagram showing the steam-assisted gravity drainage process

1.7 EOR Screening:

Considers various criteria, which are in the nature of the reservoir rock, oil density, permeability, viscosity of crude oil, depth, water, and saturated with oil is the salinity of the first step to evaluate and determine the appropriate method for improved extraction of oil and to determine a way of extraction methods triple it is important identify the different factors that affect and limit the possibility of using this method

Steam injection of economic projects to extract oil is when the depth of the reservoir is less than 3,000 feet, crude oil density of about 30, 200 milliseconds Darcy permeability, porosity of more than 25% and thermal methods successfully applied in the sandstone layers.

The degree of saturation of original oil prominent role in determining the use of a particular method roads thermal mostly been applied in the case of a high degree of saturation in oil and due to the crude oil may be heavy in this case and thus lower the degree of saturation.

Steps describe the following simplified method and process for the proposal and Test Method for improved extraction of oil:

- 1- Available information is collected and required fluids and reservoir rocks
- 2- Action analysis of the various standards that are used in the ways of the enhanced extraction of oil
- 3- Can identify a convenient way depending on the emulator between information and standards
- 4- Conduct experiments in the laboratory to study the method selected
- 5- If study agreement in previous step is appropriate to the circumstances field under study
- 6- Address economic and technical and engineering services for the way that has been selected.
- 7- In the case of the study agree in step six it can hold either test fields in case of non-compliance, it must choose another way and move me step three.

1.8 Oil Classifications:

Crude oils cover a wide range in physical properties and chemical Compositions, and it is often important to be able to group them into broad categories of related oils. In general, crude oils are commonly classified into the following types:

- Ordinary black oil
- Low-shrinkage crude oil
- High-shrinkage (volatile) crude oil
- Near-critical crude oil

1.8.1 Heavy oil classification:

The World Petroleum Conference classifies heavy oil as those showing a relative specific gravity above 0.920 – equivalent to 22.3[°]API.

The American Petroleum Institute adopts the definition of heavy oil as being that with relative specific gravity equal to or smaller than 20[°]API.

The North American taxation system has similar criterion from API, although relating the specific gravity to the reference temperature of 60°F.

In Brazil adopts the relative specific gravity as the criterion, setting a range between 10° to 22°API; those oils with specific gravity lower than 10°API are classified as extra-heavy.

In china: Heavy crude oil has a gas-free viscosity from 100 to 10,000 cp at original reservoir temperature or gravity from 10° to 20° API. For Extra heavy oil or Bitumen (Tar Sand) has a gas-free viscosity greater than 10,000 cp at original reservoir temperature or gravity less than 10° API.

Table 1-1: Classification of the heavy oil (Duan 2007)

Conventional Heavy oil			50* (or 100-10,000)	17.5<API<22.0
	Sub-class	1-1	50*-150*	
		1-2	150*-10,000	
Extra-heavy oil	II		10,000 – 50,000	12.9<API<17.5
Bitumen & Tar Sand	III		> 50,000	<10
Oil Shale	IV		Non mobile at reservoir condition	0

Note: The viscosity with * is measure under reservoir condition, and other are measured at reservoir temperature, dead oil.

Chapter two: literature review

The gravity drainage idea was originally conceived by Dr. Roger Butler, an engineer for Imperial Oil in the **1970**.(Butler 2012)

(C. V. Deutsch 2005) former Premier of Alberta created the Alberta Oil Sands Technology and Research Authority (AOSTRA) in 1974 as an Alberta crown corporation to promote the development and use of new technology for oil sands and heavy crude oil production, and enhanced recovery of conventional crude oil. Its first facility was owned and operated by ten industrial participants and received ample government support.

One of the main targets of “AOSTRA” is finding of suitable technologies for that part of the Athabasca Oil Sands that could not be recovered using conventional surface mining technologies.

In 1975, Imperial Oil transferred Butler from Sarnia, Ontario to Calgary, Alberta to head their heavy oil research effort. He tested the concept with Imperial Oil in 1980, in a pilot at Cold Lake which featured one of the first horizontal wells in the industry, with vertical injectors.

(Butler 2012) before the advent of today's horizontal drilling technology, Roger M. Butler(1980) at Imperial Oil Ltd. investigated and published drilling techniques that were being used in an "oil mine" project near Urege, Russia. Horizontal wells were drilled into reservoirs from underground tunnels to recover oil.

(Czarnecka 2013) AOSTRA initiated the Underground Test Facility in the Athabasca Oil Sands, located between the MacKay Rivers and the Devon River west of the Syncrude plant as an in-situ SAGD bitumen recovery facility in **1984**.

It was there that they first test of twin (horizontal) SAGD wells took place, proving the feasibility of the concept, briefly achieving positive cash flow in **1992** at a production rate of about 2000 bbl/day from 3 well pairs.)

The UTF project began in **1987** and involved tunneling into the Devonian limestone beneath the oil sands. Workers brought a small drilling rig into the tunnel and drilled upward into the bitumen.

According to the Alberta Research Council, UTF-based SAGD technology is covered by Canadian and US patents beginning in **1989**.

In 1995, two horizontal well pairs, the "D wells," were drilled and completed from the surface in the UTF project and are still producing.

According to Todd Zahacy, a senior research engineer at Edmonton-based C-FER Technologies Inc., "a significant portion of the current expertise, knowledge, and understanding of all aspects of SAGD drilling, completion, production and facilities requirements are the direct result of AOSTRA's UTF project."

AOSTRA was dissolved by action of Bill 7 (ASRA Amendment Act 2000) and replaced by the Alberta Energy Research Institute (AERI) with a new mandate to research and develop technology for all forms of energy. C-FER is a division of AERI.

2.1 Current application:

According to Marlin Polowick at Computalog Drilling Services in Calgary, a newer standard has emerged, using Vector Magnetics rotating magnet ranging system (RMRS; OGJ, Feb. 23, 2004, p. 47). The arrangement of the sensors is reversed in the RMRS; sensors are placed in the first (reference) well, and the second well is drilled with the RMS sub.

In the US, Derek Resources Corp. drilled the first SAGD well pair in its LAK Ranch pilot, Weston County, northeastern Wyoming, from June 24 to July 29, 2000. The wells were drilled by Sperry Sun Drilling Services, reach 1,000 ft TVD, and extend 1,800 ft horizontally into the steeply dipping Newcastle sandstone formation of the Powder River basin.²The pilot plant was operated in 2001 and 2002, and the project is under further study by the current operator, Ivanhoe Energy (USA) Inc.

