Petroleum & Coal
ISSN 1337-702

Available online at www.vurup.sk/petroleum-coal
Petroleum & Coal 55 (2) 128-132, 2013

NUMERICAL SIMULATION OF THE EROSION IN BEND PIPES CAUSED BY GAS-PARTICLE FLOWS

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Received March 1, 2013, Accepted April 29, 2013

Abstract

In this paper the erosion occurred inside the bend by gas-particles flow is studied. The simulation offlow transport through the bend is conducted using Computational Fluid Dynamics (CFD) and influence of erosion in this section is evaluated by experimental relations. It is shown that erosion occurred in regions where the momentum of particle can be transferred to surface of the bend. This momentum transfer can be occurred when the velocity of the gas flow converted to pressure by impinging or changes in direction of flow streams. Besides, the local erosion and its magnitude are also simulated and influence of erosion on bend evaluated.

Keywords*:* Erosion, Bend; Computational Fluid Dynamics; Gas-particle flows.

1. Introduction

Erosion of surfaces due to the impact of small solid particles is often considered an undesirable phenomenon. Material removal due to solid particle erosion can also be desirable, for example, blast cleaning [1], or abrasive jet micromachining [2], in which a jet of small particles is used to etch components for use in micro electromechanical systems (MEMS) and microfluidic components. In gas and petroleum industry, the gas-particle flow in curved ducts are encountered in many engineering problems, for instance, cyclone separators and classifiers, pneumatic conveying of powders in transport lines, high velocity fluidization, high speed gas flows in the bend pipes and other apparatus, equipment or devices. The economic importance of erosion in this industry has led in recent years to study the treat the erosion of ductile metals from various points of view. Much useful experimental information has been obtained, but our understanding of the basic mechanisms by which solid particles remove surface material does not appear to have been greatly improved.

Many researchers have done numerical and experimental studies on solid surface wear in gas–solid flow. They usually emphasize two problems. One is the internal wear at tube side including flow in bends [3], cyclones [4] and so on. The other is the external wear at shell side including jet [5], conical bodies [6] and bared tube bundle [7]. It is found that the prevention of wear can be enhanced by increasing flow temperature and turbulence intensity, reducing particle inertial momentum and the particle–tube collision frequency, reducing the angle of attack of solid particles [8]. Additionally, among the parameters, such as the particle incident velocity, incident angle, diameter of particle and its material properties, the wall surface roughness is one of the physical parameters that govern the particle–wall collision process and the wall collision frequency [9].

However, In spite of the convenience and benefits of the curved ducts or bends in petroleum industry, many problems are also inevitable. When particles are passed through curved ducts, the particles in the gas flow may impact the bend wall and cause undesirable erosion damage. Tilly [10] demonstrated that the rate of erosion for bends is 50 times higher than that of straight pipe. For reduction of erosion, the decrease on the momentum of the impacting particles and the changes on the range of the impact incidence angle can greatly reduce seriously the erosion damage of the pipes. Song *et al.* [11] has shown that ribbed straight pipe would be subsided the occurred erosion. Fan *et al.* [12] studied a finned pipe erosion protection method.

In this paper the simulation of process paper is conducted using Computational Fluid Dynamics (CFD) and according to the results obtained by modeling of process, the influence of erosion on the surface of the bend is evaluated.

2. Computational Fluid Dynamics (CFD)

A CFD is a numerical technique which relies on solving fundamental equations of fluid motion to earn the flow field. The most general set of equations that implies Newtonian fluid flow are the well-known Navier–Stokes equations. Because of their complexity the Navier–Stokes equations have been numerically solved, which enables to obtain approximate solutions of Navier–Stokes equations for a wide variety of flow problems. For numerical calculations, the Navier–Stokes equations are time-averaged to obtain the steady-state Reynolds averaged Navier–Stokes (RANS) equations which are solved in space to obtain the mean flow field. In association with this technique, the turbulence can be approximated in a number of methods which has gained much popularity in the past few decades is the so-called k–ε model combined with the wall-function approach, which is utilized in this study. The CFD simulations done in this paper are conducted using a commercial CFD package (FLUENT).

