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Adaptation Study of C-AICD Water Control Completion for Horizontal Wells in Bottom Water Reservoirs

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Abstract: Horizontal wells are an important technology to increase the production by expanding the reservoir drainage area to improving the economic efficiency of oilfield development. However, there are some urgent problems in developing bottom water reservoirs in horizontal wells, the most prominent one is bottom water breakthrough. C-AICD absorbs the advantages of ICD (Inflow Control Device) and AICD (Automatic Inflow Control Device). In the early stage of production, it mainly reflects the characteristics of ICD, which can balance the production profile along the horizontal production section and slow down the bottom water breakthrough. In the middle and late stage of production, it reflects the characteristics of AICD, which can slow down the bottom water breakthrough. However, there is still a lack of practical and effective theory to describe the principle of C-AICD water control completion device. In this paper, a C-AICD water control completion production prediction model for horizontal wells in bottom water reservoirs is proposed, and the applicability of C-AICD water control completion device is carried out for the five influencing factors of crude oil viscosity, formation permeability, permeability grading, production allocation, and horizontal well length. The results show that the lower the crude oil viscosity and the shorter the horizontal well length, the lower the water content, and the formation permeability, permeability grading and production allocation have limited influence on the water content.

Keywords: C-AICD, Horizontal Wells, Bottom Water Reservoirs, Adaptation

1. Introduction

Horizontal wells are an important technology to increase the production by expanding the reservoir drainage area, thus improving the economic efficiency of oilfield development [1]. With the improvement of completion optimization technology and complex horizontal well borehole trajectory control technology, horizontal wells have unique advantages in developing bottom water reservoirs [2, 3]. However, there are some problems that need to be solved when developing bottom-water reservoirs in horizontal wells, and the most prominent problem is bottom water breakthrough. Bottom water breakthrough is caused by the pressure drop formed during the production, which drives bottom water breakthrough to the horizontal well injection site. During the extraction process, as the flow pressure at the bottom of the well gradually decreases, a pressure gradient in the lower part of the reservoir with a direction approximately vertical is formed. When the pressure drop formed during the production is greater than the gravity difference formed by the difference in oil and water density, under the action of the new pressure gradient, the water cones upward and the cone formed by the cross section of the oil-water interface perpendicular to the horizontal well direction rises in a ridge shape, eventually forming the breakthrough of bottom water. After the bottom water breakthrough, the horizontal well development has problems such as premature water at the heel of the horizontal wellbore, rapid rise of water content and sharp decline of well production, which seriously restrict the horizontal well to develop bottom water reservoir efficiently [4, 5].

In 2018, Michael Konopczyns and Tendeka [6] Inc combined an ICD and an AICD to design a C-AICD device that adds an ICD upstream of the AICD, and the small pressure drop generated by the ICD allows the device to respond to bottom water ridge entry and significantly limit the imbalance of the production profile. To verify its effectiveness in controlling bottom water breakthrough, the authors modeled the device and analyzed the performance of the C-AICD in producing oil with minimal pressure drop while maximizing bottom water breakthrough control. Simulation results showed that the C-AICD was effective in suppressing bottom-water breakthrough and could produce at optimal pressure drop and maximum rate in all zones of the well bore [7]. In 2019, Pan Hao [8] et al. carried out a study on the water control mechanism of the composite intelligent water control device C-AICD, and designed a composite water control screen tube consisting of an orifice plate type ICD and a floating disc type AICD, which absorbed the advantages of ICD and AICD, and mainly reflected the characteristics of ICD in the early stage of production, balanced the production profile along the horizontal production section, and slowed down the bottom water breakthrough; it reflected the characteristics of AICD are reflected in the middle and late stages of production, and the water is automatically suppressed according to the changes of fluid characteristics of high water content [9], as shown in Figure 1.

