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Protection of Bend from Erosion Caused by Gas-Particle Flows in Town Border Station

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Abstract

One of the problems may be occurred in the Town Border Station (TBS) for reducing of natural gas pressure is a serious damage which follows the bends. In this paper the bend erosion by gas-particle flows is investigated. The process is simulated using Computational Fluid Dynamics (CFD) and solved by k-ε model. The particles momentum can easily transfer to surface of the bend and it increases the rate of erosion by disorder in pressure distribution and gas high velocity. For protecting bend form erosion a novel method is proposed. A multistage diffuser is installed before the bend, which influence on gas momentum and spread the velocity profile in pipe. Additionally, this process produces local turbulence, which helps erosion to drop. Overall results show the proposed method can notably reduce the rate of erosion until 51% and may be used as a procedure to reduce erosion in units where the gas pressure drop is their major duty, such as TBS.

Keywords: Erosion; Gas-particle flows; bend; Town Border Station (TBS); Natural gas

1. Introduction

Erosion of surfaces because of 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 parts for use in micro electromechanical systems (MEMS) and micro fluidic parts. In gas and petroleum industries, the gas-particle flows in curved ducts are met in many engineering problems. For instance, cyclone separators and classifiers, pneumatic conveying of powders in transport lines, high velocity fluidization, and high-speed gas flows in the bend pipes or other apparatus. The economic importance of erosion in this industry has led in recent years to study the erosion of ductile metals from various points of view. Much useful experimental information has

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been earned, 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 highlight 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 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 features, 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, despite the convenience and benefits of the curved ducts or bends in petroleum industry, many problems are also unavoidable. 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] showed that the rate of erosion for bends is 50 times higher than that of straight pipe. For decline of erosion, the decrease on the momentum of the impacting particles and the changes on the range of the impact incidence angle can 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 earned by modeling of process, the influence of erosion on the surface of the bend is evaluated. Afterwards a method is proposed to remain the bend from erosion damages. This method is applicable in units where the pressure reduction is its duty in gas industry.

2. Numerical details

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 gain estimated solutions of Navier–Stokes equations for a wide variety of flow problems. For numerical calculations, the Navier–Stokes equations are time-averaged to get the steady state Reynolds averaged Navier–Stokes (RANS) equations which are solved in space to gain the mean flow field.

In association with mentioned technique, the turbulence can be estimated in several methods, which have gained much popularity in the past few decades. One of them is *k–ε* model combined with wall-function approach and is used in this study. The CFD simulations done in this paper are conducted using a commercial CFD package (FLUENT). The momentum equation is defined as follows [13]:

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = \frac{\partial}{\partial x_j}\left[\mu_{\text{eff}}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] - \frac{\partial p}{\partial x_i} \quad (1)$$

The effective viscosity is computed using high-Reynolds-number form of following equation:

$$\mu_{\text{eff}} = \frac{\rho C_\mu k^2}{\varepsilon} \quad (2)$$

The transport equations for *k* and *ε* are written as:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho \mu_i k) = \frac{\partial}{\partial x_i}\left(\alpha_k \mu_{\text{eff}} \frac{\partial k}{\partial x_i}\right) + \mu_t S^2 - \rho\varepsilon \quad (3)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\mu_i\varepsilon) = \frac{\partial}{\partial x_i}\left(\alpha_\varepsilon\mu_{\text{eff}}\frac{\partial\varepsilon}{\partial x_i}\right) + C_{1\varepsilon}\frac{\varepsilon}{k}\mu_t S^2 - C_{2\varepsilon}\frac{\varepsilon^2}{k} - \frac{C_\mu\rho\eta^3\left(1-\frac{\eta}{\eta_0}\right)}{1+\gamma\eta^3}\frac{\varepsilon^3}{k} \quad (4)$$

where $\eta \sim Sk/\varepsilon$ and S, γ, α_ε, α_k , ρ, μ_t, η_0, $C_{1\varepsilon}$, $C_{2\varepsilon}$, C_μ are modulus of the mean rate-of-strain tensor, logarithmic particle Reynolds number, Inverse effective Prandtl number for ε, Inverse effective Prandtl number for k, Gas density, Turbulent viscosity and constants, respectively.