The SAGD process allowed the Alberta Energy Resources Conservation Board (ERCB) to increase its proven oil reserves to **179** billion barrels, which raised Canada's oil reserves to the third highest in the world after Venezuela and Saudi Arabia and approximately quadrupled North American oil reserves. As of 2011, the oil sands reserves stand at around 169 billion barrels.

Chapter three: Methodology

The modeling process or computer model refers to the algorithms and equations used to capture the behavior of the system being modeled. A computer simulation refers to the actual running of the program that contains these equations or algorithms. Simulation, therefore, refers to the result of running a model. In other words, you would not "build a simulation.

The simulation which will be used in this project is "STARS" Simulator which consisted in computer modeling group software "CMG".

CMG is a simulation program presented by CMG Company (computer modeling group) in Canada; this windows software provides practical solutions for oil/gas reservoir modeling in reservoir engineering.

The use of this program is to help maximize recovery of hydrocarbon assets in the most efficient way possible using efficient production processes, efficient modeling algorithms and easy-to-use software.

Main parts (software(s)) of CMG are:

- Builder (preprocessing applications)
- STARS (Steam, Thermal, and Advanced Processes Reservoir Simulator)
- GEM (Generalized Equation-of-State Model Compositional Reservoir Simulator)
- IMEX (Implicit-Explicit Black Oil Simulator)
- WINPROP (phase behavior and property program)
- 3D results

3.1 Building Model

CMG software use "**Builder**" tool to building reservoir base model.

A reservoir model for a black oil reservoir can be built by Builder simulator of CMG. It is a combination process of collecting the results and information of the field into one big unit to create the model.

Builder is a MS-Windows based software tool that you can use to create simulation input files (datasets) for CMG simulators. Builder covers all areas of data input, including creating and importing grids and grid properties, locating wells, importing well production data, importing or creating fluid models, rock-fluid properties, and initial conditions. Builder contains a number of tools for data manipulation, creating tables from correlations, and data checking. It allows you to visualize and check your data before running a simulation.

3.2 Steam Thermal and Advanced processes Reservoir Simulator

(STARS):

STARS. The industry standard in thermal reservoirs simulation, is designed to accurately and efficiently capture reservoir dynamics, over the entire life cycle of the reservoir.

Through accurate reservoir visualization, engineers will clearly see changes to the reservoir based upon fluid behavior, steam or air injection, electrical heating or chemical flood.

By using STARS, engineers are able to identify the most appropriate recovery method for the reservoir, increase confidence in field development plan to support capital expenditures; and reduce project risk.

STARS is a three-phase multi-component thermal and steam additive simulator. Grid systems may be Cartesian, cylindrical, or variable depth/variable thickness. Two-dimensional and three-dimensional configurations are possible with any of these grid systems.

3.3 Applications:

1. Advanced process reservoir simulator can be used to models virtually any recovery process, but is especially suited to non-isothermal.

2. Light and heavy oil recovery processes as well as those that require the modeling of chemical reactions and alkaline – surfactant – polymer (ASP) flooding.
3. Foamy heavy oil production and cold heavy oil production.
4. In addition, STARS can model the in situ formation of emulsions ,wax precipitation and thermal desorption.

3.4 Benefits:

1. Robust modeling for dispersed components.
2. Accurately model the physics off all in-situ recovery processes.
3. Model single wells to pad- and field scale projects.
4. Simulate formation of emulsions and foams and predict asphaltting precipitation /deposition.
5. Accurately visualize changing reservoirs dynamics.
6. Increase confidence in field development plans.
7. Design accurate development plans.
8. Decrease GOR while increasing OOIP recovery with accurate foamy oil models.

3.5 Requirements:

It just requires the basic data which are: grid system, oil, rock and reservoir properties.

STARS must be used in this project to editing the criteria that control the steam quality and essentially affect in production rate.

3.6 Steps:

1. The first step begins with opening the launcher and using "Builder" to establish the model by input reservoir and well parameters as shown below:

