"Optimization of Horizontal wells by using down Hole Inflow Control Devices"

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Abstract

Oil production currently has challenges such as excessive water production, which reduces the cumulative oil recovery, this occurs due to water coning in the reservoir which resulted to earlier water breakthrough in the wellbore. Various Down hole Flow control Devices (DFCs) including ICDs, AICDs, and AICVS are typically installed in the horizontal section of oil wells to mitigate the problem.

The study of autonomous ICDs was done by comparing the long term flow performance of such devices against passive ICDs. The study was carried out with a reservoir model representing one horizontal well (X2) with three completion alternatives: open hole, ICD and AICDs which were perforating in numerical reservoir model, the model and completion was built and designed by (Petrel 2016) software; these cases were run in the Eclipse simulator and their results were compared with the open hole.

The installation of DFCs (ICDs, and AICDs) in the horizontal well increased the oil recovery (RF) significantly, however the installation of Autonomous ICDs (AICDs) in the horizontal well perforating the oil reservoir increased more oil when compared against the passive ICDs, and this had been proved by the results of the reservoir model.

Key words: Inflow control devices, Horizontal wells.

1. Introduction

1.1 Background

Horizontal wells are associated with various problems since they are drilled at an angle making them susceptible to early water/gas breakthrough mostly motivated by factors such as frictional pressure drop, permeability variations along the wellbore and "heel toe effect". These result to uneven flow sweep at the wellbore leading to low oil production, sharp oil production rate declines, and short economic production life of the well.

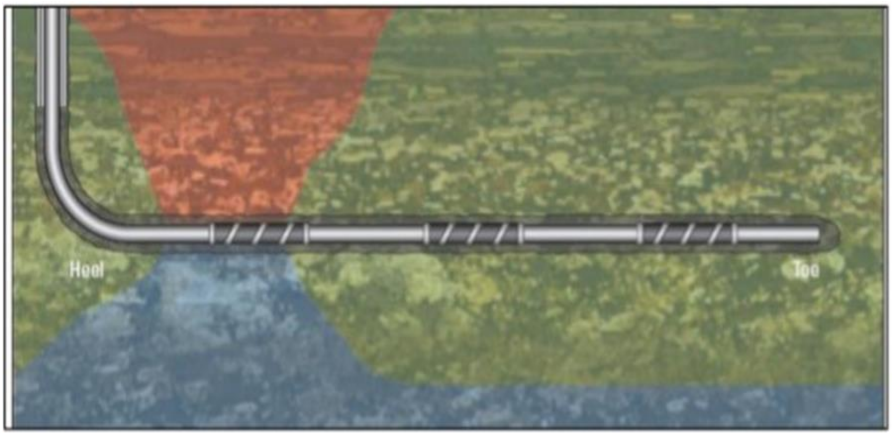

Figure (1): Horizontal well shows heel-toe effect (Sharma, et al., 2015)

1.2 Objective of the study

The main objectives of this study are to apply ICDs and AICDs in the horizontal well X2 to:

• Achieve equal or uniform flux along the length of the horizontal well.

• Reduce water production as well as improve reservoir oil recovery.

1.3 Significance

The water preferentially precedes in the form of a cone, as such its name. It yields associated problems of reduced efficiency of depletion mechanism, early abandonment of affected wells, reduced field recovery, reduced field profitability and an extra cost for handling produced water.

2 Methodology

2.1 Inflow control devices (ICDs)

Inflow control devices (ICDs) were introduced during the 1990's. ICDs are well completion devices which have been developed for the purpose of balancing fluid inflow along the wellbore by introducing an extra pressure drop in the zones with low pressure drops. Figure (2) shows the inflow control devices.

Figure (2): Inflow control devices (Schlumberger, 2020)

ICDs are devices installed in a horizontal well to solve the challenge of excessive production of gas, water or both, which are caused by earlier water/gas breakthrough and also the ICD contains screen to control excessive sand production (Osman, et al., 1990). The ICDs provide the restriction or friction of fluid to pass through the channel, nozzle or orifice as shown in Figure 3.2, where the fluid from the annulus indicated with the red arrow is flowing to the orifice then to the production pipe. The restriction of fluid provided by ICDs causes the fluid pressure drop. The ICDs are installed in the well segments with lower pressure drops so as to add extra pressure drop and balance the pressure drops in all wellbore segment and then equalize the inflow along the wellbore.

