

Examples of discriminating the downward depth and downward timing of the velocity string in the water-producing gas well

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Abstract. The problem of bottom hole effusion is an important reason for the reduction and even shutdown of natural gas wells. Downward velocity string is an important drainage gas recovery process, which can improve the flow rate of gas and discharge more liquid from the wellhead. However, the depth and timing of the velocity string is a technical problem that has been difficult to solve by field engineers. To solve this problem, this paper designs a method to select the depth and timing of the velocity string in the case of highly deviated wells and applies this method to Well X6-2 and Well X2-1 of PCOC in Ordos Basin, China. The optimization results show that when the wellhead pressure is 6.26 MPa, Well X6-2 should lower the 2-1.71 in. or 2.375-1.995 in. velocity string to 3337.9 m before the formation pressure decays to 8.800 MPa, which is most conducive to improve the liquid carrying capacity of gas wells. When the wellhead pressure is 4 MPa, Well X2-1 should lower 2-1.71in. velocity string to 3401.3 m before the formation pressure decays to 5.800 MPa, or lower 2.375-1.995 in. velocity string to 3401.3 m before the formation pressure decays to 5.900 MPa.

1 Introduction

Natural gas is the main energy source for the development of the national economy. However, natural gas extraction is always accompanied by liquids from condensate oil and water. With the continuous production of gas wells, the energy of gas wells is gradually insufficient. These liquids will gradually form fluid accumulation at the bottom of the well, causing the production of gas wells to drop sharply or even stop production.^[1]

To solve the problem of fluid accumulation at the bottom of the well and increase the production of gas wells, the oilfield site will regularly conduct drainage gas production processes to drain the fluid accumulation in the wellbore. There are several types of drainage gas recovery processes commonly used: velocity string drainage gas recovery technology, foam drainage gas recovery technology, gas lift drainage gas recovery technology, electric submersible pump drainage gas recovery technology, and jet pump drainage gas recovery technology.^[2]

Among them, lowering the velocity string to the bottom of the well is an important drainage gas production process. Generally, the larger the diameter of the tubing, the higher the output of the gas well. However, the tubing with a larger inner diameter may not be able to continue to meet the continuous liquid-carrying capacity of the gas in the wellbore in the late

stage of the gas well. At this time, you can replace the tubing with a smaller size to enhance the gas flow rate and its liquid-carrying capacity, thereby discharging the liquid from the well. It is called the velocity string drainage gas recovery technology.^[3,4]

Zhou J et al. (2013) developed a suspension and sealing device for velocity string operation, which can realize the pre-placement of slips before the velocity string is lowered, which solves the suspension, sealing, and shearing problems of the velocity string under pressure.^[5] Xie Y et al. (2013) in response to the increasing number of low-yield and low-efficiency wells in the Zizhou gas field, carried out research and field tests on velocity string drainage gas production technology, which provided new technical means for improving the development effect of low-yield and low-efficiency wells.^[6] Zhao B et al. (2013) analyzed the timing of the velocity string from two aspects of economy and technology to ensure that the cost can be recovered after the velocity string is used for production, and the role of the velocity string for drainage and gas recovery can be fully utilized.^[7] Wuchao W U et al. (2015) applied the critical liquid carrying model to study the downward time of the velocity string and believed that when the daily production began to be lower than the critical liquid carrying flow rate in a large range, it was the best time to lower the velocity string.^[8] Binbin Z et al. (2018) calculated the location of the most prone to fluid accumulation in horizontal wells by using the

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straight well section model and the inclined well section model, and clarified the optimal down-entry depth of the velocity string, which solved the problem that the velocity string cannot enter under pressure in highly deviated wells.^[9]

However, it can be seen from the above literature that the depth and timing of the velocity string have always been technical problems that are difficult for field engineers to solve, and the main reliance is still on empirical judgment. In response to this problem, this article first designs a method for identifying the depth and timing of the velocity string in the case of highly deviated wells; then this method is applied to Well X6-2 and Well X2-1 in PCOC. This identification method can provide a reference for oilfield engineers.

2 Basic data of the well and design process

This article is aimed at two highly inclined horizontal wells: Well X6-2 and Well X2-1 in PCOC, Ordos Basin, China. The basic data of the well is shown in Table 1:

Table 1. The basic data of the well.