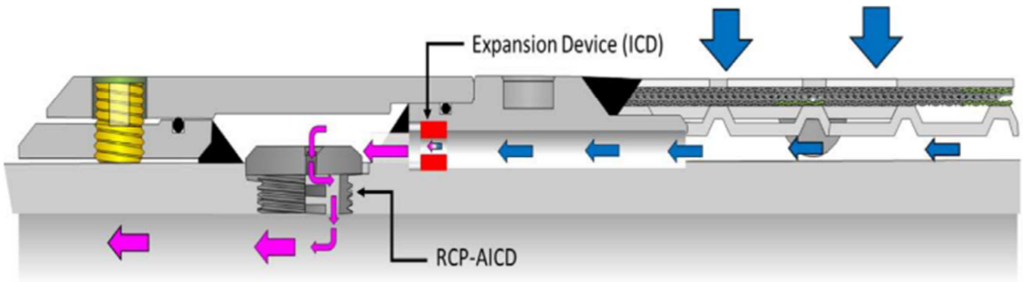

Figure 1. *Schematic diagram of C-AICD water control completion device.*

2. Production Prediction Model for C-AICD in Bottom-Water Reservoirs

In this paper, different flow models of reservoir seepage, AICD flow and wellbore flow are coupled together [10, 11]. The flow law of C-AICD water-controlled completion technology is shown in Figure 2, where the fluid enters the annulus between the casing and the wellbore through the reservoir, flows through C-AICD and finally flows into the tubing [12, 13]. When calculating the downhole production dynamics of horizontal wells in bottom water reservoirs, C-AICD is selected as the node for nodal analysis, and the flow from reservoir to bottom of well is divided into 2 parts, one part is reservoir-annulus-C-AICD inlet and the other part is C-AICD inlet - C-AICD outlet - bottom of well [14, 15].

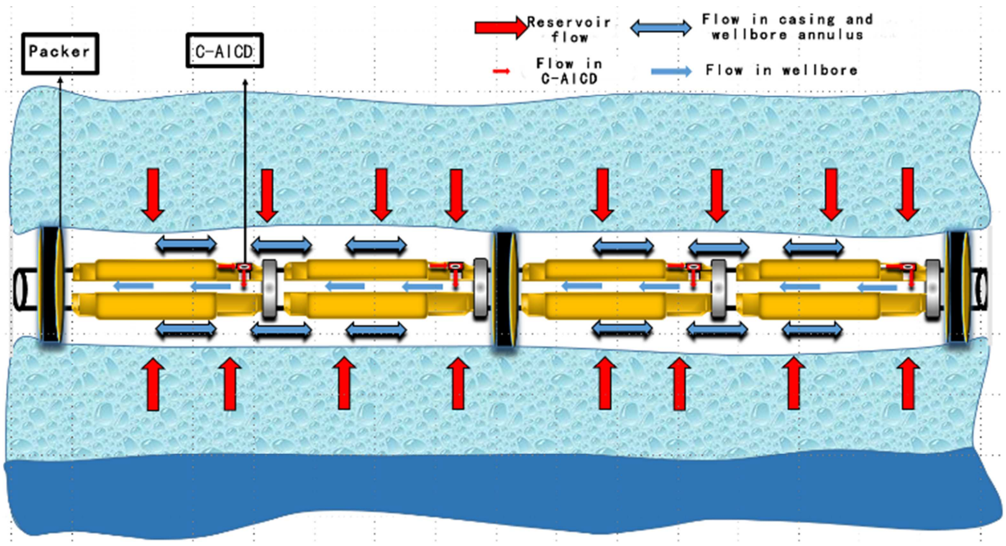

Figure 2. *Schematic diagram of the flow pattern of water-controlled completion technology.*

The packer separates the horizontal well into a number of relatively independent flow units, and in each flow unit, the fluid flow pattern is shown in Figure 3, where $P_{wb,out}=P_{wf}$, $P_{wb,in}=P_{annulus}$.

