1. Introduction:

The increasing of the energy demand is a widely discussed topic in today's society. As the Conventional oil reserves are depleting, the need for exploration of unconventional resources are increasing rapidly. Production of heavy oil has for a significant amount of time been limited by technological and economic challenges. However, with today's available advanced technology and the significant increase in oil prices, the Figure (1.1) below illustrate the world crude demand since (1987) to (May, 2014):

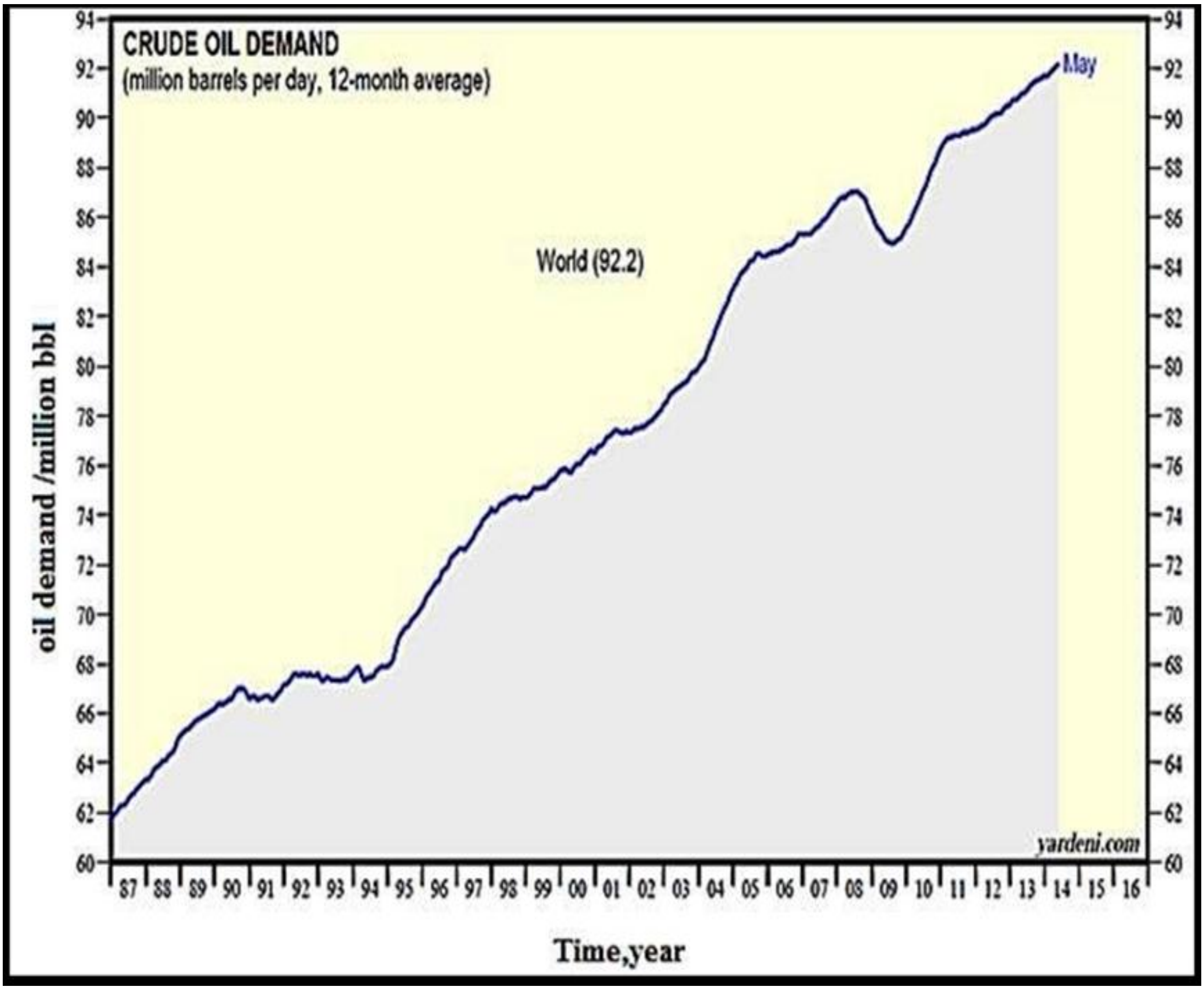

Fig..1.1: Crude Oil Demand (Oil Market Intelligence, May 2014)

1.1. Problem statement:

When petroleum reservoirs are depleted by natural drive mechanisms due to decreasing reservoir pressure only a small fraction of the oil can be produced (30-40%). Implementing a secondary recovery, water flooding, will produce a portion of this recoverable oil present in the reservoir but still there are significant quantities of residue crude oil in the reservoir.

Implementing a tertiary recovery, specifically steam flooding technique will produce a portion of this irrecoverable oil present in the reservoir by primary and secondary recovery, In this case design steam flooding project is implemented for Bantiu formation, for which the steam injection and injection rate have been determined. Under these givens this research studied theoretically the steam flooding performance for this formation; by using CMG software for predicting the performance. To investigate the performance and recovery efficiency of steam flooding to displace oil.

1.2. Objectives of the Project:

A. To determine steam injection rate.

B. To determine cumulative oil production in Fula-Central field.

C. To help in decision making of implementing of steam flooding technique on Fula-Central

1.3. Introducing to the STARS Technologies Launcher:

Many simulators and soft ware used to create models that simulate the performance of the fields. CMG, Eclipse are the most implemented softwares in the oil industry when considering enhanced oil recovery, CMG now is used over 50 countries and about 550 international companies.

The CMG technologies launcher (“launcher”) is project management application that allows keeping track of CMG simulations and launching jobs from one location. Using launcher, to set up and manage folders projects on computer that contains related simulation files. From these projects, may start builder to set up dataset, start simulator job to compute your result and load result graph or result 3D to analyze your results.

To use CMG Technologies Launcher for thermal simulation jobs it needs to deal with launcher contain such as builder and stars simulator , builder is a MS-Windows based software tool that can be used to create simulation input files (dataset) for CMG simulators. All three CMG simulators, IMEX, GEM and STARS, are supported by Builder. 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. In addition, it allows visualization and data checking before running a simulation.

STARS is CMG's new generation advance processes reservoir simulator which include options such as chemical/polymer flooding, thermal applications, steam injection, horizontal wells, dual porosity/permeability, directional permeability, flexible grids, fire flood, and many more Steam cycling

Steam with additives, dry and wet combustion, along with many type of chemical additive process, using a wide range of grid and porosity models in both field a laboratory scale. In this thesis, STARS 2008.10 is use as numerical simulator.

1.4. Thesis Outlines:

Chapter one in this research is general introduction about the oil recovery and also includes problem statement, objectives and methodology of the research. Chapter two includes literature review. Chapter three about the methodology used to predict performance of steam injection to recover the oil. Chapter four is the application of the method to predict the performance, analysis and discussion of the results. In chapter five recommendation has provided.

2. Literature Review and Theoretical Background:

2.1. Literature Review:

In 1961 estimated laboratory studies of oil recovery from a petroleum reservoir by steam injection. They studied the recovery of oil by cold water, hot water and steam injection. Different cylindrical cores of several sizes with different oils were used. Different cell dimensions with different permeability were studied. They found that both hot water injection and steam injection recover more oil than ordinary water flood.

Mr. Homoyoni in 1961 established a paper of "enhanced oil recovery using steam injection" in school of chemical and petroleum engineering at Shiraz University; he explained the need of using thermal oil recovery techniques to the cold and immobile viscous crude. This resulted in higher oil recovery compared to the ordinary water flooding.

Cycling steam injection project has been applied to many fields such like Yorba Linda 1971 with recovery about 35% of the oil in place and Tia Juana with recovery about 18%, conversion of this project to steam flooding was conducted at an optimum time, based on heat communication in the reservoir. The steam recovery has been reported as 45% to 55% foe both fields.

A feasibility study made by bagheripour haghighi,m.shabaninejad,m, in 2010 to the Iranian fractured light oil reservoir, steam flooding has been simulated for the reservoir and has been compared with conventional water injection process, a sensitivity analysis has been performed in order to study the effect of important parameters. The result show that steam flooding process is likely to be profitable for this reservoir, when compared with water injection, improving the oil recovery factor by nearly 14%.

Ali Mohebbi and Nikookar in 2010 at University of Kerman, mentioned in their paper "A steam Flood Case Study On One Extra-Heavy Southwestern Iranian Oil Reservoir" at SPE conference, the continuous steam flooding has been chosen and results have been taken under discussion. In conventional steam flooding, steam is injected continuously into injection wells, the steams heats the reservoir and mobilize oil to be produced from surrounding wells, and that the key of mobilization of heavy oil is the maintenance of reservoir temperature above certain levels as dictated by viscosity-temperature relationship for any particular oil composition.

At 2011, david Society of Petroleum Engineers (SPE) held a conference at Kuala Lumpur Malaysia about enhanced oil recovery the paper “successful steam flooding project to enhance oil recovery of low permeability, light-oil water flooding reservoir” was discussed and showed that the steam flooding is commercial technology widely used in develop heavy oil reservoir after suffering a low water injection, poor sweep, and poor injector to producer communication. Steam flooding was utilized to improve the performance and enhance oil recovery. Steam flooding project shows promising result and the productivity almost tripled.

In the journal of petroleum technology (JPT), Farouq Ali had announced that steam injection is principles enhanced oil recovery method used today accounting for 90% of all oil produced by such method. Parts estimates the total worldwide oil production rate from steam is about 400,000 BOPD (6400 m3/d oil). The U.S Produces 60% of this total, Venezuela produces 35% and Canada produces 3%. Several large projects are in planning and construction all over the world.

2.2. EOR in Sudan:

Sudan has many fields containing heavy oil; those with lighter oils, which have to date been developed using cold production, are now in decline. Numerous resources of more viscous oil are still awaiting development. It is expected that heavy oil will represent about 50% of the country’s production by 2020. An operator in the country is performing reservoir studies and investigating techniques - including CSS, SAGD and in-situ combustion - focused on resources in excess of 1 billion barrels. A pilot project is currently being designed, scheduled to start operation in 2011. A Chinese-led group tested a steam-assisted recovery project in 2009-at the field of this study, the results were encouraged so now started full field implementation-. The Sudanese Oil Exploration and Production Authority (OEPA) is currently actively encouraging more operators to consider EOR projects in the Sudan to get more production (Sturat.2011) , at 2013 CSS started also in Bambo as pilot test.

2.3. Reserves:

Reserves are petroleum (crude and condensate) recoverable from known reservoirs under prevailing economics and technology. They are given by the following material balance equation:

(Present reserves) = (past reserves + additions to reserves) – (production from reserves).

There are actually several categories of reservoirs (proven, possible…etc.), which distinctions are very important to economic evaluation. Clearly, reserves can change with time because the last two terms on the right do change with time. It is in the best interests of producers to maintain reserves constant with time, or even to have them increase.

Adding to reserves:

We can add to reserves by:

A. Discovering new field.
B. Discovering new reservoirs.
C. Extending reservoirs in known field.
D. Redefining reserves because of change in economics extracting technology.

Reserves in categories A to C are added through drilling, historically the most important way to added reserves. Given the 2% annual increase in world-wide consumption and the already large consumption rate, it has become evident that reserves can maintain constant only by discovering large reservoirs. But the discovering rate of large field is declining. More importantly, the discovering rate on large depends strongly on the drilling rate. Equally important, drilling requires a substantial capital investment even after a field is discovered.

Oil recovery processes may be subdivided into three major categories primary, secondary and tertiary .the terms primary oil recovery ,secondary oil recovery and tertiary (enhanced) oil recovery are traditionally used to describe hydrocarbons recovery according to the method of production or the time at which they are obtained .in the primary process the oil is forced out of the petroleum reservoir by existing natural pressure is reduced to a point where it is no longer effective as a stress causing movement of hydrocarbons to the producing wells water or gas is injected to augment or increase the existing pressure in the reservoir conversion of some producing wells to injection wells and subsequent injection of gas or water for pressure maintenance in the reservoir has been designated as secondary oil recovery. The oil recovered by both primary and secondary processes ranges from 20 to 50% depending on oil and reservoir properties .the goal of enhanced oil recovery process is recover at least a part of the remaining oil in place.

2.4. Primary Recovery:

The efficiency of oil displacement in primary oil recovery process depends mainly on existing natural energy in the petroleum reservoir .The amount of oil that can be displaced by the natural reservoir energy associated with a reservoir varies with reservoir type. The principle source of reservoir energy these are (willhite.1986).

A. Water drive.
B. Solution gas drive.
C. Rock fluid Expansion.
D. Gas cap drive.
E. Gravity drainage.
F. Combination drive.

2.4.1. Water Drive:

A water drive reservoir has a hydraulic connection between the reservoir and porous water saturation called aquifer may underlie all or part of the reservoir, which expands when the oil is produced creating a natural water flood at the reservoir.

2.4.2. Solution Gas Drive:

Crude oil under high pressure may contain large amounts of dissolved gas. When the reservoir pressure is reduced as fluids are withdrawn, gas come out of solution and displaces oil from the reservoir, on the order of 10% to 30% (OOIP). Recovery is low because the gas is more mobile than the oil phase in the reservoir.

2.4.3 Rock and Fluid Expansion:

When the oil is highly under saturated, much of the reservoir energy is stored in the form of fluid and rock compressibility. Pressure declines rapidly as fluid are withdrawn from an under saturated reservoir until the bubble point is reached. Then, solution gas drive becomes the source of energy for fluid displacement.

2.4.4. Gas-Cap Drive:

When a reservoir has a large gas cap, there may be a large amount of energy stored in the form of compressed gas. The gas cap expands as fluids are withdrawn from the- reservoir displacing the oil by a gas drive assisted by gravity drainage, Figure (1.2) illustrate gas-cap drive.

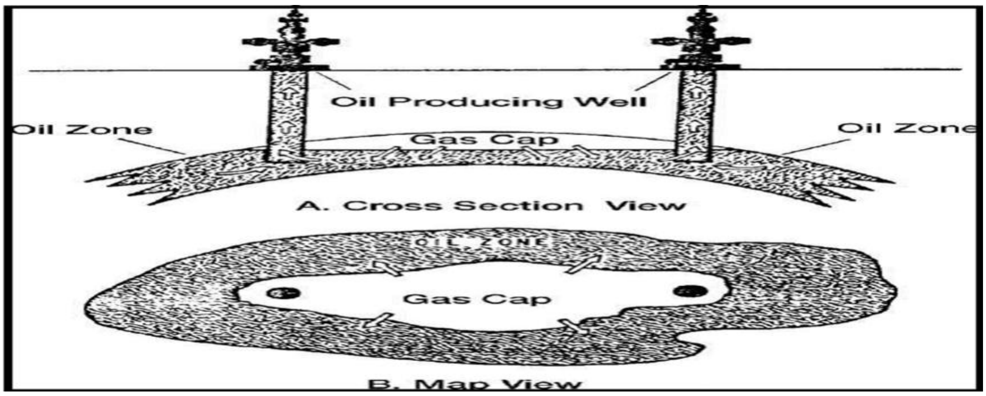

Fig.2.1: Gas Cap Drive Schematic

2.4.5. Gravity drainage:

Gravity drainage is slow process because gas must migrate up structure or the top of the formation to fill the space formerly occupied by oil. Gas migration is fast relative to oil drainage.

2.5. Secondary Recovery:

Secondary recovery methods are defined as processes that are used to increase hydrocarbon recovery from the reservoir beyond primary recovery. Typical secondary recovery methods are considered to be intervention methods implemented during the primary recovery period to improve low hydrocarbon recovery from the primary process.

Secondary oil recovery refers to additional recovery those results from conventional methods of water injection and immiscible gas injection. Usually, the selected secondary recovery process follows the primary recovery but it can also be conducted Concurrently with the primary recovery. Water flooding is perhaps the most common method of secondary recovery. In the water flooding process, water is injected into the reservoir through injection wells.

The water drives oil through the reservoir rocks toward the producing well. To improve the efficiency of the water flooding process, some chemicals are added. The decrease of the pressure in the reservoir during primary oil recovery may be stored partially by injecting gas in the reservoir to achieve a high pressure. Gas injection methods can be subdivided into three categories, pressure restoration, pressure maintenance, and gas-drive, depending upon the way in which the gas is injected into the productive formation through one well while other wells are closed until the pressure is restored through the reservoir.

This may take as long as year or more .when the desired reservoir pressure is reached, gas injection is stopped and all of the wells start producing. In the pressure maintenance method, gas from producing well is recompressed and injected into the selected wells before the reservoir pressure is totally exhausted. In this method some wells are operated as injection wells. Whereas other wells operated as production wells. In the gas-drive method gas is injected into the reservoir under pressure and a continuous gas flow is maintained from injection wells to the producing wells. The moving gas drives the oil in the form of a film, or gas bubbles a head of the gas toward the producing well .after primary oil recovery. The pressure of the depleted reservoirs can be restored by water flooding.

2.6. Tertiary recovery:

Tertiary (enhanced) oil recovery is additional recover over and above what could be recovered by primary and secondary recovery methods .Enhanced oil recovery (EOR) is oil recovered by the injecting of the materials not normally present in the reservoir. This definition covers all modes of oil recovery process and most oil recovery agent. Various methods of enhanced oil recovery process (EOR) are essentially designed to recover oil, commonly described as residual. Oil left in the reservoir after both primary and secondary recovery methods have been implemented to their respective economic limits. The different type of oil recovery methods and their division during the reservoir life stages has been illustrated in diagram (1.3).

