Study on Cuttings Starting Velocity in Air Drilling Horizontal and Highly-Deviated Wells

Sun Xiaofeng, Shao Shuai*, Yan Tie, Wang Kelin, Luan Shizhu

Institute of Petroleum Engineering, Northeast Petroleum University, Daqing 163318, China

Abstract: Air injection rate as the key parameter of drilling air is directly related to the success of drilling procedure. In the previous studies, most of air injection rate models were built based on the vertical wells, which are not appropriate for horizontal and highly-deviated well and limit the wide application of air drilling to some extent. Based on the movement analysis of cuttings, this paper assumed that after the cuttings deposit to the low side of borehole, Air is injected to carry the cuttings out of the wellbore. Then, the starting velocity model in different hole angles is established through the stress analysis of cuttings motion, which can be used to calculate the minimum air injection rate. The numerical simulation results show that starting velocity of cuttings reaches the maximum in the hole angle 60-70 degrees. The larger diameter cuttings require a high starting velocity, which is difficulty to be transported. This means some appropriate methods should be applied for air drilling procedure, like using secondary crush tools. The subsidence degree is one important factor to the calculation model, and it is necessary to study cutting subsidence degree in next step.

Keywords: In highly deviated well, air drilling, starting velocity, air injection rate, subsidence degree.

1. INTRODUCTION

Air drilling becomes one of the major techniques in oil and gas development due to its advantages in reservoir protection, high penetration rate, environmental protection, low cost and longer bit life, etc [1-5]. Volumetric requirement is the key parameter in the air drilling. Lower injection volume leads to cuttings accumulate in the wellbore and may cause various problems such as pipe stuck, high drag, higher hydraulic requirement, etc, but higher injection rate needs further requirement of equipment and result in a shorter life of drilling tools [6]. The minimum kinetic energy method and minimum speed method are usually used to calculate air volumetric requirement calculation, which are established based on the vertical wellbore. But these methods are not appropriate for horizontal and highly deviated wells [7-9]. This paper analyzed the reactions between cuttings and air in horizontal and highly deviated wells under drilling conditions, built the air speed model for cuttings start to move. The conclusion can provide a reliable basis for the hydraulic optimization in horizontal and highly deviated wells.

2. MIGRATION OF CUTTING IN HIGHLY DEVIATED SECTION

Cutting migration in air drilling can be composed of creep, saltation and suspension in horizontal and highly deviated section [10, 11]. Creeping occurs in the situation of lower air flow rate and large diameter cuttings exist and cutting scrolls and slides along with the air flow direction in the lower side of borehole. When the cuttings diameter is smaller or the air flow rates are higher, cutting migration is saltation. Only the tiny diameter cuttings can be suspended in air drilling.

Judging from the cuttings size distribution [12], three migration manners may exist at the same time in horizontal well and highly deviated well. However, the narrow structure of the well bore annulus and high air velocity leads to cuttings collided with the borehole, so suspension migration is not common. And considering the colliding cuttings not large in common, creep migration can not happen frequently. Thus, saltation is considered the main migration method in horizontal and highly deviated section.

In horizontal and highly deviated sections, since the air flow direction and cutting gravity direction are not in the same line, it is difficult to quantitatively describe the movement of cuttings and give an accurate air injection rate. Cuttings deposited at lower side of borehole is assumed at first and transported to surface by injecting air in this paper. Minimum air velocity is defined that cuttings start to move as starting velocity. The main migration manner of cuttings is saltation, once cutting starts to move it cannot deposit again. So the calculation of air injection rate based on starting velocity is reasonable.

3. ESTABLISHING THE STARTING VELOCITY MODEL

Introduce the degree of subsidence for study cutting start [13,14]. Cutting shape is assumed to be spherical, and degree of subsidence is defined as the vertical distance between lowest point of the cuttings and intersection with the downstream next cutting as Fig. (**1**).

*Address correspondence to this author at the College of Petroleum Engineering, Northeast Petroleum University, Daqing 163318, Heilongjiang, China; Tel: 0459-6503521; Fax: 0459-6503482;
E-mail: zdshaoshuai@163.com

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Dimensionless subsidence degree is defined as: $E'=E/r$

Cutting may be completely obscured by the other cuttings, or may be located at the top of other cuttings. In general, cuttings presented between this two cases.

Both $E'_{\min}=0.134$ and $E'_{\max}=1$ can be obtained from analyzing.