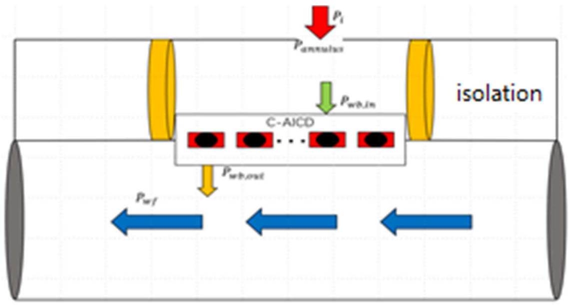

Figure 3. *Fluid flow law diagram.*

To facilitate the calculation, the reservoir grid step length along the horizontal well direction is set to the length of one AICD water control completion section, and the horizontal wellbore is similarly segmented according to the same length, which is processed by a fully implicit calculation method to construct a coupled model coefficient matrix to ensure all parameters are solved at the same time step [16].

In order to further investigate the effects of different fluid, reservoir and engineering factors on the water control effect and bottomhole flow pressure of C-AICD water control completions, was used to analyze the applicability of C-AICD water control completions for five influencing factors: crude oil viscosity, formation permeability, permeability grading, the horizontal well length and production allocation The analysis was performed using the constant production method, with the production allocation set at 1000m^3/d, to calculate the water content, oil production and bottomhole flow pressure under different influencing factors [17, 18].

Taking a horizontal well in a bottom water reservoir in an oil field as an example, the well has now entered a high water content stage with a water content of over 90%, and it is no longer economically viable to develop the well using ordinary completion methods [19]. Therefore, the well was used as the base model for water control completion and water control simulation to conduct a study on the adaptability analysis of water control completion with the parameters shown in Table 1.

Table 1. *Basic parameters of horizontal wells in an oil field.*

Parameters	Units of operation	Numerical value
Oil layer thickness	m	5
Vertical Permeability	10^{-3}μm^2	20
Horizontal permeability	10^{-3}μm^2	92.877
Crude oil viscosity	mPa.s	20
Crude oil volume factor	\	1.1
Wellbore radius	m	0.062
Oil drain radius	m	537.83
Length of horizontal section	m	450
Reservoir pressure	MPa	20
Bottom of well flow pressure	MPa	8.006
Horizontal well location	m	4.493
Density of water	Kg/m^3	1000
Density of oil	Kg/m^3	883
Porosity	\	0.3
Epidermal coefficient	\	1.261

3. Analysis of the Applicability of Crude Oil Viscosity to C-AICD Water Control Completions

When considering the influence of crude oil viscosity, the crude oil viscosity is set to 10mPa.s, 20mPa.s, 30mPa.s, 40mPa.s, 50mPa.s. The results of water control calculation are shown in Figure 4.

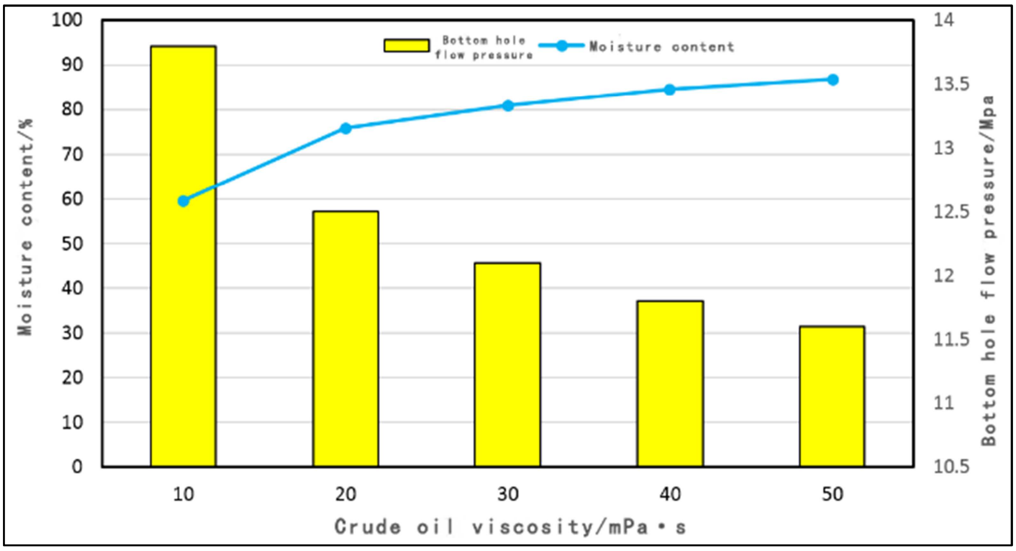

Figure 4. *Water content and bottomhole flow pressure at different crude oil viscosities.*

