Master’s Thesis 2013

Candidate: Raju Aryal

Title: Near Well Simulation of Oil Production from Heavy Oil Reservoirs

Telemark University College
Faculty of Technology
Kjølnes
3914 Porsgrunn
Norway

Telemark University College
Faculty of Technology
M.Sc. Programme

MASTER'S THESIS, COURSE CODE FMH606

Student:	**Raju Aryal**
Thesis title:	**Near well simulation of oil production from heavy oil reservoirs**
Signature:	. . . .
Number of pages:	65
Keywords:	ICD, AICD, ICV, AICV, Horizontal reservoir, choking

Supervisor:	Professor Britt Halvorsen	sign.:	. . . .
2nd Supervisor:	Haavard Aakre	sign.:	. . . .
Censor:	Dr. Vidar Mathiesen	sign.:	. . . .
External partner:	InflowControl AS	sign.:	. . . .
Availability:	Open		

Archive approval (supervisor signature)**:** sign.: . . . . **Date :** . . . .

Abstract

During the last some years, there has been a lot of discussion about the challenges in the field of heavy oil production in horizontal wells. The Autonomous Inflow control Valve (AICV), which has been developed by InflowControl AS, is self-regulated and does not require external force to control the flow. AICV is a very new technology which has the capacity to increase the recovery of heavy oil from horizontal wells. In this report, a computational study of a thin horizontal reservoir section with AICVs is presented, discussed and compared with the conventional ICDs. The near well reservoir section is modeled by using reservoir simulation software Rocx in combination with OLGA.

Two different cases were simulated for a well section of 992m. One case is with conventional ICD and another case is with AICV. Both cases were simulated with a differential pressure of 10bar. The reservoir section considered in both cases is homogeneous with permeability 5Da.

The initial total oil production rate for both cases was 2500 m^3/day. First, water breakthrough occurs in the heel side of the well due to heel-toe effect. When water break through occurs, the first AICV in the heel chokes the water production locally while the other AICVs are producing oil. In the similar manner, the other AICVs close locally after water breakthrough. Thus the water-cut is controlled and remains low. This gives a good representation of the AICV action and the recovery is increased.

AICV can works reversibly also. The meaning is that the closed AICV starts to produce oil if it encounters higher concentration of oil. This reverse AICV action was observed in simulation after 10 days of production.

The simulation shows that the recovery of heavy oil production with AICVs is increased by approximately 21% compared to conventional ICDs.

Table of contents

Preface

This thesis is completed during the spring 2013 at Telemark University College on behalf of InflowControl AS. The task description is presented in Appendix 1. First, I would like to thank to Telemark University College and InflowControl AS for letting me to work on this thesis.

A special thank is given to my supervisor Professor Britt Halvorsen from Telemark University College for her guidance and advice throughout this semester. She has been a great resource and was always available for discussion if needed. Her good knowledge in oil production field directed me to find the best solutions in the process of completing this task. I also wish to thank my co-supervisor Mr. Haavard Aakre from InflowControl AS for good guidance and counseling during the simulation.

Another great thank is handed to Mr. Rajan Kumar Thapa, Mr. Roshan Sharma and Mr. Farzan Sahari Moghaddam for their support during the thesis period. It is appreciable the helps that I got from library and IT department.

Porsgrunn, 31st May, 2013

Raju Aryal

Nomenclature

Abbreviations

AICD	Autonomous Inflow Control Device
AICV	Autonomous Inflow Control Valve
EOR	Enhanced Oil Recovery
ICD	Inflow Control Device
ICV	Inflow Control Valve
GOR	Gas Oil Ratio
LGR	Liquid Gas Ratio
WC	Water-cut

Letters and Expressions

A	Cross-sectional area	[m^2]
C_v	Valve sizing coefficient	[m^3/ (sec.$Pa^{1/2}$)]
G	Specific gravity	[-]
h	Permeable medium thickness	[m]
k	Permeability	[Darcy]
p	Pressure	[Pa]
P_e	Pressure at external radius	[m]
P_w	Pressure at wall	[m]
Q	Critical flow through valve	[Joule]
q	Volumetric flow rate	[m^3/s]
r	Radius	[m]
r_e	Effective radius of drainage area of the well	[m]
r_w	Radius of wellbore	[m]
v	Velocity	[m/s]

V_{pa}	Pore volume in the rock	[m^3]
z	Elevation or height	[m]

Greek Letters

μ	Dynamic viscosity	[Pa.s]
ρ	Mass density	[kg/m^3]

List of figures

List of tables

1 Introduction

In this section, a short objective, background and out lay of this thesis is presented. The development of different inflow control devices is reviewed to study the newly invented technology Autonomous Inflow Control Valve (AICV) in the field of heavy oil production from horizontal reservoir. The main focus is given to the oil recovery by using different inflow control devices.

1.1 Objective

The goal of this thesis is to perform a near well simulation with OLGA-Rocx using different types of inflow control devices and water drive. Two types of inflow control devices are studied. One is conventional inflow control device (ICD) and another is a very new technology Autonomous Inflow Control Valve (AICV) developed by InflowControl AS. The production performance of the well section with ICDs and AICVs is studied. A discussion and comparison of results is carried out by focusing on oil recovery.

1.2 Background

During the last years, there has been a lot of discussion about the challenges related to heavy oil production from horizontal wells. The problems related to early water or gas breakthrough during production is one of the main challenges in horizontal wells. In order to overcome this challenge, different inflow control devices were introduced. Among these, ICDs have been developed for delaying breakthrough. AICDs delay breakthrough and choke for unwanted fluid after breakthrough. ICVs close for unwanted fluid but are not autonomous. The Autonomous Inflow Control Valve (AICV) is a very new technology which is a self-regulating and do not require any control or force to regulate. Therefore, the AICV has a better ability to control the reservoir fluids that inflows from reservoir to well in comparison to other conventional ICDs.

Regarding increased oil recovery, the aim is to maximize the heavy oil production within the available water handling capacity. The meaning is that producing oil without water. This can be performed by using inflow control devices in the production wells with the ability to choke the reservoir fluids.

The reservoir considered in this thesis is a homogeneous rectangular reservoir with conventional ICD and the new technology AICV.

1.3 Report structure

This thesis report is laid as follows. A theory describing different laws and principles which are applicable to inflow control devices and flow through porous media are described in chapter 2. This chapter also describes the choking phenomenon and a short description of oil production method by water drive. The chapter 3 will continue about the different inflow control devices and their development. The CFD modeling of heavy oil reservoir with water drive is discussed in chapter 4. This chapter is an outlay on how the near well models are developed by using both conventional ICD and AICV. The chapter 4 will be ended by presenting results and discussion. Lastly, the conclusion is carried out in chapter 5.

2 Theory

This chapter will focus on different relevant laws and principles in oil production process, the choking phenomenon and a short description of oil production method by water drive.

2.1 Different laws and principles

Production of oil from the reservoir is generally governed by two fundamental principles and laws. These two fundamental relations are Darcy's law and Bernoulli's principle. Valve sizing equation is also applied in order to know about the opening size of inflow control devices.

2.1.1 Darcy's law

Darcy derived the equations of fluid flow in porous and permeable media. From experiments, he found that the velocity of the fluid (v) in a porous medium is directly proportional to the pressure gradient (dp/dx) and inversely proportional to the fluid viscosity (μ).[1]

Flow is laminar, incompressible and it should be in steady state are the assumptions of Darcy's law.

The mathematical expression for Darcy's law is written as:

$$v = \frac{q}{A} = -k \frac{1}{\mu} \frac{dp}{dx} \tag{2-1}$$

Where k is permeability with unit Da. Q, A and μ are flow rate of fluid, cross-sectional area of porous media and viscosity of fluid respectively.

If the flow of fluid takes place into the well of radius (r_w) from the external radius (r_e) under the influence of a pressure difference p_e - p_w, where p_e is the pressure at the external radius and p_w is the pressure at the well, the permeable medium thickness h is constant.[2]

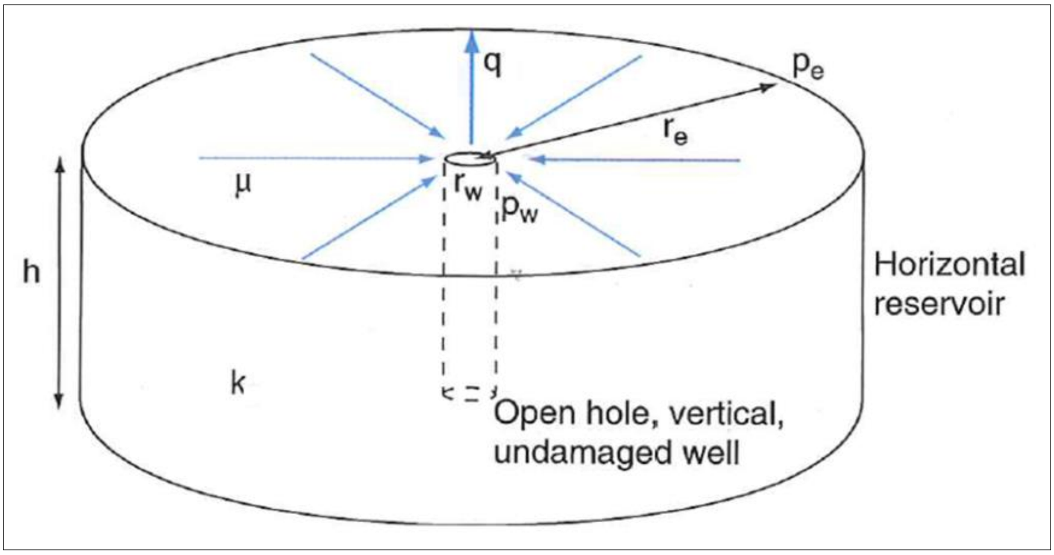

Figure 1 Radial flow in a horizontal oil reservoir[3]

The Darcy's law can be written for radial flow as:

$$\frac{q}{2\pi rh} = \frac{k}{\mu}\frac{dp}{dr} \tag{2-2}$$

$$\int_{r_w}^{r_e} \frac{1}{r} dr = \int_{p_w}^{p_e} \frac{k}{\mu} \frac{2\pi h}{q} dp \tag{2-3}$$

$$q = \frac{2\pi kh(p_e - p_w)}{\mu \ln\left(\frac{r_e}{r_w}\right)} \tag{2-4}$$

2.1.2 Bernoulli's principle

Bernoulli's equation states that the sum of the piezometric pressure and kinetic pressure is constant along a streamline for the steady flow of an incompressible, inviscid fluid. Piezometric pressure is the sum of pressure due to elevation and pressure of fluid.[4]

$$(p + g\rho z) + \rho \frac{v^2}{2} = \text{constant} \tag{2-5}$$

where p, v, g and ρ are pressure, velocity, gravity and density of fluid respectively.

This equation can be rewritten as:

$$\left(\frac{p}{\rho g} + z\right) + \frac{v^2}{2g} = \text{constant} \tag{2-6}$$

For this variation of Bernoulli's equation it has been assumed that the flow is incompressible, frictionless in steady state and that the flow follows along a streamline.[5]

Equation (2-6) may be rewritten as Equation (2-7)

$$\frac{p_1}{\rho g} + z_1 + \frac{v_1^{\,2}}{2g} = \frac{p_2}{\rho g} + z_2 + \frac{v_2^{\,2}}{2g} \tag{2-7}$$

The first, second and third terms of Equation (2-7) represent pressure energy, potential energy and kinetic energy respectively. The first term representing pressure energy is related to the pressure of fluid. Potential energy is because of the fluids height or elevation, and the kinetic energy is related to the velocity of the fluid.[5]

Suffix 1 and 2 represent two different points in the stream line or flow field.

2.1.3 Valve sizing equation

Valve sizing equation relates a relationship between pressure drop and critical flow.[6]

$$Q = C_v \sqrt{\frac{\Delta P}{G}} \tag{2-8}$$

Where Q is critical flow through the valve with unit m^3/sec. C_v and ΔP are valve sizing coefficient and pressure drop respectively. G is specific gravity.

The valve model uses a table that contains the valve sizing coefficients versus valve opening.[6]

2.2 Choking

Choking is a principle used to control production rates for regulations, avoid sand particles due to high draw down and control water and gas coning after breakthrough. In general, there are two types of well head chokes in petroleum engineering. One is positive or fixed chokes and another is adjustable chokes. The choking is performed by fixing the wellhead pressure, the flowing bottom-hole pressure and production rate.[7, 8]

Figure 2 is a typical choke performance curve which shows a relationship between flow rate and pressure ratio during choking. p_1 and p_2 are the downstream and upstream pressure respectively. The choke position changes from d_1 to d_2 during choking. q is the volume flow.

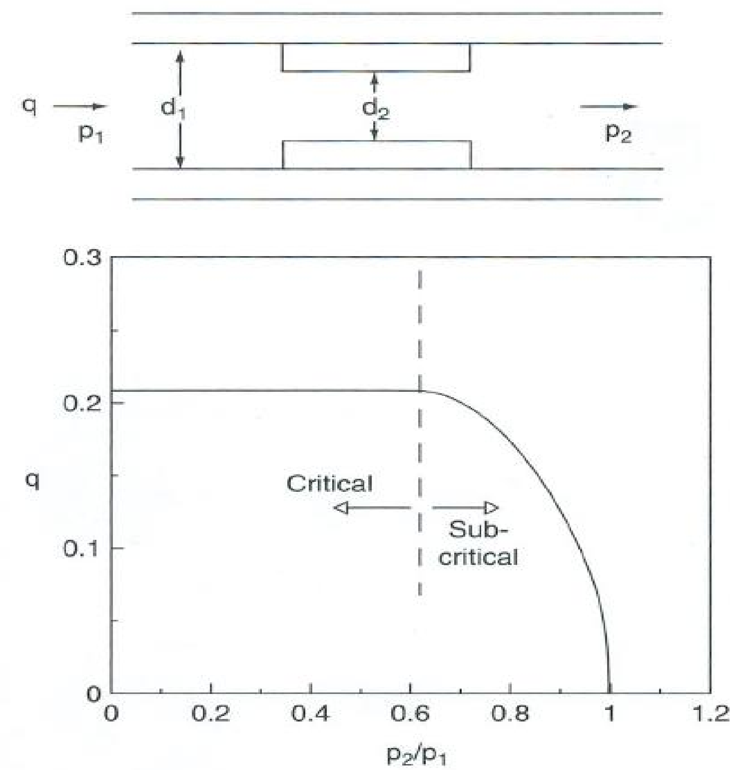

Figure 2 A typical choke performance curve[8]

The flowing bottom-hole pressure is determined by calculating pressure drop in the control device tubing for a given well-head pressure.

