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Detecting Particle Clusters in Particle-Fluid Systems by a Density Based Method

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Abstract. In this paper, the DBSCAN (Density-Based Spatial Clustering of Applications with Noise) method is proposed to detect particle clusters in particle-fluid systems. The particles are grouped in one cluster when they are connected by a dense environment. The parameters that define the dense environment are determined by analyzing the structure of the system, therefore, our approach needs little human intervention. The method is illustrated by identifying the clusters in two kinds of simulation trajectories of different particle-fluid systems. The robustness of cluster identification in terms of statistical properties of clusters in the steady state is demonstrated.

AMS subject classifications: 6207, 70C20, 76T25

Key words: Particle-fluid system, cluster, DBSCAN method.

1 Introduction

The particle-fluid system is widely applied in energy engineering, chemical industry, metallurgy and many other industrial processes [12, 18]. The particle-fluid systems exhibit multi-scale and heterogeneous structures in both time and space. In particular, the

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meso-scale structures, such as clusters and bubbles, have a significant impact on the properties of the system, making it unique in multi-phase systems [7]. For decades, a great effort on the theoretical analysis and experimental research has been devoted to understand how the meso-scale structures change the macroscopic properties of the particle-fluid system [1, 9, 17].

Understanding the self-assembly of particle clusters and the interaction between the clusters and fluid is of particular importance to the study of flow and transport mechanisms in fluidized beds, and is crucial for the operation and design of fluidized bed equipments. The particle cluster is also one of the central concepts in theoretical models that describes the multi-scale structure of the particle-fluid flow system, for example, the energy minimization multi-scale (EMMS) model [5, 6, 8].

Despite the importance of the particle clusters, detecting clusters in experiments or defining cluster from particle trajectories in the numerical simulations is not a trivial task. Soong et al. [14] proposed a criterion to identify clusters in circulating fluidized bed experiments, and this criterion is revised by other groups [13, 15, 16]. A similar idea was followed in these studies: the time-averaged solid concentration plus an integer times the standard deviation of the solid concentration is taken as a threshold; A cluster is identified if the instantaneous solid concentration at the probe tip is larger than the threshold at the same position. The integer in the threshold can be 1, 2, 3 or other numbers depending on the operating condition. The criterion can be easily applied to define clusters from particle trajectories generated from numerical simulations. A possible implementation partitions the simulation region by a grid, and calculates and the instantaneous solid concentration in each grid cell by counting the number of particles in it. If the concentration satisfies the Soong's criterion, then the grid cell is a part of a cluster. With a larger grid cell the accuracy of the statistical estimation of the concentration is improved, but the resolution of cluster is inevitably decreased. Therefore, the intrinsic uncertainty in defining cluster is the main drawback of this approach. Liu et al. [9] computed the local voidage by the Voronoi tessellation, and then partition the whole heterogeneous structure into a gas-rich phase and a solid-rich dense phase by analyzing the probability distribution of the local voidage. In their approach, clusters can be defined by the collections of inter-connected Voronoi cells, however, this definition is sensitive to the local fluctuation of voidage and the computational cost of Voronoi tessellation is expensive.

In this work, we propose to apply the DBSCAN (Density-Based Spatial Clustering of Applications with Noise) method developed by Ester et al. [4] to identify clusters in the particle trajectories from the numerical simulations of the particle-fluid systems. This approach takes the particle positions as inputs, and defines clusters with rigid and clear mathematical criterion. The DBSCAN model parameters are determined by analyzing the structure of the particle-fluid flow, thus given a criterion identifying the dense phase out of the dilute phase, our approach does not need further parameter tuning and the cluster identification process is automated.

The outline of this paper is as follows: In Section 2, the data generation protocol is described; In Section 3, the cluster identification method DBSCAN method is introduced