Study of hydrodynamics and CO_2 adsorption in multistage fluidised beds via computational and experimental investigations.

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Highlights

- Hydrodynamics of Multistage Fluidised bed (MFBR) was studied using ANSYS R21.
- The Syamlal drag model was tuned to match the experimental fluidization velocity.
- A comparison was made between the power consumption of the MFBR and the FBR.
- CO_2 capture efficiency of the bed was studied.

1. Introduction

Packed Beds are widely used in industries for adsorption-based reactions owing to their high adsorptive capacity. However, they have poor heat transfer properties as adsorption-based reactions release heat and have a higher pressure drop even at moderate gas flow rates. On the other hand, Fluidized beds have better heat transfer rates and offer more surface area but have lower gas-solid contact due to less residence time and back mixing. Hence, optimizing the reactor configuration is the only viable solution to enhance the efficiency of multiphase reactors in adsorption reactions.

The multistage counter-current fluidized bed (MFBR) is a type of reactor that allows solids to flow in a direction opposite to the gas flow. This configuration results in a higher adsorption driving force and promises a more efficient reactor. The reactor is made up of several compartments, each operating as a fluidized bed with downcomers, allowing solids to transfer from one stage to another. The staging reduces internal mixing by introducing a plug flow nature into the staged fluidized beds, reducing the CSTR effect and increasing the efficiency of using these beds in adsorption. Therefore, this reactor configuration shows promising results in making traditional reactors more efficient. (Dhoke et al., 2021)

Most studies on multistage fluidized bed reactors (MFBRs) with downcomers have focused on analyzing pressure drop variations under different operational conditions, as noted by Das & Meikap (2017) and Roy et al. (2009). However, to fully grasp the hydrodynamics of these beds, it's important to thoroughly examine the intricate interactions between gas and solid phases. With the growing concern of global warming, there's an urgent need for effective carbon capture technologies. Hence, understanding the carbon capture efficiency of these beds is vital for their successful integration into industrial processes.

In this study, the hydrodynamics and carbon adsorption efficiency of a Multistage Fluidized Bed were investigated using the Euler-Euler Two-Fluid Model (TFM) coupled with the Kinetic Theory of Granular Flow (KTGF) and the Syamlal Drag Model. To ensure the accuracy of the simulation results, they were validated with the experimental data collected by Dipa Das et al. (2017). Furthermore, the adsorption capacity was analyzed through dynamic breakthrough experiments, and energy consumption was compared to traditional fluidised beds.

2. Methods

The geometrical dimensions for the computational model was taken from Das et al. (2017) experimental setup. To create a simplified two-stage MFBR model, ANSYS SpaceClaim was utilized, and an associated Quadrilateral Mesh was generated with ANSYS Mesh. Transport equations were applied, and simulations were run with varying inlet gas velocities (0.235 m/s, 0.309 m/s, 0.353 m/s) and particle sizes (464, 512, 635 µm).

Furthermore, a three-stage MFBR lab scale setup was established to assess the reactor configuration's adsorptive capacity, and the dynamic breakthrough (DCB) graphs were analyzed while monitoring pressure drop and temperature of the bed.

3. Result and discussion

The pressure drop predicted by the model matched well with the experimental results reported by Das et al. (2017), as seen in Figure 1. Figure 2 shows the stages filling as time progresses. Further results on the gas and solid interaction, solid circulation rates, and DCBs will be discussed later.

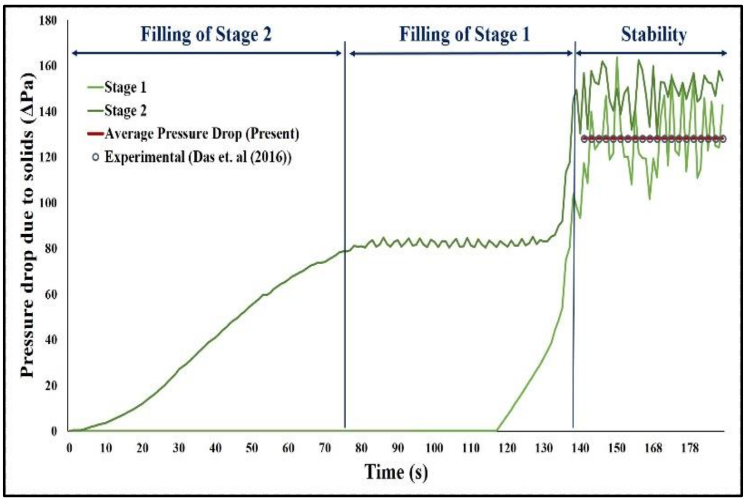

Figure 1. Pressure drop evolution with time for gas velocity, $u_g = 0.235$ m/s and solid flow rate, $g_s = 3.33$ kg/hr.

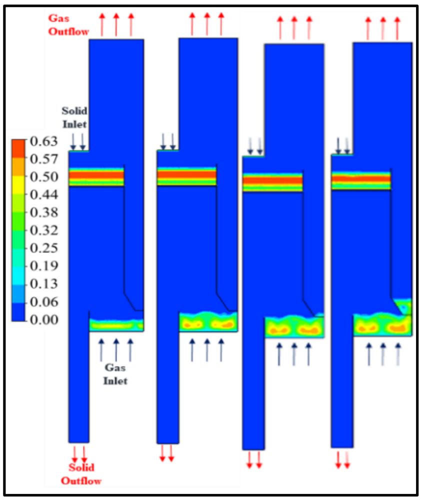

Figure 2. Stages Filling Solid Volume Profile a) t=70 b) 134 c) 150 d) 184 sec.

4. Conclusions

A thorough hydrodynamic analysis was carried out on a multistage fluidized bed with two stages, utilizing ANSYS Fluent R21. The porous zones in each stage were modeled as perforated plates. The Syamlal Drag model was carefully selected and calibrated to ensure accurate capture of the complex interactions within the fluidized bed, while also matching the experimental minimum fluidization value. The validation process proved highly successful, with the model's predictions closely aligning with the pressure drop data previously reported by Das et al. (2017).

The study investigated the solid fraction profile, as well as the solid and gas velocity profiles, and solid circulation rates for different superficial gas velocities and solid particles. Additionally, the research extended its focus to evaluate carbon adsorption efficiency and temperature distribution, comparing them to traditional fluidized bed reactors. This supplementary analysis provides vital insights into the performance of the beds concerning carbon capture adsorption reactions. The knowledge obtained from this hydrodynamic investigation carries significant implications for the efficient design of carbon capture adsorption processes.

References

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Keywords

Multistage Fluidized Bed, Hydrodynamics, CO2 Capture, Adsorption.