2.3 Oil production by water drive

The role of a successful petroleum production system is to maximize oil and gas production from the reservoir in cost effective manner. In order to achieve this challenging task, familiarization and understanding of oil and gas production system by different methods is essential. In this thesis, oil production by water drive is considered.

In this method, oil replacement by water from the aquifer may occur. When water is encountered into oil reservoir either naturally or artificially, oil is displaced by this water until the fluid saturation conditions are satisfactory.[2] There are various factors operating singly or in combine influences the replacement of oil by water. These factors are:[2]

1) By volumetric volume expansion
2) By hydraulic flow as a result of water infiltration
3) By artificial injection of water

Water injection may be carried out from the bottom or edge or it may be applied from periphery as a centerline drive or as a pattern flood. In this thesis, water-drive from the bottom of the reservoir is studied. The pressure profile of such reservoir is dependent on the pressure of oil production and the pressure of water injected. The oil produced from the water-drive field is supplied from wells located in advance of the water front in order to avoid the coning and water breakthrough.[2]

Figure 3 shows oil saturation distribution in a water drive field. The pores in the rock where oil occupies initially, is filled by water due to oil extraction by water drive as shown in Figure 3.

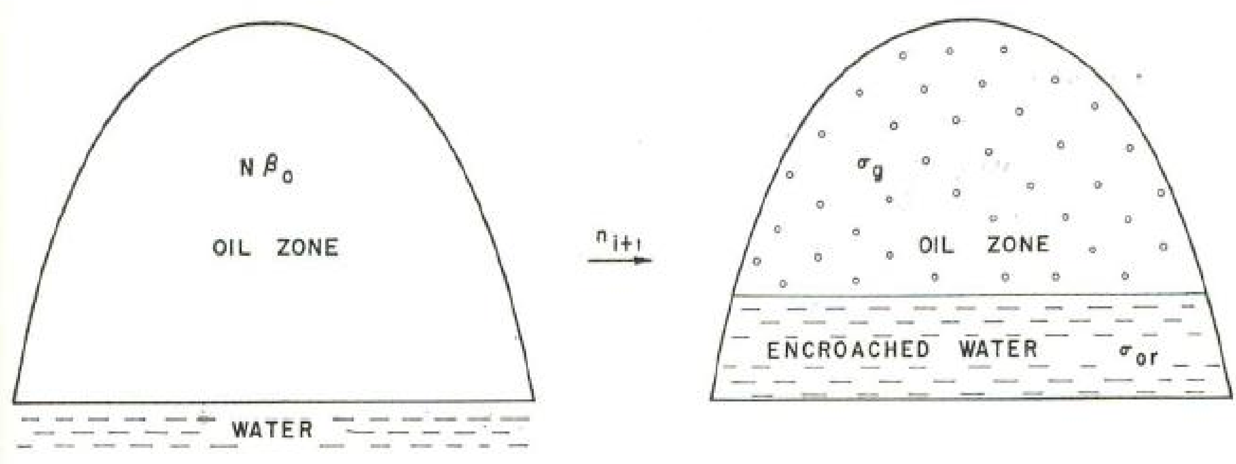

Figure 3 A typical reservoir sections with water drive from bottom[2]

3 Inflow Control Devices and their development

Now oil and gas companies are looking for solutions that unite goal-setting, modelling, monitoring and analysis of the solutions to increase the recovery. Well completions today are very different from the traditional well completions. Different technologies were implemented before and several technologies exists which increases the production of oil. The reservoir complexity has increased, making horizontal wells to increase the contact area of production pipeline with oil reservoir, and an increase in the use of multilateral wells. Production of oil from horizontal oil reservoirs has a number of potential advantages; delayed water or gas breakthrough, increased drainage area and consequently increased well productivity. But the challenges related to oil production from long horizontal reservoir has increased. One of the challenges is the heel-toe-effect.

In a horizontal oil well, the flow is coming from the toe towards the heel. The pressure at the heel is lower in comparison to that of toe, due to frictional pressure losses. As the reservoir pressure is considered constant, the pressure drop at the heel is greater than that of toe. This mechanism leads to heel-toe-effect. Figure 4 shows water, oil and gas layers with drawdown and coning effect.

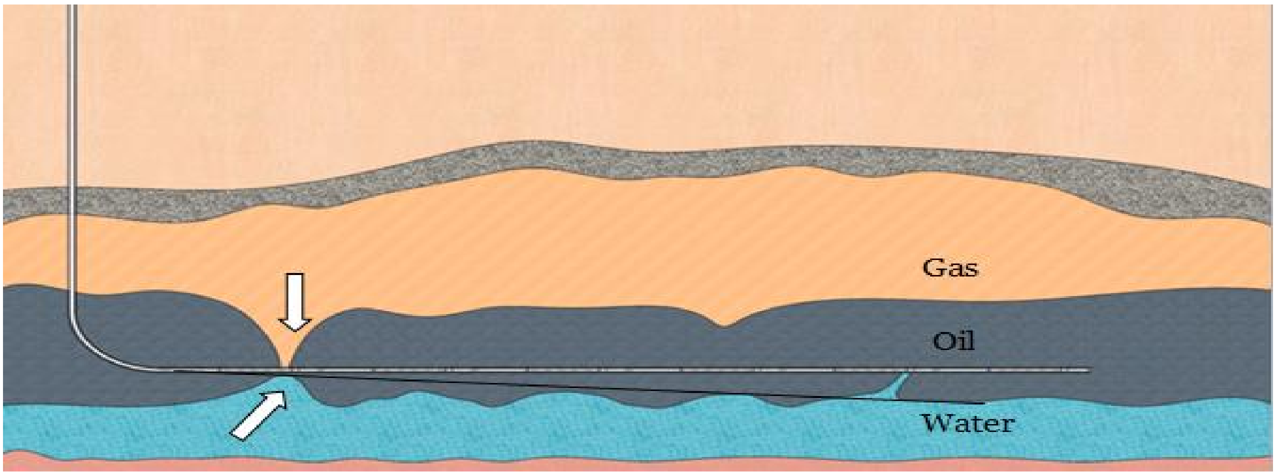

Figure 4 Gas, oil and water layers showing gas and water breakthrough

In order to overcome these challenges, several technologies exist. The common solution is that they attempt to delay the breakthrough time. Use of inflow control devices is one of the solutions of this problem. There are different devices to control zones in a reservoir. These are with an inflow control device (ICD), inflow control valve or autonomous inflow control valves (AICV).

These control devices delays the water or gas breakthrough and allows the field to produce more oil.

3.1 Mechanical Sliding Sleeves

Mechanical sliding sleeves have been used as a starting phase of the development of inflow control devices. These sleeves have been used for decades in order to control the unwanted water production and excessive GOR for selective zones. Those sliding sleeves have been proven to be very robust. But there were some limitations to the use of sliding sleeves. It can only open and shut while the choking is not achieved by this sleeve.[9]

3.2 Inflow Control Device (ICD)

An ICD is a passive device fitted on a screen joint to control the fluid flow-path from the reservoir into the production well. An example of an inflow control device is shown in Figure 5. These devices are mounted along the horizontal wells in order to improve oil production and recovery by applying restrictions to the flow.[10, 11]

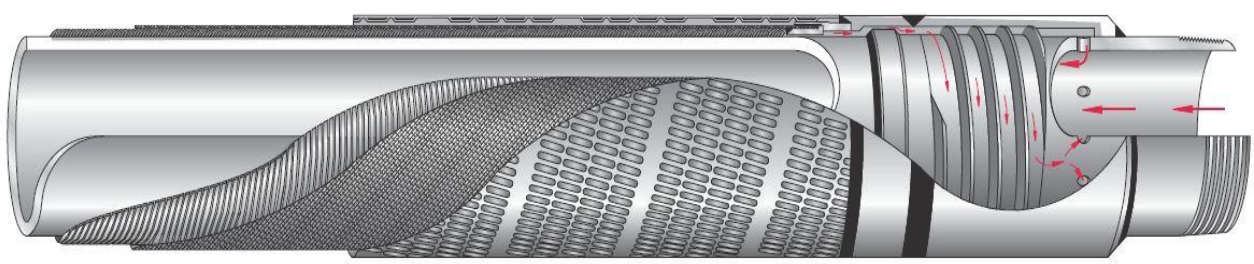

Figure 5 An ICD example[12]

The principle of ICD is to restrict the flow rate by creating an additional pressure drop. This restriction will reduce the flow rate in heel section to obtain uniform oil production along the well. The geometry of ICD's restriction is set before installation. This means that it is not possible to change the diameter of the flow restriction after installation without intervention. After a certain time of production, frictional pressure drop and variation of permeability will lead to a non-uniform pressure profile and therefore gas or water breakthrough will occur.[10, 11]

The ICDs are ports having a fixed flow area. The recovery of oil increases significantly by using ICDs compared with wells without ICDs.[13]

ICDs were first used at the Troll field in North Sea in 1992 by Norske Hydro. Weatherfords Floreg™, Baker Oil Tools Equilizer™ and Schlumbergers (Reslinks) Resflow™ are some of the well-known types of ICDs.[14]

3.3 Autonomous Inflow Control Device (AICD)

An autonomous inflow control device is a specific type of ICD which has the capacity to adjust the choking of the fluids depending upon the phases. AICDs are also mounted along the horizontal well in the same way as ICDs. The AICD chokes the flow of low viscous fluids while it allows the viscous fluid to flow. This is because of a moveable disk which is fitted in AICD as shown in Figure 6.[11, 13]

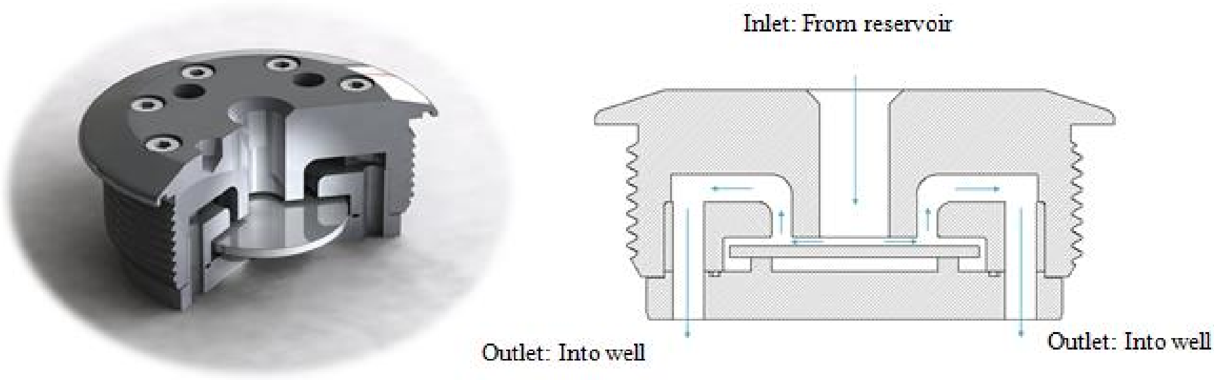

Figure 6 Statoil's Autonomous inflow control device showing flowing direction[11]

The flow path of fluid is shown by arrows. If more viscous fluid enters, the flow rate through the AICD becomes higher. At the same time the friction loss through AICD increases. Thus the pressure on the downside of the disk decreases resulting less force to move the disk upward towards inlet.[15]

By using AICD, the well performance, production and recovery are higher after breakthrough compared to conventional inflow control devices.[11, 13, 15]

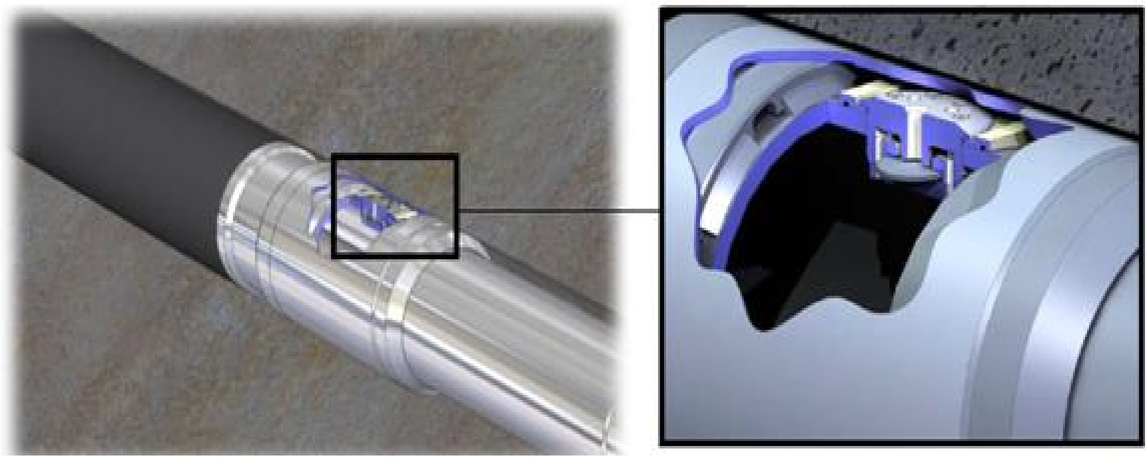

Figure 7 Base pipe with AICD [11]

3.4 Inflow Control Valve (ICV)

An inflow control valve (ICV) is a down-hole flow control valve that is controlled or manipulated from the surface by hydraulic, electric or electro-hydraulic system.[10]

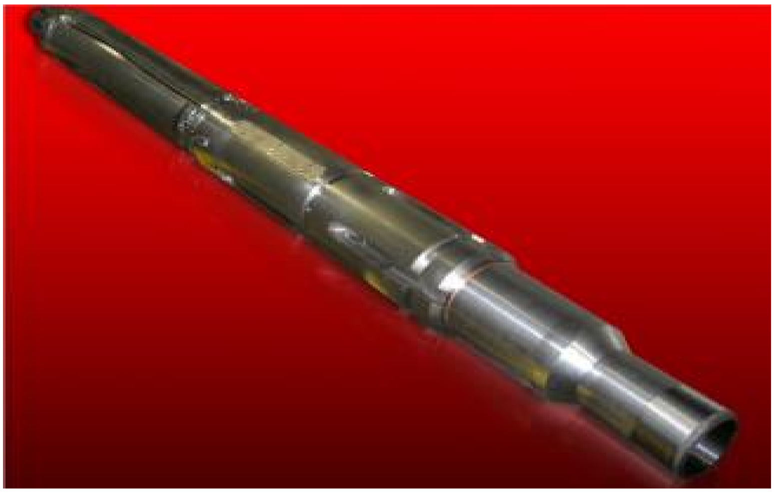

Figure 8 Example of a typical ICV[16]

ICVs do not choke initial oil production significantly, and have the ability to choke or completely shut off the gas and water at the breakthrough point. These can only be operated over a limited number of zones- for example 5 per well. Monitoring system is also present with ICVs in order to early detect the water or gas breakthrough. The ICV system consists of different five components. These components are surface control equipment, control lines, connectors, gauges to monitor the flow and the valve itself. Because of the remote monitoring and control system on the surface, ICVs are relatively expensive and can be operationally unstable.[10, 13]

The premium thermoplastic hydraulic chamber seals are designed to operate under high pressures and over temperatures ranging from 4ºC to 165ºC.[16]

3.5 Autonomous Inflow Control Valves (AICV)

An autonomous inflow control valve (AICV) shown in *Figure 9* is a very new technology developed by a Norwegian company InflowControl AS. AICV technology combines the best characteristics from both AICD and ICV.[13]

Figure 9 AICV with 1 euro coin[13]

AICVs are also mounted along the horizontal well in the same way as ICDs. By using AICV, water and gas flows are completely blocked autonomously at breakthrough. At the same time oil production will continue from other production zones through valves in order to obtain optimum oil production and recovery. This valve operates reversible also. This means it can open again when oil comes to the valve after breakthrough. The most interesting thing with AICV is that it does not need any electric or hydraulic control system. It operates self by using minor pilot flow through the laminar and turbulent flow element.[13]

3.5.1 Working principle of AICV

AICV operates by two principles. These two principles are Darcy's law and Bernoulli's principle. These two principles are followed by laminar flow element and turbulent flow element which are placed in series in pilot flow of AICV as shown in Figure 10.[13]

P_1 is the reservoir pressure, P_3 is the well pressure and P_2 is the pressure controlling the valve.

