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Erosion in ducts supplying exhaust gas to electrostatic precipitators due to gas-solid two-phase flow – numerical simulation

Introduction

Erosion of metals occurs when solid particles carried by a stream of gas or liquid impinge against the metal surface and remove microscopic particles from that surface. As a result, the destruction of the material is observed, leading to industrial equipment failure. Erosion has been the subject of research, both experimental [*Achim et al., 1999; Chen et al., 2004; Gnanavelu et al., 2009*] and theoretical [*Manickam et al., 1999; Arefi et al., 2005, Das et al., 2006*] for many years. One of the systems in which erosion may occur is duct supplying exhaust gas to electrostatic precipitator. Solid particles in the form of ash originate mainly from burning of coal. Particles suspended in the flowing gas stream act destructively on metal, such as duct housing and driving elements in the form of vanes which ensure uniform distribution of flow velocity in a cross section of the duct. The erosion leads to disturbance in the proper operation of the electrostatic precipitator, causing a reduction in its efficiency. As a result, gas at the outlet of the electrostatic precipitator contains too much solid particles.

Numerical methods which are being increasingly used to model flow phenomena in electrostatic precipitators [*Huser and Kvernvold, 1998; Skodras et al., 2006; Haque et al., 2009*], also allow modeling the erosion phenomenon.

In this article, the CFD code ANSYS CFX was used to model the erosion processes in ducts supplying exhaust gas to electrostatic precipitators. To do this, the geometric model of the system under consideration was created by means of Design Modeler software. The solution domain was first divided into a large number of finite volumes. Then the boundary conditions were applied and the model was verified numerically. The results obtained in the form of erosion distribution allow easily detecting the regions which are most vulnerable to erosion. Moreover, the quantitative analysis of this phenomenon is also possible.

Erosion calculation

The erosion was calculated based on the model developed by *Finnie* [*1960*]:

$$E = kV_p^n f(\gamma) \tag{1}$$

where:

k – constant that depends on eroding material properties
V_p – velocity of the impacting particles
n – empirical coefficient
γ – angle at which the particle strikes the material
f – dimensionless wear function:

$$f(\gamma) = \frac{1}{3}\cos^2\gamma \quad \text{if} \quad \tan\gamma > \frac{1}{3} \tag{2}$$

$$f(\gamma) = \sin(2\gamma) - 3\sin^2\gamma \quad \text{if} \quad \tan\gamma \le \frac{1}{3} \tag{3}$$

The model assumes that a hard particle with velocity V_p, approaches the eroding surface at angle,γ measured from the surface (called the impingement angle) and removes material in much the same manner as a machine tool would. It is assumed that the particle is much harder than the surface and does not break up. It is also assumed that the surface material deforms plastically during the cutting process (the material is ductile). Ductile materials, such as aluminum or structural steel, can develop a relatively large tensile strength before they rupture [*Mazur et al., 2004*].

Geometric model

The geometric model adopted for the simulation consists of an inlet duct, the diffuser and part of the electrostatic precipitator chamber. To avoid non-uniform distribution of exhaust gas velocity in a cross section, and consequently, the excessive erosion, guide vanes were located everywhere where the velocity vector should change direction. There are two curved guide vanes in the elbow region of the inlet duct and two horizontal straight vanes (upper and lower) in the horizontal section of the inlet duct. In diffuser, there are two horizontally slanted vanes (upper and lower) and two vertically slanted vanes (left and right when facing the outlet of the diffuser). The inner surface of guide vane means its view from the bottom, the outer surface – its view from the top (depending on whether the person is under or over the electrostatic precipitator).

Analysis of the simulations

In the initial phase of the flight, the ash particles encounter an elbow part of the duct, where they fall out of the main stream of gas (as the effect of the centrifugal forces of inertia) and flow toward the outside part of the duct. Solid particles strike the curved guide vanes (Fig. 1) and cause the erosion of their surfaces, mainly the inner ones.

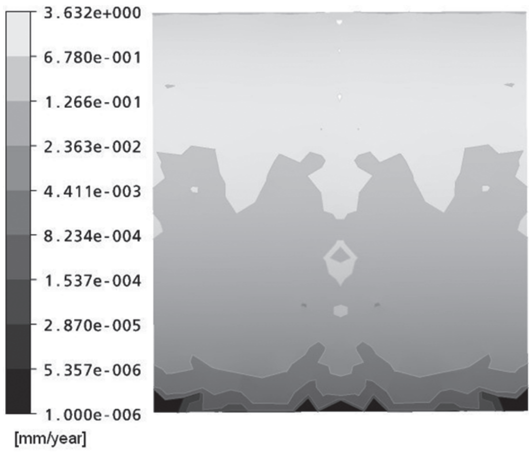

Fig. 1. Curved guide vane in the elbow (the inner surface)

The remaining particles flow to the outside surface of the housing. There, they move along that surface in the direction of the outlet, inducing erosion of the housing. After leaving the curved vanes in the elbow, particles are still under the action of the forces of centrifugal inertia that cause their streams to move up slightly. That is why the horizontal guide vanes (lower and upper) placed in a further horizontal part of duct do not intersect the streams exactly in the middle. At this stage, three independent streams (lower, middle and upper) of ash particles can be also noticed.