Types of ICDs

i. Channel-type (Helical channel) ICD

The channel-type ICD shown in Figure (3) is the type of ICD that uses surface friction to generate a pressure drop. The fluid flows through the channel type ICD by passing through the channel with a defined length, and then to the opening before entering the wellbore. The pressure drop in the channel type ICDs depends on the length of the channel and the diameter of the opening.

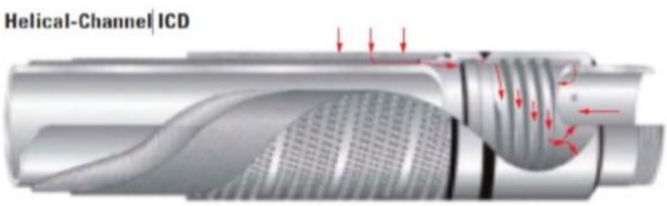

Figure (3): Helical-channel type ICD (Shevchenko, 2013)

Advantages of channel type ICDs

The main advantage of channel type ICDs is that they generate lower flow velocities, hence reduce the erosion and plugging of equipment.

Disadvantages of channel type ICDs

the disadvantage is that the restriction /pressure drop through the channel type ICD depends on the viscosities of the fluids, so when there is a big difference in viscosity between water and oil, the restriction of water will be reduced due to its lower viscosity hence the objective of reducing the water inflow will not be attained (Daneshy, et al., 2010).

ii. Orifice/Nozzle type ICD

Nozzle type ICDs shown in figure 4 provides the fluid restriction to generate a desired pressure drop. Fluid is forced to pass through a small opening (orifices) in a pipe to generate flow resistance. The pressure drop is generated due to the generated flow resistance.

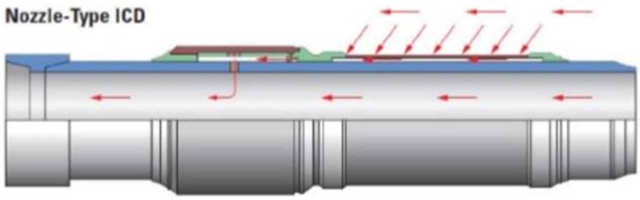

Figure (4): Nozzle type ICD (Shevchenko, 2013)

The advantage of Orifice/Nozzle type ICD is that they are simple to design and can be used in the reservoir which has a large variation in viscosity between water and oil; it can choke water easily since the pressure drop does not depend on the viscosity (Daneshy, et al., 2010). But the nozzle type ICDs are dependent on fluid velocity which makes them highly disposed to erosion from sand particles and less resistant to plugging (Fernandes, et al., 2009).

iii. Hybrid channel types of ICDs

The hybrid channel is the type of ICD which combine the restrictive, some friction and a tortuous pathway mechanism to create the pressure drop of the fluid flowing through the device. These types of ICD combine the technology of Nozzle type ICD and channel types ICD in order to mix the advantages of all two types (Zeng, et al., 2013).

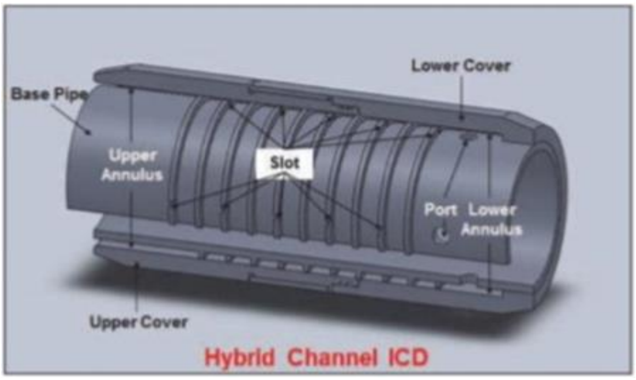

Figure (5): Section view Hybrid channel ICDs (Zeng, et al., 2013)

2.2 Autonomous Inflow Control Devices (AICDs)

To provide more limitation of unwanted fluid (gas and water) along horizontal well, a new developed Autonomous ICD (AICD) has been proposed.

Features of AICDs:

The AICDs have many features including, they are operated autonomously, are not operated from the surface, before water/gas breakthrough AICDs function as a passive ICD while after gas/water breakthrough they have an additional restriction to unwanted fluids (gas and water), the installation of AICDs does not require intervention, each device works independently for accurate response to the reservoir, they allow injection of the reservoir, treating fluids and self-regulating depending on produced fluids (Halliburton, 2020).

Types of AICDs

i. ER-AICD type:

The ER-AICD is the type of AICD which use the electrical resistivity mechanism depicted in Figure 6. The AICD has two flow paths, namely main flow path which most of the fluid is passing and secondary flow path. The secondary flow path contains a sensor which detects viscosity of the fluid and sends an electrical signal to a solenoid which has an electromagnetic effect to open the valve of the main flow path for highly viscous fluid such as oil and close valve of the main flow path for low viscous fluid such as water and gas.

