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Experimental and numerical investigations of a pseudo-2D spout fluidized bed with draft plates

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ABSTRACT

Spout fluidized beds are often utilized for gas-solid contacting operations involving physical and/or chemical transformations with simultaneous heat and mass transfer such as drying, coating, granulation, combustion, gasification etc. This is because these beds combine advantages of both spouted and fluidized beds. Since the development of the spout fluidized bed, several geometrical modifications have been proposed to optimize the bed performance. One of these modifications often applied in granulation and coating industries includes a draft tube insertion inside the bed, which results in improved performance by providing a restriction on lateral particle flow providing clear distinction for wet spout and dry annulus zones. Moreover, the insertion of the draft tube leads to a stable spouting at lower flow rates, due to the reduced bypassing of the inlet gas (from spout to annulus).

In this work, the hydrodynamic characteristics of a spout fluidized bed with draft plates was studied to identify the flow characteristics by constructing a flow regime map by image analysis and a fast Fourier transform of the measured pressure signal. In addition, the captured images were used to determine the particle velocity via particle image velocimetry (PIV). Furthermore, simulations were carried using a discrete particle model with a sub grid scale turbulence model for two regimes, namely the spouting-with-aeration and fluidized bed-spouting-with-aeration (dispersed spout), which are of most interest from an industrial view point. The obtained results were compared with previously obtained experimental data i.e. PIV. This study highlights various flow pattern observed during operation of spout fluidized bed with a draft plate over a wider operating conditions, which is useful to select proper operating conditions; whereas the experimental data can be used for computational fluid dynamic (CFD) model validation, which serve as a building block for design and scale-up at higher operational scales. Besides this, the quantitative information such as particle velocity, residence time distribution, solid mixing and circulation can be obtained after suitable post processing hence useful in optimizing the bed performance.

1. Introduction

Spout fluidized beds are often applied for gas-solid contacting operations involving physical and chemical transformations such as drying, coating, granulation, combustion and gasification. This is because these beds combine features from both spouted and fluidized beds. Moreover, intense gas–solid contact leads to efficient heat and mass exchange. Additionally, spout fluidized beds can be operated for coarse particles with wide size distributions. Since the development of the spout fluidized bed [1], a number of modifications were suggested to improve its performance. These modifications involved different geometrical configurations such as rectangular [2], conical bottom [3,4], slotted rectangular, multiple and elevated spout fluidized beds [5,6]. One of the significant modifications includes insertion of a draft tube inside the bed, which results in improved performance by restricting the particle cross flow. Moreover, a draft insertion tube results in stable spouting at lower flow rates, due to the reduced bypassing of the inlet gas (from spout to annulus). This is evident from the experimental study on spouted beds with and without draft tube by [7]. They observed a lower minimum spout velocity for a bed with a draft tube, which leads to lower energy consumption to achieve the same spouting characteristics as in a system without a draft tube. Claflin and Fane [8] imply that in conventional spouted beds, particles enter the spout channel from the annulus at various heights, leading to random particle behavior. Furthermore, additional flexibility in the maximum spoutable height without disturbing the stable spouting can be successfully achieved. Additionally, the insertion of a draft tube in a spout fluidized bed provides flexibility to control the particle velocity, bed porosity and gas phase residence time by adjusting operating parameters and geometrical configurations such as the entrainment height and the draft tube dimension.

A detailed understanding of the bed dynamics with flow transition is of primary importance for design and scale-up. This can be either

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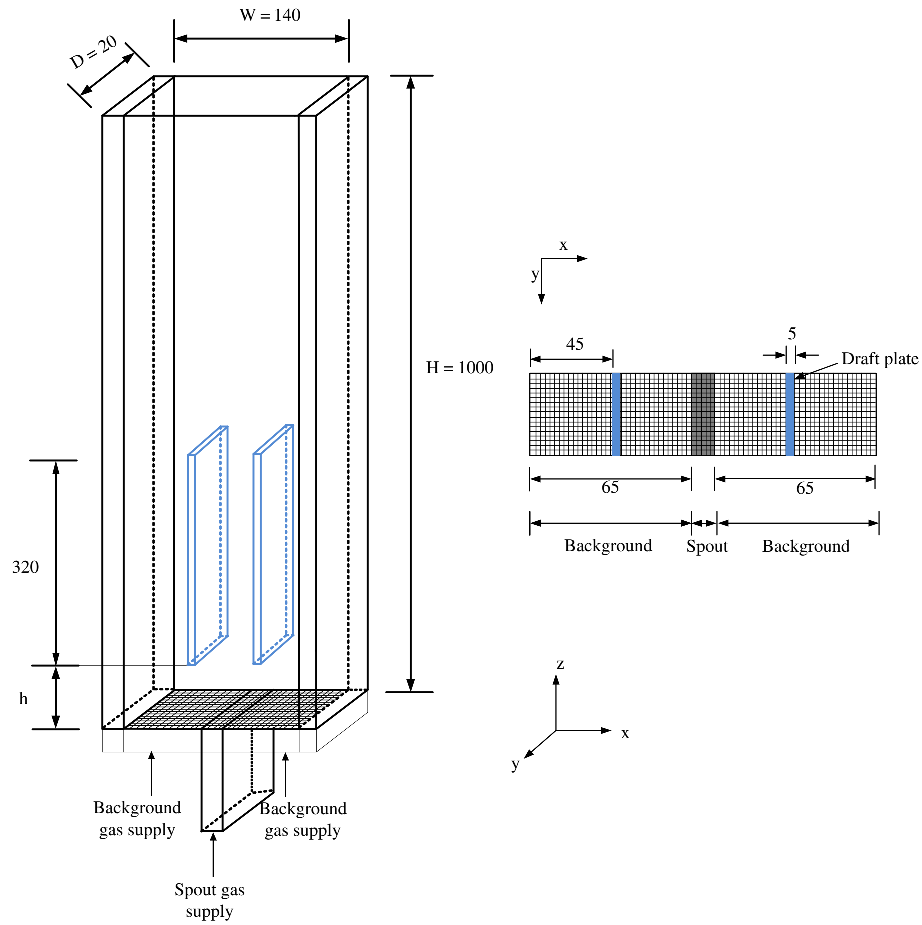