The lower stream flows over the inner surfaces of lower guide vanes, both horizontal (in the duct) (Fig. 2) and horizontally slanted (in the diffuser) (Fig. 3), causing significant erosion whereas the erosion of their outer surfaces is very small.

As regards straight horizontally oriented guide vane, erosion is noticeable only in this part which enters the ash stream, whereas almost

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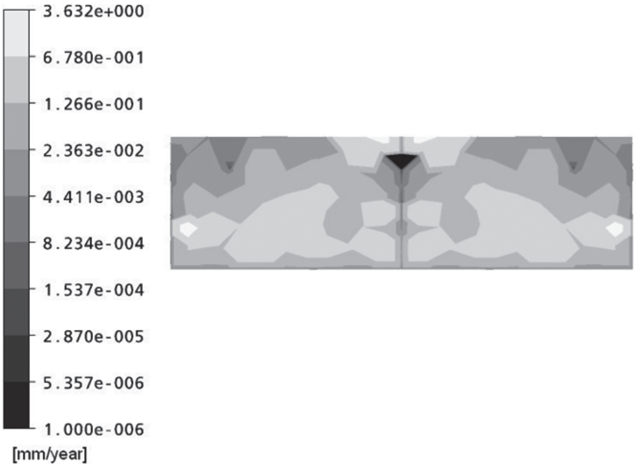

Fig. 2. Horizontal guide vane in the duct (the inner surface)

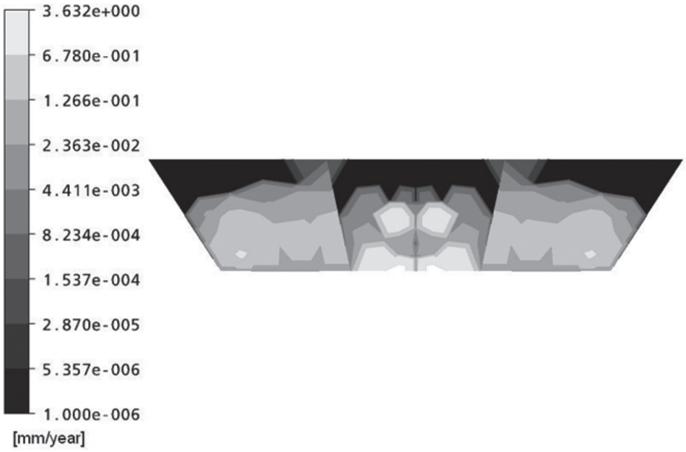

Fig. 3. Horizontally slanted guide vane in the diffuser (the inner surface)

no traces of erosion are observed in the case of vertically slanted vane. As for the middle stream, the situation is somewhat different. The upper horizontally oriented guide vane in the duct and horizontally slanted vane in the diffuser are immersed in the ash stream to a greater extent. However, in the case of the upper horizontal vane, it does not imply that it is eroded more than the lower straight vane. This is because the angle at which ash particles hit the inner and outer surfaces of the upper guide vane is much smaller. The outer surface of the horizontally slanted vane in the diffuser deflects the flow upwards. Therefore, it is greatly exposed to the action of the ash stream, and hence the extent of its damage is very high.

Vertically slanted vanes in the diffuser behave in a similar manner, i.e. their outer surfaces (Fig. 4) deflect the ash streams to the left side (left guide vane) or to the right side (right guide vane) of the diffuser.

Three major contours of erosion noticed at the outer part of these vanes identify the path of flow of each constituent stream. The unit in which the magnitude of erosion is expressed is [mm] of worn material per year. On the basis of obtained results, in the form of the distribution of erosion values, it is possible to estimate in an easy way the time of damage of material which was used in duct construction.

Conclusions

The approach presented in this article allows detecting the places most vulnerable to erosion, determination of the erosion magnitude and finding of the reason of its occurrence.

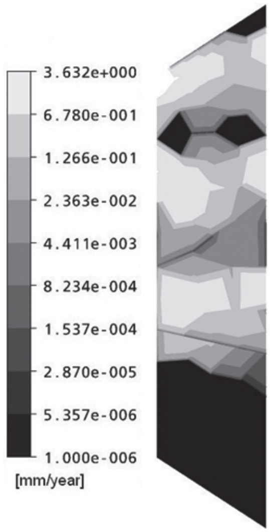

Fig. 4. Vertically slanted guide vane in the diffuser (the outer surface)

Numerical simulations using CFD software is a fast and economic way of erosion prediction in systems supplying the contaminated gas to electrostatic precipitators and could be used before their physical implementation.

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