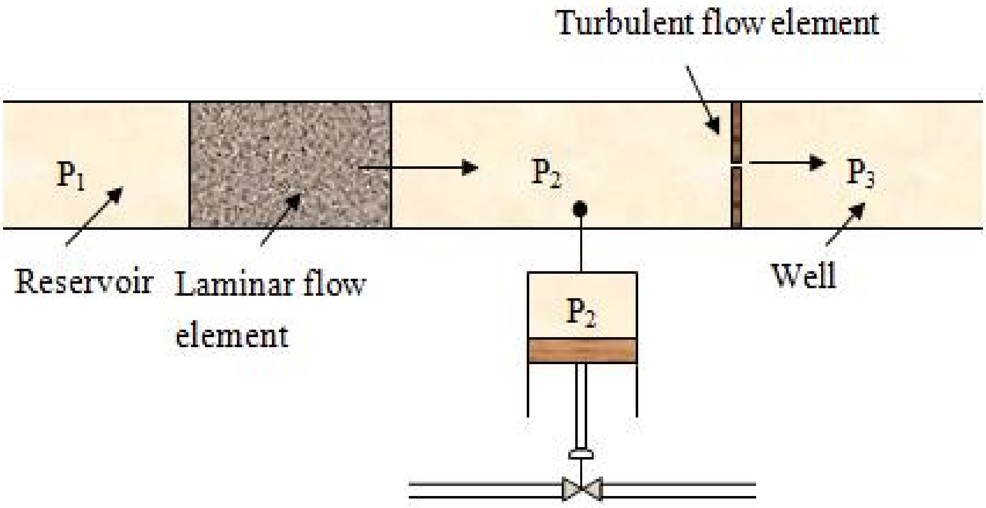

Figure 10 An illustration of AICV showing laminar and turbulent flow element[17]

The laminar flow element is pipe section with certain length, L, and diameter, D. According to Hagen-Poiseuille equation, the pressure drop (ΔP) due to uniform laminar flow in a length (L) of a pipe of diameter (D) can be expressed as equation (3-1).

$$\Delta \mathrm{p} = \frac{32 \cdot \mu \cdot v \cdot L}{D^2} \tag{3-1}$$

where μ is the fluid viscosity and v is the fluid velocity. This relation shows that the pressure drop through the restrictor is proportional to the fluid viscosity and the fluid velocity.

The turbulent flow element is an orifice like structure as shown in Figure 10.

According to Bernoulli's law from equation (2-5),

$$p_2 + \rho \frac{v_2^{\ 2}}{2} = p_3 + \rho \frac{v_3^{\ 2}}{2} \tag{3-2}$$

$$\Delta p = p_2 - p_3 = \rho \frac{v_3^{\ 2}}{2} - \rho \frac{v_2^{\ 2}}{2} \tag{3-3}$$

$$\Delta p = C \cdot \frac{1}{2} \cdot \rho \cdot v^2 \tag{3-4}$$

Where C is a geometrical constant and ρ is the density of fluid. This shows that the pressure drop through the turbulent flow element is proportional to the density and square of fluid velocity. But in this element, the pressure drop is independent of fluid viscosity.

The relationship between the pressure drop and the fluid velocity in laminar flow element is linear which is shown in Figure 11.

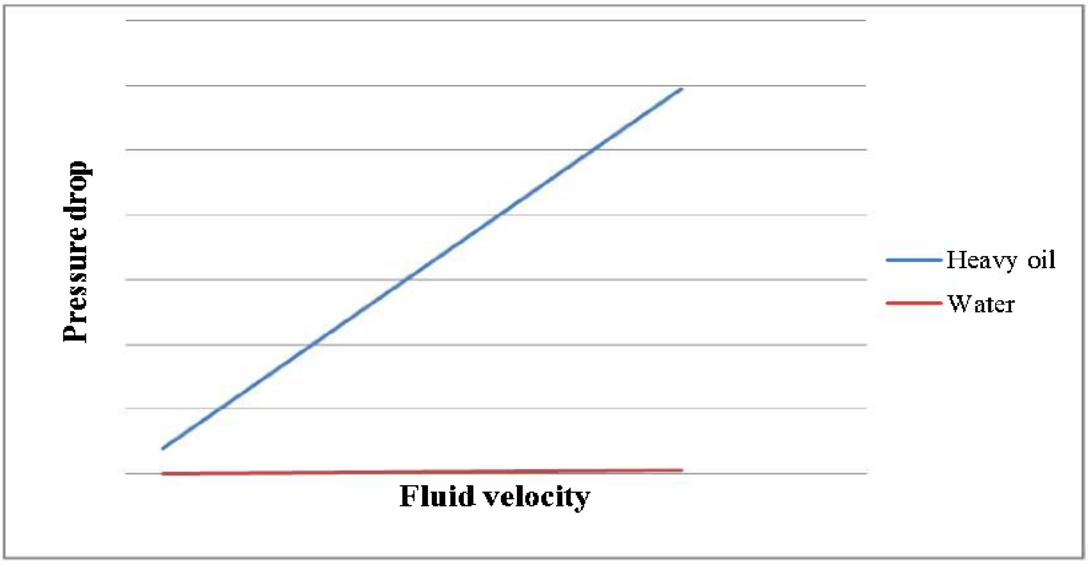

Figure 11 Pressure drop versus fluid velocity in laminar flow element

$$(P_2)_{oil} = P_1 - (\Delta P)_{oil} \quad (3\text{-}5)$$

$$(P_2)_{water} = P_1 - (\Delta P)_{water} \quad (3\text{-}6)$$

From Figure 11,

$$(\Delta P)_{oil} > (\Delta P)_{water} \quad (3\text{-}7)$$

From equation (3-7), we can express P_2 as:

$$(P_2)_{oil} < (P_2)_{water} \quad (3\text{-}8)$$

The pressure P_2 for heavy oil is lower than the pressure for water which is proven from the Figure 11 and equation (3-8).

Hence the valve keeps open for heavy oil which exerts a lower pressure on the valve and it closes for water, since the valve exerts higher pressure for same amount of fluid flow.[13]

4 Near well simulation of heavy oil production

The CFD modeling of heavy oil reservoir with water drive will be discussed in this chapter. This chapter also describes the different simulation cases in OLGA-Rocx. In this section, two cases are explained. The one case is the reservoir with conventional ICD and another with Inflow Control's new technology AICV.

For simplification, several assumptions have been made.

1. Reservoir is homogeneous.
2. Initially, the reservoir contains pure oil.
3. Oil and water layer thickness are considered constant.
4. Rectangular reservoir section is chosen.

4.1 Homogeneous reservoir section modeling

A 3D mesh for one section of heavy oil reservoir was created in Rocx. The reservoir length is 992m with a thickness of 80m and depth is 20m as shown in Figure 12. The well bore section consists of ten inflow control devices. The distance between the two inflow control devices is 99.2m. Each zone is isolated by using packers. The simulations were performed to study the AICV actions during oil production and to compare the oil production and recovery with ICD.

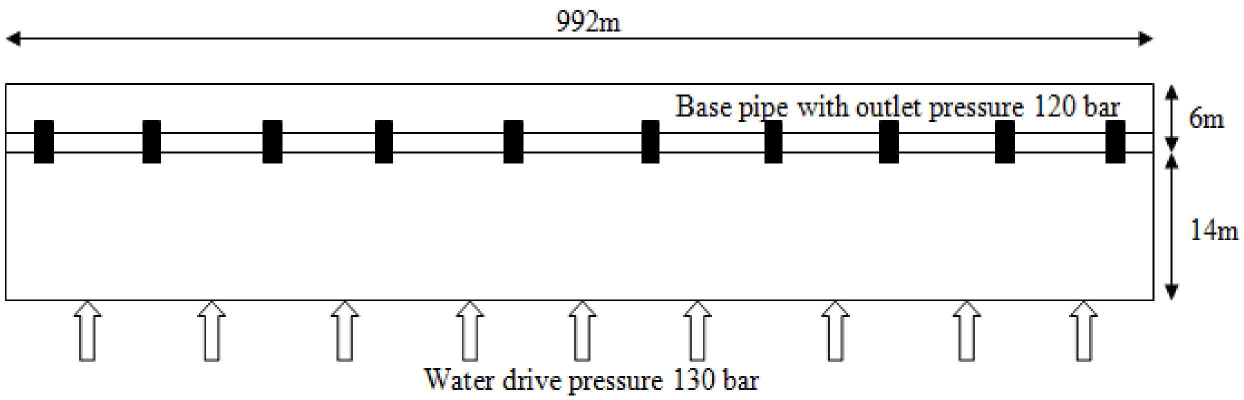

Figure 12 Reservoir geometry with base pipe and inflow control devices

Two cases for a reservoir section with water drive are simulated in order to compare oil recovery. First case is with conventional passive inflow control device and second case is with new AICV technology. Both simulations are performed by using OLGA and Rocx. In the simulation, the choking is performed by using controller with the set point of 40% for the water-cut in both cases. Different properties of the cases are summarized in Table 4-1.

Table 4-1Properties of the cases in simulations

Properties	**Value**
Reservoir Dimension	992m x 80m x 20m
Well length	992m
Well diameter	0.2m
Water drive pressure	10bar
Set point for water-cut	40%

4.1.1 Input parameters in Rocx

The input parameters in Rocx include grid, fluid and reservoir properties and initial and boundary conditions for the wellbore and reservoir. The specific input parameters for Rocx are defined in Appendix 2.

4.1.1.1 Grid

A rectangular geometry is chosen for the reservoir section. The 3D grid of the reservoir section is shown in Figure 13.

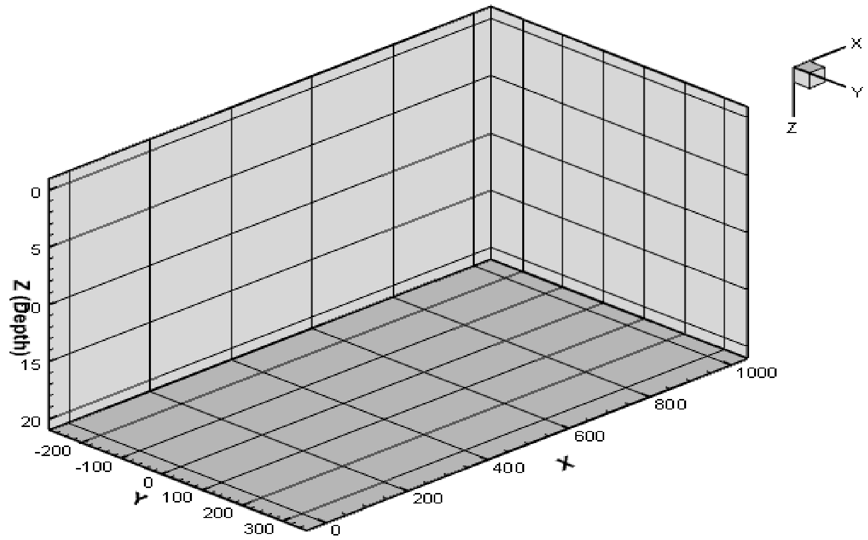

Figure 13 3D grid of reservoir section

The grid spacing in x and z direction is given as constant. In y-direction, the spacing of each grid is variable with finer grids near the wellbore. A 2D grid in XZ and YZ plane of the reservoir section is shown in Figure 14. This reservoir section is made by specifying the number of grids with spacing in x, y and z direction in the grid option in Rocx. The spacing of grids in x, y and z direction is presented in Appendix 2.

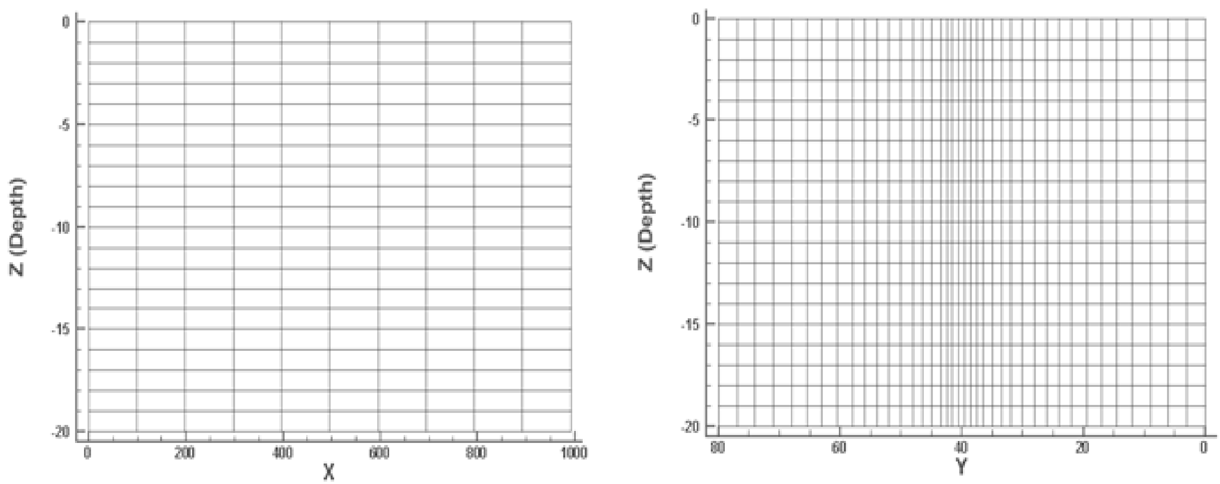

Figure 14 2D grids in XZ and YZ direction

4.1.1.2 Fluid and reservoir properties

The properties of the fluid and reservoir section are presented in Table 4-2.

