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Co-combustion of biomass and gaseous fuel in a novel configuration of fluidized bed: Combustion characteristics

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HIGHLIGHTS

- Jetting-fountain fluidized bed enables smooth co-firing of biomass and gaseous fuel.
- Applying jetting-fountain configuration reduces greatly CO, SO_2 and NO_x.
- Jetting-fountain configuration has a positive impact on combustion efficiency.
- Natural gas contribution reduces considerably CO, SO_2 and NO_x and improves combustion efficiency.

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ABSTRACT

Experimental study on co-combustion of rice straw and natural gas has been performed in a bubbling fluidized bed. The used combustor allows a novel jetting-fountain configuration and the conventional operation as well. In the jetting-fountain configuration, natural gas premixed with the air sufficient for combustion proceeds through the jet pipe to create a jet-fountain zone. Whereas only the air required for rice straw combustion passes through the gas distributor. The findings of the experiments confirm that smooth combustion of natural gas with rice straw can be performed in the novel jetting-fountain fluidized bed. This avoids acoustic effects and explosions of burning bubbles that occurs in the conventional operation. Natural gas contribution had a major impact on combustion characteristics and the performance of the combustor has been found to be much better when applying the jetting-fountain configuration. There are considerable reductions (up to 64%, 28% and 34%) in CO, NO_x and SO_2 emissions, respectively. The fixed carbon loss reduces (up to 65%) as well. Combustion efficiency records generally higher values with the jetting-fountain configuration. Combustion efficiency steadily improves with increasing natural gas contribution (up to 99.8%). Increasing bed temperature (up to 900 °C) is beneficial for reducing CO, decreasing fixed carbon loss and improving combustion efficiency. The existence of an optimum bed temperature for sulfur retention has been confirmed. As normal, NO_x increases with bed temperature.

1. Introduction

Biomass is recognized as a potential energy resource to mitigate emission of greenhouse gases [1–9]. Utilization of biomass energy at large scale could contribute to sustainable development on different fronts including, environmental, social, and economical [4,5,10]. Biomass is renewable and nearly CO_2-neutral fuel when managed in a sustainable manner [7,11]. Nowadays biomass contributes about 10-15% of the total world energy demand [1,10,12]. Moreover, using biomass for energy production assists to solve the waste disposal problem and avoids landfilling materials that ultimately decompose forming both CO_2 and methane, a more harmful greenhouse component [13].

Co-combustion with fossil fuels promotes the use of biomass and provides one alternative to achieve emission reductions. Among the other renewable energy options, co-combustion is the lowest risk, least expensive, and most efficient [14,15]. Adding biomass to a coal-fired boiler has no or slight impact on the overall generation efficiency of a coal-fired power plant [16]. Co-combustion of biomass and coal has been subjected to intensive studies that used every major type of biomass (herbaceous, woody, animal wastes, and anthropomorphic wastes) combined with different ranks of coal [17–25]. Contribution of biomass mainly reduces

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CO_2 emission. Further, Co-combustion of biomass with fossil fuels provides means to reduce SO_2, and it may also reduce NO_x emissions [24–31].

Open burning of rice straw is a serious problem in Egypt where smoke cloud be easily detected during the harvest season. Burning rice straw in the field releases pollutants that contribute to greenhouse gases without energy gain. Utilization of rice straw and rice husk in energy production is a promising option. Combustion of rice by-products in fluidized beds has been carried out in different works [32–37]. Many other works have successfully performed on co-combustion with coal [38–42] or with bitumen [43–45].

However, the combustion of gaseous fuels in fluidized beds may be characterized by acoustic effects and explosion risk [46,47]. Post-combustion of gaseous fuels in the freeboard is significant, in particular, at lower bed temperatures [46–54]. Post-combustion has been also found important in the combustion of biomass [32,55,56] and liquid fuels [57–59]. In this respect, 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 [44,56]. Moreover, other studies have indicated that the contact between gas and solids is very poor in the main bed while it is very good in the splashing zone [60,61].

