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Numerical Study of the Solid Particle Erosion on H-Type Finned Circular/Elliptic Tube Surface

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Abstract. In this paper, numerical simulations of solid particle erosion phenomena on H-type finned circular/elliptic tube surface, which is of great significance to the anti-wear design of heat exchanger, are presented. The Eulerian-Lagrangian approach is applied to simulate the dilute gas-solid flow through H-type finned circular/elliptic tubes. A semi-empirical model is adopted to predict the erosion rate. The dynamics behavior of the entrained solid particles in the flow is presented. The geometry of eroded tube surface is changed with the predicted erosion which is taken into account by a UDF and the flow field is re-solved for the eroded tube surface at every time step. The influences of ten parameters (the tube bundle arrangement, particle size, particle concentration, fluid Reynolds number, fin thickness, fin pitch, fin length, fin width, slit width and the transverse tube pitch) on the maximum erosion depth of the H-type circular/elliptic finned tube surface are investigated. Using H-type finned elliptic tube surface can effectively reduce the erosion rate of tube surface compared with that using H-type finned circular tube surface. The erosion in in-line arrangement is less severe than that in staggered arrangement. With the increase of particle size, particle concentration and the fluid Reynolds number, the erosion rate of the tube surface rises. The numerically predicted effect of Reynolds number is in good agreement with previous test data. Among the six geometry parameters, the most influential parameter is the transverse tube pitch.

AMS subject classifications: 80A20, 76Fxx

Key words: Waste heat recovery, H-type finned circular/elliptic tube, solid particle erosion, numerical simulation.

1 Introduction

In coal-fired power plants, a mass of fly ash would be produced due to the burning of pulverized coal in the boiler burners. When the high temperature gas mixed with ash

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particles flows over tube bank, the heat exchangers have to be operated in contaminated environments. The ash particles collide with the surface of the heat exchanger tubes, thus the material surface is eroded. At the most severe situation, the tube walls can be perforated, which leads to a significant reduction of the tubes' performance life. Therefore, the study on erosion process and erosion characteristics of dusty gas flowing across heat exchanger tube bundle is of great importance.

Solid particle erosion of surface is a micromechanical process that is influenced by numerous factors, including flow condition, tube bank geometry, target material, particle size and shape, particle velocity, impact angle and fluid properties. Many experiments have been conducted on the wear of a surface through the solid particle erosion. Early in the 1960 Finnie [1] experimentally studied the erosion by solid particles on different surface materials, and the results indicate that the effects of particle velocity and impact angle on the erosion of a brittle material and a ductile material are very different. The first erosion model was proposed based on his experimental results. Later, Tabakoff et al. [2] carried out the experiments to study the erosion of coal ash particles on different alloys and presented a new erosion model, which is widely adopted to predict the erosion rate of surface by coal ash particles. Bauver et al. [3] carried out well-defined experiments to predict the erosion of boiler tube and obtained the detailed erosion distribution on tube surface. Schade et al. [4] designed a test facility to investigate the characteristics of particle-wall impact and measured the restitution coefficient and friction coefficient of the particle-wall impact by this experimental setup. Li et al. [5] experimentally investigated the wear characteristics of three types of heat transfer tubes with special nickel infiltration layers and suggested that the application of this tube may effectively improve the working life of heat transfer equipment in high temperature dusty gas flows. Deng et al. [6] studied particle rotation's effects on the erosion rate of metals and proposed that the rotation direction of the angular particles has a most important effect on the erosion rate of the target materials at low impact angles. With the development of computer technology, numerical research has become an important method of erosion prediction. The numerical studies on erosion rate of heat exchanger tube bundle were widely conducted. Fan et al. [7] numerically investigated the collision frequency of coal particle and the erosion distribution of bare tube surface and claimed that the numerical results were in good agreement with the experiment data. Tu et al. [8] adopted the two-fluid turbulence model with a developed particle-wall collision model to predict the trajectories of fly-ash particles in power utility boilers and proved that the Stokes number of particles has a significant effect on the particle distribution character. Fan et al. [9] numerically studied the particle collision and bare tube erosion characteristics and suggested that the fixing fins on tubes can easily and efficiently reduce the erosion damage of tube. Lee et al. [10] numerically studied the fly-ash erosion of single tube by the Eulerian approach and the numerical results are in good agreement with experimental data. Jin et al. [11] conducted numerical simulations to investigate the erosion characteristics of two-row bare tubes and obtained particle collision and erosion distributions of tube surface. Lee et al. [12] adopted both the Eulerian and Lagrangian methods to study the particle flow