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Downer reactor flow measurements using CREC-GS-Optiprobes

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ABSTRACT

The present study describes the potential intrusive effects of CREC-GS-Optiprobes on the flow pattern in gas–solid downflow units. Granular flows and their interactions with the CREC-GS-Optiprobes are calculated using a CPFD (Computational Particle Fluid Dynamic) numerical scheme in three dimensions, using particle clusters. Once particles dispersed in the column, the numerical simulations revealed that these particles formed a relatively homogeneous suspension with cluster formation and solids accelerating until reaching a fully-developed regime. CPFD simulations showed that two axially aligned CREC-GS-Optiprobes, when placed in the fully developed flow regime, introduce minimum perturbations in the gas–solid suspension. Therefore this CREC-GS-Optiprobe creates a highly illuminated focal region where hydrodynamic parameters can be measured without significant flow disturbance. Thus, this study supports the application of fiber optic probes; such as in the case of the CREC-GS-Optiprobes, which can provide undisturbed axial particle cluster velocity, axial cluster slip velocities, cluster size and solid fraction measurements at strategically selected locations in the gas–solid downer unit.

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1. Introduction

In recent years, several research groups have studied multiphase flows in downer reactors [1–8]. Downer reactors display relatively uniform plug-flow behavior of the gas–solid suspension [9]. Due to the low back-mixing and short reaction times, downer reactors can be suitable for improving many industrial chemical processes such as fluid catalytic cracking (FCC), residual oil cracking, biomass and coal pyrolysis [10,11].

Fluid dynamic studies in downflow reactors involve complex hydrodynamics. In these systems, information about hydrodynamics is still inadequate [12]. Accurate measurement of the operational variables can provide good understanding of the multiphase flow. It is in this respect, of paramount importance, that experimental measurements be taken by using probes, such as: a) optical fiber probes [13–15], b) dual-optical density probes [16,17], c) capacitance probes [18] and d) suction probes [19]. These probes however, may alter or interrupt the flow pattern in the reactor with the intrusive effects [20] of these techniques.

The technical literature reports noninvasive techniques for multiphase reactors such as: a) high speed photography [21,22], b) laser doppler velocimetry [23], c) computational automated radioactive particle tracking technique [24] and d) electrical capacitance tomography [25]. Although these techniques do not affect the system flow pattern, they are expensive, not easy to implement, require complex result analysis and high speed computations [26] and/or have a relatively transparent optic path [27].

The Chemical Reactor Engineering Center gas–solid fiber optic probe (CREC-GS-Optiprobe) works on the principle of light backscattering. The incorporation of a Gradient Refractive Index Lens (GRIN) in CREC-GS-Optiprobe provides the unique capability of focusing a light beam in a narrow region, with high illumination density at several millimeters distance away from the probe's tip. The design of the fiber optic probe also ensures minimal flow disturbance when compared with other conventional fiber optic sensors.

There are two types of theoretical models when using the computational fluid dynamics (CFD) approach. These can be applied to study gas and solid flows. They are: a) the Eulerian–Eulerian model and b) the Eulerian–Lagrangian model. The Eulerian–Eulerian model considers the solid phase as a continuous medium interacting with the fluid phase. Conservation laws provide a set of equations of a similar structure for the gas and solid phases. These equations are complemented with constitutive relations obtained from empirical information and/or kinetic theory [28]. In particular, such a modeling approach has been successfully applied to simulate multiphase flow phenomena in risers with gas and particles moving upwards concurrently [8]. The Eulerian–Eulerian model presents some major drawbacks in describing gas–particle, particle–particle and particle–wall interactions at the microscale, in the downer reactors, given the extensive computations needed [8]. As an alternative approach in downer units, flow can be predicted with a computational particle

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fluid dynamic (CPFD) numerical method [29]. The numerical method is of the discrete element method (DEM) class. The Eulerian reference frame allows the modeling of forces using spatial gradients of properties [30]. On the other hand, the dispersed phase is treated by tracking a large number of particles through the calculated flow field [31]. DEM methods are limited in applicability, given the complex dense particle–particle interaction calculations as a result of a large number of the particles involved. DEM is usually restricted to two-dimensional solutions [30]. Furthermore, DEM considers particle-to-particle forces using a spring–damper model and direct particle contact. The CPFD method, on the other hand, does not encounter these limitations. In Computational Particle Fluid Dynamics (CPFD), each particle is considered with three-dimensional force components exerted on it. These forces are particle drag, pressure gradient, gravity and particle normal stress gradient. In CPFD, the collision force on each particle is modeled as a spatial gradient. A numerical particle in the CPFD method is identified as a group of particles sharing chemical species, size, and density properties [30]. Thus, the numerical particle is an approximation where properties are considered invariable.

