PACKING PATTERNS IN PACKED BEDS: EXPERIMENTS AND NUMERICAL SIMULATIONS

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Abstract

The way catalyst particles configure in a packed bed is likely to have a defining role in their performance as reactors, particularly in the context of deep processing applications like hydrodesulfurization. In this study, structure of packed bed has been generated experimentally, its three-dimensional structure estimated experimentally using bed freezing, sectioning and image analysis, and the formation of this bed structure is validated using a discrete-particle collision guided packing (CGP) approach.

Keywords

Packed beds, Local voidage, Packing structure, Digital packing algorithm, Image analysis

Introduction

Packed beds are employed as "trickle bed reactors (TBRs)" in various multiphase reactions such as hydrotreating, hydrocracking and other refining processes. These processes involve the reaction of a gas phase (such as hydrogen) with a small flow rate ("trickle") of a liquid phase reactant feed (such as a crude oil fraction), over the solid catalyst particle bed. In oil refining and in the petrochemicals industry, which are the primary users of packed beds, there are imperfections in the bed loading process, which prevents true homogeneity of the bed to be realized (homogenous in physical as well as hydrodynamic properties). Packing geometry depends largely on factors such as particle size, particle size distribution, shape of particle, particle surface roughness, column diameter, rate of filling the bed and the methods used to pack the catalyst bed. When a reactor bed is packed via sock loading method, it allows many orientations in trilobes or extrudates, whereas dense loading offers less orientation of particles leading to a more homogenous bed. The geometrical arrangement of packing in a bed influences the transport properties at microscopic level which in turn have significant effect on overall performance of the bed. The impact of these bed defects can be observed in variation in voidage within the catalyst bed which will obstruct the proper liquid distribution. Moreover, local velocity is different in different parts of bed owing to which wetting fraction, mass transfer coefficients, dispersion coefficient and effective thermal conductivity tend to vary everywhere in the packed volume.

Other factors such as heat transfer, hot spot formation, and hysteresis phenomena are also significantly impaired by the improper packing methods. In adiabatic TBR's, usually exothermic reactions are carried out in which case heat removal is dependent primarily on the fluid flow which again depends on voidage variation. In order to avoid the hot spot formation and runaway conditions, proper heat removal is also desired.

In this work, an attempt has been made to generate catalyst bed structure at laboratory scale through a hopper and further characterize the packing geometry in terms of voidage distribution. A packing algorithm is also applied for creation of bed structure based on collision guided packing (using the package DigiPac™). In this way, particle of any geometry can be visualized as to how it will pack inside a vessel of any geometry, giving insight into the packing structure it will form. The simulated bed and detailed particle distributions of the bed from simulation can be employed to develop a "virtual" packed/trickle bed platform where further studies of transport effects and reactor performance can be accomplished.

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Experimental

In order to map the local voidage variation in a cylindrical column, it is important to characterize the packed structure. “Resin freezing method” was employed in this study wherein an epoxy resin freezes the particles in their position without disturbing the packing structure. The procedure involves various steps (shown schematically in Figure 1) including packing of particles through hopper, inducing vibration to minimize void volume and finally filling of resin through an overhead tank. After the column has been solidified and the resin has been “frozen”, it was “sliced” in a lathe machine at fixed axial positions and cross section being photographed simultaneously. Images of cross sections of bed at different axial and radial positions were analyzed by image processing software from Nikon “NIS-Elements”.

Modeling

In order to simulate a bed, collision guided packing (CGP) algorithm is used (Jia and Williams, 2001). The advantage of using this algorithm lies in its flexibility to simulate bed with any irregular shape of packing particles. Most of the packing algorithms available usually simulate spherical or few other regular shape (cylindrical) particle. This algorithm digitizes particle as well as packing space irrespective of its irregular nature. Packing structures are represented as collection of voxels and packing space as square lattice on which these voxels move. Collision and overlapping can easily be detected by checking the occupancy of each lattice grid at a given point of time. Details of the simulation method will be provided in the presentation and the manuscript.

Results and Summary

Based on the above explained methodology, an attempt has been made to generate bed structure and characterize it both experimentally and algorithmically. Typical results are presented here comparing the data of data given by Auwerda et al. (2010). Figure 2 shows a typical cross-section of the axial plane of the packing structure for both spherical and cylindrical particles. Results are shown in Figure 3 and Figure 4 for the radial voidage profiles and axial voidage profiles respectively.

Figure 1. (a) Experimental methodology (b) Image of sliced column after bed sectioning

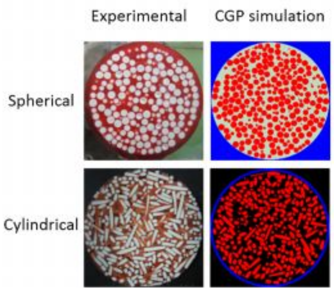

Figure 2. Images of column cross-section

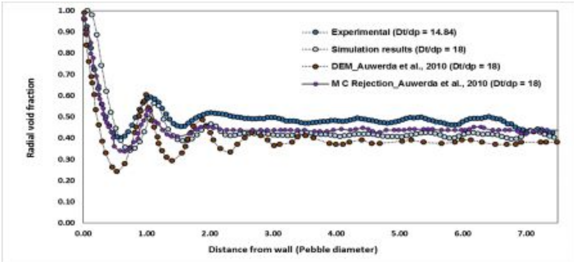

Figure 3. Variation in radial voidage

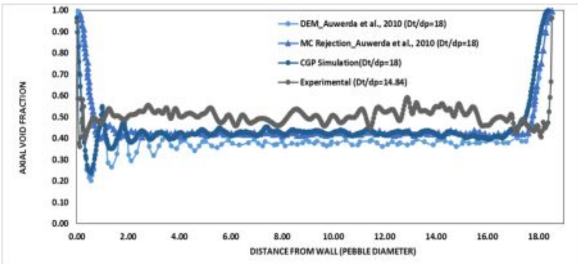

Figure 4. Variation in axial voidage

The result are in well accordance with the result obtained experimentally and shows reasonable level of accuracy.

Several other validation cases with physical arguments supporting the observations would be presented in the final manuscript and presentation.

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