DEVELOPMENT & PRODUCTION STRATEGIES FOR THIN OIL RIMS USING IMEX SIMULATOR

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A

MAJOR PROJECT REPORT ON

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UNDER THE SUPERVISION
OF
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(ISO 9001:2000 Certified)

CERTIFICATE

This is to certify that the work contained in this project titled **"Development & Production Strategies for Thin oil Rims Using IMEX Simulator"** has been successfully carried out by **Chetan Tiwari** and **Nikhil Gupta** under my supervision and has not been submitted elsewhere for the degree.

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NOMENCLATURE

A	=	flow area, ft^2
a_g	=	symmetrical flow coefficient for free gas, scf/D-psi
a_o	=	symmetrical flow coefficient for oil, scf/D-psi
a_w	=	symmetrical flow coefficient for water, scf/D-psi
B_g	=	gas formation volume factor, rcf/scf
B_o	=	oil formation volume factor, rcf/scf
B_w	=	water formation volume factor, rcf/scf
c_f	=	formation (pore space) compressibility,
c_g	=	gas compressibility, psi^{-1}
c_o	=	oil compressibility, psi^{-1}
c_t	=	total compressibility, psi^{-1}
c_w	=	water compressibility, psi^{-1}
GIP	=	Gas in Place, scf
k	=	absolute (or base) permeability, md
k_{rg}	=	gas relative permeability, fraction
k_{ro}	=	oil relative permeability, fraction
k_{rw}	=	water relative permeability, fraction
OIP	=	Oil in Place, scf
p	=	pressure, psi
q_g	=	gas production rate, scf/D
q_o	=	oil production rate, scf/D
q_w	=	water production rate, scf/D

q_t	=	total three-phase production rate, rcf/D
R_s	=	solution gas-oil ratio, scf/scf
r_w	=	wellbore radius, ft
S_g	=	average gas saturation, fraction
S_o	=	average oil saturation, fraction
S_w	=	average water saturation, fraction
T_E	=	"transmissibility" factor of flow coefficients in the "east" direction, etc.
u	=	Darcy velocity, ft^3/ft^2-D
V_p	=	pore volume of gridblock, rcf
μ	=	viscosity, cp
μ_o	=	viscosity of oil, cp
μ_g	=	viscosity of gas, cp
μ_w	=	viscosity of water, cp
ϕ	=	average porosity of the gridblock, fraction

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CHAPTER 1

INTRODUCTION

1.1 RESERVOIR SIMULATION

Reservoir simulation combines physics, mathematics, reservoir engineering, and computer programming to develop a tool for prediction hydrocarbon reservoir performance under various operating conditions.

Reservoir simulation is a tool that allows the petroleum engineer to gain greater insight into the mechanism of petroleum recovery than is otherwise not possible. It can be a most valuable tool. Not all reservoirs require a sophisticated model study and in many cases conventional reservoir studies or extremely simple computer model studies may answer the questions being raised.

Reservoir simulation models are used by oil and gas companies in the development of new fields. Also, models are used in developed fields where production forecasts are needed to help make investment decisions. As building and maintaining a robust, reliable model of a field is often time-consuming and expensive models are typically only constructed where large investment decisions are at stake.

Computer models can be valuable tools for the petroleum engineer in attempting to answer the following type questions:

1. How should a field be developed and produced in order to maximize the economic recovery of hydrocarbons?
2. What is the best enhanced recovery scheme for the reservoir? How and when should it be implemented?
3. Why is the reservoir not behaving according to predictions made by previous reservoir engineering or simulation studies?
4. What is the ultimate economic recovery for the field?
5. What type of laboratory data is required? What is the sensitivity of model predictions to various data?
6. Is it necessary to do physical model studies of the reservoir? How can the results be scaled up for field applications?
7. What are the critical parameters that should be measured in the field application of a recovery scheme?
8. What is the best completion scheme for wells in a reservoir?
9. From what portion of the reservoir is the production coming?

1.2 THE NEED FOR RESERVOIR SIMULATION

The need for reservoir simulation stems from the requirement for petroleum engineers to obtain accurate performance predictions for a hydrocarbon reservoir under different operating conditions. This need arises from the fact that in a hydrocarbon-recovery project (which involves a capital investment of hundred of millions of dollars), the risk associated with the selected development plan must be assessed and minimized. Factors contributing to the risk include the complexity of the reservoir because of:

1. The heterogeneous and anisotropic properties.
2. Regional variations of fluid properties and relative permeability characteristics.
3. The complexity of the hydrocarbon recovery mechanisms, and
4. The applicability of other predictive method that may make them appropriate.

The first three factors are beyond the engineer's control and are taken into consideration in reservoir simulation through the generality of input data built in the reservoir-simulation models and the ability of simulators. The fourth factor can be controlled through proper use of sound engineering practices and judicious use of the reservoir simulator.

1.3 TRADITIONAL MODELING APPROACHES

Traditional methods of forecasting reservoir performance generally can be divided into three categories:

1. **Analogical Method**
2. **Experimental Methods**
    a) Analog models- RC Networks, Potentiometric models and Hele-Shaw models
    b) Physical Models
3. **Mathematical Methods**
    a) Material Balance Equations
    b) Decline-Curve Analysis
    c) Analytical Methods

1.4 RESERVOIR SIMULATION APPROACH

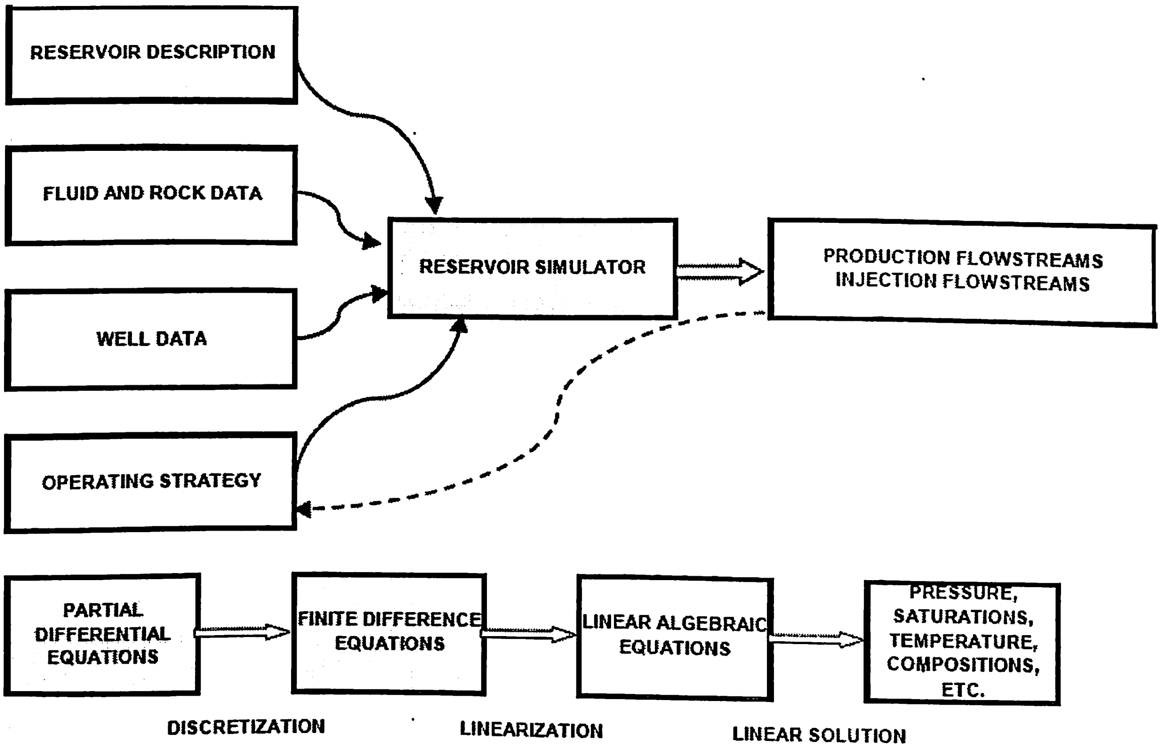
The use of reservoir simulation as a predictive tool is becoming standard in the petroleum industry. Its widespread acceptance can be attributed to:

1. Advances in computing facilities (speed and storage space).
2. Advances in numerical techniques for solving partial-differential equations (PDE's).
3. Advances in reservoir characterization techniques.
4. The development of increasingly complicated oil recovery techniques that would otherwise be complicated to analyze.

A set of algebraic mathematical equations developed from the set of PDE's with appropriate initial and boundary conditions approximates reservoir behavior in the reservoir simulation approach. These equations incorporate the most important physical processes taking place in the reservoir system, including the flow of fluids partitioned into as many as three phases and mass transfer between the various phases. The effect of viscosity, capillary and gravity forces on fluid flow are taken into consideration by use of a generalized form of Darcy's law. The advantages of this approach lie in the fact that the least number of simplifying assumptions is used for reservoir heterogeneity, mass transfer between phases, and forces/mechanisms responsible for flow. In addition, spatial variation of rock properties and relative permeability characteristics can be represented accurately in a reservoir simulator.

1.4.1 NUMERICAL MODEL OR SIMULATOR

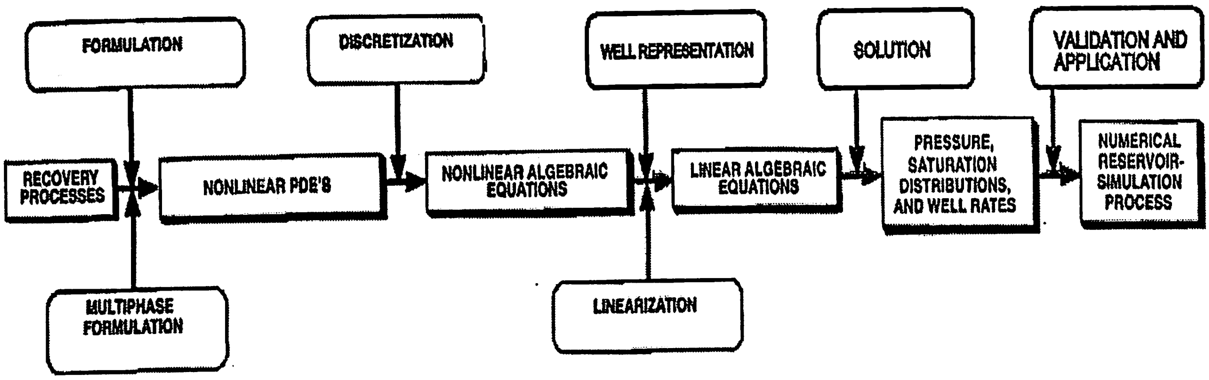
Numerical models are high speed computers to solve the mathematical equations describing the physical behavior of the processes in the reservoir to obtain a numerical to the reservoir solution of the field. These models can account for variations in reservoir properties, both in space and time. The fundamental flow equations can be applied to sub-sections of the reservoir, each of which is assumed to have homogeneous properties.



WHAT IS A SIMULATOR?

gure-1

Major steps involved in development of a simulator in give in the flowchart below.



Major steps used to develop reservoir simulators.

Figure-2

1.4.2 RESERVOIR SIMULATOR CLASSIFICATION

The classification of reservoir simulator is done in a variety of ways. The common criteria for classifying reservoir simulator are as follows:

1) BASED ON RESERVOIR AND FLUID TYPE

a) BLACK OIL OR SINGLE PHASE SIMULATOR

This simulator is used in situations where recovery processes are insensitive to compositional changes in the reservoir fluids. Some of the properties of this simulator are as follows:

- Basic fluid flow
- Oil and gas represented as single components
- Gas can be soluble in oil
- Oil can vaporize in gas
- Used for dead oil or dry gas
- Mass transfer strictly pressure dependent
- Fluid properties Bo, Bg and Rs governs PVT behavior.

b) COMPOSITIONAL SIMULATOR

This simulator is used in situations where recovery processes are sensitive to compositional changes in the reservoir fluids. Some of the properties of this simulator are as follows:

- Oil and gas represented as multi-component fluids
- Used for volatile oils or gas condensates
- Model changes in oil / gas composition
- Gas cycling
- Computationally expensive
- A cubic equation of state governs PVT behaviour

2) OTHER SIMULATORS

a) MISCIBLE SIMULATORS

- Can model solvent injection
- Injectant can have CO2 and/or enriched gas
- Requires a history-match for credible results
- Computationally faster than compositional simulators

b) CHEMICAL SIMULATORS

- For modeling polymer injection
- For modeling surfactant injection

c) THERMAL SIMULATORS

- For hot water and/or steam floods
- Huff-and-puff steam injection
- Air injection
- In-situ combustion

d) DUAL POROSITY SIMULATORS

- Naturally fractured reservoirs

3) BASED ON DIMENSIONALITY

a) TANK MODELS

- Used for rapid answers
- For average reservoir pressure
- For identifying aquifer strength
- For overall data reconciliation
- Affect of gradients are minimal
- Water influx and gas / water injection
- Many complex fields initially modeled this way

b) 1-D MODELS

- Sensitivity studies
- Effect of areal heterogeneities
- Pre-cursor to full field models
- For studying sensitivities to reservoir parameters

c) 2-D AREAL MODELS

- Frequently used
- Useful for areal flow patterns
- Pattern optimization studies
- Used for homogeneous reservoirs
- Blowout studies
- Single well radial models
- Well test analysis

d) 2-D CROSS SECTIONAL MODELS

- For studying gravity effects
- Mechanistic modeling
- Coning tendencies
- For generating pseudo relative permeability's
- For determining number of layers
- For peripheral water injection
- Gas injection
- Extended to full field profiles

e) 3-D MODELS

- Complex reservoir geometry
- Complex displacement processes
- Heterogeneous reservoirs
- Gravity effects
- Complex well geometry
- Unitization work

2) BASED ON GEOMETRY

a) CARTESIAN

- Most often used
- Suitable for all model dimensions
- Used for pattern models and full field

b) RADIAL

- Used for single well studies
- Suitable for coning studies
- Used for near well studies
- For matching well tests

c) UNSTRUCTURED

- Used to accurately capture reservoir geometry
- Can represent various well geometries
- Difficult to construct
- May add to computational costs
- Requires a pre-processor for modifying model

3) BASED ON PHASES

- Single phase
- Two phases
- Three phases
- N-component

1.5 INPUT DATA REQUIREMENT

1. Geophysical data

Geophysical data describe the envelope of a reservoir and the Seismic data are the most widely used geophysical data in reservoir simulation. These data are generated using acoustic energy at the earth's surface, transmitting this energy toward the subject formation, and measuring and recording the time required for this energy to be reflected back to the surface through subsurface strata.

2. Geological data

A geological model determines the distribution of reservoir properties such as porosity, permeability, net pay, and flow barriers and is the basis on which the reservoir simulation model is built. The map requirement can be either a single value for each reservoir layer or a contour map. The geological data sources include stratigraphy, mud logging, geochemistry, paleontology, thin section, scanning electron microscopy, and outcrop studies.

Geological data required.

- Structure top
- Net formation thickness
- Gross formation thickness
- Porosity
- Horizontal permeability
- Vertical permeability
- Initial saturations
- Endpoint saturations
- Fluid contacts

3. Engineering data

Engineering data are concerned with the dynamics and statics of reservoir fluids. The raw data used in the construction of geological models are the same as those in engineering studies:

- Core samples,
- Open hole logs, and
- Pressure-transient data

Engineering data required

- Lithology
- Net formation thickness
- Gross formation thickness
- Porosity
- Horizontal permeability
- Vertical permeability
- Initial saturations
- Endpoint saturations
- Rock compressibility
- Relative permeability
- Capillary pressure
-

These engineering data may come from

- Visual inspection,
- Routine core analysis, or
- Special analysis.

4. Well log data

Well log data are critical in measuring formation properties at in situ conditions and at the reservoir scale. As a result, the degree of scale up for these data is less than core data. Furthermore, open hole logs are run on almost all drilled wells. Thus the well log data are the most abundant data available to geologists, petrophysicists, and petroleum engineers.

Open hole log data in reservoir simulation.

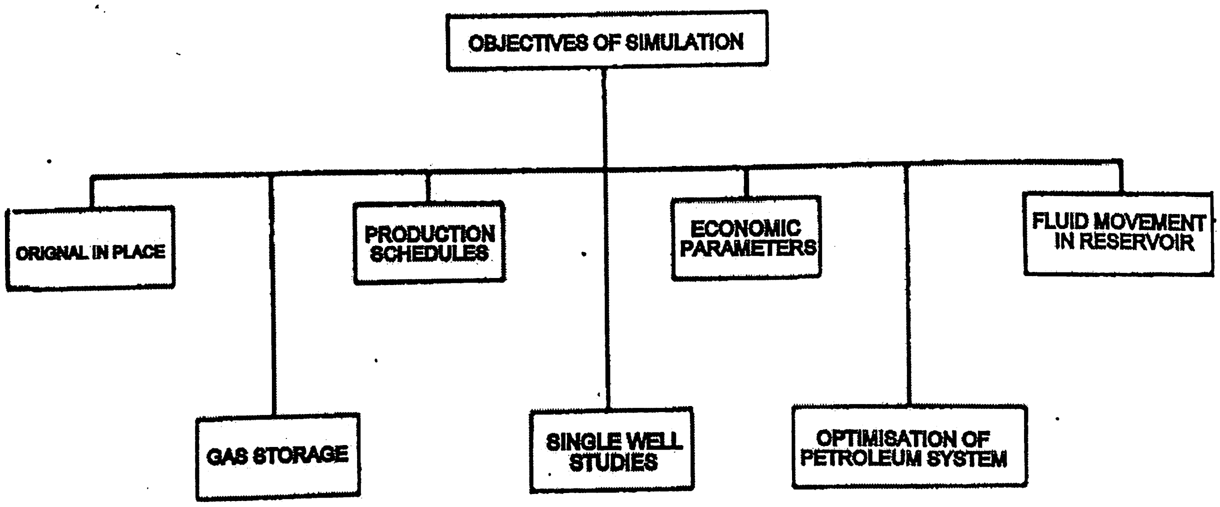
- Lithology
- Water saturation
- Gas saturation
- Porosity
- Net formation thickness
- Gross formation thickness
- Vertical pressure gradient

1.6 RESERVOIR SIMULATION APPLICATION

Reservoir simulation is generally performed in several steps:

- **Set simulation study objectives.** These objectives must be achievable and compatible with available reservoir and production data.
- **Gather and validate reservoir and production data.** The data meeting the objectives are incorporated into the simulator.
- **Design the reservoir simulator.** Once the data are gathered and validated, the simulator is designed. This step involves the four major interrelated stages outlined above: construction of a conceptual physical model, development of mathematical and numerical models, and design of computer codes.
- **History matches the reservoir simulator.** After the reservoir simulator is constructed, it must be tuned, or history matched, with available reservoir and production data since much of the data in a typical simulator needs to be verified.
- **Make predictions.** In the final application step, various development and production plans are evaluated, and a sensitivity analysis of various reservoir and production parameters is carried out.

1.7 OBJECTIVES OF SIMULATION



Objectives of simulation.

Figure-3

1.8 GOVERNING EQUATIONS

BASIC FLOW EQUATIONS

DARCY'S LAW

Darcy's Law governs the flow of fluids in the reservoir, and in simulators. The basic equation is

$$q = c(h_{w_2} - h_{w_1})$$

This states that the flow rate is proportional to the difference in water manometer heights at the two ends of the flow tube. He noted that this proportionality of flow rate to the difference in manometer heights applied regardless of the angle of the sand packed tube. We now generalize his result by recognizing that the sand pack has a particular permeability (k), area (A), length (L) and that the fluid had a particular viscosity. We would rewrite his equation as

$$q = \frac{kA}{\mu}\frac{(\Phi_2 - \Phi_1)}{L}$$

The manometer readings would be expressed as flow potential Φ.

MULTI-PHASE FLOW

Darcy's Law is extended to multi-phase flow. The pressure, gravity, and capillary effects are included in these equations. The first step is to define potentials for all three phases. Arbitrarily, we use the oil pressure as our reference pressure. This leads to capillary terms being included in the gas potential and water potential equations.

$$\Phi_o = p_o + \frac{\rho_o}{144}Z = p + \frac{\rho_o}{144}Z$$

$$\Phi_g = p_g + \frac{\rho_g}{144}Z = p + \frac{\rho_g}{144}Z + P_{cog}$$

$$\Phi_w = p_w + \frac{\rho_w}{144}Z = p + \frac{\rho_w}{144}Z - P_{cow}$$

Where,

$p_{o,g,w}$ = phase pressures, psi

p = p_o, psi

P_{cog} = o/g capillary pressure p_g - p_o, psi

P_{cow} = o/w capillary pressure p_o - p_w, psi

Z = elevation (positive upward), ft

ρ = fluid density, lb_m/ft^3

$\rho/144$ = hydrostatic gradient, psi/ft

CAPILLARY PRESSURE EFFECT

The relationship between elevation and capillary pressure is given by

$$P_{cow} = \frac{\rho_w - \rho_o}{144}(Z - Z_{FWL})$$

where, Z_{FWL} is the elevation of the "free-water level" at which $P_{cow} = 0$. A similar relationship exists for gas and oil.

CONTINUITY EQUATION

The continuity equation for flow in a porous medium is

$$\boxed{\nabla \bullet (\rho\vec{u}) = -\frac{\partial(\phi\rho)}{\partial t}}$$

This is the *continuity equation* for fluid flow in a porous medium.

DIFFUSIVITY EQUATION

LIQUID

The diffusivity equation for a liquid system in a homogeneous porous medium is:

$$\boxed{\nabla^2 p = \frac{\phi \mu c_t}{k} \frac{\partial p}{\partial t}}$$

REAL GAS DIFFUSIVITY EQUATION

To derive the diffusivity equation for a real gas, we start with the continuity equation:

$$\nabla \bullet \rho \vec{u} = -\frac{\partial}{\partial t}(\phi \rho)$$

FLUID FLOW

Diffusivity Equation

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{\eta} \frac{\partial p}{\partial t}$$

Hydraulic diffusivity

$$\eta = \frac{0.00633k}{\phi \mu c}$$

Storage Equation:

$$d(scf) = \frac{cV_p}{B} dp$$

$$\left(based\ on \quad c = -\frac{1}{V}\frac{dV}{dp} \right)$$ (Pore volume)

FINITE DIFFERENCE EQUATION

$$\frac{0.00633kA}{B\mu}\left(\frac{p_{i+1}-p_i}{\Delta x}\right) + \frac{0.00633kA}{B\mu}\left(\frac{p_{i-1}-p_i}{\Delta x}\right) = \frac{c(\phi A\Delta x)}{B}\left(\frac{p_i^{n+1}-p_i^n}{\Delta t}\right)$$

$$\boxed{\frac{p_{i+1}-2p_i+p_{i-1}}{(\Delta x)^2} = \frac{\phi\mu c}{0.00633k}\frac{p_i^{n+1}-p_i^n}{\Delta t}}$$

IMPLICIT V/S EXPLICIT F.D.E

$$\frac{\partial^2 p}{\partial x^2} = \frac{\partial p}{\partial t}$$

$$\frac{\partial^2 p}{\partial x^2} = \frac{p_{i-1}-2p_i+p_{i+1}}{(\Delta x)^2} + \vartheta(\Delta x)^2$$

Where,

$$\vartheta(\Delta x)^2 = -\frac{(\Delta x)^2}{12}\frac{\partial^4 p}{\partial x^4}(x^*,t) \quad (x-\Delta x \le x^* \le x+\Delta x)$$

$$\frac{\partial p}{\partial t} = \frac{p_i^{n+1}-p_i^n}{\Delta t} + \vartheta(\Delta t)$$

$$\vartheta(\Delta t) = -\frac{\Delta t}{2}\frac{\partial^2 p}{\partial x^2}(x,t^*) \qquad (t \le t^* \le t+\Delta t)$$

EXPLICIT FDE

The solution is only stable when $(\Delta t) < (\Delta x)^2/2$.

$$\frac{1}{(\Delta x)^2}(p_{i-1}^n - 2p_i^n + p_{i+1}^n) = \frac{1}{\Delta t}(p_i^{n+1} - p_i^n)$$

IMPLICIT FDE

The solution is unconditionally stable for any Δt

$$\frac{1}{(\Delta x)^2}(p_{i-1}^{n+1} - 2p_i^{n+1} + p_{i+1}^{n+1}) = \frac{1}{\Delta t}(p_i^{n+1} - p_i^n)$$

THE IMPES METHOD

The most common method of solving three phase reservoir simulation problems is called the IMPES Method. The name IMPES means IMplicit Pressure Explicit Saturation. This method is widely used for field scale reservoir simulation because it is fast and accurate for many reservoir problems.

