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Abstract:

Drilling horizontal wells has been provided to be useful for producing oil and gas. This meant increased production by maximizing the reservoir contact. However, due to heel-toe effect an uneven influx of reservoir fluid to the wellbore is a challenge. This may resulting in early gas breakthrough and uneven inflow down coming. These conditions can limit sweep efficiency and reduce hydrocarbon recovery. One good example of conventional heterogeneous oil reservoir with gas drive is the Troll field. This is a large gas field with relative thin oil zone.

Inflow control technology was developed and introduced during the recent years to overcome some of these challenges. Inflow control device (ICD's) have improved well performance compared to conventional wells. For high-rate horizontal wells in thin oil rim reservoirs this solutions are especially attractive.

The objective of this thesis was to evaluated horizontal well performance in a heterogeneous conventional oil reservoir with open hole and ICD's completion for two phase flow oil and gas. Simulations were performed by using OLGA coupling with Rocx as the simulating tools. Tecplot was used to present oil and gas saturation profiles in YZ direction in the reservoir. One of the goal in the thesis was to simulate with data's from a real felt with conventional oil production and comparing the results. All data's are provided in tables in the thesis, were the Troll field is in detailed described. The simulations data's are taken from earlier testing/simulations from well Q-12BH that are located on Troll field. The goal was to simulate both the open completion and ICD's completion until gas breakthrough occurred. For comparative purpose the same input criteria in Rocx were used in all cases.

After approximately 45 days of production in the open hole simulations, gas started to drained into the production well. The production flow rate was about 5000 m^3/day and after 57 days of production gas breakthrough takes place. Simulation with ICD's was also performed and in order to compare the effect of the ICD's, different restriction were tested in three different cases. Conventional oil production with ICD completion was about 1700, 1500 and 1300 m^3/day in the three different cases. Based on the simulations result it seems that most evenly distributed restriction is to be preferred over time regarding to total oil production. Gas breakthrough did not take place after 57 days as in the open hole simulations. This verifying that wells with ICD's are more effective when it comes to total oil production and preventing gas breakthrough.

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Preface

This master thesis is the result of the work entitled " Near well simulation of oil production from conventional heterogeneous oil reservoirs with gas drive". Thesis description is presented in Appendix A. This work has been carried out at Telemark University College under the supervisor Professor Britt Halvorsen.

I would like to thank my supervisor Professor Britt Halvorsen for close supervision and good collaboration. Indeed, Britt devoted her precious time to give med feedback about this work.

Many thanks also goes to my student colleagues at Telemark University College for their support during this time.

Finally, very special thanks to my family members for their support and encouragement.

Porsgrunn, 04.06.2014

Linn Spyckerelle Raastad

Nomenclature

Abbreviations

API	American Petroleum Institute
GOC	Gas Oil Contact
GOR	Gas Oil Ratio
ICD	Inflow control device
ICV	Inflow Control Valve
MD	Measure Depth
MSL	Mean Sea Level
OCW	Oil Water Contact
TWGP	Troll West Gas Province
TVD	True Vertical Depth
TWOP	Troll West Oil Province
mD	mili Darcy

Letters and Expressions

K_r	Relative permeability	[Darcy]
K	Absolute permeability	[Darcy]
K_{eff}	Effective permeability	[Darcy]
K_{rg}	Relative permeability gas phase	[Darcy]
K_w	Relative permeability water phase	[Darcy]
K_{rog}	Oil relative permeability of an oil-gas system at irreducible water	[Darcy]
K_{rgom}	End point relative permeability of gas at its maximum in oil-gas saturation system	[Darcy]
n_g	Corey exponent	[-]
S_{wir}	Irreducible water saturation	[%]
S_o	Oil saturation	[%]
S_g	Gas saturation	[%]
S_{or}	Residual oil saturation	[%]
S_{om}	Minimum oil saturation	[%]
S_{gr}	Residual gas saturation	[%]
S_w	Water saturation	[%]

1 Introduction

Drilling horizontal wells was a important step for the oil industry. This meant increased production by maximizing the reservoir contact, and it meant drilling fewer wells than with vertical drilling. Horizontal wells also enabled reserves to be produced from zones that was previously thought too difficult to reach, such as thin oil zones. Horizontal wells helped avoiding breakthrough problems, such as gas coning. One of the main challenges in horizontal wells are uneven influx of reservoir fluid to the well bore, which resulting in early gas breakthrough[1]. Variations in permeability can result in unbalanced inflow along the horizontal section and expedite gas breakthrough and uneven inflow downhole. These conditions can limit sweep efficiency and reduce hydrocarbon recovery from horizontal wells[1].

Horizontal drilling has been provided to be useful for producing gas and oil. The best example of this the Troll field. This is a large gas field, with relatively thin oil zone and the underlying water. Oil was initially considered not economically recoverable, because it was expected that the water and the gas would quickly breakthrough. But after several testing of the production with horizontal wells and floating production done by Norsk Hydro the result that where achieved was so good that it was decided to also produce oil. Troll field has at times been the Norwegian field with the highest oil production. Since Troll field have been simulated before, and the contest of this thesis is near well simulations of conventional oil production with gas drive a literature study of this field was very interesting and also to simulate with real data's from this field [2].

The past decade the use of wells equipped with Inflow Control Valves(ICV) has increased. Mostly these wells are used to control the inflow from separate reservoirs or separate reservoir zones. For high-rate horizontal wells in thin oil rim reservoirs this solution is especially attractive. Early gas breakthrough into the well can be reduced or delayed through the smart well technology. The use of inflow control devices(ICD) offers an opportunity to evenly distribute the drawdown along the well, and therefore take corrective action if an early gas breakthrough occurs. Therefore understanding gas coning behavior are very important for optimizing production and be able to set appropriate operating strategies[3]. The scope for this thesis is to do a near well simulations of oil production from conventional heterogeneous oil reservoirs with gas drive, and therefore the focus in literature part will be for gas and oil. Water and problems related to this are also important when considering reservoir simulations, but this is beyond the scope for this thesis and will not be described in the chapters. The focus will be on two phase flow, gas and oil.

Reservoir simulation is a useful tool that is widely used in field development and for reservoir analysis and description. It allows engineers to simulate their recovery schemes before implementing them on the real field. In this thesis the simulation tool Rocx will be used for near well simulations. Rocx is a reservoir simulation program and is used in combination with

OLGA. Rocx and OLGA are used to get the complete picture of fluid flow from reservoir to well and producing pipe. In this thesis OLGA and Rocx were used to do a near well simulation in a heterogeneous reservoir. One case with open hole, and the same case with wells with ICD completion. And finally comparing this cases regarding to oil production and gas breakthrough time.

A detailed description of reservoir properties and conventional oil production with gas drive are presented in chapter 2 and 3. Chapter 4 gives a detailed description of the Troll field and the well Q-12BH the simulations part are based on. To have a good background understanding for the near well simulations presented in chapter 5 is important to understand chapter 2,3 and 4.

2 Fundamentals properties of reservoir

Optimized oil production is highly favorable for oil industry due to economical aspects. Therefore, sufficient knowledge about various oil properties and parameters in the reservoir is essential. In addition, the application for recent technology is also critical in terms of oil production and recovery. Oil recovery requires an understanding of displacement and flow through porous media (reservoirs). Flow through porous media is complicated, but important for many process essential to oil recovery. Inside a reservoir there can be displacement and immiscible and/or miscible flow, with one or two phases. Sometimes three mobile phases(e.g oil, gas and water) can occur. Understanding the physics is important for the correct interpretation for reservoir simulation. The focus for this thesis are general for oil and gas phase, problems related to this two phase and their properties. The objective of this chapter is to provide a description of conventional oil and the fundamentals properties of reservoir. Based on the parameters, conventional oil reservoirs show different behavior in various conditions and have considerable influence on well performance during the production. Some of the main parameters influencing the reservoir behavior are described in this chapter.

2.1 Light oil/ Conventional oil

Oil is commonly defined as either medium-to-light or heavy grade dependent on the density of the hydrocarbon and its ability to flow. Conventional oil, which is referred to light or medium in grade, is found in reservoir rocks which have enough permeability to allow the oil to flow to a horizontal or vertical well. Light oil is liquid petroleum that has a low density and flows freely at room temperature. It has low specific gravity, viscosity and high American Petroleum Institute (API) gravity due to the presence of a high proportion of light hydrocarbon fractions. In general it has a low wax content [4].

The API gravity is used to classify oils as light, medium, heavy or extra heavy. As the weight of an oil is the largest determinant of its market value, API gravity is very important. The APU values for each weight are as follows:

- Light - API > 31.1
- Medium - API between 22.3 and 31.1
- Heavy - API < 22.3
- Extra Heavy - API < 10.0

API is calculated using the relationship :

$$\text{API gravity} = (14.5/ \text{Specific Gravity}) - 131.5$$

where the specific gravity is a ratio of the density of one substance to the density of a reference substance. Less dense oil or "light oil" is preferable to more dense oil as it contains greater quantities of hydrocarbons that can be converted to gasoline [5].

2.2 Porosity

By the definition porosity is a measure of the capacity of reservoir rocks to contain or store fluids. The reservoir rocks can be stored by fluids such as gas, oil and water. Low porosity values indicate that the reservoir has a low capacity to store these fluids, and high porosity values indicates the opposite. Porosity data are obtained from direct measurements on core samples and/or indirectly on well logs. Equation 2-1 [6]. shows how porosity is calculated.

$$Porosity = \frac{Pore\ Volume}{Bulk\ Volume} \qquad \textit{2-1}$$

Bulk volume is the physical volume of the rock which includes the pore spaces and matrix materials that constitute the rock. Pore volume is the total volume of space in the rock.

There are two types of porosities that can exist in a rock. These are termed secondary and primary porosity. Where secondary porosity develops after deposition of the rock, and primary porosity are defined at the porosity of the rock that formed at the time of its deposition. Porosity can further be classified as effective and total porosity. Where effective is the percent of bulk volume occupied by interconnected pore spaces. The ratio of the entire pore space in a rock to its bulk volume is defined as the total porosity[6]. Porosity is usually expressed as a percentage of the total rock which is taken up by pore space. For example if a sandstone may have 10 % porosity. This means 90 % is solid rock and 10 % is open space containing gas, oil or water. 10 % is about the minimum porosity that is required to make a decent oil well. Still many wells with less porosity are completed.

2.3 Permeability

Several studies from laboratory have concluded that the effective permeability of any reservoir fluid is a function of the reservoir fluid saturation and the wetting characteristics of the formation. To specify the fluid saturation when stating the effective permeability of a fluid is necessary.

In the prediction of the reservoir behavior it is important to know the relative permeability of the reservoir rock to each of the fluids flowing through. How to process relative permeability data is still a major challenge in oil industry. This has been one the major challenge in reservoir engineering for the past years. Reliable relative data may lead to successful development. Two and three-phase relative permeability are the most important properties of porous media. In order to do a good reservoir prediction in a multi-phase situation, these functions have to be specified as accurately as possible. Due to rock conditions, economic conditions, sufficient field data are seldom available, which necessitates the estimation of relative permeability data. Relative permeability data influence the flow of fluids in the reservoir. Relative permeability curves determine how much oil, gas, and water are flowing relative to each other. Relative permeability is unique for different rocks and fluids, and affects the flow characteristics of reservoir fluids and affects the recovery efficiency of oil and/or gas. Applications of relative permeability functions are reservoir simulations, flow calculations that involve multi-phase flow in reservoirs and estimation of residual oil/gas saturation. When two or more fluids flow at the same time, the relative permeability of each phase at a specific saturation is the ratio of the effective permeability of the phase to the absolute permeability as shown in formula 2-2 [7].

$$K_{r=} \frac{K_{eff}}{K} \qquad 2\text{-}2$$

where K_r are the relative permeability, K are the absolute permeability and K_{eff} are the effective permeability. Effective permeability are normally measured directly in the laboratory on small core plugs. The saturation of oil, water or gas must be specified to completely define the conditions at which a given effective permeability exists. The absolute permeability is a property of measure of the capacity of the medium and of the porous medium to transmit fluids [7].