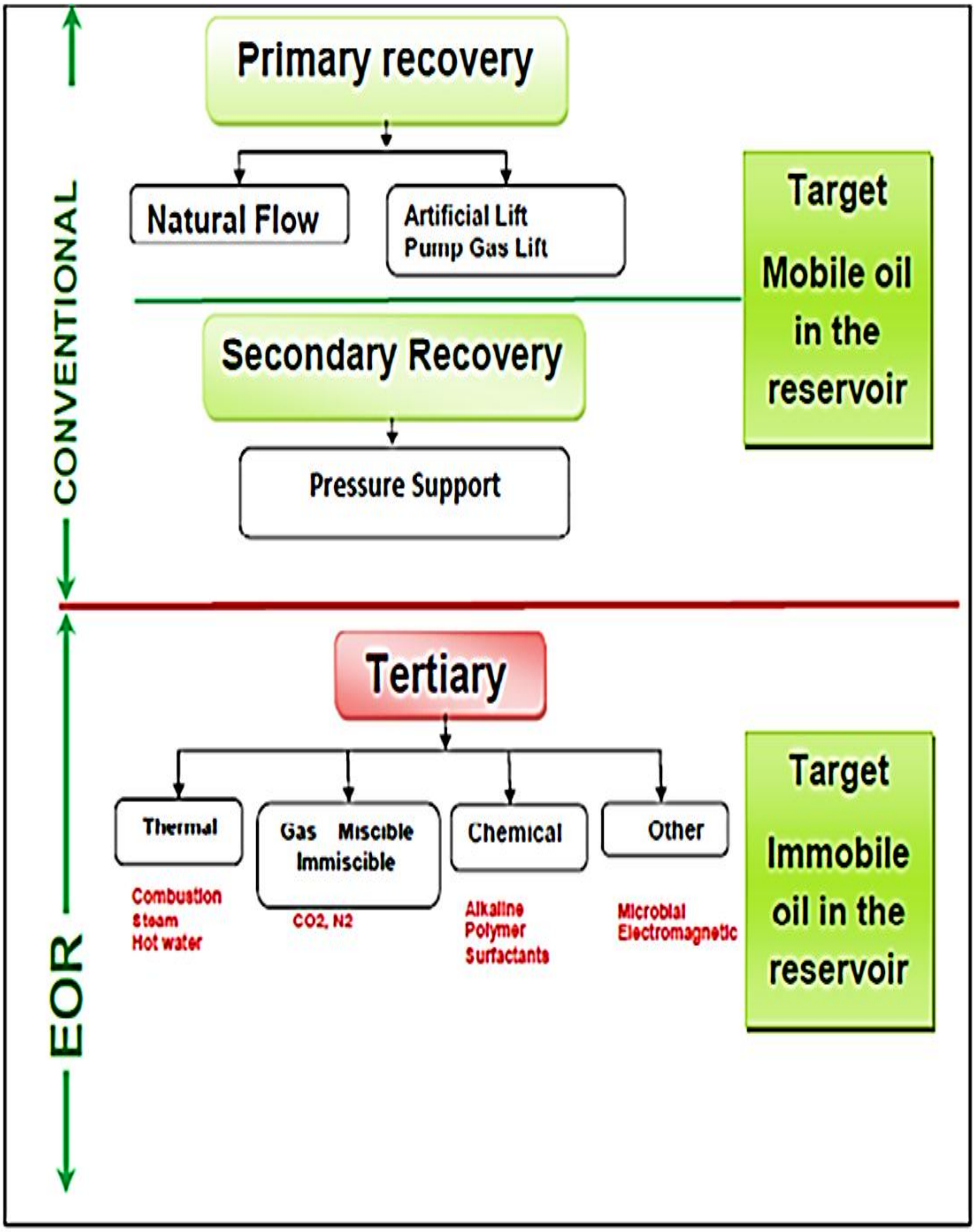

Fig.2.2: Enhanced Oil Recovery Subdivided According to the Target Oil (SPE, 84908)

2.7. Understanding Unconventional Oil:

2.7.1 Unconventional Oil Definitions and Properties:

It is the oil that is highly viscous, and cannot easily flow to production wells under normal reservoir conditions. 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 an API gravity less than 20°. Physical properties that differ between heavy crude oils and lighter grades include higher viscosity and specific gravity, as well as heavier molecular composition.

In 2010, the World Energy Council defined extra heavy oil as crude oil having a gravity of less than 10° and a reservoir viscosity of no more than 10,000 centipoises. When reservoir viscosity measurements are not available, extra-heavy oil is considered by the WEC to have a lower limit of 4°API. (i.e. with density greater than 1000 kg/m^3 or, equivalently, a specific gravity greater than 1 and a reservoir viscosity of no more than 10,000 centipoises). Heavy oils and asphalt are dense non-aqueous phase liquids they have a "low solubility and are with viscosity lower and density higher than water.

Heavy crude oil is closely related to natural bitumen from oil. Petroleum geologists categorize bitumen from oil sands as ‘extra-heavy oil’ due to its density of less than 10° °API. Bitumen is the heaviest, thickest form of petroleum. According to the U.S. Geological Survey( ), bitumen is further distinguished as extra-heavy oil with a higher viscosity (i.e., resistance to flow): “Natural bitumen, also called tar sands or oil sands, shares the attributes of heavy oil but is yet more dense and viscous.

Natural bitumen is oil having a viscosity greater than 10,000Cp, table (1.1) below represent types of oil according to density and viscosity. Natural bitumen (often called tar sands or oil sands) and heavy oil differ from light oils by their high viscosity (resistance to flow) at reservoir temperatures, high density (low API gravity), and significant contents of nitrogen, oxygen, and sulfur compounds and heavy-metal contaminants. They resemble the residuum from the refining of light oil, Figure (1.4) below represent variety of viscous oil.

Table2.1: Conventional Oil, Heavy Oil, Extra Heavy Oil and Natural Bitumen (Autumn, 2002).

Type of Oil	Density Range, Kg/m3	Viscosity Range, Pa.s
Conventional Crude Oil	< 934	<0.05
Heavy Oil	934 – 1000	0.05 – 5
Extra Heavy Oil	1000 – 1044	5 – 10
Natural Bitumen	>1044	>10

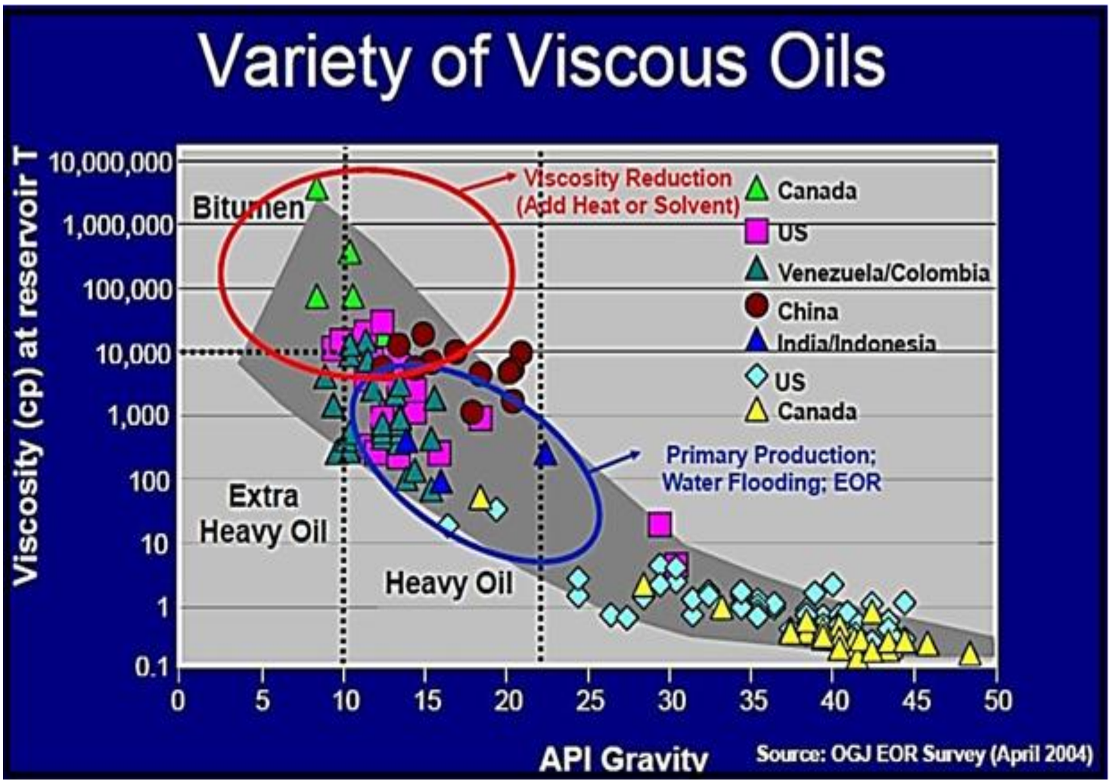

Fig.2.3: Variety of Viscous Oils With API Gravity

(OGJ EOR Survey, April2004)

Most heavy oil is found at the margins of geologic basins and is thought to be the residue of formerly light oil that has lost its light-molecular-weight components through degradation by bacteria, water-washing, and evaporation. Conventional heavy oil and bitumen differ in the degree by which they have been degraded from the original crude oil by bacteria and erosion. Often, bitumen is more viscous than cold molasses and does not flow at ambient conditions;Figure (1.5) shows some crude oil types.

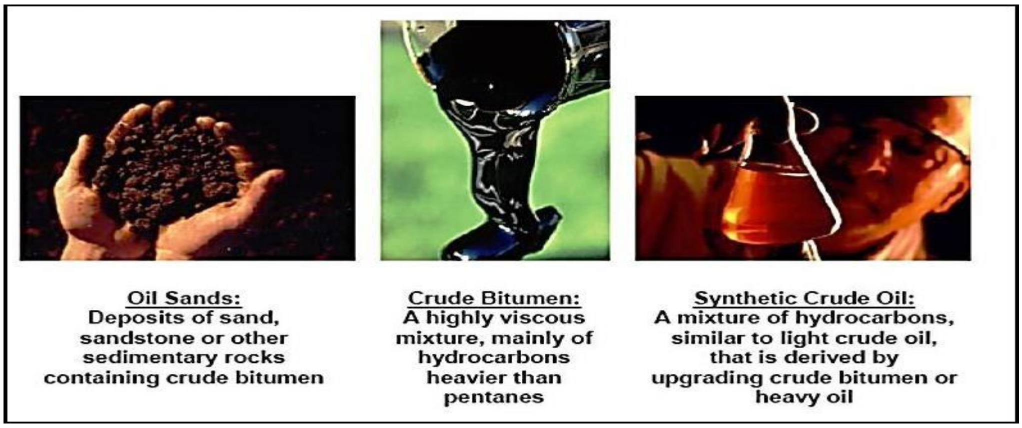

Fig.2.4: Oil Sand, Crude Bitumen and Synthetic Crude Oil

(Source: Strategy West Inc. (Nov.2007))

2.7.2. Heavy Oil Importance:

Conventional oil production has peaked and is now on a terminal, long-run global decline. However, contrary to conventional wisdom, which many embraced during back-to-back oil crises in the 1970s, oil is not running out. It is, instead, changing form (geographically, geologically, chemically, and economical). These dynamics point to a new reality. World is approaching the end of easily accessible, relatively homogeneous oil, and many experts claim that the era of cheap oil may also be ending.

The realignment of world oil prices upward, settling above $100 per barrel over the past year, is spurring a transformation of oil technology and markets. The oil industry is posting substantial profits, reinvesting significant capital, and gaining new capacities to identify, probe, recover, and process oils that were once unknown, inaccessible, unmanageable, or uneconomical. As such, oil corporations and national oil companies are developing a wide array of new oils worldwide.

Though they have been recognized as new sources of petroleum, according to the U.S. Energy Department, unconventional oils have yet to be strictly defined. In reality, new oils are emerging along a continuum from conventional crudes to transitional oils to unconventional oils, with their classification varying according to the ease of extraction and processing.

Many new breeds of petroleum fuels are nothing like conventional oil. Unconventional oils tend to be heavy, complex, carbon laden, and locked up deep in the earth, tightly trapped between or bound to sand, tar, and rock. Unconventional oils are nature's own carbon-capture and storage device, so when they are tapped, we risk breaking open this natural carbon-fixing system.

World Energy Outlook, projects that by 2035 several new oil types will replace the loss of nearly one-half of global conventional oil production. ExxonMobil concurs. Conventional crude is projected to account for only 60 percent of liquid-fuel supply by 2040, down from 80 percent in 2010, as shown in Figure (1.6).An array of new oils (oil sands, tight oil, new heavy oils, deep water oil, and eventually oil shale) is projected to fill the gap, as demand for liquid fuels continues to rise.

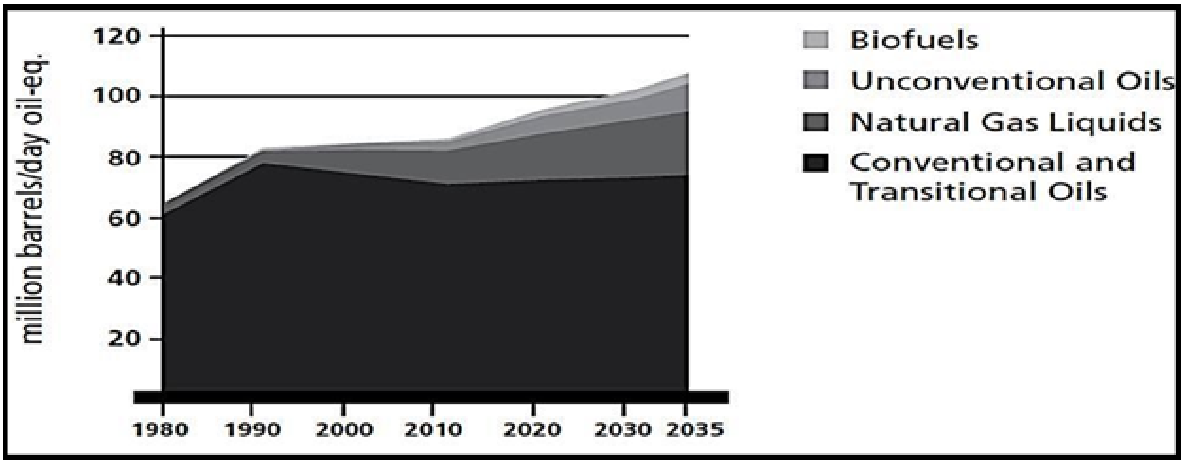

Fig.2.5: Rate of Liquid-Fuel Supply by Various Types of Oil, (International Energy Agency (IEA), "World Energy Outlook 2011")

2.7.3 Heavy oil resources:

According to World Resources Institute, concentrations of remarkable quantities of heavy oil and oil sands are found in Canada and Venezuela. The U.S. Energy Information Administration (EIA) reported in 2001 that the largest reserves of heavy crude oil in the world were located north of the Orinoco river 270-mile long by 40-

mile wide Orinoco Belt in eastern Venezuela. At that time Venezuela began authorizing "joint ventures to upgrade the extra-heavy crude resources. Petroleum de Venezuela, S.A. (PDVSA) at that time estimated that there were 270 billion barrels of recoverable reserves in the area, the same amount as the conventional oil reserves of Saudi Arabia. The Orinoco Belt in Venezuela is sometimes described as oil sands, but these deposits are non-bituminous, falling instead into the category of heavy or extra-heavy oil due to their lower viscosity. Natural bitumen and extra-heavy oil differ in the degree by which they have been degraded from the original conventional oils by bacteria. According to the WEC, extra-heavy oil has "a gravity of less than 10° °API and a reservoir viscosity of no more than 10,000 centipoise. Thirty or more countries are known to have reserves. Generally according to many estimations conventional oil, heavy oil, extra heavy oil and bitumen form 30%, 15%, 30% and 25% of proven oil reserve around the entire world respectively as shown in Figure (1.7).

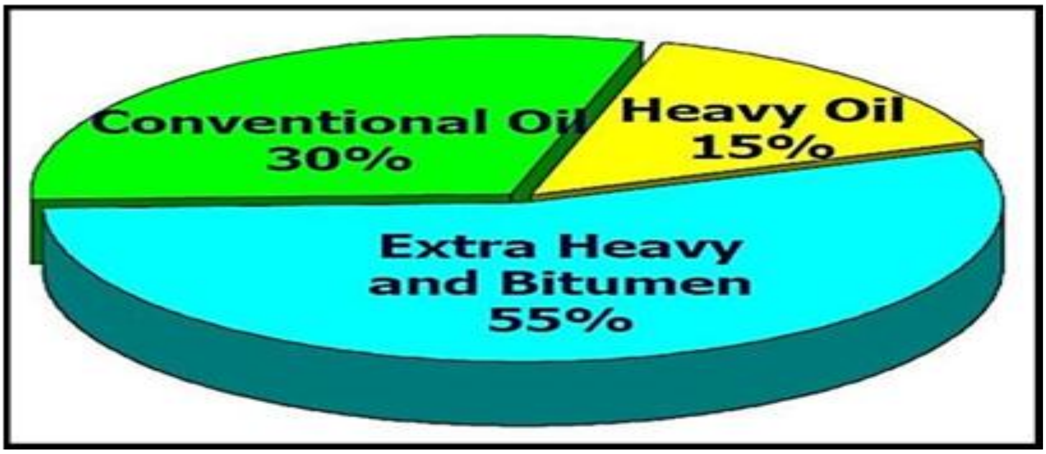

Fig.2.6: Percentage of Oil Types of World Proven Reserves (Strategy West Inc. (Nov.2007))

2.7.4. Changing Geography of Oil:

Not only is the makeup of oil drastically changing, so too is its political geography. As shown in Figure (1.8), which depicts the projected geographies of new oil (and oil derivatives) based on current knowledge, the world's oil supplies will no longer remain concentrated in the Middle East, Africa, and Russia. Twenty-first-century oil reserves will be found in the Western Hemisphere and, over the long term, they will be unearthed globally. The International Energy Agency projects that North

America is home to the world's largest stores of unconventional oils(extra-heavy oil, bitumen, and kerogen)with estimates of 50 percent more unconventional oil than total conventional reserves in the Middle East.10 Eastern Europe and Eurasia, followed by Latin America, have also been identified as part of the new geography of oil.

