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Internal circulating fluidized bed incineration system and design algorithm

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Abstract: The internal circulating fluidized bed (ICFB) system is characterized with fast combustion, low emission, uniformity of bed temperature and controllability of combustion process. It is a kind of novel clean combustion system, especially for the low-grade fuels, such as municipal solid waste (MSW). The experimental systems of ICFB with and without combustion were designed and set up in this paper. A series of experiments were carried out for further understanding combustion process and characteristics of several design parameters for MSW. Based on the results, a design routine for the ICFB system was suggested for the calculation of energy balance, airflow rate, heat transfer rate, and geometry arrangement. A test system with ICFB combustor has been set up and the test results show that the design of the ICFB system is successful.

Key words: fluidized bed; ICFB; MSW

Introduction

The process of municipal solid waste (MSW) is one of the most serious issues in terms of environmental protection. Processing of MSW without further disastrous contamination can be achieved only in modernized measures, such as incinerating and energy generating concurrently (Sheng, 1997). From the point of view of combustion, the characteristics of MSW are significantly different from that of other special fuels, such as industry solid waste and inferior coal. The MSW is generally of low quality in terms of poor caloric value, high moisture and ash content. The ignitability, combustibility and flame stability of MSW are inferior. Furthermore, they are changed dramatically with the season and location, at which the MSW are collected. From the point of view of pollution, MSW combustion products contain not only conventional pollutants as sulfur oxides, nitrogen oxides, but also chloric material. So the incinerator and facility for the combustion of MSW should be specially designed, with different structure and operation parameters for conventional fuels, such as coal and oil. The requirements for the combustion system to deal with MSW are high versatility.

Fig. 1 presents schematic diagram of dense-phase bed in ICFB (Nagato, 1991; Ohshita, 1994). The quartzite sand is exploited in the combustion system as fluidized bed material. The mass ratio of quartzite sand to fuel is about tens of times. Non-uniform wind distribution by segmented sections enables generation of large-scale circulation zones. So a complex bed structure is formed and features with a moving bed and a flowing bed. With such a structure, the MSW can be properly dried, preheated, crushed and burnt out, while the incombustible waste is discharged from bed. The rates of preheating and vaporizing of MSW can be controlled by the setting of fluidized velocity in the moving and flowing bed. And the intensity of combustion and the quantity of most dangerous pollution products, for example, PCDD and PCDF, can be controlled by the setting of the temperature in the dense-phase bed and in the free space above the dense-phase bed. So, the above characteristics of ICFB make it one of most attractive methods to deal with fuels with poor caloric value, high moisture and ash contents, and dramatically changed combustion characteristics.

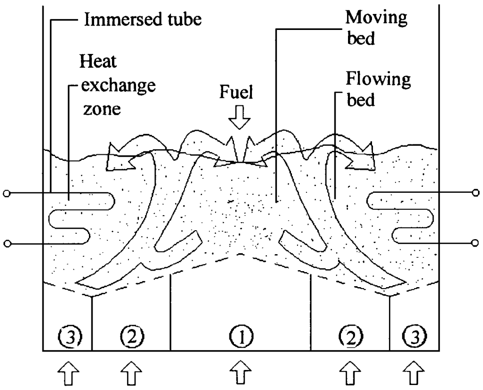

Fig. 1 Schematic of Principle of ICFB
1. high speed floow; 2. low speed flow;
3. heat exchange flow

1 Design basis of ICFB

1.1 The physical ingredient and caloric value of MSW

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As a special fuel, the MSW is different from other conventional fuels in terms of both physical contents and caloric value. Fig. 2 shows one-year variations of gross caloric value of moist basis and moisture levels in the MSW collected from area of multi-storied building, which are furnished with natural gas and central heating supply system. Sixteen sampling spots in Beijing area had been examined for a one-year period. Four typical districts are include in these sampling spots: (1) commercial and business area; (2) area of multi-storied building with both natural gas and central heating supply system; (3) area of multi-storied building with central heating supply but without natural gas; and (4) one-storied house without natural gas and central heating supply system. As reasonable simplification for the purpose of ICFB design, an average gross caloric value of moist basis and moisture level was adopted as 6000 kJ/kg and moisture level of 50 % to deal with varied features from different district and seasons.

