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Smooth combustion of gaseous fuels in a novel configuration of fluidized bed

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HIGHLIGHTS

- ▶ A novel configuration of fluidized bed has been developed and applied.
- ▶ Jet–fountain fluidized bed configuration consents smooth combustion of gaseous.
- ▶ A rapid reliable method for initial heating of fluidized bed combustor was confirmed.
- ▶ Staged air combustion technique has been applied using the novel configuration.
- ▶ The configuration reduces the power consumed in feeding gases to the combustor.

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ABSTRACT

A novel configuration has been developed and applied in burning gaseous fuels. It enables gaseous fuels to burn smoothly like a normal premixed flame avoiding acoustic effect acoustic effects and explosions due to volume combustion in bubble phase. A gaseous fuel partially premixed with air is fed through a jet pipe to be issued vertically upward in the upper part of the bed. The jet is able to establish a permanent fountain of particles in the freeboard. The remaining part of air is fed through the distributor to fluidize bed solids.

Applying the proposed configuration confirms a rapid reliable method for initial heating of fluidized bed combustor. The experiments demonstrate that the bed temperature attains 800 °C within about 10 min. The normal acoustic effects and bubbles explosion due to volume combustion were not recognized.

Temperature distribution has been measured in axial and radial directions. The obtained results indicate that applying the novel configuration dampens greatly the overheating in freeboard, in particular, at lower bed temperatures. The particles of created fountain absorb a great part of the heat released in freeboard and recover it back to the bed.

Staged air combustion technique has been also applied using the novel configuration. Propane premixed with air is fed through the distribution while the remaining part of air is fed through the jet pipe to create a fountain. The obtained results demonstrate that the freeboard temperature rise is also greatly reduced.

The power consumption in delivering gases to the combustor is found much lower when applying the proposed configuration rather than feeding all gases through the gas distributor. Moreover, bubble sizes reduce considerably in the main bed as only a part of gases passes through the main bed.

1. Introduction

Fluidized bed combustion of gaseous fuels pre-mixed with air has been widely investigated and modeled [1–15]. The combustion of gaseous fuels in fluidized bed is characterized by acoustic effects and explosion risk that vary with bed temperature. In general, as the mean temperature of the bed increases, combustion gradually moves from the freeboard to just above the distributor. At low bed temperatures, the gaseous fuel burns mainly in freeboard with explosive ignition of gases in bubbles leaving the bed [9,10]. At intermediate temperatures, the ignition may start in the bubble and combustion processes occur in the freeboard, just above the bed surface. The acoustic effects are the strongest in this temperature range, at about 820 °C for propane [5] and 890 °C for methane [11]. At higher temperature, above 930 °C for propane [3,5] and above 1000 °C for methane [2,11], combustion processes occur in bubbles just above the distributor. The explosive ignition becomes less strong and more frequent [2,11].

According to the findings mentioned above, post-combustion of gaseous fuels in freeboard is essential at low and intermediate bed

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temperatures. Post-combustion has been also found important in combustion of liquid fuels [16–19] and in combustion of solid fuels of high volatile content [20–23]. In this respect, the ejected bed particles in splashing zone play an important role as they absorb and recover a part of heat released in freeboard back to the bed. These particles also act as a heat sink that contributes in controlling freeboard temperature [22,23].

Furusaki et al. [24] and Miyauchi [25] studied the contact efficiency between gas and solids at different levels in fluidized bed reactor. They found good contact just above the distributor, but very poor contact in the bed itself. On the other hand, the contact efficiency was found very good in the splashing zone. On this account, fluidized bed is designed to operate in the turbulent flow regime to achieve high gas throughput. The very high gas velocities, relative to minimum fluidization, in turbulent beds generate a large dense splashing zone of emulsion clusters at the bed surface, plus considerable solids in the freeboard. This gives good-solids contact and additional conversion of reactant in the freeboard [26].

In this work smooth combustion of gaseous fuel is carried out applying a novel configuration for bubbling fluidized bed. The combustor has been designed taking care of the shortcomings discussed above: acoustic effects, post-combustion and gas–solids contact. It is basically a bubbling fluidized bed furnished with a spouted jet issuing in the upper part of the bed. Jet–fountain fluidized bed configuration ensures gaseous fuels to burn smoothly like a normal premixed flame, expands the splashing zone, and enhances gas–solids contact.

A single jet–fountain-fluidized bed combustor is sketched in Fig. 1. It is basically a bubbling fluidized bed furnished with a spouted jet issuing in the upper part of the bed. Multi jet may be used for a large fluidized bed. Gaseous fuel partially premixed with air is fed through the jet pipe. The remaining part of air is fed through the distributor plate to fluidize bed solids. As shown in Fig. 1 the proposed configuration has the following features: permanent jet in the upper part of the bed, large fountain of discrete particles in the freeboard and smaller bubbles in the main bed as only a part of gases passes through it.

