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Research article

PDA research on the air/particle flow characteristics in a 2000 t/d GSP pulverized coal gasifier at different swirl vane angles

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ABSTRACT

On an air-particle test facility, a particle dynamics anemometer is employed to investigate, in a small-scale gasification chamber for a 2000 t/d GSP gasifier, the influence of burner swirl vane angle (SVA: 16°, 21°, 26° and 31°) on the air/particle flow characteristics. The distributions of three-dimensional air/particle velocity, particle volume flux and particle size were obtained. Further, a novel method was provided to quantify the air-particle mixture extent with dimensionless difference of particle volume concentration. The results show that along the jet flow direction, single peak, double peaks and single peak successively appeared in the profiles of mean axial velocities. As the SVA increased from 16° to 31°, the first appeared peak of mean axial velocities in the near-wall region ($300\,\text{mm} \le r \le 352\,\text{mm}$) gradually moved toward the burner; in the region $x/d = 0.3$–4, the central recirculation zone expanded. The profile variation of particle volume flux at different SVAs was basically similar to that of air mean axial velocity. In the same cross-sections of $x/d = 1$–4, as the SVA increased from 16° to 26°, the air-particle mixture extent in the boundary of peak zone for particle volume flux rose; when the SVA increased to 31°, it reduced.

1. Introduction

The entrained flow pulverized coal gasifier (EFG) has been widely used in the Integrated Gasification Combined Cycle with the advantages of high carbon utilization, tar-free syngas and good adaptability to coals [1–3], and evolves toward higher operating pressure and larger capacity. In 2001, the Yihua Corporation built the first 700 t/d SHELL gasifier in China; in 2009, Yankuang Corporation (China) completed two 1100 t/d EFGs which were suitable for double-high coals (high ash melting point and high ash content); in 2011, the Shenhua Corporation (China) ran five 2000 t/d GSP gasifiers. However, large-capacity EFGs suffer from the problems of high temperature corrosion to burners and cooling screens and excessive levels of combustible matter in fly ash, which affect the continuous stable operation of gasifiers.

Air/particle flow characteristics are of great significance in pulverized coal combustion and gasification process. In practical situations, process parameters, such as velocity and turbulence intensity in a full-scale gasifier, are almost impossible to obtain. Cold air/particle flow characteristics are commonly believed to be unable to model actual hot flows with sufficient accuracy because of differing heat expansions within the flows in the full-size gasifier. However, following certain similar criteria, cold air/particle flow characteristics acquired in small-scale gasifiers can more or less describe those in full-scale versions. In this way, the pulverized coal combustion and gasification dynamics can be predicted to a certain extent. Therefore, the air/particle flow fields of full-scale gasifiers can be investigated by performing air/particle two-phase flow experiments in small-scale models. Furthermore, cold-flow experiment is widely used by gasifier manufacturers and other researchers for its advantages of convenience and flexibility. On those bases, optimized parameters and design can be obtained. Currently, investigations [4–10] on the air/particle flow characteristics are mainly performed by numerical simulation. Many detailed parameters of flow field are required to verify the accuracy of the numerical results. Unfortunately, there are very few cold-flow experiments related to air/particle flow characteristics of entrained flow gasifier, especially for a pulverized coal gasifier. Zhang et al. [11] measured the flow field in a new-type staged entrained flow gasifier [12] by the laser particle dynamic analyzer (LDA), and analyzed the effect of the second airflow on the three-dimensional velocity distributions. The results acquired the reasonable second nozzle position and flow rate. But particle volume flux and particle size can't be measured by the LDA. Ni et al. [13] obtained the axial velocity profile in an opposed multi-burner gasifier [14,15] by the Dual particle dynamic analyzer for mathematical model validation. However, the experiment data including tangential velocity, radial velocity and particle volume flux profiles and particle size distributions didn't be given. A full understanding of the air/particle flow

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Nomenclature

Capital letters

EFG	entrained flow pulverized coal gasifier
LDA	laser particle dynamic analyzer
PDA	particle dynamics anemometer
SVA	swirl vane angle
GAC	gasifying agent channel
CCC	coal/CO_2 channel
S	swirl number
R_i	inner radius of the swirl vane (m)
R_o	outer radius of the swirl vane (m)
NR	near-wall region (300 mm ≤ r ≤ 352 mm)
RMS	root mean square
C_v	particle volume concentration (−)
Q_p	particle volume flux ($m^3\,m^2\,s^{-1}$)
Q_a	air volume flux ($m^3\,m^2\,s^{-1}$)
ΔC_v	dimensionless difference of particle volume concentration (−)
C_{vo}	the ratio of the particle volume flow rate in the CCC to the sum of the air volume flow rate in the CCC and GAC (−)
V_p	particle volume flow rate in the CCC ($m^3\,s^{-1}$)
V_1	air volume flow rate in the CCC ($m^3\,s^{-1}$)
V_2	air volume flow rate in the GAC ($m^3\,s^{-1}$)
M_p	particle mass flow rate in the CCC ($kg\,s^{-1}$)
M_1	air mass flow rate in the CCC ($kg\,s^{-1}$)
M_2	air mass flow rate in the GAC ($kg\,s^{-1}$)
$\overline{\Delta C_v}$	average dimensionless difference of the particle volume concentration for all measurement points in the boundary of peak zone for particle volume flux (−)