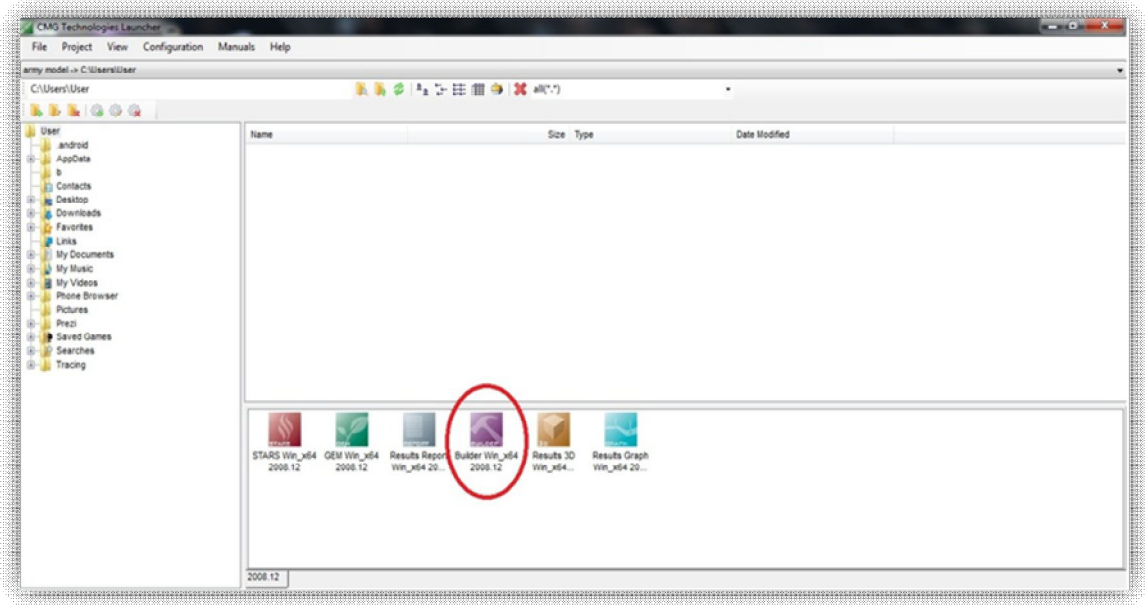


Figure 3-1: Main CMG Launcher Screen

2. Set main reservoir and well parameters and choose the desired simulator (STARS):

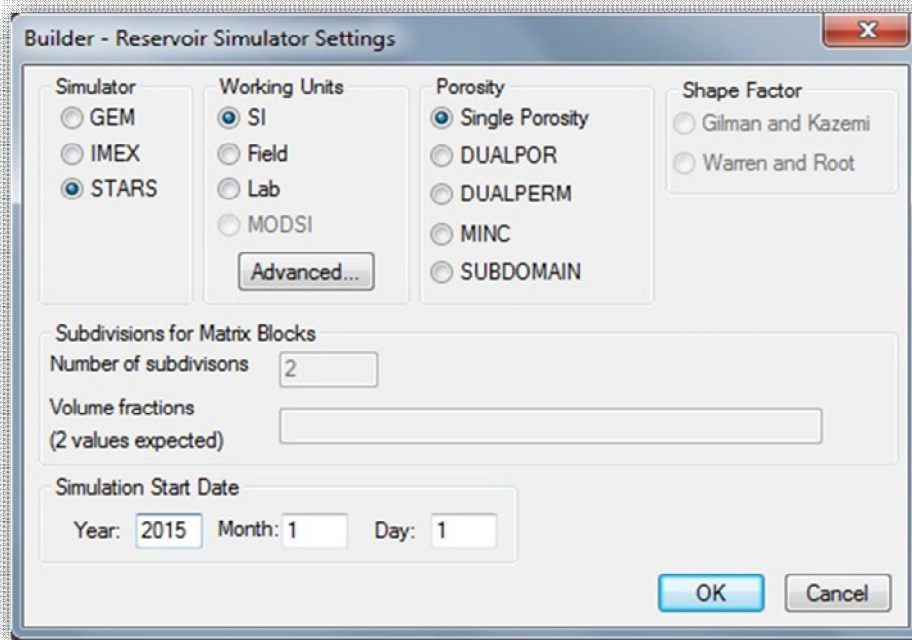


Figure 3-2: Main Reservoir Simulator Settings

3. Builder ready to import all the required data to finish reservoir modeling process.

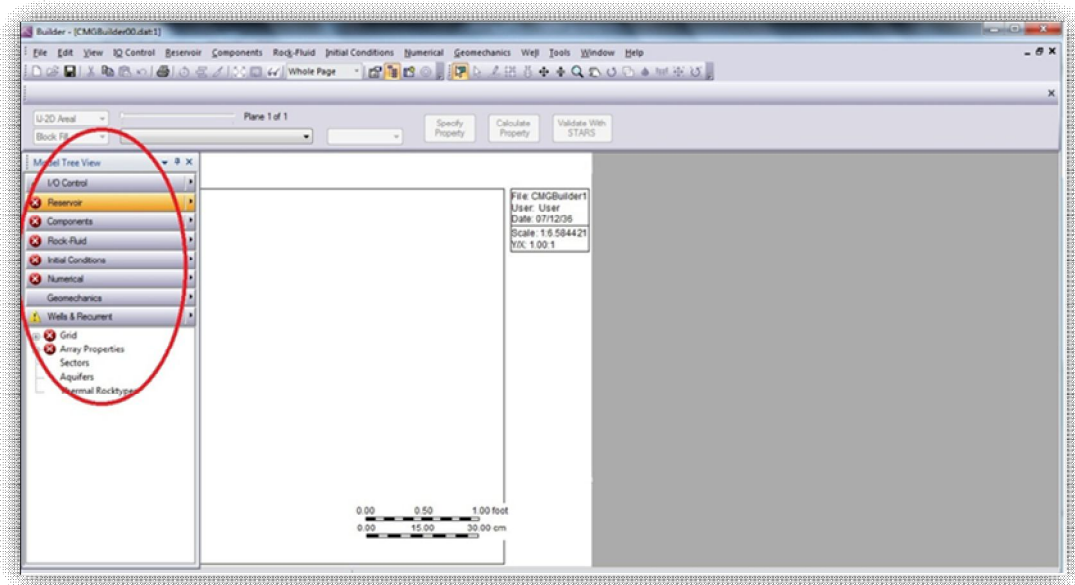


Figure 3-3: Bulider Main Screen

4- By the end of modeling, all component of "Model tree view" shown above must be ticked and the model will be ready to run and export results.

