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Applications of inflow control technologies in horizontal well in Bouri Oilfield, Libya

*Saleh hamid & Elnori Elhaddad
Department of Petroleum Engineering, Faculty of Engineering, Bani-Waleed University
*Corresponding author: Saleh.f.hamed@gmail.com

Abstract One of the main challenges facing fluids of production from horizontal wells is an irregular influx along a horizontal section because of various drawdown across the wellbore due to heterogeneity in permeability. As a result, horizontal wells suffer from early water or gas breakthrough and declining recovery factor of hydrocarbons. To avoid this problem lower completion becomes more reservoir management-oriented by installing inflow control devices (ICDs) which used to balance influx along the horizontal well section, increase sweeping efficiency and improve oil recovery . This paper focuses on the Inflow Control devices (ICDs) to identify the advantages of ICD completion, ICD applications types, what their strengths and weaknesses are, limitations of this technology and recommendations for choosing it, including the Libyan Case Study of Bouri Field in Libya. In the absence of Inflow Control devices, the gas and water flow influence oil well production, causing a reduction in oil rate, increased water and gas rate cause further oil recovery reduction, and limitations in the surface's capacity of water and gas treatment facilities.

Keywords: gas and water breakthrough, horizontal well, inflow control devices, applications.

تطبيقات تقنيات التحكم في التدفق في البئر الأفقي

*صالح فتح الله حامد و النوري الحداد
قسم هندسة النفط–كلية الهندسة–جامعة بني وليد، ليبيا
*للمراسلة: Saleh.f.hamed@gmail.com

الملخص أحد التحديات الرئيسية التي تواجه موائع الإنتاج من الآبار الأفقية هو التدفق الغير منتظم على طول المقطع ألافقي بسبب الانحدار المتنوع عبر حفرة البئر بسبب عدم التجانس في النفاذية. نتيجة لذلك ، تعاني الآبار الأفقية من اختراق مبكر للمياه أو الغاز وانخفاض عامل استخلاص النفط. لتجنب هذه المشكلة ، يصبح الإكمال المنخفض أكثر توجهاً نحو إدارة المكمن عن طريق تثبيت أجهزة التحكم في التدفق (ICDs) التي تستخدم للتحكم في التدفق على طول قسم البئر الأفقي ، وزيادة كفاءة الكنس وتحسين استخلاص الزيت. تركز هذه الورقة على أجهزة التحكم في التدفق (ICDs) لتعريف مزاياالاكمال وأنواع تطبيقات اجهزة التحكم في التدفق ICD ونقاط القوة والضعف فيها والقيود المفروضة على هذه التقنية والتوصيات لاختيارها ، بما في ذلك دراسة الحالة الليبية في حقل بوري في ليبيا. . وفي حالة عدم وجود أجهزة التحكم في التدفق ، يؤثر تدفق الغاز والماء على إنتاج آبار النفط ، مما يتسبب في انخفاض معدل النفط ، وزيادة معدل المياه والغاز ثم يؤدي إلى مزيد من تقليل استرداد النفط ، ومشاكل على السطح لمنشآت معالجة المياه والغاز .

الكلمات المفتاحية: بئر أفقي، أجهزة التحكم في التدفق ICDs، اختراق المياه والغاز، التطبيقات.

Introduction

The general idea for a smart completion (smart achievement), Oil or Gas wells drill regularly, where the main part to distinguishes them and give them the characteristic of intelligence is the method of completing wells and equipment that download during completion, whether vertical or horizontal, where they equip with modern technology devices that improve the performance of the production wells and can control the equipment for completion by an electric method or Hydraulics together, bottom hole gauges, temperature sensor, density, and viscosity sensor.

In which case do we need smart well technologies: First: In the production wells, improving the productivity of the well to control the production of the layers due to different permeabilities and reducing the high production of water. Second: In water injection wells where we need to control the injected water, so it does not go to the higher permeable area more than the low permeable area through the so-called zonal completion.