Basic parameters	Well X6-2	Well X2-1
Classification of well	Horizontal well	Horizontal well
Wellbore radius	0.108m	0.108m
Vertical well section depth sounding	0-2066m	0-1474.1m
Inclined well section depth sounding	2066-3337.9m	1474.1-3401.3m
Horizontal section length	912.4m	1776m
Casing setting depth	3337.9m	3401.3m
Tubing setting depth	3324m	3306.7m
Initial formation pressure	26.5MPa	22.7MPa

The flow chart design of the downward depth and downward timing of the velocity string is shown in Fig. 1.

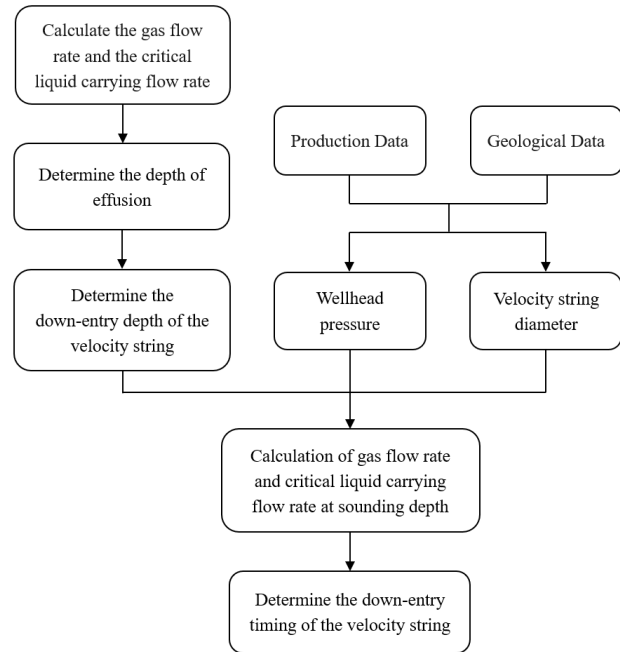


Fig. 1. The flow chart design of down-entry depth and down-entry timing of velocity string

3 Determination of the downward depth of velocity string

(1) Calculation of actual gas flow rate: Gray model is used to calculate the actual gas flow rate in vertical and inclined well sections.^[10]

$$\frac{dp}{dz} = \frac{f\rho_n V_m^2}{2d} + \rho_m g - \rho_n^2 V_m^2 \frac{d}{dz} \left(\frac{1}{\rho_n} \right) \quad (1)$$

Where f , is friction resistance coefficient; ρ_n , kg/m^3 , is natural gas density; ρ_m , kg/m^3 , is mixture density; V_m , m/s , is the apparent velocity of gas-liquid mixture; d , m , is wellbore radius; and g , m^2/s , is the acceleration of gravity.

Combining the formation pressure and the daily production under the conditions of formation temperature, the length of the horizontal section, and the radius of the wellbore, the gas flow rate in the horizontal section is converted.

(2) Calculation of critical liquid-carrying flow rate: In the vertical well section, the commonly used critical liquid-carrying flow rate models include Turner model, Coleman model, and Li Min model. Based on the Turner model, Fernando et al. considered the influence of inclination angle on the critical liquid carrying flow rate and established the Fernando model. Through comparative calculation, the Turner model and Fernando model are selected to calculate the critical liquid carrying flow rate of vertical and inclined sections of Well X6-2 and Well X2-1.

Through calculation, it is found that the actual flow rate of gas in each part of the wellbore in the vertical section of Well X6-2 and Well X2-1 is higher than the critical liquid carrying flow rate, so there is no fluid accumulation in the vertical section. The actual gas flow

rate of Well X6-2 at 3337.9 m is lower than the critical liquid carrying flow rate, and the gas flow rates above 3324 m are higher than the critical liquid carrying flow rate. Therefore, there must be effusion at the bottom of the inclined section of Well X6-2. The actual gas flow rate of Well X2-1 at 3375.7 m and 3401.3 m are lower than the critical liquid carrying flow rates, while the gas flow rates above 3278.9 m are higher than the critical liquid carrying flow rates. Therefore, there must be effusion at the bottom of the inclined section of Well X2-1.