In this modelling, the method used to account for particle erosion is based on the calculation of the path of several individual solid particles through the flow field, the so-called Lagrangian tracking method. Each particle represents a sample of particles that follow an identical path. The motion of the tracked particles is taken to describe the average behaviour of the dispersed phase.

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) used typically in Town Border Stations. The inlet and outlet diameters are defined 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 carries out from the gas flow outlet. In gas flow there are some micro (or nano) particles, which are carried by flow stream. These undesired particles can seriously damage the facilities. As seen from Figure 1, the particles have the same direction and rate with gas flow. After sudden changes in direction of pipe, particles impinge with surface of pipe and loosen their momentum. This momentum translates to surface of pipe and causes the small portions of pipe medium to peel pipe surface.

For prediction of erosion rate, the empirical equations are conducted in association with CFD method. Experimental measurements reported by Tabakoff et al. [14] 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]:

$$E = K_1\left\{1 + C_K\left[K_2\sin\left(\frac{90}{\beta_0}\beta_1\right)\right]\right\}^2 V^2\cos(1-R^2)^2 + K_3(V\sin\beta_1)^4 \quad (5)$$

where V and β_1 are the impact velocity and impingement angle, respectively. The following values are used for the variables in Eq. (5):

$$R = 1 - 0.0016V\sin\beta_1 \quad (6)$$

for β_0=20° (angle of maximum erosion)

$$C_K = \begin{cases} 1, & \text{for}\beta_1 \le 3\beta_0 \\ 0, & \text{for}\beta_0 > 3\beta_0 \end{cases} \quad (7)$$

with K_1, K_2 and K_3 material constants which are found to be:

K_1=1.505101×10^{-6}, K_2=0.296007, K_3=5×10^{-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.

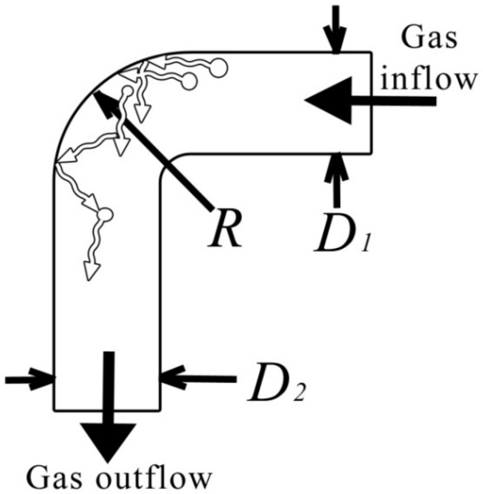

Figure 1**.** Schematic of gas-particle flow transpots through the bend

4. Results and discussion

In present work, the erosion simulation is conducted for both regular and protected bend pipes. At fist, the simulation results for regular bend is descriped. Figure 2 (a) represents the contours of pressure in a regular bend used in Town Border Station. The value of pressure on the outer side of bend is higher than that of inlet pressure and because of sudden change in bend direction, pressure value of the inner side of bend becomes fewer. This pressure is negative (vacuum) and causes the gas flow leads to this region. But pressure distribution in outer side of the bend covers around all bend surface area. The lost of momentum in the gas flow causes the pressure rising in the outer side of bend and this value may reaches to around 29 bars. Figure 2 (b) displays the contours of velocity for a regular bend. 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 roughly 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 explains the particles loosen their momentum on the surface and afterwards hastened again by capturing energy from flow stream.