For a three phase (three components) system we can simply write the three finite difference F.D.E's for oil, water and gas as follows:

OIL

$$\Delta a_o^n \Delta p^{n+1} = \frac{1}{\Delta t}\left[\left(\frac{V_p S_o}{B_o}\right)^{n+1} - \left(\frac{V_p S_o}{B_o}\right)^n\right]$$

WATER

$$\Delta a_w^n \Delta p^{n+1} = \frac{1}{\Delta t}\left[\left(\frac{V_p S_w}{B_w}\right)^{n+1} - \left(\frac{V_p S_w}{B_w}\right)^n\right]$$

GAS

$$\Delta a_g^n \Delta p^{n+1} = \frac{1}{\Delta t}\left[\left(\frac{V_p S_g}{B_g}\right)^{n+1} - \left(\frac{V_p S_g}{B_g}\right)^n\right]$$

WELL EQUATIONS

The simulation equations use pressures at the center of the grid blocks. These pressures represent material balance average pressures in the grid block. However, if a well is located in the center of a grid block, the grid block pressure, $p_{i,j}$, is not the wellbore flowing pressure, p_{wf}. These equations compute the gas flow from grid block to grid block but do not model the very high pressure gradients near the wellbore. So if a well is located in a cell, we need additional equations to relate the well performance to the cell variables. We assume that steady state flow occurs within a cell and use the following three equations:

$$q_o = J_{model}\left(\frac{k_r}{B\mu}\right)_o^n \left(p_{i,j}^{n+1} - p_{wf}\right)$$

$$q_w = J_{model}\left(\frac{k_r}{B\mu}\right)_w^n \left(p_{i,j}^{n+1} - p_{wf}\right)$$

$$q_g = J_{model}\left(\frac{k_r}{B\mu}\right)_g^n \left(p_{i,j}^{n+1} - p_{wf}\right) + R_s^{n+1} q_o$$

BOTTOM-HOLE PRESSURE, P_{WF}, AND RATE

$$q_o = J_{model}\left(\frac{k_r}{B\mu}\right)_o^n \left(p_{i,j}^{n+1} - p_{wf}\right)$$

PRODUCTIVITY INDEX OR WELL INDEX

$$J_{model} = \frac{2\pi\,(0.00633)\,kh}{\ln r_o / r_w + s}$$

CHAPTER 2

LITERATURE SURVEY

2.1 THIN OIL RIMS

Energy is fundamental to nearly all economic activity and modern standards of living. It is not surprising that as prosperity has spread, energy demand has grown. Today's high energy prices reflect that rising demand and a need for additional supplies and, in a sense, they are a symptom of the world's success. The challenge we face today is continuing to provide the energy needed to sustain economic growth and lift more people out of poverty, while also minimizing the effects of energy usage on the environment.

The increasing demand of energy and decreasing rate of Oil & Gas discoveries has placed an additional burden on the existing resources through which we receive maximum production. This type of oil is called easy oil as it posses least problems in exploiting the reservoirs economically. It now time to reduce this overburden and find promising strategies to exploit the tough oil. Under the category of tough oil comes thin oil reservoirs, thin oil rims and reservoir which have a complex strategic location where exploitation is highly economic sensitive.

Thin oil rims are those which have oil along the periphery of the reservoir and a thickness of less than 30ft. Maximizing oil recovery in thin and ultrathin (<30ft) oil rims is a challenge because of coning or cresting of unwanted fluids, regardless of well orientation and results in significant amount of oil to be left behind. Coning is the phenomenon where the contacts (GOC & OWC) move towards the reservoir due to higher drawdown. Low oil recovery factors of thin oil rims are usually connected with gas/water breakthrough. Development of thin oil rims it is one of the most challenging problems as ultimate oil recovery factor (ORF) does not usually exceed the level of 15-20%.

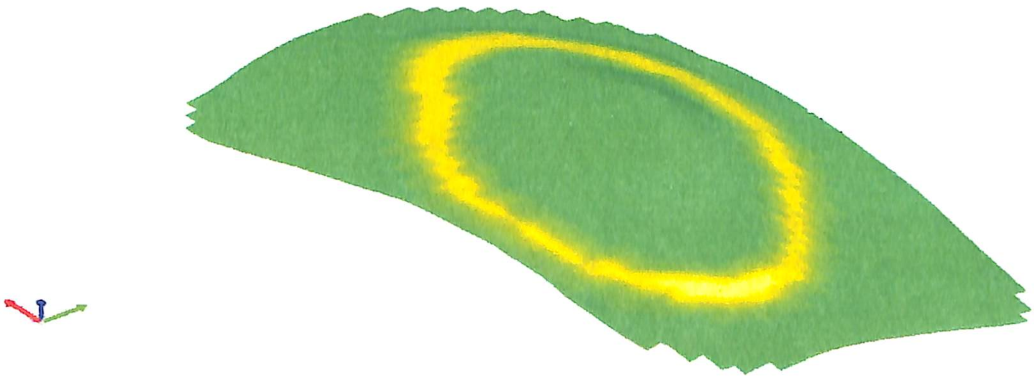


Figure-4

2.2 FORMATION OF OIL RIMS

Thin Oil Rim is formed during the migration and generation of Oil & Gas. A reservoir is filled up with oil (no gas cap), the oil is undersaturated. Now if some gas starts moving in this reservoir from the bottom, it will start pushing the oil out of the trap, oil will be retained in the trap, till the point OWC is higher then the spill point, once the OWC goes lower then the spill point, this shall migrate to some other location. As more and more gas keeps on migrating into the first trap, more and more oil is pushed out and the rim is formed.

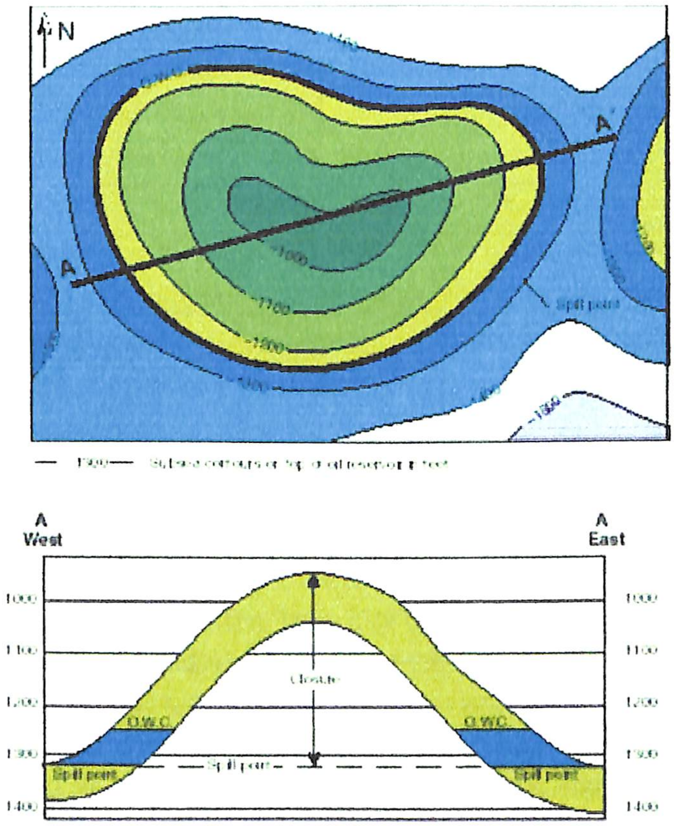


Figure-5

2.3 PRODUCTION STRATEGIES FOR THIN OIL RIMS

Conventional depletion schemes involve the use of horizontal or vertical wells for reservoir development under natural depletion. The ideal production scenario involves oil withdrawal with minimal depletion from the gas-cap to minimize loss of energy. During pressure depletion, the gas-cap will expand to provide energy support. However, the gas-cap recedes with aquifer influx.

a) VERTICAL WELLS

It is the conventional technique for the exploitation of thin oil rim. This technique gives the least recovery.

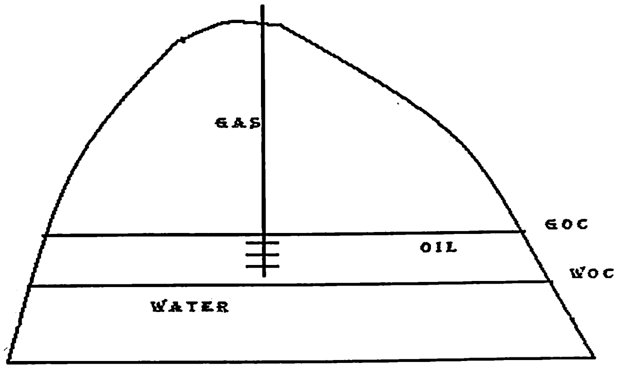


Figure-6

b) HORIZONTAL WELLS

Horizontal well successfully exploits the thin oil rim increasing the oil recovery factor. Placement of horizontal wells in a thin oil rim is a challenge and depends on relative drive indices of the gas cap and the aquifer. Typically the gas cap expands early as deletion occurs in the system. However depending on the strength and connectivity of the aquifer, a time delayed response occurs. The GOC recedes with the water influx. Ultimately cresting/coning cause the well to water cut. Even with good production practices adhered, a significant oil column is left behind at abandonment. In other words the standoff between the GOC and horizontal well may leave upwards of some feet of oil column.

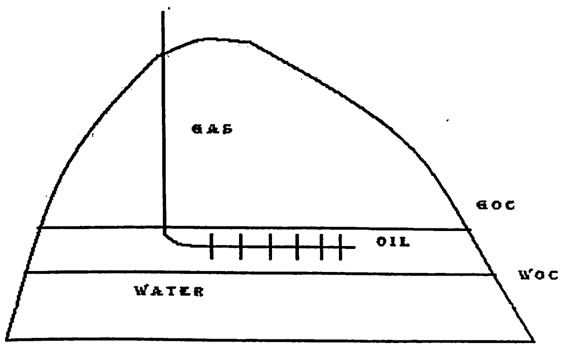


Figure-7

c) HORIZONTAL WELL AT GOC

Horizontal completion at the oil/gas interface for the reverse coning can be applied to saturated reservoirs with small or large gas caps. In this horizontal or multilateral well are completed near the gas oil interface to improve recovery. The scheme is highly effective in large gas cap reservoirs, where displacement of oil into the gas cap is thought undesirable. The idea here is to reduce drawdown significantly and expose as much as the reservoir to flow as possible.

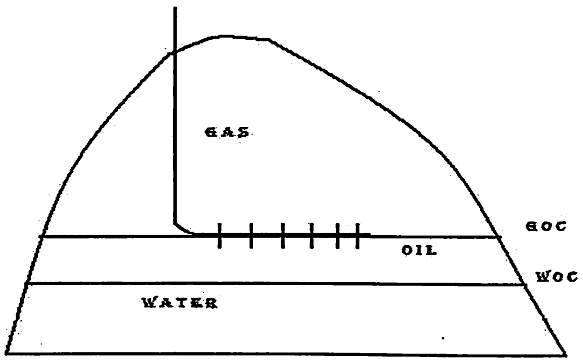


Figure-8

d) HORIZONTAL WELL WITH PERFORATION IN GAS AND OIL ZONE

In this perforation is done in both oil and gas well. It is here intended to use the energy of the large gas cap to drive the oil. Once the perforations are done at the gas zone the gas gushes in and at the same time pushes the oil. The disadvantage is that the residual oil saturation is high (ROS).

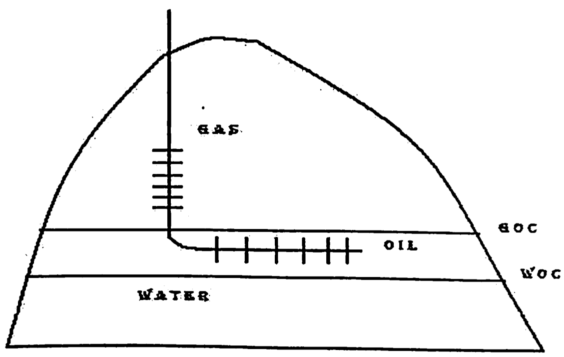


Figure-9

e) NEW METHODS FOR IMPROVED OIL RECOVERY OF THIN OIL RIMS

1. An efficient way to influence critical gas free oil rates has been discovered. This idea was used to design a novel technology of thin oil rims development. It is shown that developed technology enhances oil recovery.

Low oil recovery factors of thin oil rims are usually connected with gas/water breakthrough. Unfortunately, the critical gas free oil rates in case of thin oil rims drained by vertical wells turned out to be either low or unprofitable. Situation has significantly changed alter world-wide application of horizontal wells for oil rims development. Theoretical basis for gas/water free oil rates of horizontal wells was created. A high efficiency of critical gas free oil rate regime was confirmed by simulation and during long-term test production of two horizontal wells on the unique Troll field.

2. At the same time some studies were devoted to suppress gas/water coning process. Under certain circumstances a barrier flooding seems to be rather efficient. It is supposed to create immovable barrier along gas-oil contact from gel, foam etc. Both screen creation and barrier flooding were recommended in paper. There are some approaches consisting in dynamic pressure barrier creation along GOC or WOC. It is worth to be mentioned the suggestion based on injection of active admixture below WOC that alter interaction with oil forms the impermeable combination. Performed lab studies and theoretical investigations unexpectedly led to the new approach of oil rims development that consists in water injection above GOC and gas injection below WOC.

In spite of variety and extensiveness of the methods of oil rim development the problem of enhanced oil recovery of thin oil rims still exists and it is one of the most challenging problems at the moment. First of all it is connected with ultimate oil recovery factor (ORF) does not usually exceed the level of 15-20%.

2.4 ABOUT IMEX

IMEX is a three-phase black-oil simulator with gravity and capillary terms. 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. Gas phase appearance/disappearance is handled by variable substitution.

IMEX is a full-featured three-phase, four-component black oil reservoir simulator for modeling primary depletion and secondary recovery processes in conventional oil and gas reservoirs. IMEX also models pseudo-miscible and polymer injection in conventional oil reservoirs, and primary depletion of gas condensate reservoirs, as well as the behavior of naturally or hydraulically fractured reservoirs.

IMEX has the capabilities and features required for small to massive (100+ million grid block) simulations for screening prospects, setting up pilot designs, monitoring and optimizing field operations, and complex full field reservoir studies, all with the objective of improving production rates, ultimate recovery and value. The coupling of IMEX to surface pipeline network simulators provides a very effective solution for optimizing production from multi-field offshore developments or from large gas fields in which surface flow line constraints can affect reservoir performance and project economics.

IMEX is a full-functionality black oil reservoir simulator, which incorporates all functionality required for full-field simulation studies. IMEX has the ability to accurately model complex heterogeneous faulted structures, primary and secondary recovery processes, including horizontal and multilateral wells, and reservoir subsidence. IMEX also forms an integral part of the Petroleum Experts GAP and Neotec FORGAS products, for analysis of surface network systems, as well as having its own network modeling abilities.
IMEX models multiple fluid systems as well as multiple rock types, for stacked reservoir environments. Users can incorporate very complex geological structures utilizing geostatistical or stochastically derived reservoir parameters. As well, users can calculate various reservoir properties or parameters using a very sophisticated calculator to derive values based on the users own mathematical functions.
IMEX can model secondary recovery processes such as waterflood and gas injection, and some EOR processes such as miscible and pseudo-miscible injection, polymer injection, and WAG processes. In fact, IMEX is a four component simulator, which can be used to model oil-water-gas-solvent or oil-water-gas-polymer applications.

Primary Depletion
• Infill drilling optimization
• Horizontal well placement
• Multi-lateral well placement
• Coning studies
• Under-saturated/saturated oil reservoirs
• Gas condensate reservoirs
• Gas deliverability forecasting
• Reservoir/surface facility optimization

Secondary Recovery
• Water flooding
• Surface facilities modeling
• Polymer injection
• Dry gas injection
• Pseudo-miscible solvent injection

Some of the novel features of IMEX are:

Adaptive Implicit Formulation, Dual Porosity/Dual Permeability, Pseudo-Miscible Option, Polymer Option, API Tracking, Faulted Reservoir Option, Fully Implicit Wells, Matrix Solution Method, Local Grid, Pinched Out Layers, Reservoir Initialization, Flexible Grid System, Variable Bubble Point, Aquifer Models, Input/Output Units, Portability, Graphics, Cross flow in the Well, Condensate Modeling.

2.4.1 BUILDER

Builder is a comprehensive pre-processing package for CMG's simulators allowing isolation from keywords and a graphical editing environment. Some features of note are:
• Simulator dataset reader that greatly aids in the transfer of data from other simulator formats to IMEX format both for complete and partial datasets.
• Single button conversion to our advance process simulators GEM and STARS
• Multiple grid types can be easily created and visualized in 3D, or stereographic 3D mode: Cartesian; Corner point (orthogonal and non-orthogonal); Radial; LGR.
• Multiple input formats can be read including RESCUE allowing easy workflow from other software vendors' products.
• Drag and drop import of externally built geological models.
• Creation of maps from sparse well data points.
• Geostatistical data analysis.
• Splitting and upscaling of simulation layers.
• Well log visualization and completion diagram display.
• Automatic calculation of well completions from deviation surveys.
• Wells and aquifers can be attached to the model by simple point and click.
• Easy graphical extraction of pilot study areas for more detailed analysis.
• Logical calculator for data manipulation.
• Interface for rapid historical data import and update from company database or files.
• Tubing pressure calculator is included for providing pressure output at top-hole conditions.

Builder is a specialized software application for building reservoir simulation models. Its Windows design means that the user does not need to be familiar with the simulator language to define the model. Instead, data may be entered and edited graphically and a Microsoft Office type of interface is used to define parameters. Builder also performs automatic checking of data as it is entered, and automatic conversion of data in different units.
Builder creates simulation grids and property data for the simulators. Data may be created interactively, or imported from a variety of common industry packages, including CPS-3, ZMAP+, Petrel, Strata model, IRAP-RMS, Earth Vision, etc. Builder also fully supports the

industry standard RESCUE data transfer format. Alternatively, data may be digitized directly using WinDig or Didger 3 packages or created using the in built mapping facility. Properties such as permeability, transmissibility, etc. may also be visualized and edited, and refinement added to enhance model resolution.

Additionally, users can easily and quickly calculate reservoir properties or parameters based on mathematical formulas, or by expressions utilizing Builder's built-in calculator. Data in tabular form may be copy-and-pasted from Excel spreadsheets and reviewed and edited graphically. Builder can import well production data from third-party packages such as OFM and corporate databases. Existing perforation data may also be imported and assigned to appropriate well locations.

Builder also allows the user to quickly generate PVT tables from various correlations for input to the CMG simulators using a series of simple template panels. The menu system provides.

2.4.2 RESULTS

A RESULT is a state-of-the-art 3D post-processing package for CMG's simulators allowing rapid analysis and evaluation of simulation results. RESULTS also makes report writing and generation easy by simple copy-and-paste operations into the Microsoft Office environment. Some features of note are:

- Full 3D model manipulation.
- Theatre, room, or screen sized immersive 3D visualization to aid model understanding.
- Complete integration of production and property profile plotting with the 3D environment.
- Easy template creation and user definable preferences.
- Repeat plot facility for wells and groups to rapidly generate plots for analysis.
- Bubble plots of production volumes, and historical data comparison error, for aiding history matching.
- Logical calculator for data manipulation, allowing differences between runs to be calculated and plotted.
- Isosurfaces can be used to track fluid fronts through the reservoir.
- 3D streamlines display and well allocation factors.
- Output can be easily read into economic analysis packages such as PEEP™
- Integrated with the Microsoft Office™ environment.
- AVI file creation for generating movies for partners who do not have software.

A result is a Windows based software application for viewing the output from CMG's reservoir simulators. With Results you can visualize input data and output model results in a variety of graphs, tabular reports, 2D/3D map views, 2D/3D cross section views and full 3D stereographic perspective views. Simulation output can be animated with time to highlight important processes, and Results can be used to monitor the progress of lengthy simulation runs in real time.

2.4.3 RESULTS 3D

It used to produce complete two-dimensional (2D), three-dimensional (3D), and stereographic 3D views of a reservoir. Results 3D will display any of the grid block properties such as pressure, and oil, water, and gas saturation, as output by the reservoir simulator. Users can select the cross-section and plane number to display in 2D/3D and produce "cut-away" views in 3D mode. You can also select from the different simulation times output, or animate through all the times. Displays can be printed by any MS-Windows compatible printer or plotter, and on any of the paper sizes supported by the printer or plotter. Displayed images can also be translated into bitmaps, JPEG, and AVI movie files, and imported into most popular presentation and word processing software applications.

2.4.4 RESULTS GRAPH

It used to produce XY plots of well production and other similar quantities, and can be used to compare various simulation outputs with historical field production. Plots can be updated automatically during the simulation process. Users can also control the number of plots per page and the number of curves per plot. The template feature in Results can be used to design a customized graph which can be applied automatically to all output wells, enabling the user to generate graphs for the whole field very easily. Since Results is entirely Microsoft Office compatible output displays can be easily exported to word processing and presentation packages, enabling the user to construct reports in a matter of minutes.

CHAPTER 3

EXPERIMENTATION AND RESULTS

3.1 THE BASIC MODEL

The main objective of the project is to evaluate the various schemes i.e. production strategies used for the economic exploitation for Thin Oil Rims. The evaluation is done using a hypothetical reservoir model demonstrating a Thin Oil Rim. Maximizing oil recovery in thin and ultrathin (<30ft) oil columns is a challenge because of coning or cresting of unwanted fluids, regardless of well orientation. This project attempts to target this untapped oil.

The model is made with a grid pattern of 50*25*4 with cell dimensions 100m * 100m. The reservoir model consists of four layers. The model depicts a rich gas cap at the top and an underlain aquifer at the bottom. The reservoir grid cells have been assigned the permeability and porosity values which gives the reservoir a distinct permeability variation. The permeability variation was taken as one of the important consideration for well placement.

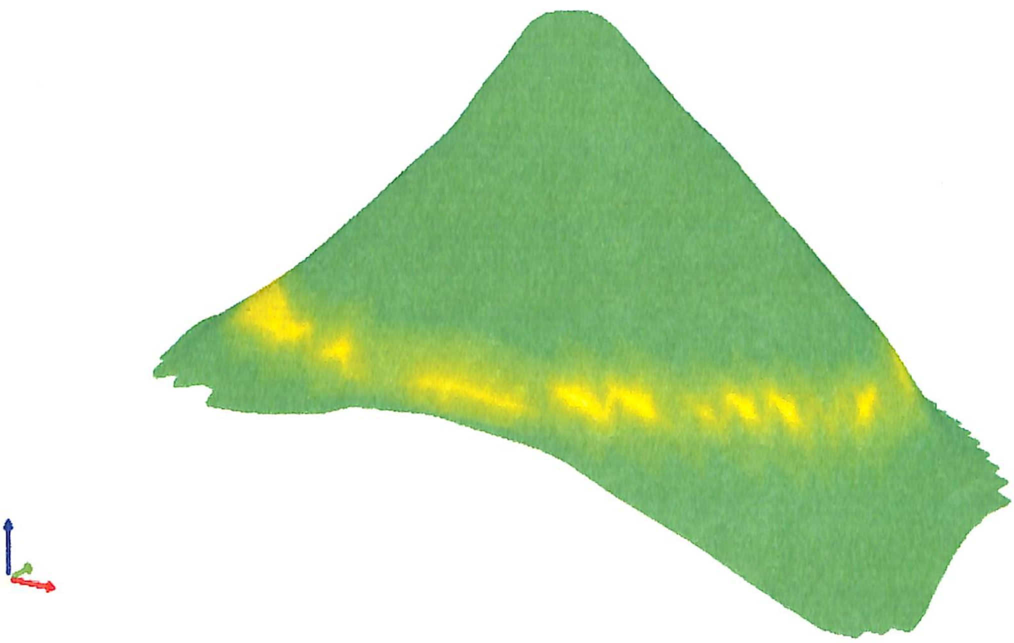


Figure- 10 IMEX, CMG

INITIAL OBSERVATION

The initial state of the reservoir in terms of important parameters is given as follows.

INITIAL OIL SATURATION

The maximum oil saturation of the reservoir is So = .7 and the minimum oil saturation is So= 0.3504. This has been depicted below using an IJ-2D Areal view.