There are several ways to complete the smart well, and the equipment that lower into the well, and these methods are:

1. Plugs and Packers.
2. Zonal Isolation (Completion).
3. Mechanical External Casing Packers MECP.
4. Inflow Control Valves ICV.
5. Inflow Control Devices ICD.
6. Autonomous Inflow Control Valves AICD [1].

Inflow control technology is a technology for the production of oilfields and is also more advanced and expensive. The sensors and valves installed down-hole to enable easy monitoring and control. The valves regulated remotely by the conditions perceived by the sensors [2].

Well-Dynamics was the first smart well implemented at Snorre oil field in the North Sea by Saga Petroleum in 1997. Since then, hundreds of smart well systems implemented around the world [3].

To optimize reserves recovery through the use of h orizontal wells, the fluid requires control through the reservoir.

The approach of inflow control devices is progressively common to use it and reducing the amount of bypassed reserved [3].

Inflow Control Devices (ICDs) has the potential to improve the sweep efficiency and clarity of a mature well completion technology that provides uniformity of the inflow profile by restricting high specific inflow segments while increasing inflow from low productivity segments [4].

The produced fluids get in the completion by means of screen and flow in the annular space between the screen and the unperforated base pipe. The restriction can be in form of channels or nozzles/orifices, but irrespective the ability of an ICD to balance the flow along the well length is due to the variation in the physical laws dominating the fluid flow in the reservoir and through the ICD. Liquid flow in porous media is usually laminar, as a consequence the relationship between the flow velocity and the pressure drop is linear. By contrast, the flow regime through an ICD is turbulent, resulting in the relationship between quadratic velocity/pressure drop [5].

Because that, horizontal wells drilled at an angle, there usually occur problems of gas and water conning at the heel of the well due to frictional pressure drop a variation of the permeability along the well, and or pressure drop along the completion's flow path due to friction losses usually known as "heel-toe effect." It has found from previous researches that the installation of Inflow ICD relieves such problems. ICD in most cases installed as a part of the sand face completion hardware. It proposed in the early 90s as a solution to the above problems associated with horizontal and multilateral wells.Inflow Control Devices are getting more and more popularity and applications in different reservoirs [6].See **Fig. 1**,**Fig. 2**, **Fig. 3**, **Fig. 4**, **Fig. 5**, and **Fig.6**,for more information and to show various types of Inflow Control Devices and Intelligent Completion Valves.

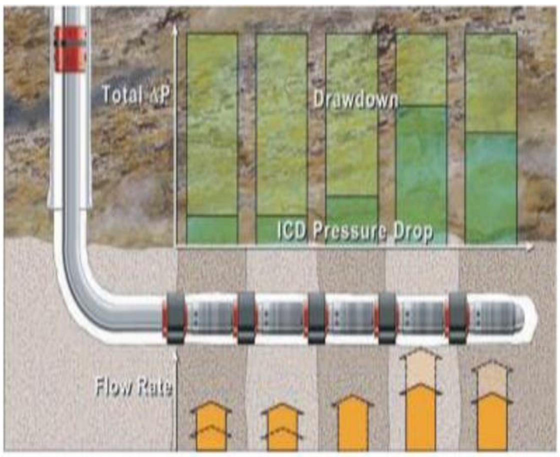


Fig. 1:ICD segments illustrating the pressure and flow rate profile created by the ICD [6].

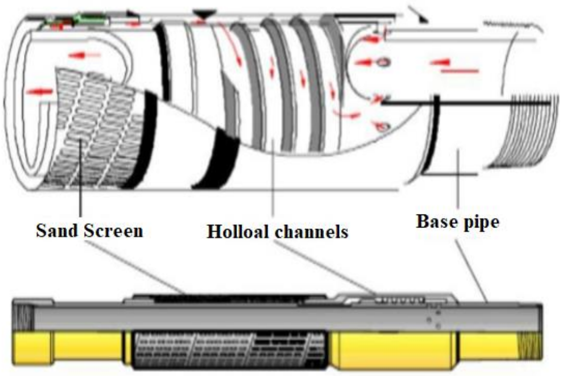


Fig. 2: The Channel type of ICD [6].

