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Anti-wear beam effects on gas–solid hydrodynamics in a circulating fluidized bed

Yunfei Xia, Leming Cheng*, Chunjiang Yu, Linjie Xu, Qinhui Wang, Mengxiang Fang

State Key Laboratory of Clean Energy Utilization, Zhejiang University, Hangzhou 310027, China

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ABSTRACT

Anti-wear beams installed on water walls of circulating fluidized bed (CFB) boilers are one of the most effective ways to protect against water-wall erosion. Beam effects from, for example, beam size and superficial gas velocity were investigated on gas–solid hydrodynamics in a CFB test rig using CFD simulations and experimental methods. The downward flow of the wall layer solids is observed to be disrupted by the beam but is then restored some distance further downstream. When falling solids from the wall layer hit the anti-wear beam, the velocity of the falling solids decreases rapidly. A fraction of the solids accumulates on the beam. Below the beams, the falling solids have reduced velocities but upward-moving solids were observed on the wall. The effect of the beam increases with width and superficial gas velocity. Wear occurs mainly above the beam and its variation with width is different above to below the beam. There is an optimum width that, when combined with beam height, results in less erosion.

Introduction

Background

Because they constitute highly efficient clean coal combustion technology, circulating fluidized bed (CFB) boilers have rapidly developed in recent years to attain larger capacity and higher steam parameters. Approximately 70 units of 300 MWe CFB boilers were built or put into operation in China in recent years. When the 460 MWe Lagisza supercritical CFB boiler went into operation in June 2009, it was the first and largest once-through supercritical CFB boiler in the world. Today, the world's largest supercritical CFB boiler is at the Baima power generation plant in Sichuan, China. It has a capacity of 600 MWe and has completed 168 h of operations as of April 14, 2013.

However, wear on heat-transfer surfaces, especially on the water wall in a CFB furnace, is a major problem and affects the security and stability of CFB boilers, which detracts from the overall benefits of these boilers.

In a CFB boiler furnace, the solid particles move up and down. They accelerate down along the water wall, which wears out anywhere along the path of the gas–solid downflow on its surface, and thus suffers continuous erosion. Cen et al. (1997) concluded that the wear rate of the water wall was proportional to the concentration of solids at its surface and speed of solids with powers typically in the range 3.0–3.5.

One efficient way to protect against water-wall erosion is to install multi-stage anti-wear beams on the water wall (Fig. 1). Such beams can effectively disrupt the gas–solid downward flow of the wall layer in the near-wall region, reducing the downflow speed and inhibiting water-wall wear. This technology has been applied in 300 MWe CFB boilers, and good results have been reported. Several different anti-wear beam designs (Fig. 2) have been proposed (Xia, Cheng, Zhang, Wang, & Fang, 2013).

Gas–solid hydrodynamics, especially the gas–solid downward flow at the wall layer, are affected by installing these anti-wear beams. Understanding their influence is very important because they affect the chemical reactions and heat transfer between gas and solids, the gas–solid and heat-transfer surfaces, and wear patterns and wear rate over the water wall. In some modified CFB boilers, installed anti-wear beams increased temperatures in the furnace as well as the exhaust gas and the amount of desuperheated water of the superheater (Cao, Liang, & Zhang, 2011; Xiao et al., 2009).

Abbreviations: NW, nearest side-wall grid region; UMS, upward-moving solids.

* Corresponding author. Tel.: +86 571 8795 3208; fax: +86 571 8795 1616.
E-mail address: lemingc@zju.edu.cn (L. Cheng).

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Nomenclature

d_p	average particle diameter (μm)
E	wear (mg/g)
E'	relative wear
E_t	total wear (mg/g)
H_s	static bed height (m)
h_{hs}	height of the higher solids concentration zone in the NW region (mm)
h_s	height of the anti-wear beam in the furnace (mm)
h_0	height of the anti-wear beam on the wall (mm)
M_s	solids mass flux at the feedback inlet (kg/s)
S	width of the anti-wear beam (mm)
t	computation time (s)
u_p	solids vertical velocity (m/s)
u_{pm}	magnitude of the particle velocity (m/s)
u_t	terminal velocity of the particles (m/s)
u_x	absolute value of the particle velocity in the horizontal direction (m/s)
u_0	superficial gas velocity (m/s)
X	X-axis of the test rig model (width, m)
Y	Y-axis of the test rig model (depth, m)
z_h	height of the wall covered by upward-moving solids (mm)
z_{lvof}	axial distance of the region of lower volume fraction of solids (mm)
z_{NW}	axial distance of the region of lower volume fraction of solids on the wall (mm)
Z	Z-axis of the test rig model (height, m)