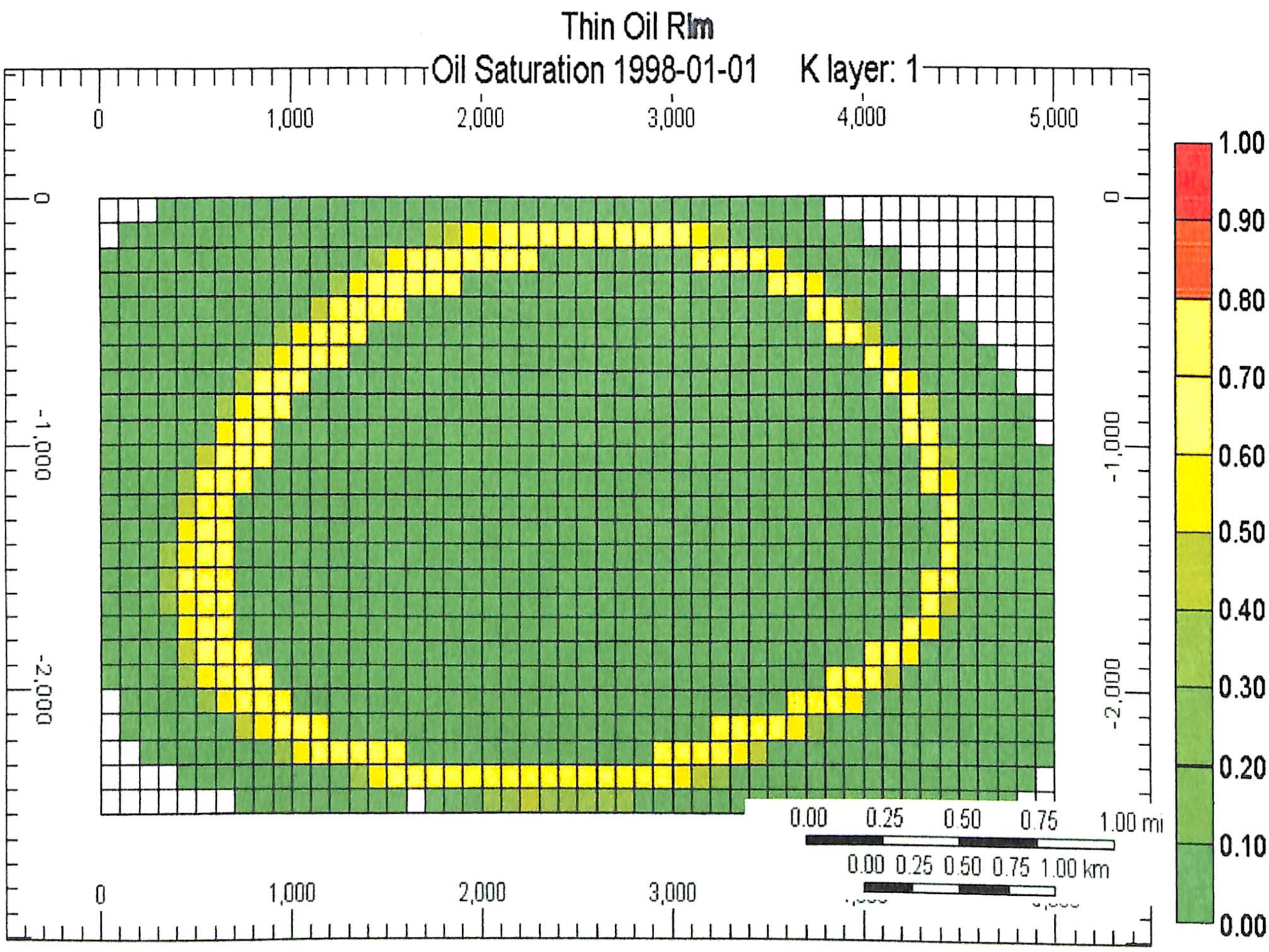


Figure- 11 IMEX, CMG

INITIAL GAS SATURATION

The maximum gas saturation of the reservoir is .7 and the minimum gas saturation is 0. This has been depicted below using an IJ-2D Areal view.

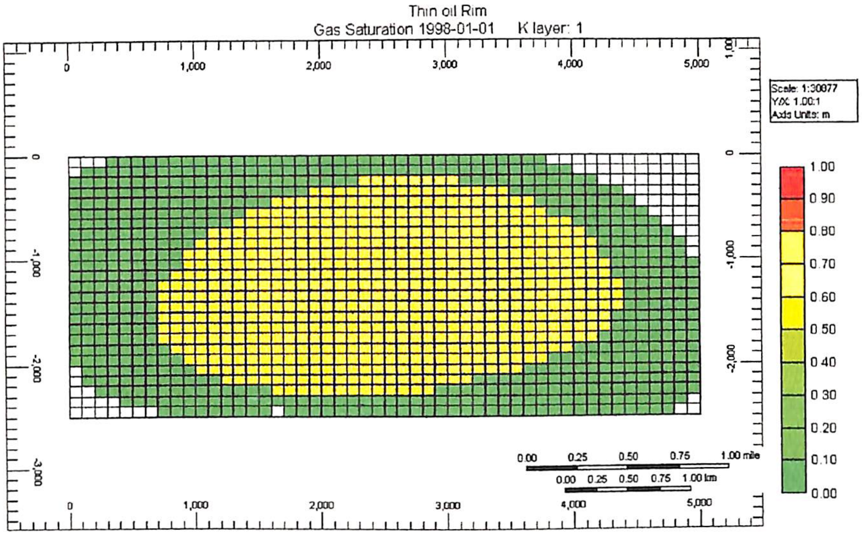


Figure- 12 IMEX, CMG

INITIAL WATER SATURATION

The maximum water saturation of the reservoir is 1.0 and the minimum water saturation is 0.3. This has been depicted below using an IJ-2D Areal view.

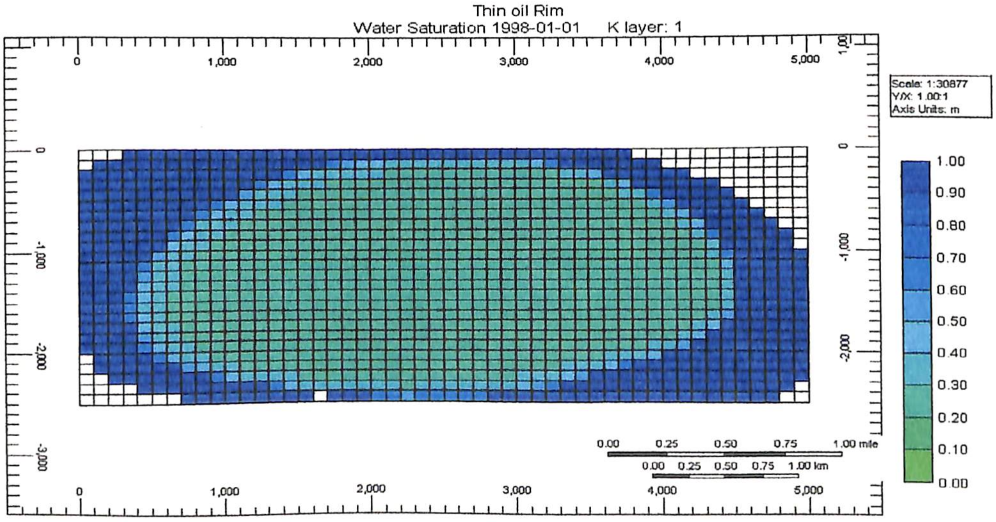


Figure- 13 IMEX, CMG

PERMEABILITY VARIATION

The permeability distribution is shown using an IJ-2D Areal view.

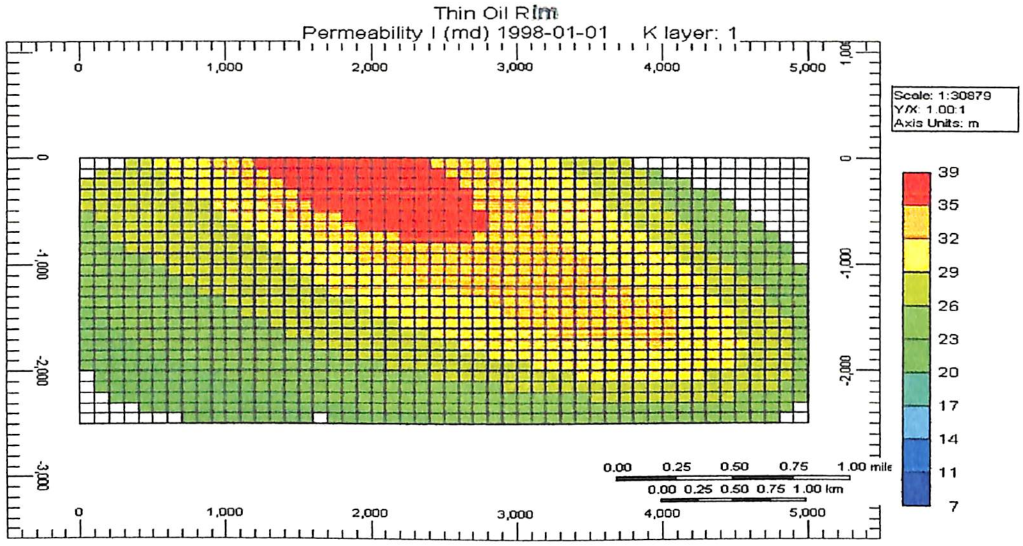


Figure- 14 IMEX, CMG

INITIAL PRESSURE DISTRIBUTION

The initial pressure distribution of the reservoir is shown using an IJ-2D Areal view.

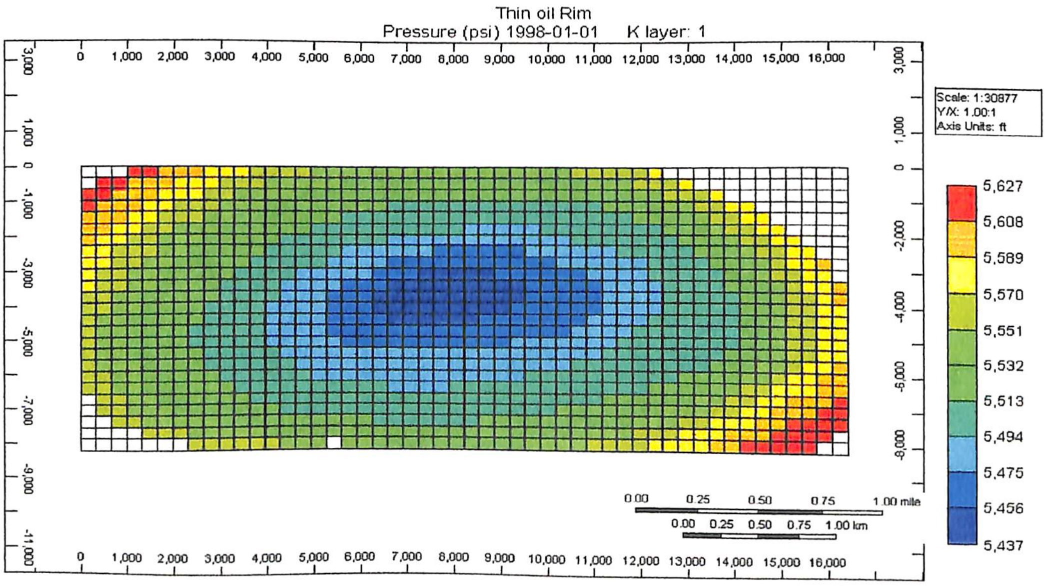


Figure- 15 IMEX, CMG

3.2 ORIGINAL OIL IN PLACE (OOIP)

The original oil in place is been calculated by the volumetric reserve estimation analysis using the formula:

$$N = AH\Phi\,(1-S_{wi})/B_{oi}$$

Where $A = 8446600\ m^2$

$H = 7\ m$

$\Phi = 26\%$

$S_{wi} = .3039$

$B_{oi} = 2.72$

Total oil in place = $3978077.90\ m^3$

= 25035103.21 bbl

= 2.503e+007bbl

3.3 BASE CASE

Conventional approach using vertical wells

The field was put on production using five vertical wells (P1, P2, P3, P4 and P5). The locations of these wells were decided based on the initial permeability distribution and initial oil saturation. Locations with highest permeability and maximum oil saturation were chosen taking care that the wells were drilled in the middle of the Oil Rim. This is shown using an IJ-2D Areal view for both permeability and oil saturation of the reservoir.

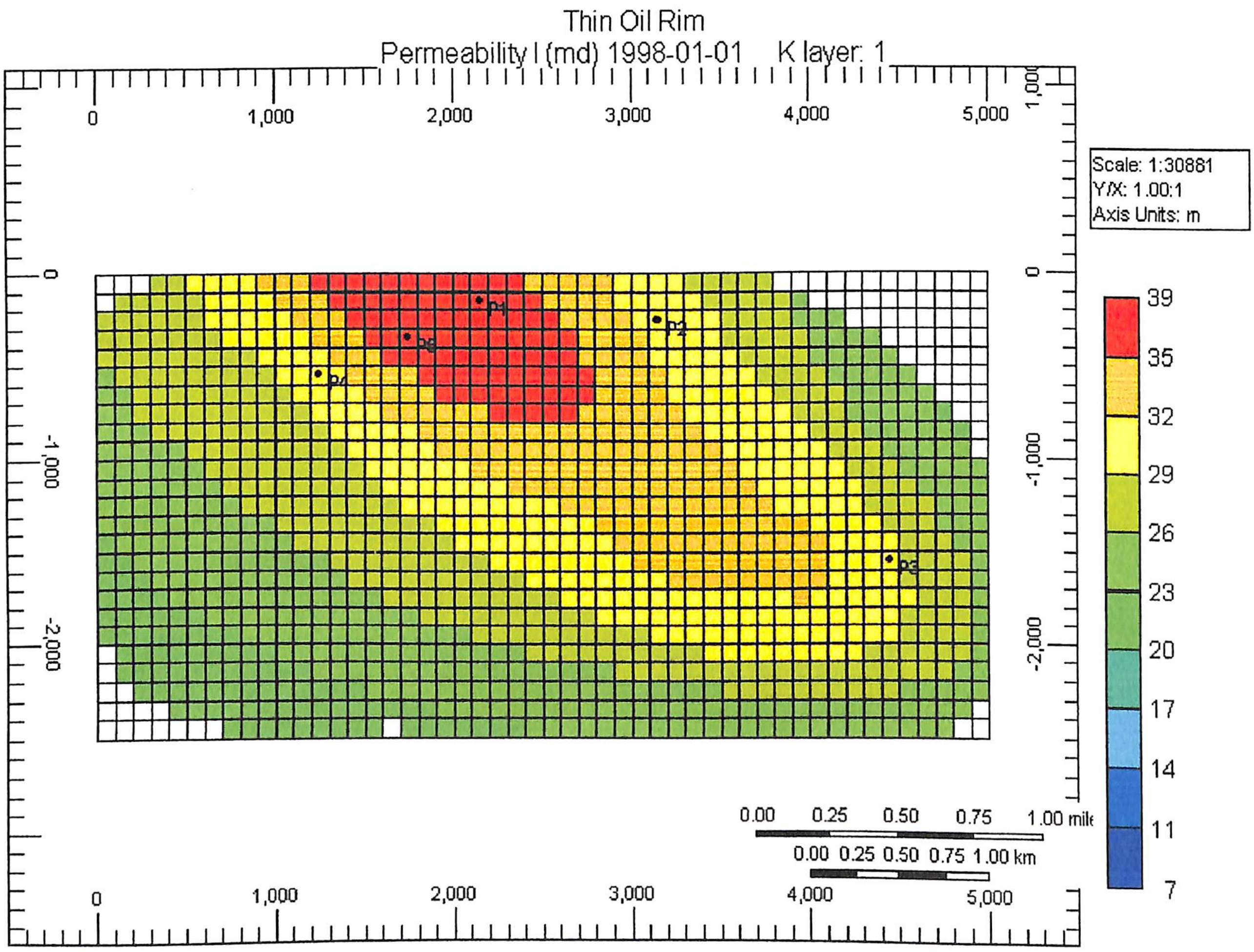


Figure-16 IMEX, CMG

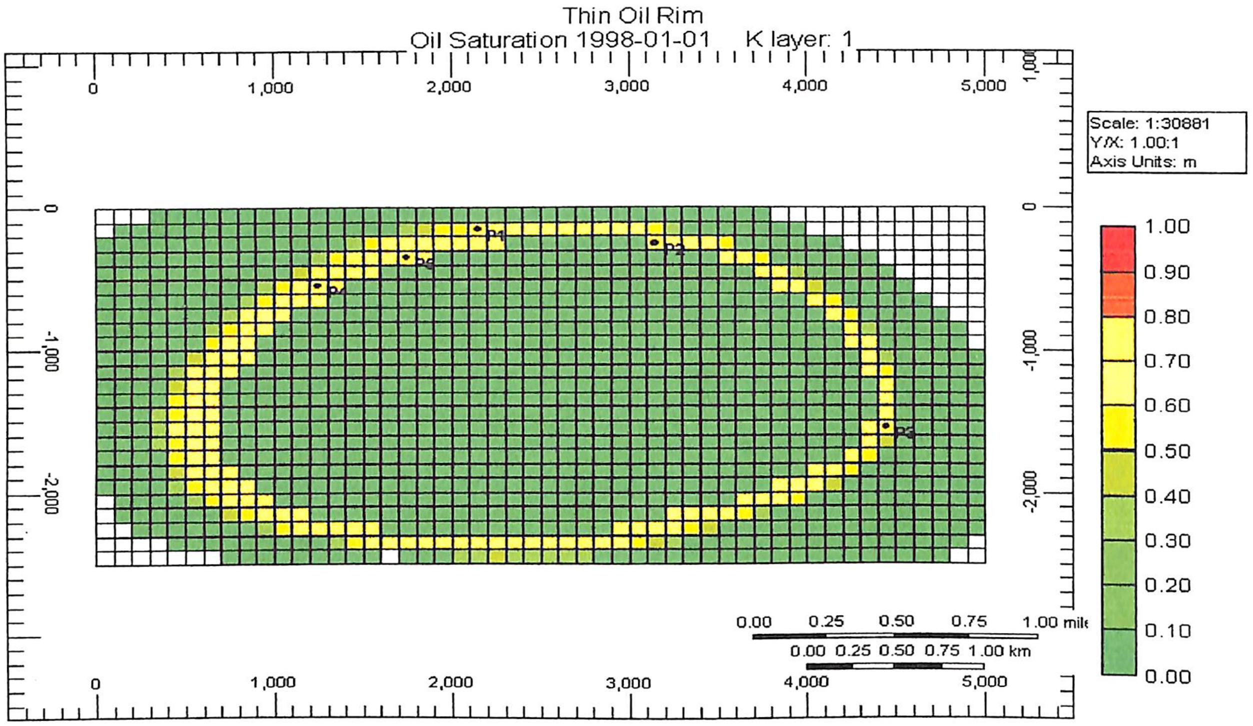


Figure- 17 IMEX, CMG

The production from the field started on 1st January 1999. The reservoir was simulated using these five vertical wells till 1st January, 2009 (a period of ten years). The performance of each well was observed for a period of two years.

INDIVIDUAL WELL PERFORMANCE

WELL P1

The well is drilled in the reservoir having the following block address (22, 2, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	38.1048 md
Oil saturation (So)	.6253
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3447

GRAPHICAL RESULT OF WELL P1

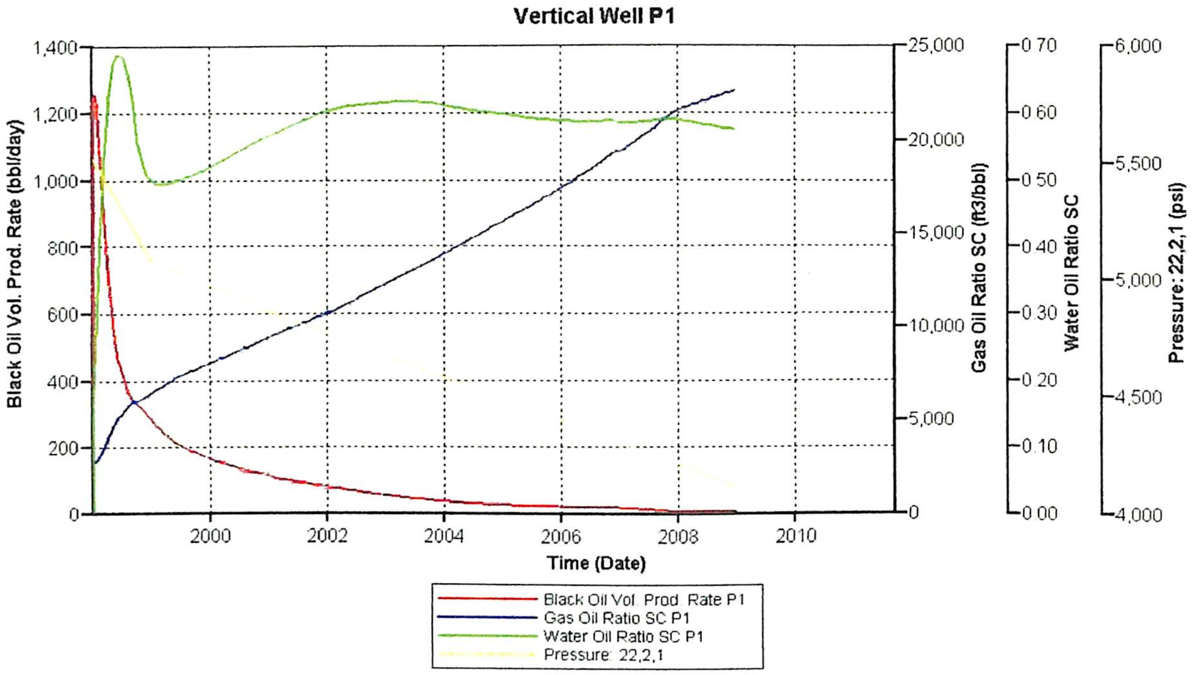


Figure-18 IMEX, CMG

Figure-18 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P1 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P1 (Table 1)

WELL 1				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5525.36	2824.76	0.00	1260.09
2000	4975.71	8084.62	0.52	166.65
2002	4771.27	10735.05	0.60	80.30
2004	4585.38	13869.19	0.61	36.31
2006	4397.33	17399.47	0.59	20.96
2008	4211.38	21550.78	0.59	5.66
2009	4115.97	22636.30	0.57	5.00

WELL P2

The well is drilled in the reservoir having the following block address (32, 3, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	31.1540 md
Oil saturation (So)	.7
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3

GRAPHICAL RESULT OF WELL P2

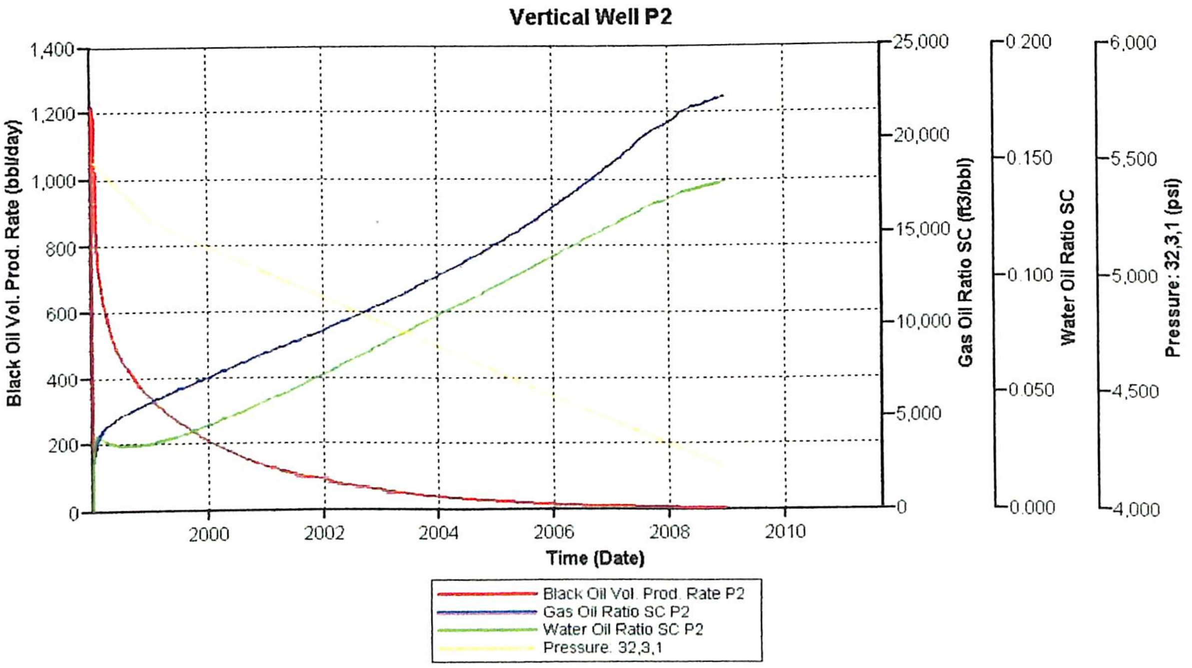


Figure-19 IMEX, CMG

Figure-19 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P2 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P2 (Table 2)

WELL 2				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5515.57	2924.85	0	1222.53
2000	5141.09	7127.73	0.0363	207.99
2002	4920.91	9673.20	0.0585	89.67
2004	4703.89	12615.69	0.084	37.87
2006	4491.44	16286.60	0.1097	14.80
2008	4283.38	20826.08	0.1344	5.77
2009	4182.63	22246.50	0.1421	2.39

WELL P3

The well is drilled in the reservoir having the following block address (45, 16, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	30.0138 md
Oil saturation (So)	.64
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3576