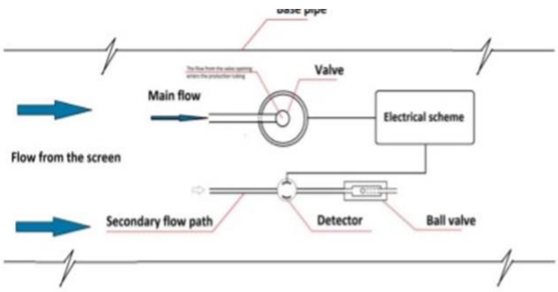

Figure (6): ER –AICD system mounted in the production pipe (Jadhav, et al., 2017)

The main disadvantages of ER-AICD are not working in the high temperature environment since they consist of electronics devices and valves which are affected by temperature.

ii. Fluidic diode type

The fluidic diode type AICD also is called Equi-flow AICDs. This kind of AICD does not contain a movable part; it is functioning depending on the changes of fluid properties (James, et al., 2017). It is functioning by directing different fluids to different pathways depending on the properties of fluids as shown in figure (7).

Important fluids properties for the AICD to operate are density, viscosity and flow rate. The inertial forces are created by densities and flow rates of the flowing fluids, whereas viscosities and flow rates create the viscous forces. AICD is working by balancing inertia and Viscous forces in the fluids.

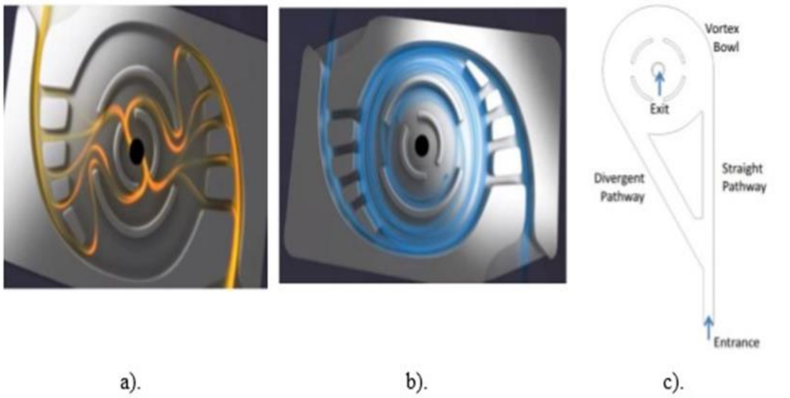

Figure (7): Fluidic diode type AICD. (a) The streamline for oil flow and (b) The streamline for water and (c) Simplified model of AICD (James,et al., 2017; Fripp, et al., 2013)

iii. RCP-AICD

Figure (8) shows the RCP-AICD, another kind of AICD used to restrict fluids of low viscous fluid such as water and gas. The AICD uses the Bernoulli principle which is expressed in the following equation:

$$P_1 + \frac{\rho v_1^2}{2} = P_2 + \frac{\rho v_2^2}{2} + \Delta P_{friction}$$

The low viscosity fluid is passing through AICD with the higher speed than high viscous fluid. The higher speed of fluid causes the pressure at the flowing side of the disc to be lower compared against the pressure on the other side of the disc (Stagnant pressure). The pressure difference on these two sides causes the disc to move towards the seats and reduce the flowing area. When the flowing area is reduced the unwanted fluid production (gas and water) will also be reduced.

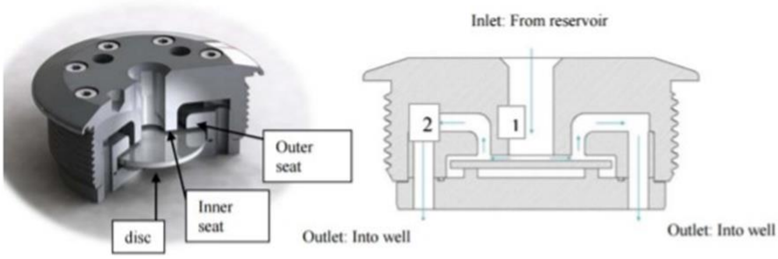

Figure (8): RCP valve (AICDs) (Halverson, et al., 2012)

Advantage and disadvantage of AICDs

There are many benefits of AICDs including facilitation of oil recovery, maximizing oil recovery, and reducing unwanted fluid production (delay water and gas production).