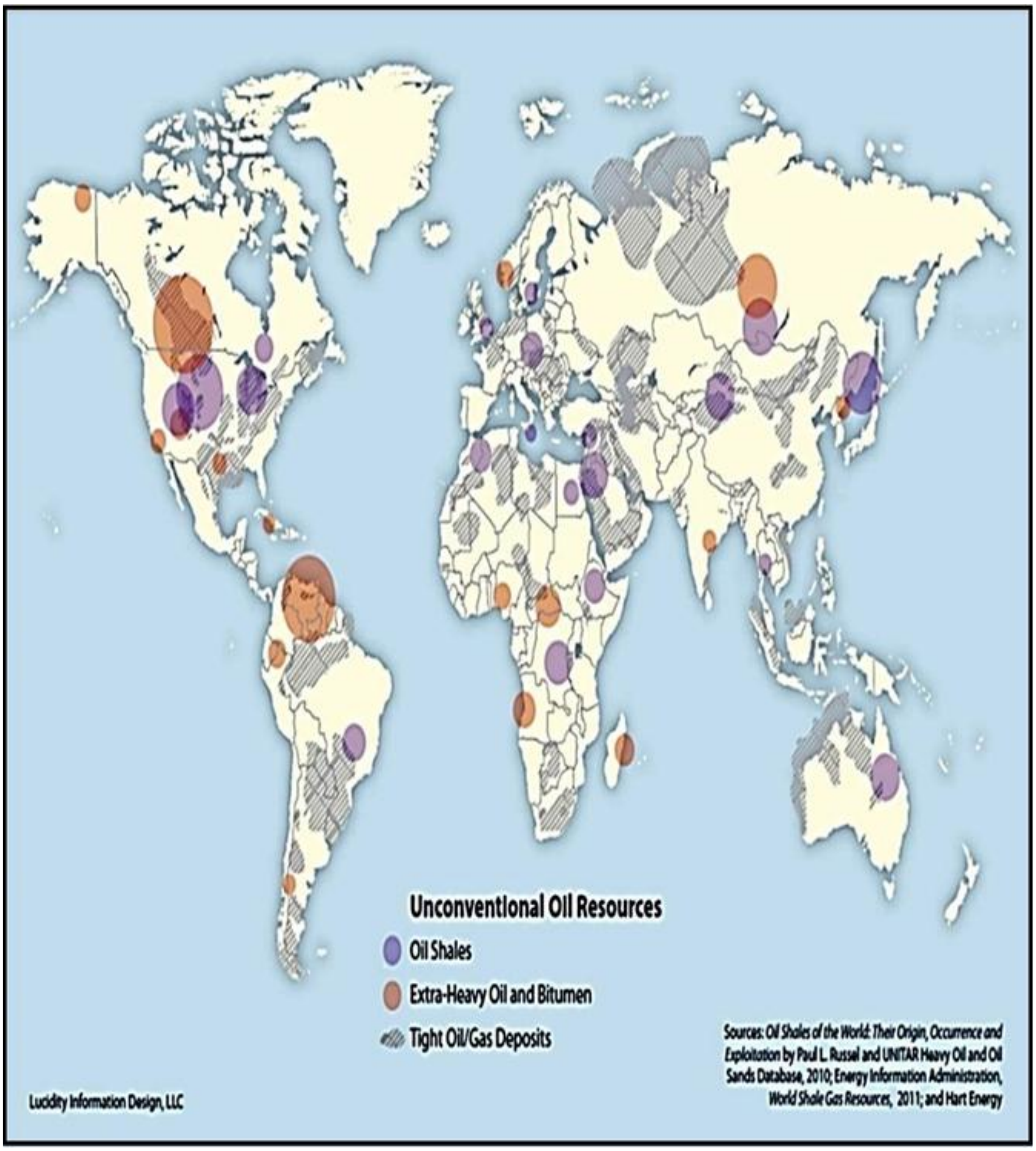

Fig.2.7: New Geographies of Unconventional Oils,(Sources: Oil Shale's of the World: Their Origin, Occurrence and Exploitation by Paul L. Russell and UNITAR Heavy Oil and Oil Sands Database, 2010; Energy Information Administration, World Shale Gas Resources, 2011; and Hart Energy.

2.7.5.Heavy Oil in Sudan:

According to Oil and Gas Journal (OGJ), Sudan contained proven oil reserves of five billion barrels as of January 2007 up from an estimated 563 million barrels of proven oil reserves in 2006. The majority of proven reserves are located in the south in the Muglad and Melut basins. It is estimated that vast potential reserves are held in northwest Sudan, the Blue Nile basin, and the Red Sea area in eastern Sudan, after separation of south Sudan there's no updated data about heavy oil reserve in Sudan as shown in Figure (1.9).

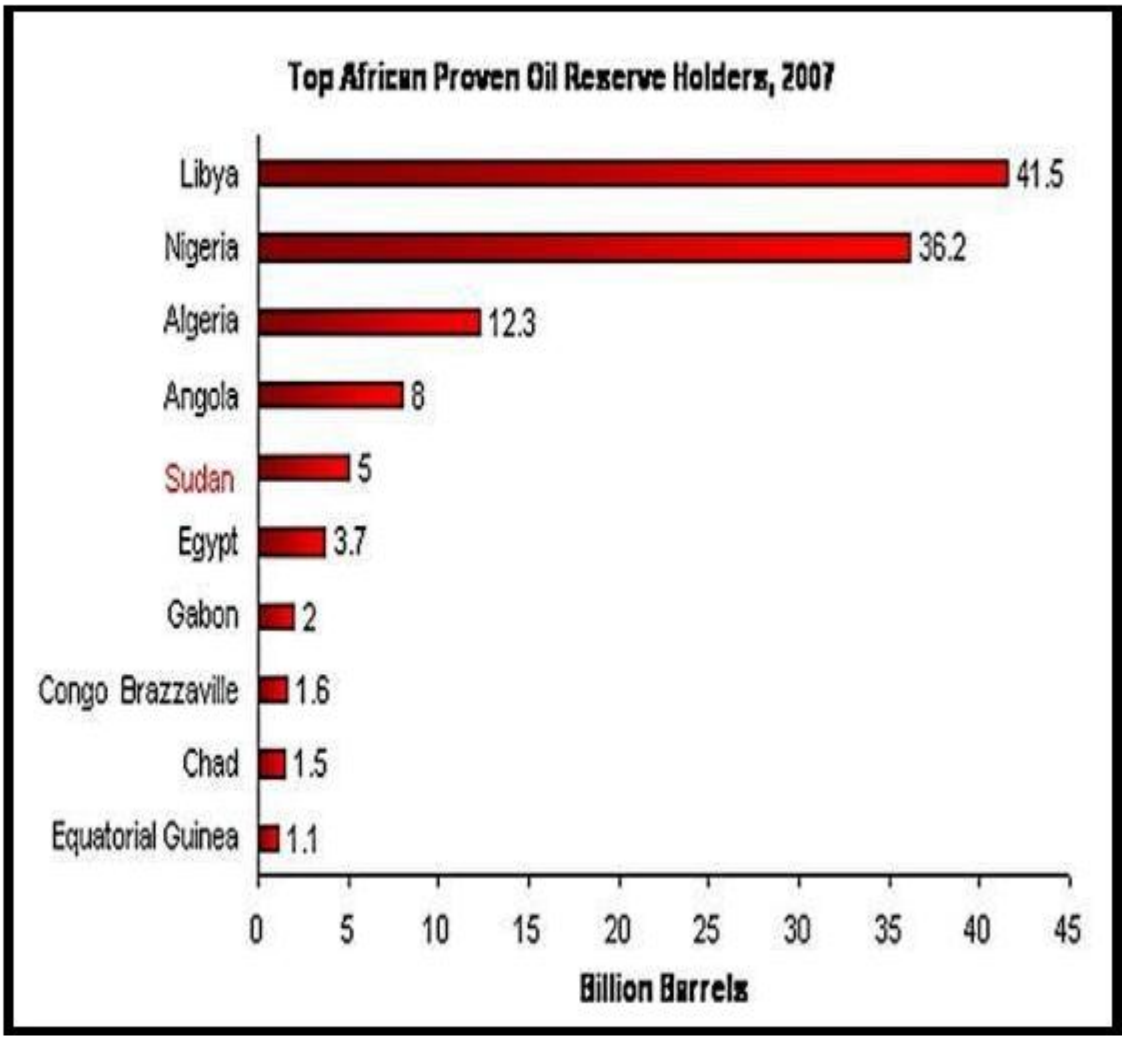

Fig.2.8: Top African Proven Oil Reserve Holder (oil and Gas Journal, 2007)

2.8. Enhanced oil recovery (EOR):

2.8.1. Definitions and Methods:

Enhanced oil recovery is defined a collection of general methods, each with its own unique capability to extract the most oil from particular reservoir. Each has been investigated rather thoroughly both from theoretical and laboratory perspective, as well as in the field. (Duraya B.A, 2007).

EOR is a term applied to methods used for recovering oil from petroleum reservoir beyond that recoverable by primary and secondary methods.

EOR also defined as synonymous with tertiary recovery. Improved Oil Recovery (IOR) and Advance Oil Recovery (AOR) have a similar meaning, except they also apply to primary and secondary methods, and sometimes EOR methods can be used earlier in the sequence, but now EOR is generally considered to follow water flooding.

According to the above definitions, clearly appear that the difference between EOR and IOR is that IOR includes all EOR process plus water flooding. Lastly, the wide definition of enhanced oil recovery (EOR) is oil recovery by the injection of materials not normally percent in the reservoir. This definition covers all modes of oil recovery processes (derive, push-pull, and well treatments) and most oil recovery agents.

In this research the main focusing will be on thermal recovery (TEOR) and more detailed about SF (steam flooding), TEOR is a part of tertiary processes defined as “any process in which heat is introduced intentionally into a subsurface accumulation of organic compounds for the purpose of recovering fuels through wells.” After hot water and heated gasses have been applied, the most common and effective vehicle used to inject heat is saturated steam.

Enhanced oil recovery can be divided into three major categories as it is illustrated in Figure (1.11) these categories are:

A. Thermal Recovery Methods:

- Steam Flooding (SF).
- In-situ Combustion
- Cycle Steam Injection (CSS).
- Steam Assisi at Gravity Drainage (SAGD).

B. Chemical Recovery Methods:

- Polymer Flooding.
- Surfactant Flooding.
- Alkaline Flooding.
- Alkaline Surfactant Polymer Flooding (ASP).

C. Miscible Gas Recovery Methods:

- Carbone dioxide injection (CO_2).
- Nitrogen injection (N_2).
- Hydrogen injection (H_2).
- Hydrocarbon gases.

Enhanced oil recovery (EOR) processes include all methods that use external sources of energy and/or material to recover oil that cannot be produced, economically by conventional means, Figure(1.10) shown EOR production rate of total number of projects around the world According to the used method.

The goal of any enhanced oil recovery process is to mobilize "remaining" oil. This is achieved by enhancing oil displacement and volumetric sweep efficiencies.

Oil displacement efficiency is improved by reducing oil viscosity (e.g., thermal floods) or by reducing capillary forces or interfacial tension (e.g., miscible floods).

Volumetric sweep efficiency is improved by developing a more favorable mobility ratio between the injected and the remaining oil -in -place (e.g., polymer floods, water alternating-gas processes).

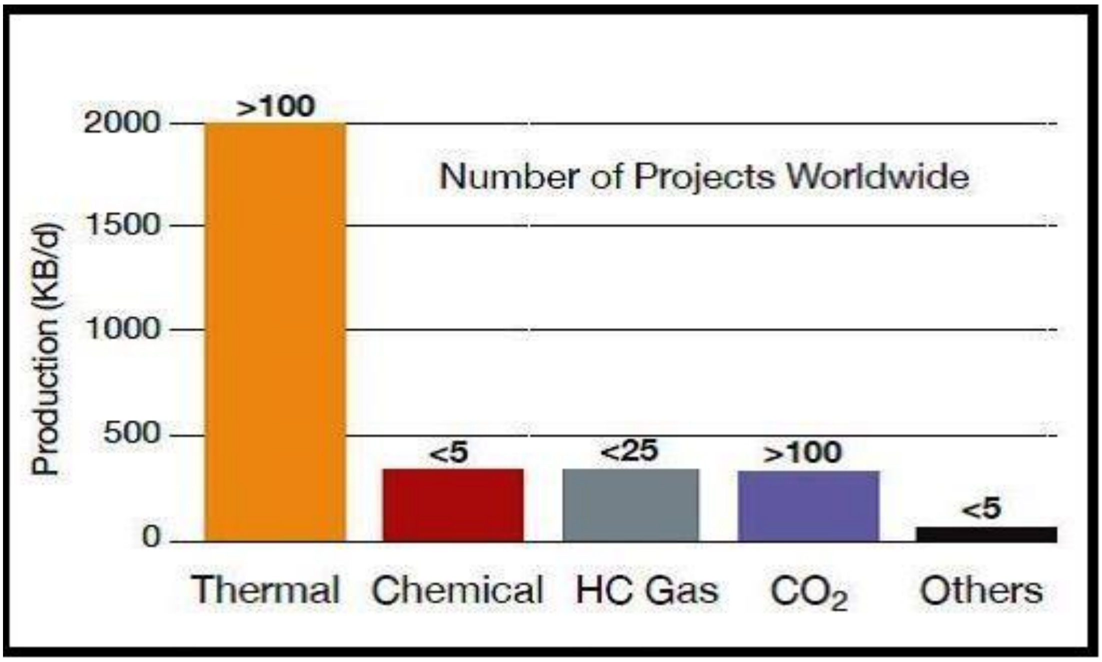

Fig.2.9: EOR Production Rate around the World According to the Used Method (Oil and Gas Journal, SPE, 2010)

2.8.2. EOR objectives and goals:

The objectives of EOR are to increase the pressure difference between the reservoir and production wells, or to increase the mobility of the oil by reduction of the oil viscosity decrease of the interfacial tensions between the displacing fluids and oil.

2.9. Thermal recovery methods:

Thermal recovery pertains to oil recovery processes in which heat plays a principal role. The most widely used thermal techniques are in-situ combustion, continuous injection of hot fluids such as steam, water or gases, and cyclic operations such as steam soaking.

Heat is applied to the crude to:

A. Reduce the viscosity of the crude.

B. Activate a solution gas drive in some instances.

C. Result in thermal expansion of the oil and hence increased relative permeability.

D. Create distillation and, in some cases, thermal cracking of the oil.

2.9.1. Cyclic Steam Injection:

It also called Steam Stimulation, Steam Soak or Huff and Puff. In this process, steam is injected down a producing well to heat up the area around the well bore and increase recovery of the oil immediately adjacent to the well. After injection of short period, the well is placed back on production. This is essentially a well bore stimulation technique, each well responding independently, the concept of CSI showed in Figure(1.11) below:

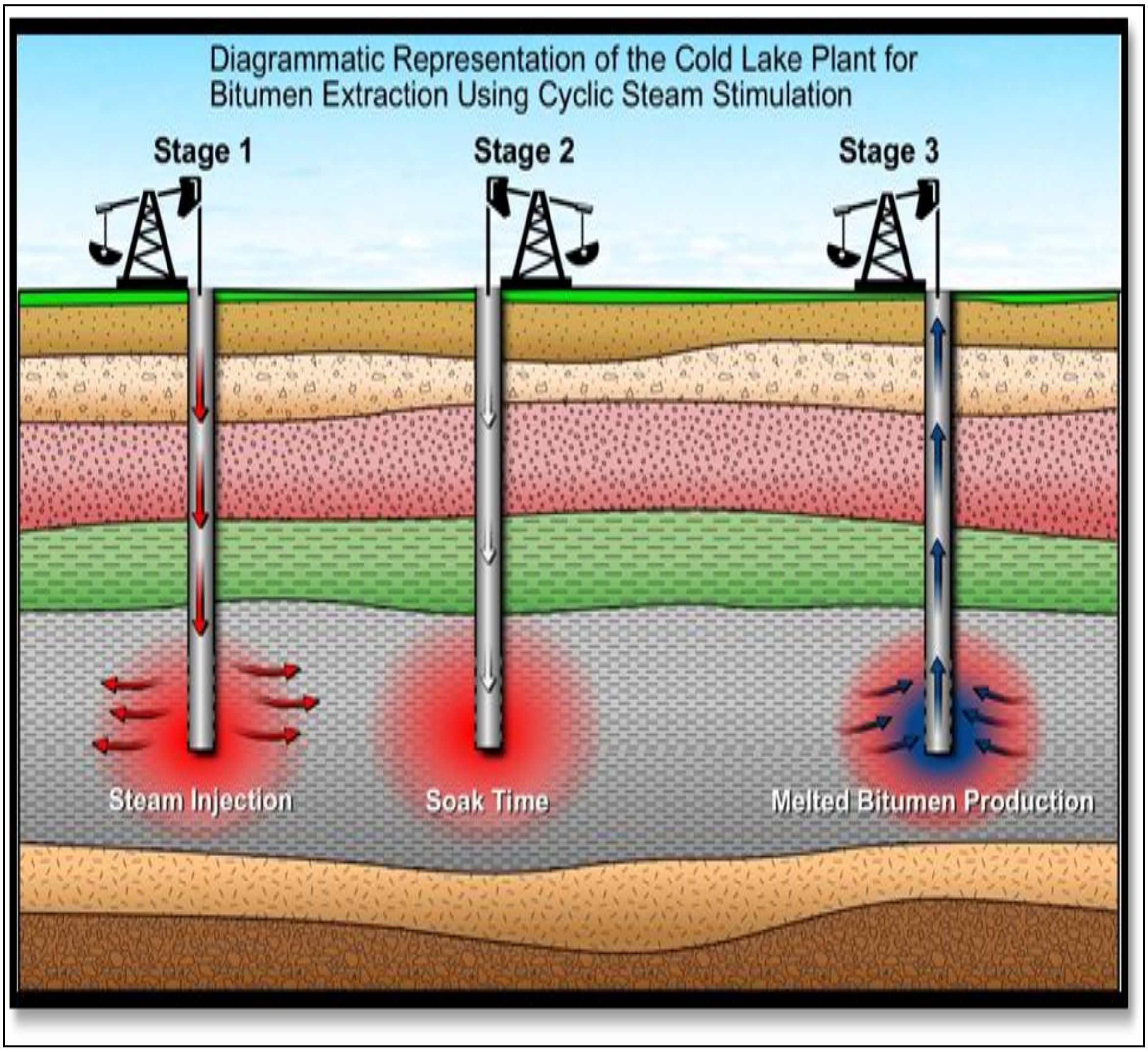

Fig.2.10: Steam Stimulation, Steam Soak or Huff and Puff

(S.Desouky, 2010)

2.9.2. In-Situ Combustion:

It also called fire-flood; this process involves in-situ combustion of portions of the oil. Air is pumped into the reservoir which either self-ignites or is ignited, depending on reservoir temperature and composition.