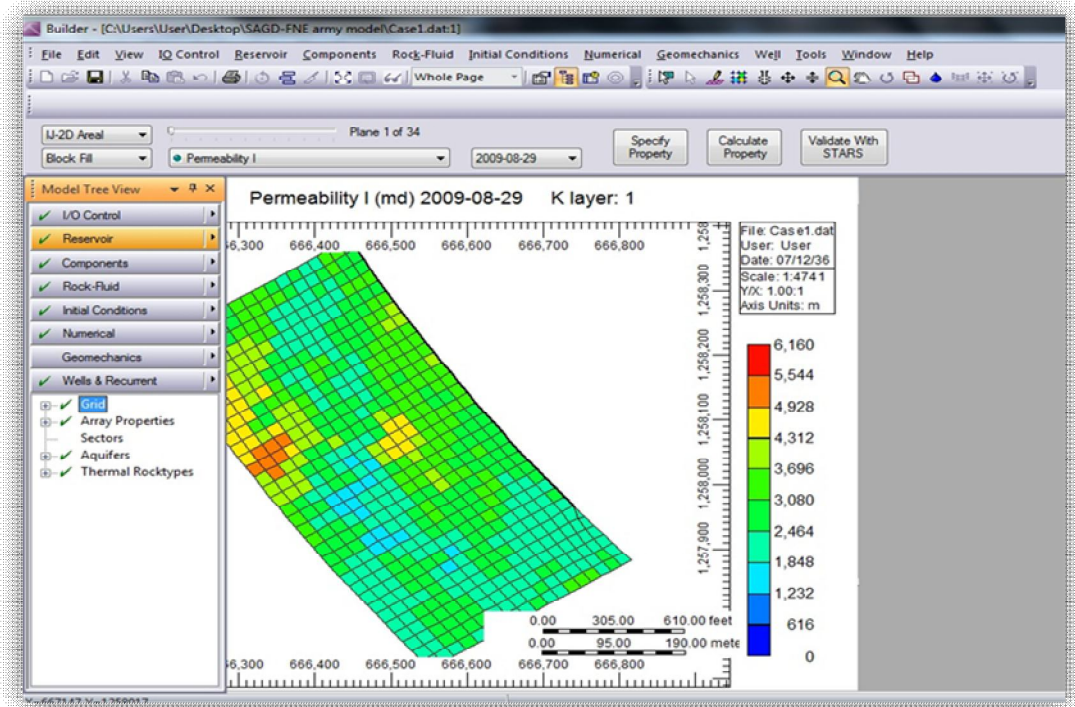


Figure 3-4: Bulider Main Screen After Input Requier Data

Chapter four: Results and analysis

FNE oilfield contains main layers Aradaiba and Bentiu1. Main zone is Bentiu1 with the average porosity 31%. It's common heavy oil massive sandstone edge-bottom water reservoir with original OWC 27m. Initial reservoir pressure **3.91 Mpa**, pressure gradient **0.74 MPa/100m**, initial temperature **43.7 °C**, and **2.65 °C/100** geothermal gradients.

The table (4-1) below shows minimal and optimum operation conditions for SAGD method with FNE field properties

Table 4-1: Steam Assisted Gravity Drainage Screening Criteria

Parameters	Minimal operation conditions	Optimum operation conditions
Depth	200 to 3700 ft	200 to 1600 ft
Rock type	Sandstone	Sandstone
Thickness	>45ft	60-100 ft
Water saturation	<40%	<20%
API gravity at 60°F	<20	<15
Viscosity	>100 cp	>1000 cp
Permeability (K)	>780 md	>3000 md
K_v/K_h	>0.25	>0.5
Porosity	>20%	>30%
Areal continuity	good	Excellent
Interest zone-specific (pay zone)		
Clay contents	<10%	0%

Table 4-2: FNE Field Properties And Screening Results.

Parameters	FNE field properties	Screening Results
Depth	500 to 600 ft	Excellent
Rock type	Sandstone	Compatible
Thickness	35 to 65 ft	fair
Water saturation	45%	Bad
API gravity at 60°F	17 to 19	Fair
Viscosity	>2000 cp	Excellent
Permeability (K)	>100	Fair
K_v/K_h	1.00 to 1.5	Excellent
Porosity	20 to 35%	Very Good
Areal continuity	Good	Good

4.1 Assumptions:

Five scenarios have been assumed to evaluate the effect of changing the injection rate, temperature and steam quality values in oil productivity from the producer well.

Table 4-3: Injection Well Parameters Assumed

	Injection rate	Temp	Steam Quality
	M³/Day	C	%
1	20	280	0.8
2	30	300	0.9
3	35	350	0.9
4	50	300	0.8
5	100	350	0.85

All above scenarios were evaluated with CMG STARS simulator to predict production data for five years, started from 1st Jan 2015 till to 1st Jan 2020.

4.2 Results and discussion:

Figure (4-1) below shows the results of cumulative oil and water for all assumed scenarios versus time:

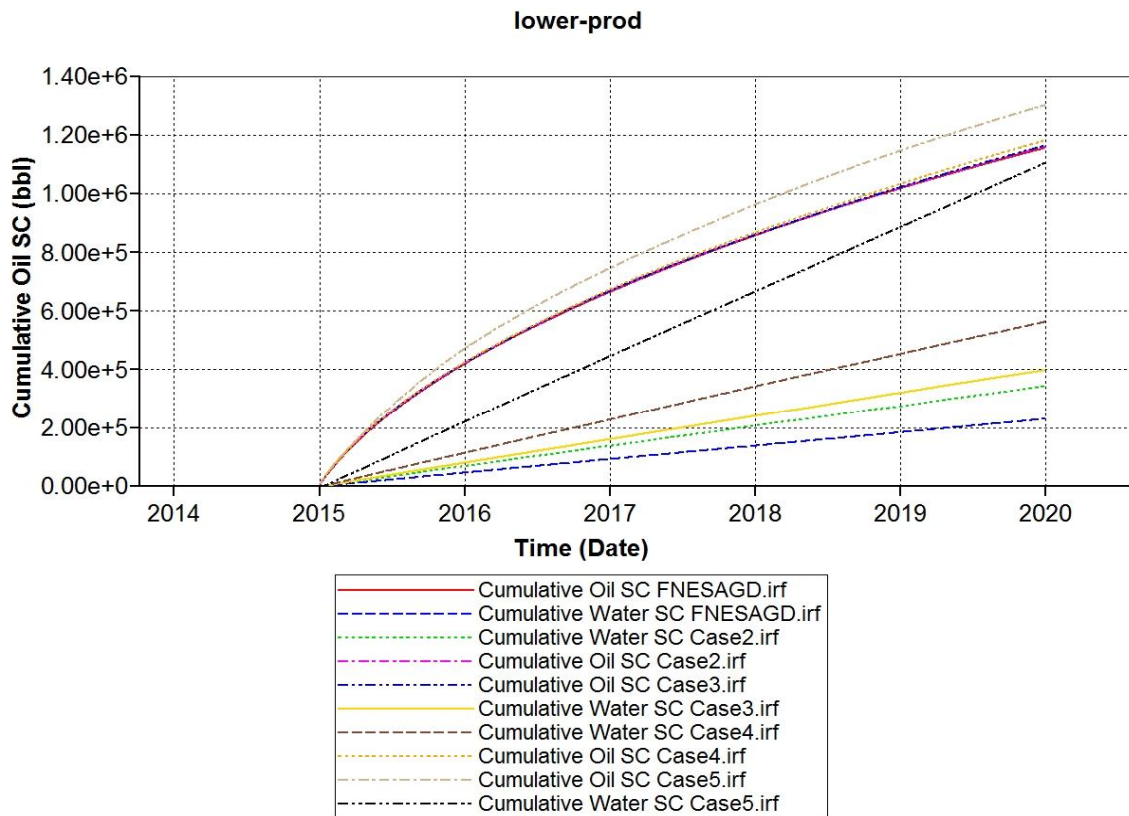


Figure 4-1: Cumulative Oil SC and Cumulative Water SC versus Time

In order to cover more consideration to choose best case from all scenarios, other production data can be compared like oil rate %, water cut% ... etc.