Table 4-2 Reservoir and fluid properties

Properties of fluid and reservoir section	**Value**	**Unit**
Oil viscosity	100	cP
Reservoir temperature	100	^{o}C
Reservoir pressure	130	Bar
Reservoir porosity	0.3	-
Reservoir permeability	5	Da

The fluid considered is black oil. Two boundary feeds are defined with different values of water-cut (WC), gas oil ratio (GOR) and liquid gas ratio (LGR).

4.1.1.3 Initial conditions

The initial conditions in Rocx include the initial saturation of water, oil and the initial pressure and temperature of the reservoir. In the beginning, the production liquid will normally be oil. Therefore the initial saturation of oil is considered as 1. The initial pressure and temperature are 130 bar and 100 $°C$ respectively.

4.1.1.4 Well and reservoir boundary conditions

Boundary conditions include the boundary pressure and temperature for well and reservoir. Ten different points are specified at each grid in x-direction, for well boundary. These points serve as a source for each inflow control devices. All of the boundary settings for each point are presented in Appendix 2. The reservoir boundary pressure and temperature are considered as the same as in the well boundary.

4.1.2 Different setup in OLGA

In OLGA, two pipeline sections named flow path and pipeline are created with source, leak and different kinds of valves. These pipeline sections are divided into 10 small sections of length 99.2m each. Each small section is comprised of one inflow control device and two packers. A water drive pressure of 10 Bar is considered as a driving force for oil production.

In the simulation with AICV, the valve is controlled with respect to water-cut in the well. The choking of AICV is controlled by using a controller with the set point of 0.08 for water-cut. This means that 92% of water is shut-off at water breakthrough. The action of AICV is that it should be totally closed for water. But 8% set point value for water-cut is defined in the AICV case in order to be able to get the simulations to work.

4.1.3 Results and discussion

A typical development for oil production from a reservoir is shown in Figure 15. In the beginning, the production liquid will normally be oil. As time passes, the production of water is increased. Production will stop when it is no longer economical to produce from the reservoir.

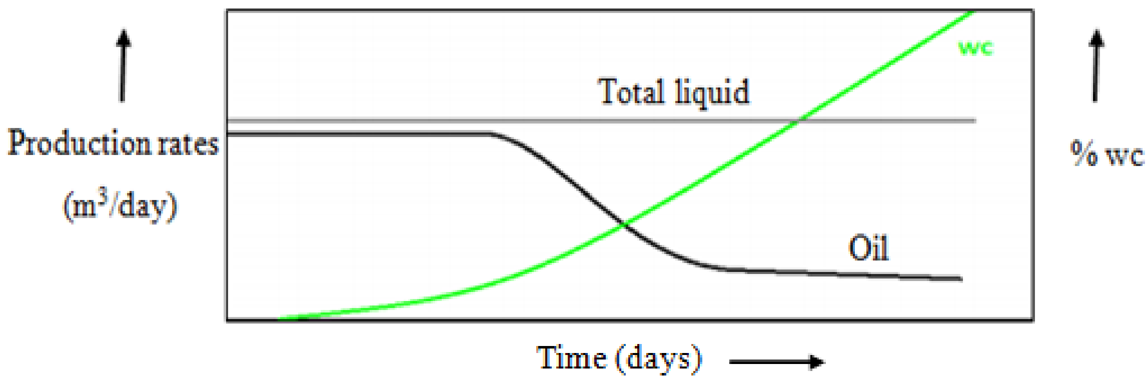

Figure 15 A typical development of oil production

Phase behaviour

The phase behaviour of the reservoir changes from the beginning of the production until water breakthrough occurs. Figure 16 to Figure 18 describe the behaviour of water flow in the reservoir in YZ-direction during production. During production, the water phase rises from the bottom of reservoir until it reaches the wellbore.

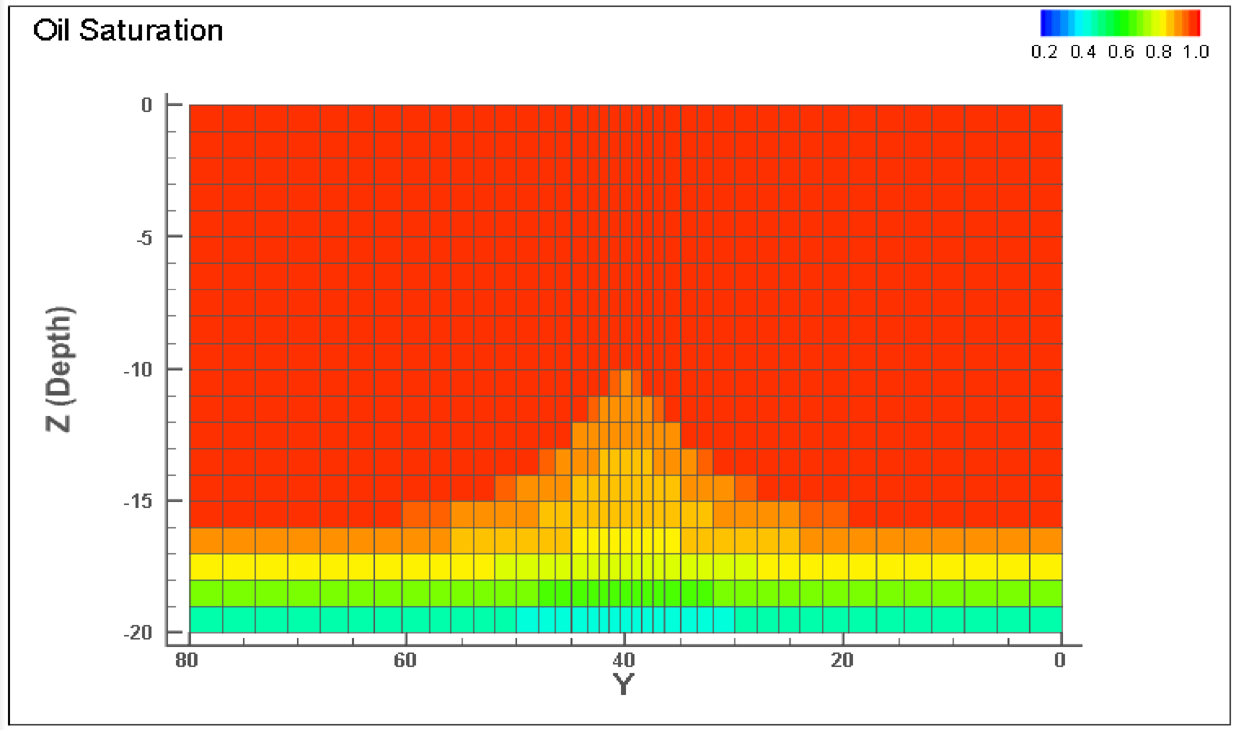

Figure 16 Saturation of oil before water break through

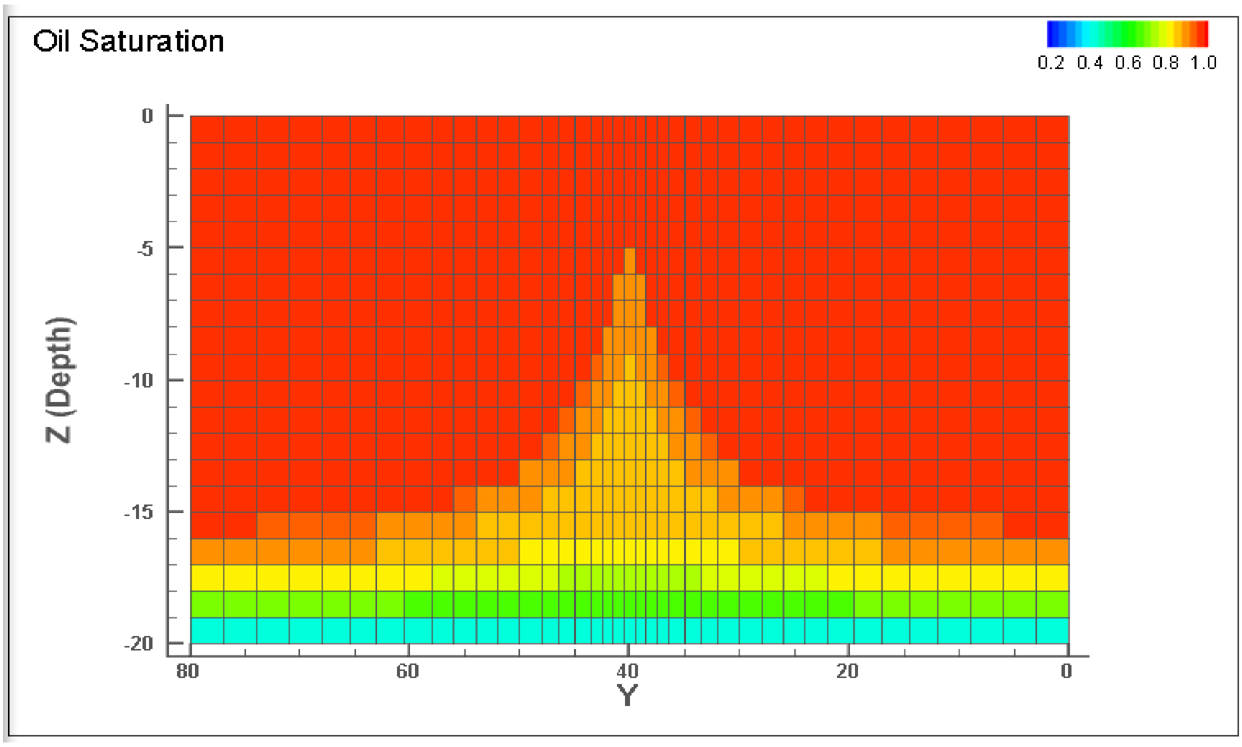

Figure 17 Saturation of oil during water break through

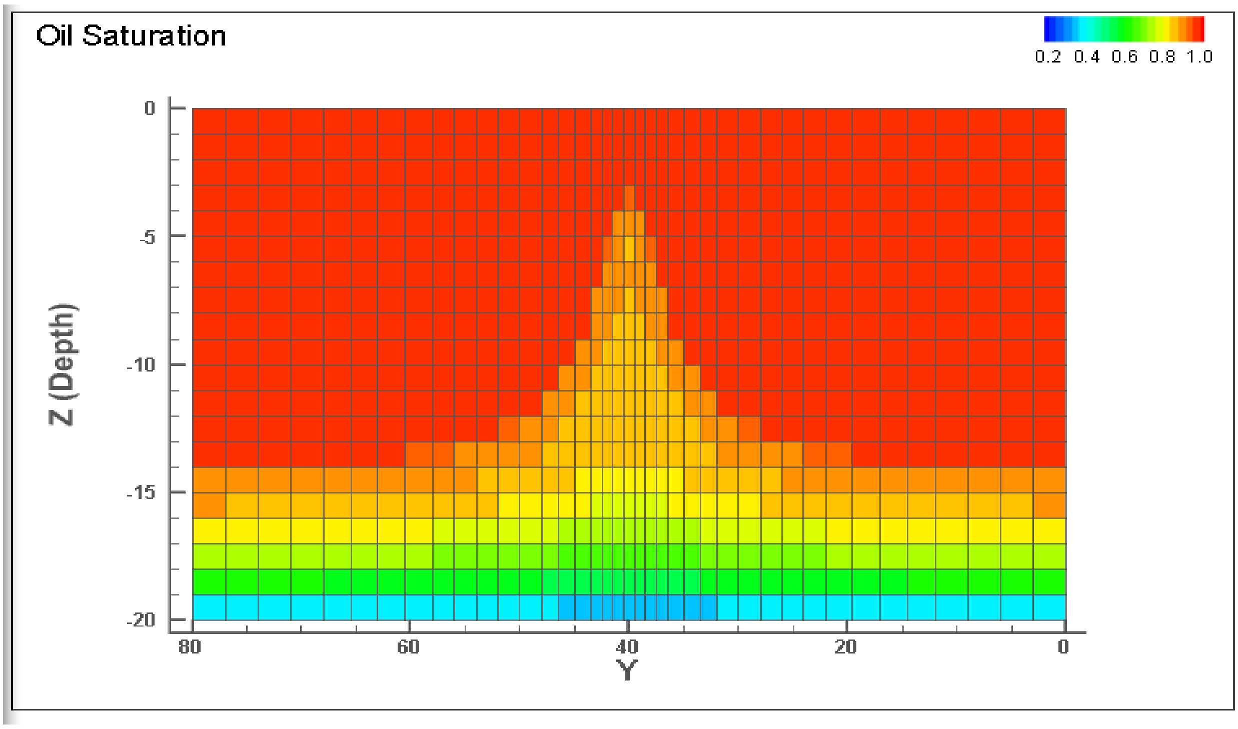

Figure 18 Saturation of oil after water break through

Initially the reservoir contains pure oil which is shown by red colour in Figure 19 and water is used as a pressure drive from the bottom of the reservoir.

