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Bed Sherwood number in fluidised bed combustion by Eulerian CFD modelling

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HIGHLIGHTS

- ▸ Eulerian CFD predicts correct response of bed Sh to fluidisation velocity.
- ▸ The bed Sherwood number drops with reactor width.
- ▸ Bed Sh can be applied to 1D models having one homogeneous gas-solid phase.
- ▸ At the same fluidisation regime, bed Sh is constant regardless of particle size.

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ABSTRACT

The objective of this research is to evaluate the average gas-to-char mass transfer coefficient predicted by a two-dimensional Eulerian multiphase CFD model in the conditions prevailing in a bench and a pilot scale bubbling and circulating fluidised bed combustors. It was found that the Eulerian multiphase CFD model is able to predict the same response of the bed Sherwood number to the fluidisation velocity as shown by the experimental results. The CFD simulations also suggest that the bed Sherwood number drops with increase of reactor width from the bench to the pilot scale. Research highlights that, in the combustion process, the bed Sherwood number is a function of Reynolds number, as well as phase mass transfer, char loading and chemical kinetics.

1. Introduction

The fluidised bed processes are characterised by the vigorous two-phase fluid dynamics, the strong coupling of chemical reactions with gas-solid mixing, and the efficient heat transfer related to the both earlier mentioned. Dominating phenomenon is the gas-solid flow dynamics, which provides an efficient gas-solid contact and mixing environment. Nevertheless, the heterogeneous reaction rates are under effect of the gas-to-bed mass transfer. Thus secondarily also local thermal conditions and chemical reaction paths are influenced by both the fluidisation regime and the related mass transfer characteristics. Further, on the overall fluidised bed reactor performance level, heterogeneous mass transfer has impact on combustion efficiency and emission performance. Therefore, understanding the heterogeneous mass transfer and being able to describe it under different fluidisation regimes are keys to the accurate fluidised bed process prediction. This concerns all fluidised bed models and analyses of reactive fluidised bed systems, and especially reactor scale-up related research and development.

Average gas-to-bed mass transfer in fluidised bed consists from two modes of heterogeneous mass transfer: phase and in-emulsion mass transfer (Kunii and Levenspiel, 1991). The both modes have a convective and a diffusive component. Two different ways of defining the heterogeneous mass transfer coefficients in the heterogeneous fluidised bed systems (Fig. 1c,d) were highlighted by Hou et al. (2010):

1. Multiphase model (mostly two-phases: emulsion-bubble or void-cluster): Fluid dynamic model provides the possibility to describe mass transfer modes separately: phase and in-emulsion mass transfer coefficients.
2. Single-phase model (plug flow and averaged conditions in calculation cell): Heterogeneous mass transfer is described with the averaged gas-to-bed mass transfer coefficient, which includes also the phase mass transfer coefficient.

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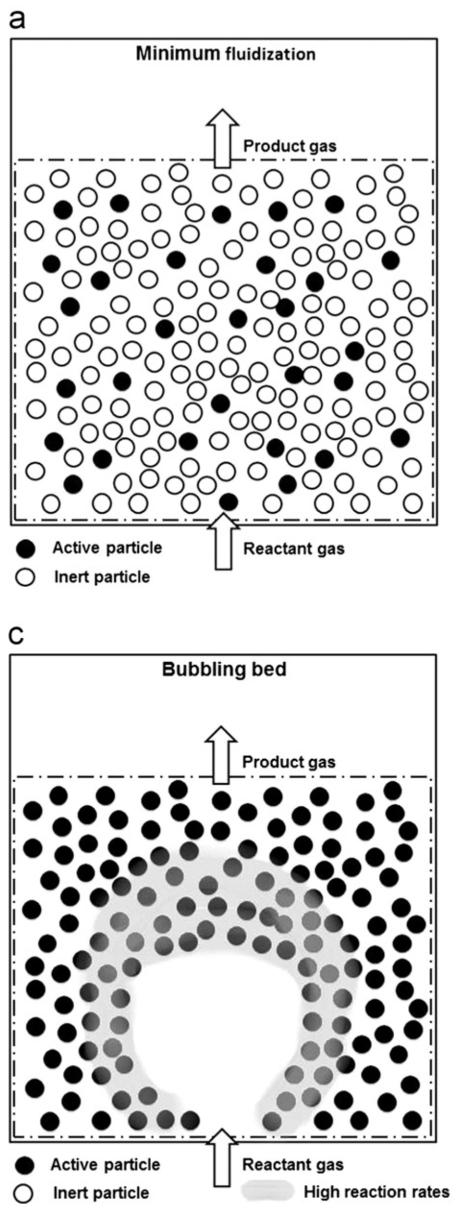

Fig. 1. Schematics of different gas-solid contact conditions in a small-diameter fluidised bed reactor or in a calculation cell of a fluidised bed reactor model. (a) Minimum fluidisation condition with inert and active particles, (b) bubbling ber regime with inert and active particles, (c) bubbling bed regime with only active particles present and (d) turbulent regime with only active particles present.

The average gas-to-bed mass transfer coefficient is usually described by the bed Sherwood number $Sh_{bed} = \overline{h}_m d_p / D$ correlation. Breault (2006) underlined a huge range (from 10^{-5} to 200) of in the literature presented Sherwood numbers in a review of gas-solid mass transfer coefficient correlations in circulating fluidised beds. The wide range can be explained by the differences in fluidisation mode, chemical kinetics, phase mass transfer and interpretation of mass transfer modes included into it. In addition, two main fluidised bed process types have different characteristics of the heterogeneous mass transfer processes:

(a) Bed consisting of only active particles: e.g. catalytic processes.
(b) Bed containing both active and inert particles: e.g. combustion and gasification processes.

Fig. 1a–d presents schematically minimum, bubbling bed and turbulent bed fluidisation regime for the above described process types of a and b. At the minimum fluidisation condition (Fig. 1a), heterogeneous mass transfer mechanisms and gas-to-bed mass transfer coefficient are same for the both process types. Table 1 presents in-emulsion Sherwood number Sh_e correlations suitable for the minimum fluidisation regime.

Fig. 1b shows the bubbling bed fluidisation mode for the bed consisting of both inert and active particles, and Fig. 1c shows the bubbling bed containing only active particles. At the bubbling bed regime, both the bubble-emulsion phase mass transfer and the in-emulsion convection are present. Two-phase theory suggests that emulsion phase is at the minimum fluidisation condition (Fig. 1a). From the different heterogeneous mass transfer mechanisms, the in-emulsion mass transfer is most widely researched. It also has a commonly accepted theory and proven empirical correlations with wide validity range. A comprehensive review of the in-emulsion Sherwood number Sh_e correlations suitable for char combustion (process type a) was presented by Scala (2007). Table 1 shows examples of the in-emulsion Sherwood number