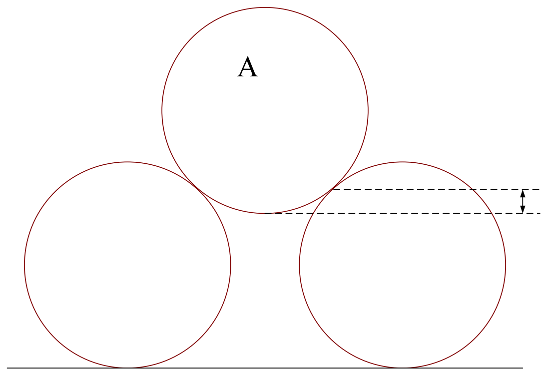

Fig. (1). The diagram of cuttings subsidence degree.

In order to simplify the starting velocity model within the range that will not deteriorate the accuracy of the model, the following assumptions are considered:

(1) Cuttings are perfect sphere;

(2) Cuttings size is uniform;

(3) Cuttings are settled low side of the borehole at first, and then air is injected.

Stress analysis of single cutting is shown in Fig. (**2**), and the forces acting on the cutting include the floating weight, the drag force of air, the lifting force and torque. When the cutting diameter is small, the lifting force can be ignored [15]. Collision force generated between the cuttings is also ignored due to the low concentration of cuttings in the annulus. The hole angle ranges from 0° to 90° and the 90° is also referred to as the horizontal section.

Floating weight of cuttings co-current with air flow is given by: flow

$$F_w=\frac{1}{6}\pi d^3\left(\rho_s-\rho\right)g \tag{1}$$

The drag force of air act on the cutting is written by:

$$F_D=\frac{1}{8}C_D\rho\pi d^2u^2 \tag{2}$$

The arms of floating weight and drag force of air are obtained by:

$$L_D=r-E=r\left(1-E'\right) \tag{3}$$

$$L_w=r(1-E')\cos\alpha+r\sin\alpha\sqrt{1-\left(1-E'\right)^2} \tag{4}$$

Under the effect of air flow, cuttings move only if:

$$F_DL_D\geq F_wL_w \tag{5}$$

Then obtain the following equation:

$$u=1.155\times\left(\frac{\rho_s-\rho}{\rho}gd\right)^{1/2}\left[\frac{(1-E')\cos\alpha+\sin\alpha\sqrt{1-\left(1-E'\right)^2}}{C_D\left(1-E'\right)}\right]^{1/2} \tag{6}$$

Equation (6) can be used to calculate the starting velocity of air drilling in horizontal and highly deviated wells.

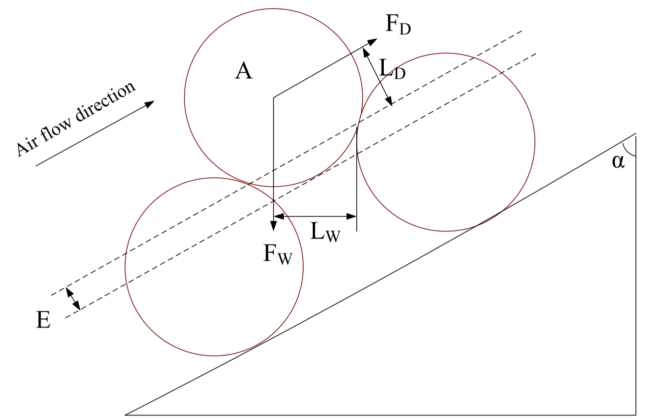

Fig. (2). Cutting stress analysis.

4. EFFECTS OF KEY PARAMETERS ON STARTING VELOCITY

The comparative analysis of cuttings transport parameters is conducted under the certain bottom pressure in a horizontal well. Starting velocity model is used to predict the air injection rate and judge whether the actual injection rate is reasonable. The change features of starting velocity with subsidence degree, cutting diameter and hole angle are discussed. Variable parameters are listed in Table **1**, and the calculated results are shown in Figs. (**3-5**).

In the horizontal section, the relationships between starting velocity and dimensionless subsidence degrees with different cutting diameters are shown in Fig. (**3**). Subsidence degree has a significant effect on starting velocity; the difference value of starting velocity with same cutting is up to 10 m/s in different subsidence degrees. In the subsequent analysis, the value of subsidence degree is 0.6.

The relationships between starting velocity and hole angles with different cutting diameters are seen from Fig. (**4**). When the hole angle is 60-70°, the starting velocity of cuttings increases to maximum. Shown in this means the air injection rate should be increased in these conditions.