The main disadvantages of AICDs the installation of AICDs in the well with small pressure loss from the toe to the heel may lead to lower oil recovery compared to open hole (Jadhav, et al., 2017).

2.2 Simulation model

The simulation was done using **Petrel 2016.3** version and ran using the Schlumberger Eclipse 100 simulator. The main benefits highlighted by the simulations runs performed are the water breakthrough management and production optimization capabilities obtained by adopting Smart well Technology. The value proposition of the technology is measured using three key parameters; reduced water production, economic oil production rates.

2.3 Model description

The reservoir model is a carbonate reservoir based on the Libyan oil field located onshore in the north of Libya (Sirte basin). The heterogeneous properties of the model make it an ideal candidate for simulating intelligent well operations.

The reservoir is one region with a water oil contact (WOC) of 8450 ft. The average reservoir pressure is 3000 psi with initial water saturation of %35.

Table 1: Reservoir properties

Field property	Value
Global Dimensions	
Model length (DX)	10000ft.
Model width (DY)	10000ft.
Reservoir top	8315 ft.
Model height (DZ)	166ft.
Grid cells (NI x NJ x NZ)	50*25*10
Total number of grid cells	12500
Average Porosity	0.17
Average Net To Gross NTG	0.95
Average PERMX (md)	2000
Average PERMY (md)	1820
Average PERMZ (md)	830
Average Initial Reservoir pressure (psia)	3000
Average Initial Water Saturation	0.35
Water oil contact – WOC	8450
Formation type	Lime stone
Drive mechanism	Water drive

2.4 Fluid Properties Description

This section deals with fluids filling the reservoir rocks. Oil, gas and formation water properties are covered under pressure- volume -temperature section PVT, the black oil model is the most common where the oil properties such as formation volume factor Bo, solution gas oil ratio Rs and oil viscosity .Table(2)explains PVT properties.

Table 2: Reservoir fluids properties

Volume formation factor(RB/STB)	1.262
Oil gravity (API)	35.5
Saturation pressure psi	2450
Solution GOR (SCF/STB)	350
Oil viscosity (cp.)	1.4
Water salinity ppm	220000
Water viscosity (cp.)	0.48
GOR @bubble point (scf/stb)	500

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2.5 Well geometry

Table (3) Well geometry

Initial completion	**6/4/2012**
Well datum(ft.)	8380
Horizontal section (Open hole)(ft.) $6_{1/8}$	8806-11002
KOP (ft.)	8404
Well status	closed
Tubing size(inch)	3½

2.6 Simulation cases

i. History matching

A historical case simulation model run was performed to validate the model. The control mode and constraints for all wells were set under the SCHEDULE section with the producers operating under a maximum liquid production rate of 2000 STB and minimum BHP of (2500 psi). The wells produced continuously since January 2017 to August 2019.

ii. Without ICD completion

The second simulation run was performed to model the reservoir behavior without intelligent technology. In this case, the wells were operated under the same constraints as the base case model. However in addition, the producers were set to a maximum water cut of 50%.Production started in September 2019 to January 2029 to predict the behavior of wells without any ICDs.

iii. With ICD completion

Unlike the historic case and without ICD case, the intelligent modifications employ down hole control of each segment. The goal is to optimize production by accelerating and maximizing oil production, while minimizing water production. Down hole control was simulated by installing the Inflow Control Devices (ICDs).as shown in figure (9)