It is calculated that the liquid flow rate in the horizontal section of Well X6-2 and Well X2-1 is much smaller than the gas flow rate. According to the Mandhane flow pattern diagram of the horizontal wellbore, it can be concluded that the flow pattern in the horizontal wellbore of the two wells is stratified flow. It indicates that there is no effusion in the horizontal wellbore.

In summary, no effusion was found in both horizontal and vertical sections of Well X6-2 and Well X2-1, and the effusion in the wellbore was found at the bottom of the inclined section. Therefore, the bottom of the inclined well section should be selected as the downward depth of the velocity string, that is, the downward depth of the velocity string in the Well X6-2 should be 3337.9 m, and the downward depth of the velocity string in the Well X2-1 should be 3401.3 m.

4 Determination of the downward time of velocity string in Well X6-2

This paper selects the outer diameter of 2 in. inner diameter 1.71 in. and outer diameter 2.375 in. inner diameter 1.995 in. two kinds of size of the velocity string for research and calculation.

By calculation, the cumulative liquid column height of Well X6-2 was 0.7 m from April 2018 to May 2020, and the formation pressure was reduced to 10.7 MPa. At this point, the wellhead pressure is 6.26 MPa, the daily gas production is 173378.7 m³/d, the gas flow rate at the bottom of the inclined section is 0.604 m/s, and the critical liquid carrying flow rate at the bottom of the inclined section is 1.9705 m/s. The actual flow rate is much lower than the critical flow rate.

4.1 The diameter of the velocity string is 2-1.71 in.

The wellhead pressure is 6.26 MPa. At this time, the velocity string with the diameter of 2-1.71 in. is inserted into the bottom of the inclined section in Well X6-2, that is, the sounding depth of 3337.9 m in Well X6-2. The actual flow rate at this point is calculated to be 4.8264 m/s, the critical liquid carrying flow rate at the bottom of the inclined section is 1.6218 m/s, and the daily output is 65052.3 m³/s. At this time, the actual flow rate is much higher than the critical flow rate, and the liquid carrying capacity of the gas well is enhanced and no effusion is produced.

Under the wellhead pressure of 6.26 MPa, the formation pressure is continuously reduced, and the actual flow rate and the critical liquid carrying flow rate at 3337.9 m are calculated. Determine the downward time of 2-1.71 in. the velocity string, and calculate the gas production. The results are shown in Table 2:

Table 2. Downward entry timing of velocity string with diameter 2-1.71 in. at wellhead pressure 6.26 MPa.

Formation pressure /MPa	Bottom hole pressure /MPa	Actual flow rate /(m/s)	Critical flow rate /(m/s)	Production /(m ³ /d)
10.700	9.859	4.8264	1.6218	65052.3
9.000	8.548	2.5973	1.7456	30732.6
8.900	8.493	2.3417	1.7514	27469.4
8.800	8.443	2.0507	1.7567	23850.5
8.700	8.394	1.7504	1.7620	20303.9

The variation of actual flow rate and critical liquid carrying flow rate with formation pressure as shown in Fig. 2:

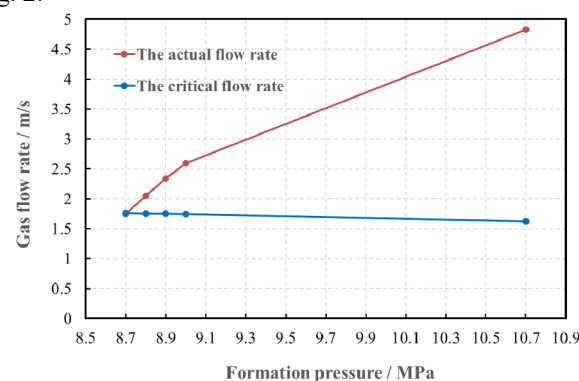


Fig. 2 The variation of the actual flow rate and critical flow rate after the diameter of 2-1.71 in. velocity string enters under the wellhead pressure of 6.26 MPa.

