



CFD simulation and experimental validation for wall effects on heat transfer of finite cylindrical catalyst[☆]

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ABSTRACT

In this paper, heat transfer of single cylindrical particle affected by wall has been investigated numerically and experimentally for Reynolds number range 2000 to 6000. The heat transfer in two different orientations, axial and cross flow over the particle has been considered in simulation with MultiPhysics Software FEMLAB version 2.3. The heat and mass transfer analogy technique has been applied for validation of the simulation results. The coated particle with naphthalene was sublimated to obtain the corresponding Sherwood numbers. The results show that the CFD model can predict the particle-to-fluid heat transfer for two situations due to trivial error (an average error of 6%) compared to experimental values. Influence of wall on heat transfer of particle in seven different bed-to-cylinder diameter ratio ($N = 1.66, 2.65, 2.75, 5, 6.66, 12$, and 18) have been discussed in different velocities. According to obtaining results, with increasing the bed-to-cylinder diameter ratio over the 12 wall have no significant consequence on Nusselt number. Due to this fact, a CFD based correlation has been proposed to consider the wall effects on particle-to-fluid Nusselt number with an average error of 2.19%.

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1. Introduction

Packed-beds are widely used in petrochemical, fine chemical and pharmaceutical industries. Detailed knowledge of flow in the void space of such packed beds is essential for understanding different characteristics of these beds. Heat transfer plays an important role in consideration of packed bed performance, and in view of this fact it had been very essential in previous studies. Consideration of single cylindrical particle heat transfer in cross flow is one of these aspects. There exist hundreds of experimental studies in terms of local and mean heat transfer in this case. The majority of these studies mainly focus on dependency of Nusselt on Reynolds and Prandtl numbers and their effects on heat transfer.

Zukauskas and Morgan have completely considered the heat transfer of cylinder [1,2]. Although the effects of free turbulence flow on heat transfer effects have been taken into account in these studies; moreover, wall effect and length to cylinder diameter ratio have been ignored. Churchill et al. [3] have proposed a correlation for calculating mean heat transfer that has been used in many other works in this field as verification case. They claimed that turbulence flow, wall effects, and channel to cylinder diameter ratio have minor effects on the heat transfer. Quarmby and Al-Fakhri [4] have scrutinized the effect of length to cylinder diameter ratio on heat transfer. They experimentally considered a range of length to cylinder diameter ratio

between 1 and 12. In so doing, they found for short cylinders (aspect ratio is smaller than 4), the effect of aspect ratio on mean heat transfer is considerable and when this ratio is bigger than 4 it can be ignored. This fact was considered by Chang and Mills [5] that led to derive a correlation in terms of Nusselt number with respect to length to cylinder diameter ratio. Because of extreme difficulty in measuring fluid flow and heat transfer inside the bed by conventional means without disturbing the packing arrangement, efforts towards improvement in modeling using computational fluid dynamics (CFD) have been recently developed. In general, 2D and 3D CFD models have been used in various fields to simulate flow profiles and heat transfer. The earliest CFD fixed bed simulations used two-dimensional models. Dalman et al. [6] investigated an axisymmetric radial plane. This work gave a first insight in flow structure in fixed beds. McKenna et al. [7] obtained valuable insight into the effect of particle size on particle–fluid heat transfer from 2D CFD study of small spherical particles. They have validated their basic models with Ranz-Marshall (RM) correlation and have shown the weakness of that correlation in predicting heat transfer from small clusters of spherical particles. Lloyd and Boehm [8] determined the sphere spacing effect on the drag coefficient and the particle to fluid heat transfer by studying on linear array of eight spheres in 2D. It was found that the heat transfer from the spheres decreased with reduction of particle spacing. The 3D models have been applied for packed beds more recently. Derx and Dixon [9] used a simple model to obtain the wall heat transfer coefficient. An eight-sphere model, in which eight spheres are located into two layers with four ones without solid–solid contact points, has been studied by Logtenberg and Dixon [10,11]. This model shows that

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