3. Physical model

The problem considered in this investigation is effect of particles carried by gas flow on the surface of the pipe and undesirable erosion occurred in this section. Figure 1 represents a schematic of curved tube (bend). Tube diameter of the inlet and outlet are defined as D_1 and D_2, respectively and they have the same value. The radius of the bend, R, displays the curvature of tube. The gas flow transports through the pipe and after passing the bend, it discharges from the gas flow outlet. In gas flow there are some micro (or nano) particles, which carried by flow stream. These particles are undesired and can seriously damage the facilities. As seen from Figure 1, the particles have the same direction and velocity with the gas flow. After sudden changes in direction of pipe, they are impinged with surface of pipe and lose their momentum. This momentum is translated to surface of pipe and causes the small portions of pipe medium to be taken apart from pipe surface.

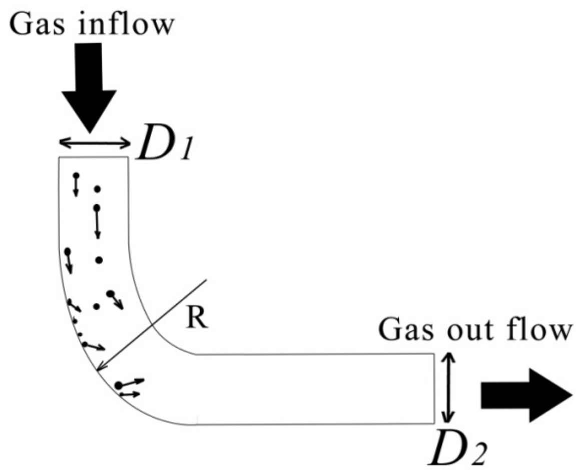

Figure 1. Schematic of bend and gas flow directions

For prediction of erosion rate, the empirical equations are conducted in association with CFD method. Experimental measurements reported by Tabakoff *et al.* [13] indicated that erosion of a target material was found to be dependent upon the particle impact velocity and its impingement angle. Experimental measurements were obtained for coal ash particles impacting steel at different impacting velocities and impingement angles. The experimental data is used to establish the following empirical equation for the erosion mass parameter, E, which is defined as the ratio of the eroded mass of the target material to the mass of the impinging particles [13]:

$$E = K_1\left\{1 + C_K\left[K_2 \sin\left(\frac{90}{\beta_0}\beta_1\right)\right]\right\}^2 V^2 \cos(1-R^2)^2 + K_3(V\sin\beta_1)^4 \quad (1)$$

where V and β_1 are the impact velocity and impingement angle, respectively. The following values are used for the variables in Eq. (1):

$$R = 1 - 0.0016V\sin\beta_1 \quad (2)$$

For β_0=20° (angle of maximum erosion)

$$C_K = \begin{cases} 1, & \text{for } \beta_1 \le 3\beta_0 \\ 0, & \text{for } \beta_0 > 3\beta_0 \end{cases} \quad (3)$$

With $K1$, $K2$ and $K3$ material constants which are found to be:
$K1=1.505101\times10^{-6}$, $K_2=0.296007$, $K_3=5\times10^{-12}$

The velocity and pressure of gas flow is specified 11 (m/sec) and 10 bars. Additionally, the diameter of pipe ($D_1=D_2$) is defined 0.25 m. the material of gas flow is Methane and its density is defined 0.66 kg/m^3.

4. Results and discussion

In Figure 2 the contours of pressure are represented in a bend. The value of pressure on the outer side of the bend is very higher than that of inlet pressure and because of the sudden change in bend direction, the pressure value of inner side of bend becomes less. This pressure is negative (vacuum) and causes the gas flow leads to this region. But the distribution of pressure in outer side of the bend covers approximately all bend surface area. The rising of pressure in outer side of bend is caused by lose of momentum in the gas flow. This value can be reached to around 29 bars.