There are roughly 4 methods to characterize relative permeability curves

1. Shape. In 2-phase relative permeability curves, the non-wetting phase is usually an S-shaped curve. The wetting phase is concave upward throughout curve.
2. Value. For example in a water-wet system, the water relative permeability curve begins at 0.0 at irreducible water saturation(S_{wir}) and increases to some value at a water saturation(1.0 - residual oil saturation S_{or}), and then increases to 1.0 at $S_w = 1.0$.
3. Effects factors. Factors that are effecting relative permeablities are fluid saturation, geometry of the pore spaces and pore size distribution, wettability and fluid saturation history(i.e imbibition or drainage).
4. Others. For example an asymptotic method to infer the relative permeability exponent of the displaced phase near its residual saturation using laboratory core-flooding data.

There are several application for using relative permeability data for example it can be used to model a particular process, for example, fluid distribution, recovery and predictions; determination of the free water surface and determination of residual fluid saturations [8].

Over many years experimental relative permeability curve measurements made on cores in the laboratories have created a need to describe these physical processes by equations. These equations which describe physical processes of flow through the core, and the actual flow in the hydrocarbon reservoir, are the relative permeability models.

There are many different relative permeability models and versions, but for this paper Corey and Stone are the two models that are been used in the simulations program Rocx. Classifications of these models are based on the following:

1. Refer to measurement of two-phase or three-phase flow processes.
2. Refer to which combination of two-phase fluids is the subject of testing(gas-oil, oil-water ,gas-water).
3. Which experimental methods are used and under which pressure, temperature conditions to obtain the relative permeability curves.
4. What is the value of wettability and interfacial tension.
5. In which direction is the flow measured: imbibition or in drainage direction.
6. On which lithological type of core is the test performed: consolidated, carbonate rock, fracured rocks etc.
7. On which calculation methods and theoretical foundations is the obtained relation based on.

These last seven points makes the classification of the largest number of relative permeability models such as capillary, statistical, empirical and network models. The complexity of multiphase flow through the porous medium and different shortcomings of measurement methods result in only approximate equations of relative permeability curves. Corey and Stone are two relative permeability models that are well known and often used in the world practice[9].

Corey's correlation

Corey (1954) proposed a simple mathematical expression for generating the relative permeability data of the oil-gas system. Corey present a set of equations for calculating gas and oil relative permeability. This approach are very popular in the absence of measured data. Corey's equations apply only to well-sorted homogeneous rocks. The Corey approximate is good for drainage processes such as gas-displacing oil. From the Corey model it is possible to calculate the relative permeability both of the gas phase, K_{rg}, and of the water phase, K_w. To use Corey correlation to estimate the K_{rg} formula 2-3 [9] are used in ROCX.

$$K_{rg} = K_{rgom}(\frac{S_g - S_{gr}}{1 - S_{om} - S_{gr}})^\wedge n_g \tag{2-3}$$

where S_{gr} is the residual gas saturation, S_{om} is the minimum oil saturation achievable when oil is displaced by gas at irreducible water saturation, K_{rgom} is the end point relative permeability of gas at its maximum in a gas-oil saturation system, and n_g is the Corey exponent.

Stone correlation

Stones correlation are a method for estimating three-phase relative permeability based on statistical probability model. To do a calculation the required data for calculation for relative permeability to oil are two sets of two-phase relative permeabilities in gas-oil with values of k_{rog} and k_{rg}, and in water-oil systems with values of k_{rw} and k_{row}. The main assumption of Stone's method is that relative permeability for gas phase and water phase are functions only of own values for gas and water saturations[9]. Beside Corey correlation another model that are used in Rocx are the Stone correlation Π. Two methods for calculating the oil phase permeability are available in Rocx. The easiest formulations is to assume that the oil relative permeability, k_{ro} , is depend only on the oil saturation, S_o, and it can be tabulated.

The second method assumes the oil relative permeability, k_{ro}, is dependent on both the water saturation, S_w, and the gas saturation, S_g. In this last method the Stone Π model is used. The model are used to evaluate the oil phase relative permeability internally in Rocx based on k_{rw}, k_{rg} and two other curves. The formula 2-4[10] gives a reasonable approximation to the three-phase relative permeability.

$$k_{ro}(S_w, S_g) = (k_{rowc})[\left(\frac{k_{row}(S_w)}{k_{row}} + k_{rw}(S_w\right)\left(\frac{k_{rog}(S_{g)}}{k_{rowc}} + k_{rg}(S_g)\right) - \left(k_{rw}(S_{w)} + k_{rg}(S_g)\right)] \qquad \textit{2-4}$$

The functions, k_{rog}, k_{row} and k_{rg} are defined by the user in Rocx, along with the constant k_{rowc}. The first curve is $k_{row}(S_g)$ measured when only oil and water are flowing. The second curve is $k_{rog}(S_g)$ measured when oil and gas are flowing at irreducible water saturation(S_{wc}). The two methods that specifying these two curves are shown in formula 2-5and 2-6 [9]

The oil permeability for water-oil system is specified by the following formula 2-5[10]

$$k_{row} = k_{rowc}(\frac{S_{w+}S_{or} - 1}{S_{wc} + S_{or} - 1})^{\wedge}n_{ow} \qquad \textit{2-5}$$

where the pre-factor k_{rowc} is the end point relative permeability of oil in water at irreducible water saturation. n_{ow} is another fitting parameter.

The oil relative permeability for an oil-gas system at irreducible water, k_{rog}, is specified by the following formula 2-6[10].

$$k_{rog} = k_{rowc}(\frac{S_{wc} + S_{g+}S_{om} - 1}{S_{wc} + S_{om} - 1})^{\wedge}n_{og} \qquad \textit{2-6}$$

where n_{og} is the fitting parameter. It is important to note that the pre-factor k_{rowc} is the same as for the pre-factor for the water-oil system. S_{om} are defined as the minimum oil saturation achievable when oil is displaced by gas at irreducible water saturation. For simplifying S_{om} is set to equal to S_{or} in the Rocx Gui input[7].

2.4 Oil and gas saturation

The pore spaces in underground rocks that form gas and oil reservoirs are always completely saturated with fluid. In the pores of the reservoir, there is never location or an opportunity where nothing exists. There pores are completely filled with some combination of the following fluids:

- Natural gas and its facility impurities in the vapor phase
- water that flowed or was injected into the reservoir
- oil and its associated impurities in the liquid phase

If the pores are in pressure communication with the source rock and the water-saturated pores happen to be near an active hydrocarbon source rock, hydrocarbons can enter the pores and occupy space. The hydrocarbon are normally less dense than the water, and the resulting buoyant force causes the gas or the oil to migrate through the permeable, porous rock until it escape at the surface. Commercial oil or gas reservoir may be the result if there is sufficient closure of the hydrocarbon accumulation. The following relationship in formula 2-7 [11] must be true at any time during the life of an gas or oil reservoir

$$S_o + S_w + S_g = 1.0 \qquad \textit{2-7}$$

where:

$$S_o = \frac{oil\ volume}{pore\ volume} = \frac{V_o}{V_p} \qquad \textit{2-8}$$

$$S_w = \frac{water\ volume}{pore\ volume} = \frac{V_w}{V_p}$$

$$S_g = \frac{gas\ volume}{pore\ volume} = \frac{V_g}{V_p}$$

Water saturation is always greater than zero, but it is more common that oil or gas saturation are zero.

One of the uses of saturation is the identification of gas/oil contact by changes of the residual saturation with depth, and indirectly it is used as a correlation variable to estimate the productivity of reservoir rocks. To evaluate the quantity of hydrocarbons that can be produced from a reservoir with a natural occurring underlying aquifer, or alternatively gas cap expansion residual fluid saturations are important reservoirs evaluations. Residual saturation is a function of texture of the porous media, clay content and clay distribution in the pores. The complexity of carbonate pore geometry requires the determination of trapped oil or gas saturation.

Residual oil(S_{or}) saturation values must carefully be reading from standard relative permeability curves. This is because sometime during coreflow experiments, the actual test has finished without reaching true S_{or}. The reason for this can be caused by unfavorable mobility ratio, high capillary end-effects or sample heterogeneity [12].

Density differences between gas and oil results in normal reservoir situations in which oil floats on water. If there is free gas phase, the gas floats on the oil. But at mention earlier in this chapter there will be some water saturation.

Factors that affect the fluid saturations and change the content in the core is by two processes:

1. the flushing of mud and mud filtrate into the adjacent formation
2. the release of confining pressure as the core is pulled to the surface.

On a microscopic level the invasion process of a water-based mud into an oil-bearing formation are shown in figures Figure 2-1,Figure 2-2 and Figure 2-3. The figures show the saturation in characteristic sand during coring and recovery.

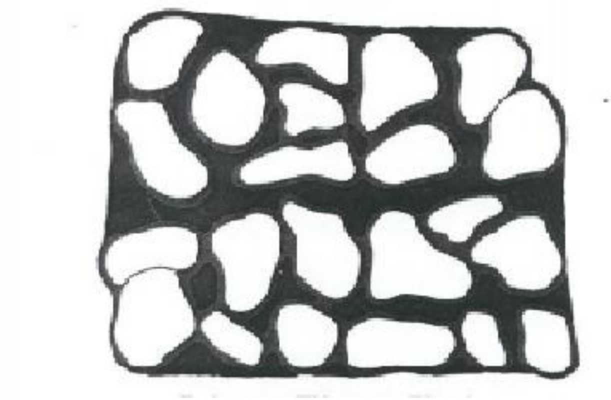

Figure 2-1 Prior to filtrate flush[11].

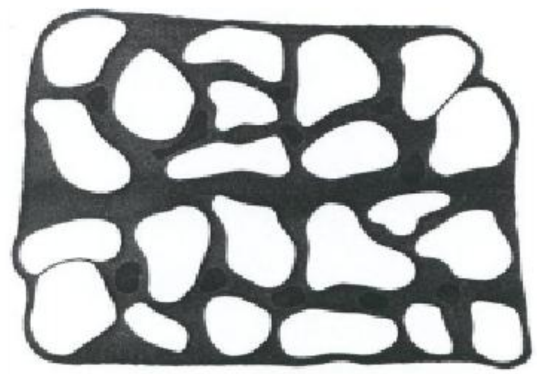

Figure 2-2 After filtrate flush during coring with water base mud[11].

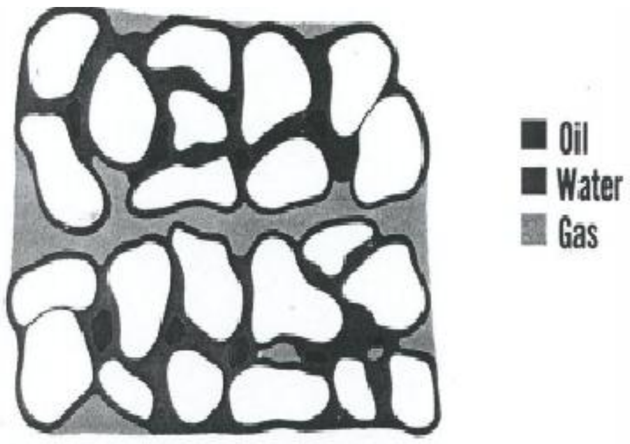

Figure 2-3 After filtrate flush and gas expansion during trip to surface[11].

The first figure is prior to being penetrated by the bit, therefore the saturations present are the connate oil and water. Figure 2 is after the bit has penetrated the formation and fluid invasion has flushed the original reservoir fluids. Water saturations increases during this time. The last figure shows the gas expansion as the core is brought to the surface.

3 Conventional oil production with gas drive

Producing oil and gas needs energy, and some of this energy that are required is supplied by nature. Because of the depth the hydrocarbon are under pressure. The water and gas in petroleum reservoirs under pressure are the two main sources that help move the oil to the well bore. This force can also sometimes moves the oil to the surface. Depending on the original characteristics of hydrocarbon reservoirs, the type of driving energy is different.

One important objective in this thesis to understand is the gas coning behavior. Well Q-12BH that are described in chapter 4.3 forms some of the basis of the simulations in this thesis, and a good understanding of gas behavior is important. A detailed description of this phenomena are described in this chapter.

3.1 Solution gas drive reservoirs

When a newly discovered reservoir is below the bubble point pressure, there will be free gas in form as bubbles within the oil phase in the reservoir. As the oil are produced, the reservoir pressure drops. Once the bubble point are reached, the natural gas that are formed in the oil will come out of the solution and formed bubbles. As the fluid pressure is reduced further the bubbles will expand. Expanding bubbles keep supporting the production until they reaches a critical saturation. A saturation where they join together and start flowing as a single gas phase. Now the gas phase because of much lower viscosity begins to flow to the wellborn much more rapidly than the oil. More and more free gas are produced with the crude oil. In this mechanism, energy of gas expansion is utilized to transport the hydrocarbons from reservoir into the wellbore. This cause the reservoir to drop. The efficiency of solution gas drive depends on the amount of gas in solution, the fluid and rock properties and the geological structure of the reservoir. Recoveries of these type of reservoirs, on the order of 10-15 % of the original oil in place. Recovery is low, because the gas phase is more mobile than the oil phase in the reservoir [13].