Heat and gases from the combustion pressurize the reservoir, and decrease viscosity both by heating and cracking. Often water is injected behind the fire front.

Mechanism :

In-situ combustion or fire flooding involves starting a fire in the reservoir and injecting air to sustain the burning of some of the crude oil.

The injection mechanism is usually done under high pressure and temperature. Air or any gas contains oxygen is injected in the reservoir to start the ignition.Then followed by continuous injection of air to sustain the burning process in addition to push the combustion front towards the producer, Figure(1.12) illustrate in-situ process

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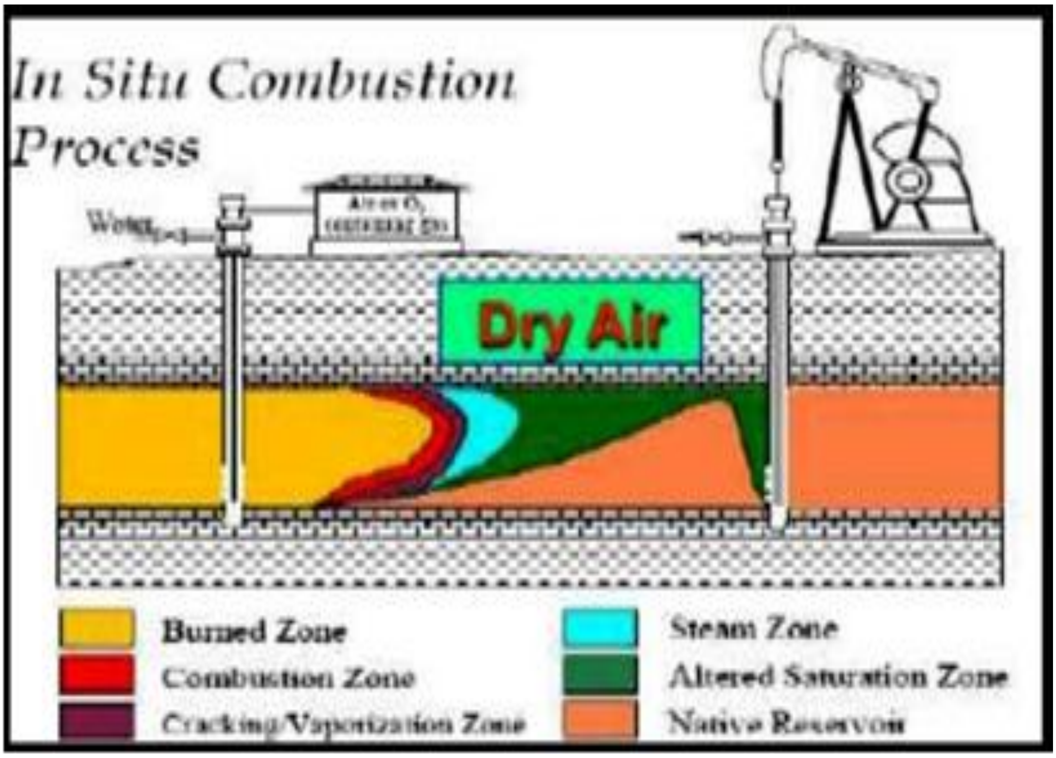

Fig.2.11: In-situ Combustion Process (Desouky, 2011)

2.9.3. Steam Assisted Gravity Drainage (SAGD):

SAGD means steam assisted gravity drainage the process implemented by drilling two horizontal wells parallel to each other, one for the injection (upper) of steam creates a steam chamber from which oil can drain towards the producer (lower).The oil which is normally immobile is heated, allowing gravity drainage towards the lower producer at the bottom.

There are two factors are controlling the mechanism, steam effect in addition to gravity effect which helps the steam to flow from the injector towards the producer.

The most typical application is as follows: Two wells are drilled, both extended in a horizontal direction with the producer being parallel to and vertically below the injector.Steam is injected into the injector (upper well), heated oil drains by gravity towards the producer, as illustrated in Figure (1.13).

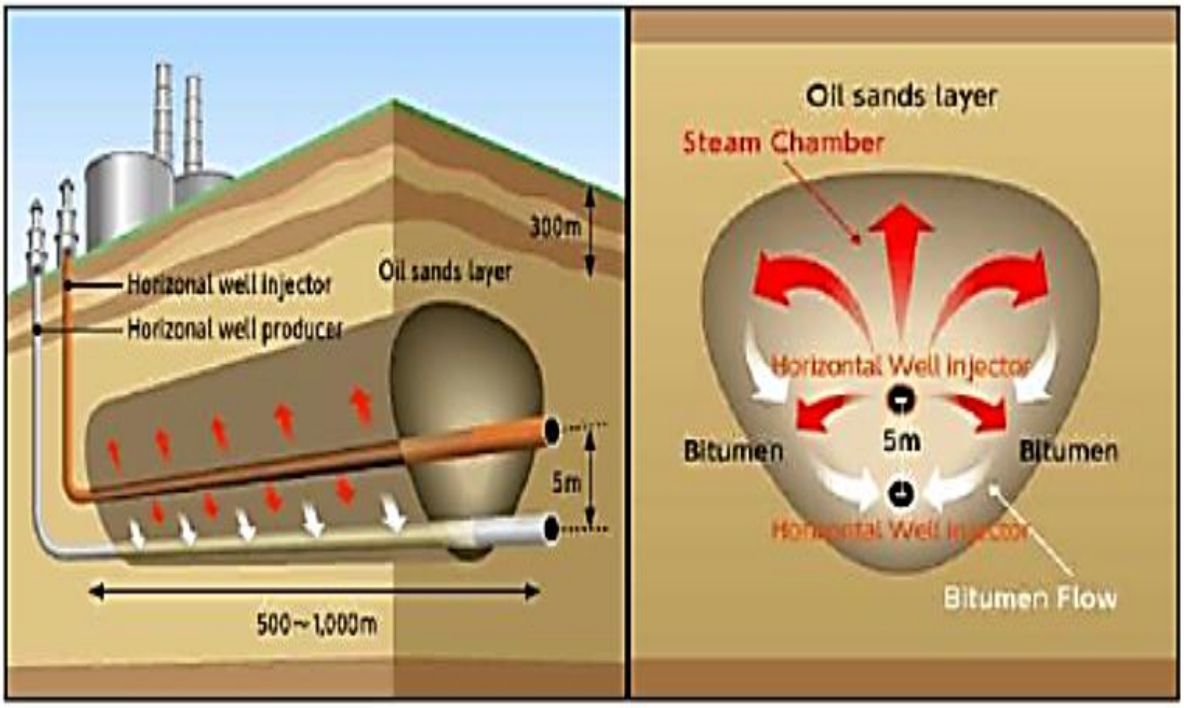

Fig.2.12: SAGD Process (Desouky, 2010)

2.9.4. Steam flooding:

The primary function of thermal recovery methods is to reduce the viscosity of the oil in place. In this process, many reservoir volumes of hot water, steam or air injected in the reservoir, which further enhances the driving forces, and the trapped oil becomes mobile.

Steam injection is currently the principal enhanced oil recovery method. The main advantage of steam injection over the other enhanced oil recovery methods is that steam can be applied to a wide variety of reservoirs. Two limiting factors are: depth (less than 5000ft.) and reservoir thickness (greater than 10 ft.). The depth limitation is imposed by the critical pressure of steam (3202 Pisa); the reservoir thickness is determined by the rate of heat loss to base and cap rock. Other reservoir parameters beneficial to steam injection are:

- **A.** Oil gravity above 50 md.
- **B.** Oil viscosity between 100-10000 cp at reservoir temperature.
- **C.** Permeability above 50 md.
- **D.** Porosity above 25% .however, this parameter should be considered as guidelines only.

Steam and water are both excellent heat carriers, but the heat content of atom mass of steam is much higher than that of water at the same temperature and pressure. The heat content of one pound of water at the same temperature and pressure is only 308btu. When the relative permeability to steam is considered, there are instances when there is a better carrier of heat than steam on a volumetric basis, but for a given amount of heat, steam introduces much less water into the formation. As a result less water is produced with the oil, and the less water produced, the more heat remains in the formation.

Hot water injection is the most basic type of thermal recovery. With fewest equipment changes, water flooding can be extended to thermal technique by heating the injected. Water recovery is increased by improved sweep efficiency and thermal expansion of crude.

Hot water injection may be preferred in shallow reservoirs containing oils in the viscosity range of 100-1000cp, but because of the excessive heat losses in surface transmission, wellbore and reservoir rock, steam injection is generally preferred. Furthermore, field tests of hot water flooding have been hampered by viscous fingering and low volumetric sweep efficiency.

The temperature of the steam is determined by the injection pressure, but its quality is determined by the characteristics of the steam generating unit. Most units utilized in oil fields put out 80% quality steam and require very high quality feed water. This is a disadvantage, especially in areas where potable water is in short supply. The amount of water needed depends on several design performance factors, but the average oil-steam ratio is 0.2 bbl/bbl of water converted into team, Figure (1.14) illustrate the steam flooding process.

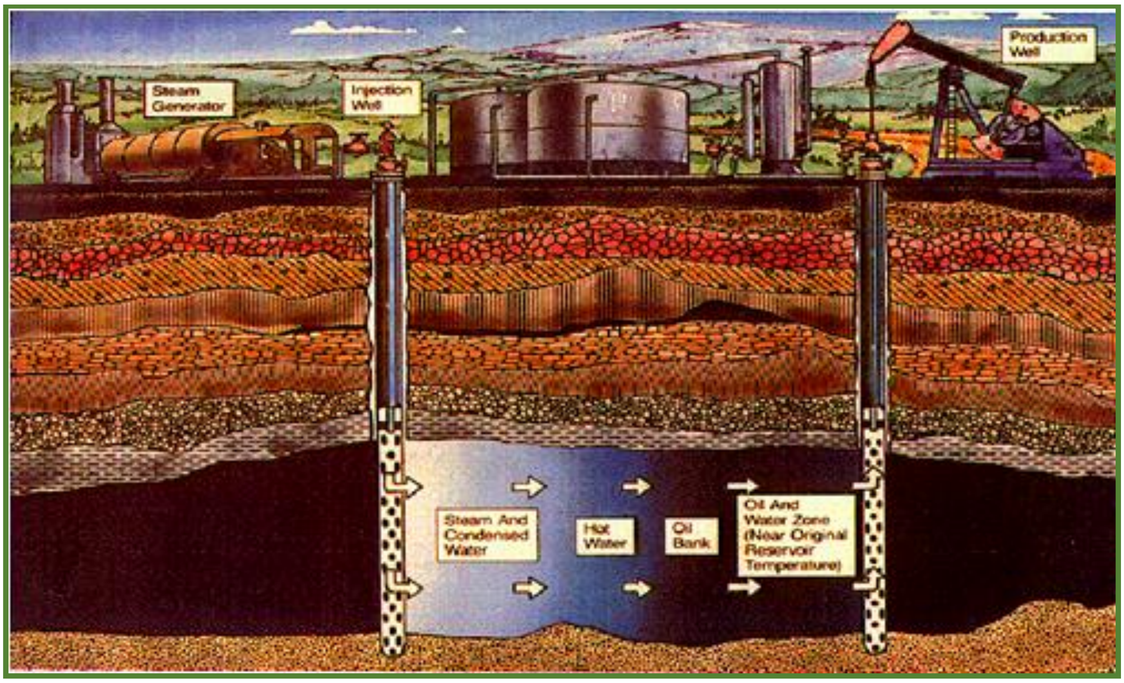

Fig.2.13: Steam Flooding Process

2.10. Flooding patterns:

One of the first steps in designing a steam flooding project is flood pattern selection. The objective is to select the proper pattern that will provide the injection fluid with the maximum possible contact with the crude oil system. This selection can be achieved by:

A. Converting existing production wells into injectors.
B. Drilling infill injection wells.

When making the selection, the following factors must be considered:

A. Reservoir heterogeneity and directional permeability.
B. Direction of formation fractures.
C. Availability of the injection fluid (gas or water).
D. Desired and anticipated flood life.
E. Maximum oil recovery.
F. Well spacing, productivity, and infectivity.

In general, the selection of a suitable flooding pattern for the reservoir depends on the number and location of existing wells. In some cases, producing wells can be converted to injection wells while in other cases it may be necessary or desirable to drill new injection wells. Essentially four types of well arrangements are used in fluid injection projects (Tarek.A, 2010):

A. Irregular injection patterns:

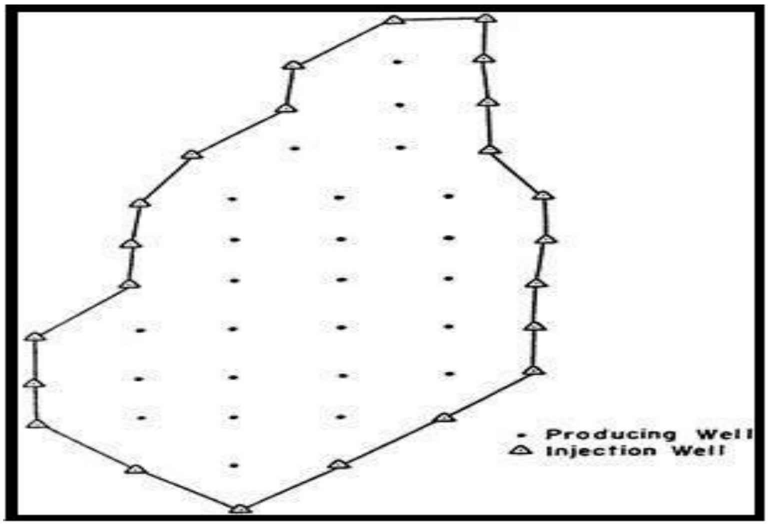

Fig.2.14: Irregular Patterns (After Cole, F., 1969).

B. Peripheral injection patterns:

In peripheral flooding, the injection wells are located at the external boundary of the reservoir and the oil is displaced toward the interior of the reservoir.

