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Original Research Paper

Experimental study on gas-solid flow characteristics in an internally circulating fluidized bed cold test apparatus

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ABSTRACT

A self-designed internally circulating fluidized bed cold test apparatus was built to investigate the gas-solid flow characteristics in a new kind of internally circulating fluidized bed furnace. The test material was circulating ash from a power plant CFB boiler. Optical fiber probes and differential pressure transmitters were employed for the measurements. The particle internal circulation rate and the solids holdup in the upper space of the furnace were studied by changing the fluidization air velocity in the main chamber, the height of partition wall and the initial static bed height. The results showed that with the increase of fluidization air velocity in the main chamber, the particle internal circulation rate increased at first then decreased. Meanwhile, the particle internal circulation rate decreased with the increase of the partition wall height and increased with the increase of initial static bed height in the main chamber. The solids holdup in the upper space of the internally CFB cold test apparatus was 1–4% of that in the normal CFB cold test apparatus. The proportion of particle external circulation rate was relatively low in the circulating system.

1. Introduction

As a new type of clean coal combustion technology, the circulating fluidized bed (CFB) combustion technology which was developed in the 1960s can burn low grade coal and at the same time release less pollutants [1]. It is also characterized by high combustion efficiency, wide load adjustment range and therefore has been widely used worldwide [2]. With the development of the CFB combustion technology, researchers around the world not only systematically investigated how to control externally circulating systems and enhance heat transfer intensity [3,4], but also studied the flow and heat transfer characteristics of the internally circulating systems [5–7]. Some engineering application solutions have been proposed. Wu and Wang [8] investigated the influences of fluidization air velocity, particle diameter and bed temperature on convection heat transfer coefficient between immersed tubes and bed materials in the in-bed heat exchanger of a 2.5 MW pilot internally circulating fluidized bed reactor with heat transfer probes. Fang et al. [9] designed a double fluidized bed solid circulating system, which could be used for biomass gasification to produce middle heating value town gas. Plastic balls and fluidized bed ash were used as bed materials. The effects of bed material, operation velocity, and bed structure on solid circulating rate between two beds were studied in a small-scale test facility by using photographic method, and its reasonable operation and design parameters were put forward. Huang et al. [10] investigated the particle flow characteristics in a clapboard-type internal circulating fluidized bed reactor using two kinds of bed material, i.e. rice husk and quartz sand. The effects of fluidization velocity, structure dimension and amount of side air on the solids circulating rate between high velocity zone and low velocity zone were studied. The recommended parameters for the design of the clapboard-type internal circulating bed gasifier were given based on the experimental data. The studies above show that, with the different purpose of engineering application, researchers focus on different factors which can influence gas-solid flow characteristics in internally circulating fluidized bed reactors. The engineering applications for the studies carried out by Fang and Huang were biomass gasifiers, therefore the test fluidization air velocities were relatively low (the fluidization number was only 1.2–2.2 and 1.8–4.5 respectively). The studies need to accurately forecast the inner loop gas-solid flow and heat transfer characteristics in different furnace structures.

High gas-solid concentration not only enhances the intensity of heat transfer, but also facilitates the abrasion of heating surfaces in the existing CFB furnaces [11]. This can be solved by installing internal heat exchanger with high heat transfer intensity in the furnace, and at the same time reducing the gas-solid concentration in the upper space of the furnace [12]. This work puts forward a

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Nomenclature

CFB	circulating fluidized bed
HTP	height of turning point
d_p	mean particle diameter, m
g	gravity, m/s
G	particle internal circulation rate, kg/(m^2 s)
G_e	particle external circulation rate, kg/(m^2 s)
G_l	local particle internal circulation rate, kg/(m^2 s)
H_i	initial static bed height in the main chamber, m
H_w	height of partition wall, m
L	effective distance between the two subprobes, m
u	fluidization air velocity, m/s
u_e	fluidization air velocity in the heat exchange chamber, m/s
u_g	fluidization air velocity in the main chamber, m/s
u_{mf}	critical fluidization velocity, m/s
v_p	instantaneous particle velocity, m/s
Z	height difference between test position and the main chamber distributor, m
Δh	height between two adjacent measuring points, m
Δp	pressure drop, Pa
Δp_b	bed pressure drop, Pa