GRAPHICAL RESULT OF WELL P3

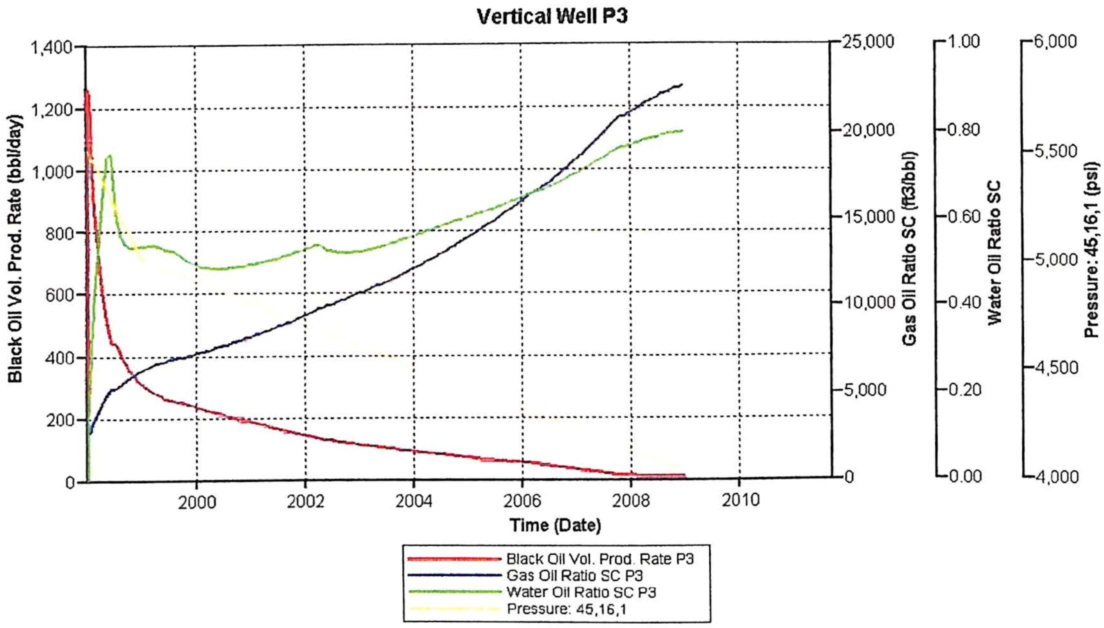


Figure-20 IMEX, CMG

Figure-20 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P3 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P3 (Table 3)

WELL 3				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5524.79	2785.70	0	1264.27
2000	4916.59	7272.92	0.494	238.40
2002	4717.20	9434.00	0.5307	144.94
2004	4520.66	12101.22	0.5609	92.13
2006	4328.57	16035.79	0.6501	54.56
2008	4138.53	21051.58	0.7685	15.72
2009	4040.52	22607.18	0.8	11.33

WELL P4

The well is drilled in the reservoir having the following block address (13, 6, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	30.7414 md
Oil saturation (So)	.688
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3112

GRAPHICAL RESULT OF WELL P4

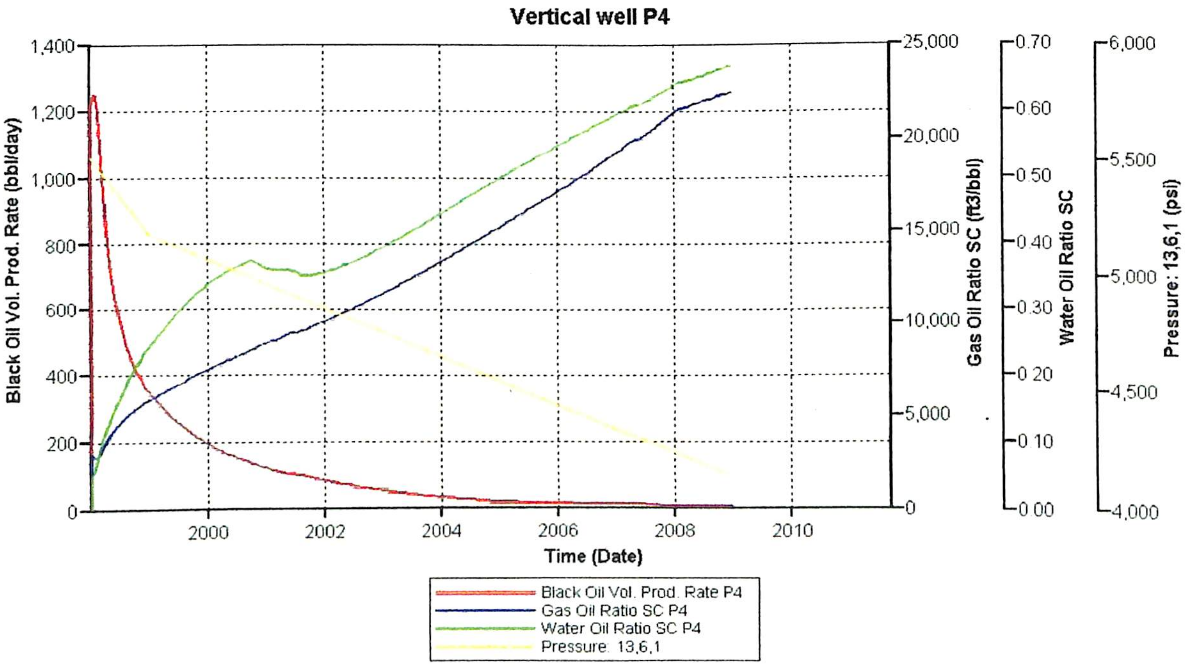


Figure-21 IMEX, CMG

Figure-21 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P4 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P4 (Table 4)

WELL 4				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5520.99	2851.03	0	1254.09
2000	5075.19	7415.24	0.3384	196.46
2002	4863.61	10025.69	0.356	87.52
2004	4651.34	13336.71	0.4462	33.04
2006	4441.92	17101.24	0.5486	15.02
2008	4240.32	21363.61	0.6394	4.93
2009	4139.61	22479.05	0.6695	4.32

WELL P5

The well is drilled in the reservoir having the following block address (18, 4, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	36.9031 md
Oil saturation (So)	.7
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3

GRAPHICAL RESULT OF WELL P5

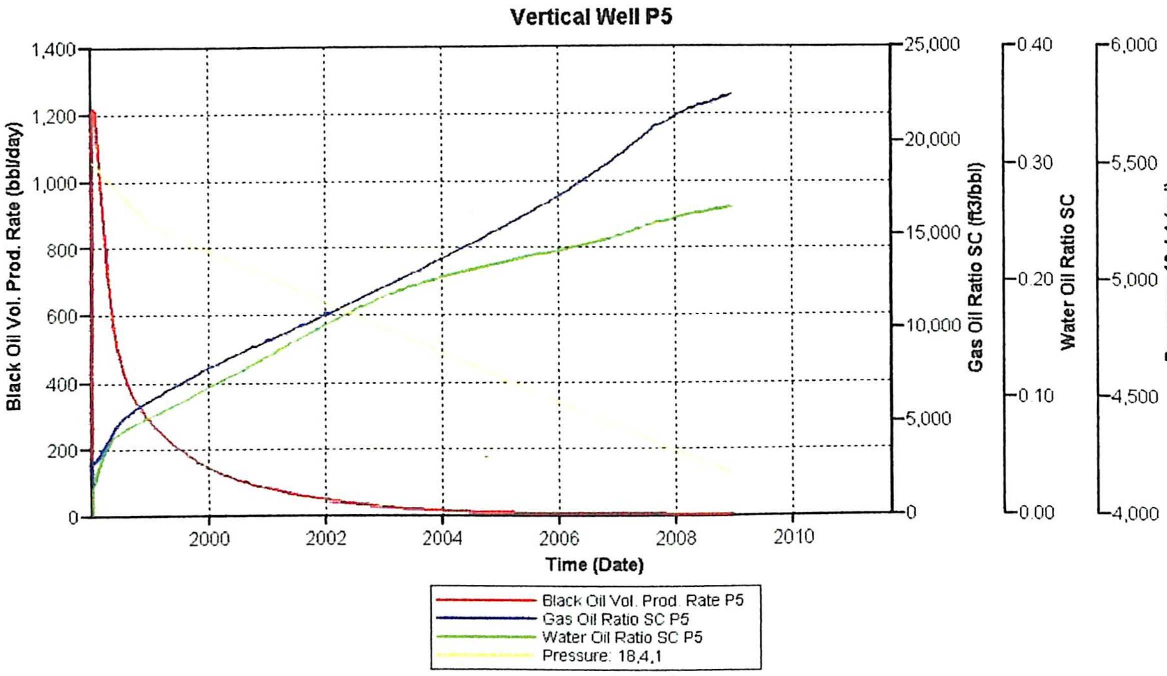


Figure-22 IMEX, CMG

Figure-22 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P5 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P5 (Table 5)

WELL 5				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5517.59	2914.79	0	1222.23
2000	5132.16	7902.53	0.1105	146.59
2002	4912.59	10667.02	0.16335	47.84
2004	4696.07	13710.45	0.2034	14.22
2006	4484.82	17055.41	0.225936	5.79
2008	4278.07	21273.96	0.254	2.53
2009	4177.51	22452.45	0.263414	1.39

FIELD PERFORMANCE

The overall field performance of thin oil rim using vertical wells as one of the production strategies is shown in the graph below:

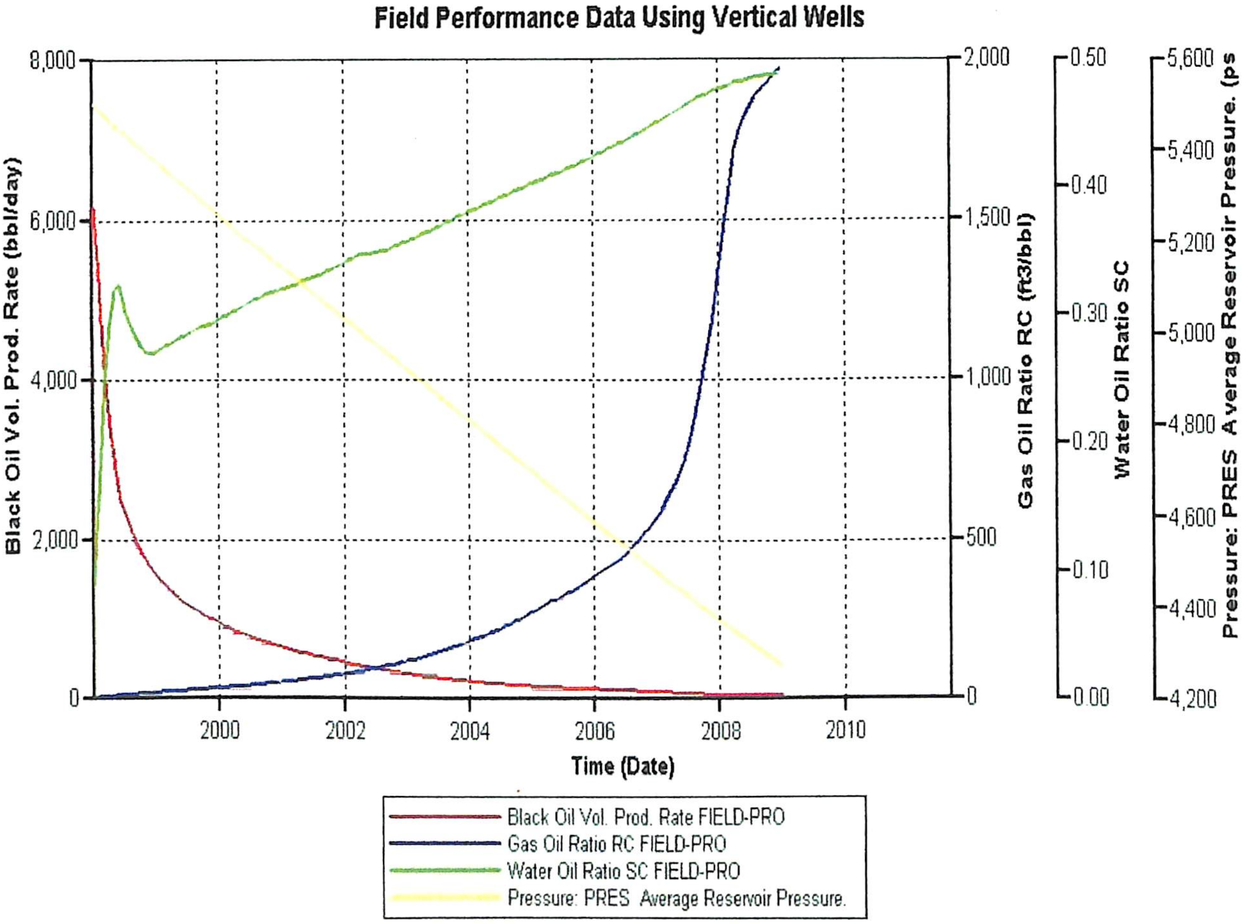


Figure-23 IMEX, CMG

Figure-23 shows the change in black oil volume production rate, GOR, WOR and pressure for the field with respect to time after the simulation run.

CUMULATIVE OIL PRODUCTION

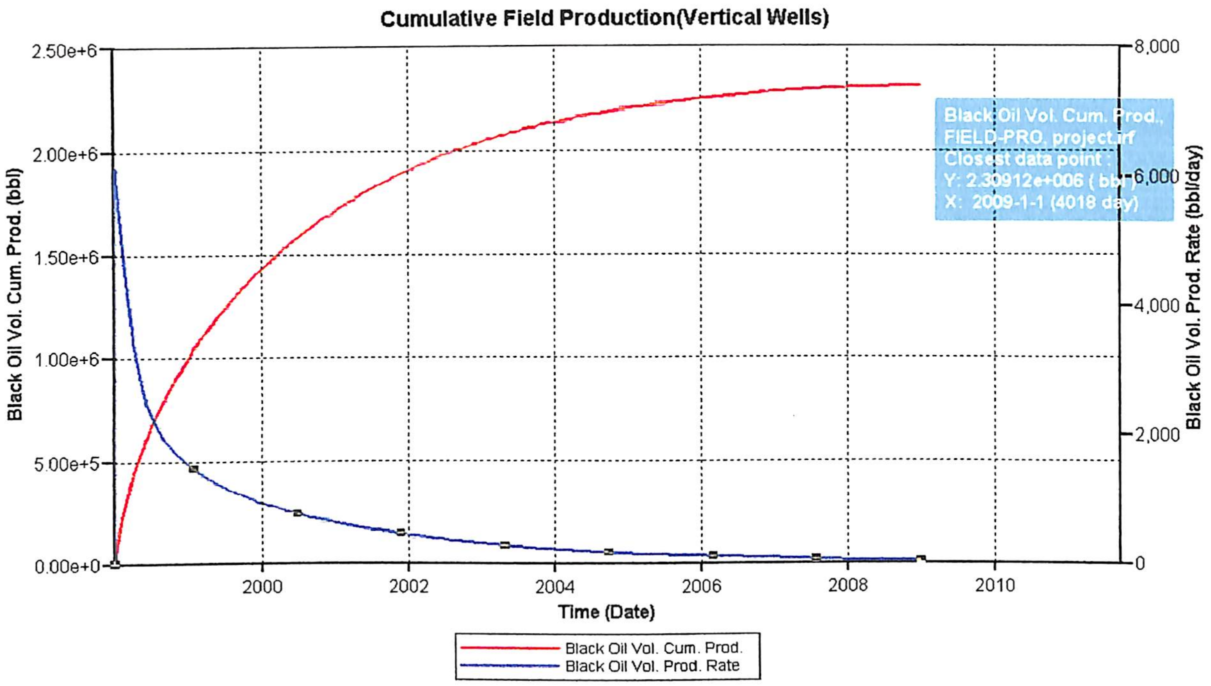


Figure-24 IMEX, CMG

Figure-24 shows the cumulative black oil production and black oil volume production rate for overall field with respect to time after the simulation run.

CONCLUSION

The production strategy used for the economic exploitation of the Thin Oil Rim in the base case 1 was done by using five vertical well. Each well is analyzed in a period of two years for the whole simulation run. For each well its pressure, GOR, WOR and the production rate is documented. It was observed that for each well when put on production gave a decent performance during the first four years of the exploitation. After this period the well production rate decreased below the economic limits. It was observed that once the well is put on production the gas cap and the aquifer expands and encroaches the oil rim. This can be easily seen by the increasing GOR of each well. It is felt that gas expansion and water encroachment may have helped the production rate in the initial years only. The reservoir pressure, too, declines steadily and thus it can be concluded that both gas expansion and water encroachment were not a help in maintaining the pressure. It was anticipated that the expansion of the large gas cap can be a help in maintaining the pressure and thereby increasing oil production from the Rim. But this was not true and the residual oil saturation was almost half of the initial oil saturation In the base case 1 it was Well 3 whose performance was most satisfactory for the whole simulation run. The cumulative production from base case I was 2.309e+006 bbl and 9.22% of the OOIP.

3.4 CASE II

Approach using horizontal wells

The field was put on production using five horizontal wells (P1, P2, P3, P4 and P5). The locations of these wells were decided based on the initial permeability distribution and initial oil saturation. Locations with highest permeability and maximum oil saturation were chosen taking care that the wells were drilled in the middle of the Oil Rim. This is shown using an IJ-2D Areal view for both permeability and oil saturation of the reservoir.

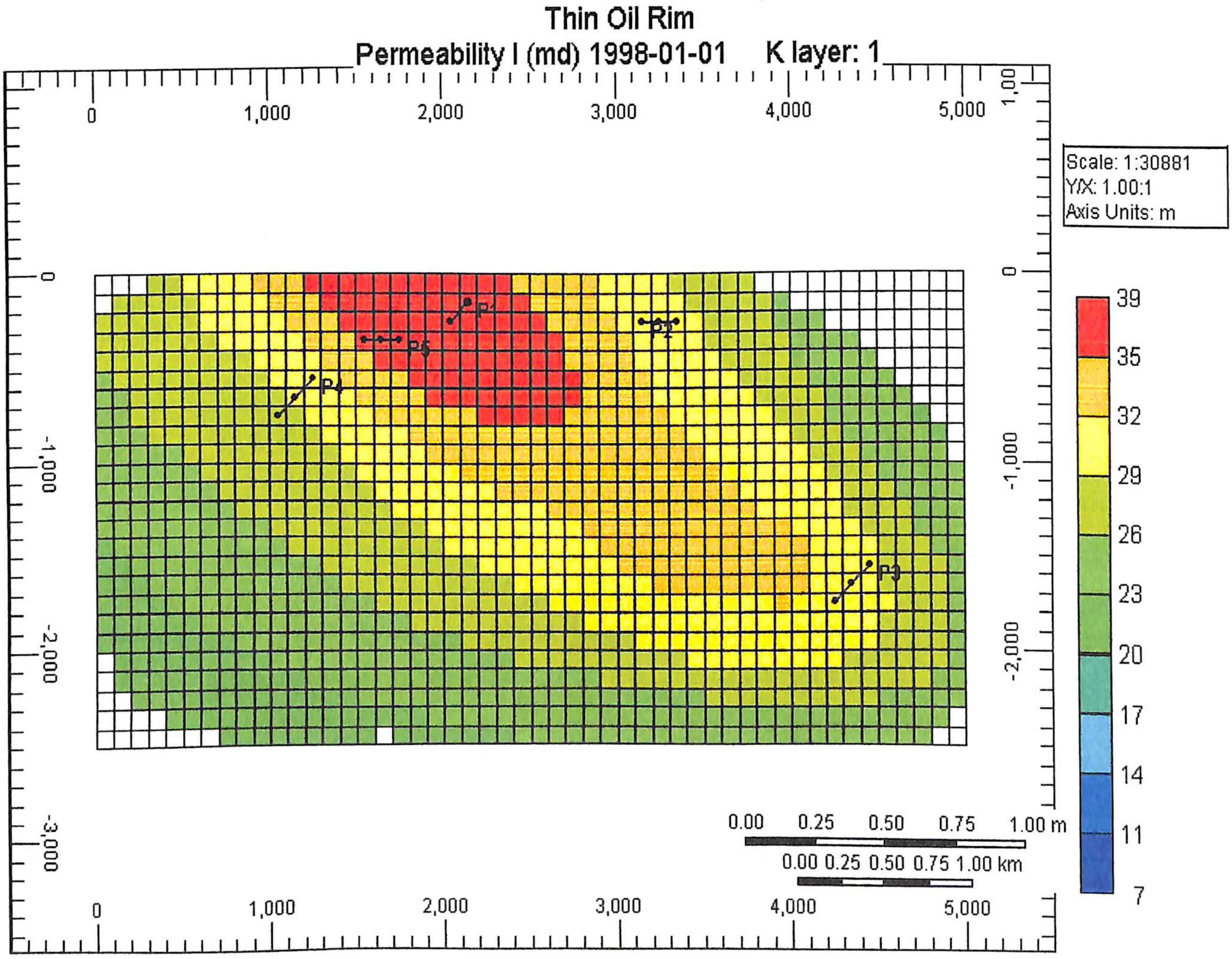


Figure-25 IMEX, CMG

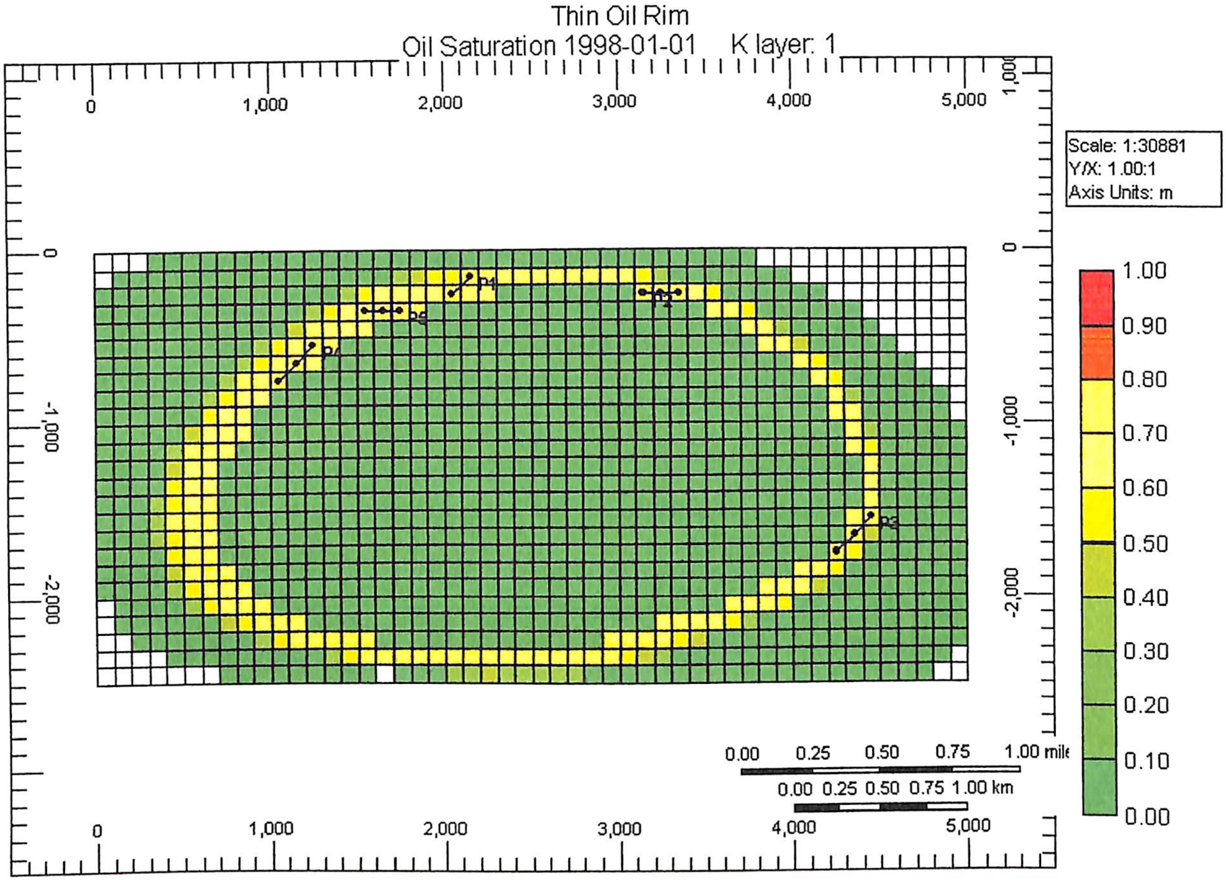


Figure-26 IMEX, CMG

The production from the field started on 1st January 1999. The reservoir was simulated using these five vertical wells till 1st January, 2009 (a period of ten years). The performance of each well was observed for a period of two years.