From Table 2 and Fig. 2, it can be seen that when the wellhead pressure is 6.26 MPa, Well X6-2 downhole enters the 2-1.71 in. velocity string to the bottom of the inclined well section. When the formation pressure decays below 8.800 MPa, the gas flow rate is lower than the critical flow rate, and the daily production is lower than 23850 m³/d. At this time, the gas well begins to continue to accumulate fluid. Therefore, under the condition of wellhead pressure 6.26 MPa, Well X6-2 should enter 2-1.71 in. velocity string to the bottom of the inclined section before the formation pressure decays to 8.800 MPa.

4.2 The diameter of the velocity string is 2.375-1.995 in.

The wellhead pressure is 6.26 MPa. At this time, the velocity string with the diameter of 2.375-1.995 in. is inserted into the bottom of the inclined section in Well X6-2, that is, the sounding depth is 3337.9 m. The actual flow rate at this point is calculated to be 4.9707 m/s, the critical liquid carrying flow rate at the bottom of the inclined section is 1.6502 m/s, and the daily output is 89642.7 m³/d. At this time, the actual flow rate is much higher than the critical flow rate, and the liquid carrying capacity of the gas well is enhanced and no effusion is produced.

Under the wellhead pressure of 6.26 MPa, the formation pressure is continuously reduced, and the actual flow rate and the critical liquid carrying flow rate at 3334.9 m are calculated. Determine the downward time of 2.375-1.995 in. the velocity string, and calculate the gas production. The results are shown in Table 3:

Table 3. Downward entry timing of velocity string with diameter 2.375-1.995 in. at wellhead pressure 6.26 MPa.

Formation pressure /MPa	Bottom hole pressure /MPa	Actual flow rate /(m/s)	Critical flow rate /(m/s)	Production /(m ³ /d)
10.700	9.534	4.9707	1.6501	89142.7
9.700	8.844	2.6617	1.7153	60901.1
9.000	8.443	2.3648	1.7567	37563.3
8.900	8.391	2.1602	1.7623	34110.1
8.800	8.340	1.949	1.7678	30630.1
8.700	8.394	1.7494	1.7620	26467.1

The variation of actual flow rate and critical liquid carrying flow rate with formation pressure as shown in Fig. 3:

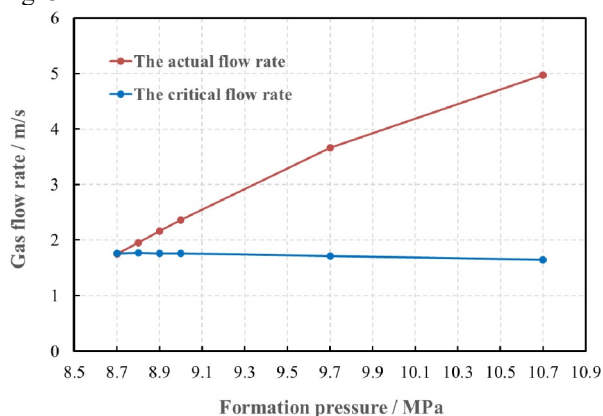


Fig. 3 The variation of the actual flow rate and critical flow rate after the diameter of 2.375-1.995 in. velocity string enters under the wellhead pressure of 6.26 MPa.

From Table 3 and Fig. 3, it can be seen that under the condition of wellhead pressure of 6.26 MPa, Well X6-2 downhole enters 2.375-1.995 in. velocity string to the bottom of the inclined well section. When the formation pressure decays below 8.800 MPa, the gas flow rate is lower than the critical flow rate, and the daily production is lower than 30630.1 m³/d. At this time, the gas well begins to continue to accumulate fluid. Therefore, under the condition of wellhead pressure of 6.26 MPa, Well X6-2 should enter 2.375-1.995 in. velocity string to the bottom of the inclined section before the formation pressure decays to 8.800 MPa.

5 Determination of the downward time of velocity string in Well X2-1

For Well X2-1, the cumulative liquid column height is calculated to be about 3 m from April 2018 to May 2020, and the formation pressure has decreased to 8.1 MPa. At this time, the wellhead pressure is taken as 4 MPa, and the daily production of gas wells is 137289.4 m³/d. The gas flow rate at the bottom of the inclined section is 0.5715 m/s, and the critical liquid carrying flow rate at the bottom of the inclined section is 2.6208 m/s. The actual flow rate is much lower than the critical flow rate.

