Abstract

The reduction of harmful emissions is an important issue to be dealt with in coal-fired power stations. There are several technologies that have been successfully applied to modern power stations to reduce the emissions of Oxides of Sulphur and Nitrogen. One of such technologies are low NOx burners which employ directed fuel and air staging to create a NOx reduction zone. One of the requirements for effective operation is to supply these burners with a uniform stream of pulverised fuel (PF). A co-requisite is to maintain a stable and continuous flow of PF through the pneumatic conveying system without incurring any particle settling. To achieve this, PF transport systems are usually designed using empirical correlations and numerical simulations. Various correlations have been developed to predict settling in horizontal pipes. These correlations however, were based on lab experimentations with pipe diameters and conveying mass flow rates much less than PF transport conditions and hence the predictions show significant variability when compared to experience. Some of the most valuable tools in predicting the onset of settling in PF systems are numerical models in the form of Computational Fluid Dynamics (CFD) simulations. Commercial codes offer multiple techniques for the analysis of gas-solid flows which differ in computational cost and physical considerations. The purpose of the numerical part of this study is to evaluate a numerical technique that can offer results that can reasonably predict the onset of settling at the most reasonable computational cost.

Comparisons of the correlations have been attempted in previous papers, some notable mentions are studies by Jones et al [1] and Gomes et al [2]. The Rizk correlation is widely regarded as the most reliable of the available correlations, however this correlation hasn't been evaluated extensively for PF transport conditions. This work compares the saltation velocities predicted by various correlations in literature to an experimental case from a study by Herbreteau and Bouard [3]. Correlations for saltation velocities by Rizk, Thomas and Matsumoto were noted as the more reliable of the correlations evaluated in predicting the minimum pressure drop for the range of particle sizes found in PF transport conditions. The effects of polydispersity were investigated using a normal distribution of particle sizes by considering minimum and maximum values of two standard deviations about the mean. It was found that a reasonable range of saltation velocities could be obtained from results from Matsumoto, Rizk and Thomas compared to using the method of polydispersity.

The correlations were compared under pneumatic conveying conditions of a typical coal-fired power station. All the correlations were found to under-predict the saltation velocities compared to the recommended minimum operating velocity of 18m/s for PF systems, most South African systems however, usually run between 20m/s and 25m/s. This means the correlations would have to be used with a safety factor of about 1.5 to be practical.

Numerical models were set up to compare results to cases found in literature including studies by Martin Sommerfeld and Bouard. These were to determine how competent the Lagrangian model could be in predicting the onset of settling and the pressure drop across a horizontal pipe. The Lagrangian model is one of the least computationally expensive models available in simulating gas-solid flows as it treats the solid phase as particle tracks in steady state considering the interactions between the solid phase and the gas and the particle wall collisions, this technique however does not consider the roughness of the conduit walls, the inter-particle collisions and the particle's rotation. Modifications can however be made to existing techniques to take additional physical effects into account as highlighted in a study on hybrid models by Pirker et al. [4].

The standard Lagrangian model was found to be insufficient when modelling the gas solid flows for the cases tested as it resulted in excessive settling of the particle tracks. This was because the physical phenomena that would redistribute the particles vertically in the conduit were not present. These phenomena include wall roughness and inter-particle collisions as these redistribute the particle's post collision trajectories randomly in the conduit. A wall roughness modification was then applied to the standard Lagrangian model which enhanced the distribution of the particle phase in the pipe. This was found to improve the mass flux profiles and pressure drop values to results that correlated better with experimental results for the 2D and 3D cases tested. The efficacy of the models was found to be dependent on the mass flow rate of solids, the particle diameters and the conveying velocity. As the conveying velocity is reduced, settling is increased resulting in regions of high particle densities. In these areas of high densities, the inter-particle collisions become more important resulting in a breakdown of the Lagrangian model. The modified Lagrangian model was however competent in predicting the behaviour of the flow until significant settling had occurred which makes it a useful tool in predicting the onset of settling for the cases tested. It was also found that the degree of wall roughness was an important parameter in adequately predicting the pressure drop across the pipe.

The verification process was conducted for a range of particle sizes and densities comparable to PF transport conditions, however there were no cases of comparable pipe diameters or PF flow rates found in literature as running tests at these scales requires significantly greater computational resources. For this reason, it would be of value to compare the results from these correlations to numerical models of this scale.