If the pressure in the reservoir is below the bubble point initially, there is more gas in the reservoir than the oil can retain in the solution. Because of the density difference this extra gas accumulates at the top of the reservoir and forms a cap. In this so called gas cap drive reservoirs wells are drilled into the crude oil producing layer of the formation. As oil production causes a reduction in pressure, the gas in the cap expand and pushes oil into the well bores. Figure 3-1 and Figure 3-2 shows the reservoir pressure and Gas Oil Ratio(GOR) trends for gas cap drive and solution gas drive mechanisms.

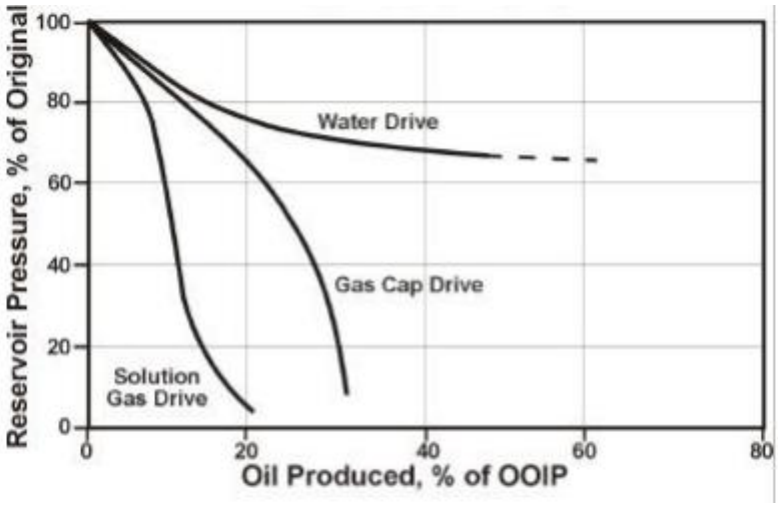

Figure 3-1 Reservoir Pressure Trends for Drive Mechanisms[14].

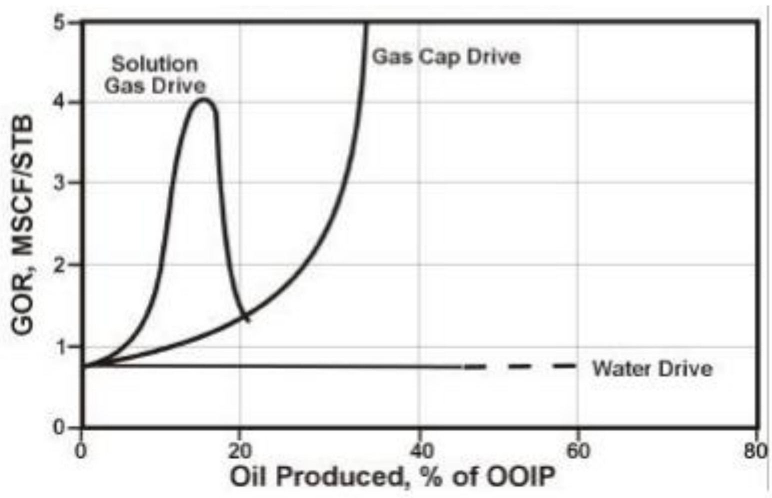

Figure 3-2GOR Trends for Drive Mechanisms[14].

The gas drive maintains the reservoirs pressure much lower than the water drive, and has higher GOR.

A solution gas drive reservoir is initially either considered to be saturated or undersaturated depending on its pressure. For a saturated reservoir (reservoir pressure ≤ bubble point), any oil production results in a drop in reservoir pressure. This causes bubbles of gas to expand.

For an undersaturated reservoir (reservoir pressure > bubble point of oil) no free gas exists until the reservoir pressure falls below the bubble point. Reservoir drive energy is only provided by the bulk expansion of the reservoir rock and liquids in this regime. If the reservoir is initially undersaturated (reservoir pressure > bubble point of oil), the reservoir pressure can drop very much as shown in Figure 3-1 and Figure 3-2. This is because of the small compressibility's of the rock oil and water, compared to the gas. Oil recovery from this type of reservoirs is typically between 20-30 % of original oil in place. Only 0-5 % of this is oil is recovered above the bubblepoint. Usually there is no production of water during oil recovery, unless the reservoir pressure drops dramatically.

A gas cap drive derives its main source of reservoir energy from expansion of the gas cap that already existing above the reservoir. The presence of the expanding gas cap limits the pressure decrease experienced by the reservoir during production. How much rate the pressure decreasing with depends on the size of the gas cap. In the early stages of such reservoir the GOR rises slowly because the pressure of the gas cap prevents gas from coming out of the solution in the oil. As production continues, the gas cap expands and pushing the gas-oil contact downwards. After some time gas-oil contact will reach the wells and the GOR will increase as shown in Figure 3-1 and Figure 3-2. The recovery of gas cap drive is slightly better than for solution drive reservoirs. The recovery of gas cap drive are 20-40 % of original oil in place. The recovery efficiency depends on the size of the gas cap. The gas cap is a measure of how much latent energy there is available to drive production [14].

3.2 Gas coning

Coning is a tendency of gas to push oil towards the well in a cone shaped contour. Right after the cone breaks through the oil column, gas production increase substantially. Lower viscosity of the phases are the reason for gas breakthrough and because of the lower viscosity they are more mobile. Gas coning cannot be avoided , but there are some strategies that allow minimizing gas inflow be delaying the breakthrough of the cone. Figure 3-3 shows how the shape of a gas cone forms in a horizontal wells. Permeability effects gas coning. From Figure 3-3 is possible to see that the heel zone has a higher permeability , which results in a wider cone. Higher permeability zones cause higher flow rates into the well and faster drainage compared to lower permeability in the toe area. Usually high-permeability reservoirs have lower drawdowns, and therefore fewer problems related to coning. Lower permeability reservoirs forms a more narrow cone, then the reservoirs with high permeability. The pressure drop along the well are typically higher, because of the high flow rates. This leads to strongly uneven drawdown, and therefore coning and inflow along the well. Uneven inflows and drawdown has a negative effect on the oil production.

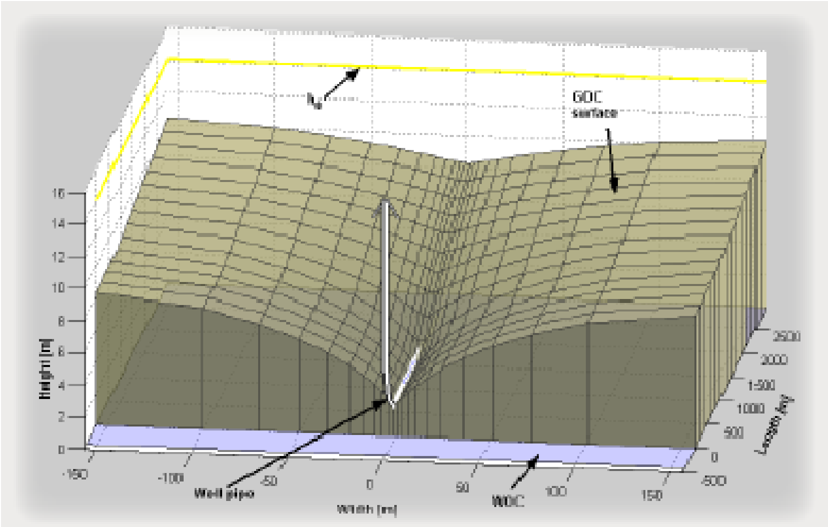

Figure 3-3 Gas coning into a horizontal well in a thin oil column[15].

Coning tendencies are directly proportional to viscosities and inversely proportional to density differences. These are to important parameters that affect coning. For example, water coning is more likely to occur at the same drawdown than gas coning. This is because the difference between water and oil density is much smaller than the difference between oil and gas density. However, gas coning occur more likely when viscosities are compared because gas is less viscous and due to the faster flow rate of gas, it is able to finger through the oil column much more easier then water.

Gas coning is highly affected by drawdown, and drawdown are proportional to fluid production rate. All these situations makes maximizing the oil production a challenge. For a production optimization both drawdown and inflow need to be reduced. Horizontal wells are a good way to reduce coning as they are able to minimize pressure drop and sustain higher production rates.

Gas coning causes a lot of challenges, but beside being a problem it also helps to drive oil towards the well using gravity driven forces. During start-up process of a well this is especially helpful. But later the strategy of dealing with gas coning requires choking back wells to keep the cone from reaching the wellbore. Preventing coning behavior means minimizing the GOR to maximize the oil production[3].

Gas coning is a big problem in many oil field applications at it reduces oil production, has a direct effect on the overall recovery efficiency of the oil reservoirs and increase cost of production. Coning is a result of an imbalance between the viscous and gravitational forces around the completion interval of an oil reservoir where a large oil rate causes a downward coning of gas into the perforations of a producing well whenever there is a change in Gas-Oil Contact (GOC) profile. When the gas get to the production well, the flow will be dominated by the gas and decreasing the oil production. Some factors that could aid the coning problem are critical production rate, breakthrough time and well performance after breakthrough[16].

4 Troll field

The near well simulations in chapter 5 are based on the reservoir properties from the Troll field. This chapter will give a insight in what the Troll field are, and what the simulation cases in the thesis are based on.

4.1 Field layout

The location of Troll field is about 80 km North West of the Norwegian city of Bergen, and the field started oil production in 1995. The discovery of the field showed a massive gas cap on top of the thin oil rim. With time and advanced technology this thin oil column became one of the most important oil field in Europe. More than 500 well track/branches have been drilled on Troll since the beginning of the production. Troll production is goverened by 106 subsea wells. All the wells are horizontal and individually controlled. The total producing interval in the field is up to 297 km. The results from this field have been good with high efficiency and well availability. The Troll field area is estimated about 750 km^2. This area are divided into two main production areas : Troll West and Troll East. Troll East operates with gas only, while Troll West operates still with the main oil producing area. Troll West is in addition divided into two provinces based on the type of reservoir fluids : Troll West Oil Province(TWOP) and Troll West Gas Province (TWGP).

The Troll field has three offshore operating production units : Troll A, Troll B and Troll C. Troll A operates on Troll East, and is a large gas processing platform with vertical wells. Troll B is a concrete floater that drains both TWGP and TWOP. Troll C is a semi-floater made of steel that has most of its operating wells on TWGP. Except one template, which is installed on the northern part of Troll East.

4.2 Reservoir characteristics

A reservoir rocks that contains petroleum must be both porous and permeable. Reservoir rocks are dominantly sedimentary (carbonate and sansstone). The three sedimentary rock types that are mostly freqyently encountered in oil fields are sandstones, shales and carbonates. Approximately 60 % of the lithology within the oil window on TWGP is formed of coarse-grained clean sand, and the rest is mostly heterogeneous sands or rich fine-grained sands. Reservoir and fluid properties for the northern part of TWGP are found in Table 4-1. The two main and most important reservoir formations on Troll are Sognefjord and Fensfjord. Where Fensfjord formation are much smaller in contributing size than Sognefjord formation. Most of the Troll wells have been drilled on Sognefjord formation. The thickness of Sognefjord varies substantially, but average is about 160 m thick. The actual reservoir is located about 1560 m from the mean sea level, this is where most of the oil wells are drilled in

Troll west. On the top of the formation there is a large gas cap present that can extend up to 200 m on TWGP. Under it lies an underlying aquifer. In the middle of those two phases is the thin oil rim. The Sognefjord formation consist of high permeability alternating sand bodies, which have excellent reservoir characteristics.

Table 4-1Reservoir and fluid properties of TWGPN during the production start-up of well 31/2-Q-12BH[3].