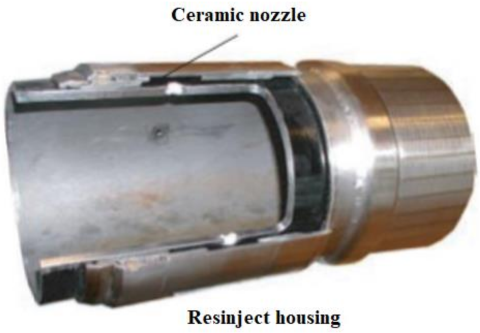
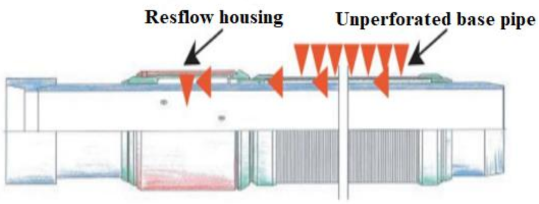


Fig. 3: Housing unit section of Nozzle type ICD [6].



NO risk plugging-nozzles at least 10 times larger than the screen slot opening

Fig. 4: The flow pattern in Nozzle ICD [6].

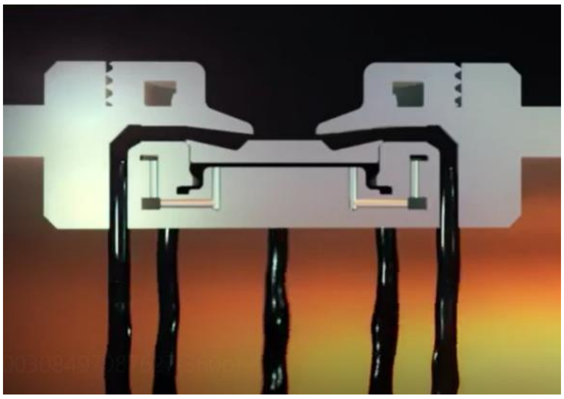


Fig. 5: Oil producing from ICV [9].

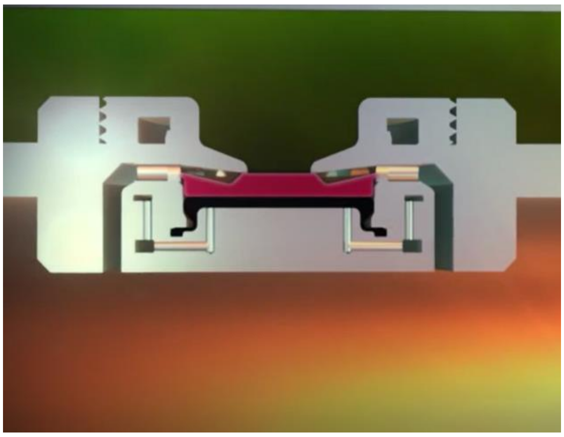


Fig. 6: ICV shut-off in gas production [9].

Properly combined with well segmentation, the ICD completion benefits include pressure profile change along the wellbore, minimizing horizontal well heel-to-toe effect, the balanced influx from high and low productive zones, reduction of gas and water coning [7].
The ICD's resistance to flow depends on the dimensions of the installed nozzles or channels. This resistance often refers to as the ICD's "strength". It sets at the time of installation and cannot adjust without recompleting the well [5].
The Channel type ICD is excellent in corrosion eradication and has a limitation in that it cannot adjust at the rig site and is sensitive to changes in fluid viscosity [6].
The nozzle type ICD has a prefabricated number of nozzles ranging from 1 to 4 inches, for each section. The pressure drop achieves when the fluid enters through the nozzle.This is according to Bernoulli's law.
Unlike the channel type ICD, the nozzle type ICD is adjustable at the rig site and the pressure drop is insensitive to fluid viscosity although it depends on the fluid viscosity [6].
Inflow Control Valves (ICV), It is valves being designed to shut-off during duty, unwanted fluid inflows at completion joints [8]. In the individual sections the Passive Intelligent Completion Valves (ICV) are installed for the well, generated in the annulus with the help of inflow control valve(ICV) and zonal isolation packers. The devices will benefit from an effect of self-change of flow variations along the wellbore. It delays mostly the water breakthrough and sometimes prevents the gas breakthrough. It improves the sweep efficiency by balancing the fluid flow at the upstream point [9].