Table 1. Variable Parameters

Hole Angle (°)	Cutting Diameter (m)	Dimensionless Subsidence Degree
0, 10, 20, 30, 40, 50, 60, 70, 80, 90	0.0008, 0.004, 0.008, 0.01	0.2, 0.4, 0.6, 0.8

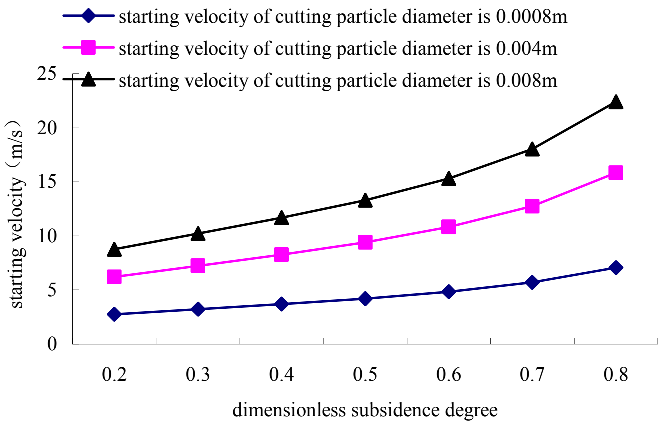

Fig. (3). The relationship between starting velocity and dimensionless subsidence degree.

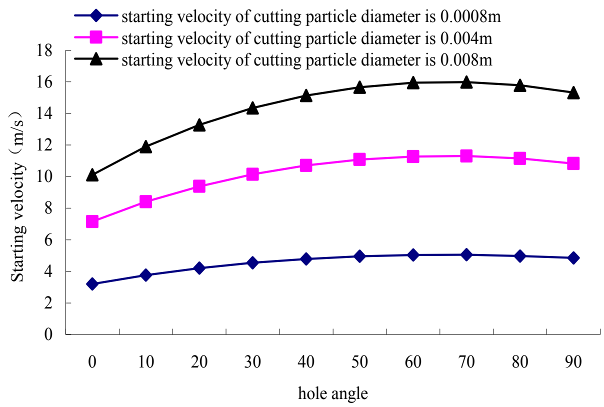

Fig. (4). The relationship between starting velocity and hole angle.

The relationship between starting velocity and cutting diameters with different hole angles are shown in Fig. (**5**). The growing trend of starting velocity with the cutting diameter is consistent in different hole angle. Cutting diameter influences the starting velocity greatly, the maximum starting velocity is obtained when the diameter reaches to 0.1m. However, the required injection rate is too high, and this means that the conventional equipments is difficult to meet the requirement. In vertical wells, Cuttings with large diameter might fall to downward or bottom hole and can be crushed again, but this moving manner does not exit in horizontal wells. Therefore, some methods should be applied to decrease the amount of large cuttings like increasing rotary speeds, using the secondary crush rock tool.

5. CONCLUSIONS

(1) The established model can calculate the cuttings starting velocity of air drilling in horizontal and highly deviated wells, and the minimum air injection rate can be accurately predicted by starting velocity.

(2) Large diameter cuttings require high injection rate to transport out of the well bore, so it is necessary to optimize other drilling parameters or using secondary crush tools to reduce the number of large cuttings.

(3) Cutting starting velocity reaches maximum when the hole angle ranges from 60 to 70° in the process of air drilling in horizontal and highly-deviated wells. At the range of the hole angles, air injection rate should be adjusted to ensure cuttings transported to the ground.

(4) The subsidence degree affects the starting velocity greatly, so further study should be conducted in next step.

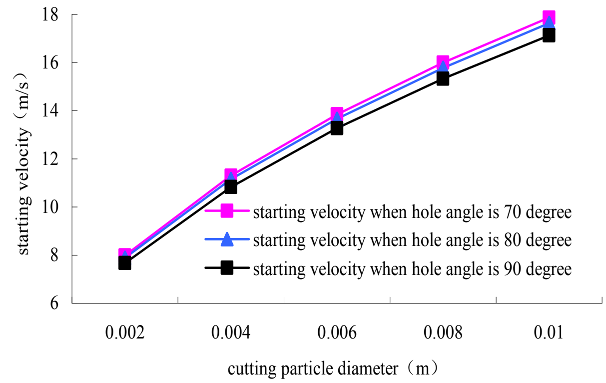

Fig. (5). The relationship between starting velocity and cutting diameter.

NOMENCLATURE

r	=	Cutting radius, m
E	=	Subsidence degree, m
E'	=	Dimensionless subsidence degree
d	=	Cutting diameter, m
ρ_s	=	Cutting true density, kg/m^3
ρ	=	Air Density, kg/m^3
g	=	Acceleration of gravity, N/kg
u	=	Air velocity, m/s
α	=	Hole angle,°
C_D	=	Drag coefficient, dimensionless
F_W	=	Buoyant weight, N
F_D	=	Drag force, N
L_w	=	The arm of buoyant weight, m
L_D	=	The arm of drag force, m

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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