Figure (4-2) below shows a direct comparison between all assumed cases in oil rate and water cut percentages at producer well for five years:

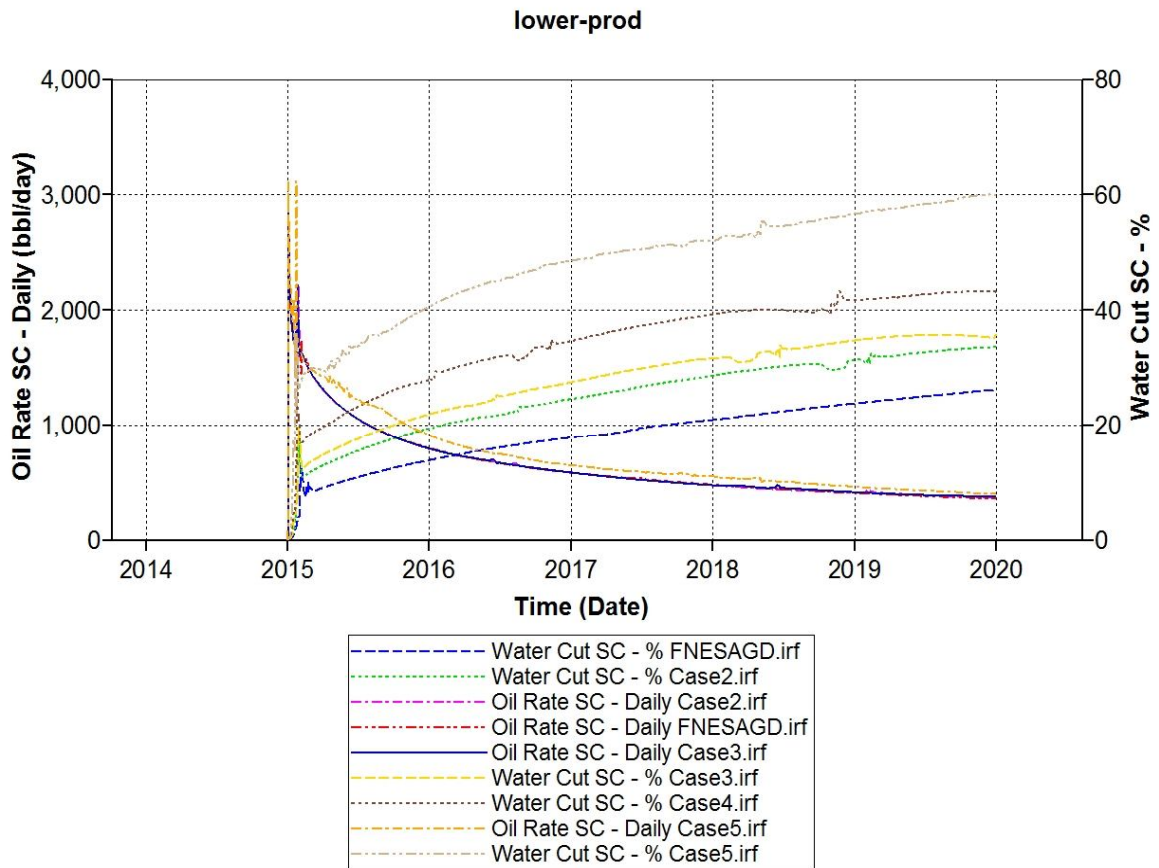


Figure 4-2: Oil Rate SC % And Water cut SC Versus Time

All these considerations are complementary to each other but the values of cumulative oil and cumulative water produced are the most important results proportion to their importance directly associated with the economical aspects.

As shown as figure (4-1) there are different values of cumulative oil and water throw selected time depending on parameters assumed at any case.

To choose the best parameters to be applied, both values of cumulative oil and cumulative water produced must be considered.

The case which gives great amounts of cumulative oil produced with relatively low amounts of cumulative water, considered the best case may be selected.

Select the best results of comparison between predicted production information

This comparison shown as next table:

Table 4-4: Predicted Production Data For Assumed Scenarios

	Injection rate	Temp	Steam Quality	Cumulative oil produced m(bbl.)	Cumulative water produced m(bbl)
	M³/Day	C	%		
1	20	280	0.8	1.15705	0.229806
2	30	300	0.9	1.16131	0.343032
3	35	350	0.9	1.16463	0.398177
4	50	300	0.8	1.18212	0.563639
5	100	350	0.85	1.30261	1.105530

By comparing all results of predicted production data given by simulator; found that cases four and five gives better results than other cases in cumulative oil produced.

That's leads to another accurate comparing between two cases in details.

The specified production data for case four are shown as figure below:

