CUTTINGS-CARRIED THEORY AND EROSION RULE IN GAS DRILLING HORIZONTAL WELL

by

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In gas horizontal drilling, the gas with cuttings will go through the annulus at high speed which will lead strong erosion to the drill tools. This paper proposes a cuttings-carried theory and modified the critical cuttings-carried model for the gas-solid flow. Meanwhile, the erosive energy is obtained through simulating the gas-solid mixture in different conditions. The study result has positive significance on the determination of reasonable injection volume by optimizing construction parameters of horizontal well in gas drilling.

Key words: *gas horizontal drilling, gas-solid flow, cuttings-carried theory, cuttings concentration, erosive energy*

Introduction

In gas horizontal drilling cuttings migrating at high speed could cause great erosion effect on the casing pipe, drill-string and wellbore [1, 2]. A cuttings-carried theory is much needed to modify the critical cuttings-carried model [1, 2], and the erosion on the wellbore is analyzed numerically to elucidate the erosion rule.

Critical cuttings-carried theory in gas horizontal drilling

Basic flow equation in gas horizontal drilling [3, 4]

The continuity equation in annulus:

$$\frac{\mathrm{d}}{\mathrm{d}x}\left[A\left(\phi_g\,\rho_g\,v_g+\phi_s\,\rho_s\,v_s\right)\right]=0 \tag{1}$$

The momentum equation in annulus:

$$Q_{mg}\frac{\mathrm{d}v_g}{\mathrm{d}x}+Q_{ms}\frac{\mathrm{d}v_s}{\mathrm{d}x}=-A\frac{\mathrm{d}p}{\mathrm{d}x}-p\frac{\mathrm{d}A}{\mathrm{d}x}-\frac{f_g}{2}\frac{Q_{mg}v_g}{D}-\frac{f_s}{2}\frac{Q_{ms}v_s}{D}-\rho_m Ag \tag{2}$$

The energy equation in annulus:

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$$Q_{mg}\frac{\mathrm{d}e_g}{\mathrm{d}x}+Q_{ms}\frac{\mathrm{d}e_s}{\mathrm{d}x}=-\frac{f_g}{2}\frac{Q_{mg}v_g^2}{D}-\frac{f_s}{2}\frac{Q_{ms}v_s^2}{D}-gQ_{mgs} \tag{3}$$

The critical cuttings-carried model in cuttings bed

Cuttings bed presents a state of bulk material accumulation. The bulk materials limit equilibrium equation can be signified as:

$$T_{\lim}=Nf_i+FA \tag{4}$$

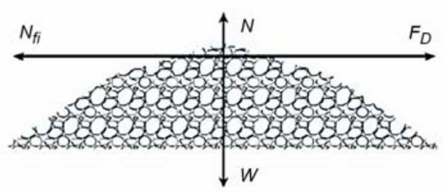

Figure 1. The force analysis of cuttings accumulation

According to fig. 1, the mechanical balance equation of particles can be deformed into:

$$F_D=f_iW \tag{5}$$

where $T_{\lim}=F_D$, $N=W$, and:

$$f_i=\mu_i+\frac{\alpha/\beta}{\mathrm{e}^{\alpha(\varepsilon-0.26)}-1+\alpha/\beta} \tag{6}$$

The theoretical critical cuttings-carried velocity equation can be derived, which reads:

$$v_g=\sqrt{\left[\mu_i+\frac{\alpha/\beta}{\mathrm{e}^{\alpha(\varepsilon-0.26)}-1+\alpha/\beta}\right]\frac{4d_s}{3C_D\rho_g}\rho_s g} \tag{7}$$

The visualization experiment of critical cuttings-carried velocity in gas horizontal drilling

Experiment phenomena

Figure 2. Rolling-saltation-continuous migration of glass particles

From fig. 2, the cuttings-carried theory in gas horizontal drilling is rolling–saltation--continuous migration.

The experimental data analysis and model modification

Table 1 shows that gas volume of saltation can be considered as critical gas volume.

Table 1. Comparison of cuttings transport modes

Cuttings	Flow rate of rolling	Flow rate of saltation	Gas volume ratio of rolling and saltation
7.8 mm	9.26 m^3/min	12.0 m^3/min	77%
6.0 mm	9.21 m^3/min	10.1 m^3/min	91%
3.0 mm	5.01 m^3/min	6.46 m^3/min	78%

Equation (7) can be modified by critical gas volume of saltation, given as:

$$v_g = 1.53\sqrt{\left[u_i + \frac{\alpha/\beta}{e^{\alpha(\varepsilon-0.26)} - 1 + \alpha/\beta}\right]\frac{4d_s}{3C_D\rho_g}\rho_s g} \tag{8}$$

The calculation equation of erosion energy is:

$$E = \frac{\rho_g \upsilon_g^2}{2}\phi_g + \frac{\rho_s \upsilon_s^2}{2}(1-\phi_g) \tag{9}$$

Examples of numerical simulation analysis

From fig. 3, the cuttings-carried theory is shown. Cuttings concentration mainly depends on gas injection rate and rate of penetration (ROP), the larger injection volume, the smaller cuttings stranded. On the contrary, the greater ROP, the bigger cuttings stranded. It can be found that under the condition of the same gas injection, ROP declines with down hole cuttings concentration at the same ratio.

