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The CREC-GS-Optiprobes and its focal region Gas–solid flow measurements in down flow reactors

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A B S T R A C T

The Chemical Reactor Engineering Center – Gas Solid – Optiprobes (CREC-GS-Optiprobe) can be used to determine particle cluster properties in down flow reactors. These properties include solid hold-up, cluster size and cluster velocity. Critical to this task is the determination of the "focal region". It is established in this study that the CREC-GS Optiprobes display an "effective focal region" smaller than the focal region calculated using geometrical and optical considerations. In this respect, an "effective focal region" of 118 μm with a standard deviation of 34 μm is established on the basis of different considerations including experimental observations. The existence of this "effective focal region" is most valuable in downer units given it makes the CREC-Optiprobe a suitable tool for measurements of clusters sizes with an average diameter of 84 μm FCC particles as well as local solid concentration.

1. Introduction

Various measurement techniques based on different working principles have been applied to measure particle flow pattern in the fluidized bed as well as other gas–solid processes. Among these techniques most commonly applied techniques are flow visualization, laser Doppler and cross-correlation techniques.

1.1. Measurement techniques for studying particle flow properties in fluidized bed

Direct visual techniques by means of high-speed photography or tracer techniques have been employed to measure particle flow properties in fluidized bed (Lu et al., 2005; Cadoret et al., 2009; Chan et al., 2010). These methods are in principle non-intrusive and suitable for providing the complete pattern of particle movement instantly. However, analysis of the results tends to be complex, time-consuming and often requires a high-speed computation system. These equipments could as well be rather expensive (Zhu et al., 2001).

In fluid dynamics research laser Doppler velocimetry (LDV) is another powerful technique (Yianneskis, 1987; Liu et al., 2005; Zaabout et al., 2010) which is reliable, accurate and easy to use. The basis of this technique is that the frequency of light scattered by a moving particle is subject to a Doppler shift and the particle velocity can be determined by measuring the shift. However, LDV can only be applied when an optic path is available to the measurement site so that it is only suitable for dilute suspensions (Lehner et al., 1999). In addition, LDV instruments are relatively expensive.

The cross-correlation analysis is a statistically based technique which is frequently used to assess the evolution of inclusions such as bubble velocity in multiphase reactors (Lee et al., 1990). In this regard, both the capacitance probe and optical fiber probe measurements can be analyzed using cross-correlation. Cross-correlation can be applied in down flow reactors using two sensors aligned at two different axial locations and the principle that individual or groups of particles are moving in dominant flow gravitational direction (Zhu et al., 2001). The maximum of the computed cross-correlation function defines a time shift. The ratio of the axial sensor distance and the time shift gives the particle cluster velocity (Islam et al., 2010).

The capacitance measurement is based on variations in dielectric capacitance caused by the change in solids concentration in a measuring volume (Tuzla et al., 1998). However, such capacitive measurements are sensitive to electrostatic effects, so that good grounding is needed to decrease interference effects.

Optic fiber probes can be designed with light-emitting and light-receiving fibers to detect reflected light from particles moving in their vicinity. Because of the simplicity, high accuracy, and relatively low cost, optical fiber probes have been widely used in recent years to

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measure particle movement in downer reactors as well as other fluidized beds (Wang et al., 1992; Lu et al., 2005; Qi et al., 2008; Ye et al., 2009; Li et al., 2009). Though various measurement techniques have been discussed and employed to determine solids concentration (solid hold-up) and particle velocities in fluidized beds, only optical fiber probes can provide simultaneous measurements of these two parameters (Liu et al., 2003).

Measurements using optical fibers are usually based either on forward light scattering between emission and detection fibers separated by a short distance, or on backscattering to an optical fiber system, with the projecting and receiving fibers arranged in rows. Design of regular backscattering fiber optic sensors suffers from four major drawbacks in fluidized bed applications: (i) the short focal distance of the optical probe, (ii) the low light intensity of the captured reflected light by the receiver fibers, (iii) the infinite measurement volumes from which the optical probes collect the ray reflections (Liu et al., 2003; Pugsley et al., 2003), and (iv) the existence of a 'blind zone' in front of the probe (Liu et al., 2003; Pugsley et al., 2003).

1.2. Major problems with backscattering sensors

Liu et al. (2003) reported that the "power ratio" which is the power of the light captured by the receiving fiber divided by that delivered by the projecting fiber, falls below 10% of its maximum value at a detection distance of 2 mm. This finding was obtained for a 100 μm fiber with a receiver fiber separation of 200 μm. One can notice that the maximum value of power ratio for this configuration was observed at a distance of only about 0.2 mm from the probe tip. Thus, these types of probes are intrinsically intrusive into the flow stream and create subsequent distortion of the flow streamlines inside the measurement volume of the probe. In turn, this distortion of the flow streamlines creates changes in the flow velocity field of either gas or solid particles and also promotes a boundary layer development at the region where the measurements are performed, specifically, at the tip of the sensor in regular fiber optic probes. As extensively reported, the gas velocity at a boundary layer is lower, thereby affecting the velocity and the trajectory of the particles as well. Also, if the probe is not small enough it may influence the concentration of solids in the measurement volume of the probe.

