Simulation of Oil Production from Heterogeneous North Sea Reservoirs with Inflow Control using OLGA/Rocx

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Abstract

Advances in drilling technology have made long, horizontal wells the preferred method to extract oil from reservoirs in the Norwegian Sector. Horizontal wells give increased oil contact, enabling production from reservoirs with shallow, high viscosity oil columns. Under these conditions, early water or gas breakthrough is a major challenge. To postpone breakthrough, inflow control devices (ICD) are installed to even out the drawdown. A new technology, Autonomous Inflow Control Valve (AICV©) also has the ability to autonomously close each individual inflow zone in the event of gas or water breakthrough. The objective of this paper was to study and compare these inflow control technologies by conducting simulations in OLGA/Rocx. A heterogeneous fractured sandstone heavy oil reservoir was modelled. The results show that during 2000 days of production, the AICV well produces 2950 m^3 more oil and 158300 m^3 less water than the ICD well. This indicates that AICV has the potential to reduce the water production significantly, and thereby increase the oil recovery.

Keywords: Inflow control, ICD, AICV, heterogeneous oil reservoir, oil production, breakthrough, multiphase flow, OLGA, Rocx

1 Introduction

Long horizontal wells are drilled to increase the contact area between the reservoir and the production well, and thereby increase the oil production and oil recovery. In the North Sea, the oil columns are very thin, and it is therefore a challenge to avoid early breakthrough of gas and water. To limit the early gas and water breakthrough inflow controllers are implemented in the inflow zones along the well. (Terry and Rogers, 2014; Geoscience News and Information, 2017) Inflow control devices adjust the inflow volume to the well, avoiding high volume flow in zones with high permeability or high drawdown. This paper focuses on the effect of inflow controllers in a heterogeneous oil reservoir with an underlying water aquifer in the North Sea. Two types of technologies are studied; a passive inflow control device (ICD) and an autonomous inflow control valve (AICV). Passive ICD is capable of equalizing the production along the well. AICV can close for unwanted fluids when breakthrough occurs. The effect of inflow controllers in different types of reservoirs has been studied by several researchers (Furuvik and Moldestad, 2017; Ugwu and Moldestad, 2016; Abbasi and Moldestad, 2016; Jonskås *et al*, 2016; Wijerathne and Halvorsen, 2015; Aakre *et al*, 2013) by using simulation tools like OLGA/Rocx, Eclipse, NETool and Aspen/Hysys. The conclusion has been that there is a high potential of increasing the oil recovery by using inflow controllers. This study includes OLGA/Rocx simulations of the oil production from the Grane field in the North Sea.

1.1 Horizontal wells

A horizontal well consists of several elements. After the wellbore is drilled in vertical direction down to the planned depth and horizontally to the design length, the production well is installed into the wellbore. The production well is composed of several sections where each of the sections include 1-2 joints of 12.19 m (40 feet) (Schlumberger, 2017). In each zone, inflow controllers can be installed to reduce or regulate the volume flow into the production well. The wellbore has a larger diameter than the production well, and the open space in between is called the annulus. Packers are used to isolate the different sections along the well to avoid water or gas flow from one section to another. In addition, sand screens are installed in each section to avoid production of sand into the well. (Halliburton, 2017) Figure 1 shows the structure of a horizontal well.

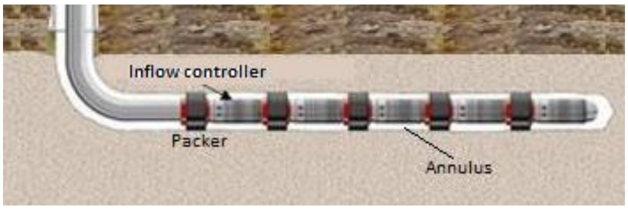

Figure 1. Structure of a horizontal well including production pipe, annulus, packers, sand screens and inflow control devices. (Halliburton, 2017)

1.2 Inflow controllers

Several inflow controllers are installed along a horizontal well; typically one controller per 12.19 m. In this study nozzle ICDs and AICVs are used in the simulations. Figure 2 shows a section of a pipeline including a nozzle ICD. The fluid flows from the annulus, via the sand screen and through the ICD into the well. The red arrows in Figure 2 illustrates the flow path. The additional pressure drop over the nozzle ICD regulates the flow rates into the well and contributes to equalize the production along the well. The nozzle ICD is passive, and is not capable of choking or closing for unwanted fluids after breakthrough. (Ellis *et al*, 2010)