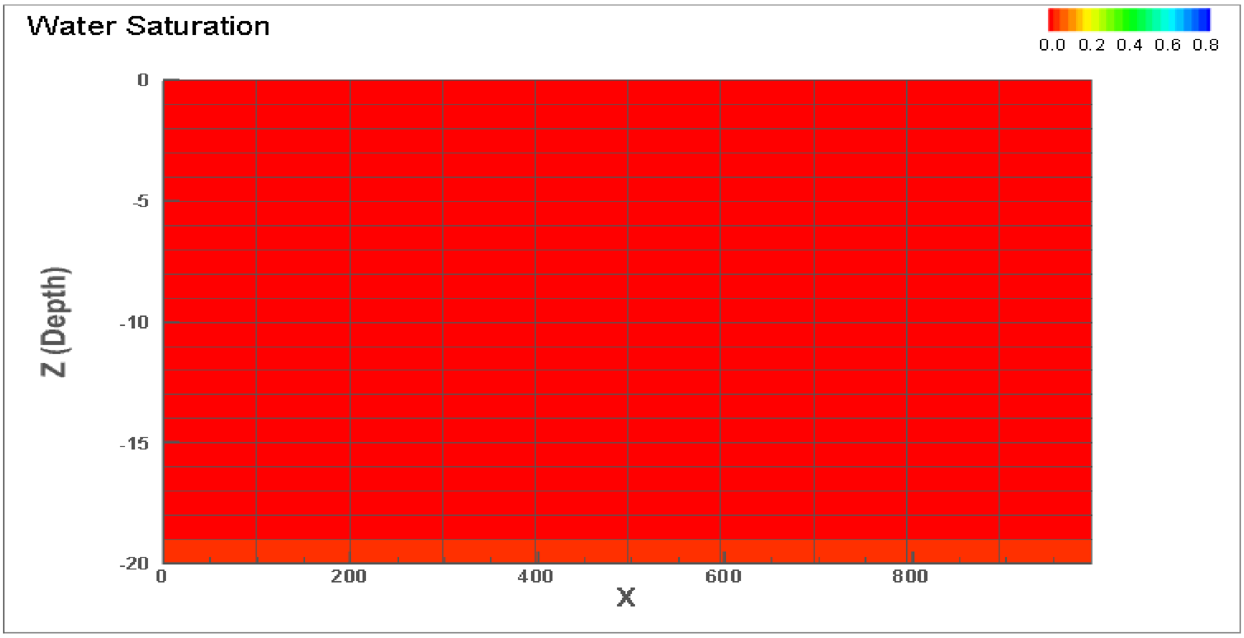

Figure 19 Saturation of water at the beginning of production

Figure 20 to Figure 22 describe the behaviour of water flow in the reservoir in XZ-direction during production. The water starts to move towards the well from the heel side. Before water break through, the saturation of water is higher at the bottom of the reservoir and it is decreasing near the well bore. As time passes, the saturation of water is increasing near the well bore.

These phase contours contribute for the understanding of the behaviour of fluid flow in the reservoir.

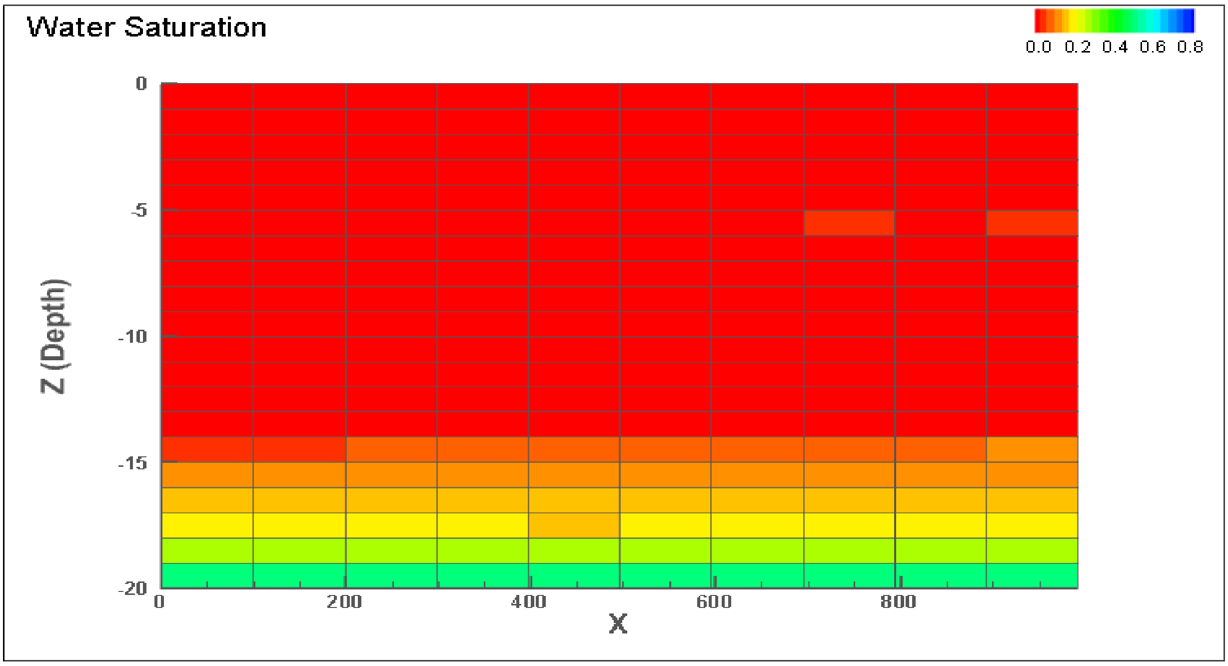

Figure 20 Saturation of water before water break through

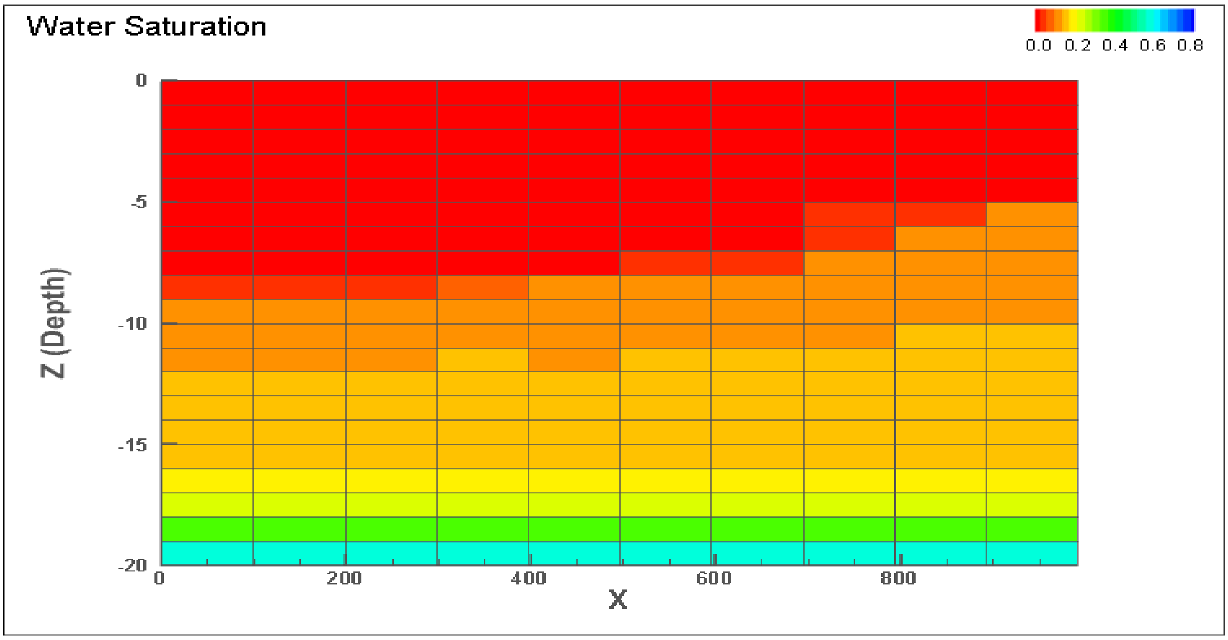

Figure 21 Saturation of water during the break through at first valve in the heel

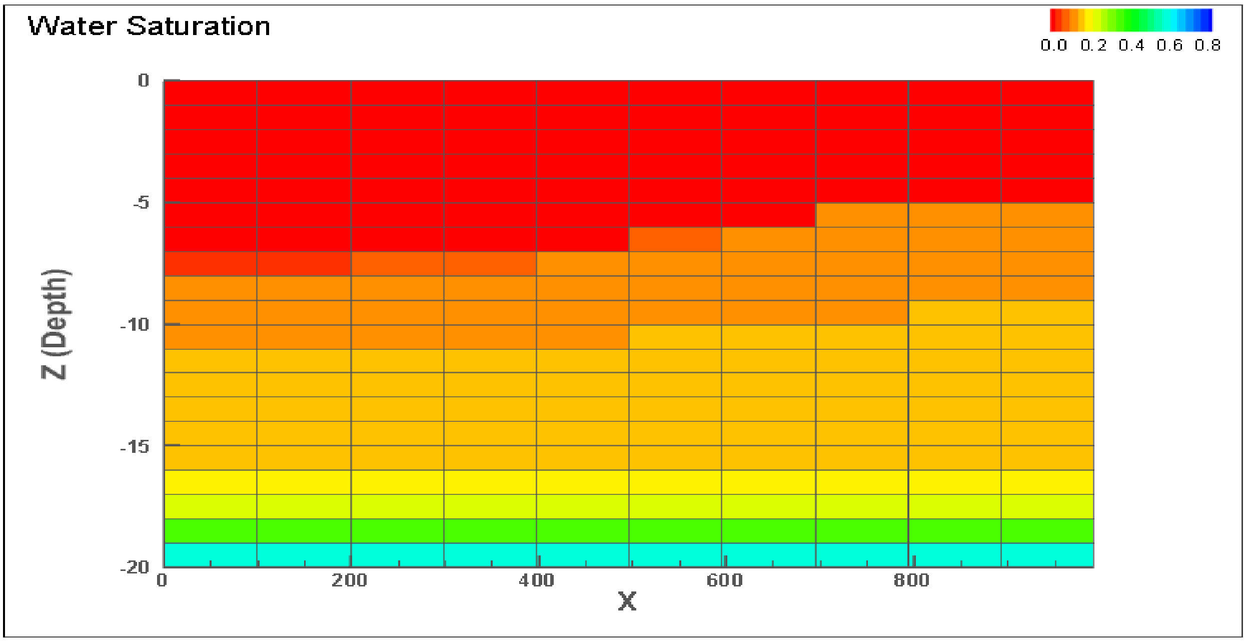

Figure 22 Saturation of water during the break through at three valves in heel side

Pressure profile

The pressure profile in the well at the beginning of production is shown in Figure 23. The pressure in the toe is 121.3 bars and it is observed that the pressure gradually decreases towards heel. This pressure difference between heel and toe is due to friction loss along the well. Thus the draw down pressure at toe is lower than the draw down at heel. This is a reason for occurring early breakthrough at the heel side of the well bore.

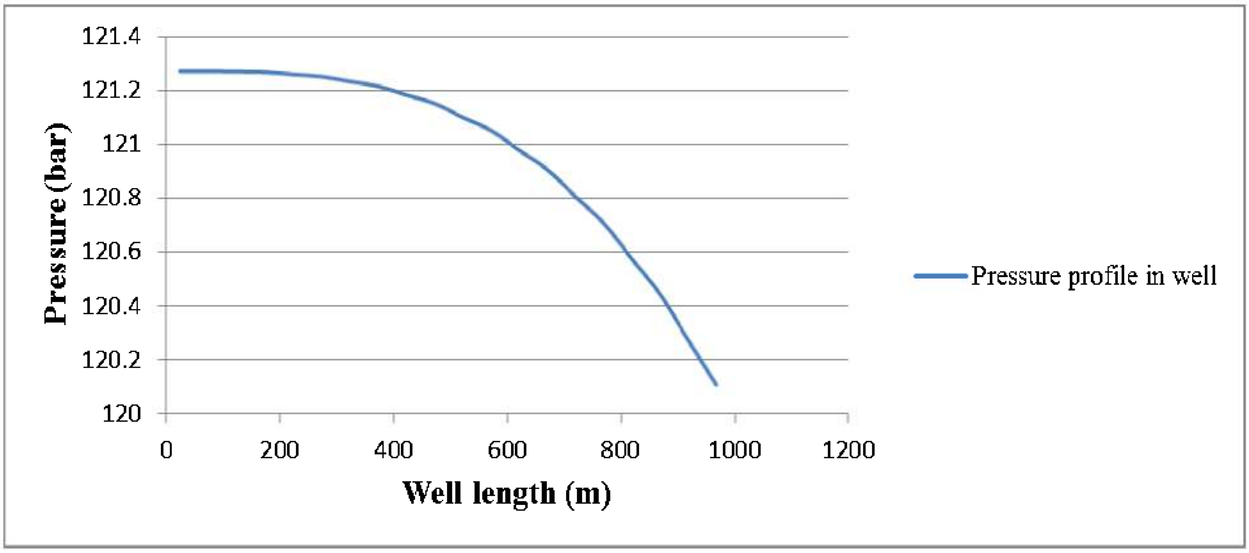

Figure 23 Pressure profile in well

The simulation for each AICV is performed with 92 % choking of water. This means that 92 % of water is choked at water breakthrough locally through each AICV.

Accumulated water flow

Figure 24 shows the accumulated water flow through the conventional ICD and the AICV.

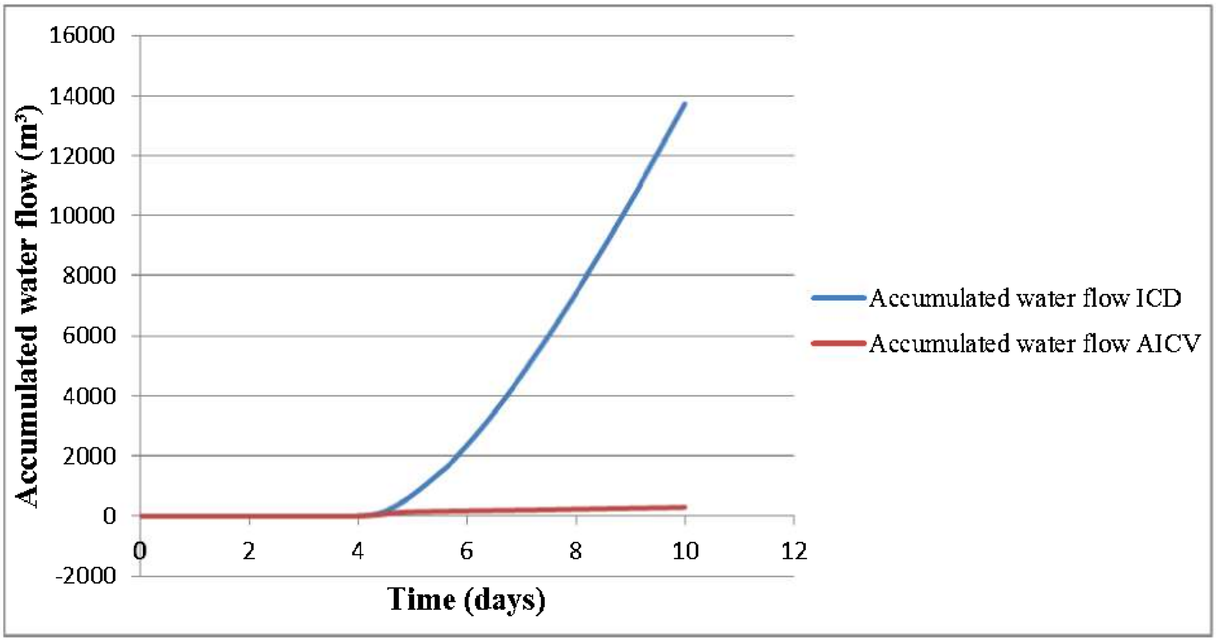

Figure 24 Accumulated water volume flow with time

According to the figure, the water production through ICD increases continuously after water breakthrough while the water production is controlled by using AICV. This is the main characteristics of AICV. This means that the AICV action is simulated successfully.

