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Controlling the freeboard temperature applying a novel design of fluidized bed

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ABSTRACT

An experimental study on controlling the temperature of gases in the freeboard applying a novel fluidized bed configuration has been carried out. A bubbling fluidized bed reactor of 300 mm ID is equipped with a jet pipe of 38.1 mm ID to adopt the novel configuration. A part of air is fed through the jet pipe to be issued vertically near the bed surface creating a large fountain of particles in the freeboard. The remaining part of air is fed through the distributor plate to fluidize bed solids. A third stream of hot air at 300 °C is introduced in the freeboard beyond the main bed to simulate a heat generation source. The hot air is evenly distributed over the reactor cross section using a special pipe. Due to contacting the hot air with the entrained particles, its temperature is dampened while the bed solids heat-up. After a certain period of time the bed temperature profile evens out. The obtained results demonstrate that the fountain particles are very effective in transporting heat from the freeboard gases to the bed that minimizes the temperature difference between them, i.e., better control of the freeboard temperature. The bed stabilizes at a higher temperature while the freeboard temperature is better controlled with increasing the jet velocity and with decreasing bed particles sizes. Moreover, by applying the novel configuration the freeboard temperature can be effectively controlled to a higher extent along the reactor height compared with the splashing zone of conventional operation.

1. Introduction

In many exothermic reactions in fluidized bed, a considerable part of gases bypasses the bed without conversion. These gases complete reactions in the freeboard producing a large quantity of heat that overheats the freeboard above bed temperature reducing the thermal homogeneity throughout. It is recommended to keep the overheating within a narrow range for better reactions stability and low pollution effects over a wide range of load control [1].

For instance, the reaction may be explosive outside a narrow temperature range; the yield of desired product to side products may be sensitive to the temperature level of operations or rapid deterioration and deactivation of catalyst. These issues can emerge in highly exothermic synthesis reactions such as Sohio process and Fischer Tropsch synthesis. The presence of entrained solids in the freeboard is important as it works as a heat sink to dampen overheating [2]. Further, high overheating may lead to higher generation of gaseous emissions or ash melting. These problems may arise in the combustion of highly volatile solid fuels where a considerable part of volatiles escapes the bed to burn in the freeboard [2–5]. On the other hand, 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. Hence, these particles act as a heat sink that contributes to controlling the freeboard temperature [3,6]. The freeboard overheating is also important in the combustion of gaseous [7–11] and liquid fuels [12–14].

Over-bed start-up is a well-known technique used for initial heating of fluidized bed reactors [15–17]. Using this technique, the flame impinges on the surface of a bubbling fluidized bed in order to heat the bed particles. The start-up time depends on the rate of heat transfer between the flame and the bed. The presence of entrained solids increases the rate of heat transfer. The later consequence makes the start-up period shorter and the fuel consumption more economic.

Furusaki et al. [18] and Miyauchi et al. [19] studied the contact between gas and solids at different levels in a fluidized bed reactor. 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 fluidized bed is

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designed to operate in the turbulent flow regime to achieve high gas throughput. The high gas velocities, relative to minimum fluidization velocity, in turbulent beds generate a large dense splashing zone of clusters at the bed surface, plus considerable solids in the freeboard. This gives good-solids contact and additional conversion of reactant in the freeboard [20].

Recently, Okasha has developed a novel fluidized-bed configuration, namely jetting-fountain fluidized-bed [21–23]. 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 as shown in Fig. 1. A part of 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–solids contact. This feature is thanks to creating a jet in the upper part of the bed, establishing a fountain in the freeboard and moderating bubbles size in the main bed. Previous work [21–23] confirms that jetting-fountain enables gaseous fuels to burn smoothly similar to a normal premixed flame. The jetting-fountain configuration reduces considerably the power consumed in feeding gases to the combustor. More importantly, applying the jetting-fountain configuration dampens the overheating in the freeboard.

This paper presents an experimental study on controlling the freeboard temperature applying the novel configuration. In this study a stream of hot air is introduced in the freeboard beyond the main bed to simulate a heat generation source. Due to the contact between the hot air and the entrained particles, the hot air temperature is dampened while the particles heat-up and recover energy back to the bed. In this case heat is mainly transferred to the bed by the entrained particles.