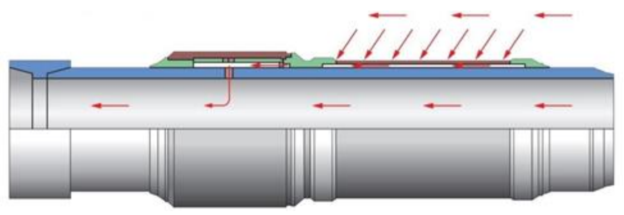

Figure 2. Pipe section with nozzle ICD. (Ellis *et al*, 2010)

Figure 3 shows an autonomous inflow controller, AICV, in open and closed position. AICV is a completely self-regulating inflow controller and does not require any electronics or connection to the surface. The AICV is in open position when oil is produced, and closes locally in zones where breakthrough of unwanted fluids occurs. The principle of AICV is described in detail in different publications (Mathiesen *et al*, 2014; Aakre *et al*, 2013; Aakre *et al*, 2014; Kahawalage and Halvorsen, 2015; Badalge and Halvorsen, 2015).

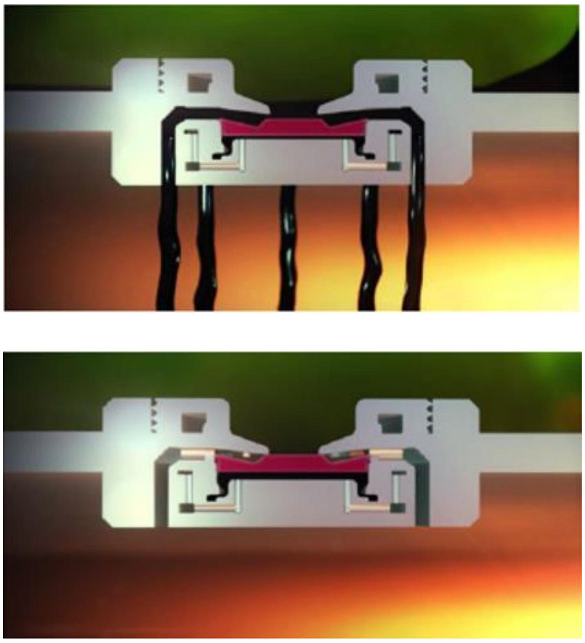

Figure 3. AICV in open (upper picture) and closed (lower picture) position. (Guadong and Halvorsen, 2015)

2 Simulation set-up

Simulations are performed using the near-well simulation tool Rocx in combination with OLGA. Rocx simulations can be run without the coupling to the OLGA software, but the combination gives more accurate predictions of well start-up and shut-down, flow instabilities, cross flow between different layers, water coning and gas dynamics. (Schlumberger, 2017) The input to Rocx and OLGA is described in Chapter 2.1 and 2.2.

2.1 Rocx

Rocx is a three-dimensional transient near-well simulation tool and is used to simulate three phase fluid flow in permeable rocks. Rocx gives information about changes in pressure, temperature and fluid saturation in the reservoir as a function of time, and the information is transferred to OLGA.

2.1.1 Grid

The dimensions of the reservoir and the position of the well are defined in Rocx. The reservoir is divided into a number of control volumes as shown in Figure 4. The simulated reservoir is 1219 m in x-direction, 308 m in y-direction and 31 m in z-direction. The total number of control volumes are 3900 (10x39x10). The grid sizes are 121.9 m in the x-direction, which is corresponding to ten pipe sections of 12.19 m each. The simulations are performed for the Grane field, where the height of the oil column is typically 31 m. The width of the reservoir is chosen to be 308 m to ensure sufficient initial volume of oil. The grid sizes in the x- and z- directions are constant, whereas in the y-direction the grid sizes is reduced towards the wellbore. This is done to be able to simulate the coning effect, and to get better prediction of the water breakthrough time. The well is located about 9 m above the lower boundary of the well. The water-oil boundary is in the bottom of the reservoir. Figure 4 shows the final grid including the position of the well.