Another problem present in regular backscattering probes is the low reflected light intensity of the signal collected by the receiver optical fiber. The intensity of the reflected light is mainly a function of the concentration, size and material properties of the moving particles. Moreover, the strength of received signal also depends on the separation distance between the emitter fiber and receiver fiber. For example, Liu et al. (2003) observed more than a 50% decrease in the probe output due to a change in separation distance from 200 to 300 μm for a 200 μm diameter single fiber. To overcome this problem, researchers traditionally opt to add more receiver optical fibers, in order to have a stronger optical signal by collecting light from different measurement regions. However, building a compact probe with a reduced size of emitter and receiver fiber bundle still remains a challenge.

The principal drawback with these designs, as in the case of coaxial and bundle fiber probes, is that the recorded signal is coming from a wider measurement region and therefore it is not adequate for localized measurements. Also, this adds more noise to the collected signal, thereby complicating its conditioning and filtering.

The other problem which exists in regular fiber optic probes is the presence of a non-defined measurement volume from which the signal is received. This is an unavoidable problem in fiber optic probe designs containing flat tip emitter and receiver fibers, due to the intrinsic "acceptance angle" property of the optical fibers. Intersection of acceptance angle cones both for the receiver and the emitter defines the measurement region of a fiber optic probe.

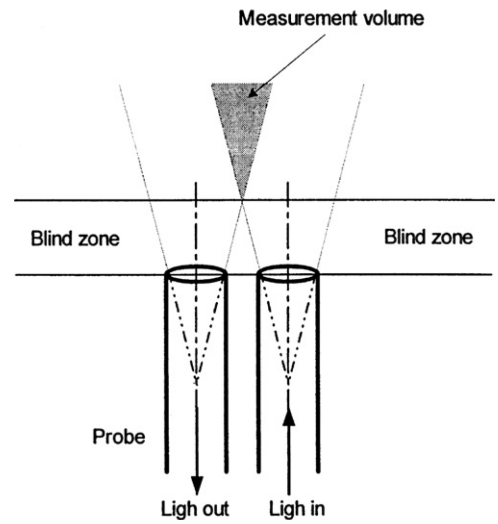

Fig. 1. Measurement volume and "blind zone" for a parallel fiber pair (Liu et al., 2003).

As it is illustrated in Fig. 1 the region where acceptance angles intersect each other extends in front of a set of flat-tipped parallel optical fibers, creating an unbound measurement volume. Reflected rays are thus collected from particles moving in an unbound flow region. Another difficulty of this configuration is that, as shown in Fig. 1, the parallel fiber may create a "blind zone", which falls either outside of the illuminated region or cannot be seen by the receiving fiber. Particles moving through this blind zone can reduce the irradiation level of the measuring volume, thus contributing with erroneous data.

Furthermore, in parallel fiber probes the highest light intensity not always come from the same localized point since the intensity of the reflected light is a function of the size of the particle or conglomerate that crosses the measurement volume. Therefore, a small particle crossing the tip of the measurement volume could reflect the same amount of light as a big conglomerate crossing a region further down from the tip of the measurement region. Another issue with this design is that the signal may be flooded with the noise created by the bigger particles or particle conglomerates crossing the measurement region far away from the tip of the measurement volume. This noise may cause difficulties for the conditioning and the analysis of the generated signal.

1.3. Attempts to improve the design of backscattering sensors

To overcome the problems previously mentioned, Magnusson et al. (2005) used a receiver optical fiber at 45° angle with respect to emitter optical fiber to confine the measuring region. However, this design brings the measurement volume closer to the emitting fiber experiencing the highest amount of disturbances at the tip of the probe, thereby reducing the accuracy of the measurements.

Several researchers (Russo et al., 1984; Verdaasdonk et al., 1991; Sobocinski et al., 1995) attempted to create a micro-lens at the tip of an emitter fiber by melting the fiber end into a ball shaped or into a hemisphere shaped. The melted fiber end focuses the light beam as it exits the fiber and concentrates the light into a very narrow point at a considerable distance far from the tip of the fiber, minimizing flow disturbances on the measurements. In this way, the melted fiber end transfers the measurement region (focal point) away from the tip of the sensor and creates a weak illuminated region before and after the focal point. Consequently,