A Choice Between Inflow Control Technologies.
The design of an advanced completion for a particular field application often includes feasibility studies on both ICV and ICD. The choice between these two technologies is not always obvious and the need for general method on making this choice recognize by the petroleum industry [5].
When selecting ICD's, it should keep simple. A more complicated design ICD can theoretically work better with multiple structure types and functions combined, but down-hole with dynamic conditions of fluid type, density, and viscosity, reservoir pressure and temperature, the flow condition is a function of time. When one section of ICD fails (plugging, erosion, or other mechanical causes), it well directly impacts the flow of the well [9].
The application areas of the ICV and ICD technologies have developed so that they overlap.
K. H. Henriksen et. Al, 2006. They used ICD completion to yield a higher recovery of oil and more sand control, the improved sand control results from screen system inflow distribution functionality. The channel type of ICD was used, it gives a high accurate of flow resistance profiles at low flow velocities, two simulations are running, one without ICD and one with ICD, the case of ICD gave an increased oil production of 200,000 stated in standard cubic metres (**Sm³**) in 17 years, the gas breakthrough delayed by approximately 100 days [10].

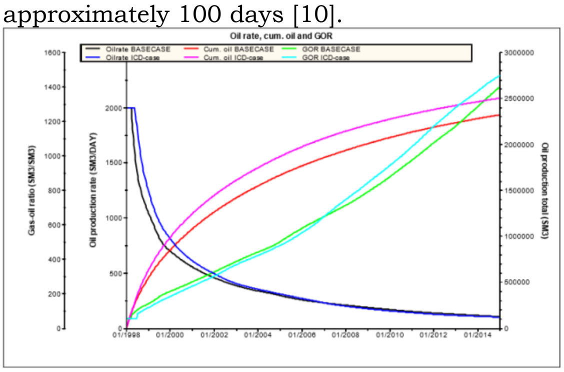


Fig 7: cumulative oil and GOR production with ICD and without ICD vs. time.

P Fernandes et al .2009, investigate how and when the ICD is used, a channel type of ICD was used, an integrated analysis method of (inflow) and (outflow) is used to generate the flow profile of a horizontal well, the horizontal well flow model with a black oil reservoir simulator (Eclipse) is used to calculate the relationship between the flow rate and pressure distribution.
Al arfi et al., (2008), discussed the case where the reservoir has a high permeability and long wellbore to represent the high flow rate condition, also, simulate the well performance with ICD and without ICD, for this case the well performance [12], are shown in Fig 8.

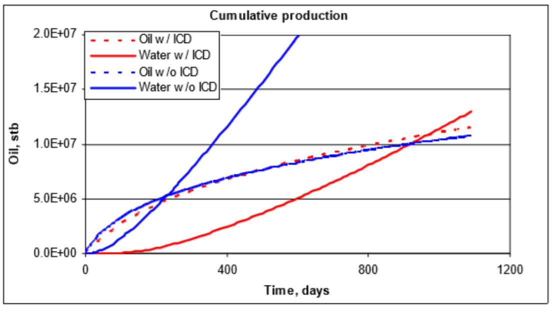


Fig 8: Cumulative production

The ICD's improves the flow condition, the oil flow rate distributed evenly, and the water production decreases [8].