Lowercase letters

b	vane thickness (m)
k	number of swirl vanes (−)
d_p	particle diameter (μm)
x	distance to the exit of the burner along the jet flow direction (mm)
r	radial distance from the burner axis (mm)
d	diameter of the CCC at the exit of the burner (mm)
u_{max}	axial maximum velocities (m/s)
n	number of measurement point (−)

Greek letters

α	swirl vane angle (°)
β	blockage coefficient (−)
τ_p	characteristic time of tracer particle (ms)
ρ_p	particle density ($kg\,m^{-3}$)
ρ_a	air density ($kg\,m^{-3}$)
υ	air kinematic viscosity ($m^2\,s^{-1}$)

characteristics by cold-flow experiment has not been reported.

In this work, a 1:3.5 scale model gasifier and a particle dynamics anemometer (PDA) measurement system are used to measure the three-dimensional velocities, volume fluxes, and particle sizes of two-phase flow in a 2000 t/d GSP gasifier at various swirl vane angles (SVAs: 16°, 21°, 26° and 31°) of the burner. The results of these experiments will therefore be useful as reference information for the design and operation of the similar EFGs.

2. Burner and gasification chamber of a 2000 t/d GSP gasifier

2000 t/d GSP gasifier consists of a single burner and a gasification chamber, as presented in Fig. 1. Of them the burner is centered on the top of the gasification chamber. From top to bottom according to the shape, the gasification chamber adopting cooling-screen structure can be divided into dome part, straight part and shrink part with the axial length of 389, 4295 and 403 mm, respectively. Besides there is an outlet straight part at the bottom of it.

Figs. 2 and 3 shows the schematic view and pictures of the burner from GSP gasifier. From the center to outward, the central channel, gasifying agent channel (GAC) and coal/CO_2 channel (CCC) are concentrically arranged in the burner. Ignition device is installed in the central channel. Twenty swirl vanes are arranged in the GAC near the gasification chamber. Three coal pipes (a, b, and c) are evenly arranged in the CCC, and are counterclockwise coiled at 120° with the same pitch in the peripheral direction. Oxygen and steam flow into the gasification chamber from the GAC. Pulverized coal is conveyed into three coal pipes by CO_2. After swirling out of these pipes, three shares of pulverized coal intermix at the bottom of the CCC and then spray into the gasification chamber. The gasifier pressure is in the range of 3.8–4.5 MPa. All the operating parameters are shown in Table 1.

Assuming that the axial velocity component at the outlet section of the swirl vanes which are fixed axial vanes remains uniform distribution, the swirl number S is calculated [16]:

$$S = \frac{[1 + (R_i/R_o)^2]}{2(1 - \beta)} \tan\alpha \tag{1}$$

where R_i and R_o are inner and outer radius of the vane, respectively; α is the SVA; and β is the blockage coefficient considering that the vane thickness is limited.

$$\beta = \frac{kb}{2\pi R_o \cos\alpha} \tag{2}$$

where b is the vane thickness, k is the number of swirl vanes. In this work, $k = 20$.

3. Experimental

The test facility is illustrated in Fig. 4. It's composed of a sucker, two

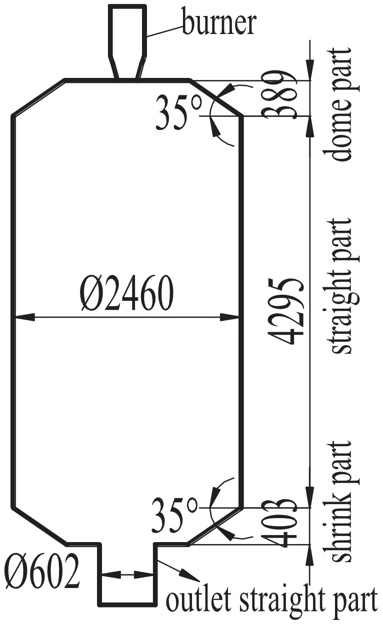

Fig. 1. 2000 t/d GSP pulverized coal gasifier (unit: mm).