In the case with ICD, there is no water production restriction in the local zone. Thus the water-cut increases continuously as shown in Figure 24.

Choke position

The choke position for ICD and AICV with time is shown in the Figure 25 for this particular case. The figure shows that the initial production is the same for both ICD and AICV cases. It also shows that both cases have fully open choke at the beginning of production. This means that the choke position is 100%. After 4 days, the water breakthrough occurs and the production of water started along with oil. This means that the water-cut increases. When water-cut reaches a value of 40% in the entire well, the controller starts to operate and the choke position begins to reduce gradually as shown in Figure 25 for both ICD and AICV cases.

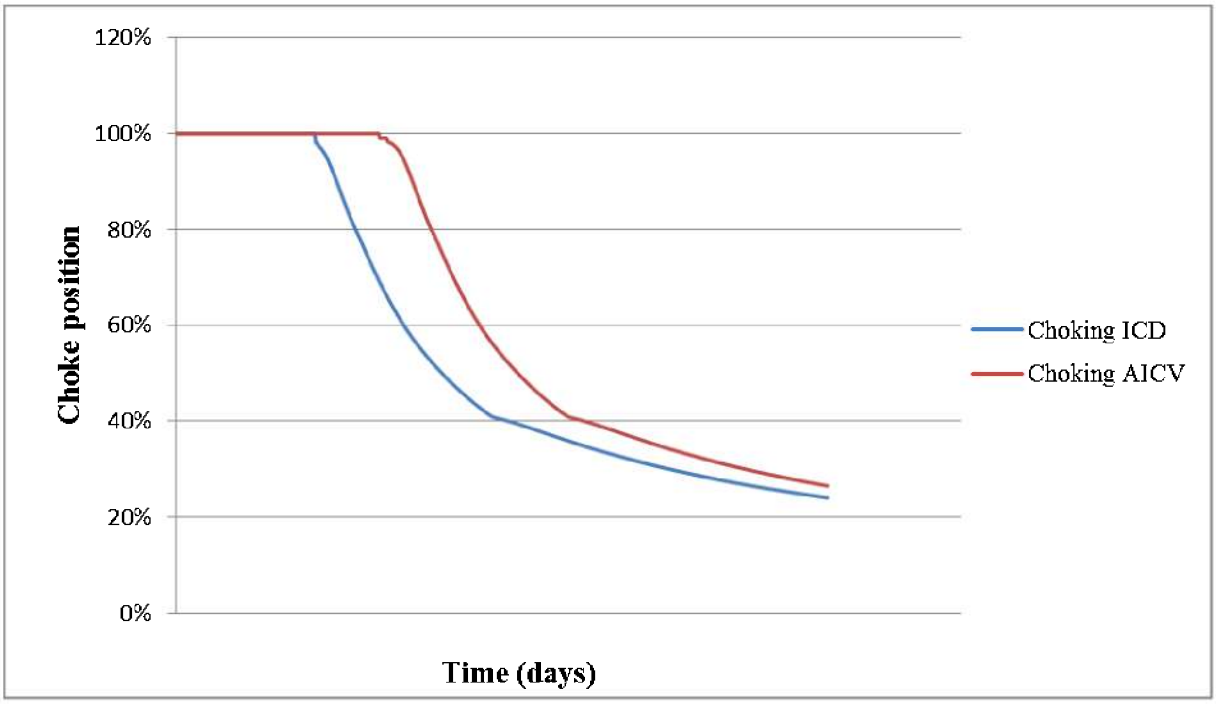

Figure 25 Choke position variations with time

The first water breakthrough occurs in the heel side of the reservoir due to draw-down effect. The first AICV in the heel chokes the water production locally while other AICVs are producing oil. After some time, break through occurs in the second AICV and that particular AICV also chokes locally. In the similar manner, other AICVs will close locally after water breakthrough in each valve. Thus the water-cut will be controlled and remain low. So that the choke position of entire well is open as 100% and remains open until the water-cut reaches the set point value.

But in the same reservoir section with ICD, there is no any water controlling mechanism that restricts the flow of water locally. The water breakthrough starts to occur from the heel side of the reservoir. The water-cut increases and reaches the set point value earlier than in AICV case. Thus, the controller on the platform starts to choke the production.

As shown in Figure 25, the production well begins to choke earlier in ICD case than in the AICV case. This early choking in ICD case leads to the reduction of oil production.

Accumulated oil production

Figure 26 shows the accumulated oil production versus time for both ICD and AICV cases. It is observed that the initial oil production is same for both cases. After water breakthrough, the cumulative oil production in the ICD case decreases earlier than in AICV case. The reason for this is because of earlier choking of well in ICD case than in AICV case. The choking of well with ICD is performed earlier since set point value for water-cut is reached earlier. This choking leads to the reduction of oil production from the reservoir.

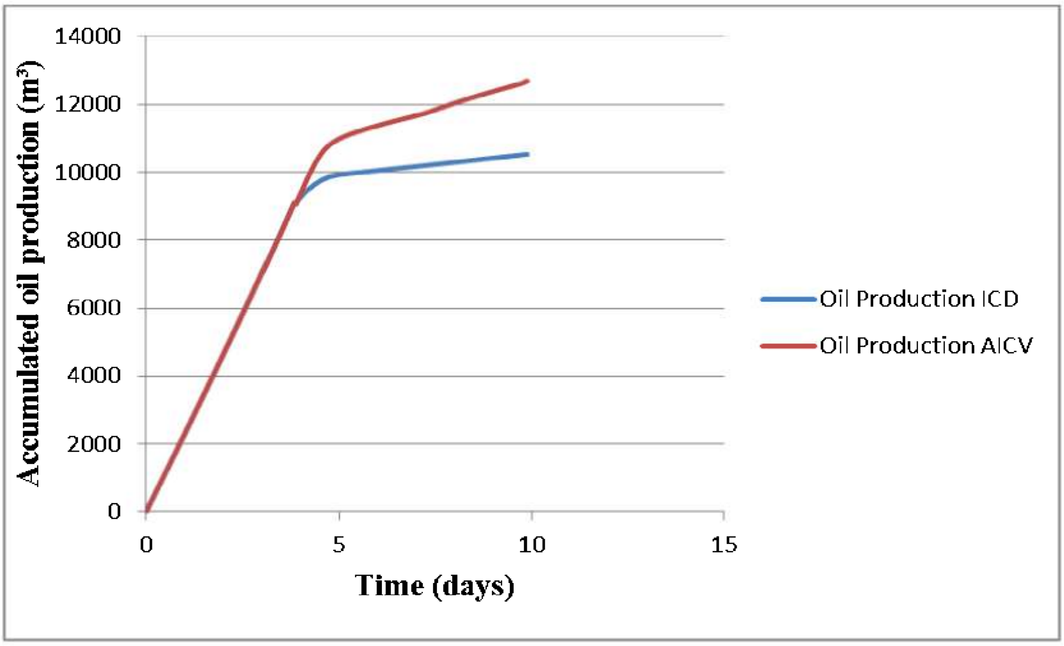

Figure 26 Variation of accumulated oil production with time

The AICVs are autonomous and does not require any external force to control.[13] Another important characteristic of AICV is that it can operate reversibly also.[18] This means that if the AICV encounters oil again, it autonomously opens and oil production continues in order to increase the recovery. The same action was observed after 10 days of production in the AICV case. Thus the accumulated oil production is further increased after 10 days as shown in Figure 27.

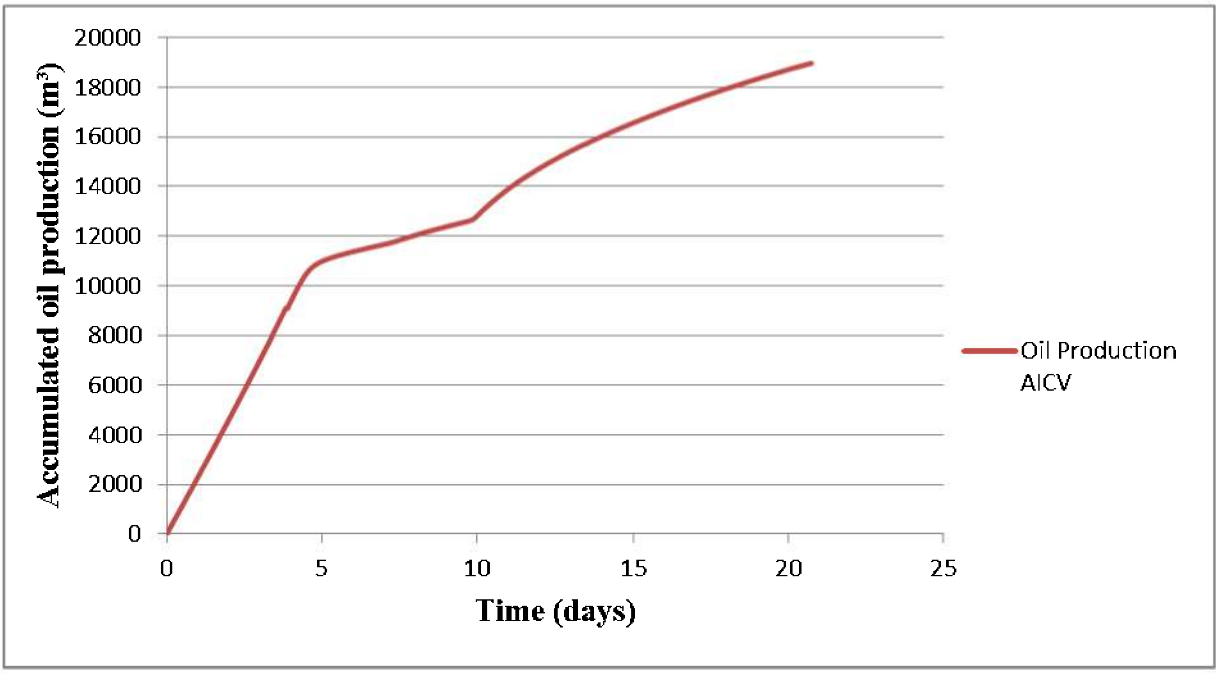

Figure 27 Variation of accumulated oil production with time for AICV case

Water movement towards the producing valve is shown in phase diagram for comparison in Figure 28 and Figure 29. These figures show the oil saturation during re-opening of AICV. Red colour is pure oil and saturation of oil is decreasing below the base pipe. These phase diagrams are taken at different days of oil production, Figure 28 at 9 days, while Figure 29 was at 11 days of production. Before day 10, oil is produced from the reservoir around the base pipe which lies 6m below the top surface. After 10 days, the production well encounters higher oil concentration from the upper part of the reservoir which contains only heavy oil, so that water-cut decreases below the set point and AICV opens autonomously and starts to produce oil.