Reservoir parameters used for Q-12 well start up	Symbol	Units	Value
Bubble point pressure	p_b	Bar	159.06
Reservoir temperature	T_{RES}	°C	68
Solution gas oil ratio at the start-up	R_{SOL}	Sm^3/Sm^3	47.8
Gas density at SC	ρ_G	kg/m^3	0.75
Oil density at SC	ρ_O	kg/m^3	890
Water density at SC	ρ_W	kg/m^3	1045
Gas formation volume factor	B_G	m^3/Sm^3	0.00765
Oil formation volume factor	B_O	m^3/Sm^3	1.136
Water formation volume factor	B_W	m^3/Sm^3	1.017
Gas viscosity	μ_G	mPa*s	0.017
Oil viscosity	μ_O	mPa*s	1.9
Water viscosity	μ_W	mPa*s	0.45
Water compressibility	β_W	1/bar	4.3*10^-5

4.3 Well 31/2-Q-12 BH

The results in chapter 5 are based on the reservoir parameters from well 31/2-Q-12 BH. The well path is located near the central communication channel on the TWGP in the Sognefjord reservoir reservoir formation about 1560m TVD MSL. The well was first leveled out in 3 CC sand, then 4A C and 4 Am sand were reached, and the total depth was set in the 4/5 heterolithic sands at 6068m MD. Clean coarse sands (c-sands) have a typically permeability of 1-30 D, micaceous sands (m-sands) with permeability lower than 600 mD, and heterolithic sands which have alternating characteristics.

The design of well Q-12 BH is similar to the one in Figure 4-1.

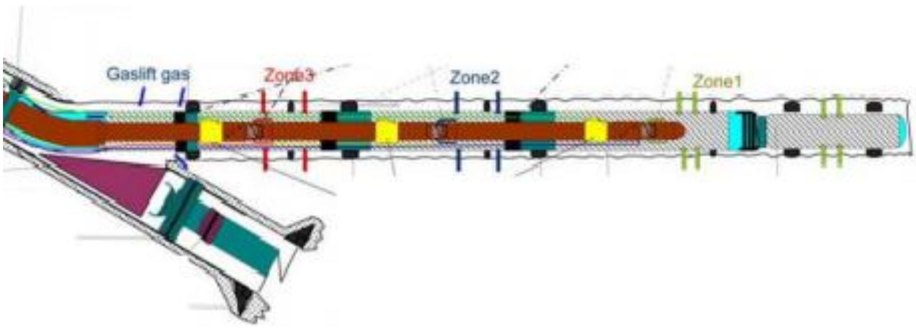

Figure 4-1 Similar design for well Q-12 BH[3].

Well 31/2-Q-12BH are separated into three production zone, this are based on its lithology. Zone 3 are starting from the heel and running mostly 3 CC sands and is the highest producing zone. Zone 2 are located in the middle section of the well and running in the 4-series sands. Zone 2 are the shortest production zone. Zone 1 is the deepest and the longest production zone in the heterolithic sands reaching up to the toe of the well[3].

The cross section of the geomodel along the drilled well path is shown in Figure 4-2. The figure are with the main three producing zones in 3 CC clean sands, 4Ac fine mica-rich sands and 4/5 heterolithic sands.

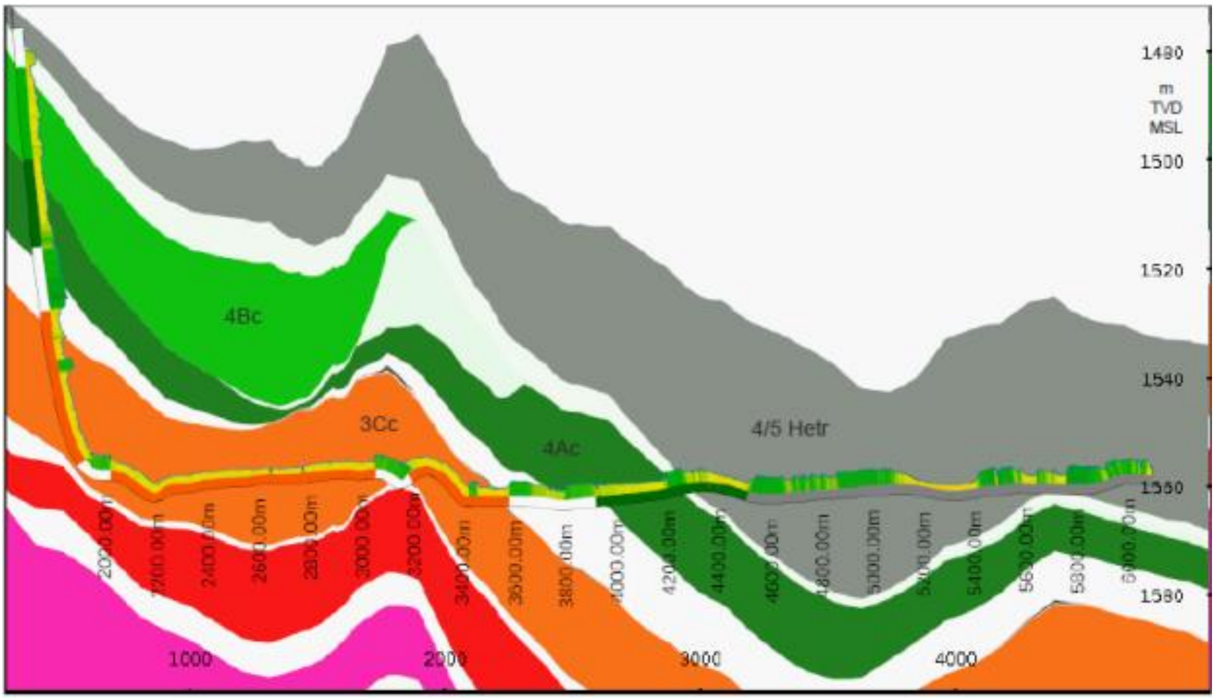

Figure 4-2 Geological cross-section of a well Q-12BH with the main three producing zones[3].

The horizontal part of the well was drilled about 0.5m above the OWC. The intention was to avoid free gas coning problems from the gas cap. It was drilled entirely with 9 1/2 drill bit from 1602.2 m MD to the total depth of 6068m MD.

4.4 Production control and history

A good strategy develops with learning and practice, and therefore knowing the field history is important. The main concern in Troll field was how to produce this thin oil rim. After many years and good horizontal well technology were received, Troll field became world known.

From Figure 4-3 and Figure 4-4 the production history of the Troll B and Troll C platforms are shown.

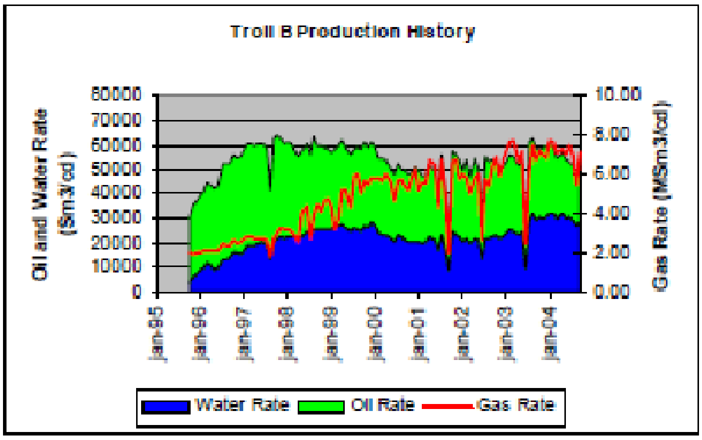

Figure 4-3 Troll B production history from year 1995-2004[15].

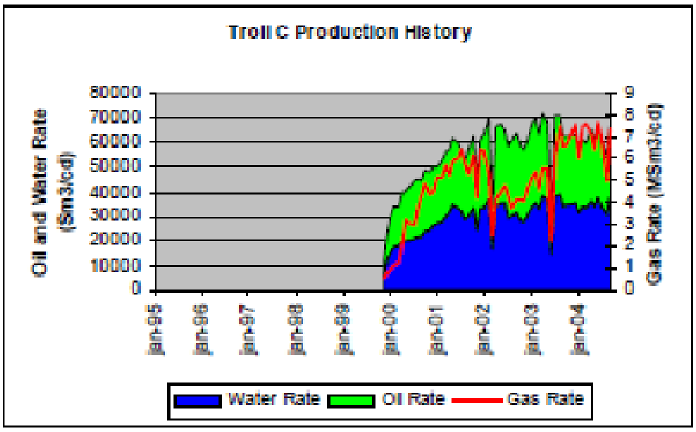

Figure 4-4 Troll C unit production history from year 1995-2004[15].

The production efficiency has been generally good on Troll. One of the challenges is to select the correct opening. Because of large variation in production history, the wells may differ in many aspect as shown in Table 4-2.

Table 4-2Different aspects in the wells

Well liquid rates	500 to 4000 (Sm^3/sd)
Well GOR	56 to 2000 (Sm^3/Sm^3)
Well water cut	0 to 95 %
Well-head pressure	30 to 110 bar
Flow line liquid rates	1500 to 13000 (Sm^3/sd)

The table with the different aspects indicate that in the initial phase the well is producing with constant GOR(solution gas/oil ratio = 56). In this phase the well will normally be produced fully open choke. Only a few wells are producing with fully open chokes on Troll B and Troll C. Usual only wells with recent or without gas breakthroughs will be produced with fully open chokes. The challenge is to select the correct choke openings to avoid unnecessary losses.

After gas breakthrough the oil rate will quickly decline with a strong increase in gas rate, GOR and well-head pressure. By opening the choke , the well-head pressure will increase for gas coning well. This is due to a lower gravitational pressure drop in the tubing due to a higher gas fraction. Gas coning is very rate sensitive, this is because of the high permeability of the Troll reservoir. The rate sensitivity also depend on how much time passes after the gas breakthrough. It is characteristics of a Troll well that the GOR versus oil rate becomes steeper with time[15].

5 Near well simulation of conventional heterogeneous reservoirs

In this chapter, well performance with open hole simulations and ICD completions are evaluated in terms of conventional oil production and gas breakthrough. For this purpose, conventional oil from a reservoir section was simulated by coupling OLGA and Rocx software. This chapter describes briefly an introduction description of OLGA and Rocx, reservoir and fluid properties that are being used for the simulations in Rocx, and the different simulation cases in OLGA-Rocx. Tecplot was used for presenting saturation and permeability profiles in the reservoirs.

5.1 Introduction to OLGA and ROCX

Optimum design and operation of offshore and onshore multiphase production systems are based on a good understanding of flow behavior and the impact of complex flow regimes on long term well performance. OLGA is a simulation software from Scandpower Petroleum Technology utilized for simulating tool used in oil industry for increasing oil production and recovery. The OLGA simulator enables well engineers to predict the transient well flow behavior and determine the optimal process to eliminate or minimize potential problems. It support building a virtual well to analyze what-if scenarios. Transient well analysis with the OLGA simulator enables well engineers to use a virtual well to predict issues and avoid problems. By utilizing OLGA as a powerful simulation tool, outcome of changes in operating conditions are predicted, because of this more cost efficient and safer operations are achieved. OLGA is based on solving six equations; two momentum, one energy and three mass conservations equations.

ROCX is a simulating program developed by SPT group in the recent years. Multiphase flow through a porous media can be simulated with the application of ROCX. The OLGA simulator sends wellbore information to the ROCX module, which then sends information for each phase back to the OLGA simulator. By coupling ROCX and OLGA complete transient near well reservoir simulation is achieved [17, 18].

During this thesis the latest version of OLGA where installed. The purpose was for a better handling of gas simulations and problem related to this with the older version.

5.2 Case study/ Set up and reservoir values

The input parameters in Rocx are the same for all the cases that were simulated, including grid, fluid, reservoir properties and initial and boundary conditions for the wellbore and reservoir. The main task in this thesis was to see at which time the gas breakthrough occurred in the different cases. For comparative purpose all the cases has the same input criteria. Some of the setting are attached in Appendix B, C and the hole setup in Rocx is shown in Appendix C. The fluid and reservoir properties that were used in the near well simulations is shown in Table 5-1. The table present a brief information about the main input parameters.

Table 5-1 Reservoir and fluid properties used in the simulations[3].

Reservoir parameters	Unit	Value
Reservoir temperature	°C	100
Reservoir pressure	Bara	136
Gas oil ratio	Sm^3/Sm^3	48
Oil viscosity	Cp	1.9
Porosity	-	0.28
API gravity	-	42.5
Gas specific gravity	-	0.7

Table 5-2 and Table 5-3 present the reservoir dimensions for Q-12 BH and the near well simulation cases in this thesis. Well Q-12 BH are approximately 6,67 times longer than the well that were simulated in this thesis.