C. Regular injection patterns:

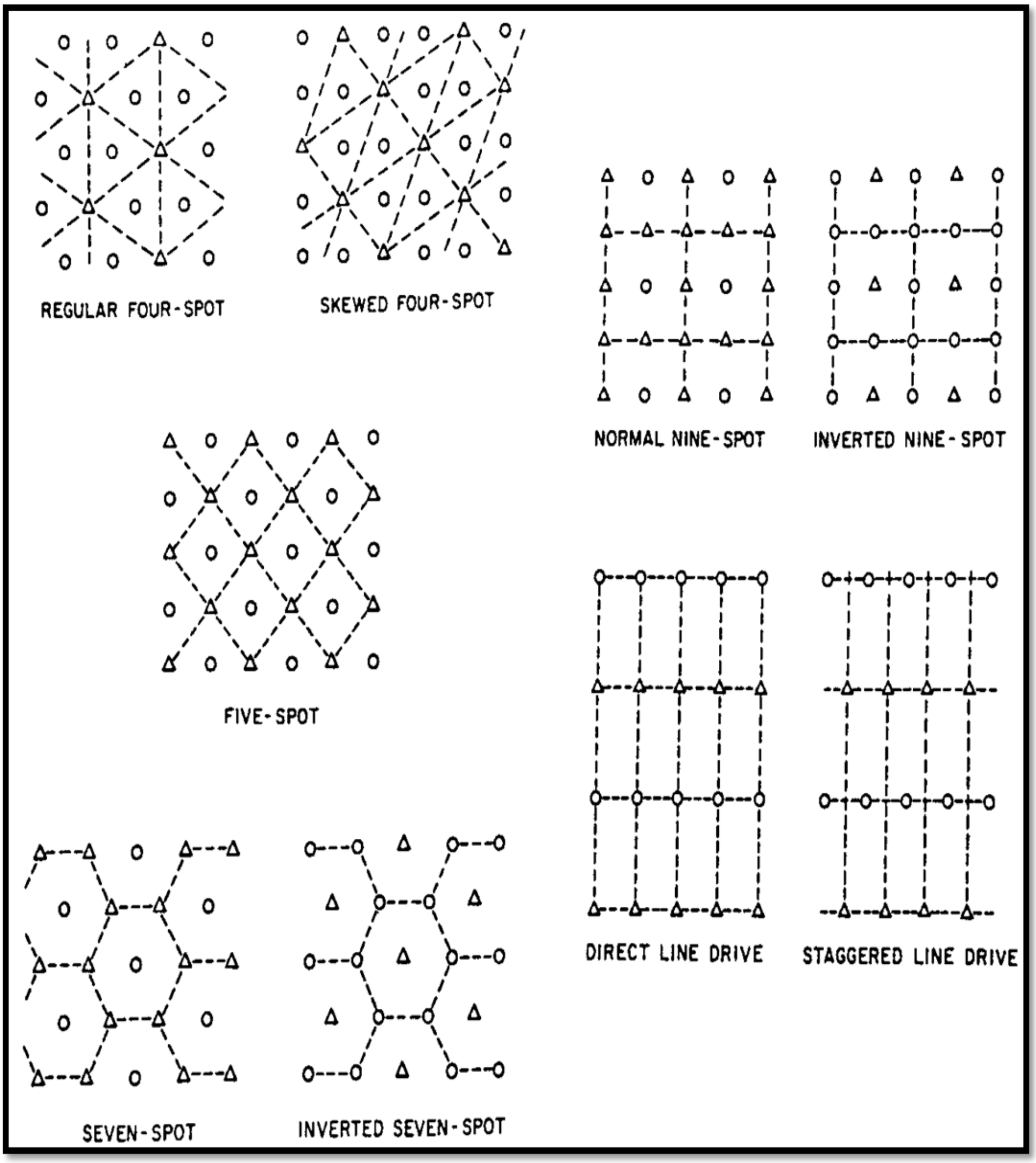

Fig.2.15: Regular Flooding Patterns (Tareq A, 2010)

D. Crystal and basal injection patterns:

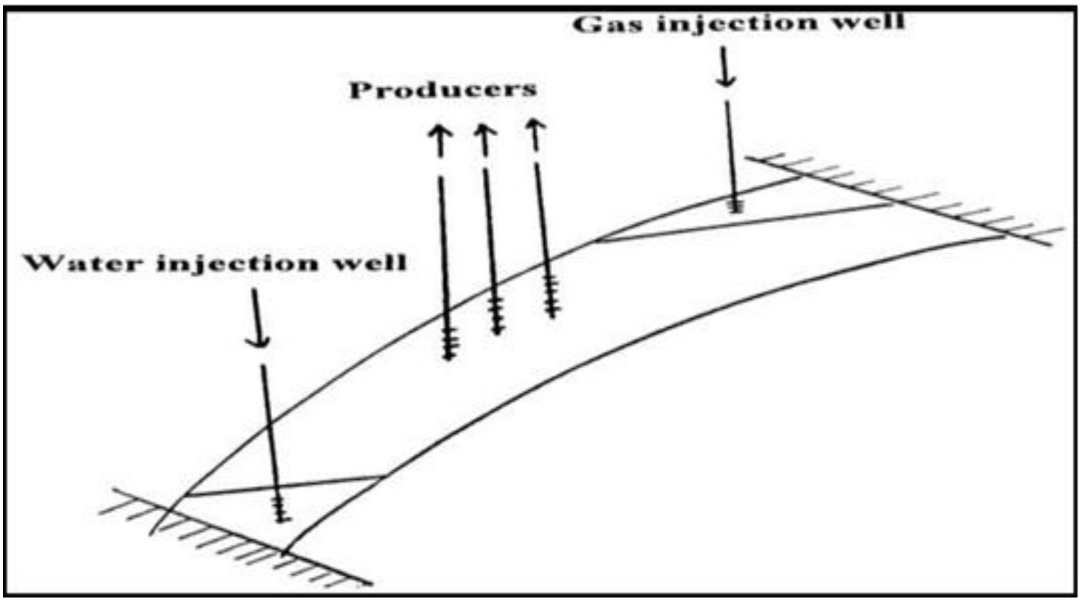

Fig.2.16: Crystal and Basal Injection Patterns (Tarek A, 2010)

2.11. Mechanism of steam flooding:

Steam flooding is a process similar to water flooding. A suitable well patter is chosen and steam is injected into a number of wells while the oil is produced from other wells. Ideally, injected steam forms a steam saturated zone around the injection well Figure (1.18).

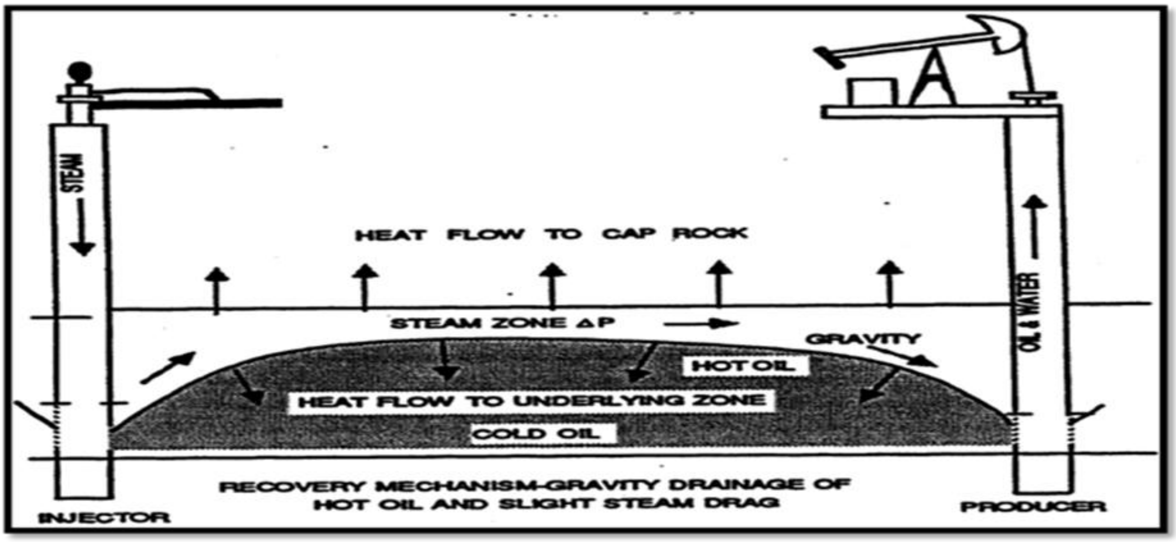

Fig.2.17: Steam Flooding Mechanism (Oil and Gas Journal, 2009)

Heat affects crude recovery by viscosity reduction, which gives greater sweep efficiency, and by crude expansion, steam distillation and solvent extraction, which improve displacement efficiency. The most obvious effect of heating a reservoir is reduction of oil viscosity.

Tow point are evident that, first, the rate of viscosity improvement is greatest at the initial temperature increases. Little viscosity benefit is gained after reaching a certain temperature. Second, greater viscosity reduction are experienced in the more viscous low API gravity crudes than in higher API gravity crudes. Heating from 100◦F to 200◦F reduces viscosity 98% for 10◦API crudes, but only 73% for 30◦API oils. These observations show that greatest viscosity reduction occurs with the more viscous oils at the initial temperature increases.

Another basic mechanism inherent in thermal recovery is expansion of reservoir oil upon heating. Crude swelling, when heated, adds energy to expel reservoir fluids. Depending on composition, oil may swell by 10% to 20% during a steam flood. This occurs to a smaller degree at the lower temperature used in hot water flooding.

Another possible benefit to recovery in steam flood is crude distillation. In the displacement of volatile oil by high temperature steam, lighter fractions of the residual oil may be vaporized. These fractions condense when contacting the colder formation, forming a solvent or miscible bank ahead of the steam zone. Other factors also contribute to recovery by reservoir heating. These include gas drive effects and possible of elative permeability characteristics.

Actual performance of the steam is considerably different from the ideal situation. When steam I injected, it usually from a finger-like channel through the easiest conduit and quickly reaches the producing well. With time and continued injection, the steam finger, being less dense than the surrounding oil, travels upward in the reservoir and blankets the oil. This override by the steam results in the upper one-third off the reservoir being swept by steam and remaining two-third being swept by hot water, thus resulting in uneven vertical sweep efficiencies.

Gravity overrides are aggravated by the presence of a gas zone. Injection of steam at the bottom of the reservoir may be effective in reducing override severity, but only when the reservoir properties and oil viscosity throughout the reservoir are homogeneous and no bottom water zone is present (since bottom water forms an easy conduit for the steam). In multilayered reservoirs, steam injection must tack place at different intervals in order to ensure even distribution of the steam throughout the oil zone. For heterogeneous reservoirs, chemicals and high temperature gel have been developed to plug steam thief zone (Donaldson, E.C, 1989).

It is often necessary to steam soak the producing wells before steam injection is being. This is done in order to reduce the backpressure that would develop at the injection well when the cold, viscous oil near the producing well move in response to the steam injection. As steam moves through the reservoir between the injector and producer, it typically creates five regions of different temperatures and fluid saturations.9 all of these Regions are shown in Figure (1.19).

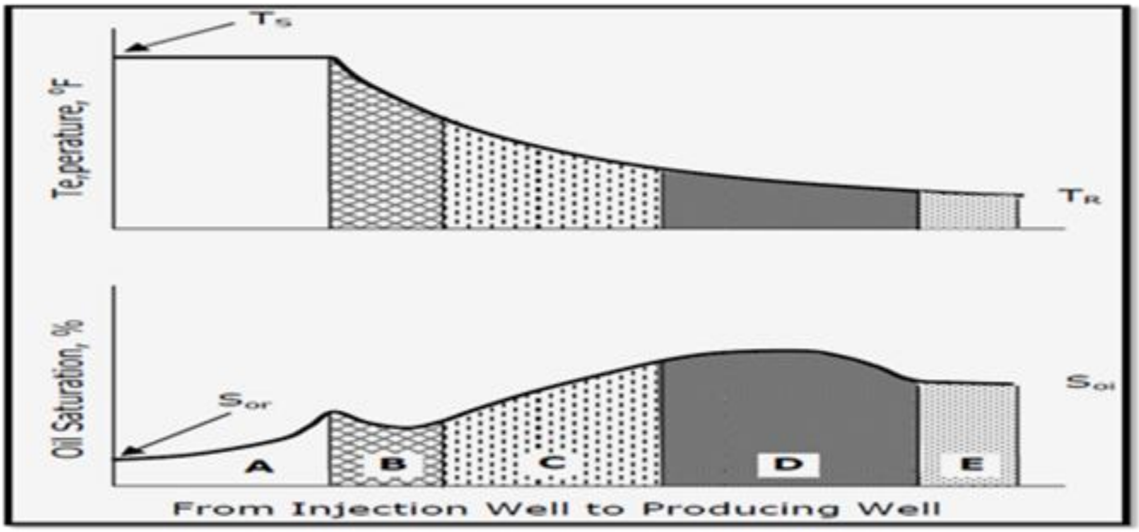

Fig.2.18: A Schematic Illustrate Steam Flooding Profile.

Legend (A: Steam Zone, B: Solvent Bank, C: Hot water Bank, D: Oil Bank-Cold Condensate zone, E: Reservoir Fluid Zone, TR: Reservoir Temperature, TS: Steam Temperature, Soi: Initial Oil Saturation)

Planning and management of the thermal oil recovery processes generally make extensive use of thermal reservoir simulations. The success of any thermal recovery project depends on the real-time reservoir performance information obtaining. Introducing one of the most common used simulators in thermal oil recovery and specially the steam injection design the CMG software.

The design of steam flood project clear understanding of steam properties and the physical mechanism involved in oil displacement by both steam and water. It is also necessary to be estimate heat losses in order to proper calculate the capacities of needed steam generating equipment.

3. Methodology:

3.1 Methodology of the Project:

A. Data were collected from FULA Field and analyzed where they were provided by the Ministry of Petroleum. Analysis has been done and founded that this field is suitable for steam flooding.

B. Pilot test area was selected.

C. Then CMG software was used for design the steam injection parameter as showed in figure (3.1).

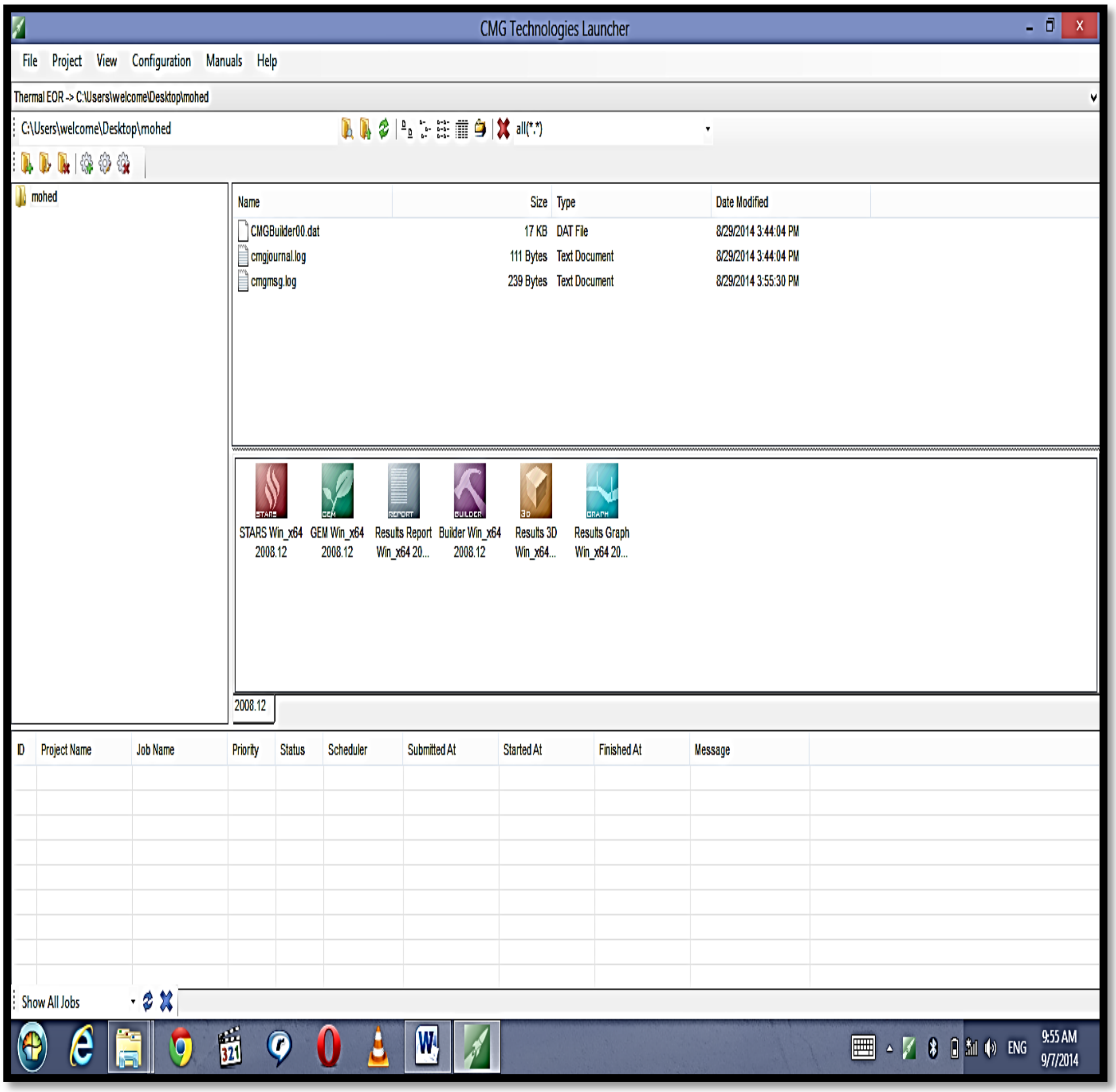

Fig.3.1: The Main Window of CMG

D. Finally recommendations were presented

The steps that have been followed illustrated in Figure (3.1):