5.1 The diameter of the velocity string is 2-1.71 in.

The wellhead pressure is 4MPa. At this time, the velocity string with the diameter of 2-1.71 in. is inserted into the bottom of the inclined section in Well X2-1, that is, the sounding depth of 3401.3 m in Well X2-1. The actual flow rate at this point is 6.1023 m/s, the critical liquid carrying flow rate at the bottom of the inclined section is 2.2063 m/s, and the daily production is 66411.6 m³/s. At this time, the actual flow rate is much higher than the critical flow rate, and the liquid carrying capacity of the gas well is enhanced and no effusion is produced.

Under the wellhead pressure of 4 MPa, the formation pressure is continuously reduced, and the actual flow rate and critical liquid carrying flow rate at 3401.3 m are calculated. Determine the downward time of 2-1.71 in. the velocity string, and calculate the gas production. The results are shown in Table 4:

Table 4. Downward entry timing of velocity string with diameter 2-1.71 in. at wellhead pressure 4 MPa.

Formation pressure /MPa	Bottom hole pressure /MPa	Actual flow rate /(m/s)	Critical flow rate /(m/s)	Production /(m ³ /d)
8.100	7.351	6.1023	2.2063	66411.6
7.100	6.479	5.1207	2.3535	49051.7
6.500	5.992	4.197	2.4492	37141.3

6.300	5.839	3.8084	2.4817	32850.4
6.100	5.690	3.3717	2.5146	28379.5
6.000	5.619	3.134	2.5307	26073.5
5.900	5.549	2.8849	2.5470	23718.8
5.800	5.480	2.6181	2.5632	21314.7
5.700	5.413	2.3395	2.5793	18860.3

The variation of actual flow rate and critical liquid carrying flow rate with formation pressure as shown in Fig. 4:

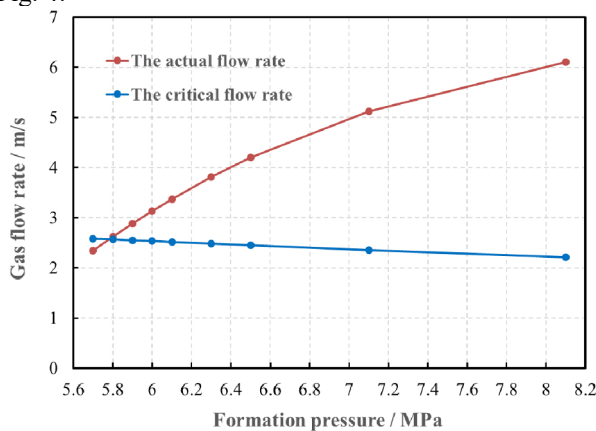


Fig. 4 The variation of the actual flow rate and critical flow rate after the diameter of 2-1.71 in. velocity string enters under the wellhead pressure of 4 MPa.

From Table 4 and Fig. 4, it can be seen that under the condition of wellhead pressure of 4 MPa, Well X2-1 downhole enters 2-1.71 in. velocity string to the bottom of the inclined well section. When the formation pressure decays below 5.800 MPa, the gas flow rate is lower than the critical flow rate, and the daily production is lower than 21314.7 m³/d. At this time, the gas well begins to continue to accumulate fluid. Therefore, under the condition of wellhead pressure of 4 MPa, Well X2-1 should enter 2-1.71 in. velocity string to the bottom of the inclined section before the formation pressure decays to 5.800 MPa.

5.2 The diameter of the velocity string is 2.375-1.995 in.

The wellhead pressure is 4MPa. At this time, the velocity string with the diameter of 2.375-1.995 in. is inserted into the bottom of the inclined section in Well X2-1, that is, the sounding depth is 3401.3 m. The actual flow rate at this point is calculated to be 6.4374 m/s, the critical liquid carrying flow rate at the bottom of the inclined section is 2.2543 m/s, and the daily production is 91523.2 m³/s. At this time, the actual flow rate is much higher than the critical flow rate, and the liquid carrying capacity of the gas well is enhanced and no effusion is produced.