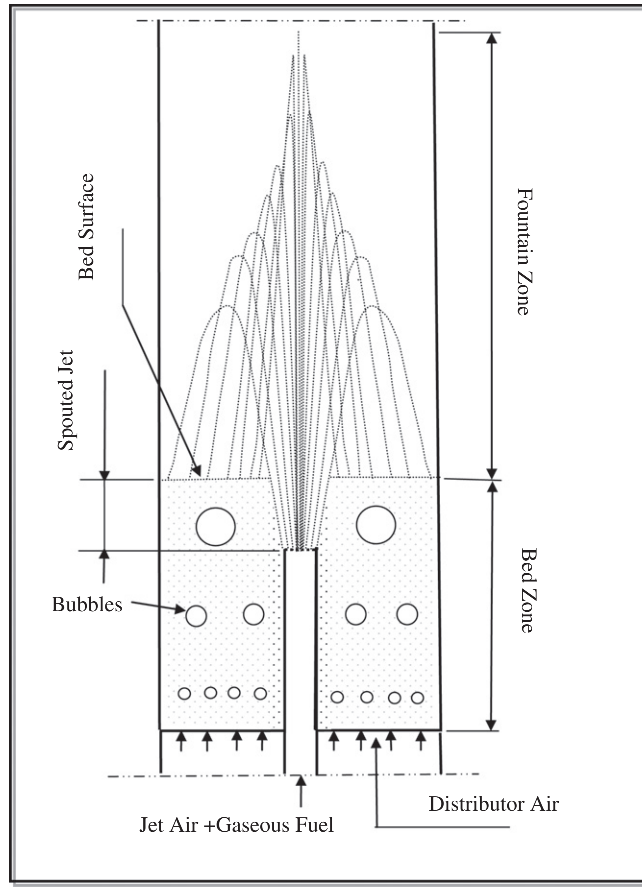

Fig. 1. Jet–fountain fluidized bed combustor configuration.

2. Experimental set up

A bubbling fluidized bed combustor has been modified to adopt the jet–fountain configuration. Fig. 2 shows a schematic of the combustor. It consists of fluidization column of 300 mm inner diameter and 3300 mm height.

A nozzle type plate is used to distribute the primary air at the bottom of the fluidization column. The air serves in fluidizing bed materials. A stainless steel tube of 38.1 mm inner diameter is used to feed jet-gases vertically upward. It passes through the center lines of the plenum chamber and the gas distributor plate to the center line of the fluidization column. The tube is designed to be movable in the vertical direction in order to adjust the location of the jet outlet regarding the bed surface.

The column is implemented with 21 portals to insert probes for measuring purposes. It is also furnished with two eyeglasses to enable visualizing the freeboard of fluidization column. Two taps, PTD are used to measure the pressure drop from the plenum to the freeboard. Two additional taps, PTJ, are used to measure the pressure drop from the jet pipe entrance to the freeboard. PTD and PTJ taps in the freeboard are located at 240 cm above the distributor.

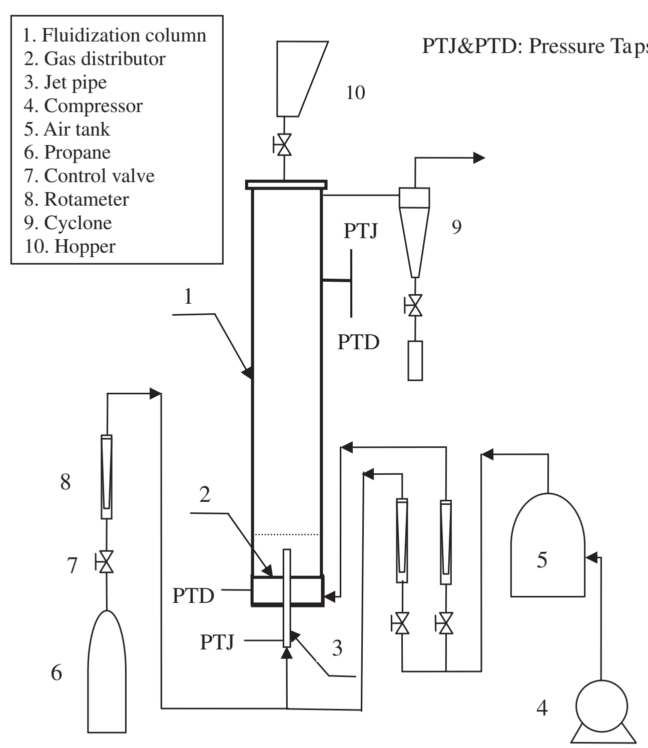

Fig. 2. Bubbling fluidized bed combustor adopting jet–fountain configuration.

3. Results and discussion

3.1. Initial heating of fluidized bed combustor

Some experiments have been carried out to examine initial heating of the combustor described in Fig. 2 Silica sand of (0.5–