(1) The water content is positively correlated with the viscosity of crude oil. With the increase of crude oil viscosity, the water content keeps rising, but the rising rate tends to slow down. When the crude oil viscosity increases from 10mPa.s to 20mPa.s, the water content rises the fastest, and the water content rises by 16.2%.

(2) When producing at a fixed production rate, the increase in crude oil viscosity will lead to a rapid decrease in oil production. When the crude oil viscosity increases from 10mPa.s to 20mPa.s, the oil production decreases

at the fastest rate, and the oil production decreases by $162.4 m^3/d$.

(3) The flow pressure at the well bottom is negatively correlated with the crude oil viscosity. As the viscosity of crude oil increases, the wellbore flow pressure decreases, similar to the water content. when the viscosity of crude oil increases from 10 mPa.s to 20 mPa.s, the wellbore flow pressure decreases at the fastest rate, decreasing by 1.3 MPa. when the viscosity of crude oil exceeds 20 mPa.s, the wellbore flow pressure gradually tends to increase with the viscosity of crude oil.

4. Analysis of the Applicability of Formation Permeability to C-AICD Water Control Completion Wells

When considering the influence of formation permeability, let the extreme difference of different permeability be the same, eliminate the influence of permeability extreme difference, and the results of water control calculation are shown in Figure 5.

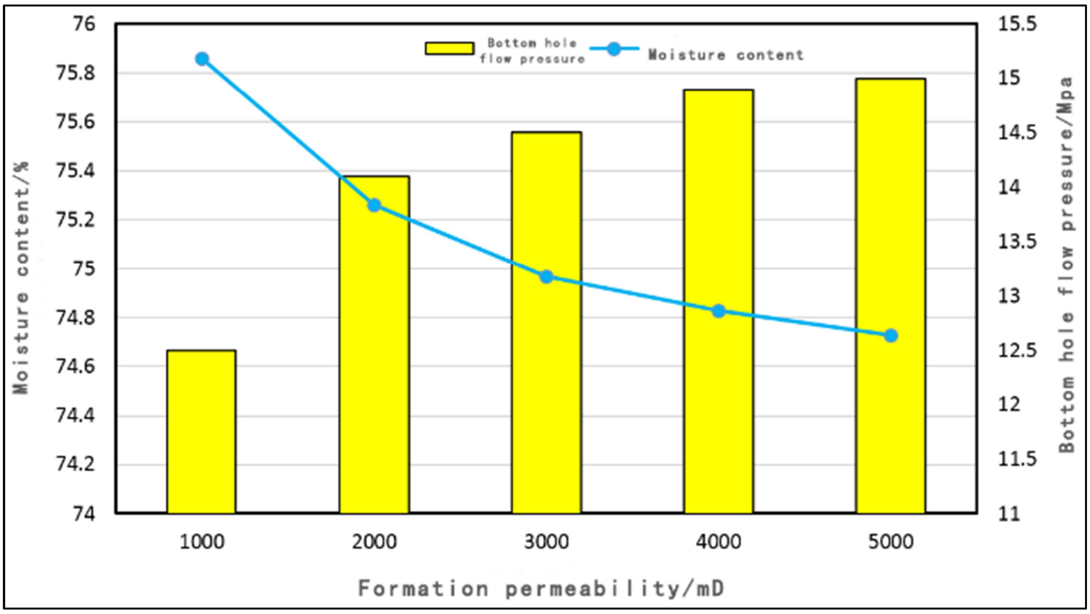

Figure 5. *Water content and well bottom flow pressure at different formation permeability.*

(1) Water content and formation permeability are negatively correlated. With the increase of formation permeability, the water content keeps decreasing, but the rate of decrease tends to slow down continuously. When the formation permeability increases from 1000md to 2000md, the decrease rate of water content is the fastest, and the water content decreases by 0.6%.