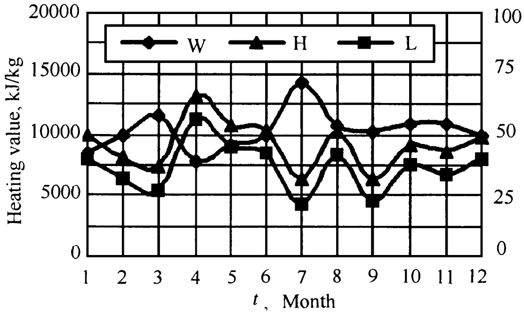

Fig. 2 Heating value and water content in MSW

1.2 Fluidized ratio

Four kinds of representative fluidizing patterns (Fig. 3) can be obtained through adjustment of airflow rates at high-speed and low-speed air chambers separately in the test rig of ICFB. Each flow pattern consists of more than two basic flowing modes. They were name as: (1) flowing bed, in which fluidized particles move vigorously with the around airflow; (2) moving bed, in which fluidized particles descend slowly; (3) static bed, in which fluidized particles keep still and (4) bubbling bed, in which fluidized particles move in a small scale. Large-scale internal circulation flow is formed only in the pattern of Fig. 3 (D), consisted of flowing bed and moving bed.

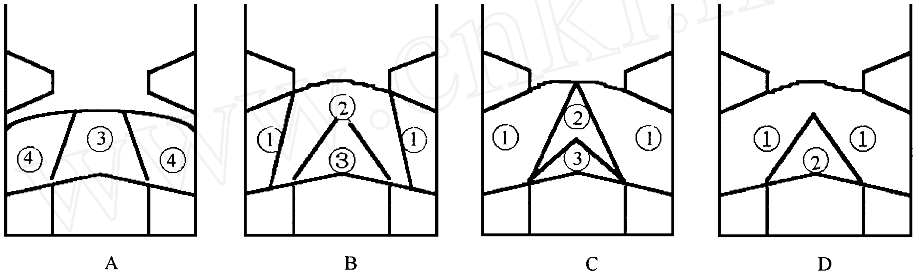

Fig. 3 Typical flow patterns in the dense-phase bed of ICFB

It has been demonstrated from experiments that large-scale internally circulating flow, without existence of static bed, could be obtained at the condition that the apparent fluidized velocity is 6 u_{mf} - 16 u_{mf} at high-speed air chamber and is greater than 1.3 u_{mf} at low-speed air chamber. So generally, airflow conditions of ICFB were arranged at 4 u_{mf} - 20 u_{mf} for high-speed airflow and 0.5 u_{mf} - 2.0 u_{mf} (Tian, 1999) for low air speed airflow.

2 Design of combustion system

With consideration of the limited MSW preparation capacity in a laboratory scale system, the specified load of ICFB was decided as: 1000kg MSW with gross caloric value of 6000 kJ/kg and moisture level of 50 % in 16 working hours each day. Then, the theoretical airflow rate is:

$$Q_l = MQ_h\beta = 0.0314(\text{kg/s}), \tag{1}$$

where M (kg/s) is the specified load, Q_h (kJ/kg) is the mean gross caloric value of moist basis; β(kg/kJ) is the consumed air mass for complete combustion of MSW contributing 1 kJ heat. According to approximate ingredients of MSW, β is the calculated to be 0.3008 by the method from reference (Sheng, 1997). With excess air coefficient α taken as 1.6, the total air supply rate for the combustion system is:

$$Q_m = Q_l\alpha = 0.0502(\text{kg/s}). \tag{2}$$

Volatile matter in the MSW reacts with secondary air in the free space above dense-phase bed. Results from energy balance calculation show that local excess air coefficient at a value of 0.7 not only maintains combustion of MSW solid and volatile matter in the dense-phase bed, but also keeps the temperature within 700-800 ℃ in dense-phase bed region. This temperature range is favorable both for control of poisonous emissions as NOx and chloric gas and for the safe discharging below melting point for non-combusible matters as glass or metal. On the basis of above calculation, the ration of primary air to secondary air mass flow was taken as 7∶9. So the primary air mass flow rate is:

$$Q_1 = \frac{7Q_M}{16} = 0.0220(\mathrm{kg/s}). \tag{3}$$

The mean diameter of the selected fluidized particles is $d_p = 0.6 \times 10^{-3}$m. So the initiative fluidized velocity for the fluidized particles at 800 °C is:

$$u_{mf} = d_p^2(\rho_s - \rho_g)\, g/(1650\mu) = 0.1207(\mathrm{m/s}),$$

meanwhile:

$$Re = \rho u d/\mu = 0.537 < 20. \tag{4}$$

The area ration of high-speed primary air region to low-speed primary air region was taken as $A1 : A2 = 1 : 1$. The mean velocities of high- and low-speed airflow are $v_1 = 8u_{mf}$ and $v_2 = u_{mf}$ respectively. Then the bed area is:

$$A = 2Q_1/(\rho_g(v_1 + v_2)) = 0.1231(\mathrm{m}^2). \tag{5}$$

Actually, the area of fluidized bed was round off to $0.5\mathrm{m} \times 0.24\mathrm{m} = 0.12\mathrm{m}^2$.

3 System of ICFB

As shown in Fig. 4, the main body of ICFB consists of air chamber segment, dregs discharging segment, dense-phase bed, transition segment, secondary air segment and gas emission outlet segment. It was assembled with several sections. These sections were connected by flanges. Each section was constructed with a multiple-layer wall of lightweight structure. The inner layer is made from refractory material of 60mm, the outer is steel sheet, and the insulation material of 20mm is in between. The main body has a size of 1200mm long, 800mm wide and 3600mm high. The air chamber segment consists of air-cap, air-distribution plane, air chamber and pressure expanding segment. Ten air-caps are uniformly installed on the 15 (declined air-distribution plane, six of them for high-speed airflow zone and the other for low-speed airflow zone. In dregs discharging portion, the dregs with certain amount of bed sand can be discharged continually or spasmodically. They were separated by means of screening. The non-flammable material was discharged and the bed material was fed back to dense-phase bed again. In dense-phase bed, heat-transferring tubes are installed in flowing bed and moving bed respectively to study its heat-transferring characteristics. In transition segment, the size of furnace chamber grows gradually as the gas flows downstream, increasing resident time of poisonous gas in high-temperature region, favorable for degradation of harmful ingredient. A branch of air is supplied to the transition segment to adjust the combustion speed. The secondary air inlet and bed material recycling inlet are installed in secondary air segment. The gas production outlet segment enlarges the furnace height further and increases gas resident time in high temperature. The introduction of secondary air supplies sufficient oxidant for combustion and keeps the temperature in gas phase higher than that in dense-phase bed. The free space was used to refer the all of transition segment, secondary air segment and gas production outlet

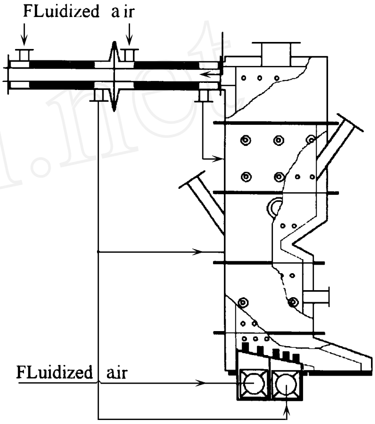

Fig. 4 Experimental setup and system of ICFB

4 Results and discussions

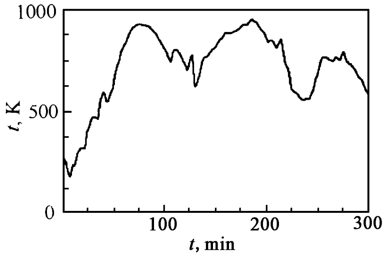

Fig. 5 Temperature in free space

Experiments were carried out with two kinds of MSW. One is real MSW collected from area of multi-storied building. The other is synthetic MSW that is made up of paper, plastics, food, frond, textile, non-flammable material and water with gross caloric value of 4700 kJ/kg and net caloric value of 3500 kJ/kg.