Main Functions of ICVs and ICDs

1. **Remote control** - ICVs deliver reservoir and production management advantages giving more flexible field development, increased value of information، improved clean-up etc.
2. **Flow conduit diameter** - The ICV's reduced inner flow conduit diameter increases the "heel-toe" effect compared to an ICD for comparable borehole sizes.
3. **Multilateral well applications** - ICVs, unlike ICDs, can only install in the well's mother bore because of limitations of control umbilical technology to connect to both the mother bore and laterals at the junction.
4. **Design, Installation procedure complexity, Cost and Reliability**–ICV Technology is more complex; hence ICDs have the advantage in terms of simpler design and installation, and lower costs. Although the simplicity of the ICD would imply greater reliability, there is little or no available operational data to support this, particularly when considering the greater likelihood of ICD plugging, due to scale, asphaltenes, waxes, etc., compared to ICVs.

Fig.9: ICV vs. ICD comparison framework for oilfield applications [5].

ICD Applications Types

Different ICD configurations and scenarios normally investigated to arrive to an optima completion solution for a particular well and reservoir. This sensitivity analysis determines nozzle size, number and location along the completion and to test a need for well segmentation / zonal isolation [10, 11].

The Methodology

The methodology of this paper is a qualitative method. It provides descriptions of Inflow Control devices and information about beliefs, opinions and relationships with other tools.

According to previous studies of ICD devices applications, and analysing what have presented by researchers. This work compared and identify the similarity and the differences and focuses on the Inflow Control devices (ICDs) to identify**,** the advantages of ICD completion, ICD applications types, what their strengths and weaknesses are, limitations of this technology and recommendations for choosing it, including the Libyan Case Study of Bouri Field in Libya. The development of this research to achieve and optimize best results in the future.

Review Case Study

1. Libyan Case Study of Bouri Field

The field discovered in the 1970s, and subsequently developed with two platforms (DP3 and DP4) and 82 development wells. Since start-up, oil production often affects by high water cut and gas-oil ratio due to conning and fingering phenomena through the extensive fracture network of this carbonate reservoir. The operator was establishing an advanced method of controlling gas and water encroachment in a fractured carbonate reservoir characterized by high vertical permeability. The Bouri field has two horizontal wells, drilled at the end of 2009, where ICD completion technology was implemented.

Reservoir Challenges of Bouri Field

Bouri field is a carbonate reservoir of fair horizontal permeability, and high vertical permeability, the field still produces under primary recovery mechanism, is above bubble-point pressure, and supported by strong bottom and edge water drive and strong gas cap drive, the reservoir has a high content of H_2S and CO_2.

1. ICD functions and operations

Reservoir fluids enters the screen and flows through the ceramic nozzles, when the fluid enters the nozzles, the potential energy transforms into kinetic energy, which absorbs in the main flow through the base pipe, thus resulting in a pressure drop between the annulus and the tubing.

Different nozzle sizes are available, making it possible to design ICD completion to the required well geometry and flow rates, the ICD nozzle setting can be pre-set, or alternatively may perform on-site making the system very flexible for real-time operations use [7].

2. Material technology

The Bouri Field produces with a high content of H_2S and CO_2, needing nickel alloy metallurgy to overcome the severity of the environmental conditions. All equipment ran in hole, including ICD and base-pipe, built in Inconel 825 or 28Cr-32Ni materials, including inserts for all ceramic nozzles used.

3. Nodal analysis simulation

Prior to ICD installation, sensitivity constrains to run nodal analysis should determine or agreed upon allowing to define the completion layout: nozzle number and sizing for each ICD segment, as well as minimum number and location of ICD

completion segments / compartments or zonal isolators.
In our case the wells are open hole, and completion with ICD's tested for various parameters. The results affected by permeability variations in the reservoir and fractures, thus showing that a proper time solution requires to realize the best final design.
Wellbore hydraulic simulation was done in both injection and production cases, in production case, the results shows good potential in decreasing total Gas-Oil Ratio throughout gas-breakthrough, in injection mode, the results show good injection performance, thus achieving the main goals of using ICD's.
The ICD nozzle configuration adjusted at the well site before running the final completion.
The main challenge in Bouri, beside the heel-to-toe effects, was the strong gas cap above the oil column, expected to have an important impact on production performance with time.
The final design of the ICD system was finally compared with open hole (without ICD) scenario, assuming breakthrough in various parts of the well. The ICD case showed better management of the well, the GOR reduced to almost 2/3 in the case of heel gas breakthrough.