Table 5-2 Reservoir dimension for well Q-12 BH

Parameter	Symbol	Units	Zone 3	Zone 2	Zone 1
Length of a zone	L_z	m	1277	1150	1558
Total length of the zone	L_{TOTAL}	m	3985		
Width of the reservoir	W_R	m	120	120	120
Thickness of the reservoir	h	m	20	20	20
Wellbore radius	r_{wb}	m	0.12	0.12	0.12

Table 5-3Reservoir dimensions for near well simulations

Parameter	Symbol	Units	Zone 3	Zone 2	Zone 1
Length of a zone	L_z	m	200	200	200
Total length of the zone	L_{TOTAL}	m	600		
Width of the reservoir	W_R	m	120	120	120
Thickness of the reservoir	h	m	20	20	20
Wellbore radius	r_{wb}	m	0.1	0.1	0.1

In order to simulate conventional oil production, a driving force of 10bar between the pipe and gas drive from the top of the reservoir was created. The well pressure were set to 126 bar. This is a higher driving force then they use in well Q-12BH simulations. Three different pressure well pressure was created with respect to the different zones. The pressure settings for the well is to be find in table B.3 in Appendix B.

Two main feed are defined in the simulations. Feed 1 is almost pure gas and feed 3 are an oil stream with a GOR at 48 as shown in Table 5-4. Since three phase simulations was out of the scope of this master thesis, no water was assumed.

Table 5-4 Main feeds in the simulations

Feed	Ratio Type	Value	Water-Cut
Feed 3	GOR	48	0.0001
Feed 1	LGR	0.001	0

The reservoir are divided into 6 regions with different permeabilties. The permeability are varying in both xy-direction and z-direction. The different horizontal and vertical permeability values are shown in Table 5-5 and Table 5-6. The well Q-12BH (that the simulations cases are based on) are explained in chapter 4. The permeabilities datas are taken from the well test of Q-12BH. Well Q-12BH is divided into 3 zones as shown in Figure 4-2. Zone 3 will be grid 5 and 6, zone 2 are grid 3 and 4, and zone 1 are for grid 1 and 2 in OLGA layout shown in chapter 5.3and 5.4.

Table 5-5Horizontal permeability data's[3]

Grid number	Permeability values	Unit
1	1503	mD
2	1503	mD
3	1510	mD
4	1510	mD
5	6134	mD
6	6134	mD

Table 5-6Vertical permeability data's[3]

Grid number	Permeability values	Unit
1	1017	mD
2	1017	mD
3	954	mD
4	954	mD
5	4245	mD
6	4245	mD

Behind the permeability data's in the tables above, necessary calculations and log data's are calculated. The data's and the formula for the permeability calculations are shown in formula B.1 and Table B.2 in Appendix B. Both vertical and horizontal permeability logs were divided into zones. Table B.2 in Appendix B shows the lithology that is based on the synthetic permeabilily logs.

The relative permeability data is provided in Table B.1 in Appendix B. Figure 5-1 show a graphical display of this data.

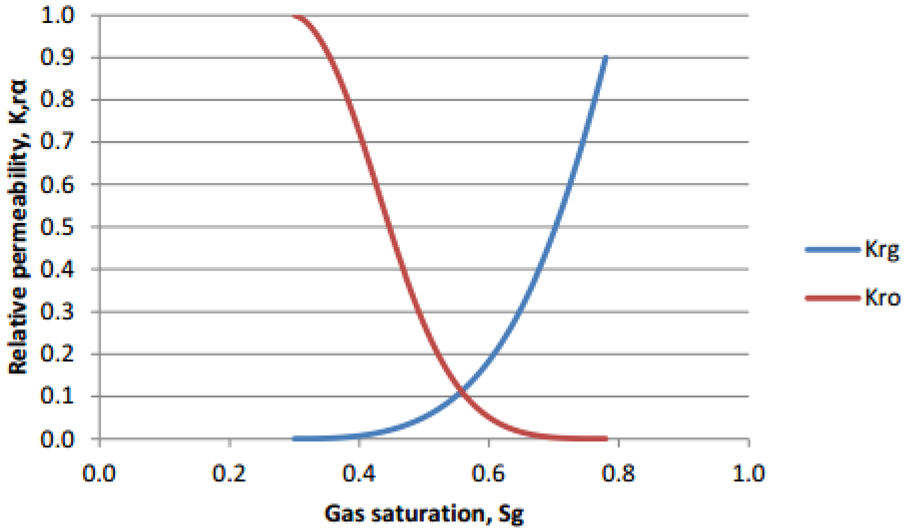

Figure 5-1Relative permeability curves for gas and oil with respect to gas saturation[3].

Formula 5-1[10] was used to get oil saturation data's from Figure 5-1.

$$S_o = 1 - S_g \qquad 5\text{-}1$$

where S_g is the gas saturation and S_o is the oil saturation.

5.3 Simulations with open hole wells

The purpose with the simulations was to see at which time the gas breakthrough occurred. Early gas breakthrough is as mention a big problem, and good strategies are wanted to provide this phenomena. Light oil has a low viscosity and the cases was simulated in a reservoir which has oil viscosity 1.9 cP. Lower viscosity of the phases makes them more mobile and one reason for gas breakthrough. Gas coning are unpredictable, in some cases it may take months/year or maybe right after a new well is put on stream for the gas to reach the well. In generally it will occur at an early stage in the wells life because the oil column becomes thinner as the field matures. To understand the well's behavior becomes more difficult once the cone reaches the well.

A open hole completion is preparation of an oil well without setting a production casing or liner opposite the producing formation. The reservoir fluids will then flow unrestricted into the open wellbore. Gas coning tendencies must be studied carefully for the reasons that the completion design allows no contingency for shutting off unanticipated gas production [19]. The layout for the open hole simulations is present in Figure 5-2.

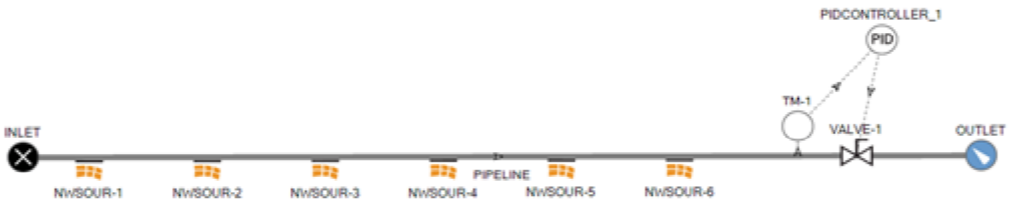

Figure 5-2Open hole layout

When oil production begins, the overlying gas layer start to down come toward the base pipe due to the 10 bar difference created between the base pipe and the overlying gas drive. In the high permeable region the gas layer moves faster compared to the lower permeable region. The result from the simulations regarding to gas breakthrough time, accumulated rates and flow rates from the production well are shown in Figure 5-3, Figure 5-4 and Figure 5-5.

The trends shows that oil flow rate decrease as the gas flow rate increases. And after approximately 57 days the gas breakthrough occur.

Volumetric oil flow rate increase rapidly up to 5000 m^3/day and starts to decrease further as the gas flow rate increases. After 45 days of production, gas started to flow into the production well. The gas breakthrough takes place after 57 days as shown in Figure 5-3.

The near well sources was simulated until 600 meters, but the pipeline was set to 800 meters for including the PID-regulator. Therefore, the profile trends flats out after 600 meters. The permeability difference from zone 1-2 are quite small, so accumulated and flow rate of oil trends are not that steep in this area. The trend are more slope because of the small permeability difference, until the highest permeability zone after 400 meters. In this zone the volumetric oil rate increases to the highest at 5000 m^3/day.

The accumulated and the volumetric oil flow rate increases after the permeability increases. In the highest the accumulated oil are 160 000 m^3.

The results from the simulations are shown in Figure 5-3, Figure 5-4 and Figure 5-5.

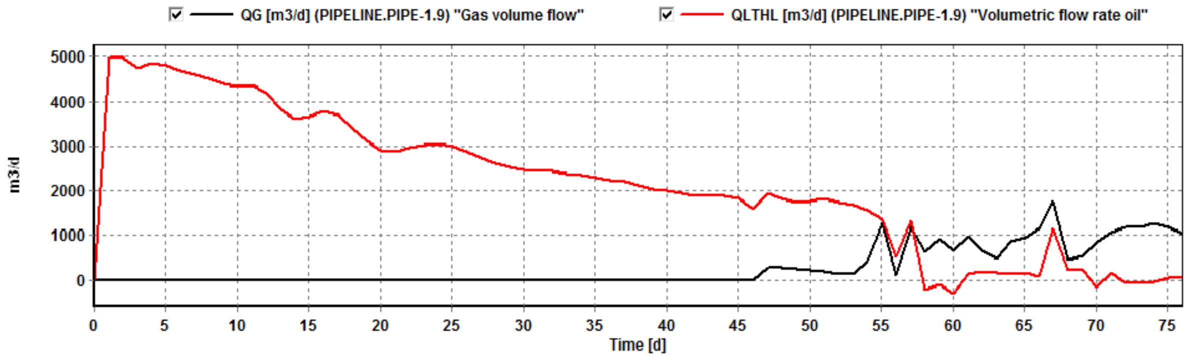

Figure 5-3 Volumetric flow rate oil after 75 days of production

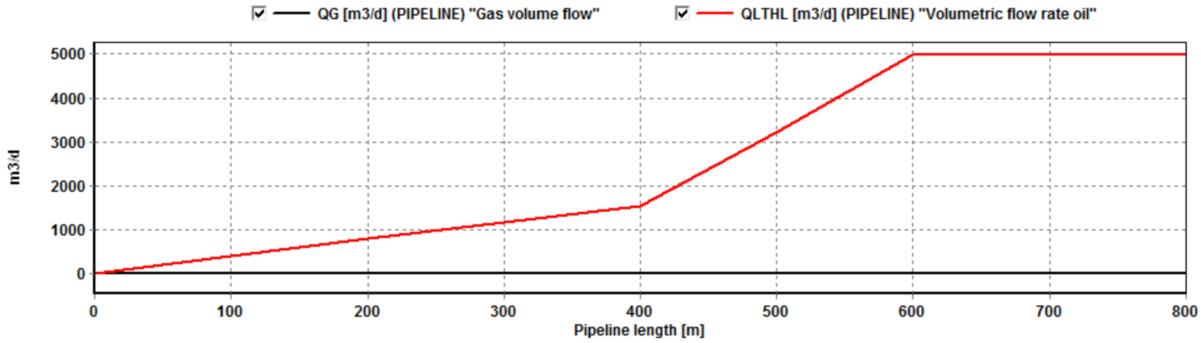

Figure 5-4 Volumetric oil flow rate trend from the well

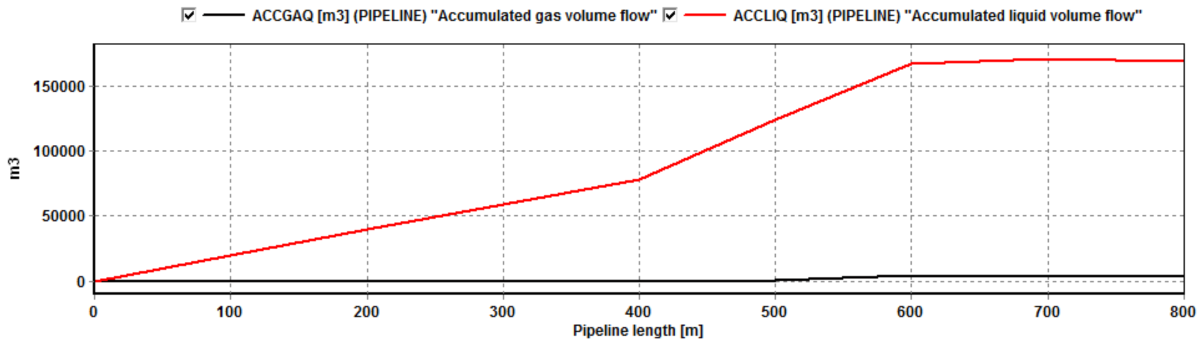

Figure 5-5Accumulated oil rate trends from the well

5.4 Simulations with ICD completion

Long horizontal wells are increasingly being used to maximum reservoir contact and improve the productivity and injectivity of producer. Heterogeneities in reservoir rock properties (particular in porosity and permeability) lead to variable rates of inflow to the well, and risk gas breakthrough. The main production problems for horizontal wells are caused from drawdown along the horizontal well and uneven inflow. The drawdown are often larger at the heel than at the toe for wells without inflow control. Because of this the production along the wellbore is not uniform, but rather increasing from the toe towards the heel. In addition, the tendency for gas coning is much higher in the heel if such a pressure profile is presented.