Greek letters

γ_g	gas viscosity (m^2/s)
γ_s	solids viscosity (m^2/s)
ε_r	relative volume fraction of solids
ε_s	volume fraction of solids
ϕ_s	sphericity of a particle
θ	impact angle of the particle on the wall surface (°)
ρ_b	solids bulk density (kg/m^3)
ρ_g	gas density (kg/m^3)
ρ_s	solids real density (kg/m^3)

For a large commercial CFB boiler, such as the 300 MWe CFB unit and the 600 MWe supercritical CFB boiler, on-site measurements are not permissible because they would influence the normal operations. Numerical simulations of variations in gas–solid hydrodynamics resulting from the anti-wear beam and laboratory-scale experimental investigations are sensible alternatives to on-site measurements.

Literature overview

Kim et al. (Kim, Choi, Shun, Kim, & Kim, 2008; Kim et al., 2007) measured the erosional tube thickness profiles of water walls in a large commercial CFB furnace using an ultrasonic thickness gauge. They concluded that the wear rate of the water wall at some positions in the furnace was large in relation to the gas–solid hydrodynamics on the water-wall surface. Lockhart, Zhu, Brereton, Lim, and Grace (1995) found that in a CFB model the erosion was more severe at the crest of the membrane tubes than along the fin because the crests of tubes were more exposed to impacts by particles with substantial horizontal components of velocity, whereas the fins were protected by layers of particles traveling parallel to the surface.

Fig. 1. Anti-wear beams on the water wall.

Because they have significant effects on the wear and heat transfer over the water wall, the gas–solid hydrodynamics in the wall layer have been studied extensively. In terms of numerical simulations, Zhang, Lu, Wang, and Li (2010) simulated the gas–solid hydrodynamics of a 3D, full-loop, 150 MWe CFB boiler using the Eulerian–Eulerian model and reported good results for the core-annular structure with data on the volume fraction of solids and the solids velocity in the wall layer. The gas–solid hydrodynamics in the wall layer were also obtained (Hartge, Ratschow, Wischnewski, & Werther, 2009; Mathiesen, Solberg, & Hjertager, 2000) using numerical simulations of their CFB units.

In terms of experimental studies, Hartge, Budinger and Werther (2005) carried out measurements with water-cooled probes in a 235 MWe CFB boiler in Poland. They found that the wall layer thickness increased as the bed height decreased and that the solids-falling velocity in the wall layer may be up to 8 m/s. Chandel and Alappat (2006) investigated the characteristics of the wall layer in a CFB test rig using a high-speed video camera to trace particles.

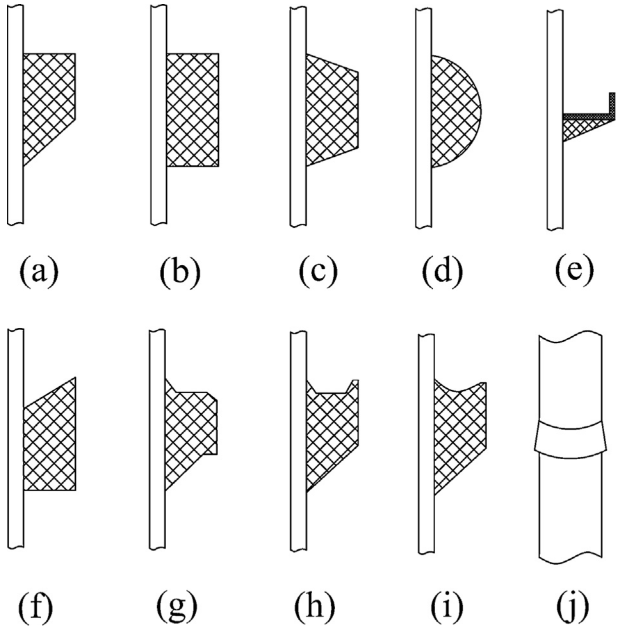

Fig. 2. Different anti-wear beam designs.