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Numerical simulation for erosion effects of three-phase flow containing sulfur particles on elbows in high sour gas fields

Enbo Zhang [a], Dezhi Zeng [a,*], Hongjun Zhu [a], Shuanggui Li [b], Dongbo Chen [b], Jie Li [c], Yanyan Ding [c], Gang Tian [c]

[a] State Key Laboratory of Oil & Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, China
[b] Research Institute of Engineering and Technology, Northwest Oilfield Company, Sinopec, Urumqi 830011, China
[c] Engineering Technology Research Institute of Xinjiang Oilfield Company, Karamay 834000, China

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ABSTRACT

Sulfur particles carried by high-speed flow impact pipelines, which may cause equipment malfunctions and even failure. This paper investigates the scouring effect of mist gas containing sulfur particles on elbows in highly sour gas fields. The multiphase-flow hydrodynamic model of the 90° elbow was established by using the computational fluid dynamics (CFD) method. The scouring effects of the gas-liquid mist fluid with the water-liquid fraction of 20% and particles with the diameter of 0.01–0.05 mm on elbows were explored within the flow velocity range of 0–20 m/s. In addition, the influences of secondary collision, mean curvature radius to diameter (R/D) ratio, inertial force, drag force, and Stokes number on trajectories of sulfur particles were studied. Moreover, the influences of hydrodynamic parameters of multiphase flow on corrosion inhibitor film were analyzed with the wall shear stress as the reference value. Serious erosion mainly occurred in the extrados of elbow as well as the junction between downstream pipeline and the intrados of elbow, the maximum erosion area occurs at 61.9°. When the incident position of the particle was far away from the top of the inlet plane, the probability of secondary collision became smaller. Furthermore, the erosion rate decreased with the rise in the R/D radio. The maximum erosion rate of elbow increased with the increase in the Stoke number. The maximum erosion rate reached 0.428 mm/a at 0.05 mm particle diameter and 20 m/s fluid velocity. The wall shear stress increased with the increase in fluid velocity and mass flow rate of particle, the fitting function of the wall shear stress curve was the Fourier type. The results indicated that high-velocity particles had a serious erosion effect on elbows and affected the stability of the corrosion inhibitor film. The erosion effect could be retarded by controlling the velocity and diameter of particles. The results provided technical supports for the safe production in highly sour gas fields.

1. Introduction

When solid particles carried by high-speed flow hit a surface, they may cause serious surface damages. Due to the variations in temperature, pressure, and other factors in the production process of natural gas with the high sulfur content, sulfur deposition occurs [1–3]. Sulfur deposition can block the production layer, reduce the productivity of gas wells, and cause equipment malfunctions (Fig. 1). The above failures may even result in enormous financial loss and severe threats to the public and environment [4]. Taking Tarim oil field for example, the drilling pipe and relief pipe frequency failure caused by particle-gas erosion in gas drilling processing has been increasing each year [5]. Particle erosion is a complex phenomenon depending on many parameters such as characteristics of carrier fluid, mass flow of sulfur particles, geometries of fitting components, the material of wall surface, and the integrality of corrosion product film [6]. Under the static flow,

* Corresponding author.
E-mail address: zengdezhiswpu@163.com (D. Zeng).
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Fig. 1. Erosion on the inner wall of an elbow.

