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Research Paper

Effect of freeboard deflectors in the fixed bed combustion of biomass

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HIGHLIGHTS

- The influence of deflectors on the temperature, emissions and burning rate in a fixed bed biomass combustor is studied.
- Deflectors have stronger influence on near-wall temperatures compared to centreline temperatures.
- Results show that deflectors affect NO, CO and CO_2 emissions.
- Deflectors don't have a significant impact on the burning rate.

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ABSTRACT

Deflectors have been used in the freeboard section of industrial combustors to reduce radiant heat loss through flue gases and for particle emissions abatement. Freeboard deflectors can also reduce the draft force of flue gases and affect flow dynamics. There have been no systematic studies to investigate the effects of deflectors on the temperature profiles and emissions in laboratory scale fixed bed biomass combustors.

This research includes experiments conducted over lean conditions (λ_{total}) on fixed bed combustor, with a freeboard deflector located at different axial locations. The aim is to characterize the effects on temperature distribution (near-wall and near-centreline) and gaseous emissions (NO, CO, CO_2) over a range of primary and secondary air flow rates. Experimental results indicate that deflectors affect upstream near-wall temperatures, but their impact depends on relative (axial) position (*H*). The presence of a freeboard deflector however decreases near-wall temperatures in the downstream which may be due to aerodynamic effects. Deflectors do not appear to affect the centreline temperature profiles downstream of the secondary air. Furthermore, results reveal that deflectors do not have significant effects on the fuel consumption rate when expressed via the burning rate (kg m^{-2} s^{-1}). Results also showed that NO, CO and CO_2 emissions are also affected by the presence of a deflector in the mid-range of combustion stoichiometry ($\lambda_{primary}$ = 0.439–0.509). However, deflector effects were found to be most prominent for NO and CO emissions by reducing and rising their levels, respectively.

1. Introduction

Biomass has become one of the most used forms of renewable energy. Thermal, biological and mechanical processes are the major techniques that are used to convert biomass fuels to energy [1]. Pyrolysis, gasification and combustion are major sub-processes within the thermal conversion [2]. Biomass combustion is widely seen as one of the most suitable conversion technologies that can convert biomass resources and can help generate both heat and power because of its high fuel flexibility [3–5]. Commercial-scale combustors (non-fluidised), which have megawatt thermal capacity, typically incorporate moving grates [6], whereas fixed bed combustors (<50 kW) incorporate fixed grates and are used in small-scale applications. Such units are used for laboratory scale research or employed for household applications [7,8]. There are two different bed configurations in fixed bed combustors based on the direction of the flame front propagation; counter-current and co-current. In co-current configurations, the flame front and air (oxidizer) stream move downstream in the same direction, whilst in a counter-current configurations ignition starts at the bed top with the flame front propagating upstream against the direction of primary air [9,10]. Fig. 1 shows two different types