4. Dynamic model simulations

A well with ICD technology first modelled using the hydraulic simulation software, 3D modelling offers additional advantages to evaluate ICD performance as a function of the changing reservoir fluid characteristics, viscosity, density and velocity through well life.
In this particular, the scenarios generated by hydraulic nodal analysis model are integrated into reservoir simulator. The inflow and outflow performance used to generate the flow profile of a horizontal well and additional frictional pressure drop created by the ICD completion with time, to estimate total oil recovery and develop the final design scenarios.
In order to evaluate the potential upside of the ICD design, the two Bouri horizontal wells simulated in Full Field Reservoir Model (FFM), The design procedure consisted of several phases. Hydraulic simulator first used to evaluate different ICD scenarios.
The next step was to simulate the nozzle size configurations to assess the ICD field performance in time, as extreme caution is required to avoid any over-restriction to oil production, the nozzle configurations selected for the dynamic simulation were:

i. **Configuration A:** 4 nozzles per ICD joint (joint length 31.5 ft).
ii. **Configuration B:** 4 nozzles with about half of the area of **configuration A** per ICD joint (joint length 31.5 ft).

A total of 69,120 cells introduced into full field reservoir model (FFM) with an average cell size of (48 x 48 x 28) ft for well#1 and well#2.
The final scenarios were done with nozzle selection recommended by the hydraulic nodal simulator, and constrained by the field and network controls to investigate the estimated benefit of the ICD completion systems:

i. Open hole case: FFM with segment/branch structure and local grid refinement near wellbore for well#1 and well#2.
ii. ICD case: FFM with ICD completion in well#1 and well#2.

The FFM for both cases was run from 2009 for 10 years.

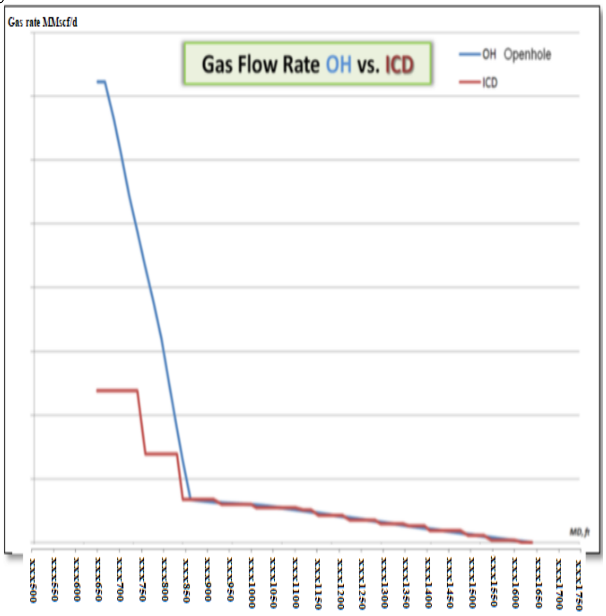


Fig. 10: Cumulative gas production (from the heel)

The advantages of ICD completion

presented where open hole case has early gas breakthrough at the heel of the well, while ICD's are minimizing the gas coning.
The figures below show that the ICD options and oil production over the open hole case in both wells, representing a production increase of 51% for well#1 and 12% for well#2 respectively