Figs. 5—7 show the temperature-time curves in each segment during the test including ignition, normal load, replacing the fuel, stopping fuel supply and extinction.

MSW fuel is fed into the furnace from above the moving bed, where the air speed is relatively low. The clumps of MSW are wrapped around by the bed sand. They descend slowly in the dense-phase bed, so the possible impact of heavy MSW pieces onto the bed is avoided. The fuel is partially preheated and dried during this period. After they reached the bottom of the dense-phase bed, they are carried into flowing bed by the strong movement in the bed. Because flowing bed is in the condition of high temperature, high velocity and sufficient oxidant (air), the partially dried MSW clumps are ignited immediately and combust strongly to keep the high temperature in the flowing bed. Because of vigorous crosswise diffusion rate, high temperature bed material in the flowing bed moves back into the moving bed rapidly to compensate the loss of bed sand in moving bed, and to preheat and dry the newly fed MSW clumps. Fig. 7 shows the temperature curves of flowing bed, furnace centerline and moving bed. The results demonstrate that the temperature in the flowing bed is significantly higher than that in the moving bed. This is implied that the combustion process is accomplished primarily in the flowing bed. Preheating and drying of newly fed MSW occur primarily in the moving zone. Because of vigorous mixing of bed material in the micro scale range as well as in the circulating process between flowing and moving bed, the MSW dried in moving bed is moved to flowing bed. And the heat released by the combustion of MSW in flowing bed is transferred to moving bed to preheat and dry MSW.

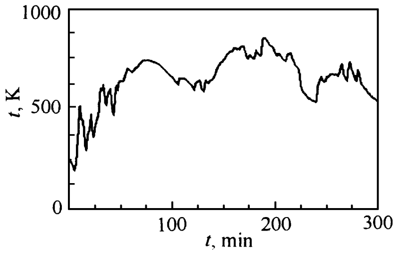

Fig. 6 Temperature in transition segment

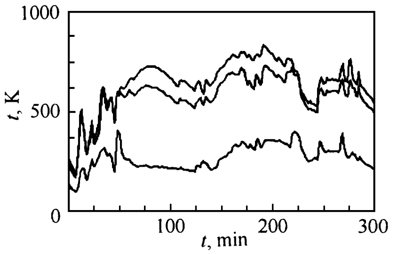

Fig. 7 Temperature in dense-phase bed

The comparison between Fig. 5 and Fig. 7 shows that the temperature in free space is higher than that in dense-phase flowing bed. The temperature increase in free space is about 150 ℃ or even higher. The free space temperature reaches as high as 900 ℃—1000 ℃. This can be explained that the addition of secondary air sustains further combustion of volatile material. This relatively high temperature is favorable for degradation of poisonous mass in the combustion products, such as PCDD and PCDF. The temperature in dense-phase bed is ranged from 700 ℃ to 800 ℃. This relatively low bed temperature is convenient from following three points: (1) for reduction of pollutants such as NOx; (2) for safe discharge of low melting point solid waste non-flammable MSW with low melting point, and (3) for avoidance of blocking wind-cap.

5 Conclusions

Experiments in a lab ICFB demonstrate successful incineration of MSW without any auxiliary fuel. The temperature distribution in the ICFB is suitable for the burning-out of MSW, reduction of several pollutants, partially degradation of PCDD and PCDF, and successfully accomplishments of the discharging of low melting point waste. These proved that ICFB is an advanced system in handling of MSW and other low-grade fuels. Some key parameters for the ICFB system design algorithm are suggested according to the study results.

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