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Experimental investigations into the flow characteristics of pneumatically conveyed biomass particles using an electrostatic sensor array

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HIGHLIGHTS

- Electrostatic sensors are constructed as an array across the diameter of the pipe.
- The sensor array is distributed along an intrusive blade across the pipe diameter.
- Both velocity and concentration profiles of biomass particles are measured.
- Experiments were conducted on a 50 mm bore pipeline with willow as a test fuel.
- Effects of particle size and shape on the flow characteristics are studied.

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ABSTRACT

As countries across the world are pushing towards the increased use of renewable sources of energy the burning of biomass fuels makes up an important part of this strategy. Many coal fired power stations have been converted to co-firing and in some cases are being completely biomass fuelled. However, due to their variability in size, shape and the complex nature of gas–solids two-phase flow the monitoring of biomass particles in a pneumatic conveying pipeline is difficult. This paper presents the results of experimental investigations carried out using a novel electrostatic sensor array that is capable of measuring the particle velocity and concentration profiles over the whole diameter of the pipe. Experimental tests were carried out on horizontal and vertical pipe sections with different particle sizes of a common biomass fuel – willow, over a range of flow conditions. Results from the experiments indicate that smaller biomass particles have more stable flow characteristics across the whole diameter of the pipe.

1. Introduction

The ability to accurately monitor the mass flow rate of pneumatically conveyed fuel is important in improving burning efficiency and reducing slagging and emissions. Power plants across the world have been converted to co-firing with a mixture of coal and biomass as well as solely biomass fuelling in order to increase the proportion of renewable energy generated.

There are several challenges in monitoring the complex flow characteristics of pulverised biomass inside a pneumatic conveying system. The first is that the pulverised fuel is conveyed in a dilute phase with particle concentration being less than 0.1% of the pipe volume [1], meaning that any sensor used to measure the particle flow will have to be sensitive enough to detect such low concentrations. Second is the shape of biomass particles which are elongated due to their fibrous structure meaning that the particle spin is more apparent compared to the spherical shape of pulverised coal. The third is that the particle size of pulverised biomass distributes over a much wider range than coal thus making particle flow in the pipe much more complex.

Various methods have been developed to monitor particle velocity and concentration in a pneumatic conveying pipeline. These include capacitive [2,3], radiometric [4], optical [5,6] and ultrasonic [7] sensing techniques. All of these sensor paradigms have the advantage of being nonintrusive and are capable of determining both particle velocity and concentration. Capacitive sensors, however, have a disadvantage in that they are sensitive to moisture in biomass, which can significantly change the dielectric properties of the fuel being monitored, leading to substantial errors in the concentration measurement. The radiometric method could outperform, in principle, all other techniques, but suffers from the

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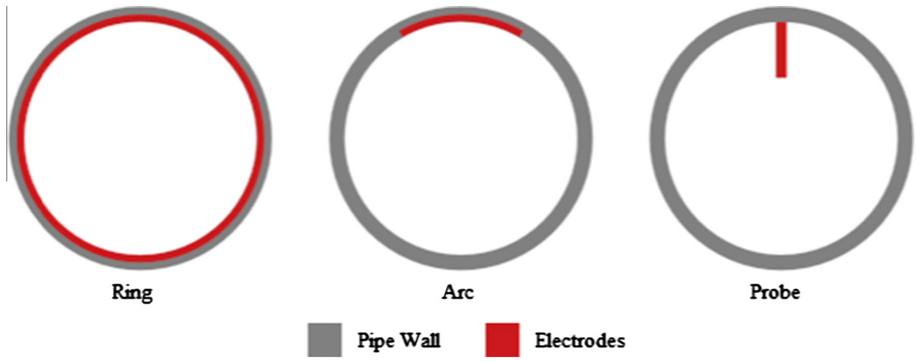

Fig. 1. Different designs of electrostatic electrodes.

