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A study on fluidized bed combustion characteristics of corncob in three different combustion modes

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ABSTRACT

This paper presents results obtained from corncob combustion in a pilot scale vortexing fluidized bed combustor (VFBC). Three combustion modes including direct combustion, staged combustion and flue gas recirculation (FGR) combustion were employed, and their combustion and pollutant emission characteristics were studied. In addition, the effects of combustion fraction and bed temperature on pollutant emission characteristics were investigated. The experimental results show that the combustion fractions vary with different combustion modes, resulting in different CO and NO emission characteristics. Staged and FGR combustions can reduce the NO emission concentration. Under similar working condition, NO concentration decreases by 30% in FGR mode, while 15% in staged mode compared with direct mode.

1. Introduction

Corn (maize) is an important crop with its annual production being the top among all agricultural grains in the world. The amount of its byproducts such as corn straw and corncob is enormous. More than 1.3 billon tons byproducts generated each year in North America (Kim and Dale, 2004). The LHV of corncob is about 4400 kcal/kg, which is similar to corn stern and leaf. However, its fertilizing value is less than one-tenth of that of corn stern or leaf (Avila-Segura et al., 2011). Therefore, corncob is suitable for burning as a fuel instead of serving as a fertilizer. Due to the abundant supply of corncob in the world, a lot of research attention is focused on the new techniques of converting corncob to biomass energy forms. Tippayawong et al. (2006) used the heat from corncob combustion in a 1.0 m ID × 2.0 m in height combustor for tobacco drying. The temperature stability in this corncob combustion proved that corncob is suitable for replacing wood as an alternative fuel.

FBC is recognized as one of many viable technologies in dealing with corncob combustion (Lin et al., 1995; Shafey and Taha, 1992). FBC has the potential for cleaner combustion because of its lower operation temperature (700–900 °C), which significantly reduces the formation of thermal NO*x* and prompt NO*x* (Leckner and Karlsson, 1993; Werther et al., 2000). In previous studies, many experimental investigations were carried out to understand the formation and reduction mechanism of pollutant emission produced by corncob combustion in FBC. Youssef et al. (2009) studied the corncob combustion in a 0.145 m ID × 2.0 m in height CFB. The results showed that the lowest emissions of the CO and NO*x* occurred when the excess air ratio is 24%. Butuk and Morey (1987) evaluated the thermal efficiency of a combustion system using corncob. However, few studies focused on the NO*x* lowering techniques by using staged combustion and FGR.

Meanwhile, some fossil fuels, such as lignite and anthracite were mixed with corncob in some combustion research works. The co-combustion characteristics in the fluidized-beds were also investigated (Lin et al., 2010; Trif-Tordai et al., 2010). The results

Abbreviations: VFBC, vortexing fluidized bed combustor; FGR, flue gas recirculation; LHV, lower heating value; FBC, fluidized bed combustor; CFB, circulating fluidized bed; ID fan, induced draft fan; E_A, excess air ratio (%); Y_i, the combustion fraction in the each zone (%); S_b, the stoichiometric oxygen in the bed zone (%); V_{1st}, the volumetric flow rate of first air (N m^3 min^{-1}); V_{FGR}, the volumetric flow rate of FGR (N m^3 min^{-1}); C_{FGR}, the oxygen concentration of FGR at the outlet of ID fan (%); V_{C,O_2}, the oxygen consumed in the each combustion zone (N m^3 min^{-1}); V_{T,O_2}, the total oxygen consumed in the VFBC (N m^3 min^{-1}); V_{PRI}, the volumetric flow rate of primary gas (N m^3 min^{-1}); V_{2nd}, the volumetric flow rate of secondary air (N m^3 min^{-1}); V_T, the volumetric flow rate of total air (N m^3 min^{-1}); V_{TO}, the volumetric flow rate of oxygen in the primary gas (N m^3 min^{-1}); T_b, bed temperature (°C); Q_r, the heat of chemical reaction (kcal/kg); Q_m, the heat taken into the bed by fuel and air (kcal/kg); Q_v, the heat generated by the combustion of turndown particles from the vortexing effect (kcal/kg); Q_i, the heat loss from the incomplete combustion (kcal/kg); Q_l, the heat loss from the furnace (kcal/kg); V_n, flow rate of the flue gas generated from the combustion of 1 kg corncob (kg/kg); c_f, the specific heat of flue gas (kcal/kg °C).

