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Short communication

Lateral particle size segregation in a riser under core annular flow conditions due to the Saffman lift force

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ABSTRACT

It has been observed under certain flow conditions that there is a measured increase in fine particle concentration at the center of the circulating fluidized bed riser just below the exit to the cyclone. It is hypothesized that the Saffman force might be responsible for this phenomena. Therefore, this research paper discusses the likelihood of the existence of "Saffman" forces, or lift due to viscous shear, in cylindrical, circulating fluidized bed (CFB) risers operating in the core annular regime.

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1. Introduction

Circulating fluidized beds (CFB's) have been widely used in a variety of industries, including the electrical generation, chemical and pharmaceutical industries, because of their high level of mixing of gas and solid phases, resulting in excellent mass and heat transfer characteristics [1–2]. The operating parameters of a CFB are largely determined based upon the specific application in question; but in general, the process involves a gas-solid matrix where the gas is the byproduct of a thermal process, such as the combustion of fossil fuels. The benefits of this process (i.e. enhanced mixing and gas-solid surface area contact) motivate the investigation of the multi-phase flow dynamics that govern the behavior of gas-solid mixtures within the riser. Due to the large solid mass flow rates associated with CFB operations, it is critical to understand and model the properties of the multi-phase fluid. Among the areas of interest to researchers are parameters that optimize absorption while permitting conditions for maximum energy generation efficiency, as well as methods and control practices that minimize the degradation of equipment and optimize the mass consumption rate of solids. However, because of the high temperatures and complex, chaotic nature of CFB hydrodynamics [2], it is not trivial to fully describe and characterize the behavior of the multi-phase gas-solid matrix.

In order to get a better understanding of riser dynamics under safer, more transparent conditions, cold flow circulating fluidized beds (CFCFBs) are often used to obtain an understanding of the particle behavior that may then be extrapolated to a full-scale industrial system.

One area of CFB hydrodynamics that has been of interest to research is that of particle segregation within the CFB riser. This is of interest to design and process engineers due to the importance of particle size on the reaction kinetics taking place within the CFB. In general, non-homogeneous gas-particle reactions proceed at a rate that is strongly influenced by the surface area–to–volume ratio of the solid particle. The smaller the particle, the faster the chemical reactions between the particle and surrounding gas will occur. Significant particle segregation may result in sections of the CFB riser being more chemically active than other sections, possibly leading to bed instabilities.

Numerous studies have looked at segregation by particle size and/or weight axially along the CFB riser height [3–5]. In general, these studies have demonstrated a trend in which the mean particle size decreases with increasing height within the CFB riser. Other studies [6–9] have explored particle segregation in the lateral (or radial) direction within the CFB riser. These experimental studies have examined the segregation behaviors of particles that differ in either size or density. They have shown that, for a given vertical location within the CFB riser, there is a higher concentration of larger (or heavier) particles within the downward flowing annulus near the wall of the riser, and a higher concentration of smaller (or lighter) particles in the upwards flowing core region. This observed trend becomes more and more pronounced with higher vertical locations, leading to more than one investigation to observe a concentration of fines in the core of the riser near the exit [6]. A similar trend of large lateral segregation of particles hear the riser exit was observed by the authors while conducting the experiments detailed in the following section. In addition to the experimental studies, a number of models have been developed and proposed, but so far none have been able to fully capture the dynamics of this axial segregation [3,8,10].

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In an effort to explain these observed trends, the authors postulate that the force responsible for the segregation is that of "lift due to viscous shear" or "Saffman force" named after P.G. Saffman who proposed its existence in 1965 [11]. In early studies by Karri and Knowlton [6], this concentration of fines in the riser core required the existence of downward flow in the annular region, and this exists in an interval of mass flux rates that is dependent upon fluid velocity; however, later studies saw evidence of this segregation present in both upwards and downwards flow in the annular region [7]. The segregation, unique to riser flow of this nature, warrants further investigation as to the physical nature of the forces present on the particles inside the riser. Therefore making the purpose of this publication be to explain and characterize the observed phenomena in order to increase the efficiency of the riser itself, as well as further develop the knowledge of particle behavior under a broader spectrum of similar flow conditions.

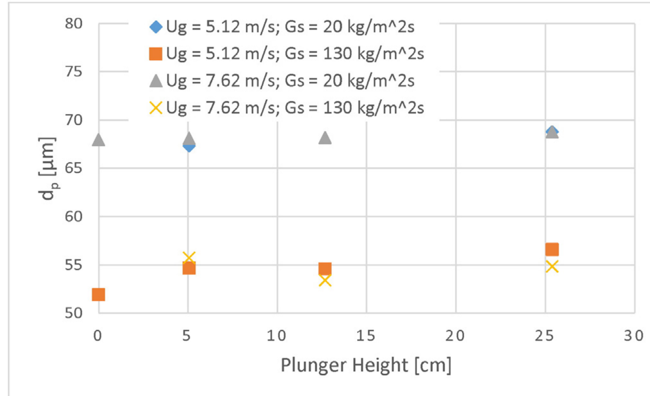

Fig. 2. Particle diameter vs. plunger height.