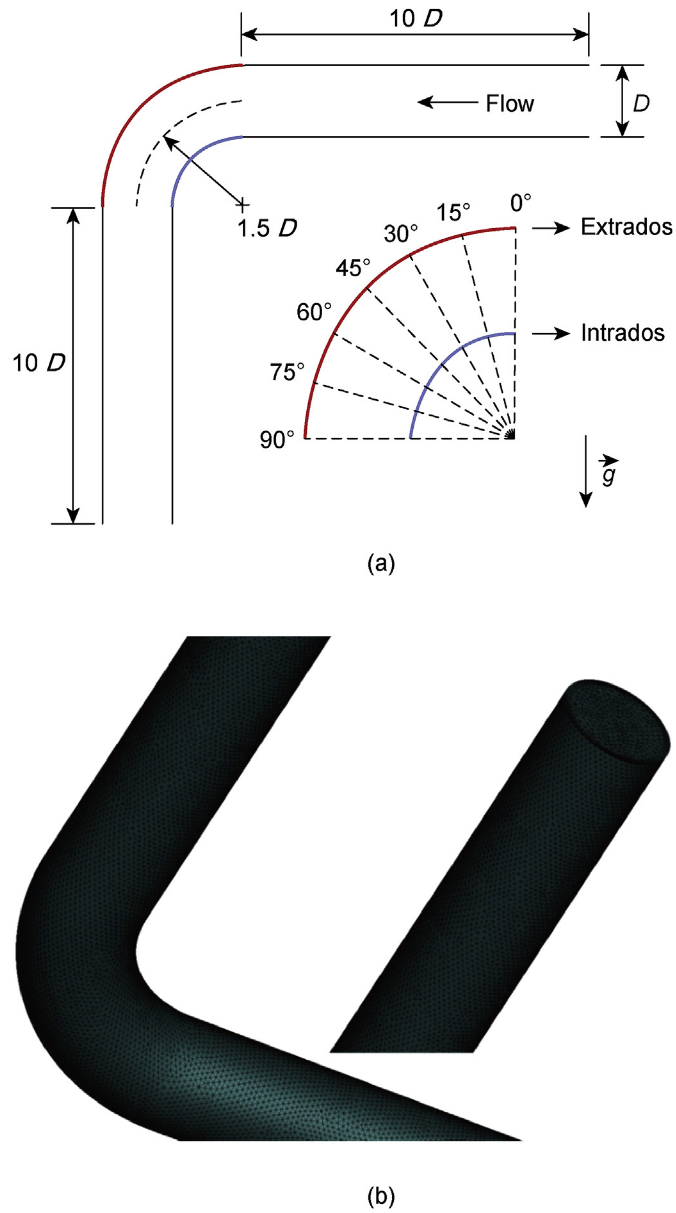

Fig. 2. Schematic diagram of computational domain and mesh of elbow: (a) Computational domain and the coordinate system of elbow; (b) Grid distribution of elbow.

corrosion product film is formed due to the action of corrosive medium, which may reduce the penetration rate. When the flow has a certain velocity, wall shear stress affects the inner wall of a device and peels off the formed corrosion product film, thus increasing the penetration rate [7]. Previous studies indicated that the erosion rate of elbows was about 50 times higher than that of straight pipelines [8]. At present, hard particles like sand particles are used as solid phase in most solid-gas erosion studies. However, compared with sand, sulfur particles have different characteristics such as smaller density, lower hardness and easy rebound. The erosion effects of sulfur particles on elbows and trajectories of sulfur particles in elbows were rarely reported. It is necessary to precisely explore the flow characteristics of conveying medium and collisions between sulfur particles and elbows in highly sour gas fields.

Corrosion inhibitor film is the main method to control corrosion in high sour gas fields. The film can effectively prevent the direct contact between the corrosion medium and the inner wall of pipes. Previous experimental data showed that the performance of corrosion inhibitor film significantly varied with the conditions of flowing medium [9].

Due to the turbulent dispersion of continuous carrier fluid, flowing medium generates shearing forces on the inner wall of pipelines. Moreover, the corrosion inhibitor film attached to the wall is ruined and the corrosion resistance loses due to the shear stress of flow [10]. Although a lot of experimental data were obtained in previous works, the stability of the corrosion inhibitor film under the flowing medium conditions in high sulfur gas fields was seldom investigated. The sulfur particle erosion was seldom studied and the scouring effects of gas-liquid multiphase flow containing sulfur particles on corrosion inhibitor film were unknown. The stability of corrosion inhibitor film under actual production conditions was not sufficiently explored. Conveying systems usually require special pipeline fittings, which cause abrupt changes in flow direction. As one of the most common parts of pipelines, an elbow is a typical vulnerable component of the conveying system and easily destroyed under the large mass flow of particles and fast carrier gas. Therefore, it is necessary to precisely explore the erosion effects of sulfur particles on elbows and the stability of corrosion inhibitor film. In some cases, the gas discharge capacity of high-yield gas wells is about 0.5 million to 1.0 million m^3/d, and sometimes may reach 1.2 million m^3/d [5]. Under such a huge output, sulfur-particle-laden gas flow with a high velocity, which may attain 20 m/s maximally. According to the actual production conditions, erosion experiment is dangerous and experimental installation is not perfect, so numerical simulation is employed in this paper.

In recent years, Computational Fluid Dynamics (CFD) technology has been widely used in many industrial fields. Afterwards, multiphase flow simulation with the discrete phase model of CFD software had been extensively explored in various fields, including the effects of parameters of the continuous phase on erosion scars [11,12], simulation of erosion rate [13,14], and modification of the erosion model [15,16]. In fact, the sites of erosion scars and the penetration rate of elbows are not only related to the physical parameters of fluid medium, but also depended on the trajectories of solid particles. Moreover, previous predictions of erosion scars were performed under different conditions by employing numerical simulation and the influences of hydrodynamic parameters of

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