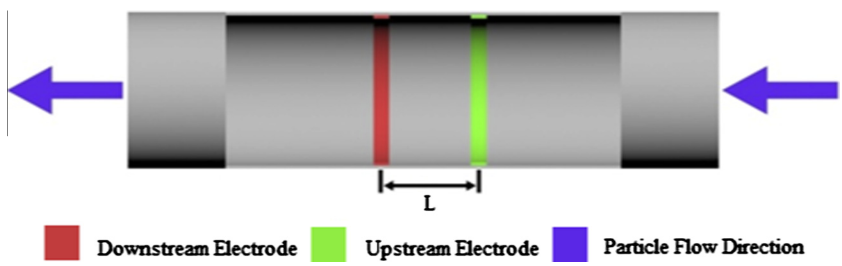

Fig. 2. Electrode configuration inside a pipe.

disadvantage of containing a radioactive material in the sensing system and associated administrative inconvenience dealing with stringent health and safety regulations. The drawback of using optical sensors lies in the requirement of a transparent window on the pipe to access the flow and the incorporation of an air purging mechanism to prevent the window from contamination due to fine dust accumulation. Electrostatic sensors, due to their simplicity, robustness and low cost, have the advantage over other sensors. Previous types of electrostatic sensors include ring, arc and probe electrodes [8–12], which are illustrated in Fig. 1. Electrostatic array sensors based on multiple ring and arc shaped electrodes have been used for the velocity measurement of pneumatically conveyed particles [10,11].

Ring electrodes are completely non-invasive since they lie flush with the pipe wall and consequently do not impede the particle flow in the pipe. They do, however, have disadvantages in that they are sensitive to particles close to the pipe wall. Nevertheless, when ring electrodes are used to measure the particle velocity through cross-correlation, the correlation coefficient between the upstream and downstream signals is limited because different parts of the pipe cross section can have different velocities depending upon the flow conditions [8]. Moreover, ring electrodes have a shortcoming that they are constructed inside pipe spool pieces, meaning that flanges are required to install the spool piece which is difficult to retrofit onto some existing systems.

Arc electrodes are very similar in design to ring electrodes except the latter are segmented individual sections of a ring which only cover a small portion of the circumference of the pipe wall [10,11]. Qian and Yan [10] used electrostatic sensor arrays with arc electrodes to monitor the local particle velocity of a flour/biomass mixture, making them much more able to accurately determine particle velocity. However, just like ring electrodes, arc electrodes are also built into pipe spools making installation difficult and costly.

Unlike ring and arc electrodes, probe electrodes are invasive in that they come into direct contact with the particle flow in the pipe. Nevertheless, this does not cause a problem in a dilute flow due to the low particle concentration (less than 0.1% by volume) coupled with the fact that the electrodes take up a very small proportion of the cross sectional area of the pipe. Shao et al. [8] assessed the performance of probe electrodes through a combination of practical on-line experimentation and off-line finite element modelling. It was found that a probe electrode with an electrode depth of 0.3–0.5 of the pipe diameter would give a

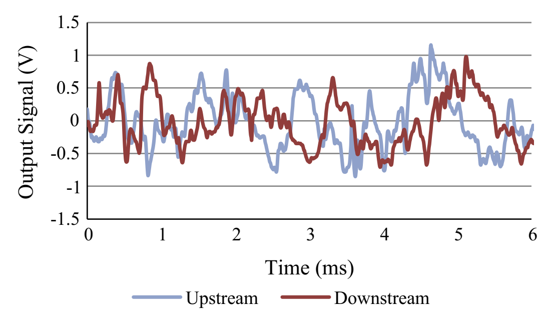

Fig. 3. Typical upstream and downstream signals from the electrostatic sensors.

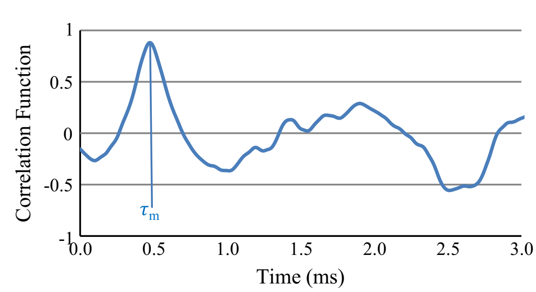

Fig. 4. Correlation function between the upstream and downstream signals.