Inflow control device are known to restrict the flow rate from the well. The flow rate with ICD's are lowered by the additional pressure drop they cause. The additional pressure drop that are caused helps to increase well's volumetric oil recovery. ICD contribute towards a more uniform production profile and are able to lower GOR by delaying gas breakthrough. The ICD screen that are used on the Troll field are shown in Figure 5-6.

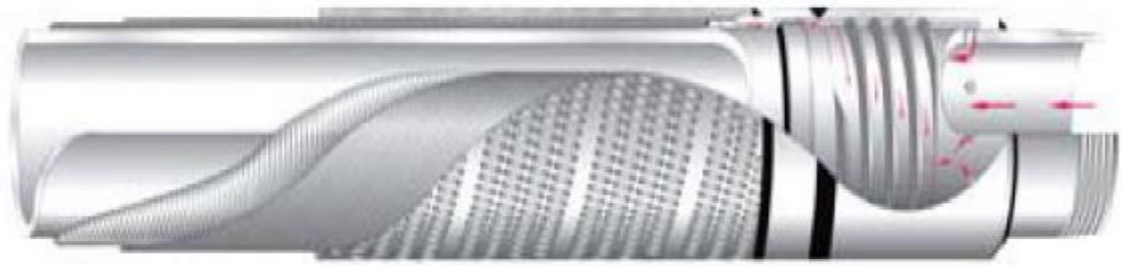

Figure 5-6 Premium ICD screen used on the Troll Field[3].

ICD's set at intervals along horizontal open hole section, are designed to redistribute downhole pressure to optimize fluid inflow along the entire producing interval of a horizontal well.

Oil production with ICD completion were simulated. Schematic view over the OLGA layout including the base pipe, ICD's and packers used for the production is presented in Figure 5-7

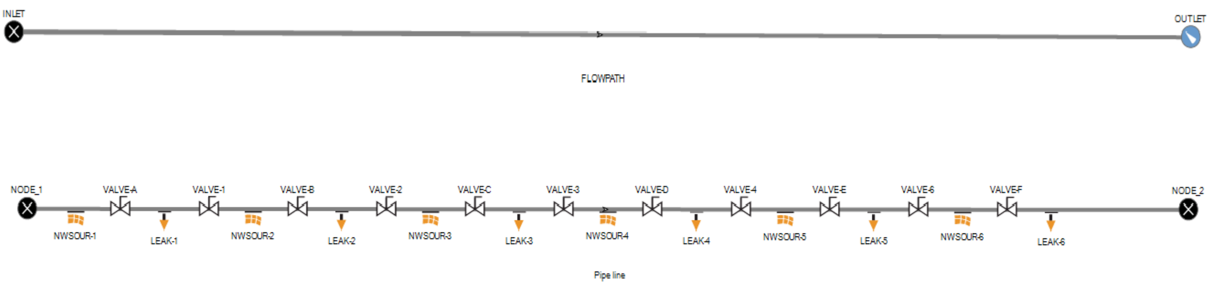

Figure 5-7 Layout for ICD cases in OLGA

where every section maintain near well source, ICD , leak and a packer. To prevent a early gas breakthrough and to combat challenges with vertical wells, a completion strategy using ICDs and packers are been used. Delaying and minimizing gas breakthrough are some of the reason why this completion are used.

Packers is a standard component of the completion hardware of oil and gas wells and its used to provide a seal between the outside of the production tubing and the inside of the wellbore wall. The packers remain during the well production. The packers are used to isolate the perforactions for each zone. In this case packers are used to protect the casing from casing leaks perforations and isolate producing zones.

For comparitive purpose three different cases were simulated with different restriction on the ICD's. To se how this affect the oil prodution and coning effect. The different restricion setup is presentet in Table 5-7.

Table 5-7Restriction setup in OLGA

	Restriction valve A [mm]	Restriction valve B [mm]	Restriction valve C [mm]	Restriction valve D [mm]	Restriction valve E [mm]	Restriction valve F [mm]
Case 1	12	12	10	10	8	8
Case 2	10	10	9	9	7	7
Case 3	10	10	10	10	8	8

Zone 3 is the zone with highest permeability, and for this reason valve E and F has highest restriction in this zone. Comparing to the two other zones with lower permeability. The restriction effect in the different cases regarding to accumulated oil and oil flow rate are shown in Figure 5-8 and Figure 5-9.

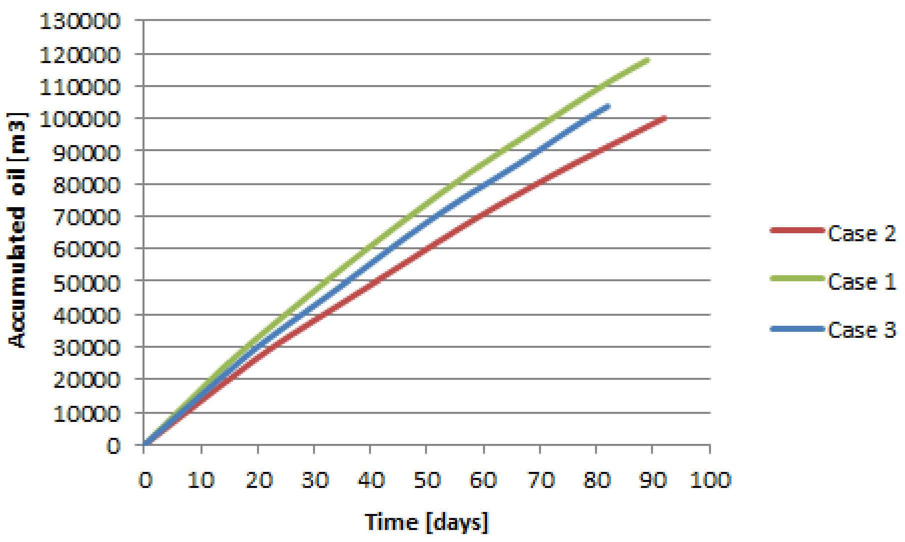

Figure 5-8 Accumulated oil volume profiles for ICD with three different cases

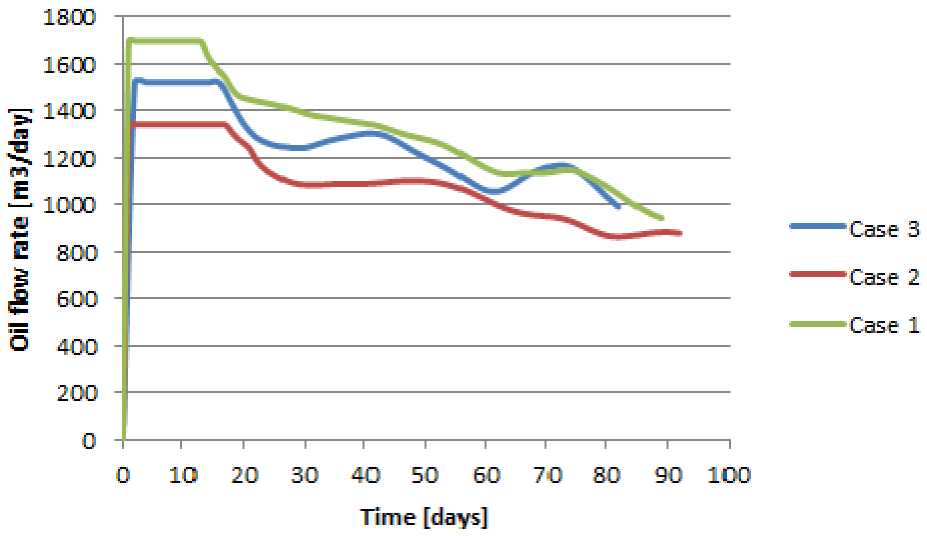

Figure 5-9 Oil flow rate profiles for ICD completions for three different cases

The excel sheet that the graphs above are based on is attached in Appendix E. Case 1 with the lowest restriction have the highest accumulated oil rate at approximately 120 000 m^3. From the simulation results it can be seen that case 2 with the lowest restriction has lowest accumulated oil rate at 100 000 m^3. Case 3 with the most even distribution in restrictions has accumulated oil rate at 105 000 m^3.

Case 1 has the highest volumetric oil flow rate at 1700 m^3/day from the production well, comparing to case 2 with the lowest production oil flow rate at 1300 m^3/day.

For all the cases Tecplot were used to see different saturation profiles and permeability profile. The Tecplot profiles are showed in YZ-direction from the reservoir. A picture of the reservoir geometry in YZ-direction with the streamlines is attached in Appendix D.

Case 1 with the lowest restriction has more narrow saturation profile than profile for case 2. Because of low restriction on the ICD's, gas will have more down coming effect and gas breakthrough will happen faster. This creates a more narrow saturation profile.

From the saturations profile it can be seen that in case 1 more gas has reached closer to the production well comparing to case 2. Because of the low restriction on the ICD's in case 1 this is expected. Case 3 has the most evenly distributed restrictions and over time this seems to be the best solutions regarding to oil production. This will in a higher way prevent gas coning and later gas breakthrough, then lower restrictions cases. The ICD's causes a flow restriction of gas and oil flowing from the reservoir and into the well, that it will make the inflow profile more uniform.

A gas breakthrough didn't take place in the ICD simulations after 57 days as in the open hole simulations. This verifying that well with ICD's are more effective when it comes to prevent gas breakthrough and total oil production.