Under the wellhead pressure of 4 MPa, the formation pressure is continuously reduced, and the actual flow rate and critical liquid carrying flow rate at 3401.3 m are calculated. Determine the downward time of 2.375-1.995 in. the velocity string, and calculate the gas production. The results are shown in Table 5:

Table 5. Downward entry timing of velocity string with diameter 2.375-1.995 in. at wellhead pressure 4 MPa.

Formation pressure /MPa	Bottom hole pressure /MPa	Actual flow rate /(m/s)	Critical flow rate /(m/s)	Production /(m ³ /d)
8.100	7.049	6.4374	2.2542	91523.2
7.100	6.246	5.2633	2.3979	66366.1
6.100	5.561	3.2952	2.5442	37065.3
6.000	5.505	3.3534	2.5573	33534
5.900	5.452	2.7191	2.5699	29961.9
5.800	5.401	2.4133	2.5822	26351.7

The variation of actual flow rate and critical liquid carrying flow rate with formation pressure as shown in Fig. 5:

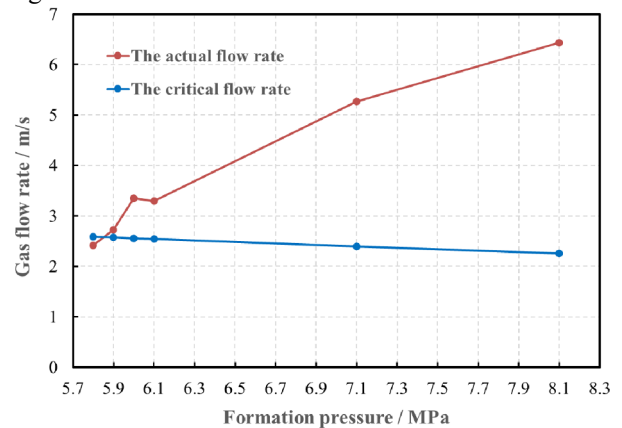


Fig. 5 The variation of the actual flow rate and critical flow rate after the diameter of 2.375-1.995 in. velocity string enters under the wellhead pressure of 4 MPa.

From Table 5 and Fig. 5, it can be seen that under the condition of wellhead pressure of 4 MPa, Well X2-1 downhole enters 2.375-1.995 in. velocity string to the bottom of the inclined well section. When the formation pressure is reduced to below 5.900 MPa, the gas flow rate will be lower than the critical flow rate, and the daily production is lower than 29961.9 m³/d. At this time, the gas well begins to continue to accumulate fluid. Therefore, under the condition of wellhead pressure of 4 MPa, Well X2-1 should enter 2.375-1.995 in. velocity string to the bottom of the inclined section before the formation pressure decays to 5.900 MPa.

6 Conclusions

In this paper, a method is designed to select the downward depth and timing of the velocity string in the case of highly deviated wells. The method is applied to Well X2-1 and Well X6-2 in PCOC, Ordos Basin, China. The specific results are as follows:

(1) The method flow of velocity string down-entry depth and down-entry timing identification for highly deviated horizontal wells is as follows: Firstly, the gas flow rate of vertical section and inclined section is calculated, and the gas flow rate of horizontal section is calculated by combining geological data and production data. Then the critical liquid carrying flow rate of the vertical section and inclined section is calculated by using the liquid carrying model of the gas well, to determine the depth of gas well effusion and determine the depth of velocity string. Finally, the diameter of the velocity string determined by the production data and the down-entry depth calculated previously is used to calculate the actual flow rate and the critical liquid carrying flow rate at the sounding depth combined with the wellhead pressure, to determine the down-entry time of the velocity string.

(2) For Well X6-2, the down-entry depth of the velocity string should be 3337.9 m at the bottom of the inclined section. Under the condition of wellhead pressure of 6.26 MPa, Well X6-2 should lower the 2-1.71 in. velocity string or 2.375-1.995 in. velocity string to the bottom of the inclined section before the formation pressure decays to 8.800 MPa.

(3) For Well X2-1, the down-entry depth of the velocity string should be 3401.3 m at the bottom of the inclined section. Under the condition of wellhead pressure of 4 MPa, Well X2-1 should lower the 2-1.71 in. velocity string to the bottom of the inclined section before formation pressure decays to 5.800 MPa, and lower the 2.375-1.995 in. velocity string to the bottom of the inclined section before formation pressure decays to 5.900 MPa.

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