INDIVIDUAL WELL PERFORMANCE

WELL P1

The well is drilled in the reservoir having the following block address (21, 3, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	38.1052
Oil saturation (So)	.7
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3

GRAPHICAL RESULT OF WELL P1

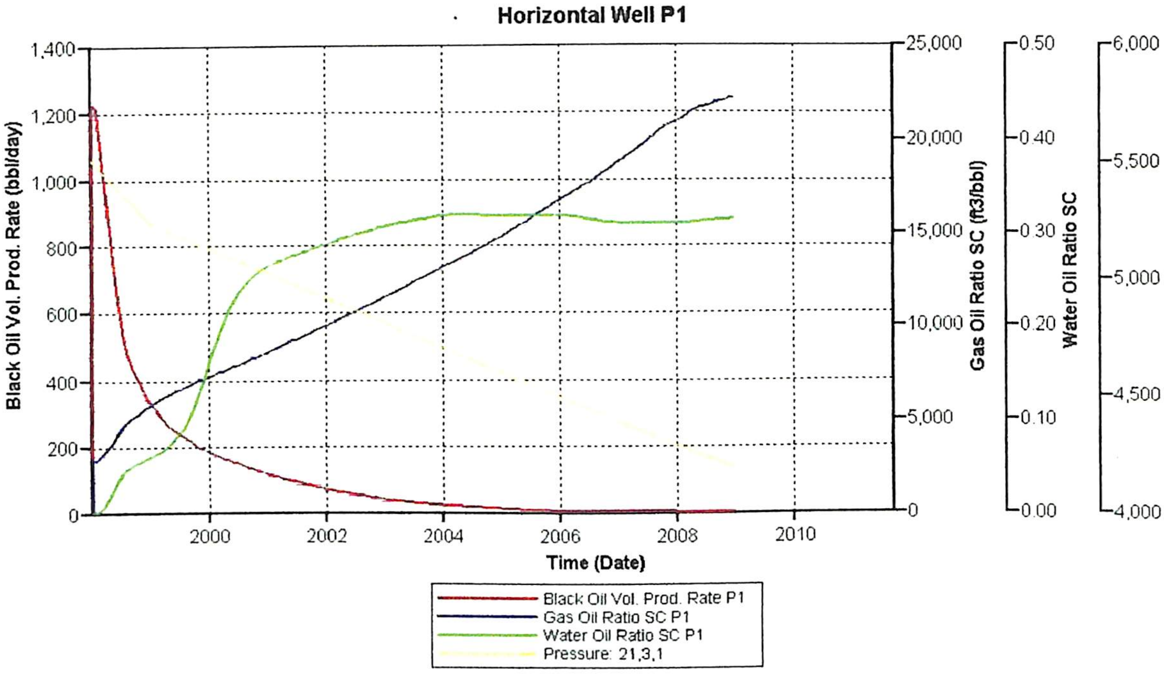


Figure-27 IMEX, CMG

Figure-27 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P1 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P1 (Table 6)

WELL 1				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5525.52	2895.41	0	1227.79
2000	5166.07	7371.63	0.16138	186.91
2002	4929.67	10037.76	0.2878	73.63
2004	4716.17	13115.78	0.3182	24.66
2006	4508.35	16748.22	0.3185	6.70
2008	4304.36	20928.80	0.3092	4.10
2009	4203.87	22235.00	0.3143	1.33

WELL P2

The well is drilled in the reservoir having the following block address (32, 3, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	30.49
Oil saturation (So)	.7
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3

GRAPHICAL RESULT OF WELL P2

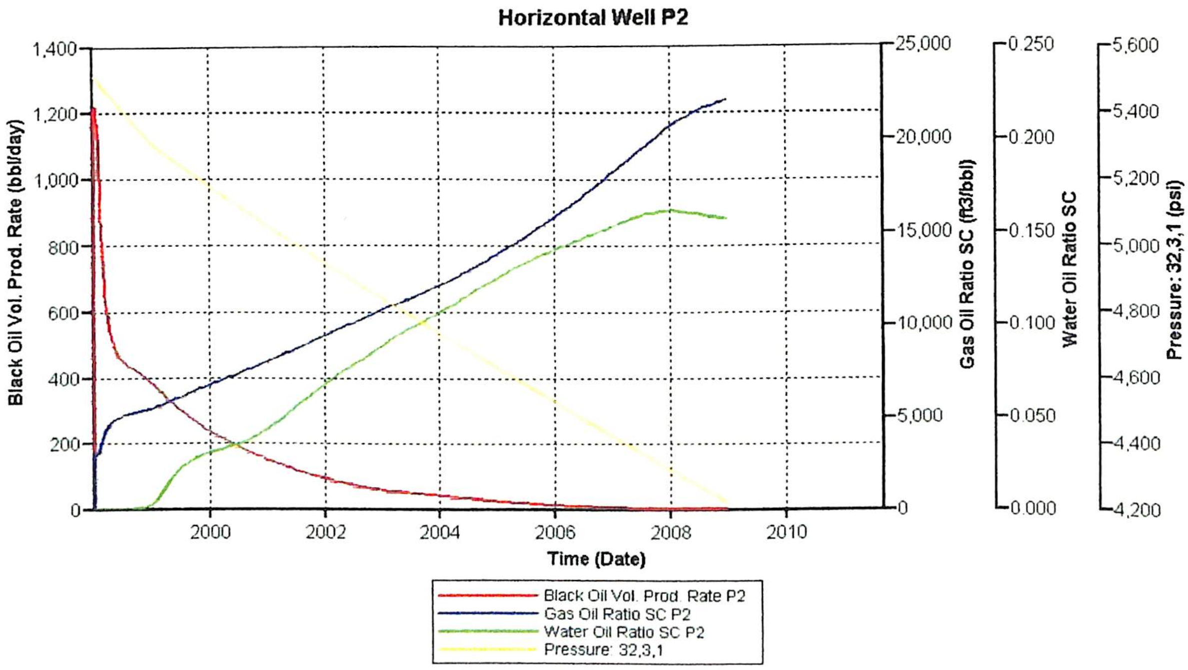


Figure-28 IMEX, CMG

Figure-28 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P2 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P2 (Table7)

WELL 2				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5515.73	3229.5	0	1221.47
2000	5179.56	6752.8	0.03068	236.82
2002	4950.92	9420.2	0.06385	93.20
2004	4738.66	12159.2	0.10693	41.89
2006	4529.96	15837.4	0.140502	12.95
2008	4321.05	20145.2	0.161904	2.67
2009	4219.65	22068.6	0.15746	0.88

WELL P3

The well is drilled in the reservoir having the following block address (43, 18, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	31.09
Oil saturation (So)	.69
Gas Saturation (Sg)	0
Water Saturation (Sw)	.307

GRAPHICAL RESULT OF WELL P3

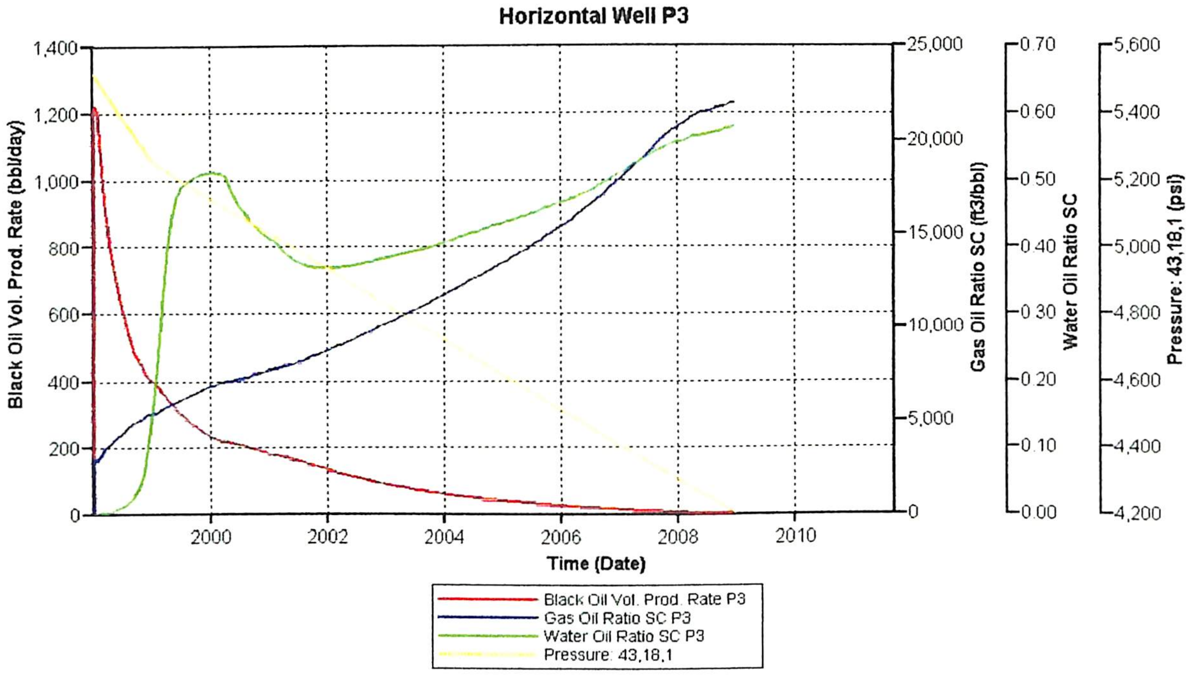


Figure-29 IMEX, CMG

Figure-29 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P3 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P3 (Table 8)

WELL 3				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5524.95	2900.0	0	1224.7
2000	5134.19	6839.0	0.5133	236.2
2002	4937.52	8758.9	0.3679	134.6
2004	4725.16	11701.5	0.4063	60.2
2006	4513.13	15357.3	0.466	26.0
2008	4306.20	20603.3	0.555	6.3
2009	4203.12	21989.8	0.5809	3.2

WELL P4

The well is drilled in the reservoir having the following block address (11, 8, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	29.53
Oil saturation (So)	.69
Gas Saturation (Sg)	0
Water Saturation (Sw)	.307

GRAPHICAL RESULT OF WELL P4

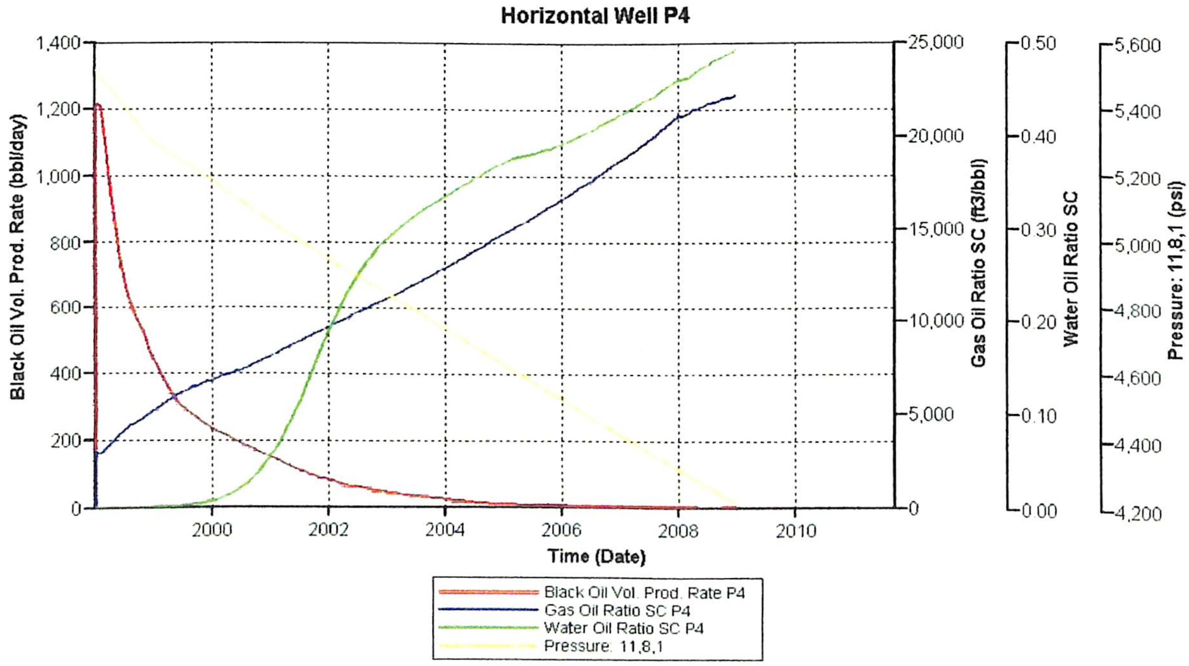


Figure-30 IMEX, CMG

Figure-30 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P4 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P4 (Table 9)

WELL 4				
YEAR	Pressure(psi)	GOR (ft3/bbl)	WOR	Production(bbl/day)
1998	5521.15	2922.97	0	1215.40
2000	5181.61	6767.71	0.0068	235.33
2002	4960.08	9646.00	0.181265	83.65
2004	4734.89	12922.28	0.33568	23.45
2006	4519.89	16598.57	0.392453	4.23
2008	4310.58	21046.66	0.46044	1.76
2009	4208.46	22171.65	0.493326	0.62

WELL P5

The well is drilled in the reservoir having the following block address (16, 4, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k) 33.68

Oil saturation (So) .683

Gas Saturation (Sg) 0

Water Saturation (Sw) .316

GRAPHICAL RESULT OF WELL P5

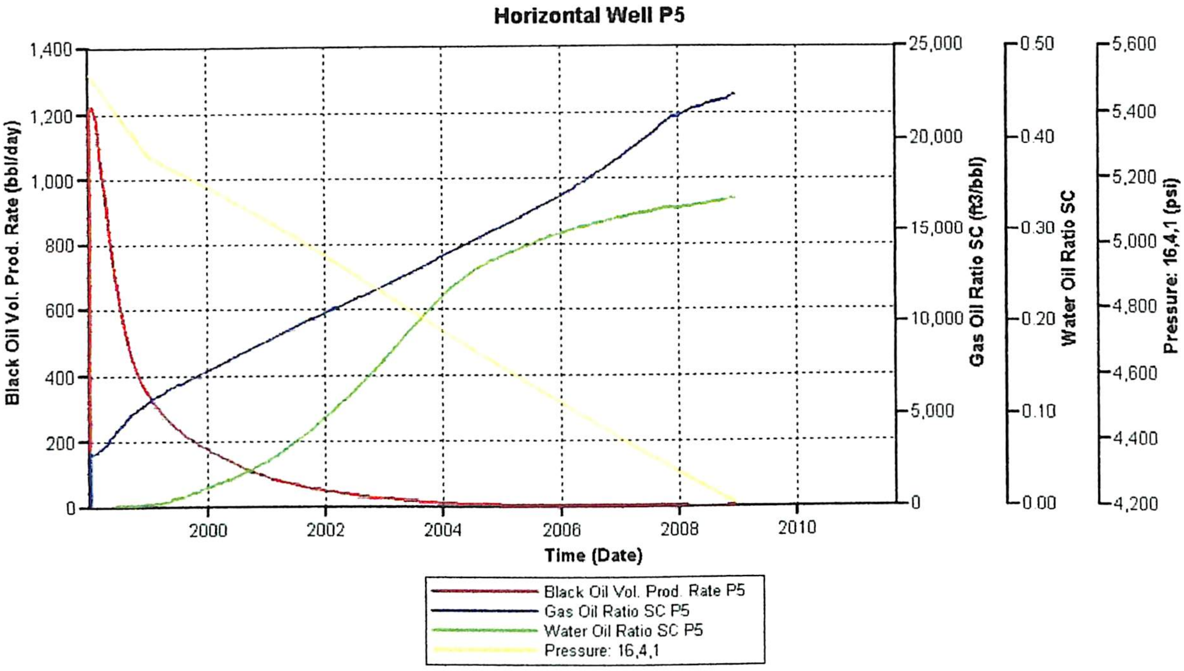


Figure-31 IMEX, CMG

This figure shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P5 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P5 (Table 10)

		WELL 5		
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5517.75	2913.85	0	215212.71
2000	5165.73	7419.91	0.02135	205441.79
2002	4937.02	10503.09	0.097857	196113.28
2004	4724.94	13572.47	0.227872	187031.47
2006	4512.64	16904.10	0.2969	182600.38
2008	4303.31	21171.98	0.3248	1.47
2009	4201.02	22346.53	0.33633	0.37

FIELD PERFORMANCE

The overall field performance of thin oil rim using Horizontal wells as one of the production strategies is shown in the graph below:

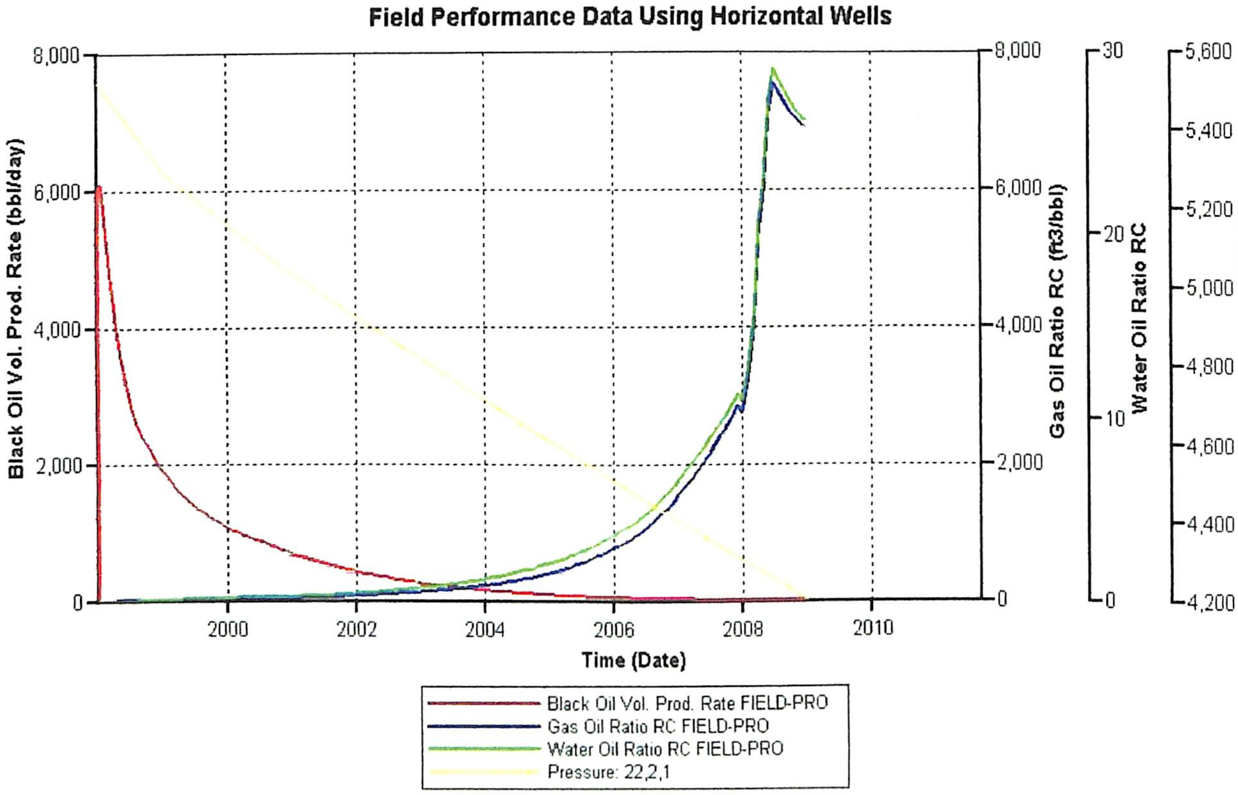


Figure-32 IMEX, CMG

Figure-32 shows the change in black oil volume production rate, GOR, WOR and pressure for the field with respect to time after the simulation run.

Cumulative Oil Production

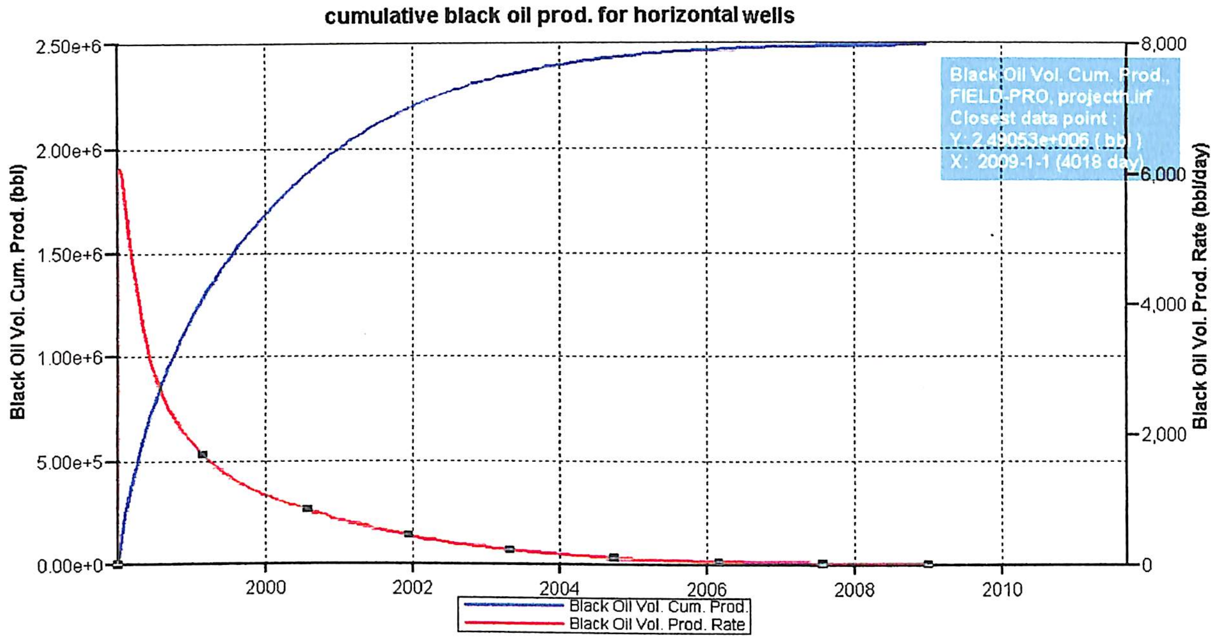


Figure-33 IMEX, CMG

Figure-33 shows the cumulative black oil production and black oil volume production rate for overall field with respect to time after the simulation run.

CONCLUSION

The production strategy used for the economic exploitation of the Thin Oil Rim in the case II was done by using five horizontal wells. Each well is analyzed in a period of two years for the whole simulation run. For each well its pressure, GOR, WOR and the production rate is documented.

The use of horizontal wells was in anticipation to increase recovery from the thin oil rim. Five horizontal wells were drilled based on the high permeability distribution and the oil saturation. Comparison with the vertical wells case I, higher recovery was seen. The cumulative production from case II is 2.49e+006 and 10% of the OOIP.

3.5 CASE III

Approach using Horizontal wells near GOC

The field was put on production using five Horizontal wells near GOC (P1, P2, P3, P4 and P5). The locations of these wells were decided based on the initial permeability distribution and initial oil saturation. Locations with highest permeability and maximum oil saturation were chosen taking care that the wells were drilled in the middle of the Oil Rim. This is shown using an IJ-2D Areal view for both permeability and oil saturation of the reservoir.