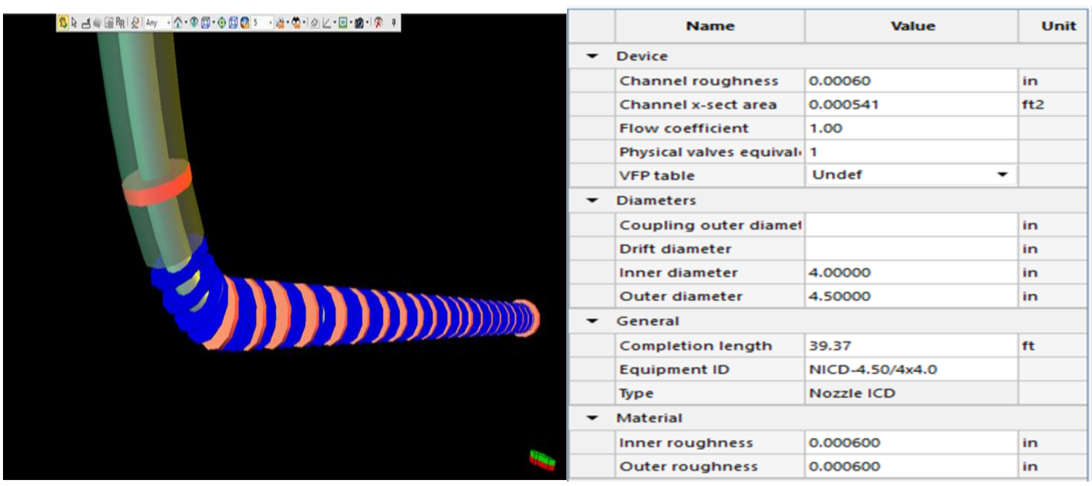

Figure (9) well X2 with ICDs and parameters

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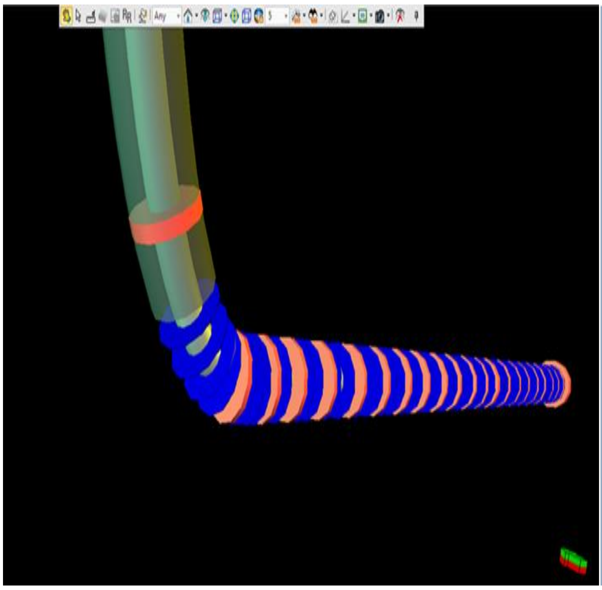
iv. With AICD completion

In this case AICD completions were run instead of nozzle ICDs as shown in figure (10) and many parameters were changed to compare the results with nozzle ICDs.



Name	Value	Unit
Device		
AICD strength	0.00019	
Critical water fraction	0.4	
Flow rate exponent	2	
Flow scale factor	1	
Flow scaling method	Use 'Flow scale factoı	
Fluid density	62	lbm/ft3
Fluid viscosity	1.65	cP
Gas flowing fraction d	0.5	
Gas flowing fraction vi	0.5	
Max viscosity ratio	6	
Oil flowing fraction de	1.1	
Oil flowing fraction vi:	1	
Physical valves equival	5	
Transition region widtl	0.05	
VFP table	Undef	
Viscosity function expc	1.5	
Water flowing fractior	0.55	
Water flowing fractior	0.5	
Diameters		
Coupling outer diamet		in
Drift diameter		in
Inner diameter	4.00000	in
Outer diameter	4.50000	in
General		
Completion length	39.37	ft
Equipment ID	AICD_EQ2	
Type	Autonomous ICD	
Material		
Inner roughness	0.000600	in
Outer roughness	0.000600	in

Figure (10) well X2 with AICDs and parameters

3. Results and discussion

Results of interest are the relation between oil and water production and well completion strategies.

i. History match case result

To validate the model by comparing the results with real observed data (oil production, water production and water cut) as shown in figure (11) the well was historically matched