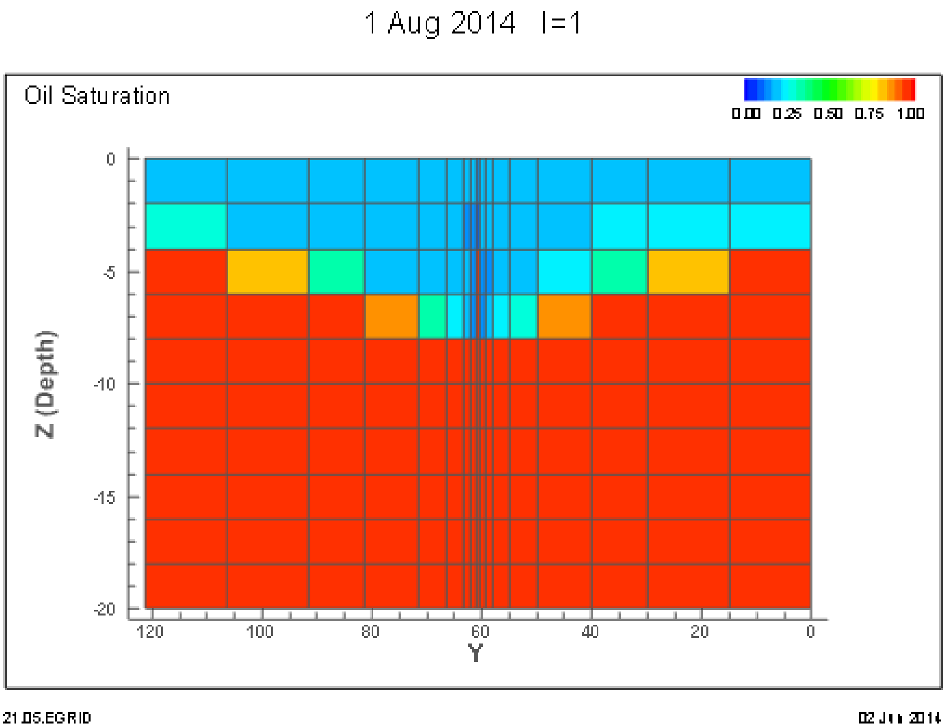

Figure 5-10 Saturation profile of case 1

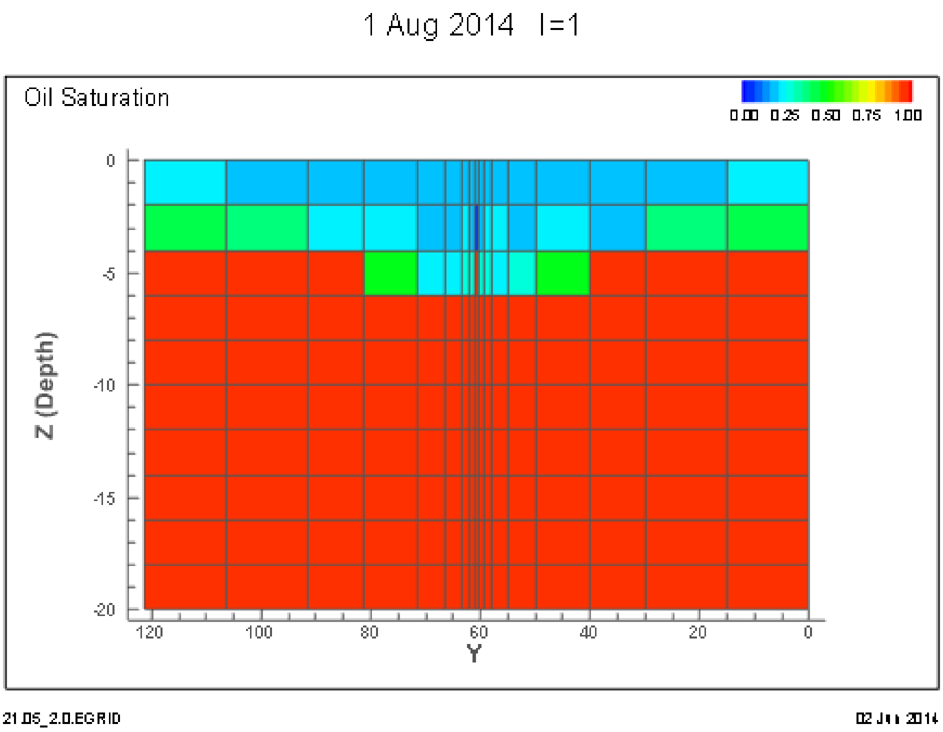

Figure 5-11 Saturation profile of case 2

6 Conclusion and Future Work

The completion of horizontal wells can be done by different ways and it depend on the production constrains and the reservoir characteristics. The selection of completion method is directly influenced by the degree of rock consolidation, the need for gas shut off, the anticipated flow rate, the completion longevity, the shale reactivity and a stability, the sand production and the degree of grain sorting.

In this thesis Rocx were used for near well simulations. Coupled with OLGA a complete picture of gas and oil flowing from the reservoir to the production well was achieved. Near well simulations of oil production from conventional heterogeneous oil reservoirs with gas drive are described in detail.

One of the subtask was to find a field with conventional oil production and simulate with reservoir properties data's. This was done, and Troll field fitted the criteria and simulation data's was based on this field.

A literature study of conventional oil production with gas drive was done, where the focus was especially on relative permeability, oil and gas saturation.

Also, near well simulations with OLGA-Rocx in a heterogeneous reservoir with open-hole and ICD completion wells were performed during this thesis. The different cases was compared regarding to gas breakthrough time and oil production. Cases were simulated with data's from well Q-12BH in the Troll field. With an assumption on two phase flow, oil and gas. The production flow rate from the open hole cases was around 5000 m^3/day. After approximately 45 days of production gas started to flow into the production well, and gas breakthrough takes place after 57 days of production.

Three different cases were simulated with ICD's completion. For comparative purpose regarding gas breakthrough, different restriction was set on the ICD's. The case with the lowest restriction has the highest production flow rate at 1700 m^3/day. To interpret from the saturation profile this case also had a more coning shape and more gas near the production well. The case with the highest restriction had the lowest producing rate at 1300 m^3/day, but less gas saturation near the production well. Based on these simulations is seems that most evenly distributed restrictions is to be preferred over time regarding to oil production and preventing gas breakthrough.

Gas breakthrough did not take place in the ICD simulations after 57 days as in the open hole simulations. This verifying that well with ICD's are more effective when it comes to prevent gas breakthrough and total oil production. So the negative effect of gas breakthrough will be delayed by using ICD's in production pipe.

Suggestions for future work

Some future work needs to be done to complete gas breakthrough in simulations with ICD's. A more precisely comparison to the earlier testing/simulations of well Q-12BH needs to be done. For example extend the wellbore up to total 3985 meters, compare the different productions flow rate in the three different production zones and adjust down pressure driving force. In general adjusting so the comparison can be more accurate with previous testing data's of well Q-12BH.

References

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Appendices

Appendix A: Master's Thesis task description
Appendix B: Well Q-12 BH settings
Appendix C: ROCX settings
Appendix D: Reservoir geometry
Appendix E: Excel

Appendix A

Telemark University College

Faculty of Technology

FMH606 Master's Thesis

Title: Near well simulation of oil production from conventional heterogeneous oil reservoirs with gas drive

TUC supervisor: Prof. Britt Halvorsen

Task background:

Traditionally, oil reservoirs were accessed by drilling vertical wells. This is simple and straight-forward technique, but with limited reservoir contact per well. Therefore, in order to access more reservoir contact, techniques and devices have been developed to drill horizontal wells. Multi-lateral wells have been installed by several oil companies to maximize the reservoir contact.

Early gas breakthrough is a big challenge in production of light or conventional oil at the Norwegian Continental Shelf (NCS). Early gas breakthrough occurs in high permeable zones or in fractured zones in the reservoir. The negative effects of gas breakthrough may be delayed by inflow control devices (ICD). Well completion with ICDs consists of a large number of ICDs disposed at regular intervals along its entire length. The ICDs causes a flow restriction of the fluid flowing from the reservoir and into the well, and will make the inflow profile more uniform. The result is a significant increase in the recovery compared to open-hole wells. A better understanding of the multiphase reservoir condition is required.

Task description:

In this project Rocx will be used for near well simulations. Rocx is a reservoir simulation program and is used in combination with OLGA to get the complete picture of fluid flow from reservoir to well and production pipe. OLGA-Rocx, can be used to calculate the production potential from different types of reservoirs and to study the gas coning in the reservoir. Simulations with OLGA-Rocx can give a more total picture of the near well conditions.

The project will focus on:

1. Literature study on conventional oil production with gas drive
2. Focus on relative permeability, oil and gas saturation.
3. Near well simulations with OLGA-Rocx in a heterogeneous reservoir with:
    - open-hole wells
    - wells with ICD completion.
4. Comparing the different cases.

Practical arrangements:
Necessary software will be provided by TUC.

Signatures:

Linn Raasted

Student (date and signature):

Britt Halvorsen

Supervisor (date and signature):

Appendix B

Table B.1 : Relative permeability values for gas and oil with respect to gas saturation

S_g [-]	K_{rg} [-]	S_o [-]	K_{ro} [-]
0.3	0	0.2	0
0.58	0.1	0.41	0.1
0.6	0.2	0.43	0.2
0.61	0.3	0.48	0.3
0.62	0.4	0.5	0.4
0.65	0.5	0.511	0.5
0.69	0.6	0.5765	0.6
0.74	0.7	0.6	0.7
0.78	0.8	0.612	0.8
0.8	0.9	0.65	0.9
-	-	0.7	1

Formula B.1: The formula for arithmetic avreage permeability [3].

$$k_{z,h,v} = w_1 + k_1 + w_2 \cdot k_2 + .. + w_n \cdot k_n$$

where k is the average permeability of a certain layer out of the many that can be present in one zone, and w is the weight. h and v stand for horizontal and vertical and subscript Z stands for the zone.

Table B.2 : Penetrated lithology layers of Q-12BH and weighted arithmetic average permeabilities [3].

Zonal length	Top MD (m)	Bottom MD (m)	Length (m)	Stratigraphy	Kh (mD)	Kv (mD)
ZONE 3	2059	2064	5	Packer	6153	4258
1277m	2064	3031	967	3CC(2)	7282	5058
	3031	3175	144	3CM(2)	199	103
	3175	3340	165	3CC(3)	4771	3222
ZONE 2	3340	3345	5	Packer	1517	958
1150m	3345	3395	50	3CC(3)	4531	3022
	3395	3438	43	? (M)	67	32
	3438	3551	113	3CC(3)	2681	1720
	3551	3891	340	4AM(2)	447	257
	3891	4172	281	4AC(2)	1913	1188
	4172	4258	86	? (M)	42	20
	4258	4481	223	4AC(2)	2320	1485
	4481	4495	14	4_5HETR	82	41
ZONE 1	4495	4500	5	Packer	1503	1017
1558m	4500	6058	1558	4_5HETR	1503	1017

Table B.3 Pressure settings in NETool [3].

Pressures in NETool (FCV openings 6,5%, 27%, 23%)					
Parameter	**Symbol**	**Units**	**Zone 3**	**Zone 2**	**Zone 1**
Reservoir pressure	p_{RES}	Bar	136,22	136,48	136,38
Sandface pressure	p_{SF}	Bar	136,05	135,74	135,61
Average annulus pressure	p_{ANN}	Bar	135,54	135,21	135,40
Annulus pressure (at DHG)	p_{ANN_DHG}	Bar	134,16	133,59	135,39
Average tubing pressure	p_{TUB}	Bar	128,78	133,69	135,32
Flowing tubing hole pressure (at DHG)	p_{TUB_DHG}	Bar	125,52	132,79	134,66
Drawdown (p_{RES} - p_{SF})	Δp	Bar	0,17	0,74	0,77
Pressure drop across ICDs (p_{SF} - p_{ANN})	Δp_{ICD}	Bar	0,51	0,53	0,21
Pressure drop across stinger (p_{ANN} - p_{TUB})	Δp_{STI}	Bar	6,77	1,52	0,08

Appendix C

```
#               Version:                1.2.1.0
#               Input file created by Input File Editor
#               05/21/2014              06:18:12    PM


*GEOMETRY       RECTANGULAR

#               Number of grid blocks in horizontal and vertical direction
#               -------------------------------------------------------
#               nx                      ny          nz
                6                       17          10

                dx                      const       100
                dy                      j           15          15          10          10
                dy                      j           1.5         1           0.4         1
                dy                      j           5           10          10          15
                dz                      const       2
#
#               Direction vector for gravity
#               ---------------------------
                gx                      gy          gz
                0                       0           1
*FLUID_PARAMETERS


                blackoil
#
#               Black                   oil         option      data
                --------------------
                gormodel                Lasater
                massfrac

                rsgo_bp_tuning          off

                oilvisc_tuning          on

                gor                     48
                gasspecificgravity      0.7
                apigravity              42.5
```

```
                oilvisc              1.9
                visctemp             100
                viscpress            136
#
#               Black oil component data
                ------------------------
                ncomp                3

                label                BO_Oil_0
                type                 oil
                apigravity           42.5

                label                BO_Gas_0
                type                 gas
#               gasspecificgravity   0.7
#               h2smolefraction      Not        used
#               co2molefraction      Not        used
                n2molefraction       Not        used

                label                BO_Water_0
                type                 water
                waterspecificgravity 1

#
#               Black oil feed data
                -------------------
                nfeed                4

                label                Feed_3
                oilcomponent         BO_Oil_0
                gascomponent         BO_Gas_0
                gor                  48

                watercomponent       BO_Water_0
                watercut             0.0001
                label                Feed_1
                oilcomponent         BO_Oil_0
                gascomponent         BO_Gas_0
                lgr                  0.001

                watercomponent       BO_Water_0
```

watercut	0
label	Feed_2
oilcomponent	BO_Oil_0
gascomponent	BO_Gas_0
glr	0

watercomponent	BO_Water_0
watercut	0
label	Feed_0
oilcomponent	BO_Oil_0
gascomponent	BO_Gas_0
gor	0

watercomponent	BO_Water_0
watercut	0

*RESERVOIR_PARAMETERS

#

Permeability (mDarcy) in principal directions

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#	Porosity					
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	por	const	0.28			
#						
	compr	reference_pressure				
	rock_compr	0	0			
#						
	swc	sor	sgr			
	0	0.2	0.3			
	krw					
	0.1	0				
	0.11	0.003				
	0.12	0.005				
	0.15	0.013				
	0.2	0.025				
	0.25	0.038				
	0.3	0.05				
	0.35	0.082				
	0.4	0.114				
	0.45	0.145				
	0.5	0.177				