(2) When the production is fixed, the increase of formation permeability can effectively increase the oil production, but there is a limit to the oil enhancement effect. When the formation permeability exceeds 5000md, the increase of oil production is gradually less than $1 m^3/d$ for every 1000md increase in permeability.

(3) The flow pressure at the bottom of the well was positively correlated with the formation permeability. As the formation permeability increases, the well bottom flow pressure rises continuously, similar to the water content. when the formation permeability increases from 1000md to 2000md, the well bottom flow pressure rises at the fastest rate, increasing by 1.6MPa. when the formation permeability exceeds 2000md, the well bottom flow pressure gradually slows down with the rise in formation permeability.

5. Analysis of the Applicability of Permeability Grading to C-AICD Water Control Completion Wells

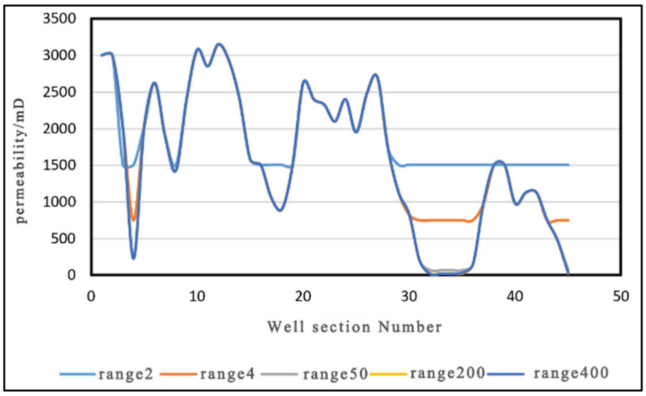

Figure 6. *Distribution of permeability with different polar differences.*

When considering the effect of permeability polar difference, as shown in Figure 6, the permeability polar difference is set to 2, 4, 50, 200 and 400, and the results of the water control simulation are shown in Figure 7.

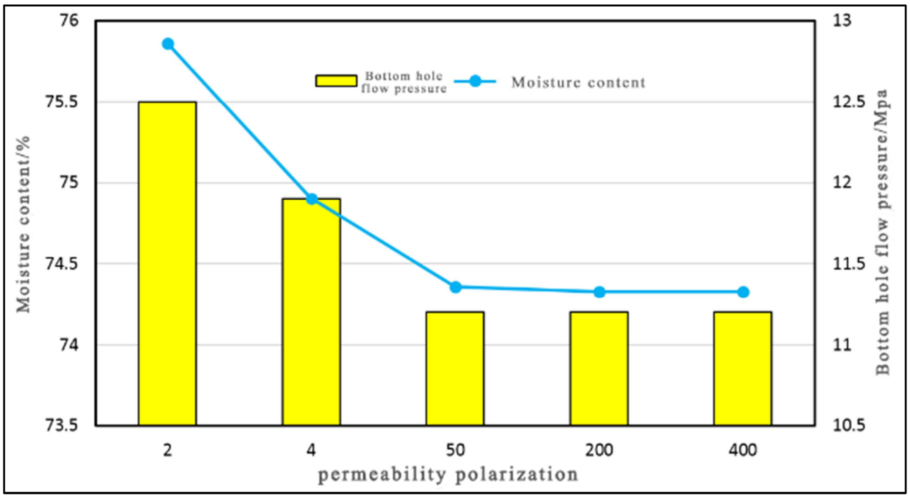

Figure 7. *Water content and bottom of well flow pressure at different permeability polarization.*

(1) Water content is negatively correlated with permeability polar difference. With the increase of permeability polar difference, the water content keeps decreasing, but there is a limit to this decreasing trend. When the permeability polar difference increases from 2 to 50, the water content decreases obviously, while after the permeability polar difference exceeds 50, the water content hardly decreases when the permeability polar difference continues to increase.