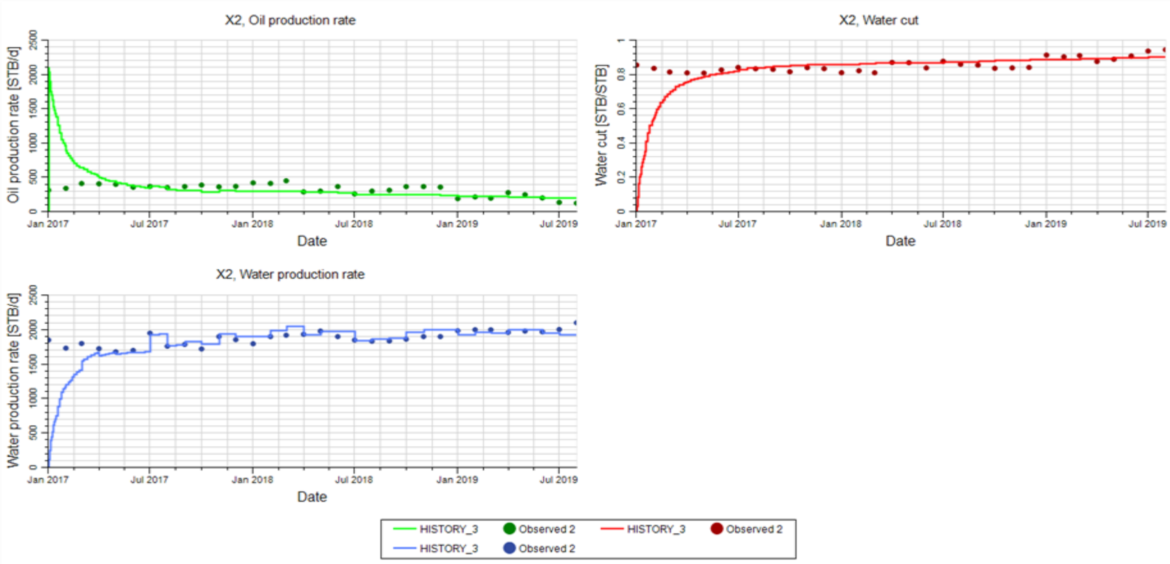


Figure (11): Production history match for well X2

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ii. Without ICD case (open hole completion)

- **Oil production**

Oil production was very low and reached to 100STB/D as shown in figure (12)

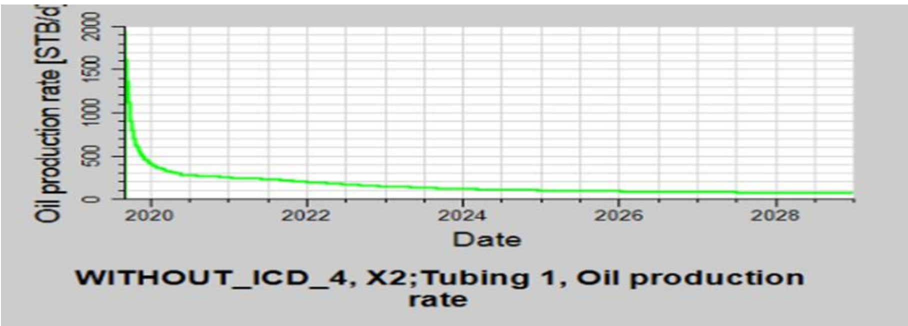

Figure (12): Oil production for well X2

- **Water cut &production**

Water cut was high and reached to about 98% and more water was produced as shown in figure (13) and the water production rate was high as shown in figure (14).

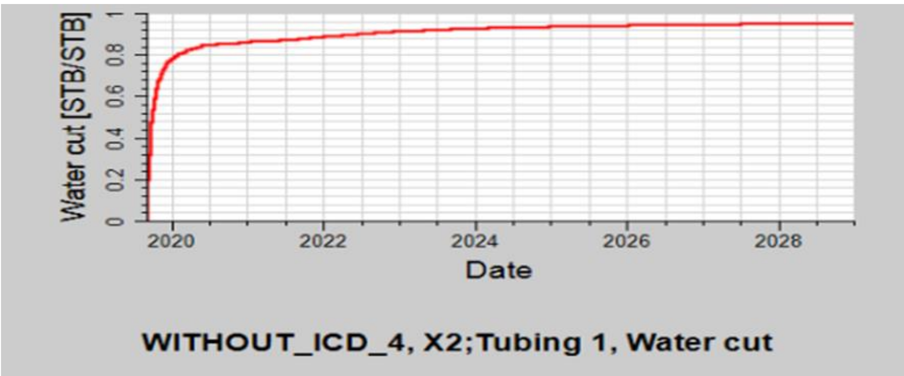

Figure (13): Water cut for well X2

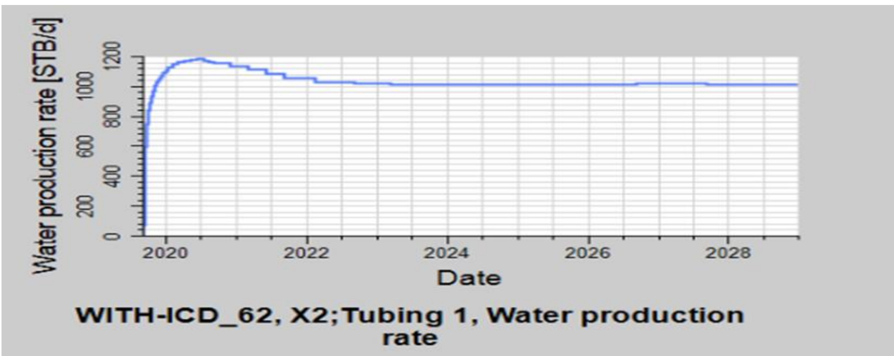

Figure (14): Water production for well X2

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iii. with ICD completion

- **Oil production**

Oil production was optimized and increased to 900 STB/D with ICD completion comparing with open hole completion as shown in figure (15).