Fig. 1. Schematic representation of a pseudo 2D spout fluidized bed with draft plates with entrainment height (h) (all dimensions in mm).

achieved by performing experiments or simulations. However, it is troublesome to perform the experiments on larger scale, because it is difficult to access the relevant areas experimentally. Over the past few decades, the dynamics of gas-solid systems has been studied using multi-scale simulation approaches [9]. For gas–solid systems, commonly used simulation approaches for laboratory scale contactors are mainly subdivided into two groups viz Eulerian–Lagrangian (discrete model) and the Eulerian–Eulerian approach (continuum model). In both approaches the gas phase dynamics is described by the volume-averaged Navier–Stokes equations. In the Eulerian–Lagrangian approach the motion of the solids phase is obtained by solving Newton's law of motion for individual particle, whereas in the Eulerian–Eulerian approach the solids phase is considered as a continuum. Another promising development involves the use of smooth particle hydrodynamics (SPH) for describing the gas–solid flow in fluidized beds [27]. There exist few studies on dynamics of spout fluidized beds either by the Eulerian–Lagrangian or Eulerian–Eulerian approach. Link et al. [10] performed simulations to study the hydrodynamics of a pseudo 2D spout fluidized bed ($W \times D \times H = 0.15 \times 0.015 \times 1\ m^3$) by using a discrete particle model (DPM) and validated their results by employing particle image velocimetry (PIV) and digital image analysis (DIA). Link et al. [11] extended these studies to a 3D spout fluidized bed. Furthermore, Link et al. [2] studied the flow characteristics in a 3D spout fluidized bed ($W \times D \times H = 0.15 \times 0.084 \times 1\ m^3$, with spout dimension of $W \times D = 0.022 \times 0.012\ m^2$) using positron emission particle tracking (PEPT). They also studied a cylindrical spout fluidized bed ($D = 0.4$ m) using a fiber optical probe [12]. Link et al. [13] have reported DPM simulations of a pseudo 2D spout fluidized bed granulator by considering

Table 1
Physical properties of the particles used in the experiments.

Property	Glass particle	γ-Aluminum oxide	Unit
d_p	1 ± 0.05	0.9–1.1	mm
ρ_p	2526	1040	kg/m^3
u_{mf}	0.64	0.33	m/s
e_n	0.97	0.74	–

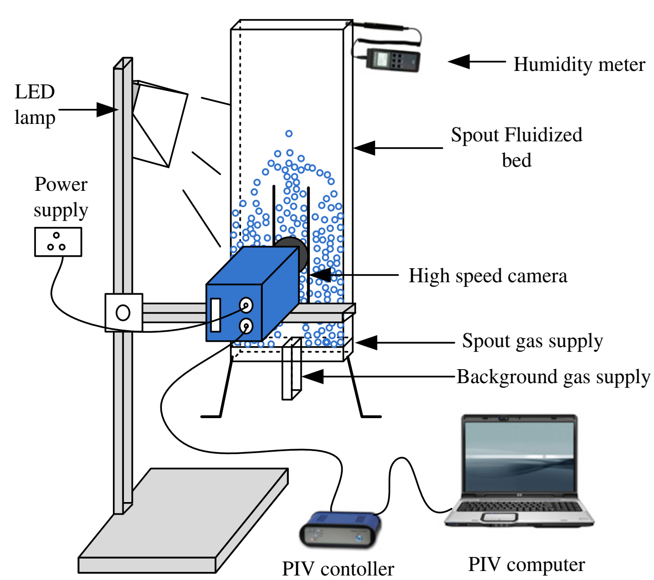

Fig. 2. Schematic representation of PIV setup for spout fluidized bed with draft plates.