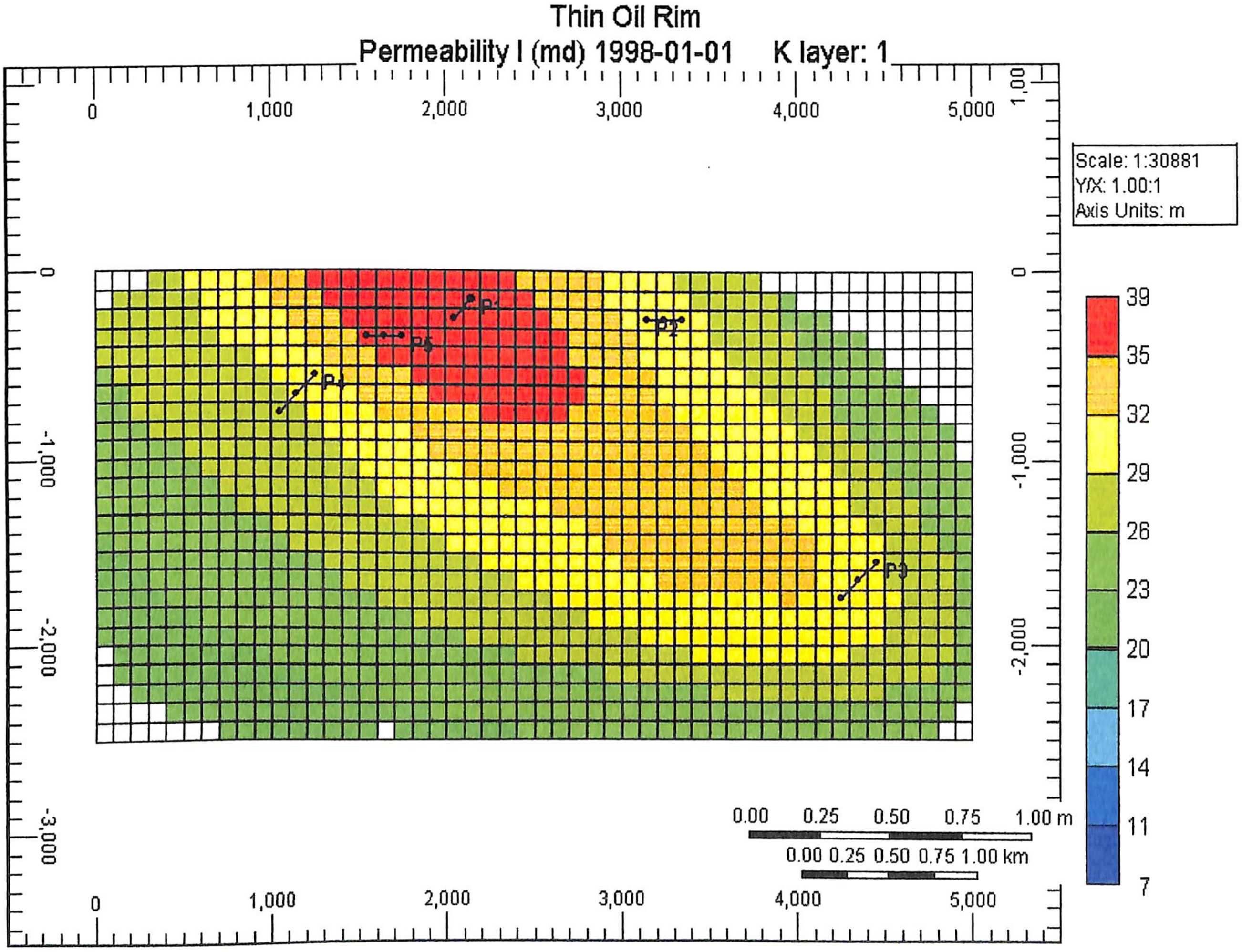


Figure-34 IMEX, CMG

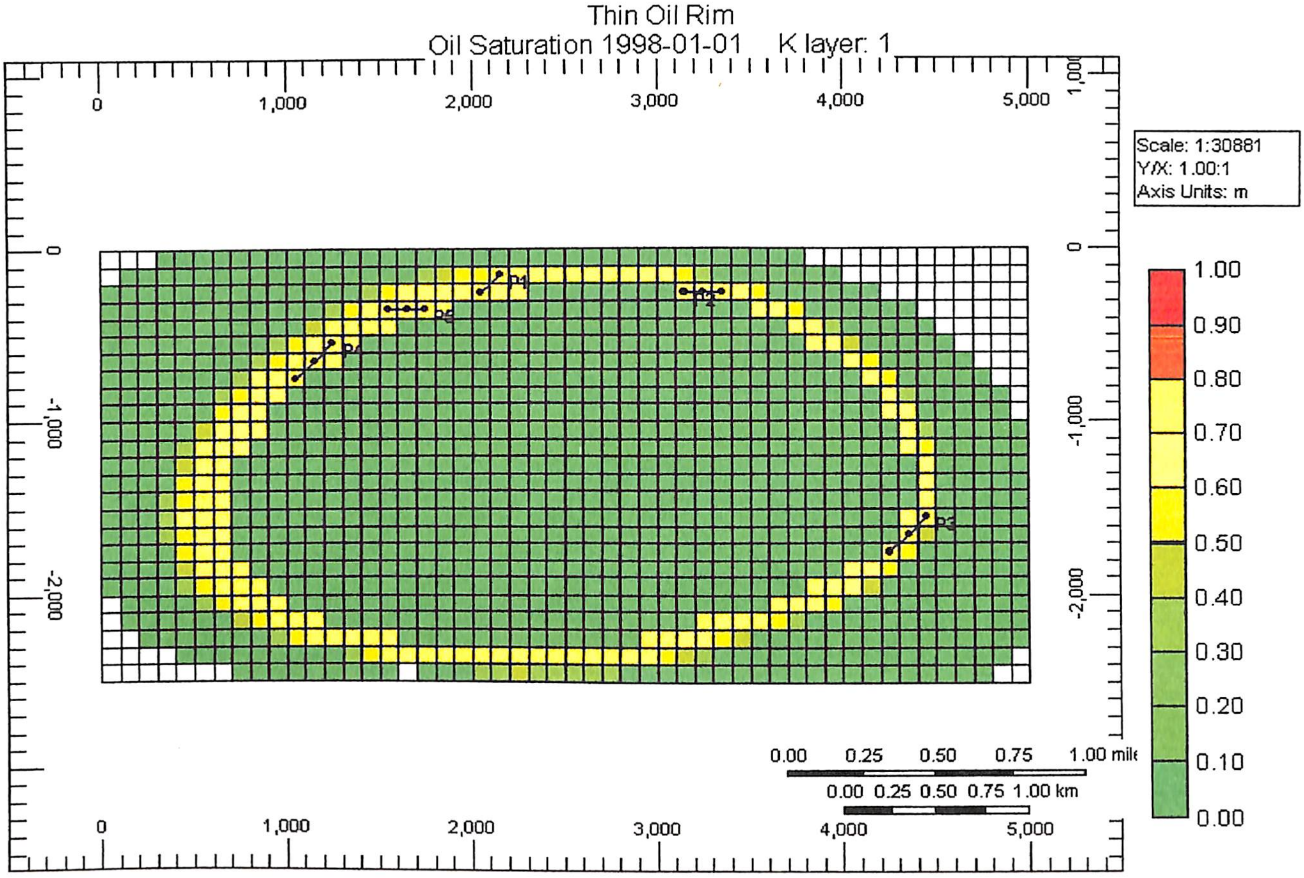


Figure-35 IMEX, CMG

The production from the field started on 1st January 1999. The reservoir was simulated using these five vertical wells till 1st January, 2009 (a period of ten years). The performance of each well was observed for a period of two years.

INDIVIDUAL WELL PERFORMANCE

WELL P1

The well is drilled in the reservoir having the following block address (21, 3, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	38.105
Oil saturation (So)	.69
Gas Saturation (Sg)	0
Water Saturation (Sw)	.303

GRAPHICAL RESULT OF WELL P1

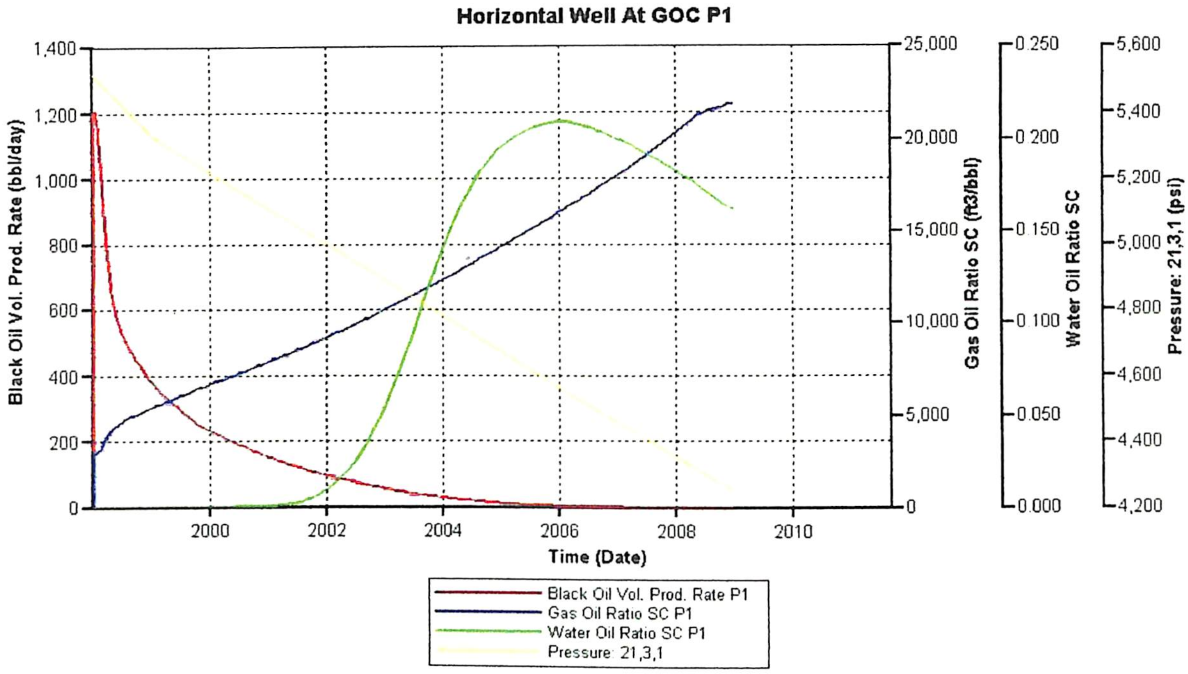


Figure-36 IMEX, CMG

Figure-36 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P1 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P1 (Table 11)

WELL 1				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5519.9	2899.33	0	1218.03
2000	5135.65	7322.2	0.1613	186.85
2002	4920.26	9980.78	0.2878	73.58
2004	4708.08	13133.1	0.3181	25.23
2006	4498.24	16771.4	0.3185	6.7
2008	4292.53	20956.76	0.3092	4.1
2009	4191.49	22264.87	0.3146	1.7

WELL P2

The well is drilled in the reservoir having the following block address (32, 3, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	30.49
Oil saturation (So)	.696
Gas Saturation (Sg)	0
Water Saturation (Sw)	.303

GRAPHICAL RESULT OF WELL P2

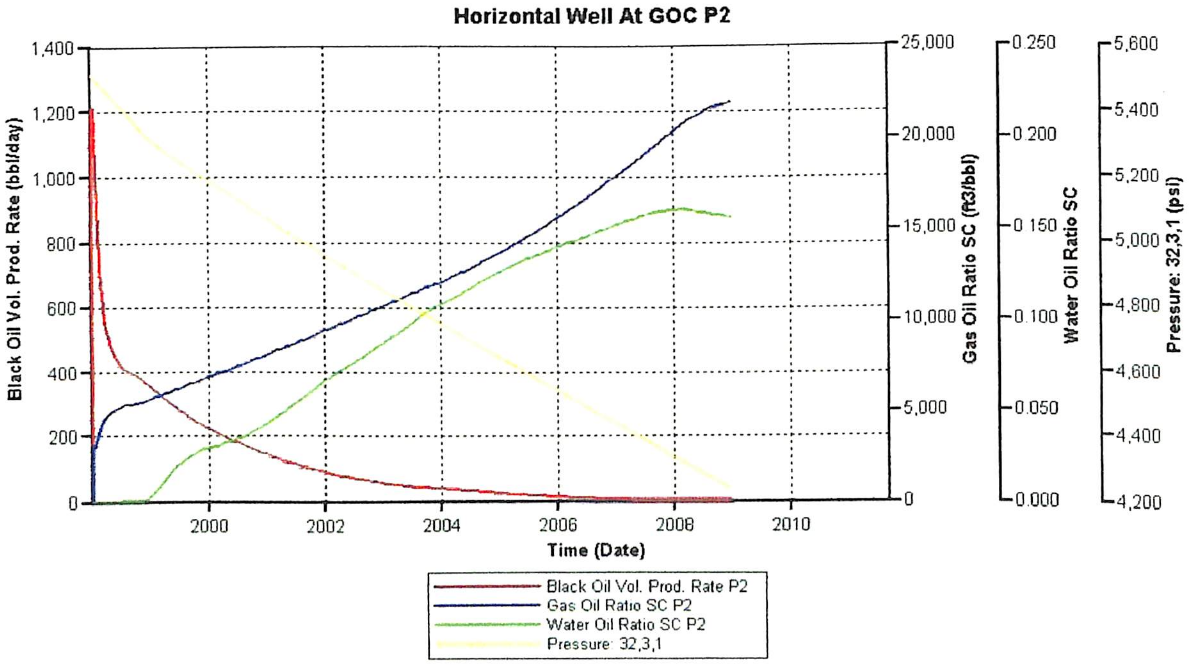


Figure-37 IMEX, CMG

Figure-37 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P2 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P2 (Table 12)

well p2				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5515.53	2896.97	0	1219.01
2000	5179.35	6761.1	0.03	236.79
2002	4950.47	9431.94	0.06	93.21
2004	4738.5	12175.9	0.106	41.02
2006	4529.8	15858	0.141	12.96
2008	4320.9	20734.4	0.16	2.66
2009	4219.49	22098.3	0.157	0.88

WELL P3

The well is drilled in the reservoir having the following block address (42, 49, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	31.157
Oil saturation (So)	.687
Gas Saturation (Sg)	0
Water Saturation (Sw)	.312

GRAPHICAL RESULT OF WELL P3

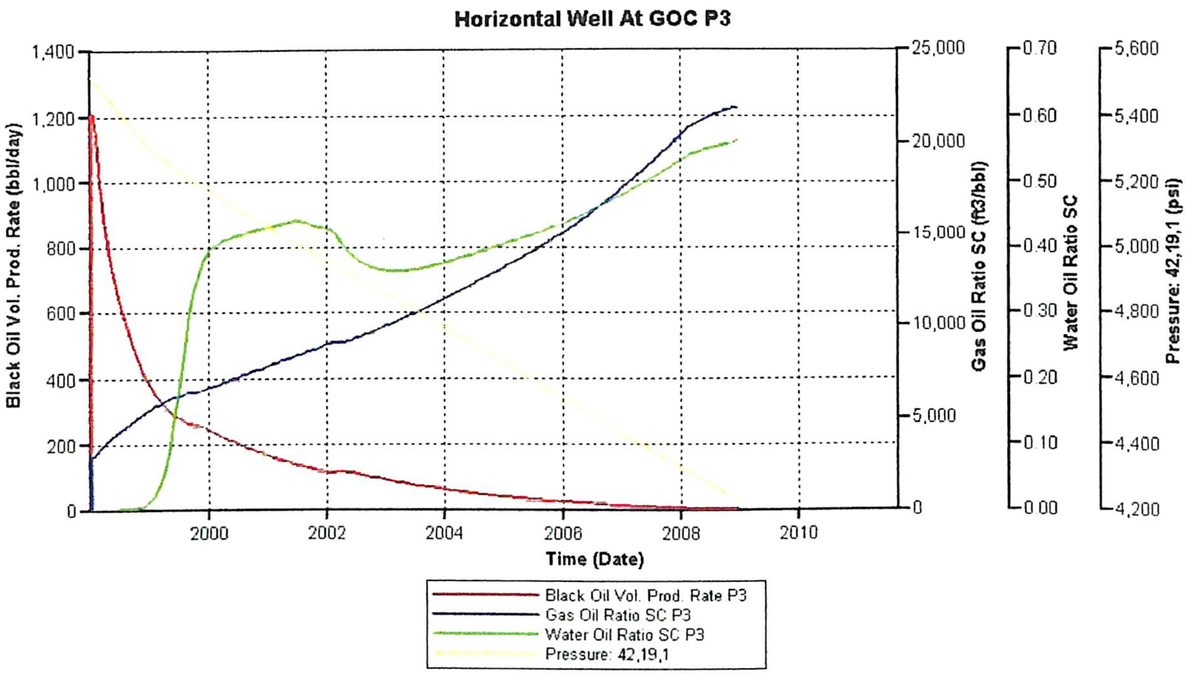


Figure-38 IMEX, CMG

Figure-38 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P3 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P3 (Table 13)

well p3				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5520.82	2903.97	0	1216.08
2000	5246.18	6848.22	0.511	235.07
2002	5022.88	8770.76	0.367	134.52
2004	4802.02	11717.1	0.406	60.19
2006	4583.4	15378	0.466	26
2008	4369.37	20593.3	0.555	6.37
2009	4265.83	22018.9	0.58	3.18

WELL P4

The well is drilled in the reservoir having the following block address (10, 9, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	29.53
Oil saturation (So)	.687
Gas Saturation (Sg)	0
Water Saturation (Sw)	.307

GRAPHICAL RESULT OF WELL P4

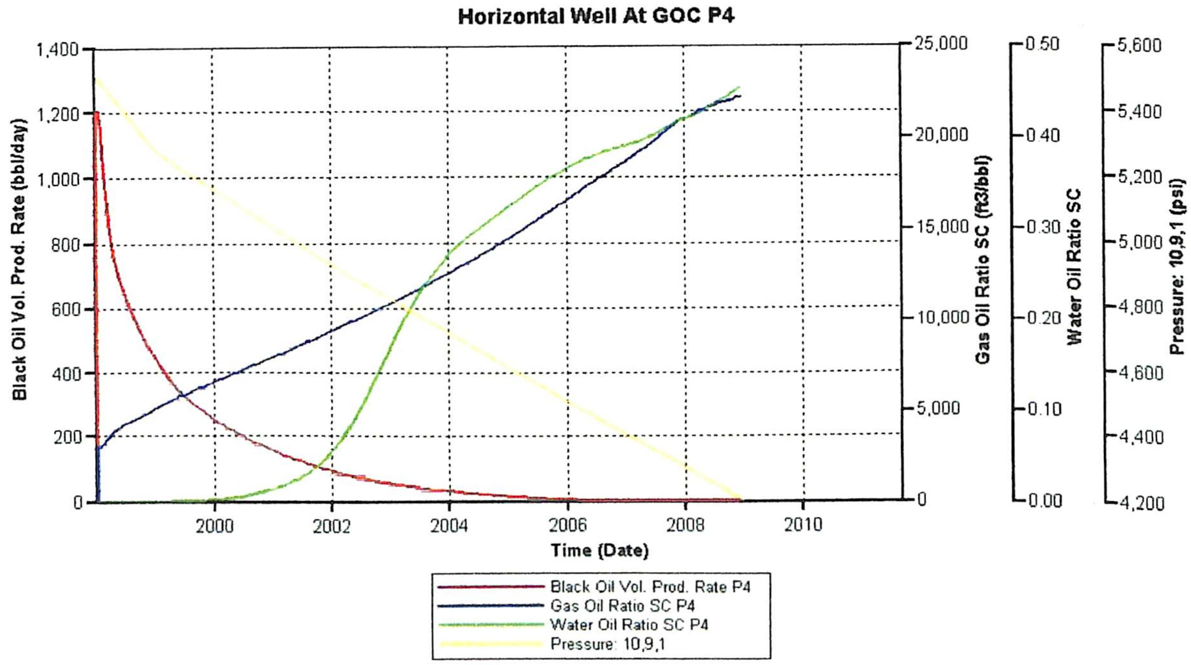


Figure-39 IMEX, CMG

Figure-39 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P4 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P4 (Table 14)

WELL 4				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5518.46	2906.9	0	1214.73
2000	5186.04	6776.8	0.006	235.2
2002	4951.8	9668.9	0.18	86.08
2004	4738.34	12939.5	0.335	23.44
2006	4524.23	16944.9	0.392	4.22
2008	4314.28	21076.9	0.46	1.76
2009	4212.16	22252.1	0.493	0.61

WELL P5

The well is drilled in the reservoir having the following block address (7, 15, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	36.36
Oil saturation (So)	.691
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3085

GRAPHICAL RESULT OF WELL P5

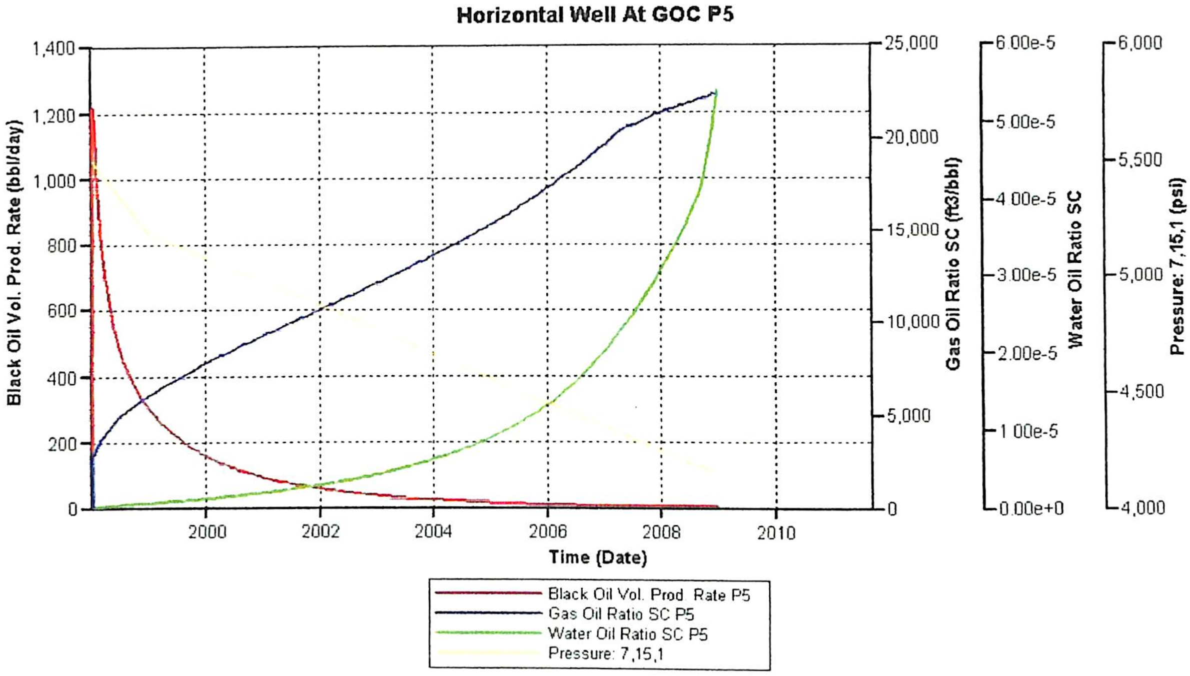


Figure-40 IMEX, CMG

Figure-40 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P5 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P5 (Table 15)

WELL 5				
YEAR	**Pressure(psi)**	**GOR (ft3/bbl)**	**WOR**	**Production(bbl/day)**
1998	5522.44	2917.7	0	1220
2000	5180.6	7355.6	0.02	177.52
2002	4964.52	1051.5	0.097	49.53
2004	4733.03	13590.7	0.227	10.62
2006	4515.16	16927.3	0.29	2.259
2008	4306.85	21152.1	0.324	1.466
2009	4205.45	22376.5	0.33	0.368

FIELD PERFORMANCE

The overall field performance of thin oil rim using horizontal wells near GOC as one of the production strategies is shown in the graph below:

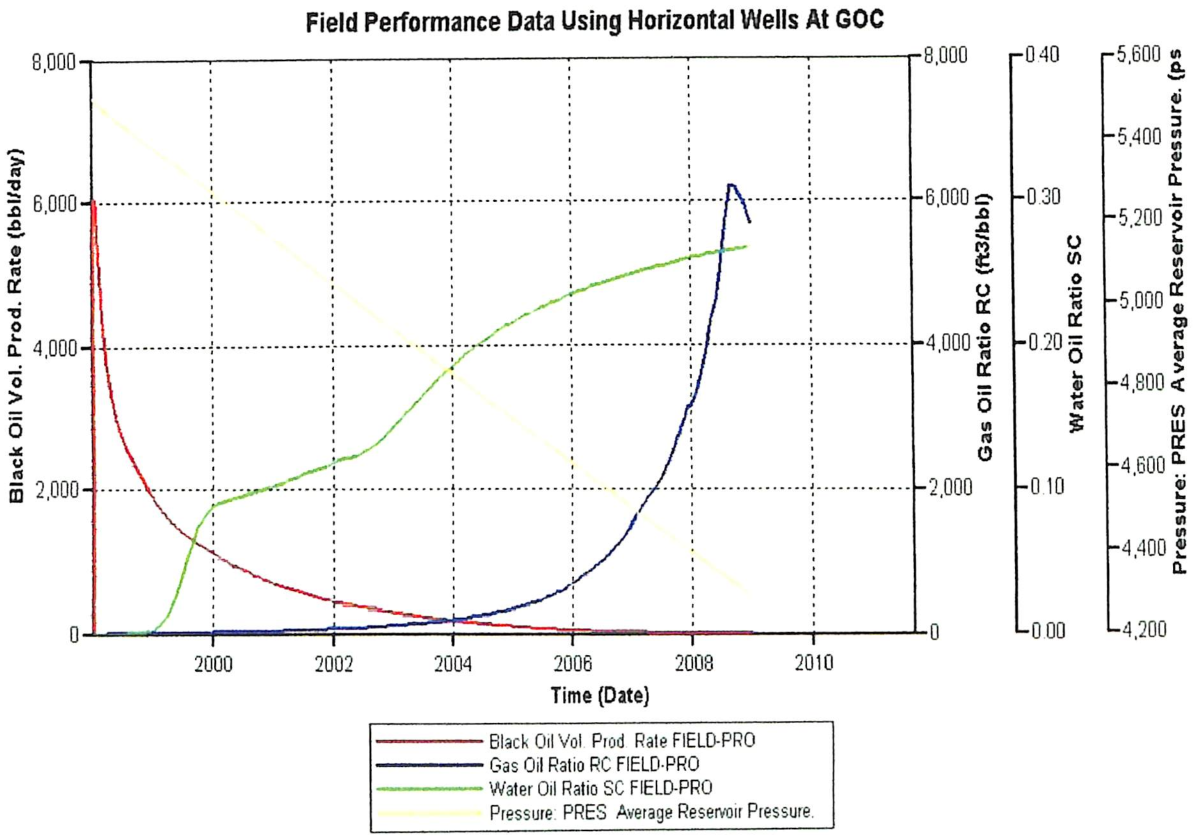


Figure-41 IMEX, CMG

Figure-41 shows the change in black oil volume production rate, GOR, WOR and pressure for the field with respect to time after the simulation run.

