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Active fuel particles dispersion by synthetic jet in an entrained flow gasifier of biomass: Cold flow

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ABSTRACT

Pulverized fuel (PF) burners play a key role for the performance of PF fired gasification and combustion plants, by minimizing pollutant emission, fuel consumption and hence fuel costs. However, fuel diversity in power generation plants imposes limitations on the performance of existing PF burners, especially when burning solid fuel particles with poor flowability like biomass sawdust. In the present study, a vertically downward laminar flow was laden with biomass particles at different particle mass loading ratios, ranging from 0.47 to 2.67. The particle laden flow was forced by a synthetic jet actuator over a range of forcing amplitudes, 0.35–1.1 kPa. Pulverized pine particles with a sieve size range of 63–112 μm were used as biomass feedstock. Two-phase particle image velocimetry was applied to measure the velocity of the particles and air flow at the same time. The results showed that the synthetic jet had a large influence on the flow fields of both air and powdered pine particles, via a convective effect induced by vortex rings that propagate in the flow direction. The particle velocity, particle dispersion and hence inter-particle distance increased with increasing forcing amplitude. Moreover, particles accumulated within a specific region of the flow, based on their size. The effect on particle dispersion was more pronounced in the forced flows with low mass loading ratios.

1. Introduction

As global energy demand continues to increase, the use of renewable energy sources can serve as an alternative solution to reduce energy demand and to improve energy security with reduced greenhouse gas emissions as a benefit. Recently, there has been an increasing effort to integrate biomass into the major CO_2 emitting sectors, e.g. energy and transportation since biomass is renewable and CO_2 neutral. Gasification is one of the cleanest and most versatile ways to convert biomass into high value-added commercial products, e.g. biofuel or commodity chemical products. Entrained flow gasification (EFG) is a well proven, commercially available gasification technology for coal, producing high quality syngas with little or no tar. Although there has been recently promising progress towards entrained flow gasification of biomass, there still remains some challenges that come from biomass properties. Biomass particles differ from coal particles in many aspects such as particle size, shape, texture and chemical composition. Retrofitting existing entrained flow coal gasifiers to accommodate biomass can produce some technical hurdles. For instance, bulky and fibrous woody biomass leads to inconsistent feeding [1,2]. This is because fibrous biomass often has low bulk density and high cohesive forces [3].

Entrained flow gasifiers are operated at low air/fuel equivalence ratios (≈0.4) in order to convert energy into chemical energy of combustible gases instead of heat [4]. At low air/fuel ratios, particles are packed tightly together, occupying high volume fractions. Quantitatively, mass loading ratio (biomass feeding rate to carrier gas flow rate) can be ca. 2 for oxygen blow entrained flow gasifier compared with ca. 0.2 for air-blown burners. The review study by Sirignano [5] reported that close-packed particle arrays produce different reaction environment in terms of temperature and gas composition than that for isolated particles. Similar findings were obtained in an experimental study of Göktepe et al. [6] showing that highly packed particles produce higher volume fractions of soot than loosely packed particles or isolated particles. It is therefore important to investigate means to control the particle dispersion.

A conventional way to control particle dispersion in powder burners is to impose a swirling flow that will enhance particle dispersion via centrifugal effects and prolong the residence time [7]. An alternative way is to control the flow with a synthetic jet actuator that generates a pulsed flow by periodic forcing a fluid back and forth through a small opening. In this way, momentum can be transferred to the flow with zero-net mass flux while simultaneously enhancing the mixing

