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Experimental study on propane combustion in a novel fluidized bed configuration

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ABSTRACT

Experimental study on propane combustion has been performed in a novel fluidized bed configuration. This configuration has a jet that issues vertically in the upper part of the bed while allowing two methods of feeding. The first method is through jetting air–propane mixture that ensures smooth combustion avoiding burning bubble explosion. The second method enables staged-air combustion technique. Initial heating has been carried out by jetting propane partially premixed with air. The remaining part of air is fed through the distributor plate to fluidize bed solids. The proposed configuration enables a rapid and reliable method for initial heating of a fluidized bed combustor. The obtained results demonstrate that by applying the novel configuration, the freeboard overheating is greatly reduced. In accordance, the in-bed cooling load increases with increasing the secondary air ratio when applying the novel configuration. Alternatively, the temperature of the lower part of the freeboard fairly decreases while the temperature of the upper part considerably increases when applying the conventional method of air staging. Additionally the in-bed cooling load was found to significantly decrease with secondary air. The results also indicate that the novel configuration is more effective in reducing NO_x. On the other hand, CO didn't exhibit significant change with increasing secondary air ratio applying the novel configuration while CO multiplies in the case of conventional operation.

1. Introduction

Fluidized bed combustion of gaseous fuels is used in many industrial applications such as incineration of highly moisture wastes, solid particle calcination, co-firing with low grade fuels and initial heating of fluidized bed reactors [1]. Combustion of gaseous fuels is also inherent to many processes such as selective oxidation of alkanes and biomass gasification [2]. Understanding gaseous fuel combustion and its detailed mechanism are essential for process design, safety, and emission control. Fluidized bed combustion of gaseous fuels premixed and non-premixed with air has been widely investigated and modeled [1–16].

The combustion of gaseous fuels in fluidized beds is characterized by acoustic effects and explosion risk that vary with bed temperature [13,16]. At low bed temperatures, gaseous fuels burn mainly in the freeboard with explosive ignition of gases in bubbles leaving the bed [1,9–15]. As the mean temperature of the bed increases, combustion gradually moves from the freeboard to just above the distributor. 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 at this temperature range, at about 820 °C for propane [14,15] and 890 °C for methane [13,16]. At higher temperature, above 930 °C for propane and above 1000 °C for methane, combustion processes occur in bubbles just above the distributor and explosive ignition becomes more frequent but less strong.

Post-combustion of gaseous fuels in the freeboard is essential at low and intermediate bed temperatures. Post-combustion has been also found important in the combustion of liquid fuels [17,18] and in the combustion of solid fuels of high volatile content [19–21]. In this respect, the ejected bed particles in the splashing zone play an important role as they absorb and recover a part of the heat released in the freeboard back to the bed. These particles also act as a heat sink that contributes to controlling the freeboard temperature [20,22].

Furusaki et al. [23] and Miyauchi et al. [24] studied the contact between gas and solids at different levels in a fluidized bed reactor. The fluidized bed is designed to operate in the turbulent flow regime to achieve high gas throughput. Good contact was found just above the distributor while very poor contact was found in the bed itself. On the other hand, the contact was found very good in the splashing zone. 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-solid contact and additional conversion of reactant in the freeboard [25].

Recently, Okasha has developed a novel fluidized-bed configuration for burning gaseous fuels that is taking care of the shortcomings discussed above: acoustic effects, post-combustion, and gas–solid

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contact [26]. This novel configuration, namely jetting-fountain fluidized-bed combustor is shown in Fig. 1. It is basically a bubbling fluidized bed furnished with a spouted jet issuing in the upper part of the bed as indicated by dotted lines. Multi-jets 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. Jetting-fountain configuration is characterized by excellent gas–solid contact. This feature is, thanks to creating a jet in the upper part of the bed, establishing a fountain in the freeboard and moderating bubble size in the main bed. Jetting-fountain configuration enables gaseous fuels to burn smoothly similar to a normal premixed flame avoiding acoustic effects and explosions due to volume combustion in bubble phase. It enables a rapid and reliable method for initial heating of fluidized bed reactor. The jetting-fountain configuration reduces considerably the power consumed in feeding gases to the combustor.

This paper presents an extensive experimental study on combustion of propane in the novel jetting-fountain fluidized-bed combustor configuration. The inherent initial heating method is re-tested. The post combustion and overheating in the freeboard are examined at different conditions by measuring the axial and radial temperature distributions. Staged combustion applying jetting-fountain configuration is studied where the freeboard overheating, in-bed cooling load, and gaseous emissions are considered.