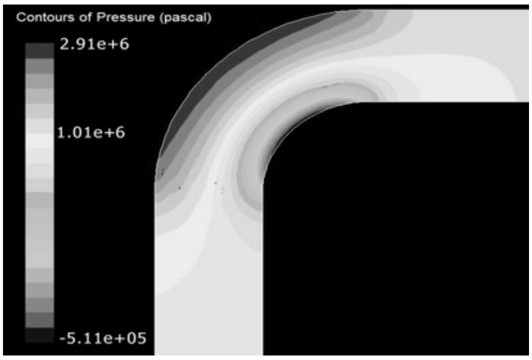

Figure 2. Contours of pressure in considered bend

In Figure 3 the contours of velocity are displayed. The inlet velocity increases in inner side of the bend because of the vacuum, as mentioned above, and the velocity at outer side of bend is approximately low. The erosion is directly related to velocity of gas flow, of course, the velocity of particles. Thus, the low velocity of gas flow at outer side of the bend demonstrates that the particles lose their momentum on the surface and subsequently accelerated again by capturing energy from flow stream.

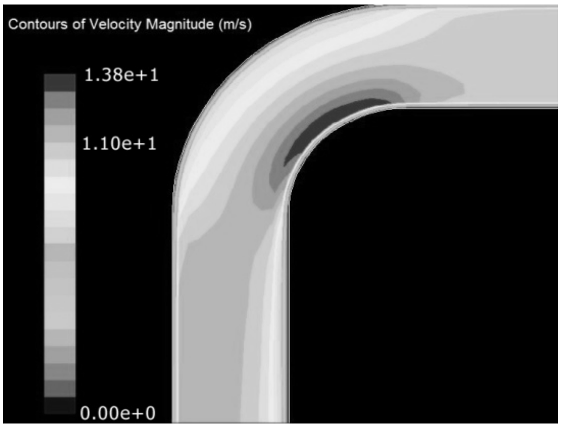

Figure 3. Contours of Velocity in considered bend

The erosion mass parameter is a parameter that represents the amount of eroded mass relative to particles conveyed by the gas flow. Figure 4 shows the erosion mass parameter in each section of the bend. As seen from Figure 4, the amount of erosion at outer side of the bend is 4×10^{-4} and this value envelopes all sections of the bend. The minimum calculated erosion mass parameter is also accounted for 2.5×10^{-6}. After passing the bend, the inner side of the pipe is also eroded because of impinging of particles to this area as a reflex action.

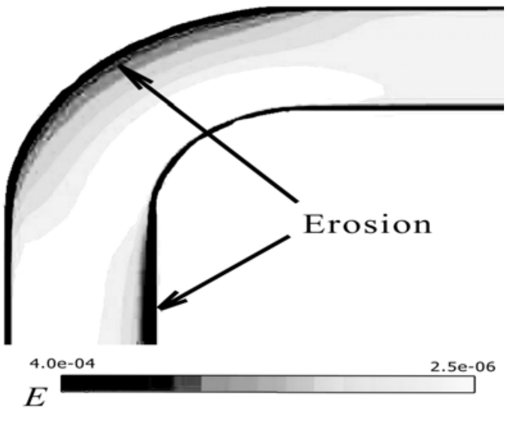

Figure 4. Contours of erosion mass parameter for considered bend

5. Conclusions

The erosion of the bend by gas-particle flows is conducted using Computational Fluid Dynamics (CFD). The method used for solving the Navier-Stokes equation numerically, is k-ε model combined with wall-function approach. The contours of the pressure and velocity of the gas flow are shown that the bend can be eroded if the velocity of the gas-particle flow is converted to static pressure and momentum transfer from particles to bend medium. This momentum transfer is occuuring when the flow would have the sudden changes in direction and velocity. Furthermore, the amount or erosion and the places where it could be occurred is investigated. It is worthy to mention that if the sudden momentum transfer occurred in the bend, all sections of the bend may be seriously eroded by impinging of particles floated in gas flow.

6. References

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