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ScienceDirect

Energy Procedia 120 (2017) 643–648

Energy Procedia

www.elsevier.com/locate/procedia

INFUB - 11th European Conference on Industrial Furnaces and Boilers, INFUB-11

Unified Ignition – Devolatilization model for fixed bed biomass Gasification/Combustion

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Abstract

Counter-current flame propagation through fixed packed beds serves as a canonical form for understanding biomass thermochemical conversion phenomenon – this is due to the 'universal behavior' of fuel consumption rate per unit area with superficial velocity variation. This behavior is directly related to the particle density scaled ignition time being independent of biomass type, varying only with superficial velocity. But when the devolatilization time exceeds ignition time for a particle, the predicted fuel consumption rates will be higher than the actual values due to overlap of ignition and devolatilization. This situation is relevant for larger particles (> 30 mm equivalent sphere) and thin wood chips, due to sharp edges aiding quick ignition. The current work aims at generalizing the 'universal propagation model' to account for this effect which is critical to designing grate furnaces. Towards this, packed bed experiments were performed in a 500 mm dia, 1 m height cylindrical reactor with groundnut shell briquettes (GSB; dia 100 mm, lengths varying from 40 to 110mm) and pellets (dia 8mm and length varying between 15 to 20mm) at a superficial velocity of 20 and 30 cm/s. The fuel mass flux is calculated by two methods 1) from the slope of time-mass curve 2) from time-Temperature plots measured at fixed thermocouple locations along the reactor. Fuel flux measured using the two methods match closely for pellets, but with GSB, the fuel flux from method 2 is higher than method 1 by about 15 %. This indicates that subsequent fresh layer of biomass ignites before complete devolatilization of the previous layer leading to oxygen starvation. This also indicates a transition from ignition controlled to devolatilization rate controlled flame propagation, consistent with the expectations based on variation of ignition and devolatilization time with particle size measured for single particles in an earlier study at our lab. These results are used to develop a unified ignition-devolatilization model for single particle combustion, which is used to modify the 'universal propagation model' to account for particle size and shape effects. The predictions from this model are shown to closely match with the observed results.

Keywords: Biomass, Fixed bed, Grate furnace, Ignition-Devolatilization, Modeling

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10.1016/j.egypro.2017.07.212

1. Introduction

Agro-residue based briquettes are increasingly used for medium scale process steam generation and other applications. With maximum capacity required in such applications limited to 10 tons/hr of steam, cross-current grate firing is the most preferred configuration. Generally, systems designed for wood chips are adopted for briquettes with design changes by trial and error. While many attempts have been made to model processes on a grate it is not clear how far these ideas have been translated into design principles which can be used by practitioners. A review of these modeling efforts can be found in [1]. Varunkumar et al [2] sought to remedy this by recognizing the equivalence between cross- and counter-current packed bed configuration through a coordinate transformation. By using the 'universal flame propagation' (denoted UFP hereafter) behavior of counter-current configuration, which is well understood in terms of a simple diffusion controlled model capable of capturing the abundant data available from earlier work [3], a simple kinematic equation connecting the grate parameters (speed and length) with system design parameters (steam generation rate, initial bed height) is obtained in [2]; the essential idea being that the residence time of fuel particles on the grate must be at least equal to the conversion time determined by the UFP model. This model is shown to rationalize the current design and further suggestions for improvement are brought out in [2]. This effort also brought out certain minor limitations of application of UFP model to practical grate furnaces. This is related to the assumption of 'ignition' controlled propagation which leads to the kinematic grate equation being valid for only particles of size less than 30mm (equivalent sphere). This aspect is elucidated with single particle experiment that show the devolatilization time to exceed the ignition time for particles larger than 30mm (see Fig. 8 in [2]) thereby bringing out the need for modification of the UFP model. The need for further experiments with larger briquette particles in a 500mm lab scale counter-current reactor is brought out in [2]. Current work reports experimental results from such a reactor and attempts to improve the UFP model with a new *'unified ignition-devolatilization'* framework.

2. Experiments

Experiments are carried out in a cylindrical furnace 500mm in diameter and 1200mm in length made of SS310 insulated with high grade ceramic wool. A schematic of the experimental setup is shown in Fig. 1. The entire reactor is mounted on a weighing scale (10 g accuracy, 200 kg max) for mass loss measurement and thermocouples are placed at a uniform distance along the length of the reactor for measuring flame propagation rate. Air is fed through the grate by a centrifugal blower metered through a calibrated orifice plate. For uniform distribution, air stream is split and fed as three jets separated at 120 degrees at the bottom of the reactor through the grate.

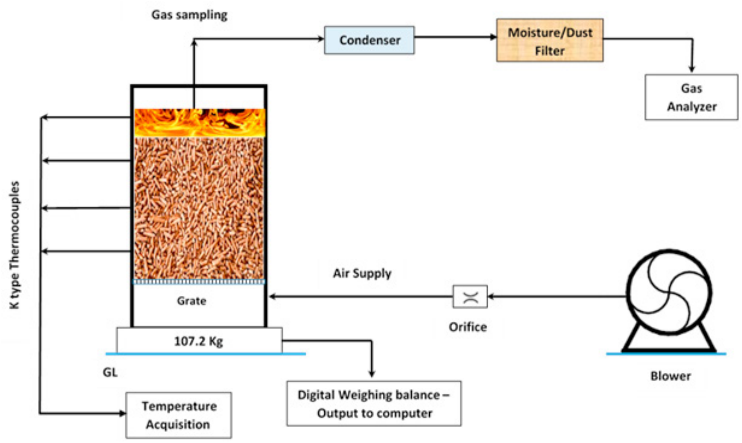

Fig. 1. Schematic of the Experimental setup

Online sampling of gas is made from the top of the reactor through a sampling line connected with condenser, dust/moisture filter and gas analyzer downstream (results not reported here). A total of seven experiments - six with groundnut shell briquettes and one control experiment with Oorja pellets were done. The properties and the pictures of the biomass used in the experiment are given in Table 1 and Fig. 2 respectively.