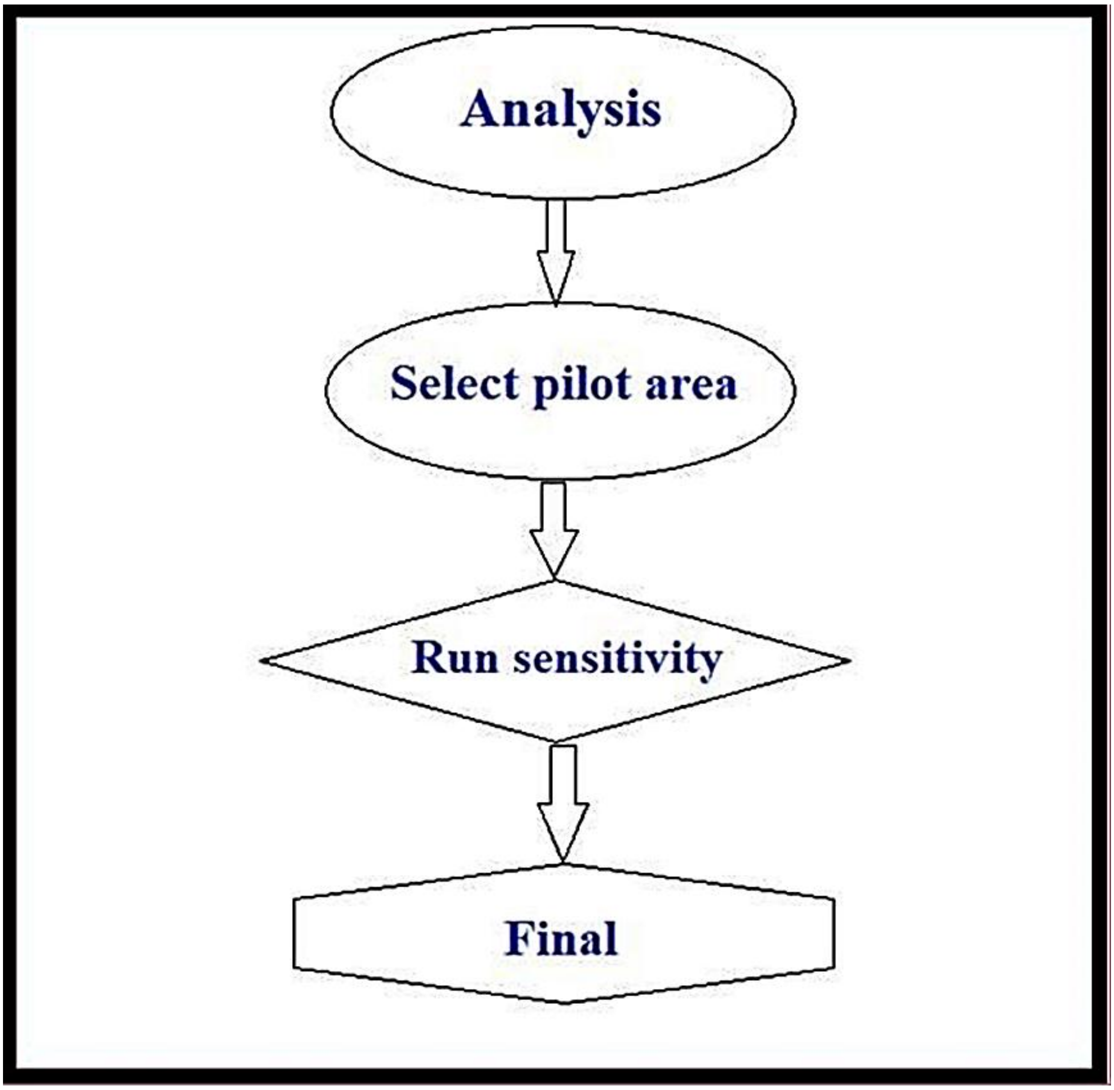

Fig.3.2: Methodology Steps

After the screen made by petro energy ,resulted that the steam flooding is the best method due to the field criteria.

4. Result and discussion:

4.1. Field Introduction:

Fula field lies in North-Northwest (NNW) part of Muglad Basin. The area is divided into three main blocks namely Fula Main. Fula North and Fula Central Figure (4.1). Petro-Energy has drilled wells in different fault blocks and discovered oil in Aradeiba Bentiu and Abu Gabra formations. The target reservoirs in DH field are Aradeiba, Bentiu and Abu Gabra formation. The lithology of these reservoirs is mainly sandstone inter-beded with shale.

G.Fula oilfield located in the Southern part of Fula sub-basin. It covers an area of 625 km^2.The reservoirs in DH Oilfield has an average porosity about 27.5% for Aradeiba

Formation, and 32% for Bentiu formation and 18% for Abu Gabra formation; and the average net pay is 4.2 m, 28.7m, and 1.5 m respectively Fula Main includes Fula-1 & Fula-3. Fula North-76 Fig (4.2) is a small structure located in the north of Fula North field. Three reservoirs have been developed: Aradeiba, Bentiu& Abu Gabra. Oil arrived KRC on Jul., 2004.

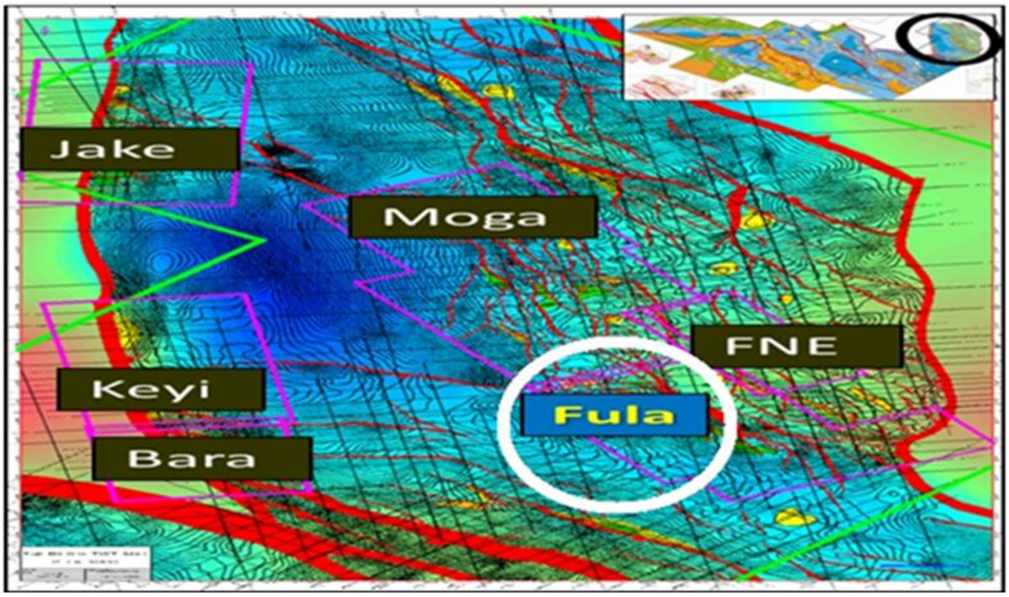

Fig.4.1: Fula Sub-basin Top Bentiu TWT Map

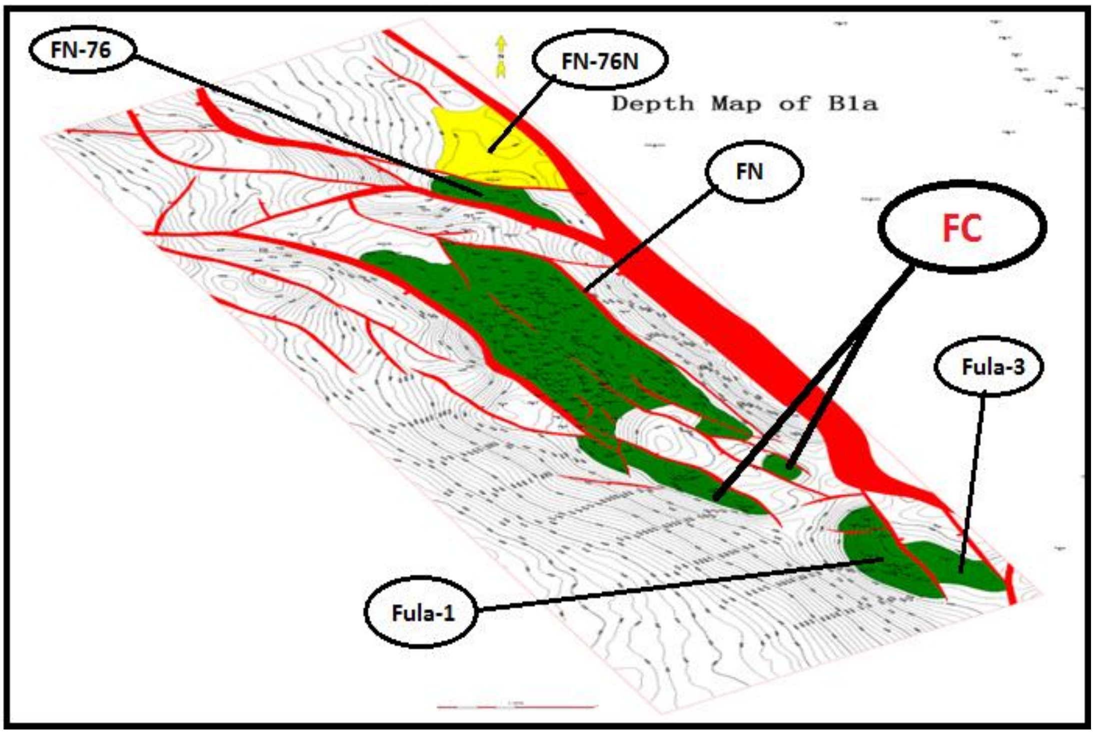

Fig.4.2: Main Blocks: Fula North, Fula Main,and Fula Central.

After grate analysis in Fula central we found that the most suitable way to increase recovery factor is steam flooding because it's has a low recovery factor and high STOIIP as shown in table below (4.1).

Table 4.1: Status of Hydrocarbon Resources in Fula

Field	STOIIP	RF	NP	2012 Prod	2013 Prod	RF to Date
	MMSTB	(%)	MMSTB	MMSTB	MMSTB	(%)
FN (Aradeiba)	96.2	17.4	9.01	0.13	0.17	9.4
FN (Bentiu)	311.4	32.3	53.49	5.69	1.41	17.2
FN-76 (Bentiu)	40.0	32.3	0.18	0.09	0.04	0.5
Fula Central	**48.4**	**17.3**	3.33	0.31	0.13	6.9
Fula Main	82.4	14.1	4.95	0.27	0.19	6.0
Total	578.4	26.0	70.96	6.48	1.93	12.3

The Average production June 2013 for Fula field include oil, water cut and liquid and total of them shows in table (4.2) below.

Table 4.2: Average Production June 2013 for Fula field

Field	**Average June 2013 Production**		
	Liquid	Oil	Water cut
	STB/D	STB/D	(%)
Fula North	20,571	9,540	53.4
FN-76	333	313	6.0
Fula	2,121	769	63.7
Fula Central	2,046	813	60.3
Total	25,071	11,435	54.4

4.2. CMG software:

The main window of **CMG** software ,in this window we have four options ,the first option is **STARS** which use to run reservoir model and the second & third options are Result in graph and 3-D ,the fourth option is Builder which use to build or create reservoir model Figure(4.3).

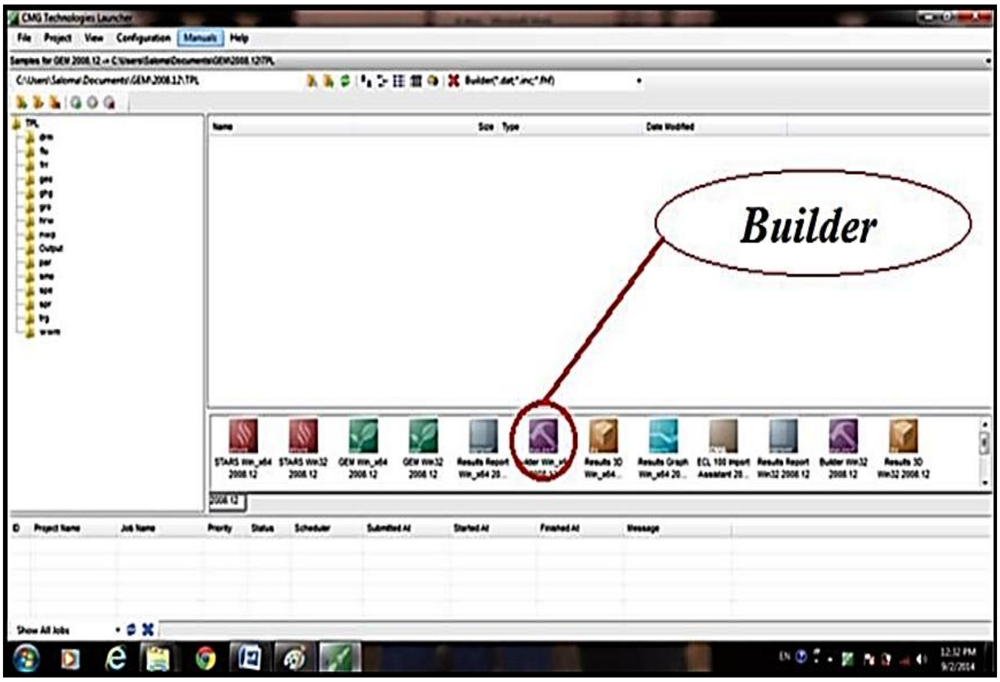

Fig.4.3: Shows the Main Window of CMG

4.3. Data required:

4.3.1. Reservoir rocks and fluids properties:

Table 4.3: Reservoir Rocks and Fluids Properties

Parameters	Fula Central	
Formation	**Aradeiba**	**Bentiu**
Average Formation Top (mKB)	**1146**	**1343**
Initial Reservoir Pressure, (psi)	**1574**	**1713**
Temperature ,°C	**61.2**	**64.5**
Porosity ,%	**22.5**	**24.8**
Permeability ,md	**12**	**170**
Oil Gravity, °API	**17.65**	**15.66**
Viscosity @ 50°C, cp	**1042**	**5196.5**
Formation Volume Factor, RB/STB	**1.11**	**1.11**

According to the data in the above table (4.3), reservoir modelbuilt;Figure (4.4) show the structure map for Fula central in two dimensions.

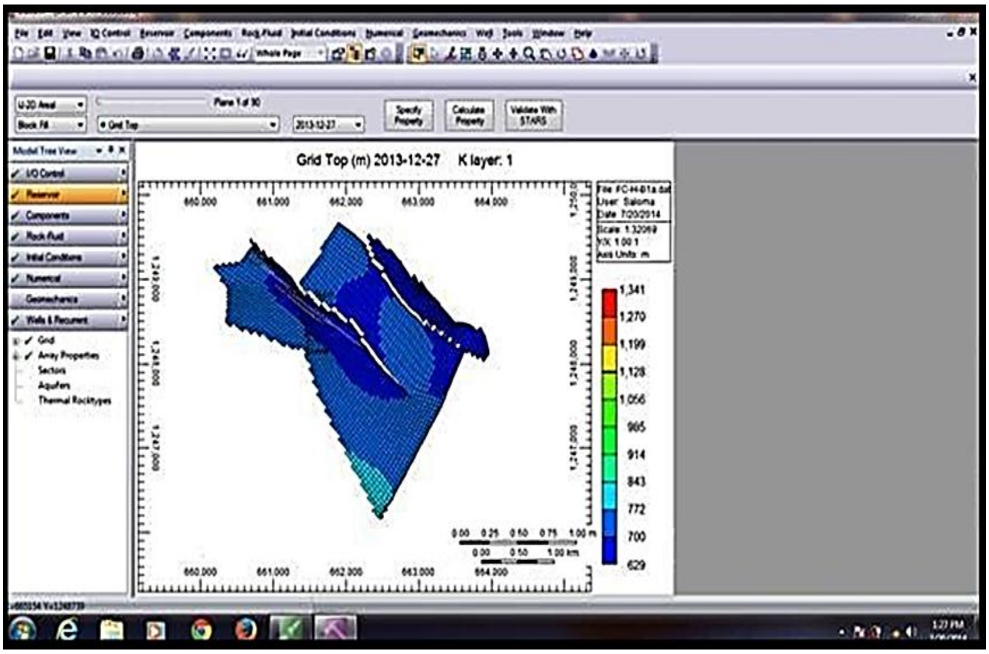

Fig.4.4: Structure Map of Fula central

Then after that the pilot test location was chosenof the wells FC-13, FC-18 andFC-20, as shown in Figure (4.5):

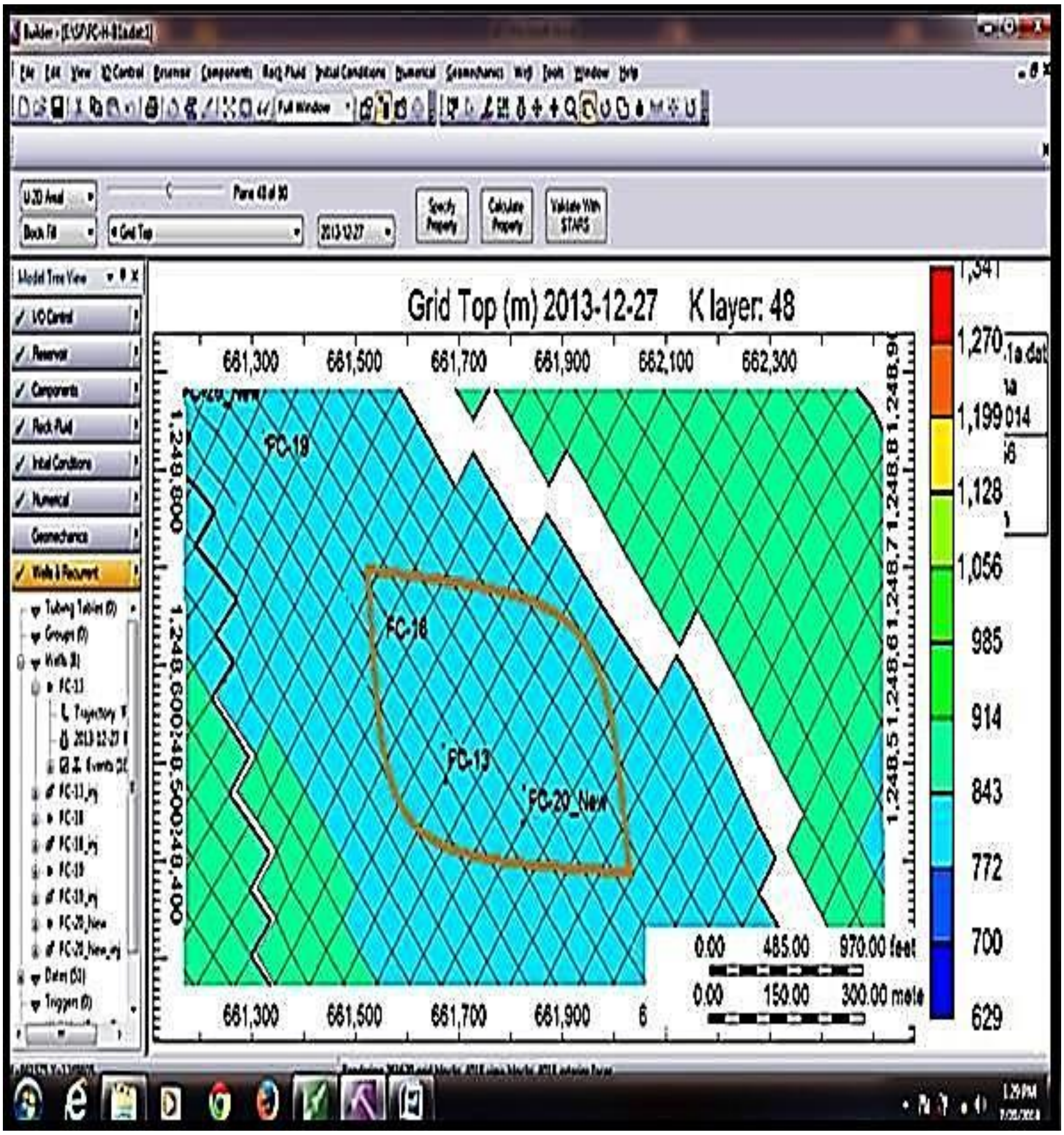

Fig.4.5: The Location of the Wells.