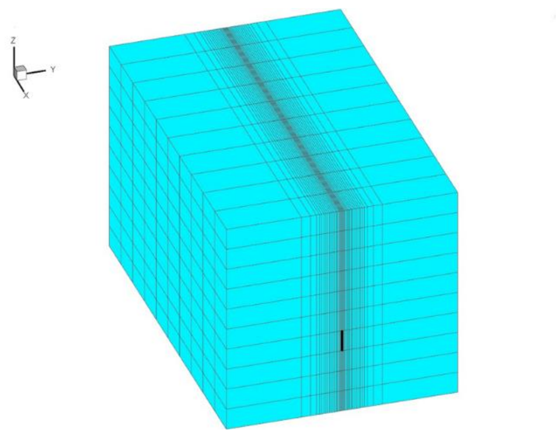

Figure 4. Final grid including the position of the well

2.1.2 Permeability

This paper presents the simulations of a homogeneous reservoir with one high permeable zone, also considered as a fracture. Figure 5 shows the permeability in the reservoir. The x-z permeability is 5000mD in the homogeneous part of the reservoir (blue colour), and 35000mD in the high permeable zone (orange colour). The vertical (z) permeability is 1/10 of the horizontal (x-y) permeability.

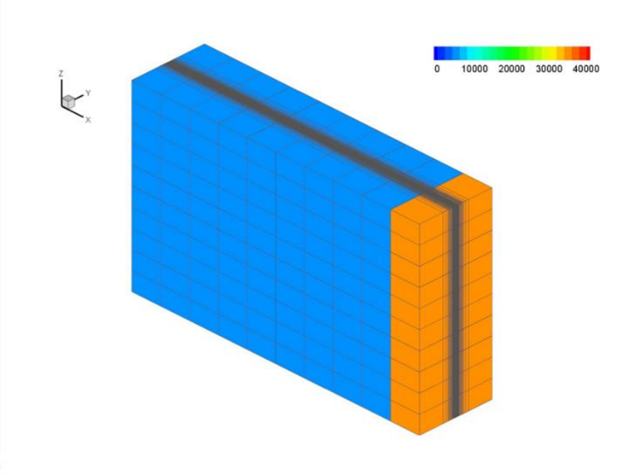

Figure 5. Permeability in the reservoir.

The relative permeability is defined as the ratio of the effective permeability to the absolute permeability, and is highly dependent on the type of reservoir. The relative permeability curves for oil and water, for water-wet sandstone at Grane, is calculated based on the Corey correlation. The Corey model is derived from capillary pressure data and is accepted as a good approximation for relative permeability curves in a two-phase flow. The required input data is limited to the irreducible water saturation (Swc) and the residual oil saturation (Sor), and their corresponding relative permeabilities. (Furuvik and Moldestad, 2017; Tangen, 2017) Swc defines the maximum water saturation that a reservoir can retain without producing water, and Sor refers to the minimum oil saturation at which oil can be recovered by primary and secondary oil recovery.

The relative permeability curves implemented in the simulations are presented in Figure 6. The blue line represents the relative permeability for water (Krw) and the red line represent the relative permeability for oil (Kro).

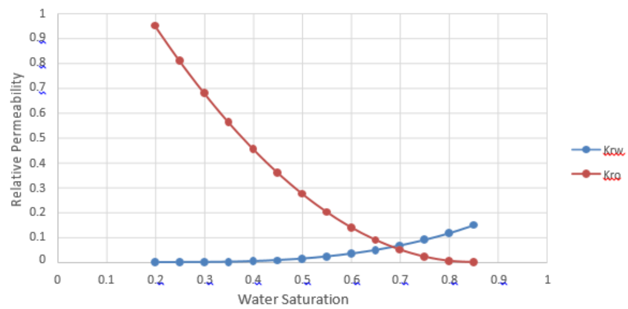

Figure 6. Relative permeability curves for water and oil.

2.2 OLGA

OLGA is a one-dimensional transient dynamic multiphase simulator used to simulate flow in pipelines and connected equipment. OLGA consists of several modules depicting transient flow in a multiphase pipeline, pipeline networks and processing equipment. The OLGA simulator is governed by conservation of mass equations for gas, liquid and liquid droplets, conservation of momentum equations for the liquid phase and the liquid droplets at the walls, and conservation of energy mixture equation with phases having the same temperature. (Schlumberger, 2017)

2.2.1 Set- up in OLGA

The set-up in OLGA includes the annulus, the pipeline, packers and inflow controllers. The annulus is the space between the rock and the pipeline. Figure 7 shows a schematic of the location of the annulus and well in the reservoir.