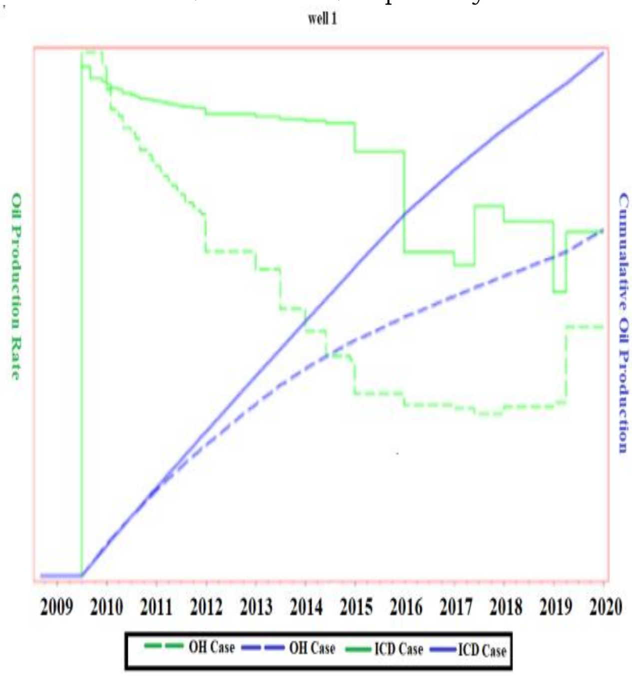


Fig.11: Well#1 oil rate and cumulative oil production.

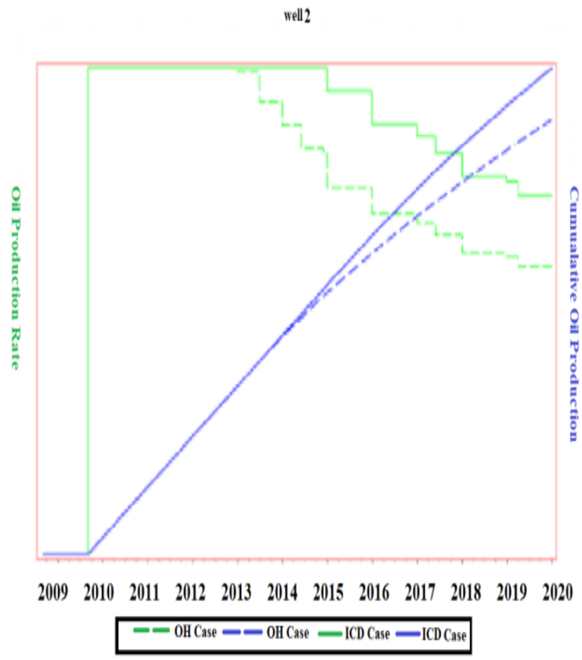


Fig. 12: Well#2 oil rate and cumulative oil production.

This is because the reservoir drawdown equally distributed, and the entire wellbore experiences inflow rather than mainly just portions toward the heel.

Without ICD's the gas flow dominates well production, causing reduction in oil rate as shown in figures below, increased gas rate causes a further oil recovery reduction due to limitations in the capacity of the surface gas treatment facilities. The use of ICD reduces the gas the total gas production about 10% in the well#1 and 19.5% in the well#2 comparing to the open hole case [7].

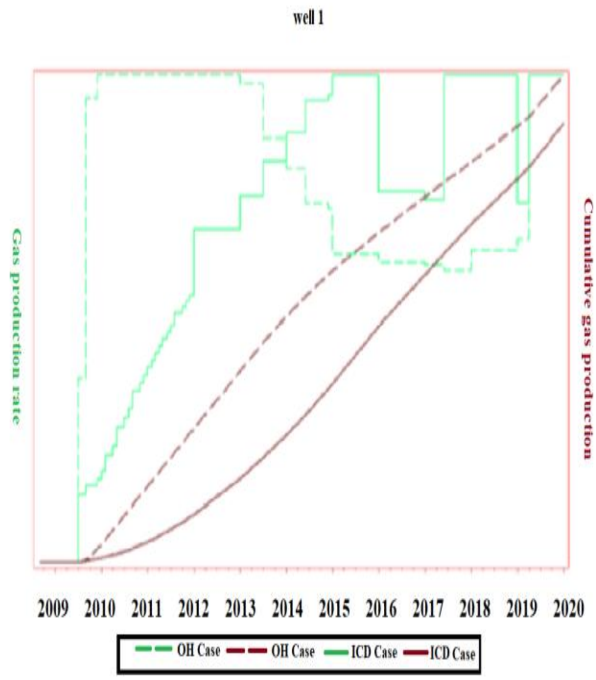


Fig. 13: Well#1 cumulative gas production and gas production rate.