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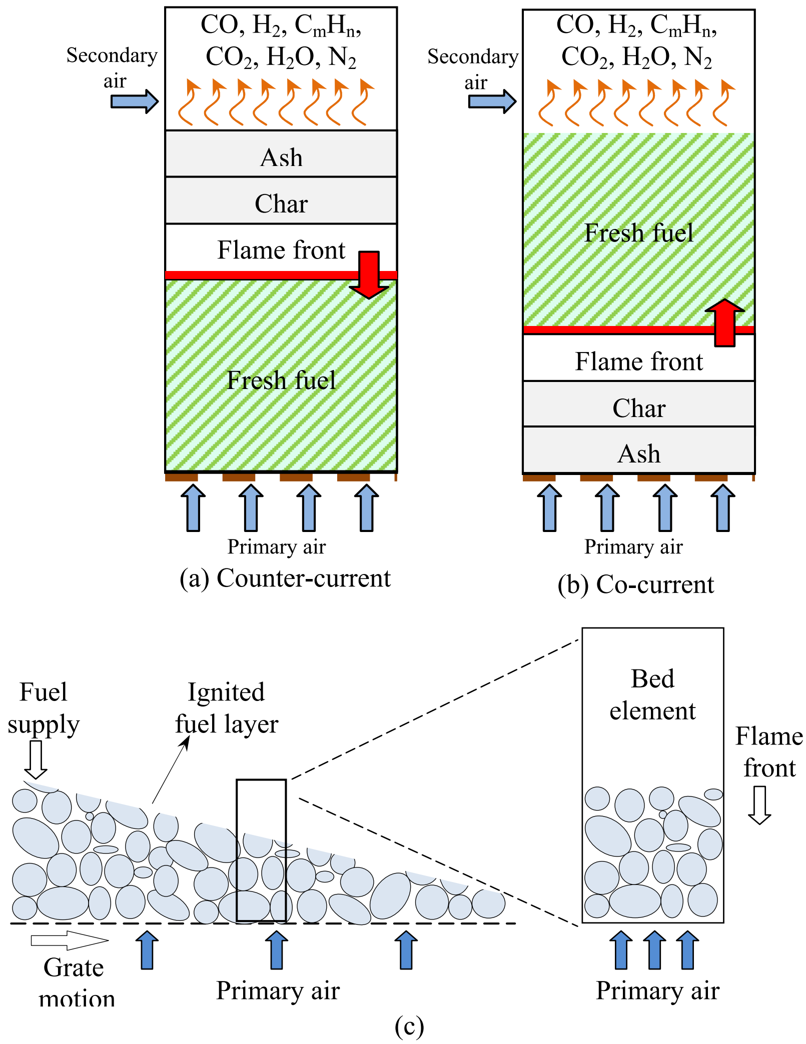

Fig. 1. Thermal conversion in two different types of fixed bed combustion: (a) counter-current and (b) co-current conversion. (c) Simulation of a moving bed furnace by fixed-bed model.

of stationary bed systems (Fig. 1a and b) and the analogy between combustion in a fixed bed and moving grate combustors (Fig. 1c). As such, the results of a fixed bed model can be applied as a good approximation to simulate an industrial moving grate bed due to the relatively small horizontal gradients in mass and heat transfer compared to the vertical gradients that exist in industrial-scale combustors [11,12]. Fig. 1c shows a moving bed and the similitude formed by (vertical) sections with a fixed bed. The main advantage of small-scale combustors is that they offer lower costs in terms of both capital and operation. In addition, in comparison with industrial-scale burners, laboratory scale testing is easier to control and apply data acquisition and thus results in better reproducibility.

Parameters that affect the combustion process in fixed bed combustors can be categorized into three different groups: fuel (chemical) composition, fuel (physical and geometrical) morphology and operating conditions (primary and secondary air flows) [13]. As such, the primary air flow rate (Q_p), secondary air flow rate (Q_s), air-to-fuel ratio, combustor wall insulation and fluid flow characteristics (laminar or turbulent) inside the chamber are major operating conditions that influence conversion performance, burning rate and emissions [14–16]. Burning rate and ignition speed are dependent on the primary air supply rate [16–19] whilst gaseous emissions (especially NO) are affected by secondary air, which increases O_2 concentration in the secondary zone of reactor [20,21]. Wall insulation affects the ignition, burning rates and temperature profiles inside the fixed bed combustor [15,22]. Wall temperature is another important factor because it also affects the temperature profile in the combustor's fuel bed and post-bed gases within the freeboard. Most combustors are therefore not isolated but can even be cooled using water jackets or similar heat exchanger systems.

Particulate matter species and gaseous emissions such as CO, HC, NO_x, SO_x, as well as volatile organic compounds are primary pollutants formed in biomass combustion [23,24]. In commercial burners, particle removal systems such as electrostatic precipitators, fabric filters, cyclones, absorption and wet scrubbing units and deflectors are applied before the exhaust gases are released through the chimney into the atmosphere [25–27]. In industrial combustors, (geometrical) deflectors have also been employed to improve combustion performance and decrease particle emissions [27]. Deflectors affect the draft force of the flue gases and increase residence time, which results in reduced particle emissions. Furthermore, this affects temperature distributions in the post-bed (freeboard) zone [28]. Whilst few studies into the effects of freeboard deflectors have been made, published work [27–30] indicates that deflectors will likely affect the wall temperatures and flow dynamics in the freeboard region of packed beds. The effects