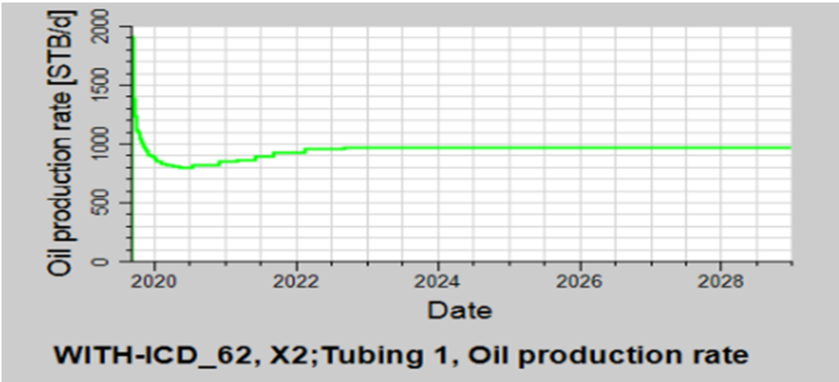

Figure (15): Oil production for well X2

- **Water cut & production**

The performance of ICDs was expressed by the restriction of water inflow in the wellbore. Figure (16) shows the results of produced water (WC) Water cut decreased to 50% where the water production decreased.

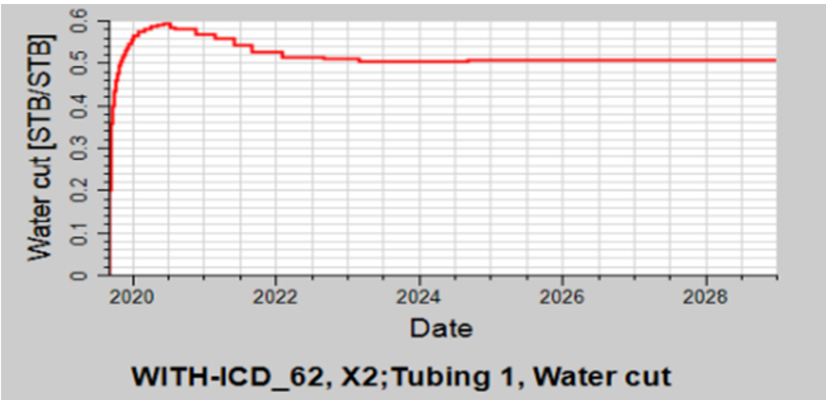

Figure (16): Water cut for well X2

iv. With AICD completion case

i. Oil production

Oil production rate was successfully increased to 1200 STB /D and optimized with AICD completion as shown in figure (17).

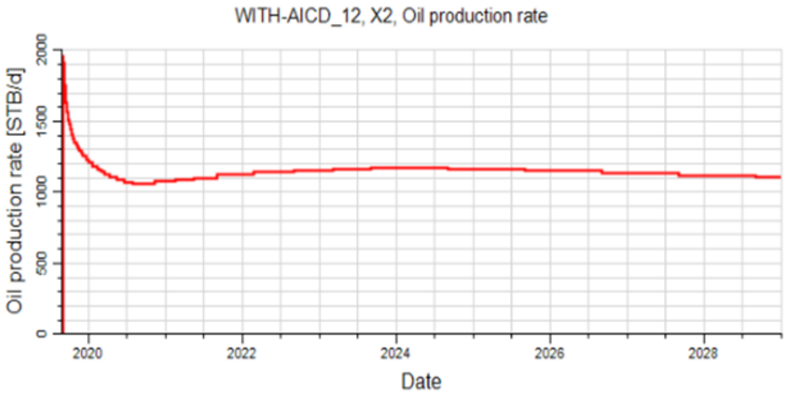

Figure (17): oil production for well X2

ii. Water production & water cut

The performance of AICDs was expressed by the restriction of water inflow in the wellbore. Figure 4.19 shows the results of produced water (WC) Water cut decreased to 40% where the water production decreased as shown in figure (18).