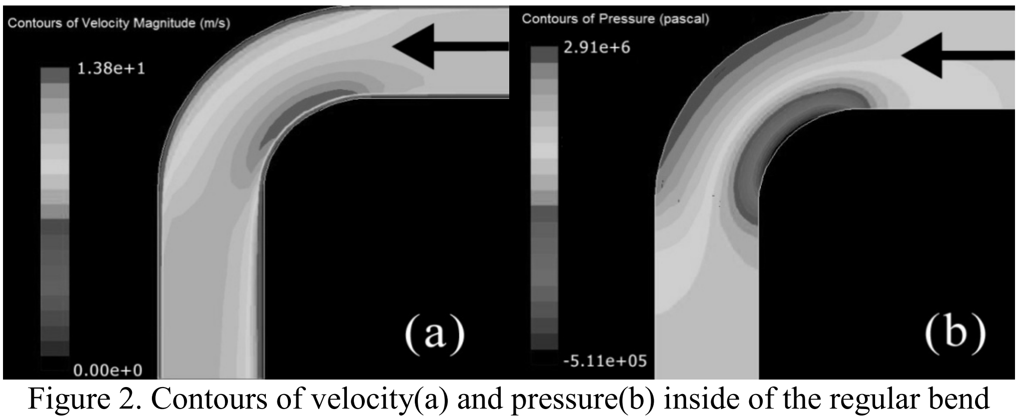

Figure 2. Contours of velocity(a) and pressure(b) inside of the regular bend

For erosion decline in bends, a novel method is developed and examined. The technique used here is to reduce momentum and velocity adjustment throughout the bend sections. This velocity adjustment causes the effect of momentum on the sides of bend becomes negligible. After passing spread velocity flow through the bend, the velocity increases again and the flow recovery to its previous conditions with a little lost of energy. For a describing the method, multistage diffuser is arranged before the bend. The feature of diffuser is drop of velocity and increasing of pressure. Thus, this multistage diffuser reduces the velocity of the gas flow moderately. If a single diffuser or throttling valve is used, the pressure reduces suddenly and this pressure drop leads some serious damages in pipeline. Some shocks on momentum and local turbulence providing by multistage diffuser can drop momentum moderately and spread velocity through the bend by. Assembling some curved blades before the bends or multistage diffusers provides local turbulence. For the next section a nozzle is set up after the bend to compensate the gas flow velocity to proper value. It should be mentioned this method has energy losses, which may influence on gas flow pressure. As mentioned, the TBS is a place for drop of gas pressure to distribute it into urban pipelines.

Figure 3 (a) shows the contours of velocity in a protected bend. In multistage diffuser the gas flow velocity increases and then it reduces because of energy lost and local turbulence. These changes in gas flow velocity lead the gas velocity spread throughout the bend. Thus, the outer side of bend is not highly impacted. Figure 3 (b) can show this action. As seen, the gas pressure gives out throughout the bend, and all regions have nearly same pressure contours. The pressure reduces insignificantly after passing the multistage diffuser. The conclusion can be drawn is the gas flow velocity reduces and spread throughout the bend sides, while the pressure variations is negligible. It is worthy to mention the simulation is done based on the isolated tube and bend. Thus, heat transfer effect isn't considered in this modeling. This process has some energy lost may be notable, but energy lost is helpful in remarked process.