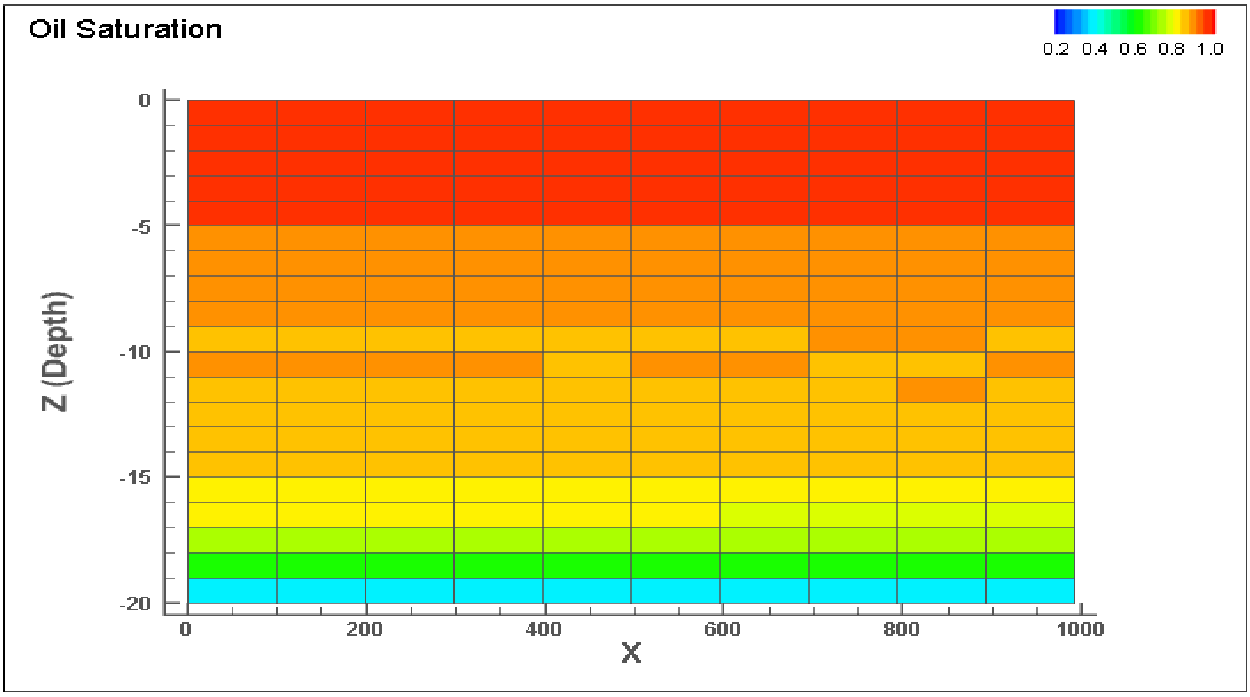

Figure 28 Phase diagram at 9 days for AICV case

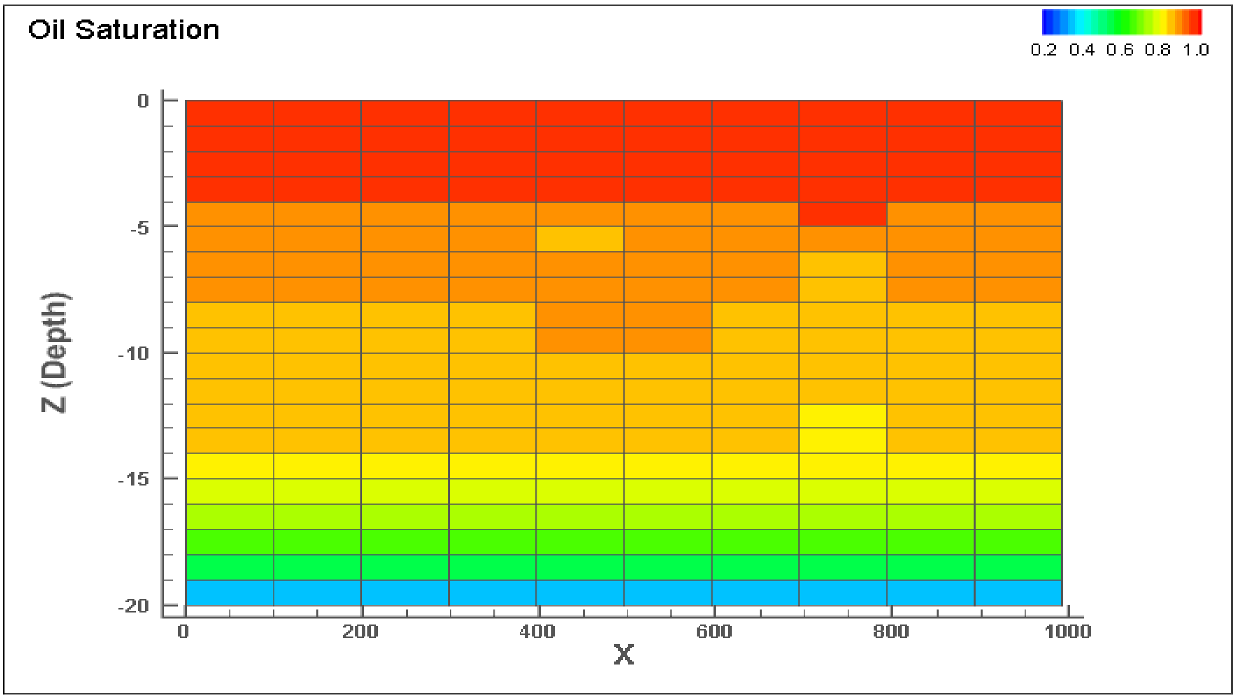

Figure 29 Phase diagram after 10 days for AICV case

Figure 30 shows the initial oil production rate from the well. For both ICD and AICV cases, the initial oil production rate is approximately 250m^3/day from 99.2m section and 2430 m^3/day from the whole reservoir section with ten valves.

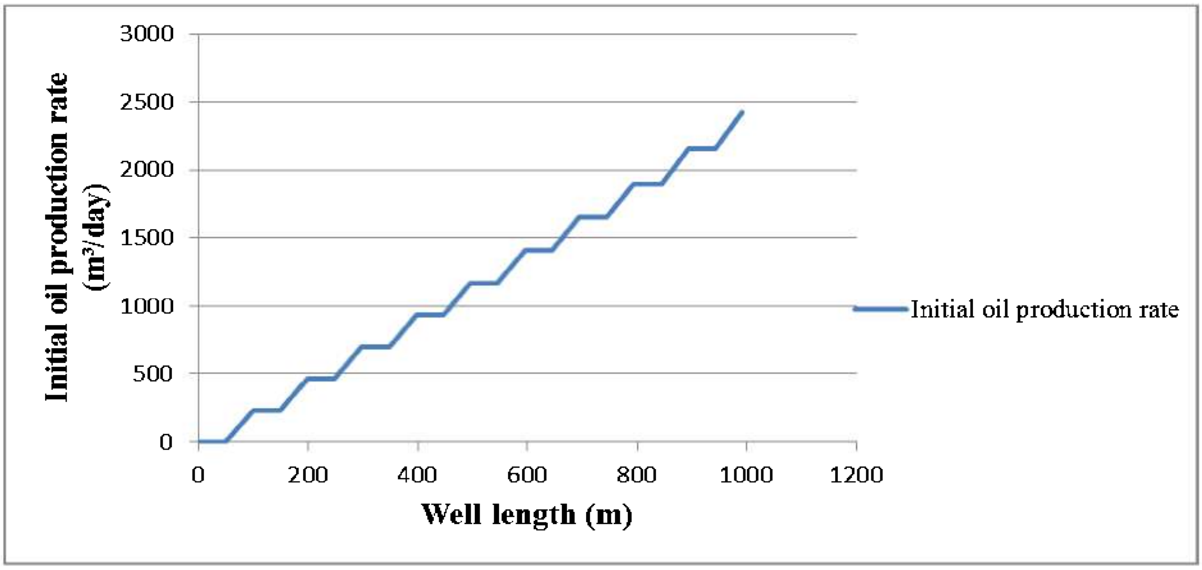

Figure 30 Initial oil production rates for both ICD and AICV cases

In AICV case, the initial oil production is same as in ICD case. The accumulated oil production is increased by using AICV which is shown in Figure 26.

This simulation shows that the recovery with AICV is increased by approximately 21% compared to conventional passive ICD.

According to Figure 31, the water breakthrough occurs after 3.9 days through inflow control device on the heel side and after 4.2 days on the toe side of the reservoir. It can be observed that the water-cut is increasing after water breakthrough in ICD case. The reason for this is that the local devices in this zone have not any water production restriction. At water breakthrough, the accumulated oil production is approximately 9500m^3 for ICD case.

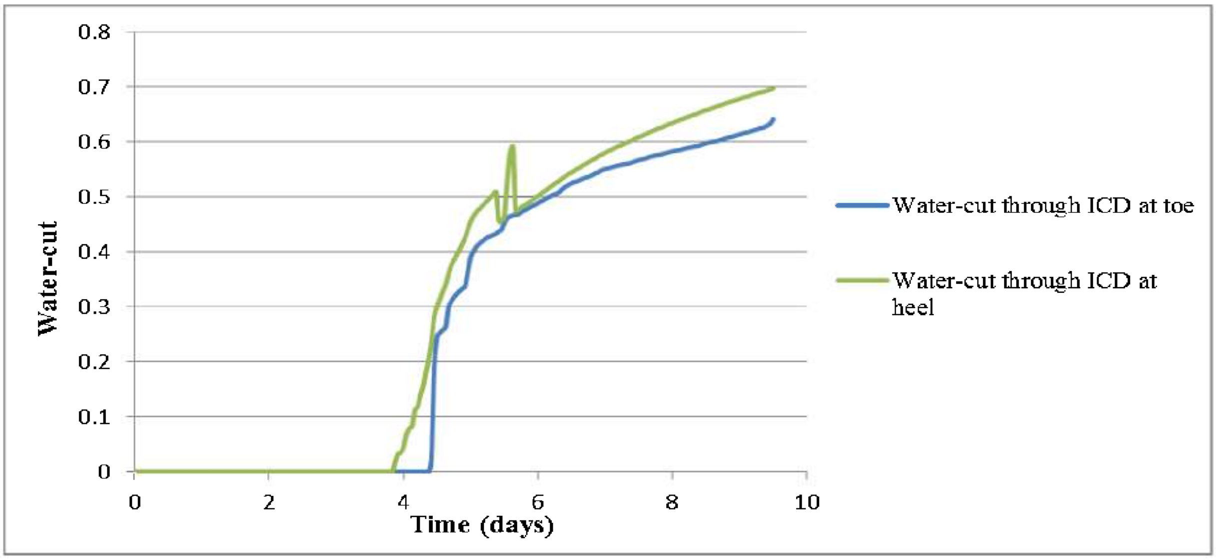

Figure 31 Water-cut through local device in the case with ICD

5 Conclusion

The aim of this thesis is to perform a near well simulation of heavy oil reservoir section using different types of inflow control devices and water drive. OLGA-Rocx was used as a software tool in order to simulate oil production, including the AICV behavior.

AICV is self-regulated and does not require any external force to control. When water breakthrough occurs, the AICV chokes the water production autonomously. This valve is also reversible. This means that if the AICV encounters oil again, it autonomously opens and oil production continues in order to increase the recovery. The reverse action of AICV was simulated successfully.

Two simulation cases for a thin horizontal reservoir section of 992m with water drive were considered. One case is with the conventional ICD and another is with InflowControl's new technology AICV. The simulation cases were controlled with respect to the water-cut in the entire well. When the water-cut reaches a value of 40% in the entire well, the controller starts to operate and the choke position begins to reduce gradually.

The initial total oil production for both cases was 2500m^3/day. The water-cut in the entire well increases more rapidly in the case with ICD than with AICV. The ICD case reaches the 40% water-cut value earlier than AICV case. Thus the well with ICD begins to choke the production earlier than the AICV case. This choking reduces the final accumulated oil production in the well in ICD case. The simulation shows that the recovery of heavy oil production with AICVs is increased by approximately 21% compared to conventional ICDs.

References

1. Ahmed, T., *Reservoir engineering handbook*. 2006, Amsterdam: Elsevier. XV, 1360 s. : ill.
2. Pirson, S.J., *Oil reservoir engineering*. 1958, New York: Mcgraw-Hill. x,735 s. : ill.
3. Bellarby, J., *Well Completion Design*, ed. I. Edition. Vol. 56. 2009. 726.
4. Crowe, C.T., D.F. Elger, and J.A. Roberson, *Engineering fluid mechanics*. 2001, New York: Wiley. XI, 714, [36] s. : ill.
5. Streeter, V.L., *Fluid mechanics*. 1983, London: McGraw-Hill. 562 s.
6. Group, S., *User Manual, version 7.1.4*. SPT Group.
7. Economides, M.J., A.D. Hill, and C. Ehlig-Economides, *Petroleum production systems*. 1994, Englewood Cliffs, N.J.: PTR Prentice Hall. X, 611 s. : ill.
8. Guo, B., W.C. Lyons, and A. Ghalambor, *Petroleum production engineering: a computer-assisted approach*. 2007, Amsterdam: Elsevier. XIX, 288 s. : ill.
9. Sigurd M. Erlandsen and Svein Omdal, S.A., *Trend Breaking Completions.* 2008
10. F.T. Al-Khelaiwi and V.M. Birchenko, H.W.U., SPE; M.R. Konopczynski, Well Dynamics-Halliburton, SPE; and D.R. Davies, Heriot Watt University, SPE, *Advanced Wells: A Comprehensive Approach to the Selection Between Passive and Active Inflow-Control Completions.* SPE Production & Operations, 2010. **Volume 25, Number 3**: p. pp. 305-326.
11. Vidar Mathiesen, H.A., Bjørnar Werswick, Geir Elseth, Statoil ASA, *Autonomous Valve, A Game Changer Of Inflow Control In Horizontal Wells.*, in *Offshore Europe, 6-8 September 2011, Aberdeen, UK*2011, Society of Petroleum Engineers: Aberdeen, UK. p. 10.
12. V.M. Birchenko, K.M.M., D.R. Davies, *Reduction of the horizontal well's heel–toe effect with inflow control devices.* Journal of Petroleum Science and Engineering, 2010. **75**(1-2): p. 244-250.
13. Haavard Aakre, I.T.U.B.H., Telemark University; Bjørnar Werswick, InflowControl; Vidar Mathiesen, InflowControl, *Smart well with autonomous inflow control valve technology*, in *SPE Middle East Oil and Gas show and exebition*2013, Society of Petroleum Engineers: Manama, Bahrain.

14. Aadnoy, B.S. *Autonomous Flow Control Valve or "intelligent" ICD*. [cited 2013 18.03.2013]; Available from: http://www.hansenenergy.biz/HANSEN_Energy_Solutions/InflowControl2008B.pdf.

15. Martin Halvorsen; Geir Elseth, S.O.M.N., Statoil ASA, *Increased oil production at Troll by autonomous inflow control with RCP valves*, in *SPE Annual Technical Conference and Exhibition*2012, Society of Petroleum Engineers: San Antonio, Texas, USA.

16. Halliburton. *HS Series Interval Control Valves*. Available from: http://www.halliburton.com/public/wd/contents/Data_Sheets/web/H06970_HS_Series_ICV.pdf.

17. Maduranga Amaratunga, K.P., Anita Bjerke Elverhøy, Truls Erik Haugen, Raju Aryal and Farzan Sahari Moghaddam, *CFD MODelling of heavy oil production with inflow control device* 2012.

18. 25/05/2013]; Available from: http://www.inflowcontrol.no/.

Appendices

Appendix 1: Master's Thesis task description

Telemark University College

Faculty of Technology

FMH606 Master's Thesis

Title: Near well simulation of oil production from heavy oil reservoirs

Student: Raju Aryal

TUC supervisor: Prof. Britt Halvorsen

External partner: InflowControl AS, Haavard Aakre (co-supervisor)

Task background:
InflowControl AS is a technology company in the oil service that develop products and services related to increased oil recovery and production. The company focus on different types of Inflow Control Devices (ICD) and plan to use the ICD technology in heavy oil production. The technology will ensure an increased oil production and recovery.

Task description:
The oil industry uses various technologies to increase the recovery of oil from the existing reservoirs and enhance the well performance. Heavy oil represents a massive world resource more than twice the size of global reserves of light or conventional oil.

ICD (Inflow Control Device) technology is developed to increase the recovery of oil especially from heavy oil reservoirs. A better understanding of the multiphase reservoir condition is therefore required. In most reservoirs, there are oil, water and gas. Maximum oil production with minimum water and gas is the optimal case. ICDs choke back the unwanted gas and water, while the oil is produced.

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 heavy oil reservoirs and to study the water gas coning in the reservoir.

The project will focus on:

1. Literature study of heavy oil production.
2. Perform near well simulation with OLGA-Rocx using different types of ICDs and water drive.
3. Comparing the different cases regarding oil recovery.

Address: Kjølnes ring 56, NO-3918 Porsgrunn, Norway. **Phone:** 35 57 50 00. **Fax:** 35 55 75 47.

Practical arrangements:
Necessary software will be provided by TUC.