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showed that co-combustion of corncob and coal could significantly reduce the NO*x* emission. The alkali metal elements such as K, Na, and Ca of corncob have good desulfurization effect and this reduces the SO_2 emission significantly. Moreover, because corncob has higher volatile ratio than coal, the volatile of corncob releases rapidly and combusts in the freeboard, leading to higher freeboard temperatures. However, due to the insufficient combustion time of volatile, the CO emission concentration increases with the ratio of corncob in the mixture.

Corner tangential firing technology is originally applied in the pulverized coal-fired boiler. From the previous studies on the corncob combustion in fluidized-bed combustors, the volatile released from corncob is carried up from the bed zone and combusts in the freeboard. In addition, due to the lower solid voidage in the

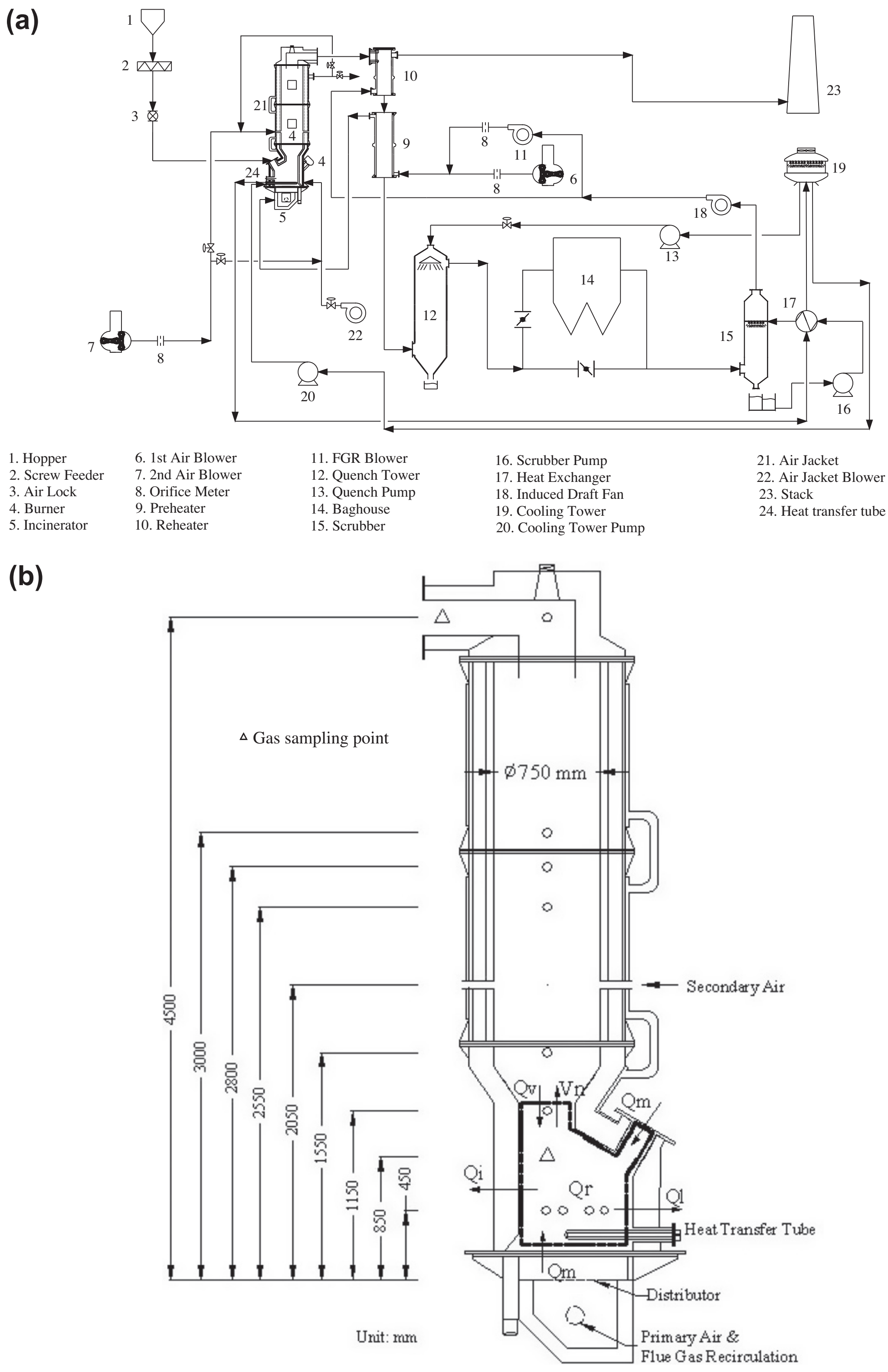

Fig. 1. Vortexing fluidized bed combustor system.