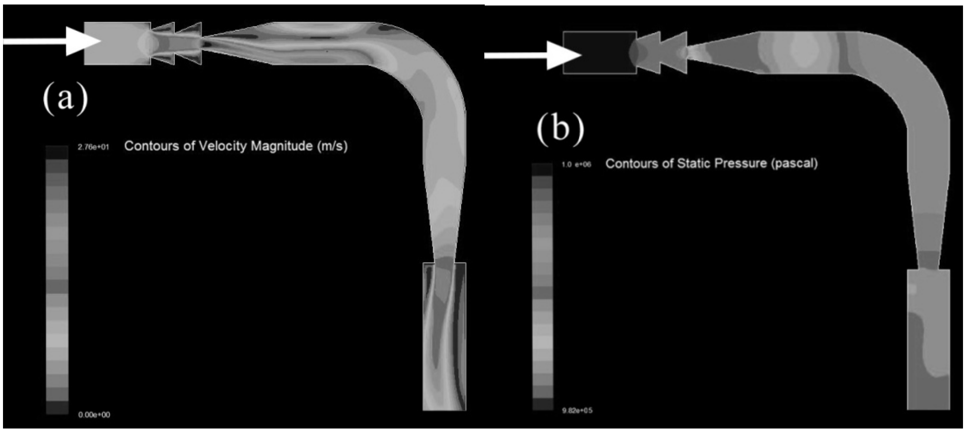

Figure 3. Contours of velocity and pressure inside of the protected bend

The erosion mass parameter is a feature that represents quantity of eroded mass to particles transferred by the gas flow. Figure 4 shows the erosion mass parameter in each section of the bend. As seen from Figure 4 (a), the erosion quantity at the outer side of regular bend is 4×10^{-4} and this envelops all bend sections. The minimum calculated erosion mass parameter is also accounted for 2.5×10^{-6}. After the bend, inner side of pipe is also eroded because of particles impinging to bend area as a reflex action. Figure 4 (b) displays erosion quantity for protected bend. In protected bend the erosion is occurred only in one regions remarked by arrow. The high-speed gas relieved from multistage diffuser is responsible for remarked erosion. For erosion drop in this region, multistage diffuser must be set up a bit far from bend. In protected bend the rate and erosion quantity are low and this may display influence of the proposed method to erosion drop.

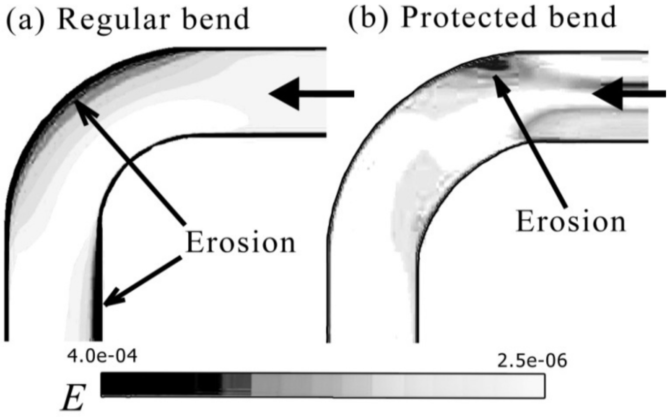

Figure 4. Contours of eroded mass parameter for both regular and protected bends

For quantitative evaluations on erosion process, Figure 5 and Figure 6 are provided. In Figure 5 the rate of erosion for target material relative to rate of impinging particle is computed in different bending angles. The bending angle is an angle describing the curvature position of outer side of the bend and is ranged from 0 to 90 degrees. As it is shown, the maximum erosion occurs in bending angles between 30-50 degrees. In lower and higher bending angles the erosion rate will decrease. Figure 6 displays the erosion reduction as the percentage form for protected bend with respect to regular bend. As it is shown, the protected device can significantly reduce the erosion rate in bend pipes. The minimum reduction is around 25% in bending angle of 15 degree. Furthermore, the maximum erosion reduction is approximately 70% in bending angle of 45 degree. The mean erosion reduction is also calculated of 51% and this value demonstrates the strong effect of protected device. It should be noted that increasing of gas flow rate causes the fluid velocity and the amount of impinging particles to increase, and hence, in this condition the erosion rate will increase. Furthermore, the particle size and its density have also notable effect on erosion rate. However, decreasing of particle size, number and density in fluid flow will help to erosion reduction.