2. Experimental set-up and test matrix

As previously stated, in a separate study looking at the effects of riser end geometry, the authors conducted experiments in a 15.3 m tall circulating fluidized bed with a bed diameter of 0.3 m. For these experiments, a plunger was installed above the riser exhaust to allow for variation of the height of the riser top above the outlet (see Fig. 1). Tests were conducted with an 80/20 mixture of 80 μm and 20 μm glass beads (for an average diameter of 68 μm) using superficial gas velocities of 5.12 and 7.62 m/s and solids flux rates of 20 and 130 kg/m^2 s. Under these operating conditions, a dense upward flow (aka pneumatic transport) regime was observed within the CFB riser for the lower solids flux cases, and core-annular flow conditions was observed for the higher solids flux cases.

Experiments were conducted with the plunger located at different heights above the riser outlet. For each experiment, particle velocities and average particle diameters were measured below the exit near the wall via high speed video, as well as near the riser centerline using a fiber optic probe. The data obtained from these measurements, and presented in Figs. 2 and 3, show that the height of the plunger above the riser exit had little to no effect upon the measured average particle diameters. As seen in Fig. 2, the average particle diameter for the lower solids circulation rate suggests little in the way of segregation, whereas there is a significant level of segregation evident in the higher solids circulation rate data. While the data presented in Fig. 3 shows a little more scatter, a similar trend is evident when comparing the average particle diameter and bed voidage. These results are in agreement with the earlier observations of Karri and Knowlton [6].

As shown in Fig. 2, when the CFB is operating within the core-annular flow regime (as evidenced by the higher solids flux rates), the

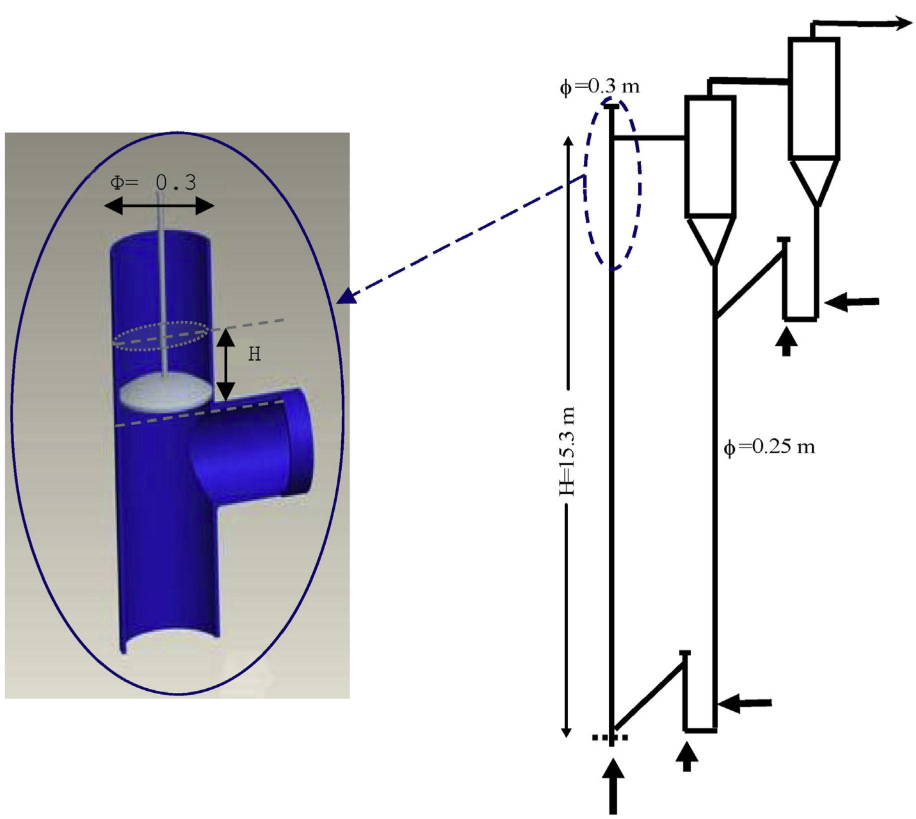

Fig. 1. Schematic of CFB with the loop seal solids return loop and *T*-shape riser exit with insert depicting adjustable baffle in the blind-T exit fully extended to the top of the crossover (h/Φ = 0).