In this work co-combustion of rice straw and natural gas in fluidized bed has been investigated. To avoid the shortcomings discussed above, a novel configuration of bubbling fluidized bed developed by Okasha [62–66] has been applied. The novel configuration, namely the jetting-fountain fluidized bed, is characterized by excellent gas–solids contact. The different advantages of the novel configuration can be found in the literatures [62–64]. Different from spout fluidized bed that was introduced to improve spouted bed performance [67], the jetting-fountain configuration is developed to improve the performance of bubbling fluidized bed. Another distinct feature of the jetting-fountain configuration different from previous spouted bed configurations is that the height of spouted jet is independent of the bed height. This feature makes the design more flexible and the flow regimes considerably different. Applying the jetting-fountain to co-combustion of rice straw and natural gas has been carried out. Gaseous emissions have been characterized including CO, SO_2 and NO_x. The impact on fixed carbon loss and combustion efficiency has been assessed as well. Influence of fuels blending ratio on combustion characteristics has been also studied. Impact of bed temperature has been also considered.

2. Experimental set-up and procedure

2.1. Apparatus and technique

A bubbling fluidized-bed combustor has been modified to adopt the jetting-fountain configuration as shown in Fig. 1. It consists of fluidization column of 300 mm ID and 3300 mm height. Column parts are all insulated using blankets of ceramic wool. The thickness of this layer is about 60 mm with the exception of the bed zone which has blankets with a thickness of about 100 mm. The bed zone has one meter height starting from the distributor plate. A nozzle-type plate is used to distribute the gases at the bottom of the fluidization column. These gases serve 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.

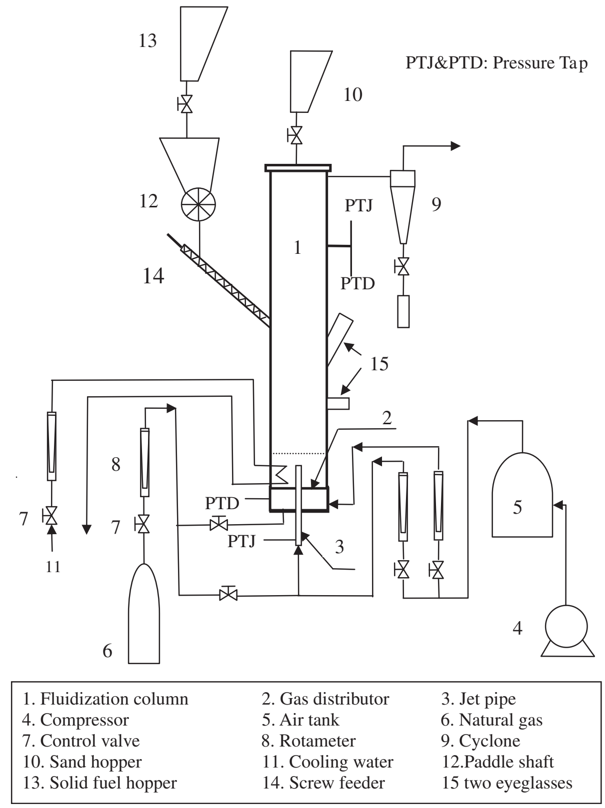

Fig. 1. Bubbling fluidized bed combustor adopting jetting-fountain configuration.

In conventional operation all the air is pre-mixed with natural gas and delivered through the gas distributor. In the jetting-fountain configuration, on the other hand, natural gas premixed with the air sufficient for combustion proceeds through the jet pipe to create a jet-fountain zone. Whereas only the air required for rice straw combustion passes through the gas distributor, see Fig. 2. The flow rates of natural gas and air are measured with rotameters. The measuring error ranges of used rotameters are within 3% for natural gas and 2% for air.

The combustor is equipped with a continuous over-bed fuel feeding system using a calibrated paddle shaft. The shaft is driven

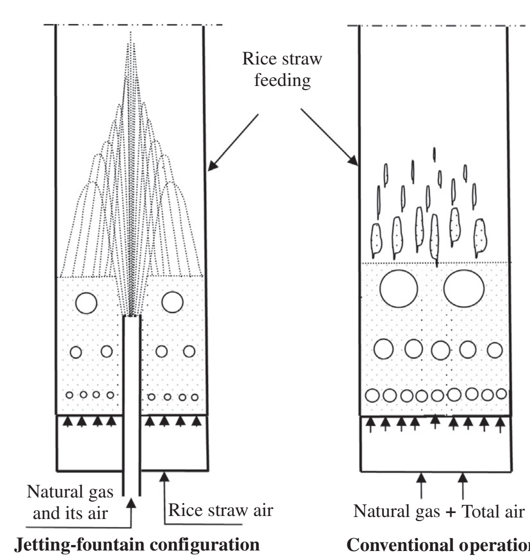

Fig. 2. Methods of feeding gases and rice straw pellets.