(2) When producing at a fixed volume, an increase in the extreme difference of permeability can improve oil production, but there is a limit to the oil enhancement effect.

(3) The flow pressure at the bottom of the well is negatively correlated with the permeability polar difference. With the increase of permeability polar difference, the well bottom flow pressure decreases continuously, similar to the water content, the permeability polar difference increases from 2 to 50, the well bottom flow pressure decreases rapidly, when the permeability polar difference exceeds 50, the increase of permeability polar difference has little effect on the well bottom flow pressure.

6. Analysis of the Applicability of Horizontal Well Length to C-AICD Water Control Completions

When considering the effect of horizontal well length, the horizontal well length is set to 0.5L, 0.75L, L, 1.25L, 1.5L, wherein, when the horizontal well length is 0.5L, the permeability of the first 23 segments is selected for calculation and the last 22 segments are excluded; when the horizontal well length is 0.75L, the permeability of the first 33 segments is selected for calculation; For a horizontal well length of 1.25L, 11 segments are added to the horizontal well length L (45 segments), and the permeability of each segment is 500 md; for a horizontal well length of 1.5L, 22 segments are added to the horizontal well length L (45 segments), and the permeability of each segment is 500md. The results of the water control calculation are shown in Figure 8.

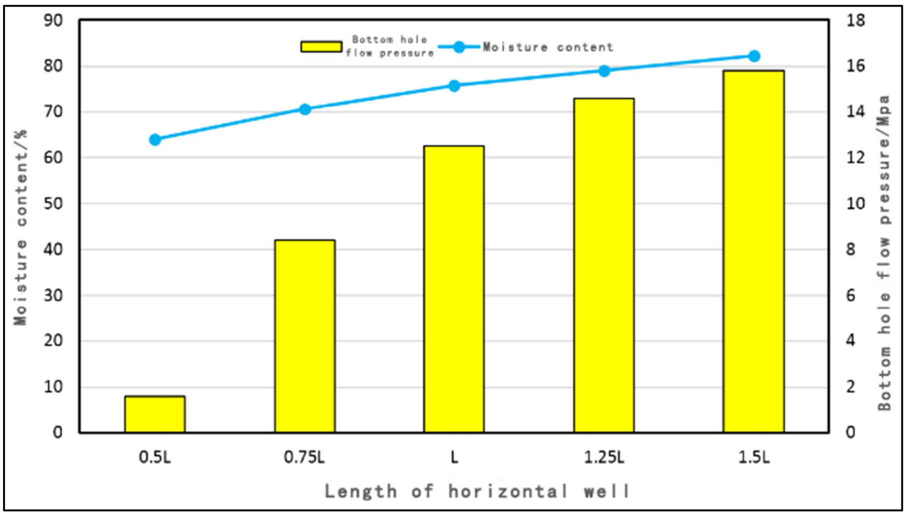

Figure 8. *Water content and bottom flow pressure at different horizontal well lengths.*

(1) The water content rate is positively correlated with the length of horizontal wells. As the horizontal well length increases, the water content rate increases continuously and at a faster rate, for example, when the horizontal well length increases from 0.5L to 1.5L, the water content rate increases by 18.3%.
(2) When producing at a fixed production rate, the increase in horizontal well length led to a rapid decrease in oil production. When the horizontal well length increased from 0.5L to 1.5L, the oil production decreased by 183m^3/d.
(3) There is a positive correlation between the bottom flow pressure and the horizontal well length. With the increase of horizontal well length, the bottom flow pressure keeps increasing, especially when the horizontal well length increases from 0.5L to 0.75L, the bottom flow pressure increases by 6.8MPa, which is a huge increase.

Therefore, when C-AICD water-controlled completions are used for constant production, increasing the horizontal well length can effectively increase the bottomhole flow pressure, but it is also accompanied by higher water content and lower oil production.