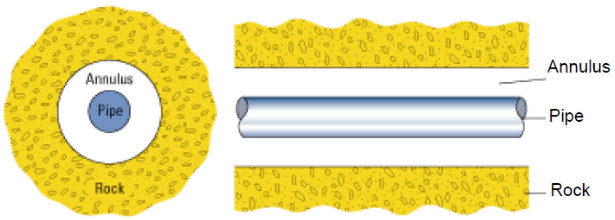

Figure 7. A schematic of the pipe and the annulus. (Schlumberger, 2007)

The OLGA version used in this project has no available routines for annulus simulations. The production well and annulus are therefore defined as two separate pipelines, as presented in Figure 8. The lower pipeline illustrates the annulus, and the upper pipeline illustrates the production well.

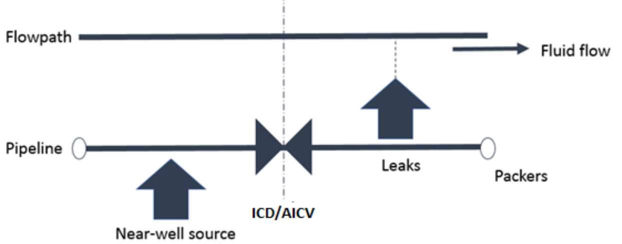

Figure 8. Representation of single zone of well. (Timsina, 2017)

In OLGA, the inflow controllers are defined as valves. ICDs are passive inflow controllers and are therefore modelled as fully open valves. The AICVs are operating in open or closed position depending on the properties of the surrounding fluids. There are no options to choose autonomous inflow controllers in OLGA, and the function of the AICV was modelled as a valve where the valve opening was adjusted based on the water cut (WC). Figure 9 illustrates one pipe section including the flow from the reservoir (NWSOUR-2) to annulus, one inflow controller (VALVE2), two packers (PACKER and PACKER-2) and the flow through the inflow controller to the production well (LEAK).

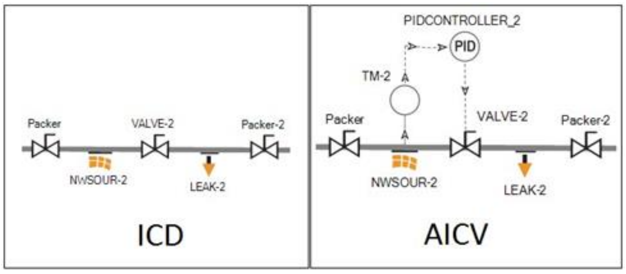

Figure 9. Set-up of ICD and AICV in OLGA.

The ICD and the AICV both have an inlet diameter of 19.5 mm. Transmitters and PIDs are used to model the function of the AICVs. The transmitters register the WC. If the WC is higher than the set point given for the PID, the AICV will begin to close. When the AICVs are in closed position, the flow area of the valves is reduced to 0.8% of the flow area in fully open position. The diameters of the pipeline and the annulus are set to 0.1397 m (5.5") and 0.2159 m (8.5") respectively. The roughness of the well is assumed $1.5 \cdot 10^{-4}$ m. The production well has a length of 1279.5m and are divided into 20 sections of 121.9 m and one outlet part (60.95 m), including a PID controller to adjust the total flow rate to the downstream facilities. Figure 10 shows the outlet part of the well including the choke and the PID controller.

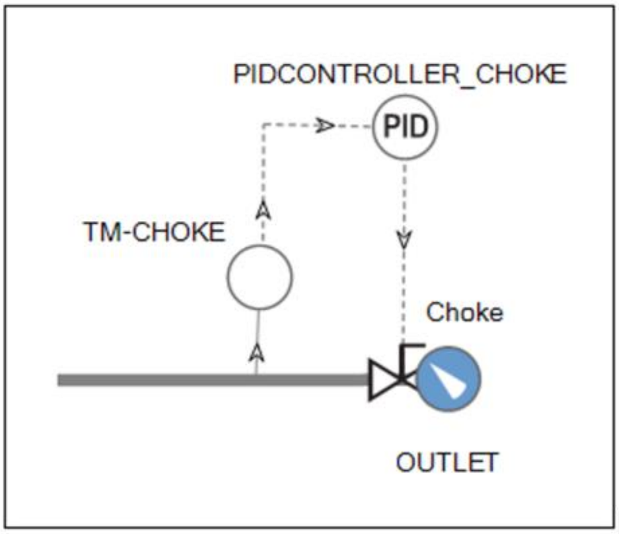

Figure 10. Flow control at the outlet of the well.