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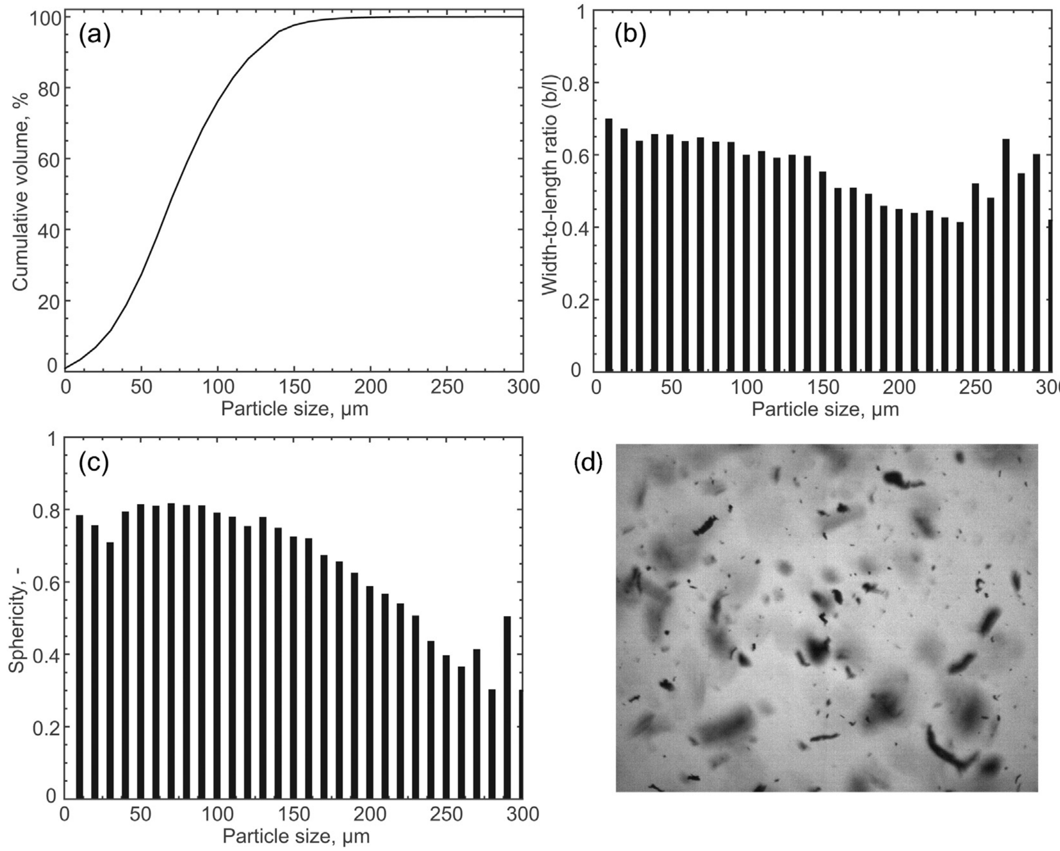

Fig. 1. (a) Particle size distribution of pine sawdust with a sieving size of 63–112 µm (b) width-to-length ratio (*b*/*l*) (c) particle sphericity (d) snapshot of pulverized pine particles recorded by CAMSIZER XT.

of gases via a convective effect induced by trailing vortex rings [8]. It has been shown by many researchers that the flow fluctuations are more pronounced in low flow velocity cases, and this effect will decay and vanish downstream the excitation point. Moreover, several studies on particle-laden flows have reported that the vortex rings result in the gathering of solid particles in two different flow regions: a high shear region, between vortex rings, and a high vorticity region, the vortex rings themselves. This phenomena is referred to as "preferential accumulation" and has been reported by Balanchandar and Eaton [9] and Tamburello and Amitay [10].

To the best of the authors' knowledge, there is no available literary information on the motion and dispersion behaviour of non-spherical

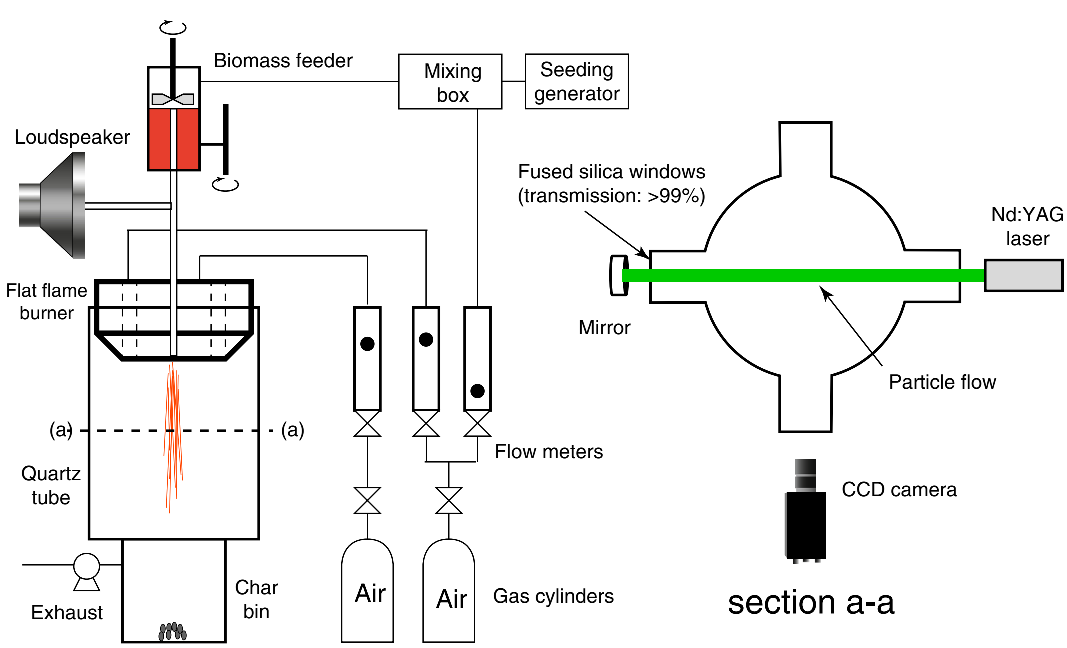

Fig. 2. Schematic diagram of experimental set-up.