Applied Mathematical Modelling 40 (2016) 8708–8721

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Erosion of plugged tees in exhaust pipes through variously-sized cuttings

Yong Huang*, Li-hong Zhu[1], Hua-lin Liao, De-yong Zou, Jing-yin Wang

College of Petroleum Engineering, China University of Petroleum, Qingdao 266580 P R China

ARTICLE INFO

Article history:
Received 1 June 2014
Revised 29 April 2016
Accepted 11 May 2016
Available online 26 May 2016

Keywords:
Gas drilling
Plugged tee
Erosion
Computational fluid dynamics (CFD)
Variously-sized cuttings

ABSTRACT

A plugged tee is the easily-worn part of an exhaust pipe used in gas drilling. It comprises three segments: the inlet, buffer, and outlet. The contact part of the inlet and outlet segments is called the inside joint, and the contact part of the buffer and outside segments is called the outer joint. Computational fluid dynamics (CFD) was used to simulate the erosion of a plugged tee through identically-sized and variously-sized cuttings. Variously-sized cuttings were described using Rosin–Rammler (R–R) distribution functions, and the maximal erosion rate of the erosion appearing on the buffer and joint was quantified. The motion trajectories and mass concentration distribution of cuttings were specified. The results show that an increase in particle size led to distinct motion trajectories of cuttings and a change in the erosion position of the plugged tee. The high-concentration regions of the plugged tee are distributed mainly at the inside and outside joints and the buffer. The erosion of joints is caused by small cuttings, and the erosion of the buffer segment increases with increased particle size of the cuttings. The location of the maximal erosion shifts from the joints to the buffer wall when the distribution index or characterization factor of the particle size increases. This shift is attributed to the distinct particle trajectories of variously-sized cuttings. The maximal erosion rate was determined, and it was shown that the erosion rate was sensitive to changes in the distribution index.

1. Introduction

In gas drilling a gas-based fluid is used as the circulating medium. To facilitate the effective carrying of cuttings generated in the drilling process to the ground, the velocity of the fluid in the borehole is very high, and its highest velocity approximates 100 m/s [1,2]. The gas–solid two-phase fluid results in various degrees of erosion of the wellbore, drilling tools, ground equipment, and other parts [3–7].

The exhaust pipe comprises the hose and elbow and is a necessary channel for returning cuttings. The elbow is used to convert the direction of the flow and is therefore an easily-worn part. Erosion of the elbow is an important issue in gas drilling [8–11]. According to field experience, elbows typically fail at every 30 m of drilling depth because of piercements. This results in having to change the elbow frequently, thereby negatively affecting drilling efficiency.

The erosion of the elbow through the flow that consists of compressed air entrained in the high-speed cutting is regarded as solid particle wear, and research has focused mainly on the 90° elbow. Edwards et al. [12] proposed an erosion model

* Corresponding author. Tel.:+86 18563979479; fax:+86 532 86981936.
E-mail addresses: huangyongjlu@163.com (Y. Huang), zhulihongjd_2005@163.com (L.-h. Zhu).
[1] Tel.: +86 13756927679.

http://dx.doi.org/10.1016/j.apm.2016.05.009

Nomenclature

A_{face}	calculated unit area of the wall surface, m^2
B_h	Brinell hardness of the plugged tee material
C_D	drag coefficient
C_{unit}	unit conversion constant
$C_{1\varepsilon}$	empirical constants
$C_{2\varepsilon}$	empirical constants
d_s	diameter of cutting, m
F_x	additional forces that may be acting on the cuttings, N
$\vec{g}$	gravitational acceleration vector, N/kg
G_k	production term for turbulence energy k caused by an average velocity gradient
k	turbulence energy, J
m_p	mass flow of the cuttings, kg/s
$N_{\text{particles}}$	number of collisions of the cuttings
p	pressure, pa
$p(x, y, z, t)$	pressure field, pa
R_{erosion}	erosion rate of the wall surface, kg/m^2/s
$R'_{erosion}$	unit density of the erosion rate, kg/m^2/s
S_i	generalized source term of the momentum conservation equation
t	time, s
u_i,u_j	velocity components of the fluid, m/s
u'_i,u'_j	pulsation velocity components of the fluid, m/s
u_s	velocity of the cuttings relative to the wall surface, m/s
$\overline{V_s} = \overline{V_s}(x, y, z, t)$	velocity vector of the particle, m/s
$\overline{V_g} = \overline{V_g}(x, y, z, t)$	velocity vector of the airflow, m/s
x	particle size, mm
y	cumulative mass fraction under the sieve of the x particle size, g
α	impact angle of the cutting particle to the wall surface
∇p	pressure gradient, pa/m
ε	turbulent dissipation rate
μt	turbulent viscosity, pa s
ρ	fluid density, g/m^3
ρ_{wall}	density of the wall material, g/m^3
ρ_s	cutting density, g/m^3
σ_k	corresponding Prandtl numbers of k
σ_ε	corresponding Prandtl numbers of ε

for simulating the erosion of a 90° elbow using Computational fluid dynamics (CFD) software. Chen et al. [13] compared the erosion between a right-angle elbow and a plugged tee and determined that the position of the maximal erosion rate is at an angle of 45° to the elbow. Liu et al. [14] calculated the extent of wear of an elbow's 90°using a numerical simulation and suggested that the wear is related to particle velocity, impact angle, and concentration. Yao et al. [15] studied the elbow wear of an exhaust pipe with identically-sized cuttings and determined that the maximal erosion position was in the range of 45°–60°. Lin et al. [16] and Yao et al. [17] ffectively reduced particle erosion by changing the inner wall surface structure of an elbow.

The aforementioned studies have proven that the maximal erosion position of a 90° elbow decreases the service life of an elbow. Therefore, plugged tees have been used instead of 90° elbows. The plugged tee features a buffer segment that acts as a buffer space for the gas–solid two-phase fluid and decreases the erosion rate. It is widely used in industry, and its erosion under conditions of identically-sized particles, which is different from the plugged tee erosion in gas drilling, is discussed in Deng et al. [18].

In gas drilling, variously-sized cuttings are generated by the advance of the bit. The compressed air entraining these variously-sized cuttings flows through the exhaust pipe and results in the erosion of the plugged tee. The particle-wall interactions cause erosion. If the particle size is changed, motion trajectories as well as the impact velocity, impact angle, and collision position change. Therefore, studying plugged tee erosion with variously-sized cuttings is crucial. In this study CFD was used to simulate plugged tee erosion under conditions of a gas–solid two-phase flow. Particle-wall interactions in plugged tee erosion are discussed, and the motion trajectories of variously-sized cuttings are presented. The ultimate erosion rate is closely related to the impact velocity and collision angle. The erosion extent and distribution are affected by the particle size. Research in this area is crucial to enable reducing plugged tee erosion and provide a theoretical basis for optimizing the design of plugged tees as well as prolonging their service life.