Cumulative Oil Production

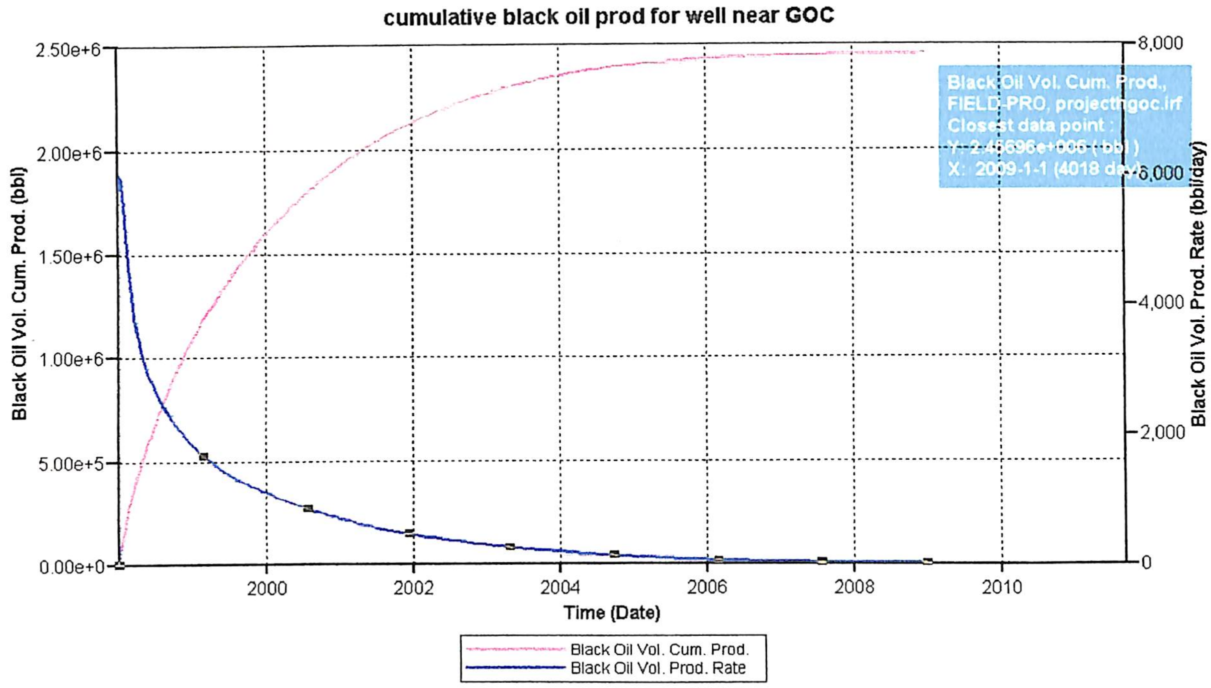


Figure-42 IMEX, CMG

Figure-42 shows the cumulative black oil production and black oil volume production rate for overall field with respect to time after the simulation run.

CONCLUSION

The production strategy used for the economic exploitation of the Thin Oil Rim in the base case III was done by using five horizontal wells near GOC. Each well is analyzed in a period of two years for the whole simulation run. For each well its pressure, GOR, WOR and the production rate is documented.

The given strategy was thought in lieu of the fact that a horizontal well placed in the middle of the pay zone was not be able to drive the oil above it as shown in fig. In order to deploy this remaining oil it was thought that the wells drilled at GOC can be helpful in driving the oil with the help of water as use of gas causes high residual oil saturation to be left behind. But due to poor aquifer activity the results were not satisfactory. Moreover, the field showed a high GOR rate and steep decline in production during the simulation run. Comparison with the base case (Vertical wells) a higher recovery was seen. The cumulative production from case III is 2.45696e+006 and 9.8% of the OOIP.

3.6 CASE IV

Approach using Horizontal sensitive wells

The field was put on production using five horizontal sensitive wells (P1, P2, P3, P4 and P5). The locations of these wells were decided based on the initial permeability distribution and initial oil saturation. Locations with highest permeability and maximum oil saturation were chosen taking care that the wells were drilled in the middle of the Oil Rim. This is shown using an IJ-2D Areal view for both permeability and oil saturation of the reservoir.

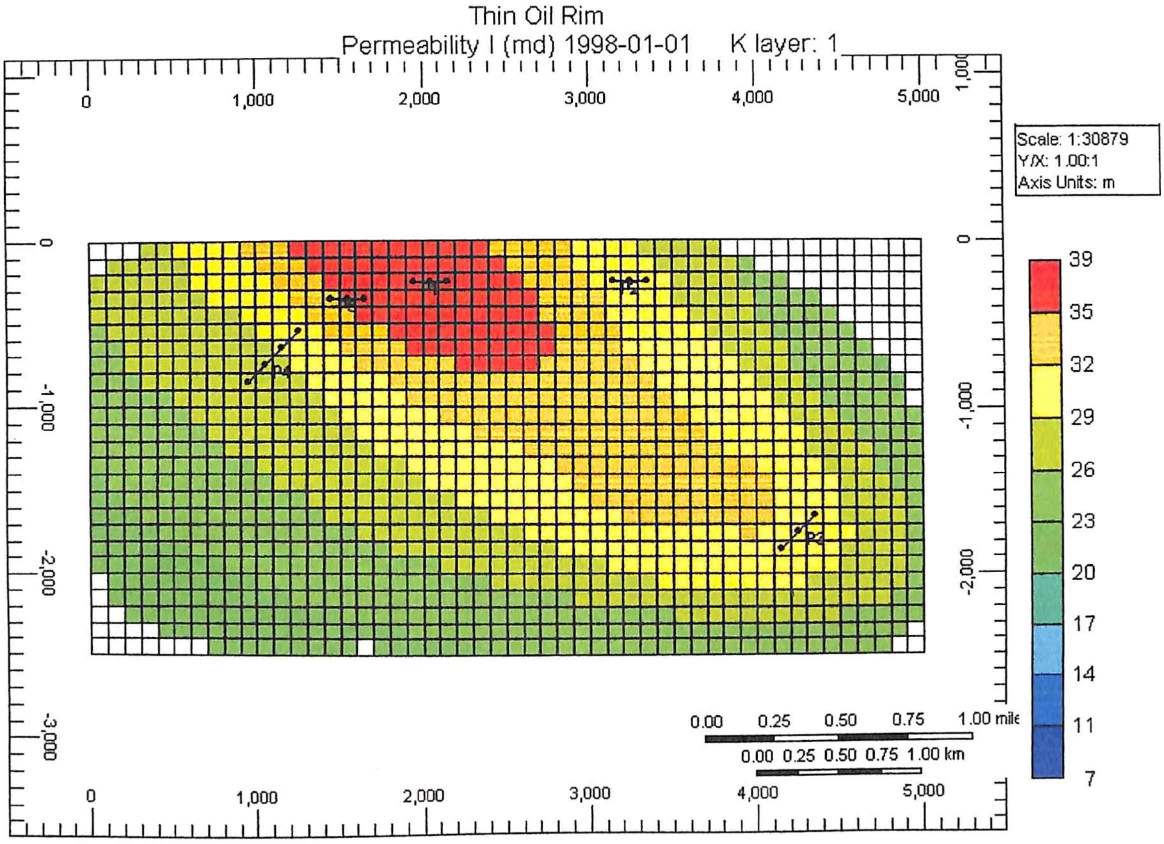


Figure-43 IMEX, CMG

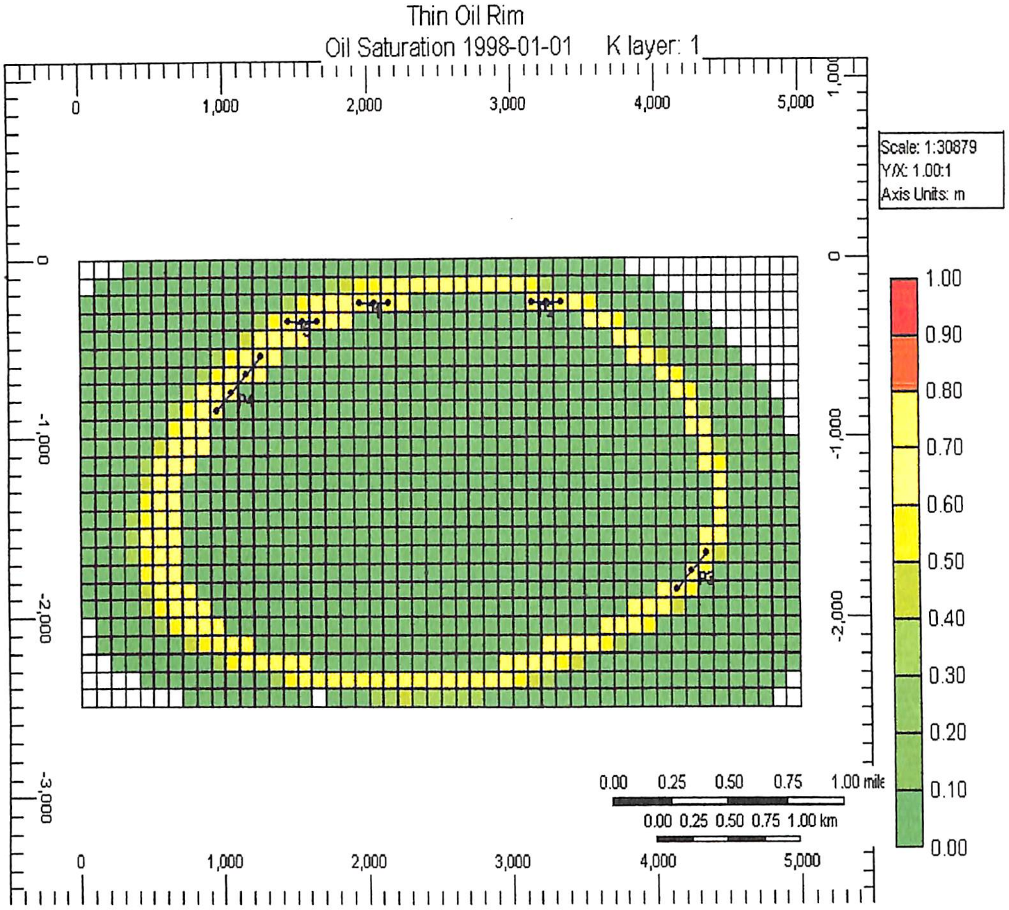


Figure-44 IMEX, CMG

The production from the field started on 1st January 1999. The reservoir was simulated using these five vertical wells till 1st January, 2009 (a period of ten years). The performance of each well was observed for a period of two years.

INDIVIDUAL WELL PERFORMANCE

WELL P1

The well is drilled in the reservoir having the following block address (20, 3, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	38.1052
Oil saturation (So)	.7
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3

GRAPHICAL RESULT OF WELL P1

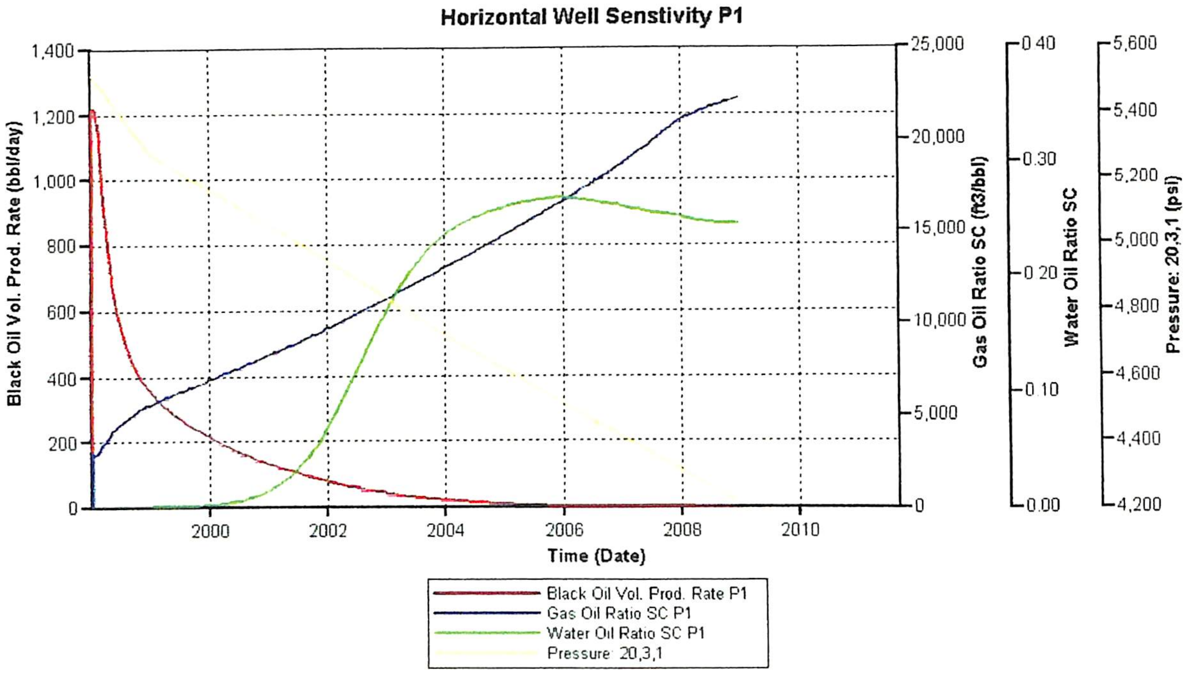


Figure-45 IMEX, CMG

This figure-45 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P1 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P1 (Table 16)

WELL 1				
YEAR	Pressure(psi)	GOR (m3/m3)	WOR	Production(bbl/day)
1998	5517.6	2912.3	0	1220.2
2000	5191.1	6980.9	0.001	214.6
2002	4963.9	9712.7	0.06	79.16
2004	4750.1	12983.1	0.23	21.3
2006	4534.8	16613.5	0.26	3.02
2008	4324.5	21067.3	0.25	0.4
2009	4221.8	22196.7	0.24	0

WELL P2

The well is drilled in the reservoir having the following block address (32, 3, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	30.49
Oil saturation (So)	.7
Gas Saturation (Sg)	0
Water Saturation (Sw)	.3

GRAPHICAL RESULT OF WELL P2

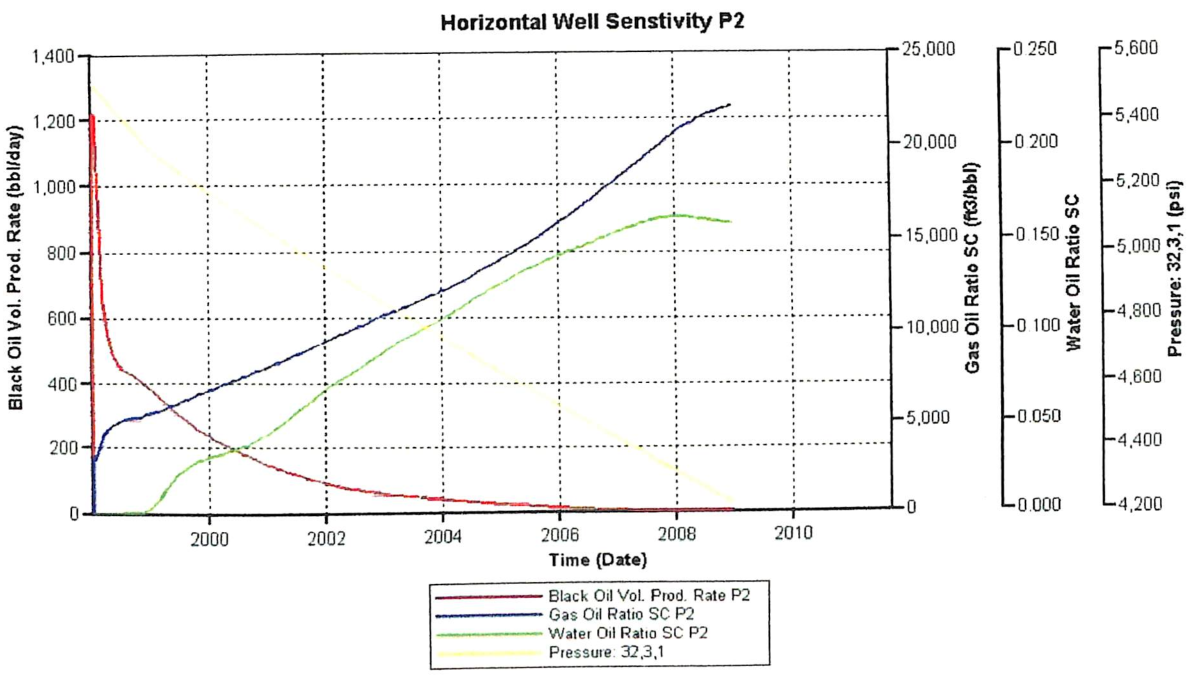


Figure-46 IMEX, CMG

Figure-46 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P2 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P2 (Table 17)

WELL 2				
YEAR	Pressure(psi)	GOR (m3/m3)	WOR	Production(bbl/day)
1998	5515.7	2841.44	0	1221.4
2000	5179.9	6629.05	0.03	237.1
2002	4952.9	9163.59	0.06	93.8
2004	4742.4	11893.2	0.10	41.5
2006	4534.3	15471.2	0.144	13.2
2008	4325.8	20214.6	0.16	2.71
2009	4224.1	21628.4	0.15	0.88

WELL P3

The well is drilled in the reservoir having the following block address (43, 18, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	31.09
Oil saturation (So)	.69
Gas Saturation (Sg)	0
Water Saturation (Sw)	.308

GRAPHICAL RESULT OF WELL P3

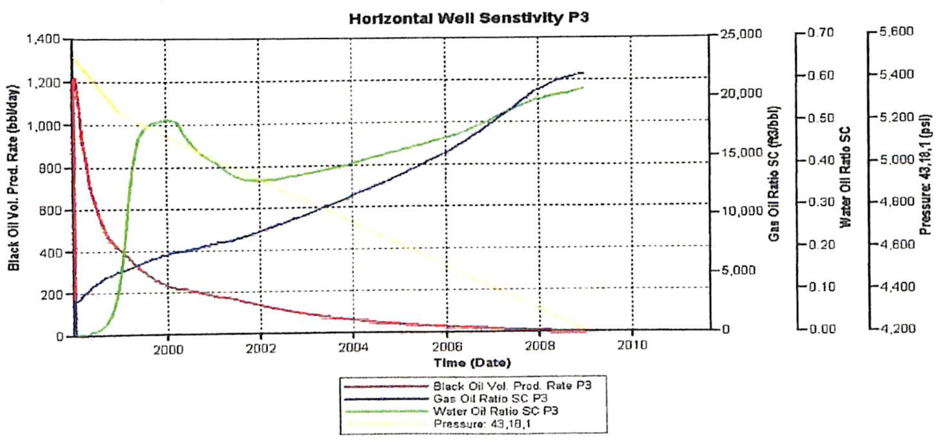


Figure-47 IMEX, CMG

Figure-47 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P3 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P3 (Table 18)

WELL 3				
YEAR	**Pressure(psi)**	**GOR (m3/m3)**	**WOR**	**Production(bbl/day)**
1998	5524.9	2900.05	0	1216.6
2000	5125.8	6836.95	0.51	236.3
2002	4939.1	8742.37	0.31	135.1
2004	4728.6	11650.89	0.44	60.9
2006	4517.2	15256.70	0.46	26.7
2008	4310.8	20563.56	0.55	6.3
2009	4207.6	21947.14	0.57	3.1

WELL P4

The well is drilled in the reservoir having the following block address (10, 9, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	29.53
Oil saturation (So)	.69
Gas Saturation (Sg)	0
Water Saturation (Sw)	.307

GRAPHICAL RESULT OF WELL P4

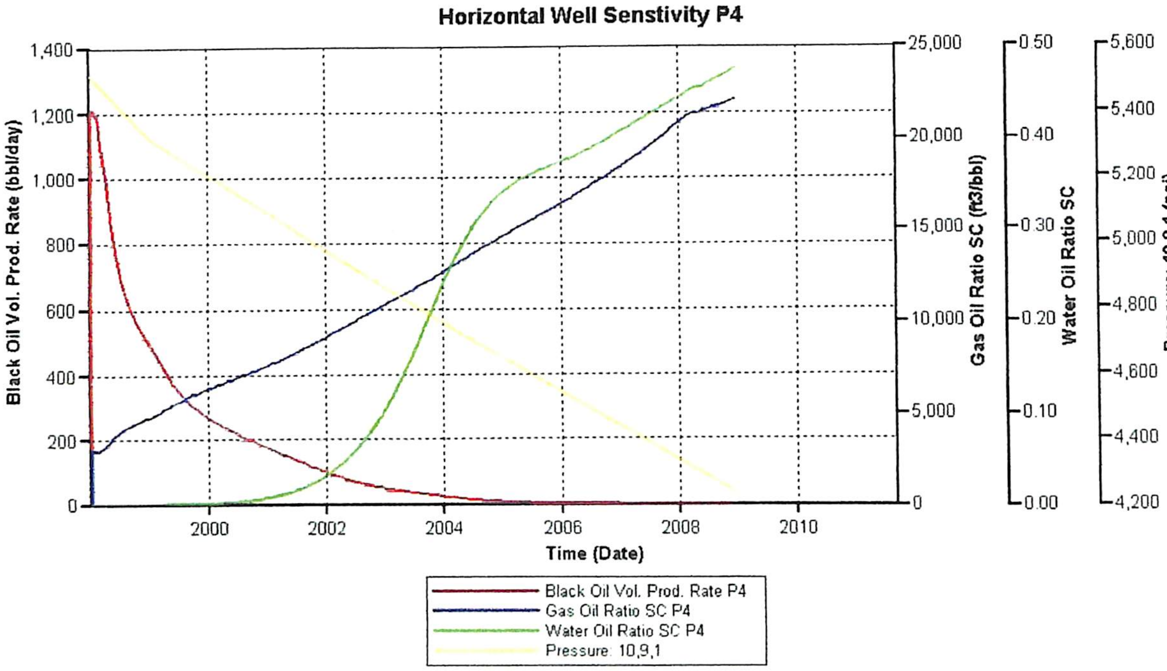


Figure-48 IMEX, CMG

Figure-48 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P4 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P4 (Table 19)

WELL 4				
YEAR	Pressure(psi)	GOR (m3/m3)	WOR	Production(bbl/day)
1998	5521.1	2934.31	0	1202.4
2000	5199.5	6407.23	0.0009	271.1
2002	4989.3	9206.07	0.03	100.1
2004	4765.1	12680.90	0.24	24.1
2006	4542.9	16386.62	0.37	2.3
2008	4330.	20785.42	0.44	0.02
2009	4228.2	22093.54	0.47	0.05

WELL P5

The well is drilled in the reservoir having the following block address (16, 4, 1). The various reservoir parameters are as follows which were taken into consideration for choosing the given well location:

Permeability (k)	35.68
Oil saturation (So)	.683
Gas Saturation (Sg)	.316
Water Saturation (Sw)	0

GRAPHICAL RESULT OF WELL P5

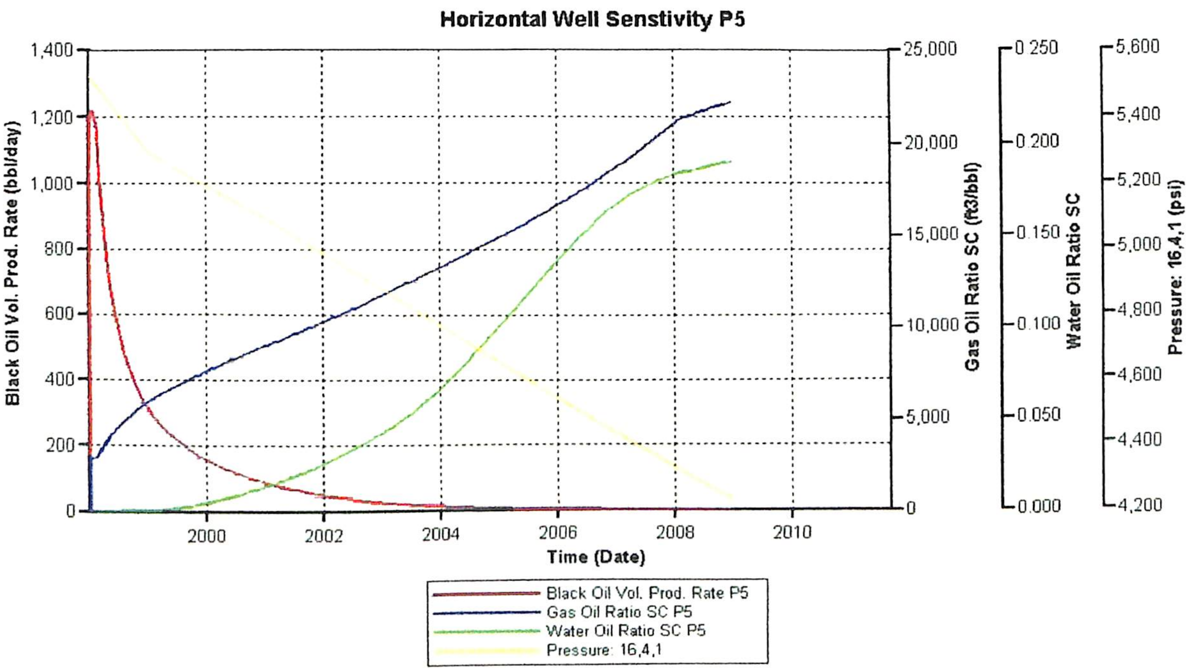


Figure-49 IMEX, CMG

Figure-49 shows the change in black oil volume production rate, GOR, WOR and pressure for the Well P5 with respect to time after the simulation run.