The aim of this work is to study the change in hydrodynamic behavior of gas–solid down flows when external objects such as fiber optic probes are introduced in the flow. A 3D visualization has been developed using the CPFD software. Determination of local flow properties and their changes using numerical simulation provides confirmation of the minimum intrusive effects of the CREC-GS-Optiprobe.

2. Experimental setup

Fig. 1 provides a schematic diagram of a 2-m downer reactor with a 0.02632 m internal diameter used in the CREC laboratories for experimental fluid dynamic studies. A detailed description of the experimental unit and experimental procedure can be found in previous study of our group [1,5,6,32]. The downer air distributor is configured with sixteen 0.5 mm holes distributed evenly around the circumference of the column and angled downwards 45° with respect to the vertical. These high velocity jets allow the intimate mixing of gas and solid particles [5] in the reactor. This feeder configuration allows one to assume that there is a uniform solid and gas distribution at the downer entry, as adopted in the present model. The unit ends in a cyclone where gas and particles are separated. The downer unit of Fig. 2 shows the CREC-GS-Optiprobes and the associated laser beam-optical-data acquisition system as implemented in the CREC laboratories. This set up allowed the experimental characterization of the gas–solid flow and the simultaneous measurements of particle clusters

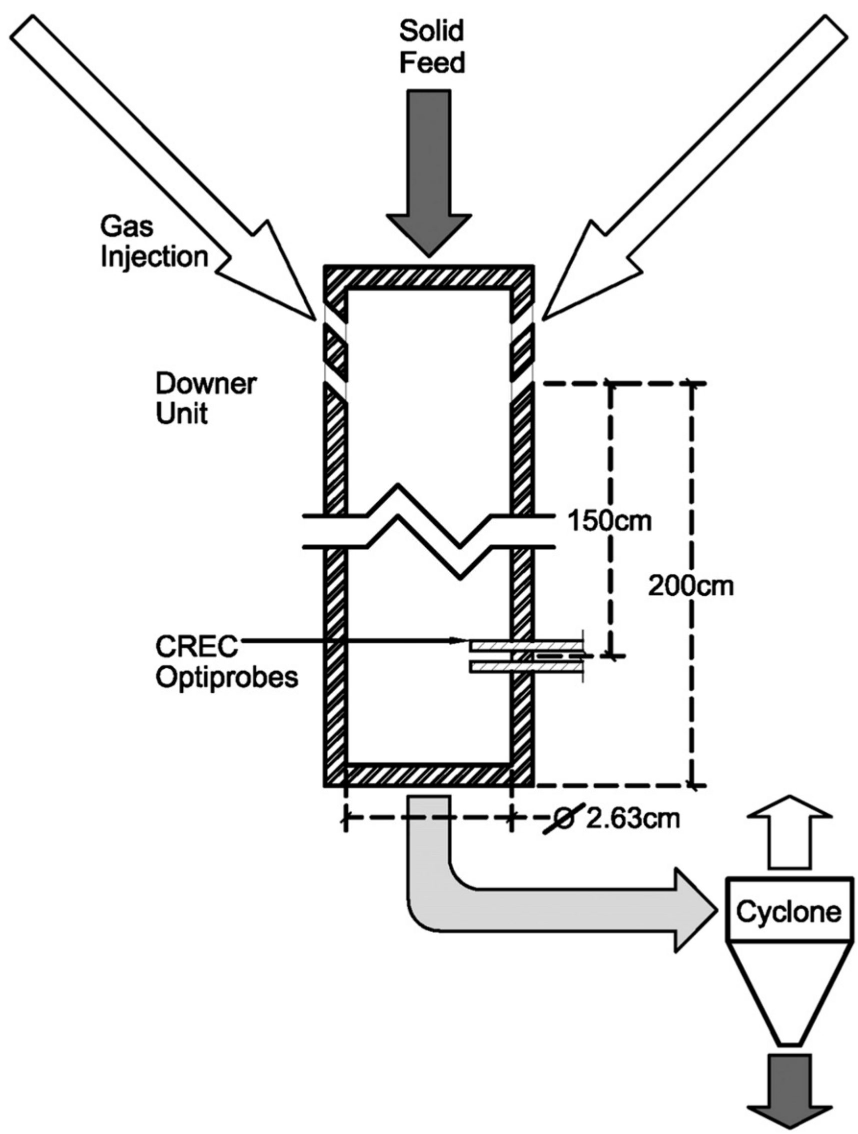

Fig. 1. Schematic representation of the downer reactor model unit used in the CPFD calculations. The location of the 2 axially separated CREC-GS-Optiprobes is shown.

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