Advanced Powder Technology 25 (2014) 281–291

Contents lists available at SciVerse ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

Design optimization of the bell type blast cap employed in small scale industrial circulating fluidized bed boilers

Xuanyu Ji [a,*], Xiaofeng Lu [b,*], Yinhu Kang [b], Quanhai Wang [b], Juan Chen [c]

[a] College of Mechanical and Power Engineering, Chongqing University of Science & Technology, Chongqing 401331, People's Republic of China
[b] Key Laboratory of Low-grade Energy Utilization Technologies and Systems, Chongqing University, Ministry of Education, Chongqing 400044, People's Republic of China
[c] Sichuan Special Equipment Inspection Institute, Chengdu 610061, People's Republic of China

ARTICLE INFO

Article history:
Received 18 December 2012
Received in revised form 16 April 2013
Accepted 29 April 2013
Available online 9 May 2013

Keywords:
Circulating fluidized bed boiler
Bell type blast cap
Horizontal jet
Resistance coefficient

ABSTRACT

Blast cap is the key component of air distributor in circulating fluidized bed (CFB) boilers. Its configuration and performance affects the fluidization quality of the bed, as well as the boiler performance. With the advantage of controlling the jet penetration characteristics and the resistance coefficient individually, bell type blast cap has been widely applied in big-scale utility CFB boilers. Moreover, the inner circuitous gas pass of the bell-type blast cap is able to prevent the bed material from flowing backward into the air chamber effectively, and its tube shield is also convenient to be maintained and replaced. Consequently, the bell-type blast cap is also fit for the small scale industrial CFB boilers with lower operation and maintenance levels in spite of higher manufacturing cost. At present, bell type blast cap is mainly applied in the large scale utility CFB boilers, seldom employed in the small scale industrial CFB boilers with lower bed pressure drop. In the study, aim to acquire favorable fluidization quality and reasonable pressure drop of the bed of small scale industrial CFB boiler, the air jet penetration characteristics of the bell type blast cap were investigated in static beds composed of two typical solids in CFB individually, and the impacts of the inner configuration on blast cap's resistance characteristics were studied via numerical simulation. The detailed design principle and approach of bell type blast cap was proposed finally based on the study results.

1. Introduction

Blast cap is the key component of air distributor in circulating fluidized bed (CFB) boilers. Its configuration and performance affects the fluidization quality of the bed, as well as the boiler performance [1–4]. Generally speaking, the exit jet penetration characteristics and resistance characteristics are the most important properties for a blast cap. First of all, for acquiring uniform fluidization and avoiding poor fluidization locally in the bed, the jet penetration length need to be higher enough to reach the middle zone between two adjacent blast caps; On the other hand, proper resistance of the blast cap is able to make the gas velocity distributed in a uniform profile above the air distributor, thus to ensure the fluidization quality, and meanwhile keep the power consumption of air blowers at a economical level. Practical operational experiences indicated that: the appropriate ratio of the air distributor resistance over the whole fluidized bed is proposed to be 25–30%. In the range, the fluidization quality and the economical efficiency of power consumption are able to be well balanced [3,5].

With the development of circulating fluidized bed (CFB) boilers, various types of blast caps had been invented and commercial applied successfully, such as column type blast cap, mushroom type blast cap, pig-tail-shaped blast cap, Γ-shaped blast cap, T-shaped blast cap, arrow type blast cap, and bell type blast cap [6–8]. Among these blast caps, the bell type blast cap (Fig. 1) had been widely used in large scale CFB utility boilers; it could be attributed to its capability of controlling the exit jet penetration characteristics and the resistance coefficient individually. Meanwhile, the inner circuitous gas pass of the bell type blast cap was able to prevent bed material from flowing backward into the air chamber effectively, and its tube shield was also convenient to be maintained and replaced. Consequently, the bell type blast cap was also fit for the small scale industrial CFB boilers with lower operation and maintenance levels.

At present, bell type blast cap was mainly applied in the large scale utility CFB boilers, but seldom employed in the small scale industrial CFB boilers. It was because that the manufacturing process of bell type blast cap was more complex than normal blast cap and its manufacturing cost was relatively higher accordingly; And

* Corresponding authors. Tel./fax: +86 18990511698 (X. Ji), tel./fax: +86 23 65102475 (X. Lu).
E-mail addresses: jixuanyu@sina.com (X. Ji), xfluke@cqu.edu.cn (X. Lu).