The PID is controlling the total flow rate of oil and water from the well. The set point is 1200 m^3/day, and is calculated based on production data from the Grane field. The PID controller parameters are summarized in Table 1.

Table 1. PID controller parameters

Parameter	*Value*
Set point	1200 m^3/day
Initial opening	0.10 %
Maximum opening	100 %
Minimum opening	0.10 %
Amplification	-0.18
Sample time	60.0 s
Integral time	540 s
Derivate time	0.00 s

3 Results

Simulations using ICDs and AICVs were performed for 2000 days. The set point for the water cut through the AICVs was set to 90%. This means that the AICVs start closing when the fluid from the reservoir contains 90% water.

The oil and water flow rates through AICVs and ICDs as a function of time are shown in Figure 11 and 12 respectively. The plots are divided into three time intervals. Time interval 1 (T1) represents the period when all the valves are open (0-500 days), Time interval 2 (T2) represents the period when the AICVs produce more oil than the ICDs (500-1600 days), and Time interval 3 (T3) is the period from the end of T2 to the end of the simulation (1600-2000 days). AICVs and ICDs have the same inflow area in fully open position, and are therefore producing equal quantities of oil and water during T1.

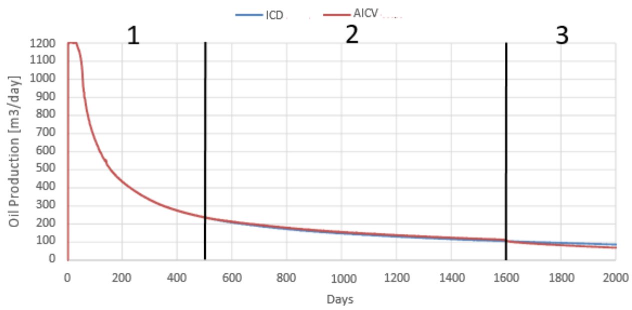

Figure 11. Oil production through ICD and AICV.

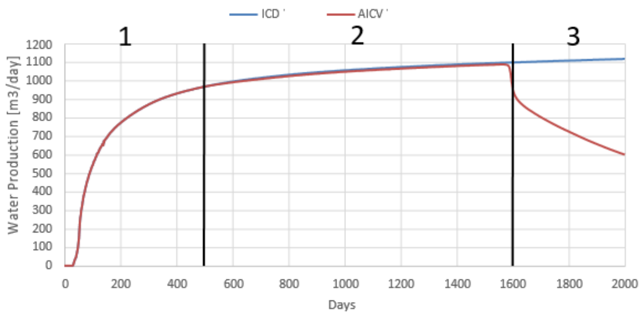

Figure 12. Water production through ICD and AICV.

The deviation in oil and water flow rates through the two inflow controllers is not clearly observed until the end of T2. In T3, the ICDs are producing significantly more water than the AICVs.

Figure 13 illustrates the closure characteristics of the AICVs. The water fraction (0-1) and the valve opening (0-1) are given at the y-axis, and the x-axis represents the time in days.

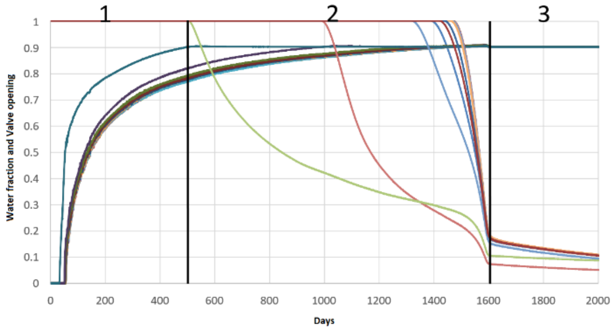

Figure 13. Closure characteristic for the AICV.

The AICV located in the high permeability zone (35000 mD) starts closing after 500 days of production. The next well, located near the heel section of the well, starts closing after about 1000 days. After about 1600 days, all the AICVs are nearly closed.