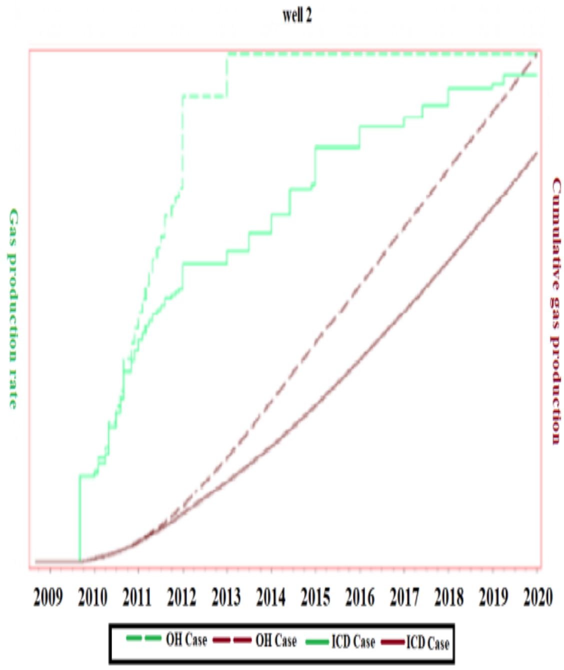


Fig. 14: Well#2 cumulative gas production and gas production rate.

Results and Discussion

The main objective of this study was to identify the ICD applications in terms of production and pressure distribution control, also, it deals with the idea of materials selection suitable for applying according to the reservoir conditions in terms of the equipment resistance to the produced fluids (the material selection has done in the presence of some sour gas such as CO2 and the H2S). Considering that this study Conducted on a carbonate reservoir, thus the need to use sand control equipment is considered unimportant in contrast to the experiment referred to reference [9], where the ICD was used with the control equipment of sand production to achieve the best performance of the wells by controlling sand and gas production.

Through studying the previous case studies, was distinguished that at the beginning of the use of the ICD, gas production significantly controlled, in exchange for an increase in oil production, but after a period the gas production increases at high rates, this increase in gas production because of several reasons, the most important of which are:

1.Producing high quantities of oil compared to gas.

2. Reservoir pressure decline over time, as it can producegas at low pressures.

3. Geological reservoir and permeability distribution through it.

4.Poor performance of the device due to weathering caused by the flow of fluids through it or because of corrosion caused by the production of sour gases such as H2S & CO2.

5.The gauges and sensing probs used in the reservoirs can also get affected by the deposited wax especially in offshore wells

Conclusion

Early water and gas breakthrough cause reduction in potential hydrocarbon recovery in the absent of Inflow Control Devices and install these devices to enhance oil recovery.

The impact of an inflow control device on oil recovery is a function of time because reservoir conditions will change during the life of a well and this impact can be beneficial or detrimental to production during Poor performance of the devices

Without ICD's the gas flow dominates well production, causing reduction in oil rate as shown in figures below, increased gas rate causes a further oil recovery reduction due to limitations in the capacity of the surface gas treatment facilities. The use of ICD reduces the gas the total gas production about 10% in the well#1 and 19.5% in the well#2 comparing to the open hole case [7].

Recommendations

In order to achieve the best performance of the ICD, several factors must be taken into consideration, the most important of them

1. Taking into account the reservoir geology and performing the appropriate completion operations on this basis.
2. Choose the right device in terms of design based on reservoir conditions.

Abbreviations and Acronyms

(ICT): Inflow Control Technology
(ICD): Inflow Control Devices
(ICV): Intelligent Completion Valves
(FFM): Full Field Reservoir Model
(ICV): Inflow Control Valves

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