0921-8831/$ - see front matter
http://dx.doi.org/10.1016/j.apt.2013.04.016

Nomenclature

d	mean diameter, m
G	generations of turbulent energy caused by velocity gradient and buoyancy, kg/ms^3
h	solids bed height, m
k	correction coefficient
p	pressure, Pa
u_0	initial jet velocity, m/s
v	axial velocity of the jet stream, m/s
Y_m	term representing the influence of compressible turbulent fluctuation expansion on the dissipation rate
ε	dissipation rate of the turbulence energy, m^2/s^3 voidage of the bed
κ	turbulence energy, m^2/s^2
μ	turbulent viscosity, Pa s
ρ	density, kg/m^3
σ	Prandtl number
ξ	resistance coefficient

Subscripts

j	jet stream
ε	dissipation rate of the turbulence energy
κ	turbulence energy
s	solids
eff	effective

most importantly, the resistance coefficient of normal bell type blast cap was also relative higher, thus it was fit for the large scale utility CFB boiler with higher bed pressure and could not adapt to the lower bed pressure of small scale industrial boiler. In the study, aim to acquire favorable fluidization quality and reasonable pressure drop of the bed of small scale industrial CFB boiler, the exit jet penetration characteristics of the bell type blast cap was investigated in static beds with two typical solids in CFB individually, and the impacts of the inner configuration on blast cap's resistance characteristics were studied via numerical simulation. The detailed design principle and approach of bell type blast cap was proposed finally based on the study results.

2. Contents and methods

2.1. Experimental apparatus and arrangements for the study of jet penetration characteristics

The jet from the tube shield ostioles of the bell type blast cap entered the bed with higher initial gas velocity and suffered the physical process of diffusion subsequently. Under the effects of radial expansion and solids being entrained into gas–solid boundary layer, the jet momentum and velocity decreased. When the axial drag force of the jet on the solids was attenuated too weak to overcome the internal friction force of bed solids, the jet had reached its maximum penetration position, i.e. the jet penetration length. To avoid poor fluidization locally in the bed, penetration length of the horizontal jet should at least reach the middle zone between two adjacent blast caps. The study results of Chyang et al. [9] indicated that: when the jet initial velocity was kept constant, the maximum penetration length of horizontal jet in bed existed at the fluidization number range of 0.6–1.0; and in the static bed with the fluidization number being zero, bed solids could produce stronger resistance against the jet, leading to a relatively shorter penetration length. During the boiler startup process, the bed fluidization state at the riser bottom was gradually transformed from static bed to fluidized bed. It was indicated that if the jet could reach the middle zone between adjacent blast caps in static bed at the beginning of startup, the bed was able to be well fluidized all the time. Consequently, the study of exit jet penetration characteristics of bell type blast cap was simplified to be normal jet penetration characteristics in static bed in the investigation.

Fig. 2 presented the cold test rig employed in the study of jet penetration characteristics, which was composed of the main experimental apparatus, air supplying system, data measuring system and data acquisition system. The main apparatus system was a cube made of plexiglass with dimensions of 385 mm (length) × 385 mm (width) × 1000 mm (height). It was transparent and made the observation in the tests convenient. The cube was filled with real CFB solids at a certain height initially, and five circular nozzles with inner diameters of 5 mm, 7 mm, 10 mm, 13 mm, and 16 mm were installed in the lower regions of the cube, closed to the lateral edges. Measuring holes was set at the wall faced the nozzles for fixing the dynamical pressure measuring system, and some of the nozzles were applied as measuring holes for each other. In the experiments, Raghunathan type Pitot tube [10], which held smaller inner diameter and flat sampling holes was adopted for the dynamical pressure measurement to avoid solids jam at top of the probe, as shown in Fig. 3. The gas velocities distribution along the jet axis was measured by the Pitot tube from one position to another, and for each measuring position, the corresponding gas velocity was acquired by averaging ten continuous test values. The penetration length was observed and measured by the rulers attached on the cube walls.

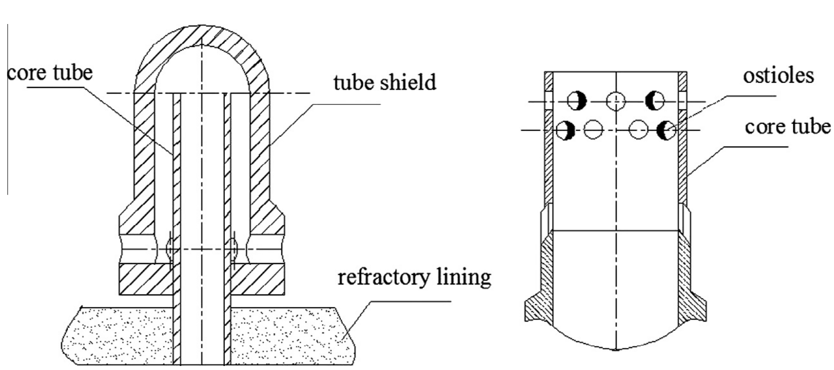

Fig. 1. Configuration of the bell-type blast cap.