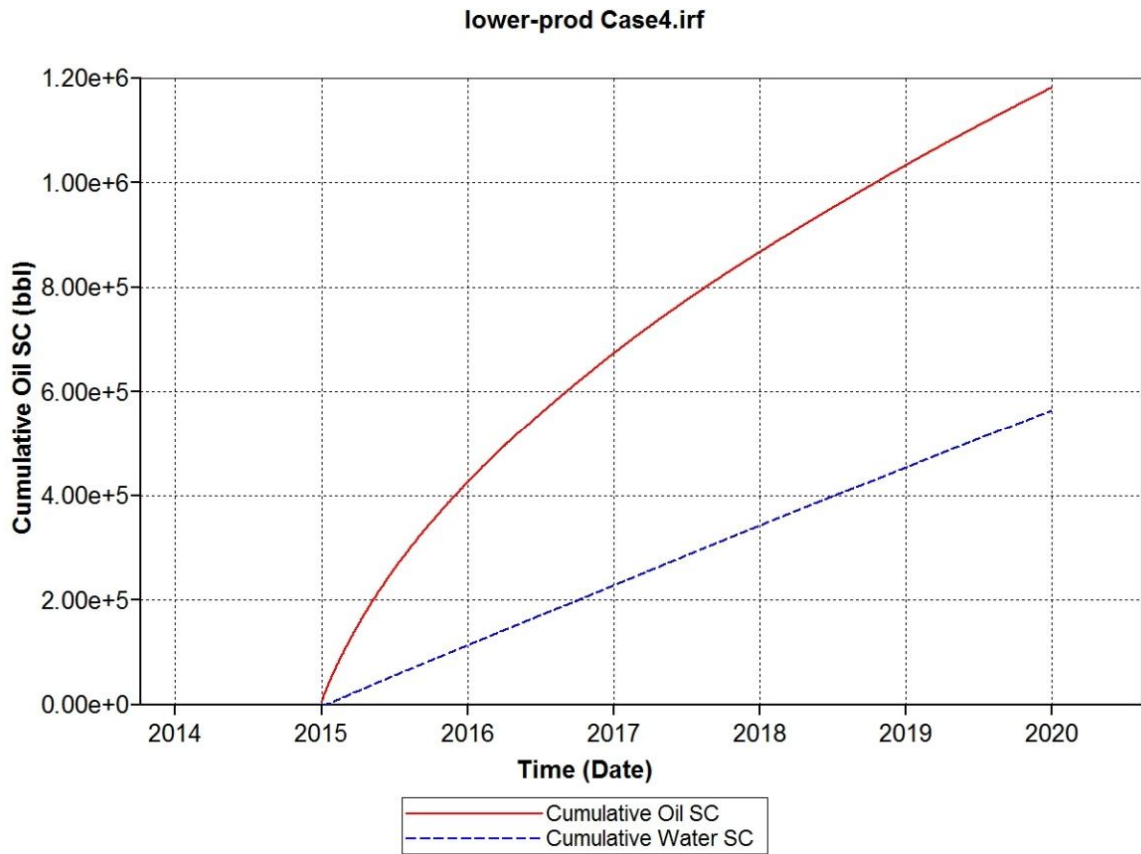


Figure 4-3: Production Data of Case Four Through Time

Figure (4-3) illustrates that the value of cumulative oil produced at case four relatively high compare to amount of water produced during the specified time period.

At end of selected time period the amount of cumulative oil reach to **(1.18212)** million barrel, with **(0.563639)** million barrel of cumulative water produced.

On the other hand the specified production data for case five are shown as figure below:

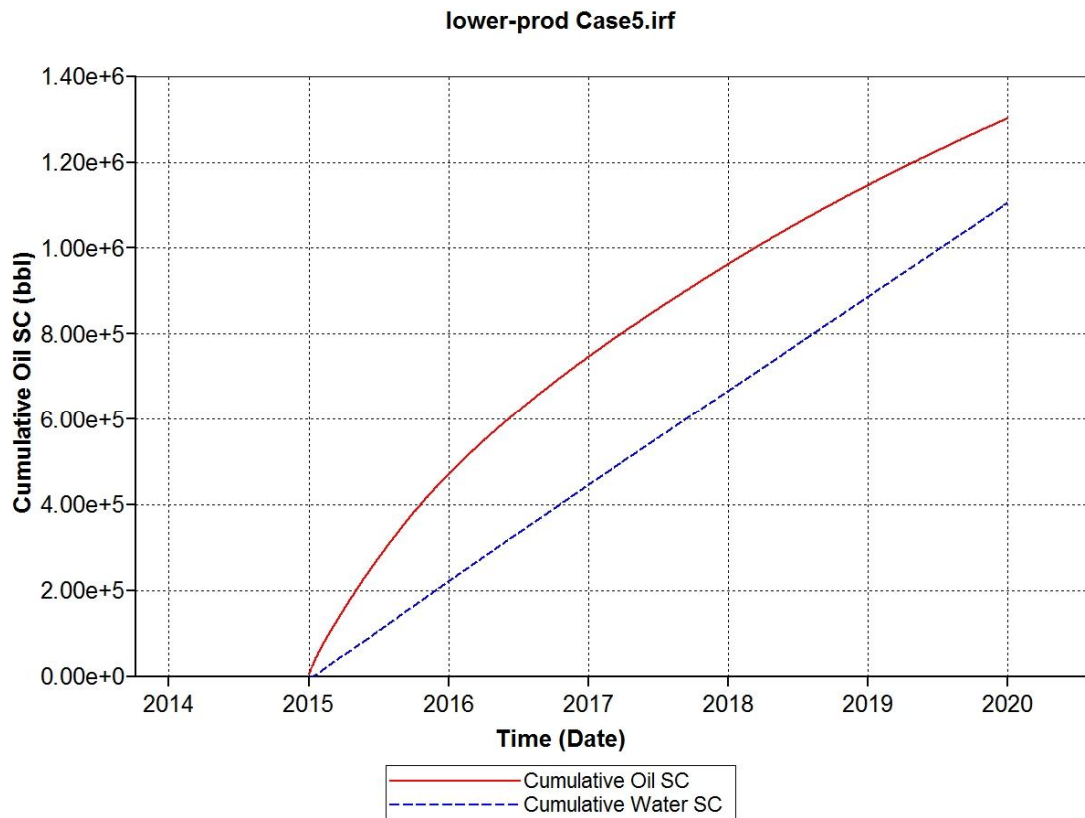


Figure 4-4: Production Data For Case Five Through Time

The result shows a convergent amount between cumulative oil (**1.30261**) million barrels and cumulative water (**1.105530**) million barrels at 1st Jan 2020.

That's mean a huge amount of water will be produced at end of the same time period of production.

From all above, the result of comparison tend to case four due to following considerations:

- 1- Cumulative water produced value at the beginning of production time of case five with almost equal to the amount cumulative oil produced.
- 2- The exits value continuous to raise with time till reach a very large quantity at the end of time period which cannot be acceptable.
- 3- The amount of cumulative water produced at case four, may be more acceptable than same amount at case five.
- 4- The amounts of cumulative oil produced at both cases are convergent.

5- More amount of water produced lead to more water treatments to processing and dispose.

To show the capability of “SAGD” method, another comparison can be made between production data which gained by “case four” parameters and other production data by using one conventional vertical production well with perforations at the same layer.