TABULATED RESULTS OF WELL P5 (Table 20)

WELL 5				
YEAR	Pressure(psi)	GOR (ft3/m3)	WOR	Production(bbl/day)
1998	5517.7	2922.2	0	1207.4
2000	5181.7	7579.1	0.004	160.1
2002	4948.6	10304.8	0.02	52.4
2004	4737.9	13266.4	0.06	12.8
2006	4527.4	16579.8	0.13	2.01
2008	4318.3	21023.9	0.18	0
2009	4216.2	22193.7	0.19	0

FIELD PERFORMANCE

The overall field performance of thin oil rim using vertical wells as one of the production strategies is shown in the graph below:

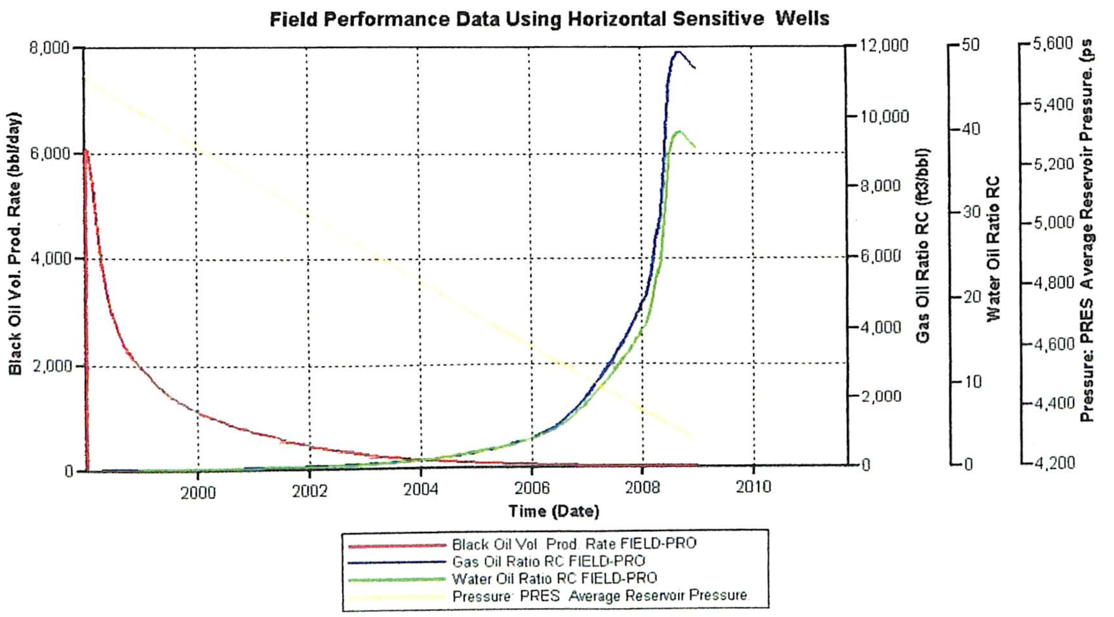


Figure-50 IMEX, CMG

The figure-50 shows the change in black oil volume production rate, GOR, WOR and pressure for the field with respect to time after the simulation run.

Cumulative Oil Production

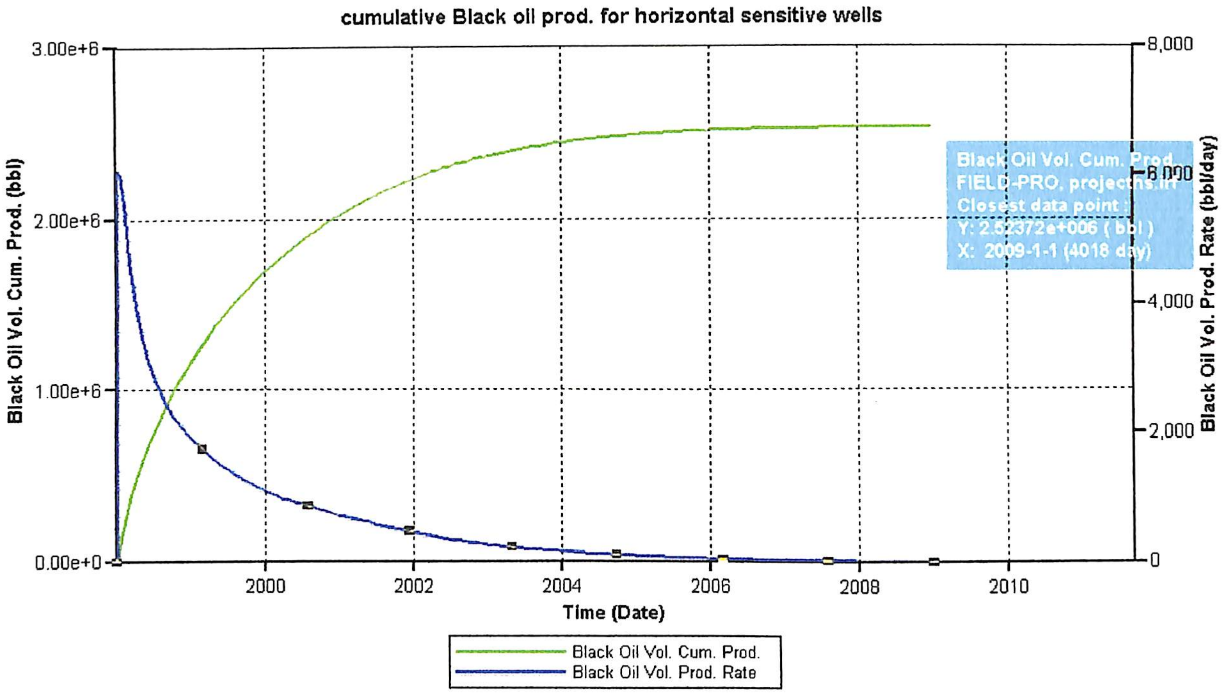


Figure- 51 IMEX, CMG

Figure-51 shows the cumulative black oil production and black oil volume production rate for overall field with respect to time after the simulation run.

CONCLUSION

The production strategy used for the economic exploitation of the Thin Oil Rim in the case II was found most satisfactory with highest recovery. Now a sensitivity analysis was done for the Case II in order to increase the recovery. It's the optimization of the position of the horizontal well with respect to the drive indices, the permeability variation and how the interface moves with time which is a very crucial factor in determining the ultimate recovery. The analysis is done in the same manner using five horizontal wells but in this case their position is changed based of the above stated factors. Each well is analyzed in a period of two years for the whole simulation run. For each well its pressure, GOR, WOR and the production rate is documented.

Comparison with the vertical wells case I, higher recovery was seen. The recovery from case IV is 2.5237e+006 and 10.18% of the OOIP.

3.7 CUMULATIVE OIL PRODUCTION IN A SINGLE GRAPH

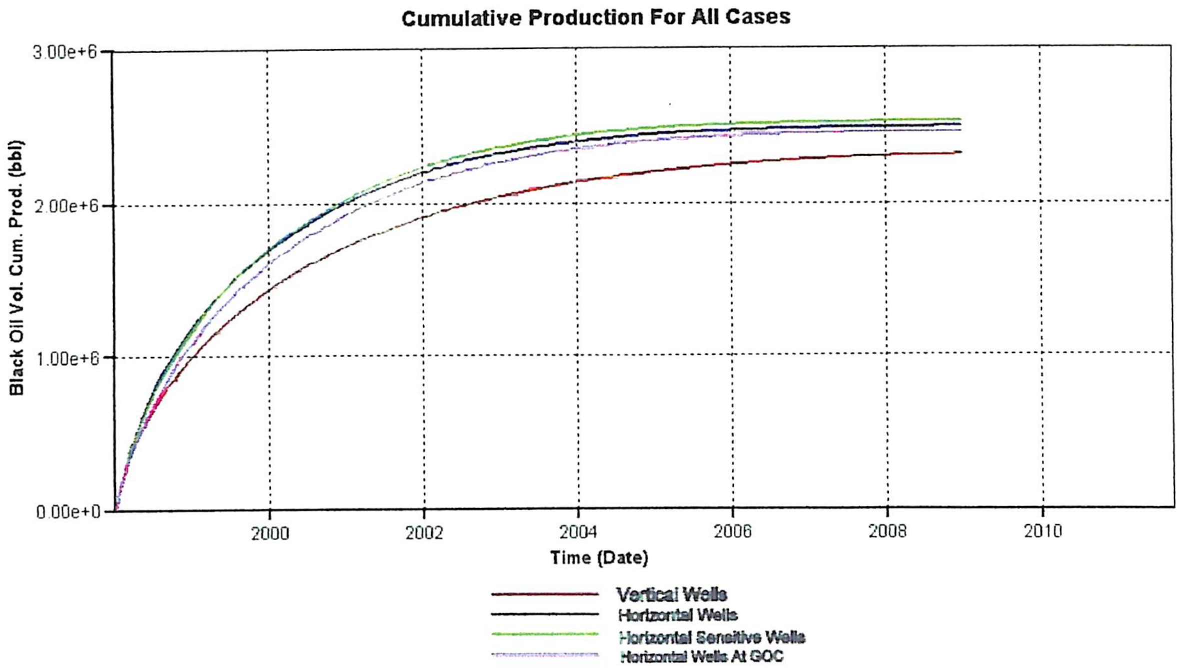


Figure-52 IMEX, CMG

Figure-52 shows the cumulative black oil production for the overall field with respect to time for all the four cases.

FINAL CONCLUSION

The project on the Development & Production Strategies for Thin Oil Rims Using IMEX Simulator helped us to understand the CMG (Computer Modeling Group) software.

The project helped us understand how to simulate a thin oil rim and similarly how we can get results from simulation any other project. Simulation dose not mean varying any parameter any time but the change made must be justifiable. The project helped us to understand the various parameters that can be varied to optimize the result. It also help to have a better understanding of the reservoir engineering as we could observe the effects of modified reservoir or operational parameters.

The thin oil rim was produced using four production strategies namely vertical wells, horizontal wells, horizontal wells near GOC and a sensitivity analysis done on case II for improved recovery. After the base case (Vertical Wells) it was observed that pressure and production rate was declining drastically with sufficient water cut and high GOR. Now when the rim was exploited using horizontal wells there was an increase in the overall recovery with high GOR and water cut. The third case was the use of the horizontal well near the GOC which was used as anticipation that the maximum oil will be recovered as it will be able to deploy the oil untreated oil as shown in fig1 (annexure 1). Finally, a sensitivity analysis on case II (Horizontal Wells) was done to increase the recovery. This analysis was done by using the concept of optimizing the well placement using the following parameters 1) interface movement 2) saturation and permeability variation. The recovery form each case in represented in terms of the OOIP and is as follows:

1) Vertical Wells	9.22% of the OOIP
2) Horizontal Wells	10% of the OOIP
3) Horizontal Wells near GOC	9.8% of the OOIP
4) Horizontal sensitivity analysis	10.18% of the OOIP

It is clearly seen that the best results are shown by case IV which is also reflective from the graph shown in figure-52 IMEX, CMG where the total cumulative production is highest from case IV.

ANNEXURE-I

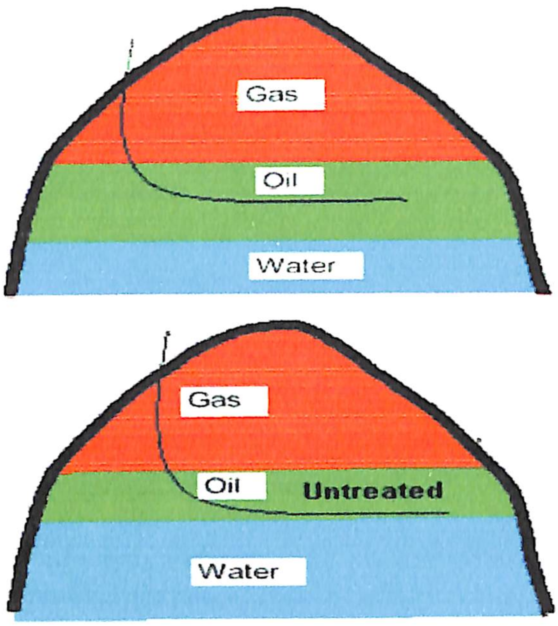


Figure-A

Figure: shows the residual oil saturation left in the reservoir if horizontal well is drilled in middle of the oil zone.

ANNEXURE –II

Input Data File

```
********************************************************************************
** mxsmo040.dat:   Dry Gas Injection into Volatile Oil Field (PVTVO Table)      **
********************************************************************************

**********************************************************************************
**********
**                                                                              **
** FILE:  (a demo template)            MXsmo040.DAT                             **
**                                                                              **
** MODEL: 50x25x4 GRID         38  WELLS SPACING                                **
**       Volatile Oil Model with undersaturated gas properties input using PVTVO Table   **
**       Dry Gas injection to maintain pressure                                 **
**                                                                              **

**********************************************************************************
**********
**                                                                              **
**                                                                              **

**********************************************************************************
**********

**********************************************************************************
*
** CONTACT:   CMG,  (403)531-1300;  282-6495 (fax);support@cmgl.ca   (Internet) **

**********************************************************************************
*
```

RESULTS SIMULATOR IMEX

```
********************************************************************************
** I/O Control Section                                                          **
********************************************************************************

TITLE1  'Thin Oil Rim'
TITLE2  'DRY GAS INJECTION'
```

```
INUNIT SI
OUTUNIT SI
INTERRUPT INTERACTIVE
RANGECHECK ON
WPRN WELL TIME
WPRN GRID 0
WPRN SECTOR 1
WSRF WELL 1
WSRF GRID TIME
WSRF SECTOR 1
OUTDIARY WELLSTATUS HEADER 20
OUTPRN WELL BRIEF
OUTPRN GRID SO SW SG PRES
OUTPRN TABLES ALL
OUTSRF GRID ALL
OUTSRF RES ALL
PSPLIT ON

*********************************************************************************
** Reservoir Description Section                              **
*********************************************************************************

GRID *VARI 50 25 4
KDIR *DOWN
PINCHOUT-TOL 0.0002
DI CON 100.
DJ CON 100.
DK ALL
        2*0. 0.1827 0.5196 0.88226 1.2351 1.50455 1.7849 2.06594 2.31712 2.59636
        2.9095 3.21627 3.35948 3.48063 3.57436 3.67292 3.7839 3.90778 4.01561 4.07068
        4.12705 4.06715 3.94849 3.8062 3.6553 3.4798 3.29505 3.17486 3.10415 3.07343
        2.94226 2.73241 2.37443 1.92126 1.50579 1.04729 0.60529 0.11266 11*0. 0.00143
        0.48036 0.93041 1.34826 1.74931 2.16675 2.54497 2.85554 3.18862 3.49198
        3.82309 4.18086 4.56678 4.77027 4.93651 5.06887 5.20645 5.34764 5.4791
        5.55356 5.57398 5.61836 5.53791 5.38802 5.23004 5.01049 4.77374 4.5614
        4.43027 4.38733 4.37094 4.16403 3.89543 3.48147 3.056 2.60006 2.11934 1.65707
        1.15749 0.67535 0.19861 9*0. 0.59708 1.11075 1.60804 2.11482 2.56241 3.02303

DTOP
        1354.42 1352.34 1350.12 1344.65 1339.4 1334.69 1330.97 1326.41 1321.62
        1316.64 1310.87 1305.43 1301.1 1296.62 1293.76 1291.53 1289.46 1287.59
```

1285.87 1284.29 1282.45 1281.47 1280.79 2*1280.28 1280.93 1282.11 1283.07
1284.46 1286.5 1288.65 1291.57 1295.63 1301.11 1304.12 1306.47 1309.14
1313.24 1317.44 1322.28 1327.37 1333.25 1338.85 1343.91 1349.28 1351.92
1353.79 1352.81 1353.88 1355.06 1352.03 1348.97 1343.04 1337.3 1331.8 1326.5
1322.18 1317.27 1311.83 1306.22 1299.96 1295.26 1291.82 1287.87 1284.12
1281.39 1278.69 1276.09 1273.99 1271.93 1269.57 1267.97 1266.48 1265.07
1264.33 1264.35 1265.22 1265.41 1266.31 1267.67 1269.48 1271.93 1276.16
1282.01 1287.21 1291.72 1297.71 1302.82 1307.31 1312.09 1317.85 1323.93

NULL ALL
2*0 37*1 11*0 41*1 9*0 42*1 8*0 44*1 6*0 45*1 5*0 46*1 4*0 47*1 3*0 48*1
2*0 49*1 0 600*1 0 49*1 2*0 48*1 4*0 45*1 7*0 42*1 4*0 37*1 11*0 41*1 9*0
42*1 8*0 44*1 6*0 45*1 5*0 46*1 4*0 47*1 3*0 48*1 2*0 49*1 0 600*1 0 49*1
2*0 48*1 4*0 45*1 7*0 42*1 4*0 37*1 12*0 40*1 9*0 42*1 8*0 43*1 7*0 44*1
6*0 44*1 6*0 45*1 5*0 46*1 4*0 47*1 3*0 47*1 3*0 48*1 2*0 48*1 2*0 49*1
0 49*1 0 349*1 2*0 48*1 3*0 46*1 6*0 43*1 9*0 39*1 7*0 37*1 12*0 40*1 9*0
42*1 8*0 43*1 7*0 44*1 6*0 44*1 6*0 45*1 5*0 46*1 4*0 47*1 3*0 47*1 3*0
48*1 2*0 48*1 2*0 49*1 0 49*1 0 349*1 2*0 48*1 3*0 46*1 6*0 43*1 9*0 39*1
5*0

MOD 7:7 25:25 1:4 = 0
39:39 1:1 1:4 = 0
1:1 21:21 1:4 = 0
1:1 2:2 1:4 = 0
3:3 1:1 1:4 = 0
41:41 2:2 1:2 = 0
44:44 1:1 1:2 = 0
50:50 10:10 1:2 = 0
17:17 25:25 1:2 = 0

NETGROSS CON 0.8

POR ALL
0.173039 0.177327 0.181754 0.186205 0.190796 0.195393 0.199328 0.205913
0.213694 0.222197 0.231558 0.241982 0.251431 0.257244 0.262268 0.266299
0.269879 0.271942 0.272841 0.272443 0.27105 0.268375 0.263881 0.257075
0.248384 0.242079 0.236037 0.22969 0.222858 0.21579 0.208731 0.201554 0.195252
0.189653 0.183768 0.177728 0.171354 0.164471 0.15698 0.148803 0.139164
0.129808 0.120457 0.111108 0.102178 0.0969465 0.0934358 0.089759 0.0860764
0.0822105 0.171159 0.1755 0.179698 0.183949 0.188113 0.192018 0.195918
0.199797 0.207727 0.216482 0.225155 0.23391 0.243224 0.25153 0.257098 0.261707

```
PERMJ EQUALSI * 1
PERMK EQUALSI * 0.20

CPOR   3.20149E-06
PRPOR  38000.00

SECTORARRAY 'Layer1' IJK
     1:50 1:25 1:2 1

SECTORARRAY 'Layer2' IJK
     1:50 1:25 3:4 1

MODEL VOLATILE_OIL
********************************************************************************
** Component Property Section                                  **
********************************************************************************

PVTVO  BG
**  psat      rs       rv       bo      bg      viso     visg    bg(dg)  vg(dg)
 101.32    0.0      0.00000  1.0     1.35118  0.180    1.35118 1.35118  1.35118
 4926.30   21.8867   0.000027  1.1436   0.02779  0.17945  0.01470 0.02777  0.01473
 8372.75   41.5325   0.000033  1.2175   0.01597  0.16769  0.01553 0.01598  0.01553
 14576.30   83.2489   0.000059  1.3447   0.00899  0.14546  0.01773 0.00902  0.01756
 21469.18  143.3570   0.000119  1.5225   0.00617  0.12204  0.02159 0.00620  0.02068
 29740.60  254.5648   0.000264  1.8504   0.00472  0.09578  0.02856 0.00467  0.02507
 38012.04  530.0487   0.000656  2.7030   0.00420  0.06721  0.04125 0.00387  0.02973
 39816.28  801.7297   0.001026  3.6174   0.004144 0.06200  0.05026 0.00374  0.03097
 DENSITY OIL   707.8528
 DENSITY GAS   0.90482
 DENSITY WATER  985.00
 CVO  0.00
 BWI  1.0750
 CW   4.16e-7
 REFPW 38012.04
 VWI  1.00
*CVW  0.00
 CO  1.0e-6

 ROCKFLUID
********************************************************************************
```

** Rock-Fluid Property Section **
****

```
RPT 1
SWT
**    SW       KRW      KROW     PCGW
 0.300000 0.000000 0.850000 100.000000
 0.317500 0.000038 0.787054 63.360000
 0.335000 0.000300 0.725743 54.890000
 0.352500 0.001013 0.666112 49.060000
 0.370000 0.002400 0.608210 44.470000
 0.387500 0.004688 0.552091 40.620000
 0.405000 0.008100 0.497813 37.280000
 0.422500 0.012863 0.445440 34.320000
 0.440000 0.019200 0.395044 31.630000
 0.457500 0.027338 0.346707 29.170000
 0.475000 0.037500 0.300520 26.900000
 0.492500 0.049913 0.256589 24.780000
 0.510000 0.064800 0.215035 22.790000
 0.527500 0.082388 0.176003 20.910000
 0.545000 0.102900 0.139669 19.130000
 0.562500 0.126563 0.106250 17.440000
 0.580000 0.153600 0.076026 15.830000
 0.597500 0.184238 0.049381 14.280000
 0.615000 0.218700 0.026879 12.800000
 0.632500 0.257213 0.009503 11.370000
 0.650000 0.300000 0.000000 0.000000

SLT
**    SL       KRG      KROG
 0.650000 0.400000 0.000000
 0.666500 0.342950 0.009503
 0.683000 0.291600 0.026879
 0.699500 0.245650 0.049381
 0.716000 0.204800 0.076026
 0.732500 0.168750 0.106250
 0.749000 0.137200 0.139669
 0.765500 0.109850 0.176003
 0.782000 0.086400 0.215035
 0.798500 0.066550 0.256589
 0.815000 0.050000 0.300520
```

```
0.831500 0.036450 0.346707
0.848000 0.025600 0.395044
0.864500 0.017150 0.445440
0.881000 0.010800 0.497813
0.897500 0.006250 0.552091
0.914000 0.003200 0.608210
0.930500 0.001350 0.666112
0.947000 0.000400 0.725743
0.963500 0.000050 0.787054
0.980000 0.000000 0.850000

KROIL *STONE2 *SWSG

INITIAL
***********************************************************************************
** Initial Conditions Section                              **
***********************************************************************************
VERTICAL BLOCK_CENTER WATER_oil_GAS
REFDEPTH 1250.
REFPRES 38012.
PDEW CON 0.0
PB   CON 0.0
DWOC 1280.
DGOC 1255.

NUMERICAL
***********************************************************************************
** Numerical Control Section                               **
***********************************************************************************
DTMAX 30.0
NORM PDW   1500.0
NORM PRESS 1500.0
CONVERGE MAXRES OIL 0.05


RUN
***********************************************************************************
** Well and Recurrent Data Section                              **
***********************************************************************************

DATE 1998 01 01.
```

```
DTWELL 1.0
AIMWELL WELLNN


GROUP 'GROUP1' ATTACHTO 'FIELD'

GEOMETRY K 0.086 0.39 1. 0.


WELL 1 'P1' ATTACHTO 'GROUP1'
PRODUCER 'P1'
OPERATE MAX STG 1e5 CONT
OPERATE MIN BHP 500. CONT

PERF GEO 'P1'
** if jf kf ff
      9 6 1 1.
      9 6 2 1.
      9 6 3 1.
      9 6 4 1.

WELL 2 'P2' ATTACHTO 'GROUP1'
PRODUCER 'P2'
OPERATE MAX STG 1e5 CONT
OPERATE MIN BHP 500. CONT

PERF GEO 'P2'
** if jf kf ff
      12 4 1 1.
      12 4 2 1.
      12 4 3 1.
      12 4 4 1.

WELL 3 'P3' ATTACHTO 'GROUP1'
PRODUCER 'P3'
OPERATE MAX STG 1e5 CONT
OPERATE MIN BHP 500. CONT

PERF GEO 'P3'
** if jf kf ff
      18 4 1 1.
```

```
        18 4 2 1.
        18 4 3 1.
        18 4 4 1.

  WELL  4 'P4'  ATTACHTO  'GROUP1'
  PRODUCER 'P4'
  OPERATE MAX STG  1e5 CONT
  OPERATE MIN BHP  500. CONT

PERF GEO   'P4'
**  if jf kf  ff
        23 4 1 1.
        23 4 2 1.
        23 4 3 1.
        23 4 4 1.

  WELL  5 'P5'  ATTACHTO  'GROUP1'
  PRODUCER 'P5'
  OPERATE MAX STG  1e5 CONT
  OPERATE MIN BHP  500. CONT

  PERF GEO   'P5'
**  if jf kf  ff
        27 4 1 1.
        27 4 2 1.
        27 4 3 1.
        27 4 4 1.
DATE 1999 01 01
  DATE 2000 01 01
  DATE 2001 01 01
  DATE 2002 01 01
  DATE 2003 01 01
  DATE 2004 01 01
  DATE 2006 01 01
  DATE 2007 01 01
  DATE 2008 01 01
  DATE 2009 01 01

STOP
```

REFERENCES

1. Ahmed Tarek, "Reservoir Engineering Handbook", Elsevier Publications, 2001.
2. Aziz Khalid, "Petroleum Reservoir Simulation" Applied Science Publishers, 1979.
3. CMG, IMEX Manual.
4. Craft B. C Hawkins, M.F, "Petroleum Reservoir Engineering", London Constable and Company Limited, Copyright 1959.
5. SPE 123989, A.I. Hasan, I.O. Center NTNU Stanford University.
6. SPE "Production Strategy for Thin Oil Columns in Saturated Reservoirs", C.S.Kabir, Chevron Energy Technology Company.
7. SPE 108700, F.T. Alkhelaiwi, Heriot-Watt University and Saudi Aramco.