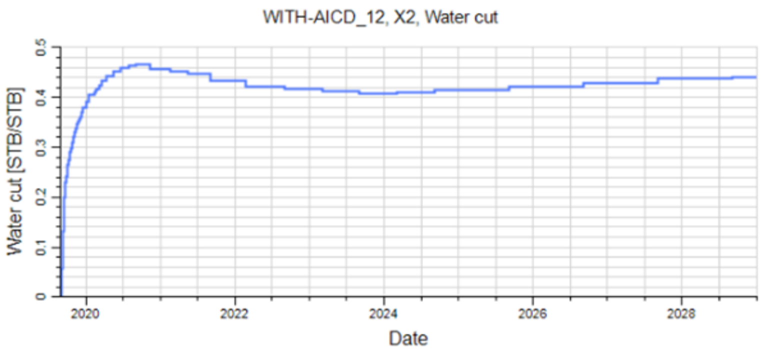

Figure (18): Water cut for well X2

4. Conclusion

• Reservoir model with a horizontal well has been built by Petrel 2016 and run in the Eclipse simulator for different completions including the open hole and ICDs completion.

•The installation of DFCs (ICDs, and AICDs) in the horizontal well increased the oil recovery (RF) significantly, however the installation of Autonomous ICDs (AICDs) in the horizontal well perforating the oil reservoir increased more oil when compared against the passive ICDs, and this had been proved by the results of the reservoir model.

• Well X2 whereby producing with AICDs completion increased the RF by 257% when compared against the open hole completion, while producing with the ICDs completion increased the RF by 192% when compared against the open hole completion.

• Well X2 in which after nine years open hole had a WC of 95%, a well completed with AICDs had a reduction to 42% WC, and a well completed with ICDs had a reduction to 50% WC when compared to the open hole.

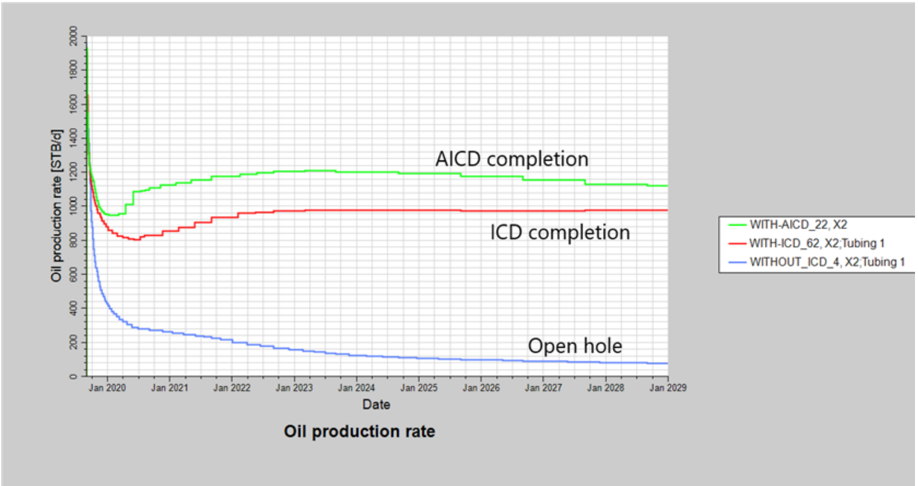

Figure (19): Oil production of well X2

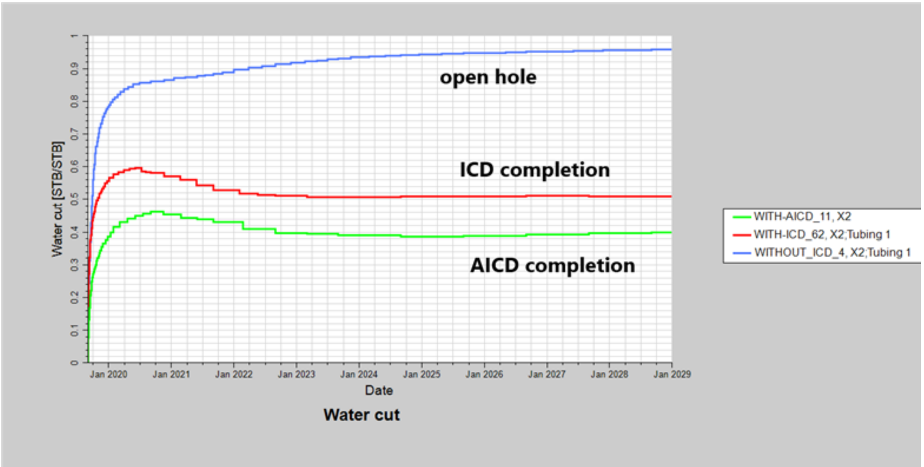

Figure (20): Water cut for well X2

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