Greek letters

ε	voidage, %
ε_s	solids holdup, %
ε_{sl}	local solids holdup, %
ρ_s	real density of test material, kg/m^3
τ	time lag, s

new kind of internally circulating fluidized bed furnace [13] in order to develop a thermal oil furnace which strictly requires security of the heating surfaces and controllable heat transfer intensity. In the past research on internally circulating system, most of the particles flow down along the furnace wall from upper space of furnace and form the internally circulating system. Therefore, the gas-solid flow characteristics in the upper space of furnace have been at the state of fast fluidization. To avoid abrasion of heating surfaces, the solids holdup in the upper space of the furnace should be reduced as much as possible. Consequently, particles should be blown to the internal heat exchanger instead of being entrained upwards to the upper space of the furnace. In this new kind of internally circulating fluidized bed furnace, the gas-solid flow characteristics is at dilute phase flow state in the upper space of furnace and is at fast fluidization state in the middle part of the furnace. This new kind of internally circulating fluidized bed furnace makes full use of buried tube heat transfer in the internally circulating system and is characterized by high efficiency and safety performances. In this new kind of furnace, the furnace is separated into separate chambers: the main chamber and the heat exchange chamber. The two chambers are placed in the furnace parallelly and are separated by partition wall. They share the upper space in the furnace. The fluidization air velocity in the main chamber is higher than that in the heat exchange chamber. In this way, the coarse and fine particles will be separated. Therefore, combustion and heat transfer will be decoupled [14]. The heat exchange chamber is in fact a bubbling fluidized bed with fine particles where the gas-solid flow is not severe. In this kind of internally circulating fluidized bed furnace, the amount of the particles carried by the fluidization air from the main chamber to the heat exchange chamber directly influences the heat transfer intensity in the heat exchange chamber. Enough and continuous particles which circulate internally are the key to control the heat transfer in the furnace. In order to design and operate this kind of internally circulating fluidized bed furnace successfully, a good knowledge of the particle internal circulation rate (G) is required.

This work investigated the gas-solid flow characteristics in a self-designed and built internally circulating fluidized bed cold test apparatus.

2. Experimental details

2.1. Experimental apparatus

As shown in Fig. 1, the main body of the internally circulating fluidized bed cold test apparatus consisted of a centrifugal blower, two uniform-pressure wind boxes, a furnace, a partition wall, a cyclone and a loop seal. The furnace with a height of 3200 mm was separated into two chambers: a main chamber with a cross section of 390 mm × 265 mm and a heat exchange chamber with a cross section of 390 mm × 610 mm. The two chambers were placed in the furnace parallelly and were separated by partition wall. The cross section of the upper space of the furnace was 390 mm × 520 mm. The height difference between the heat exchange chamber distributor and the main chamber distributor was 720 mm. The partition wall was composed of 6 pieces of modular partition panel, the height of each partition panel was 100 mm. The height of the partition wall could be adjusted according to the experimental condition. There was a row of reflux holes at the bottom of the partition wall.

The fluidization air was induced from a centrifugal blower whose maximum air volume was 4219 m^3/h with pressure head of 15 kPa. After quantitative control by valves and gas flowmeters, the fluidization air was sent into the main chamber and the heat exchange chamber through the uniform-pressure wind boxes.

2.2. Measuring methodology

As shown in Fig. 1, 8 pressure measuring points (P1–P8) were located along the height of the furnace with equal interval. The first

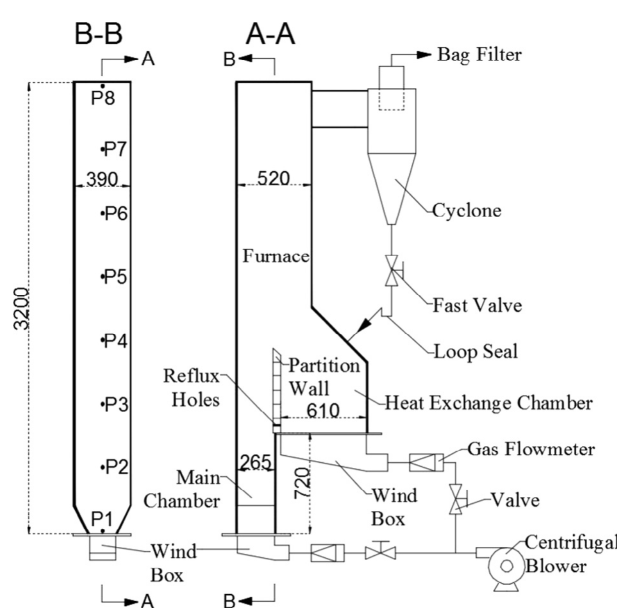

Fig. 1. Schematic diagram of experimental apparatus.