After creating the reservoir model relative permeability data must be createdby editing the rock-fluid properties and defining a new rock-fluid type for the pilot test this step could be achieved by double click on the rock-fluid types icon, a window will open then the new created rock type must be selected, as shown in Figure (4.6)

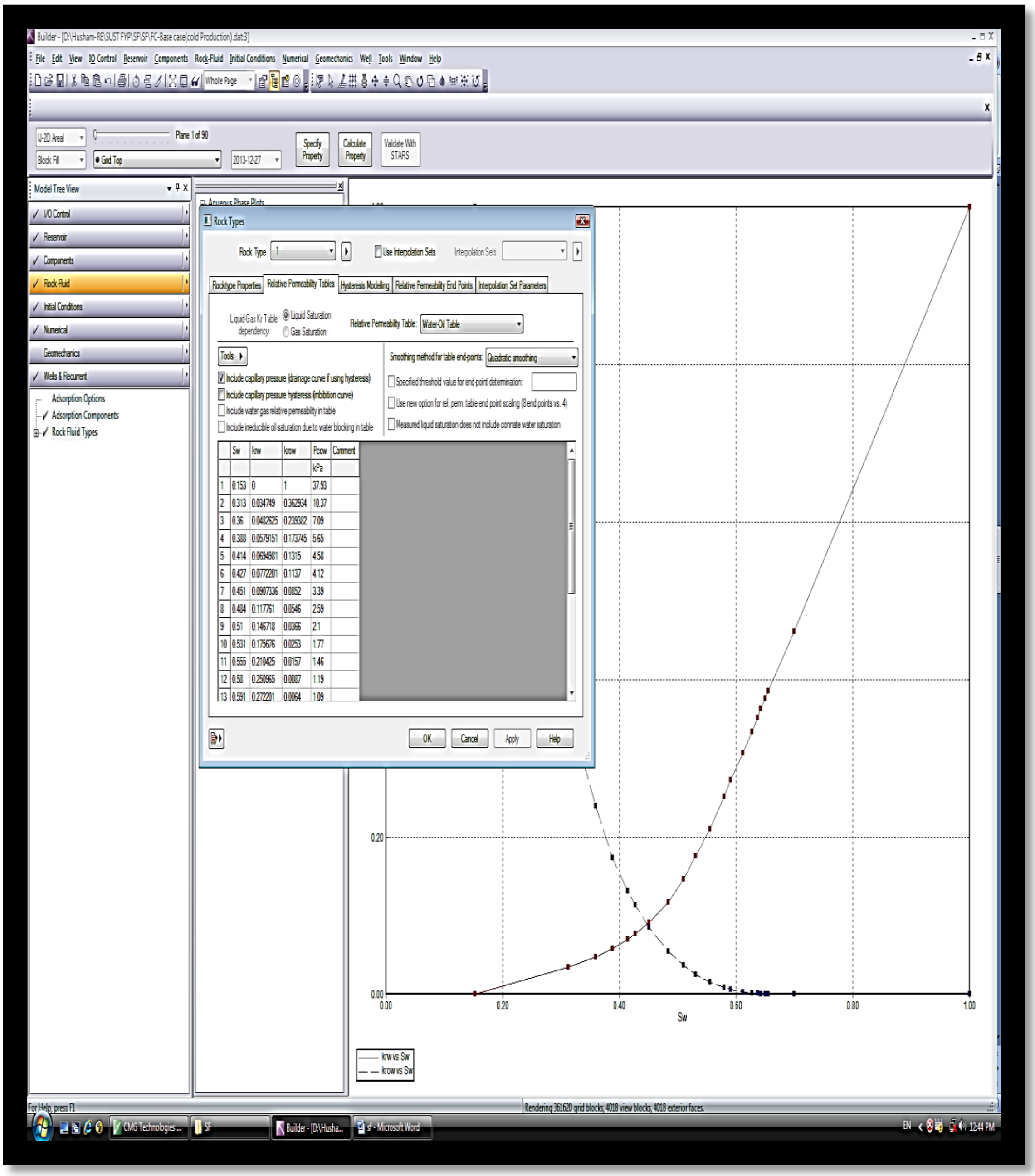

Fig.4.6: Relative Permeability Data and Curve

Table 4.4: The Data of Relative Permeability Curve.

Sw	Krw	Krow	pc
0.153	0	1	37.93
0.313	0.034749	0.362934	10.37
0.36	0.0482625	0.239382	7.09
0.388	0.0579151	0.173745	5.65
0.414	0.0694981	0.1315	4.58
0.427	0.0772201	0.1137	4.12
0.451	0.0907336	0.0852	3.39
0.484	0.117761	0.0546	2.59
0.51	0.146718	0.0366	2.1
0.531	0.175676	0.0253	1.77
0.555	0.210425	0.0157	1.46
0.58	0.250965	0.0087	1.19
0.591	0.272201	0.0064	1.09
0.612	0.30695	0.0033	0.92
0.627	0.333977	0.0018	0.81
0.637	0.351351	0.0012	0.75
0.642	0.362934	0.0009	0.72
0.65	0.376448	0.0006	0.68
0.655	0.3861	0.0004	0.65
0.7	0.46139	0	0
1	1	0	0

The Figure below shows the relative permeability curve and the resultedresidual oil saturation the (Sor) equals0.7.

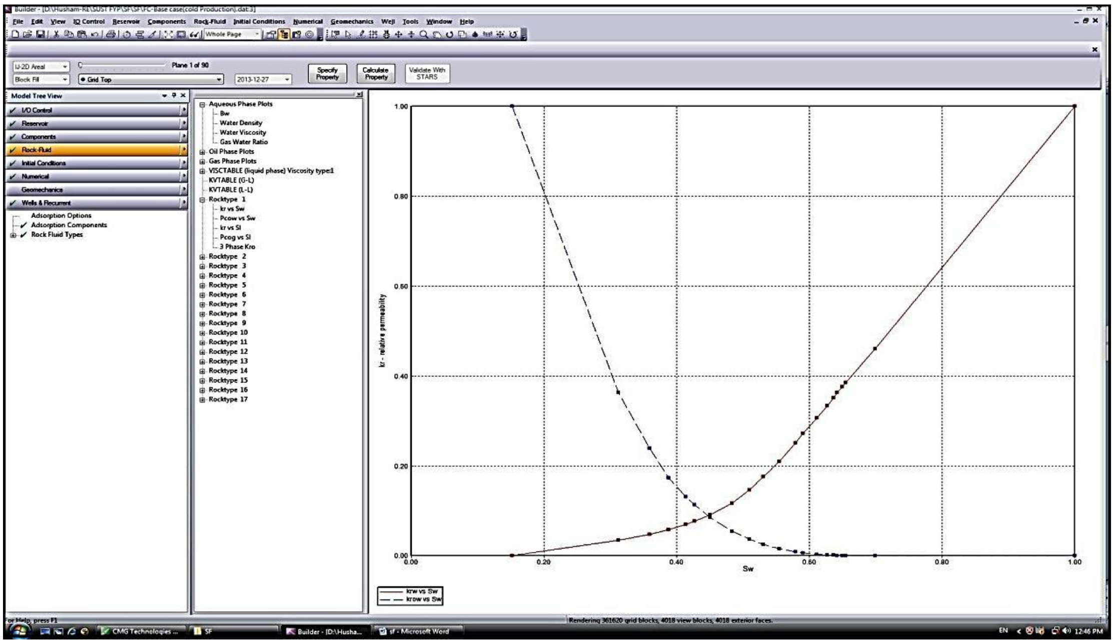

Fig.4.7: Relative Permeability Curve.

4.3.2. Wells and Recurrent:

After creating relative permeability curve, double click on well and recurrent / well FC-13 / ID & Type and set it as a producer well but in shut-in situation as shown in Figure (4.8):

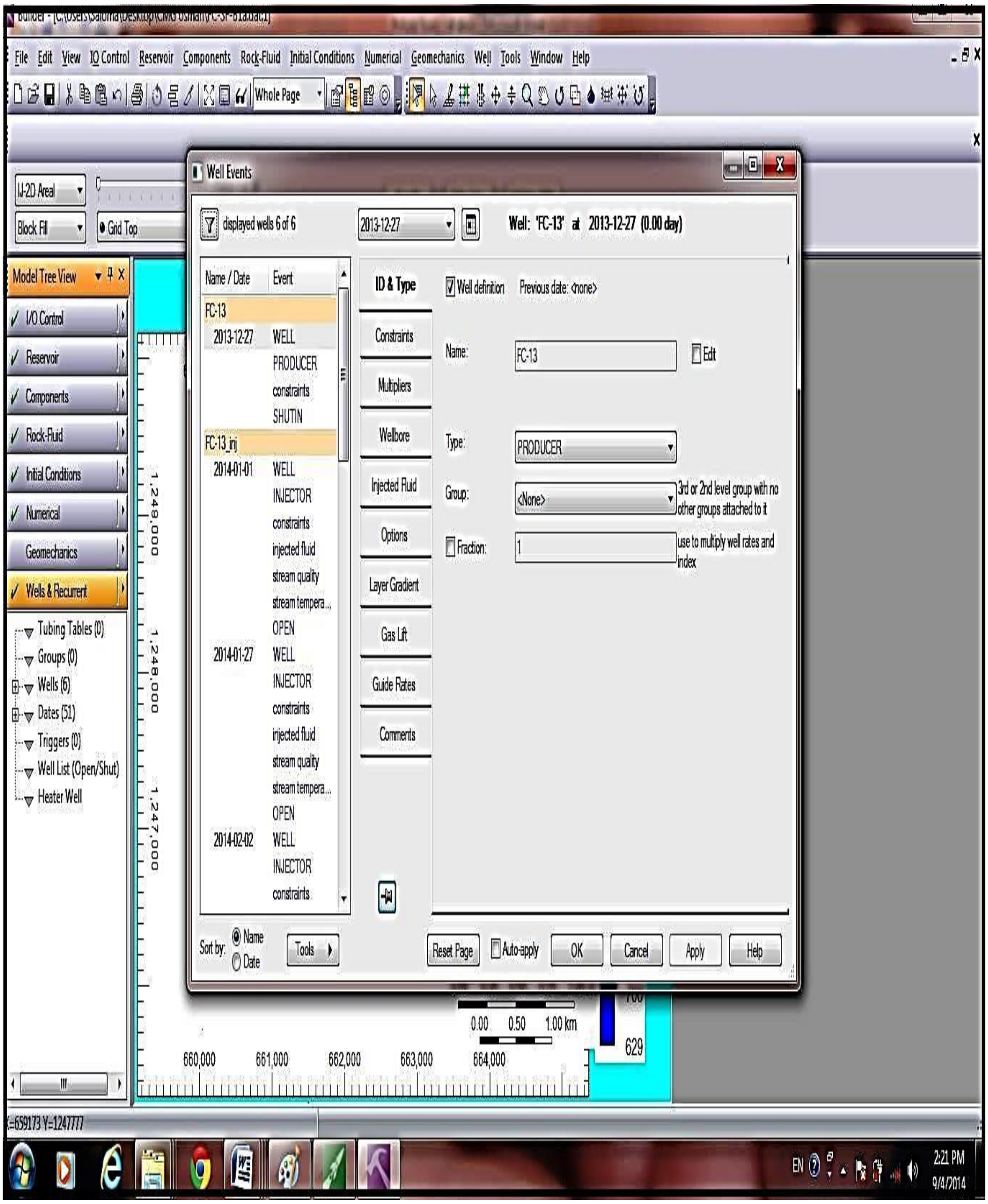

Fig4.8: The Type of Well FC-13.

Then the well FC-13defined as injector but it is open as shown in Figure (4.9) below:

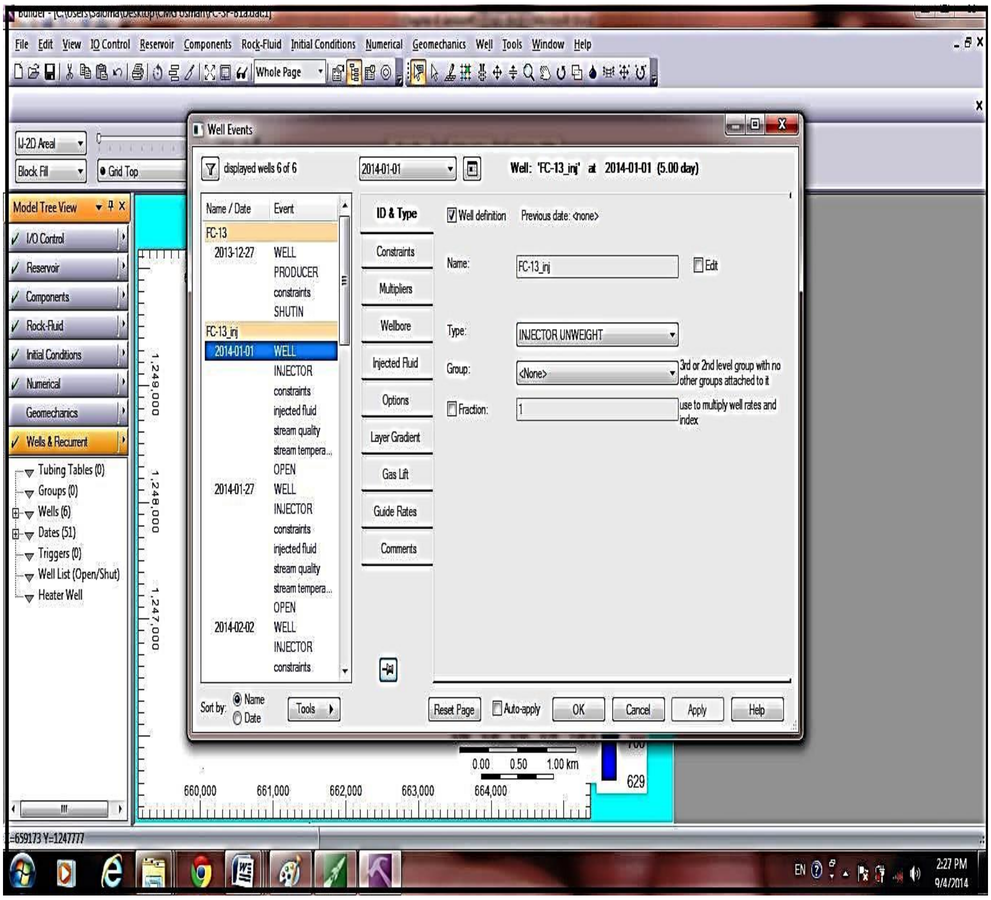

Fig.4.9: the Well FC-13 as an Injector.