7. Analysis of the Applicability of Production Allocation to C-AICD Water Control Completion Wells

When considering the effect of production allocation, the production allocation was set to 700m^3/d, 1000m^3/d, 1300m^3/d, 1600m^3/d, 1900m^3/d, and the results of water control calculation are shown in Figure 9.

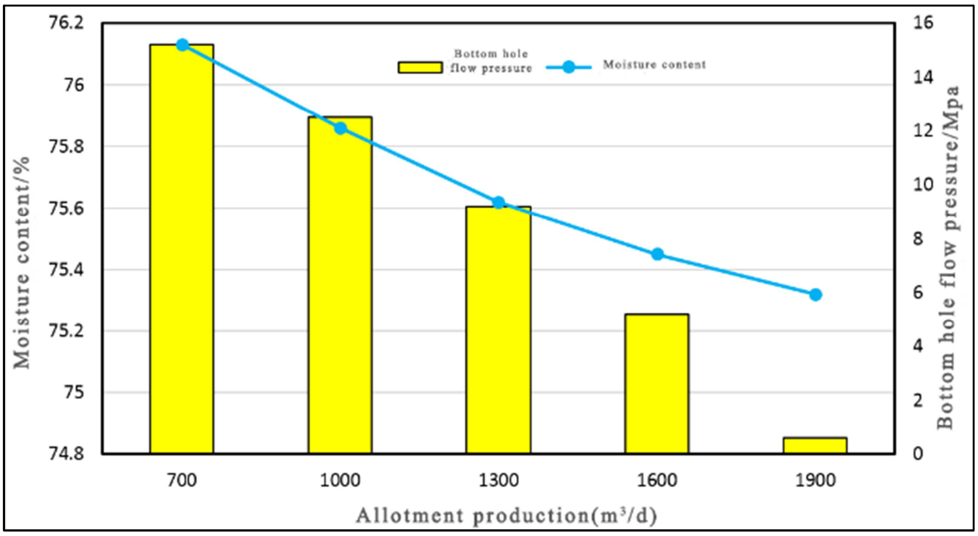

Figure 9. Water content and bottomhole flow pressure at different production ratios.

(1) The water content was negatively correlated with the allocation yield. With the increase of allocation yield, the moisture content decreased continuously, and this decreasing trend was approximately linear.
(2) When producing at a fixed production rate, the increase in the matched production can improve the oil production, but the oil enhancement effect is limited. For example, although the production allocation increased by 1200m^3/d, the final oil production only increased by 8m^3/d, taking 700m^3/d and 1900m^3/d as examples.
(3) The relationship between bottomhole flow pressure and production allocation is negative. As the production allocation increases, the bottom flow pressure decreases, especially when the production allocation is 1900m^3/d, the bottom flow pressure is only 0.6 MPa, at this time the bottom flow pressure is seriously insufficient, which will cause the well to stop production. Therefore, when C-AICD water-controlled completions are used for constant production, the production allocation should not be too large, otherwise it will lead to non-production.

8. Conclusion

(1) With the development of technology, a new type of C-AICD water control completion technology for bottom water reservoirs has emerged, which combines the features of ICD technology and AICD technology and can produce better water control results both in early and late production.
(2) The C-AICD water-controlled completion flow of horizontal wells in bottom-water reservoirs is divided into different spatial scale flows such as reservoir seepage flow, C-AICD nozzle flow and horizontal wellbore tubular flow, and a set of C-AICD integrated coupled model of horizontal wells in bottom-water reservoirs is established.
(3) The applicability analysis of crude oil viscosity, formation permeability, permeability grading and production allocation was conducted. The results show that the lower the crude oil viscosity and the shorter the

horizontal well length, the lower the water content, and the formation permeability, permeability grading, and production allocation have limited effects on the water content.

(4) In the future, Continuous pack-off can be added into the C-AICD water-controlled completion production prediction model of horizontal Wells in bottom-water reservoirs to study the water-controlled effects of different types of packers.

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