Signatures:

Student (date and signature): 06/02/2013

Supervisor (date and signature): 06.02.2013

Appendix 2: Rocx setting

```
#   Version: 1.0.0.0
#   Input file created by Input File Editor.
#   4/27/2013 12:29:29 PM
#   ModelDescription:Case I: Reservoir section 992X80X20 with pipeline at 6 mtr from top of
reservoir section.
#   Oil Viscosity: 100 cP
#   Reservoir permeability: 5 Darcy
#   Pressure in reservoir: 130 bar


*GEOMETRY RECTANGULAR

#   Number of grid blocks in horizontal and vertical direction
#   ----------------------------------------------------------
#   nx    ny    nz
    10    39    20

    dx    const    99.2
    dy    j    3    3    3    3    2.5    2.5    2.5    2.5    2    2    2    2    2    1.5    1.5    1.5    1    1    1
1
    1    1    1    1.5    1.5    1.5    2    2    2    2    2    2.5    2.5    2.5    2.5    3    3    3    3
    dz    const    1

#   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    0
    gasspecificgravity    0.64
    oilspecificgravity    0.85
    oilvisc    100
```

```
   visctemp    100
   viscpress    30

#   Black oil component data
#   ------------------------
   ncomp    3

   label    BO_Oil_0
   type    oil
   oilspecificgravity    0.85

   label    BO_Gas_0
   type    gas
   gasspecificgravity    1
#      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
   lgr    0.99

   watercomponent    BO_Water_0
   watercut    0.0001
   label    Feed_1
   oilcomponent    BO_Oil_0
   gascomponent    BO_Gas_0
   glr    0.0001

   watercomponent    BO_Water_0
   watercut    0.99
   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
#   ---------------------------------------------
   permx    const    5000
   permy    const    5000
   permz    const    5000

#   Porosity
#   --------
   por    const    0.3

#              compr    reference_pressure
   rock_compr    0    0



#   swc    sor    sgr
   0    0    0

   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
0.1 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 /

krg
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 /

Pcow
0 1
1 0 /

```
   Pcgo
   0    0
   1    1    /

*BOUNDARY_CONDITIONS

manual

#   Injection flow rates
#   --------------------
#   nsource
   0

#   ix    iy    iz    ntime    time    mw    mo    mg    temp

#   Production pressures
#   --------------------
#   npres_bou
   11

#   i    j    k    idir    type    name    ntime    time    pres_bou    temp_bou    Sw_bou    So_bou
Sg_bou    Feeds
   1-10    1-39    20    3    res    Oil_cap_drive    1    0    130    100    1    0    0    [Feed_1 1]
#   i    j    k    idir    type    rw    name    ntime    time    skin    WIFoil    WIFgas    WIFwater
pres_bou    temp_bou    Sw_bou    So_bou    Sg_bou
   10    20    6    1    well    0.1    P10    1    0    0    1    1    1    130    100    0    1    0    [Feed_3
1]
   9    20    6    1    well    0.1    P9    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]
   8    20    6    1    well    0.1    P8    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]
   7    20    6    1    well    0.1    P7    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]
   6    20    6    1    well    0.1    P6    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]
   5    20    6    1    well    0.1    P5    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]
   4    20    6    1    well    0.1    P4    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]
   3    20    6    1    well    0.1    P3    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]
   2    20    6    1    well    0.1    P2    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]
   1    20    6    1    well    0.1    P1    1    0    0    1    1    1    130    100    0    1    0    [Feed_3 1]

*INITIAL_CONDITIONS

#   Feed
   feed const [Feed_3 1] /

manual

#   Saturations
#   -----------
   sw    const    0
   so    const    1
   sg    const    0
```

```
#   Pressures
#   ---------
    Po    const    130

#   Temperatures
#   ------------
    T    const    100

*TEMPERATURE off

*INTEGRATION

#   tstart    tstop
    0    0

#   dtmin    dtmax    dtstart    dtfac    cflfac
    0    360    0.01    10    1

implicit Linsolver

*WELL_COUPLING_LEVEL
    4

*OUTPUT

#   cof_time    cof_rate
    1    1

#   ntplot
    4
    P4
    P3
    P2
    P1

    Dt_Trend
    0    3600    /

    Dt_Prof
    0    3600    /

    screen_info    1

*END
```

Appendix 3: OLGA settings for ICD case

1. Introduction

Project	OLGA
Case description	Blackoil case
Date	
Author	SPT Group
Restart File	

2. Simulation Options

Overall setting	Flow model	OLGA
	Mass eq scheme	1STORDER
	Compositional model	BLACKOIL
	Debug	OFF
	Drilling	OFF
	Phase	THREE
	Elastic walls	OFF
	Void in slug	SINTEF
	Steady state	OFF
	User defined plug-in	OFF
	Temp. calc.	WALL
	Wax deposition	OFF
	Restart	OFF
Integration	Simulation starttime	0
	Simulation stoptime	100 d
	Minimum time step	0.1
	Maximum time step	3600

4. System Layout - Table

4.1 Summary

4.1.1 Overall

No. of Branches	No. of Pipes	No. of Sections
2	2	60

4.1.2 Flows

Branches	No. of Pipes	No. of Sections	Min. Section Length	At	Max. Section Length	At
PIPELINE	1	20	49.6 M	PIPE-1	49.6 M	PIPE-1
FLOWPATH_1	1	20	49.6 M	PIPE-1	49.6 M	PIPE-1

4.2 Layout

Pipe no.	Branch	Label	Diameter	Roughness	XEnd	YEND	Wall
1 - 1	PIPELINE	PIPE-1	0.2 M	2.8E-05 M	992 M	0 M	WALL-1
2 - 1	FLOWPATH_1	PIPE-1	0.2 M	2.8E-05 M	992 M	0 M	WALL-1

5. Insulation and Walls

5. 1 Material

Label	Density	Conductivity	Heat Capacity	E-modulus
MATER-1	7850	50	500	
MATER-2	2500	1	880	

5. 2 Walls

Label	Material	Wall thickness	Elastic
WALL-1	MATER-1	0.009	OFF
	MATER-2	0.02	
	MATER-2	0.02	
WALL-2	MATER-1	0.0075	OFF
	MATER-2	0.02	
	MATER-2	0.02	

6. Boundary Conditions

6. 1 Nodes

Label	Type	Pressure	Temperature	GMF
INLET	CLOSED			-1
OUTLET	CLOSED	50 bara	22	-1
NODE_1	CLOSED			-1
NODE_2	PRESSURE	120 bara	100	-1

6. 2 Heattransfer

Branch	Pipe	Interpolation	Houteroption.	Hambient	Tambient
PIPELINE	PIPE-1	SECTIONWISE	HGIVEN	1E-06 W/M2-C	100
FLOWPATH_1	PIPE-1	SECTIONWISE	AIR	1E-06	100

6. 3 Initial Conditions

Branch	Pipe	Mass Flow	VoidFraction
PIPELINE	PIPE-1	0	0
FLOWPATH_1	PIPE-1	0	0

7. Equipment

7. 1 Valves

Label	Branch	Pipe	Section	Diameter	Opening	CD
VALVE-4	PIPELINE	PIPE-1	9	1	0	0.84
VALVE-A	PIPELINE	PIPE-1	2	20 mm	1	0.84
VALVE-1	PIPELINE	PIPE-1	3	1	0	0.84
VALVE-B	PIPELINE	PIPE-1	4	20 mm	1	0.84
VALVE-2	PIPELINE	PIPE-1	5	1	0	0.84
VALVE-C	PIPELINE	PIPE-1	6	20 mm	1	0.84
VALVE-3	PIPELINE	PIPE-1	7	1	0	0.84
VALVE-D	PIPELINE	PIPE-1	8	20 mm	1	0.84
VALVE-E	PIPELINE	PIPE-1	10	20 mm	1	0.84
VALVE-5	PIPELINE	PIPE-1	11	1	0	0.84
VALVE-F	PIPELINE	PIPE-1	12	20 mm	1	0.84
VALVE-6	PIPELINE	PIPE-1	13	1	0	0.84
VALVE-G	PIPELINE	PIPE-1	14	20 mm	1	0.84
VALVE-7	PIPELINE	PIPE-1	15	1	0	0.84
VALVE-H	PIPELINE	PIPE-1	16	20 mm	1	0.84
VALVE-8	PIPELINE	PIPE-1	17	1	0	0.84
VALVE-I	PIPELINE	PIPE-1	18	20 mm	1	0.84
VALVE-9	PIPELINE	PIPE-1	19	1	0	0.84
VALVE-J	PIPELINE	PIPE-1	20	20 mm	1	0.84

7. 2 Position

Label	Branch	Pipe	Section
POS-1	FLOWPATH_1	PIPE-1	1
POS-2	FLOWPATH_1	PIPE-1	2
POS-3	FLOWPATH_1	PIPE-1	3
POS-4	FLOWPATH_1	PIPE-1	4
POS-5	FLOWPATH_1	PIPE-1	5
POS-6	FLOWPATH_1	PIPE-1	6
POS-7	FLOWPATH_1	PIPE-1	7
POS-8	FLOWPATH_1	PIPE-1	8
POS-9	FLOWPATH_1	PIPE-1	9
POS-10	FLOWPATH_1	PIPE-1	10
POS-11	FLOWPATH_1	PIPE-1	11
POS-12	FLOWPATH_1	PIPE-1	12
POS-13	FLOWPATH_1	PIPE-1	13
POS-14	FLOWPATH_1	PIPE-1	14
POS-15	FLOWPATH_1	PIPE-1	15
POS-16	FLOWPATH_1	PIPE-1	16
POS-17	FLOWPATH_1	PIPE-1	17

POS-18	FLOWPATH_1	PIPE-1	18
POS-19	FLOWPATH_1	PIPE-1	19
POS-20	FLOWPATH_1	PIPE-1	20

Appendix 4: OLGA settings for AICV case

1. Introduction

Project	OLGA
Case description	Blackoil case
Date	
Author	SPT Group
Restart File	

2. Simulation Options

Overall setting	Flow model	OLGA
	Mass eq scheme	1STORDER
	Compositional model	BLACKOIL
	Debug	OFF
	Drilling	OFF
	Phase	THREE
	Elastic walls	OFF
	Void in slug	SINTEF
	Steady state	OFF
	User defined plug-in	OFF
	Temp. calc.	WALL
	Wax deposition	OFF
	Restart	OFF
Integration	Simulation starttime	0
	Simulation stoptime	100 d
	Minimum time step	0.1
	Maximum time step	3600

4. System Layout - Table

4.1 Summary

4.1.1 Overall

No. of Branches	No. of Pipes	No. of Sections
2	2	60

4.1.2 Flows

Branches	No. of Pipes	No. of Sections	Min. Section Length	At	Max. Section Length	At
PIPELINE	1	20	49.6 M	PIPE-1	49.6 M	PIPE-1
FLOWPATH_1	1	20	49.6 M	PIPE-1	49.6 M	PIPE-1

4.2 Layout

Pipe no.	Branch	Label	Diameter	Roughness	XEnd	YEND	Wall
1 - 1	PIPELINE	PIPE-1	0.2 M	2.8E-05 M	992 M	0 M	WALL-1
2 - 1	FLOWPATH_1	PIPE-1	0.2 M	2.8E-05 M	992 M	0 M	WALL-1

5. Insulation and Walls

5. 1 Material

Label	Density	Conductivity	Heat Capacity	E-modulus
MATER-1	7850	50	500	
MATER-2	2500	1	880	

5. 2 Walls

Label	Material	Wall thickness	Elastic
WALL-1	MATER-1	0.009	OFF
	MATER-2	0.02	
	MATER-2	0.02	
WALL-2	MATER-1	0.0075	OFF
	MATER-2	0.02	
	MATER-2	0.02	

6. Boundary Conditions

6. 1 Nodes

Label	Type	Pressure	Temperature	GMF
INLET	CLOSED			-1
OUTLET	CLOSED	50 bara	22	-1
NODE_1	CLOSED			-1
NODE_2	PRESSURE	120 bara	100	-1

6. 2 Heattransfer

Branch	Pipe	Interpolation	Houteroption.	Hambient	Tambient
PIPELINE	PIPE-1	SECTIONWISE	HGIVEN	1E-06 W/M2-C	100
FLOWPATH_1	PIPE-1	SECTIONWISE	AIR	1E-06	100

6. 3 Initial Conditions

Branch	Pipe	Mass Flow	VoidFraction
PIPELINE	PIPE-1	0	0
FLOWPATH_1	PIPE-1	0	0

7. Equipment

7. 1 Valves

Label	Branch	Pipe	Section	Diameter	Opening	CD
VALVE-4	PIPELINE	PIPE-1	9	1	0	0.84
VALVE-A	PIPELINE	PIPE-1	2	20 mm	1	0.84
VALVE-1	PIPELINE	PIPE-1	3	1	0	0.84
VALVE-B	PIPELINE	PIPE-1	4	20 mm	1	0.84
VALVE-2	PIPELINE	PIPE-1	5	1	0	0.84
VALVE-C	PIPELINE	PIPE-1	6	20 mm	1	0.84
VALVE-3	PIPELINE	PIPE-1	7	1	0	0.84
VALVE-D	PIPELINE	PIPE-1	8	20 mm	1	0.84
VALVE-E	PIPELINE	PIPE-1	10	20 mm	1	0.84
VALVE-5	PIPELINE	PIPE-1	11	1	0	0.84
VALVE-F	PIPELINE	PIPE-1	12	20 mm	1	0.84
VALVE-6	PIPELINE	PIPE-1	13	1	0	0.84
VALVE-G	PIPELINE	PIPE-1	14	20 mm	1	0.84
VALVE-7	PIPELINE	PIPE-1	15	1	0	0.84
VALVE-H	PIPELINE	PIPE-1	16	20 mm	1	0.84
VALVE-8	PIPELINE	PIPE-1	17	1	0	0.84
VALVE-I	PIPELINE	PIPE-1	18	20 mm	1	0.84
VALVE-9	PIPELINE	PIPE-1	19	1	0	0.84
VALVE-J	PIPELINE	PIPE-1	20	20 mm	1	0.84

7. 2 Position

Label	Branch	Pipe	Section
POS-1	FLOWPATH_1	PIPE-1	1
POS-2	FLOWPATH_1	PIPE-1	2
POS-3	FLOWPATH_1	PIPE-1	3
POS-4	FLOWPATH_1	PIPE-1	4
POS-5	FLOWPATH_1	PIPE-1	5
POS-6	FLOWPATH_1	PIPE-1	6
POS-7	FLOWPATH_1	PIPE-1	7
POS-8	FLOWPATH_1	PIPE-1	8
POS-9	FLOWPATH_1	PIPE-1	9
POS-10	FLOWPATH_1	PIPE-1	10
POS-11	FLOWPATH_1	PIPE-1	11
POS-12	FLOWPATH_1	PIPE-1	12
POS-13	FLOWPATH_1	PIPE-1	13
POS-14	FLOWPATH_1	PIPE-1	14
POS-15	FLOWPATH_1	PIPE-1	15
POS-16	FLOWPATH_1	PIPE-1	16
POS-17	FLOWPATH_1	PIPE-1	17

POS-18	FLOWPATH_1	PIPE-1	18
POS-19	FLOWPATH_1	PIPE-1	19
POS-20	FLOWPATH_1	PIPE-1	20