2. Experimental set-up

A bubbling fluidized bed combustor has been modified to adopt the jetting-fountain configuration as shown in Fig. 2. It consists of a fluidization column of 300 mm ID 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 ID 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 centerline 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 combustor also contains a heat exchanger system consisting of three horizontal movable pipes. By virtue of this system, bed

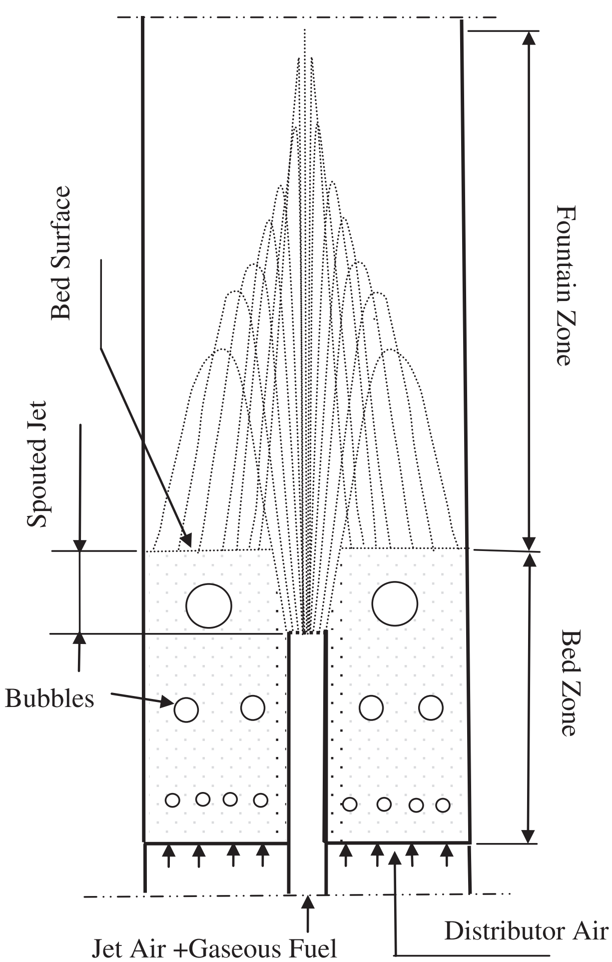

Fig. 1. Jetting-fountain fluidized bed combustor configuration.

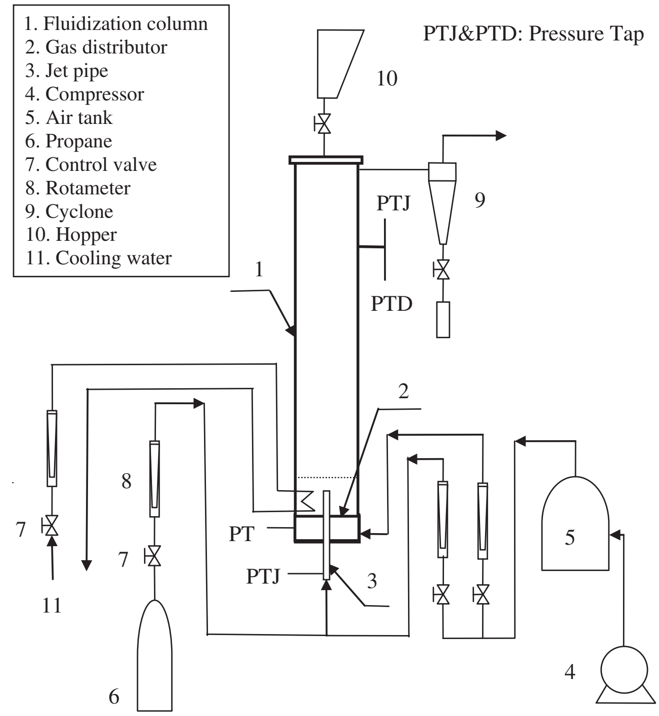

Fig. 2. Bubbling fluidized bed combustor adopting jetting-fountain configuration.

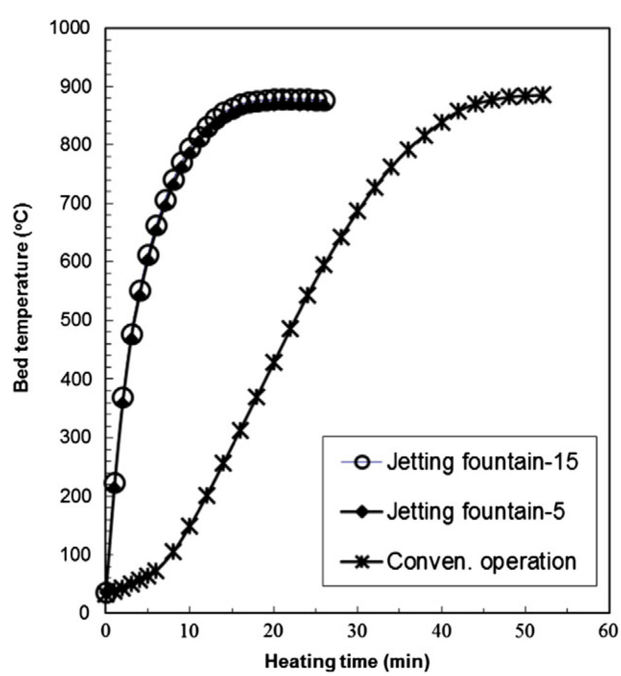

Fig. 3. Bed temperature history.