The accumulated volume of oil and water as a function of time are presented in Figure 14 and 15 respectively. Figure 14 shows that the AICVs are producing slightly more oil than the ICDs during T2, whereas the ICDs are producing more oil during T3. Figure 15 shows that ICD produce significantly more water than AICV during T3.

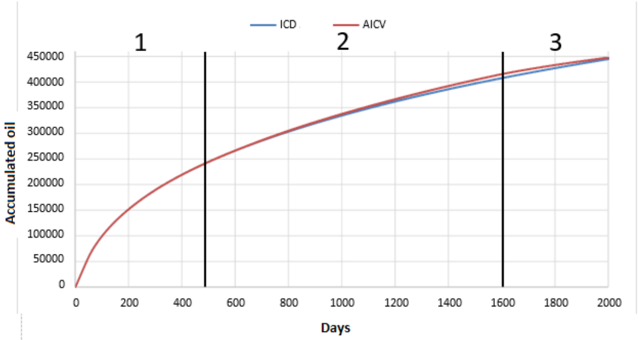

Figure 14. Accumulated oil as a function of time through ICD and AICV.

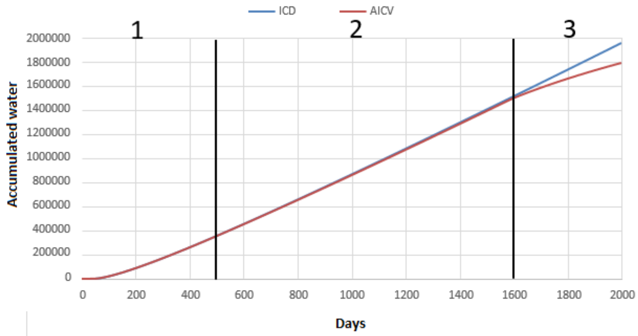

Figure 15. Accumulated water as a function of time through ICD and AICV

The results, given as the difference between the accumulated oil and water volume for the two cases, are summarized in Table 2. Positive values indicate higher production with AICV than ICD.

Table 2. Difference between accumulated oil and water production through AICVs and ICDs.

Time interval	*Δ Accumulated oil [m^3]*	*Δ Accumulated water [m^3]*
T1	0	0
T2	7000	-9300
T3	-4050	-149000
Total	2950	-158300

The AICV well is producing 7000 m^3 more oil than the ICD well in T2, whereas the ICD well is producing 4050 m^3 more oil than the AICV well during T3. Regarding the water production, AICVs are producing less water than ICD during T2 and T3. Totally, during the time period of 2000 days, the AICV well is producing 2950m^3 more oil and 158300m^3 less water than the ICD well.

In the simulations, the ICDs and AICVs were designed with the same ICD strength. The ICD strength is defined as the pressure drop over the inflow controller when 1 m^3 of fluid is passing through. A high ICD strength is used to delay the water breakthrough. However, the AICVs are activated to close when the water reaches the well, and the AICVs can therefore be designed with a lower ICD strength. In that case, the AICVs would be able to produce oil at higher flow rates, and the production time could be reduced. The choke on the total flow was restricting the production to 1200 m^3/day. The choke could also be adjusted based on the total water cut. In that case, the initial oil production would be higher, water breakthrough would occur earlier, and the advantage of using AICVs might be more significant. This can be taken into consideration in further studies.

In a horizontal well at Grane, the length of each section is 12.19 m, and each section includes one inflow controller. In the simulations, sections of 121.9 m was used and one large inflow controller was replacing 10 normal inflow controllers. This was done to reduce the simulation time, and may have an effect on the production rates. However, both the technologies, AICV and ICD, were effected in the same way. Further simulations are needed to study the effect of using long compared to short sections.

4 Conclusion

The objective of this work was to study the effect of inflow controllers in a heterogeneous oil reservoir with an underlying water aquifer in the North Sea. The study included near-well simulations of oil production, using the reservoir software Rocx in combination with OLGA. Two types of technologies were studied; a passive inflow control device (ICD) and an autonomous inflow control valve (AICV). The results show that during 2000 days of production, the well with AICV completion produces 2950 m^3 more oil and 158300 m^3 less water than the well with ICD completion. This indicates that AICV technology can increase oil production and simultaneously decrease water production in reservoirs with fractures or other heterogeneities.

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