Then choose the constrains icon of well FC-13inj, the rate of volume injected is 205 m3/day as shown in Figure (4.10) below:

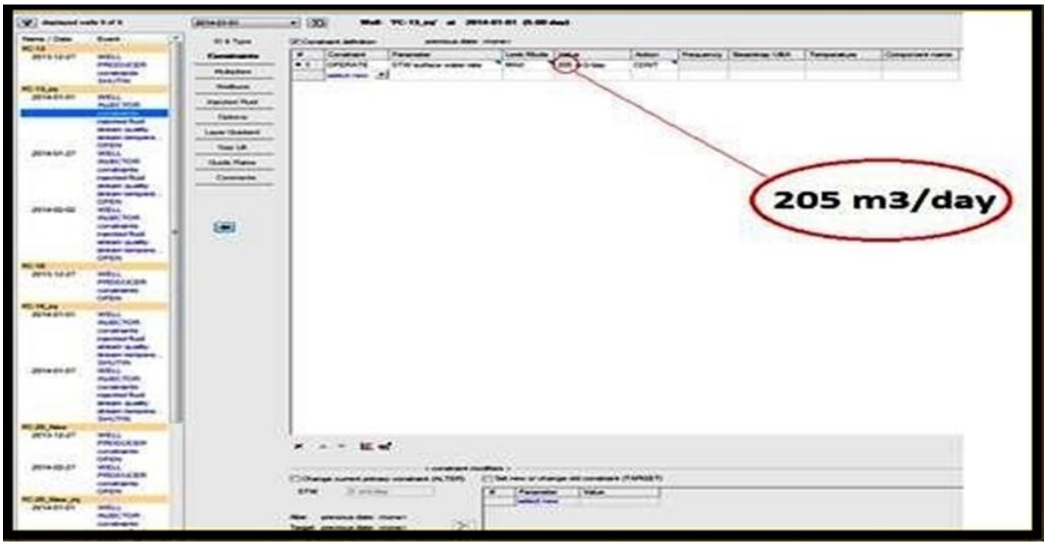

Fig.4.10: Rate of Volume Injected.

4.4. Steam parameters:

After changing the temperature many times, the injectionfluidtemperature is 330 C and steam quality 0.5, injection rate 205m3/day. For five days steam injection period .as shown in Figure (4.11) below.

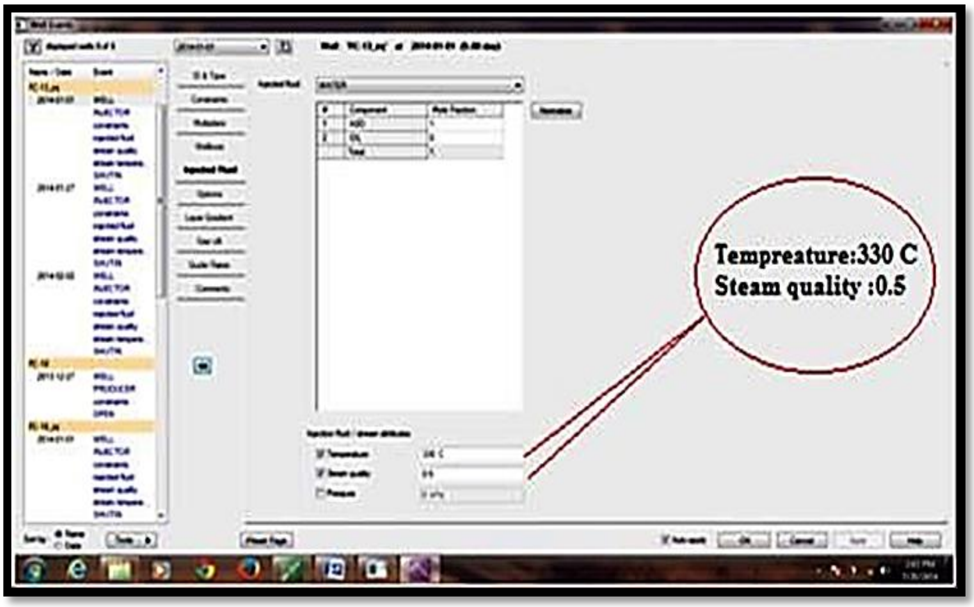

Fig.4.11: Steam Injection Parameters.

Then the model run for well FC-18 only without steam flooding and the cumulative oil production for production interval from 27/12/2013 to 1/1/2016 is 5,150 bbl as showed in Figure (4.12) below.

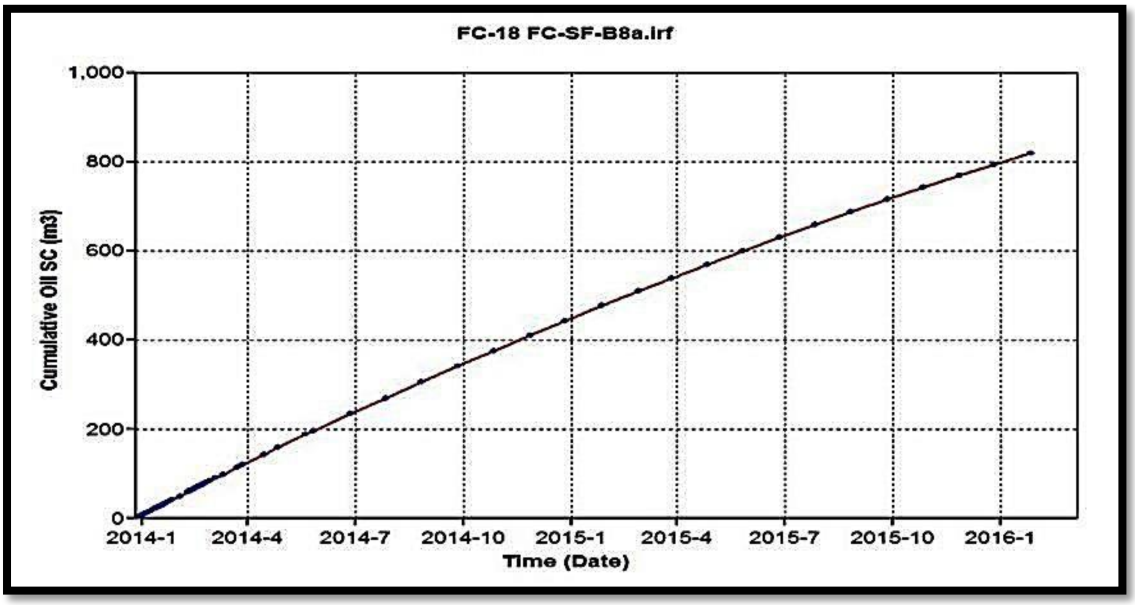

Fig.4.12: Cumulative Oil Production of FC-18

Thenthe nature production of well FC-20 plottedand the cumulative oil production will be 13,276 bbl at the same period as shown in Figure (4.13) below.

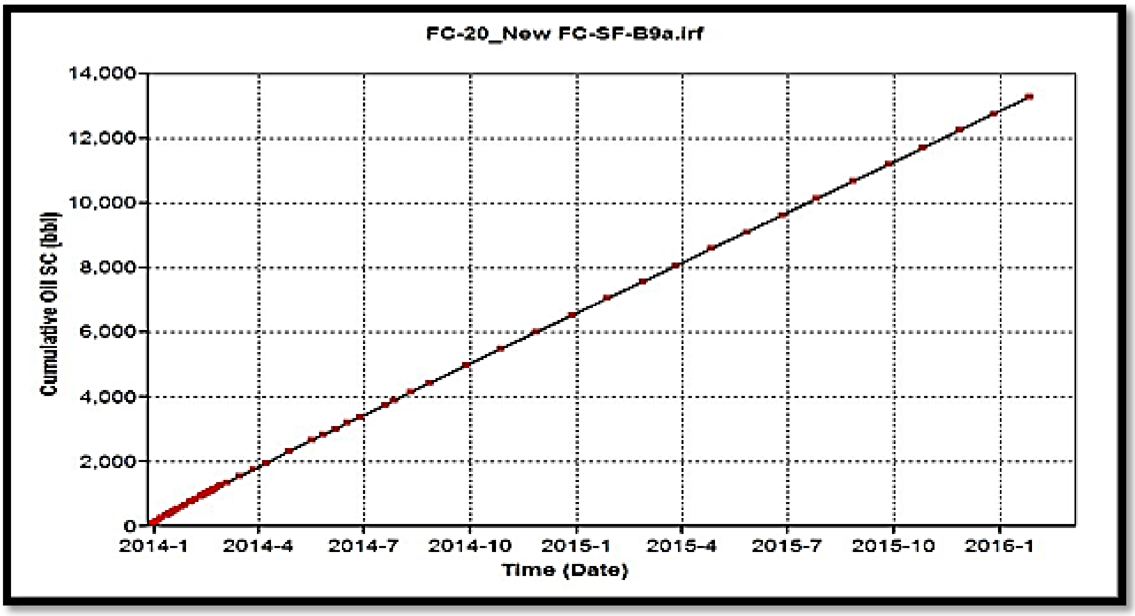

Fig.4.13:Cumulative Oil Production of well FC-20.

After that the runs are implemented on the model for both steam flooding and Base case separately for each condition, and then the cumulative oil production curves for two years plotted with time as showed in figure (4.14).

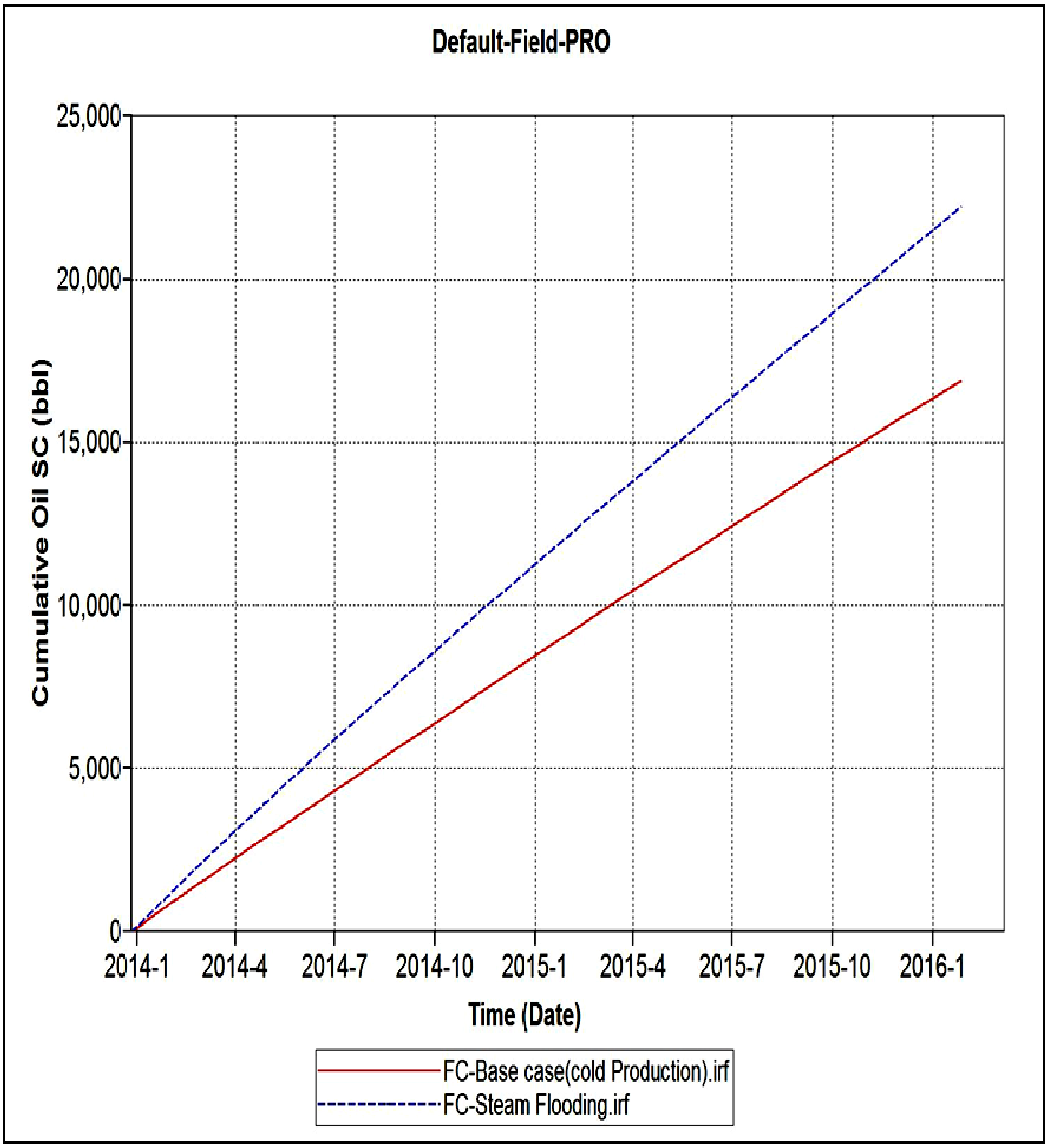

Fig.4.14: Cumulative Oil Production(Base case & steam flooding)

Finally plotting(Base case, steam flooding) with oil production rate and cumulative oil production in only on plot as shown in Figure (4.15.)

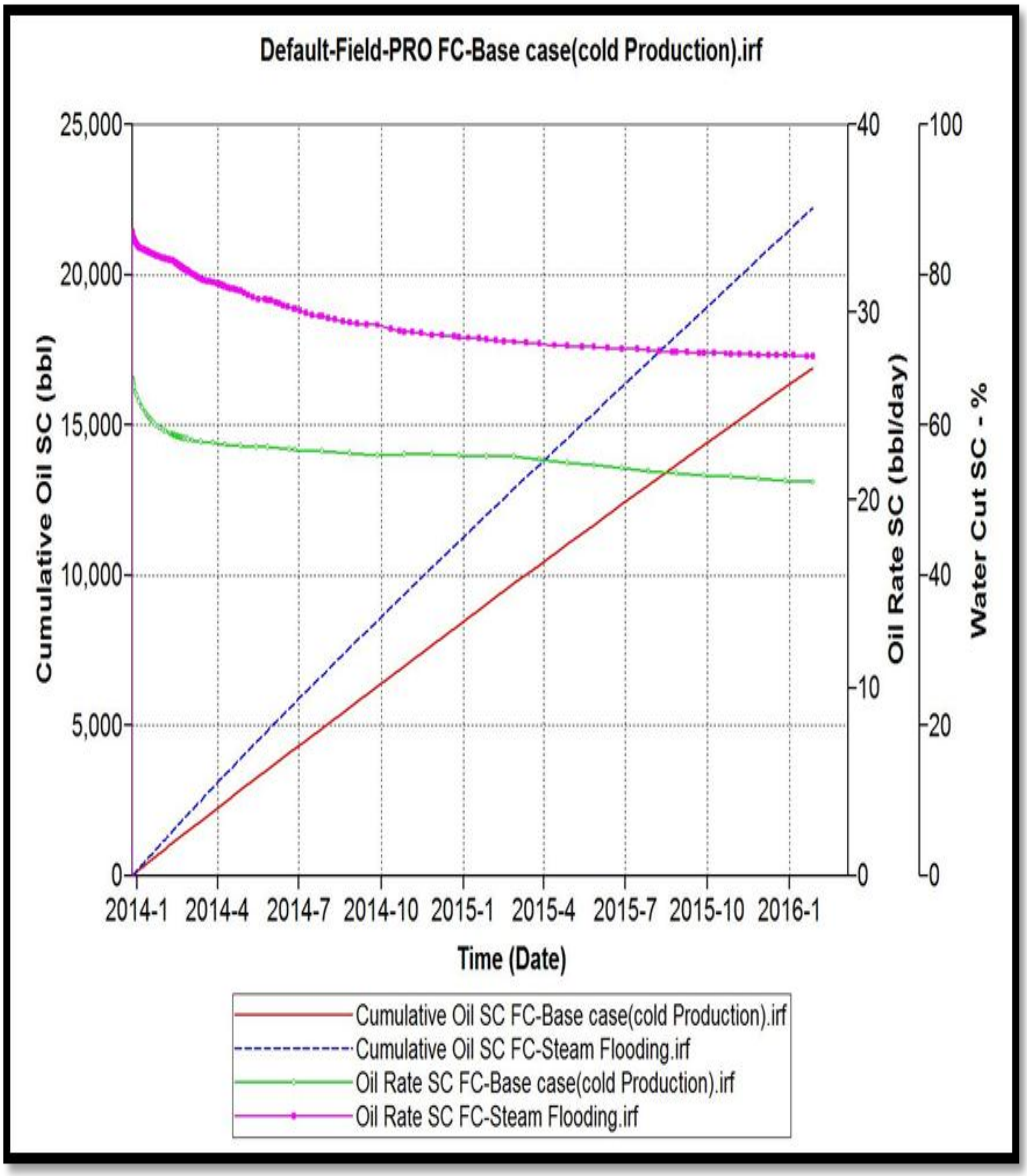

Fig.4.15: Base Case, Steam Flooding and Oil Rate in Both Case.

4.5. Results and Comparison:

Figure (4.15) illustrate that the cumulative oil produced by base case (cold production) is 16,904 bbl but when steam flooding technique was implemented the cumulative oil production was increased to 22,230 bbl. The table (4.5) below shows that:

Table 4.5: The Cumulative Oil for Both Base Case and Steam Flooding

Case	Cumulative Oil Production(bbl)
Base Case	16,904
Steam Flooding	22,230
Production Increased by Steam Flooding	53,26

4.5.1. Total Volume Injected:

It's the volume of the fluid injected during to specific period and it can be determined by multiply the optimum injection rate with optimum specific period.

Final injection rate = 205 m^3/day.

Injection period = two years

The injected temperature = 330 C

Steam quality= 0.5.

5. Conclusion and Recommendation:

5.1. Conclusion:

- **A.** Steam Flooding Pilot area has been selected from existing wells.
- **B.** FC-13 has been change from producer to injector.
- **C.** Two runs has been conducted one as steam flooding and compare it with other without steam (base case).
- **D.** The result show that the injection of 205m3/d of steam for two years can give us 5326 bbl additional to base case.
- **E.** The recovery factor after injection became 31%.

5.2. Recommendation:

- **A.** It’s highly recommended to do detail design for steam injection parameter (injection rate, steam temperature and quality).
- **B.** Economic evaluation should be done for this pilot before implementation of steam flooding.

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