0.55	0.233	
0.6	0.289	
0.65	0.344	
0.7	0.4	
0.75	0.48	
0.8	0.56	
0.85	0.64	
0.9	0.72	
0.95	0.86	
1	1	/

kro

0.2	0	
0.41	0.1	
0.43	0.2	
0.48	0.3	
0.5	0.4	
0.511	0.5	
0.5765	0.6	
0.6	0.7	
0.612	0.8	
0.65	0.9	
0.7	1	/

krg

0.3	0	
0.58	0.1	
0.6	0.2	
0.61	0.3	
0.62	0.4	
0.65	0.5	
0.69	0.6	
0.74	0.7	
0.78	0.8	
0.8	0.9	/

Pcow

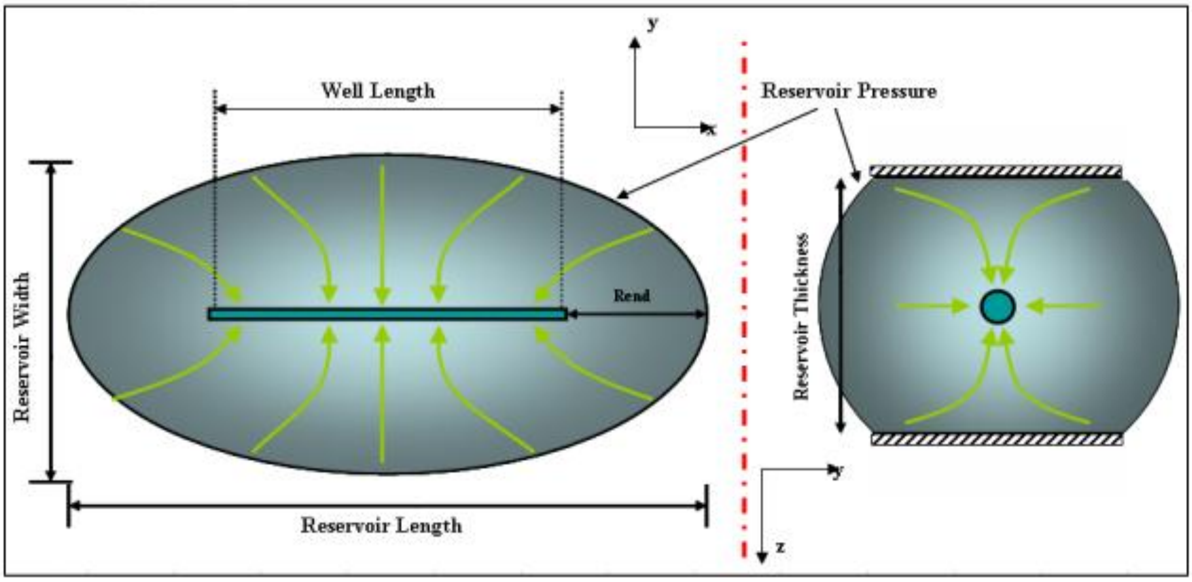
0	0	
1	0	/

```
Pcgo
0        0
0.8      0      /

*BOUNDARY_CONDITIONS

manual


#        Injection flow rates
         --------------------
         nsource
         0
#
         ix   iy   iz   ntime   time   mw   mo   mg   temp
#
#        Production pressures
#        --------------------
         npres_bou
         7
#        i j k idir type name ntime time pres_bou temp_bou Sw_bou So_bou Sg_bou Fee
         1-6 1-17 1 3 res Gas_cap_drive 1 0 136 100 0 0 1 [ Feed_1]
#        i j k idir type rw name ntime time skin  WIFoil WIFgas WIFwater  pres_bou temp_
         Sg_bou
         1   9   10   1   well   0.2   P1   1   0   0   1   1   0   136   100   0   1   0
         [Feed_3]
         2   9   10   1   well   0.2   P2   1   0   0   1   1   0   136   100   0   1   0
         [Feed_3]
         3   9   10   1   well   0.2   P3   1   0   0   1   1   0   136   100   0   1   0
         [Feed_3]
         4   9   10   1   well   0.2   P4   1   0   0   1   1   0   136   100   0   1   0
         [Feed_3]
         5   9   10   1   well   0.2   P5   1   0   0   1   1   0   136   100   0   1   0
         [Feed_3]
         6   9   10   1   well   0.2   P6   1   0   0   1   1   0   136   100   0   1   0
         [Feed_3]
```

```
*INITIAL_CONDITIONS

#                    Feed
manual               feed           const     [Feed_3   1]       /



#                    Saturations
                     -----------
                     sw             const     0
                     so             k         1    1    1    1    1    1    1    1    1
#                    sg             k         0    0    0    0    0    0    0    0    0
#
                     Pressures
                     ---------
#                    Po             const     136
#
                     Temperatures
                     ------------
*TEMPERATURE         T              const     100

*INTEGRATION         off

#

                     tstart         tstop
#                    0              0

                     dtmin          dtmax     dtstart   dtfac     cflfac
implicit             0              3600      0.01      5         1

*WELL_COUPLING_LEVEL Linsolver


*OUTPUT              2

#

                     cof_time       cof_rate
#                    1              1
```

	ntplot		
	6		
	P1		
	P2		
	P3		
	P4		
	P5		
	P6		
	Dt_Trend		
	0	3600	/
	Dt_Prof		
	0	3600	/
*END	screen_info	0	

Appendix D



Reservoir geometry including yellow streamlines

Appendix E

Accumulated oil [m3]				Flow rate oil [m3/day]			
Time/days	Case 1	Case 2	Case 3	Time/days	case 1	case 2	case 3
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00		1343.22	1698.65	1.00		1342.74	1698.61
2.00	3041.41	2686.37	3397.52	2.00	1520.58	1342.73	1698.30
3.00		4028.21	5096.01	3.00		1342.63	1698.03
4.00	6083.05	5371.18	6793.13	4.00	1520.37	1342.52	1698.02
5.00		6714.10	8491.54	5.00		1342.52	1698.09
6.00	9123.20	8055.78	10190.02	6.00	1520.34	1342.54	1698.14
7.00		9398.74	11887.28	7.00		1342.56	1698.16
8.00	12164.59	10741.71	13585.80	8.00	1520.33	1342.57	1698.17
9.00		12083.42	15284.33	9.00		1342.55	1698.17
10.00	15204.77	13426.38	16982.86	10.00	1520.37	1342.54	1698.17
11.00		14769.32	18680.11	11.00		1342.52	1698.09
12.00	18245.00	16110.99	20378.34	12.00	1520.36	1342.52	1697.47
13.00		17453.91	22074.56	13.00		1342.51	1692.05
14.00	21286.36	18796.82	23737.90	14.00	1520.24	1342.49	1632.79
15.00		20138.42	25352.36	15.00		1342.39	1597.37
16.00	24325.38	21481.05	26935.23	16.00	1518.60	1341.98	1567.47
17.00		22822.66	28487.36	17.00		1339.66	1537.86
18.00	27309.80	24149.98	30004.71	18.00	1430.34	1308.41	1493.42
19.00		25443.84	31482.31	19.00		1281.50	1465.77
20.00	30070.48	26715.82	32942.50	20.00	1344.16	1262.13	1454.53
21.00		27968.25	34393.14	21.00		1239.50	1448.15
22.00	32699.23	29184.99	35838.95	22.00	1288.67	1195.41	1442.40
23.00		30364.33	37278.16	23.00		1164.93	1437.50
24.00	35245.78	31517.89	38713.87	24.00	1262.39	1143.12	1432.72
25.00		32651.98	40143.32	25.00		1127.48	1427.24
26.00	37757.23	33772.59	41567.93	26.00	1249.15	1113.49	1420.76
27.00		34880.18	42984.45	27.00		1101.79	1413.54
28.00	40246.57	35977.79	44395.13	28.00	1242.15	1093.49	1406.84
29.00		37067.43	45797.89	29.00		1088.09	1399.12
30.00	42730.00	38154.76	47192.56	30.00	1242.72	1085.84	1389.76
31.00		39240.04	48578.22	31.00		1084.19	1383.02
32.00	45228.22	40323.41	49959.05	32.00	1256.36	1084.34	1377.82
33.00		41408.83	51334.29	33.00		1085.63	1374.43

34.00	47757.40	42495.81	52707.08	34.00	1272.54	1087.38	1370.72
35.00		43583.99	54075.78	35.00		1088.88	1366.41
36.00	50314.33	44672.24	55440.23	36.00	1284.06	1089.61	1362.19
37.00		45762.88	56800.61	37.00		1089.29	1358.24
38.00	52893.00	46851.62	58157.12	38.00	1293.91	1088.61	1354.52
39.00		47939.86	59509.98	39.00		1088.39	1350.87
40.00	55489.89	49028.35	60859.10	40.00	1302.70	1089.04	1346.95
41.00		50117.69	62202.68	41.00		1090.48	1342.18
42.00	58096.85	51209.71	63542.13	42.00	1302.25	1092.58	1336.17
43.00		52302.99	64874.90	43.00		1095.11	1328.85
44.00	60688.78	53400.04	66199.77	44.00	1286.39	1097.62	1320.49
45.00		54498.34	67516.08	45.00		1099.81	1311.85
46.00	63235.17	55599.16	68823.96	46.00	1259.28	1101.48	1303.73
47.00		56701.23	70124.19	47.00		1102.49	1296.58
48.00	65723.72	57803.29	71416.58	48.00	1229.28	1102.82	1290.40
49.00		58906.44	72704.31	49.00		1102.41	1284.78
50.00	68154.44	60008.67	73986.45	50.00	1202.12	1100.98	1279.10
51.00		61107.74	75262.56	51.00		1098.54	1272.63
52.00	70533.60	62205.06	76531.48	52.00	1176.61	1094.92	1264.71
53.00		63296.91	77791.56	53.00		1090.10	1254.86
54.00	72859.75	64384.48	79040.84	54.00	1149.54	1083.86	1243.09
55.00		65465.12	80276.66	55.00		1076.25	1230.19
56.00	75128.87	66536.23	81500.47	56.00	1118.32	1067.30	1215.70
57.00		67598.98	82708.09	57.00		1057.10	1200.42
58.00	77332.87	68649.88	83901.58	58.00	1086.49	1046.03	1185.12
59.00		69690.48	85078.78	59.00		1034.18	1170.36
60.00	79478.87	70719.01	86241.77	60.00	1061.16	1021.93	1156.78
61.00		71734.05	87393.29	61.00		1009.66	1145.22
62.00	81592.01	72738.12	88533.46	62.00	1056.97	997.79	1136.61
63.00		73731.04	89666.92	63.00		987.40	1131.86
64.00	83723.99	74712.78	90798.80	64.00	1077.71	978.38	1131.09
65.00		75687.42	91930.30	65.00		970.77	1133.06
66.00	85910.86	76655.24	93065.46	66.00	1110.47	964.76	1135.79
67.00		77617.80	94201.85	67.00		960.24	1137.57
68.00	88164.04	78576.46	95338.43	68.00	1140.62	956.87	1135.95
69.00		79532.17	96474.38	69.00		954.25	1134.93
70.00	90464.97	80484.17	97609.48	70.00	1159.19	951.76	1136.59
71.00		81434.64	98747.48	71.00		948.67	1140.58
72.00	92794.78	82381.45	99891.24	72.00	1168.17	944.37	1145.46
73.00		83323.17	101038.30	73.00		938.41	1149.25

74.00	95127.07	84257.96	102188.90	74.00	1160.90	930.47	1149.57
75.00		85183.80	103335.20	75.00		920.56	1143.14
76.00	97417.88	86098.90	104473.20	76.00	1127.96	909.09	1133.24
77.00		87000.97	105601.20	77.00		896.97	1120.97
78.00	99631.38	87893.32	106715.10	78.00	1083.50	885.98	1107.61
79.00		88773.37	107815.80	79.00		876.60	1093.38
80.00	101749.20	89646.42	108901.90	80.00	1035.35	869.65	1078.27
81.00		90513.97	109972.40	81.00		865.60	1062.28
82.00	103775.50	91378.92	111025.40	82.00	991.50	864.36	1045.46
83.00		92243.88	112062.30	83.00		865.45	1027.92
84.00		93110.79	113081.40	84.00		868.32	1010.07
85.00		93981.14	114083.00	85.00		872.02	993.51
86.00		94854.20	115068.50	86.00		876.23	978.31
87.00		95732.47	116040.80	87.00		879.83	964.73
88.00		96613.93	116999.40	88.00		882.54	953.10
89.00		97497.47	117947.40	89.00		883.96	943.61
90.00		98381.79		90.00		884.06	
91.00		99265.43		91.00		882.60	
92.00		100145.60		92.00		879.60	