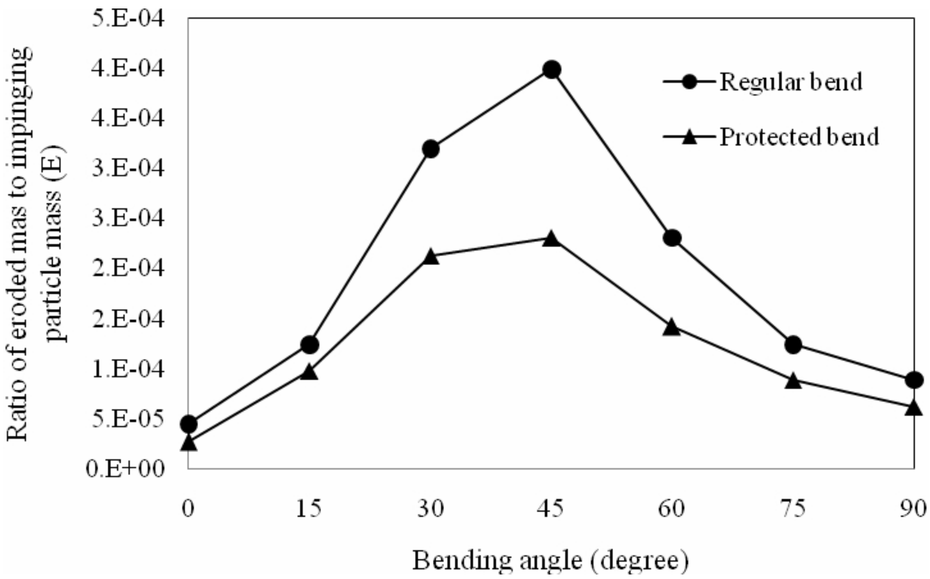

Figure 5. Comparision of eroded mass with respect ot impinging particle mass for both regular and pretected bends in different bending angles.

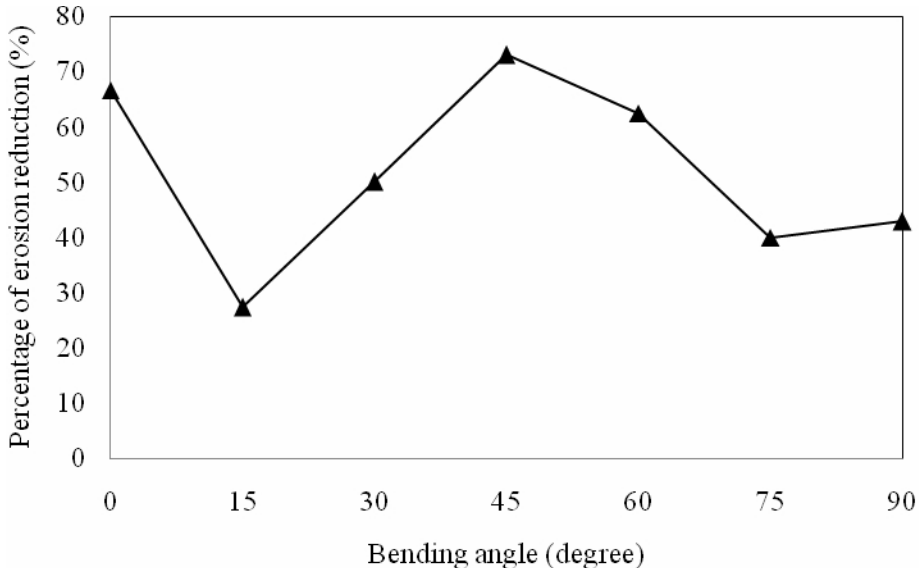

Figure 6. Erosion reduction for protected bend with respect to regular bend in different bending angles.

5. Conclusion

A novel method for protecting of bend from erosion in gas-particles flow in Town Border Station (TBS) is proposed. The method summarizes the setting up of multistage diffuser and nozzle before and after the bend, respectively. The proposed method is simulated using Computational Fluid Dynamics (CFD) and solved by k-ε model. While the methane gas under proper condition with some particles transports through the bend, it affects on the surface of bend. It is shown the disorder in pressure distribution and velocity causes the rate of erosion to be increased. In this case, the particles momentum can easily transfer to surface of the bend. Thus, the small portions peel from the bend surface. In proposed method, the velocity and pressure spread throughout the bend and therefore, some local turbulence is produced. This procedure causes the rate of erosion to be notably decreased and this method can be used for protecting the bend from erosion. The maximum erosion reduction is reported of 70% and the mean erosion reduction factor is computed around 51% over whole of bend.

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