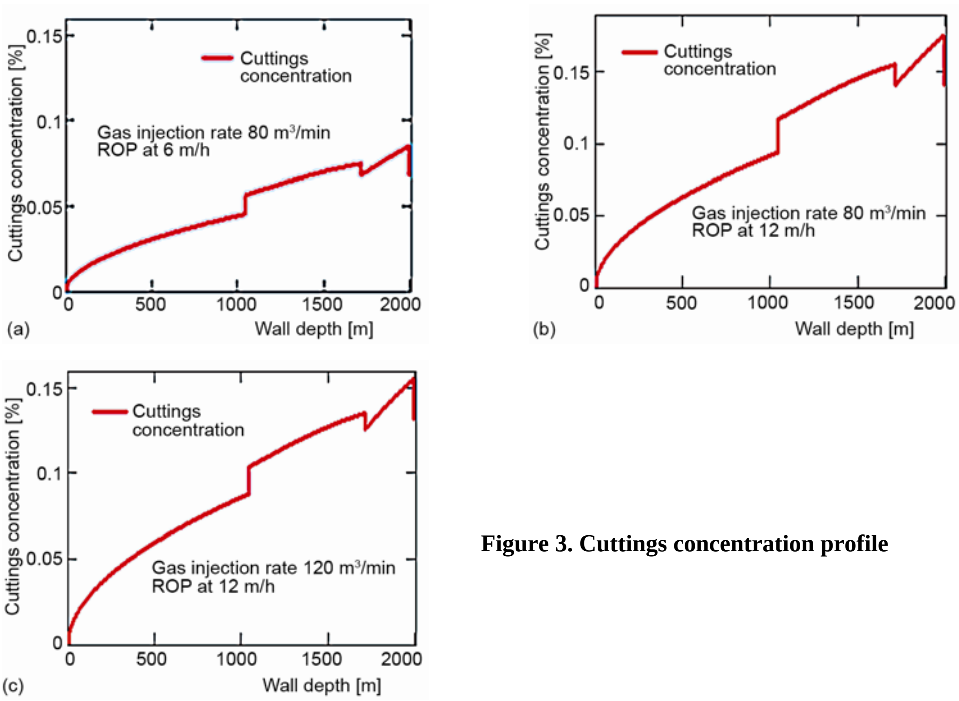

Figure 3. Cuttings concentration profile

Figure 4 shows that in the total erosion, gas erosion energy accounts for absolute subject position, and cuttings erosion energy accounts for a tiny part.

Conclusions

- The cuttings-carried theory is rolling–saltation-continuous migration. It is an important characteristic of cuttings migration that cuttings strike will generate cuttings saltation.

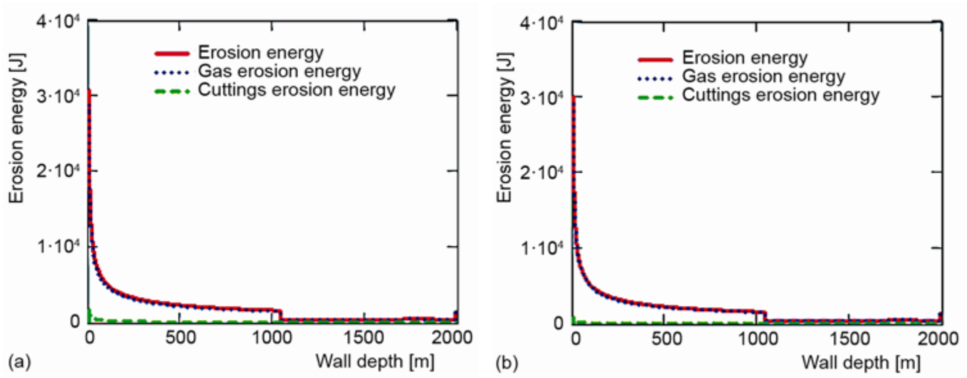

Figure 4. Erosion energy profile (gas injection rate 120 m^3/min, ROP 6 m/h and 12 m/h)

- Cuttings concentration mainly depends on gas injection rate and ROP, the larger injection rate, the smaller cuttings stranded. The increase of gas injection can improve hole cleaning extent, but less obvious than the reduction of the ROP.
- In the total erosion, annulus gas erosion energy can account for absolute subject, and cuttings erosion energy accounts for only a tiny part which mainly depends on the ROP.

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Nomenclature

A – pipe flow area, [m^2]
D – pipe diameter, [m]
f_g – gas resistance coefficient, [–]
f_{pe} – aerodynamic coefficient, [–]
f_{re} – gas aerodynamic coefficient, [–]
f_s – cutting resistance coefficient, [–]
p_g – gas pressure, [Pa]
Q_{mg} – gas flow rate, [m^3min^{-1}]
Q_{ms} – cutting flow rate, [m^3min^{-1}]
v_g – gas velocity, [ms^{-1}]
v_s – cuttings velocity, [ms^{-1}]

Greek symbols

ρ_g – gas density, [kgm^{-3}]
ρ_m – mixture density, [kgm^{-3}]
ρ_s – cuttings density, [kgm^{-3}]
ϕ_g – gas volume fraction, dimensionless
ϕ_s – cuttings volume fraction, dimensionless

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