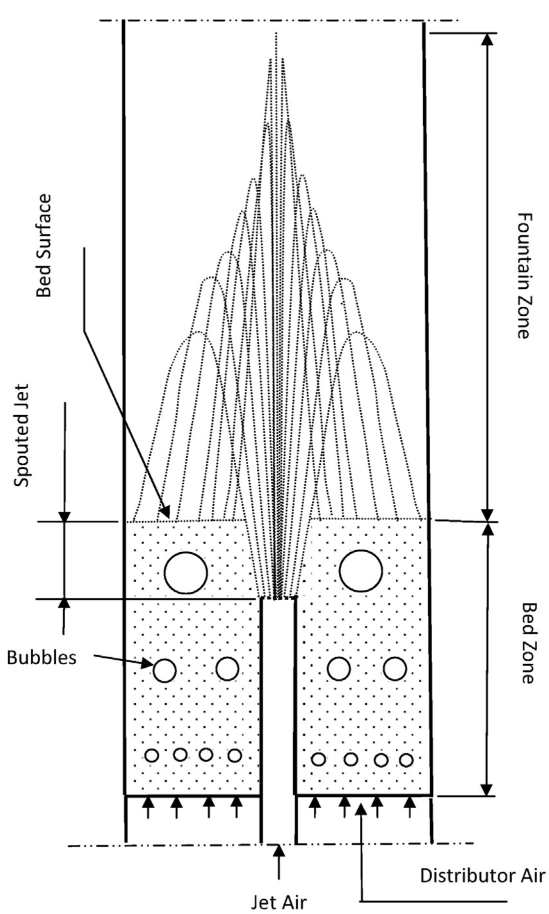

Fig. 1. Jetting-fountain fluidized bed reactor configuration.

2. Experimental set-up

A bubbling fluidized bed consists of fluidization column of 300 mm ID and 3300 mm height, shown in Fig. 2, is used in this study. The combustor has been modified to adopt the jetting–fountain configuration. The fluidization column is well insulated to minimize heat losses. 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 jetting 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. For more details of the experimental set up, see Ref. [24].

The air is heated using an electrical heater of 40 kW. Hot air is introduced through a perforated horizontal pipe with 22.2 mm ID as shown in Fig. 3. The pipe has a ring shape with 200 mm diameter.

The fluidization column is equipped with 25 portals to insert probes for measuring purposes. It is also furnished with two eyeglasses to enable visualizing the freeboard of fluidization column. Two PTD and PTJ taps in the freeboard are located at 240 cm above the distributor. 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.

Thermocouples, type-K, have been used to measure temperatures at different positions. Temperatures have been measured at different heights above the distributor, at 15 and 30 cm in the bed, and at 80 cm in the freeboard. Wall temperature has been also measured. Temperatures of air streams have been measured at the plenum chamber and at the inlet of hot air. All thermocouples were connected to a computer through a data acquisition system.

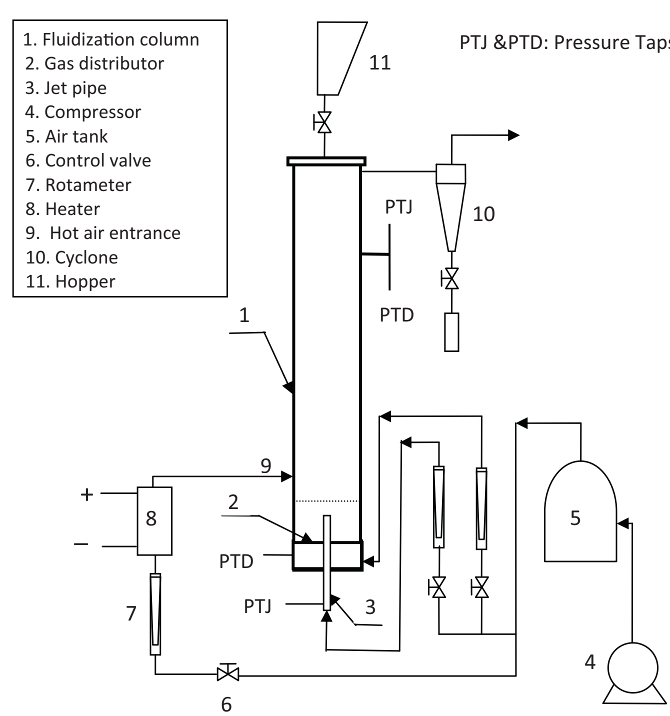

Fig. 2. Bubbling fluidized bed reactor adopting jetting-fountain configuration.