The results of this comparison will show as next figure:

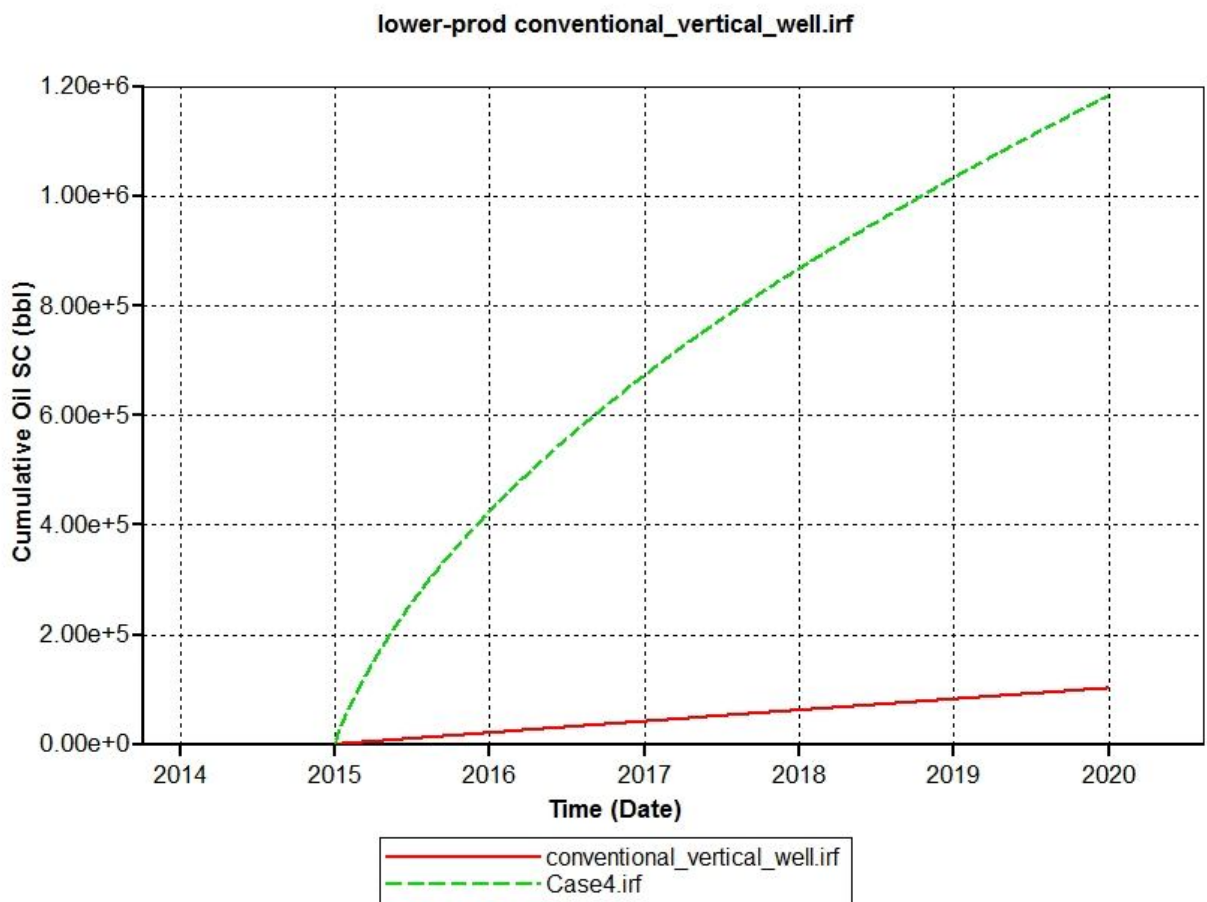


Figure 4-5: Comparison In Production Data Between “SAGD” Method and Conventional Vertical Production Well.

It’s clear at above figure the horrible different in cumulative oil produced at any date from beginning till to end of time period.

The variance between two methods reach about 1,000,000 barrel of oil at the end of time period.

As shown above, the capabilities of EOR processes can be clear now after this previous comparison which shows the different between a conventional primary recovery and a tertiary recovery by using SAGD process tend to one million barrel.

By comparing the cumulative oil produced by implement SAGD method _in case four _ with the cumulative oil produced by using conventional horizontal producing well at the same layer the result will shown as figure below:

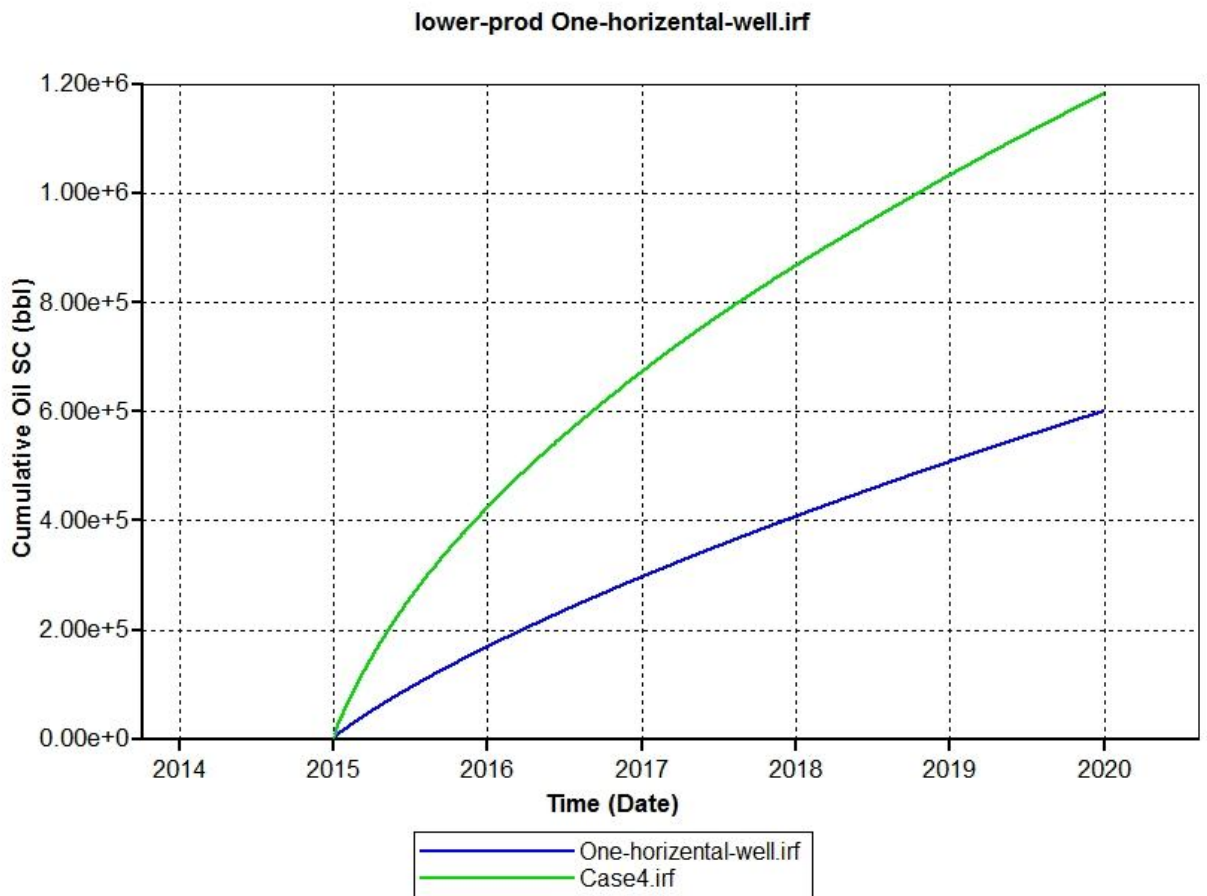


Figure 4-6: “SAGD” Method And One Horizontal Production Well Production Data Versus Time

The figure above indicates that the quantity of cumulative oil produced with SAGD method is almost equal two times of the same quantity if only one horizontal production well would apply without steam injection.

The comparison between SAGD, one horizontal well and vertical well at the same layer can gives brief clarification about SAGD capabilities.

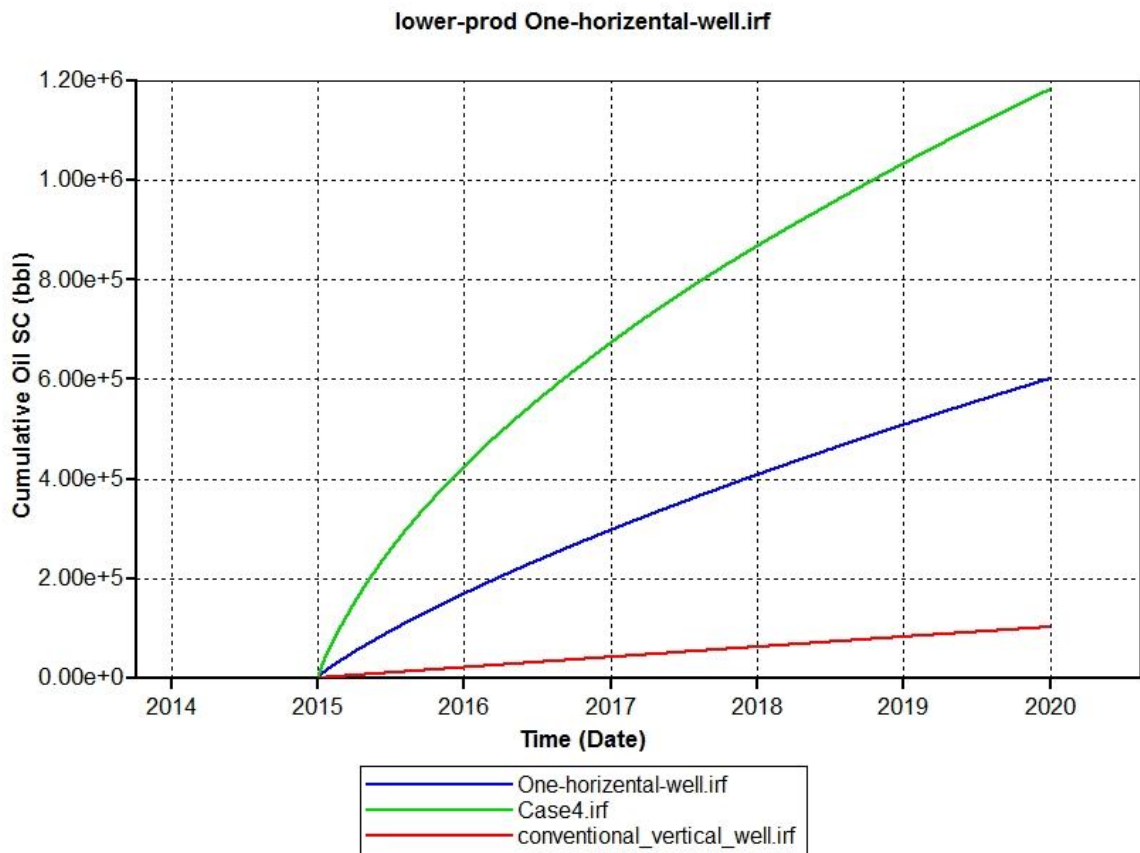


Figure 4-7: Production Data Of Cold Horizontal Well, Vertical Well And SAGD Method Versus Time

As a matter of fact that implementation of horizontal wells gives more oil productivity than vertical wells, figure (4-7) shows that the effect of horizontal wells in SAGD methods.

As known that SAGD method is combination method between horizontal wells concept, steam injection and gravity drainage, though figure (4-7) shows the affect of one cold conventional horizontal well which gives (600,000) barrel productivity for five years, and the effect of steam injection and gravity drainage on a horizontal well which raise the oil productivity from same layer and time period up to (1,200,000) barrel.

Chapter five: Conclusion and recommendations

Conclusion:

- SAGD processes are one of the most successful technologies for the recovery of heavy crude-oil and are widely applicable at different types of oil fields, where thermal processes are required, as reached under ideal operation conditions recovery factors over 50%.
- The application of (SAGD) method has shown successful in the FNE field as it increases the cumulative oil produce from **200,000** barrel (if conventional vertical well is used) to **1,200,000** barrel after five years from time officially opened (almost **667** bbl/day as production rate)
- The optimum injection parameters to be used in FNE field are:
(Injection rate = **50** m³/day), (temperature = **300** C) and (Steam quality = **0.8**).
- Acceptable amount from water productivity are obtained by using the method with suitable injection parameters mentioned above (almost **313** bbl/ day).
- Although FNE field not considered as ideal field to apply SAGD method and that's for concerning the screening criteria, though good result was obtained when applied which may favor much researches later to be conducted.

Recommendations:

- Considering the economical vision before the application of the process in any reservoir, profits from produced oil can be estimated and compared to overall production cost; this due to the high cost of horizontal wells drilling comparing to the vertical wells.
- The process may give more powerful results if it has been applied in appropriate areas of Sudanese oil fields considering the geological factors and suitable screening factors.

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