The influence of reactor geometry and scale on the hydrodynamics of fluidised bed fast pyrolysis reactors

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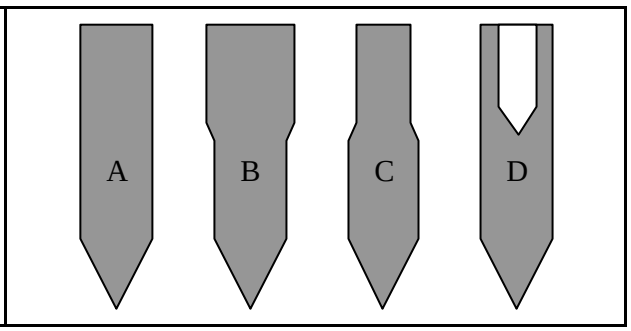
The effect of fluidised bed geometry and scale on hydrodynamics and entrainment of sand and char is considered by CFD analysis of different configurations with validation by experimentation. The main hydrodynamic parameters of bubble velocity and size and modelled, and their effects on sand and char entrainment in fluidised bed fast pyrolysis are predicted. Optimisation is performed in two respects both to obtain better reactor designs, and also to improve the computatio nal speed of the modelling effort.

Introduction

Fluidised beds are the most commonly employed type of reactor for achieving fast pyrolysis of biomass for bio-oil production. There are a number of advantages supporting this choice, in particular fast heat transfer and good temperature control. Fluidised beds are very complex systems, however, and design and scale up is mostly based on empirical relationships and pilot plant work. Advances in computing capabilities and numerical methods over the last decade allow a more fundamental treatment of fluidised bed modelling using computational fluid dynamics (CFD).

A key feature of fast pyrolysis is the need to separate the by-product char from the vapours as quickly and as completely as possible as char is a vapour cracking catalyst and can significantly reduce yields if not efficiently removed. The use of CFD to improve design and performance prediction of fluid beds has been extended to consider separation of char from fluidising sand and to evaluate the role of reactor geometry in achieving this separation as effectively as possible [1]. The reactor geometries considered in this paper are illustrated in Figure 1.

Figure 1 Reactor geometries.
A Orthodox fluid bed
B Expanded freeboard
C Constricted freeboard
D Dummy cyclone to constrict freeboard



Theory

The fluidised bed is modelled using the two-phase theory, with both phases modelled as interpenetrating continua. The particulate phase is therefore treated as if it was a proper fluid. The interaction between the two phases is taken account of by using inter-phase transfer terms. In the case of momentum the inter-phase transfer is based on the Ergun equation. For the estimation of entrainment, individual particles are also considered and tracked through the freeboard. For the numerical solution of the equations a number of resolutions both in time and space were considered. The stability of the solution procedure to numerical errors and a number of options to improve it and thereby raise the speed of arriving at a converged solution reflecting physical reality were also investigated.

Experimental Rigs

CFD predictions were made both for new and so far untried configurations, a number of existing experimental fast pyrolysis reactors and also for comparison with cold flow rigs built specifically for validation of the CFD work. The fast pyrolysis reactors were 1 kg/h and 10 kg/h rigs at Aston

University and a 250 kg/h pilot plant built by Wellman in Oldbury, England. Cold flow model work was performed on a glass replica of the 1 kg/h fast pyrolysis rig, which was modified to test the effect of changing reactor geometry. A 2D model (that is with one of the three dimensions significantly smaller than the other two) cold flow model is in the process of being built and will be used to investigate the scope for extrapolation from 2D to 3D work, and also for easier variation of geometry and scale.

Results

?? A number of hydrodynamic parameters are predicted, notably bubble velocity and size, and bed expansion.

?? It was found that increasing the scale of the bed also increases the scale of overall flow patterns and the terminal size of bubbles. Furthermore, the nature of the flow patterns changes on larger scales with a preference to up movement in the centre and down movements at the side of the bed developing.

?? Entrainment of both char and particularly sand was found to be particularly sensitive to scale and the selectivity of separation changes with scale. For optimisation, geometry and scale therefore have to be considered together. For example on larger units the bulk of sand losses could result from surging, rather than continuous entrainment, which is illustrated in Figure 2.

?? The numerical treatment was found to require a higher resolution with space for physical accuracy when the scale was increased. The speed of solution and its stability were also sensitive to very high or very low fluidisation velocities and certain changes in geometry.

?? A simple freeboard widening as an example of a geometric modification and particle tracking are illustrated in Figure 3 and Figure 4.

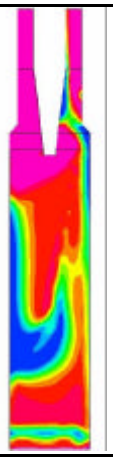


Figure 2 Sand surging on a large scale volume fractions shown dark (blue) = sand, light (pink) = air

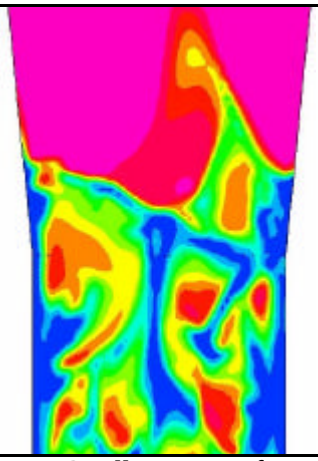


Figure 3 Illustration of freeboard widening

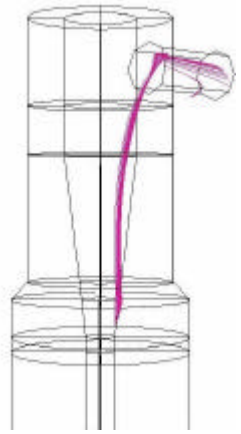


Figure 4 Illustration of particle tracking

Acknowledgement

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References

1 Gerhauser H, Generalis SC, Hague RA, Bridgwater AV, "CFD for the Modelling of Entrainment in Fluidised Bed Fast Pyrolysis of Biomass", pp 1281-1295 in Progress in Thermochemical Biomass Conversion, Ed. Bridgwater AV, (Blackwell, Oxford, UK 2001)