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Effect of louver baffles on hydrodynamics and gas mixing in a fluidized bed of FCC particles

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ABSTRACT

The effect of louver baffles on the particle concentration profiles, pressure fluctuations, bed expansion, and gas mixing of a fluidized bed was investigated in a transparent 2-D column of cross-section 500×30 mm and height 6 m over a broad range of operating conditions covering both the bubbling and turbulent flow regimes. Visual observations, pressure fluctuations and steady gas tracer experiments showed that louver baffles can break bubbles, as indicted by the lower amplitudes and higher mean frequencies of differential pressure fluctuations, but they were only effective for superficial gas velocities $<\sim 0.7$ m/s for the FCC particles considered in this study. The ability of louver baffles to break bubbles reached a maximum near the onset of the turbulent flow regime. A gas cushion of low particle concentration appeared below the louver baffle, and its height increased with increasing superficial gas velocity, indicating increasing suppression of solids backmixing. Internal emulsion circulation was promoted above the louver baffle, causing an uneven distribution of gas flow. The addition of louver baffles reduced the upstream tracer gas concentrations by 80–90%, indicating a significant decrease in the backmixing fluxes of both gas and solids across the baffle layer. The tracer gas concentrations above the louver baffles increased resulting from the promoted emulsion circulation by louver baffles.

1. Introduction

In gas–solids fluidization, solid particles are transformed into a fluid-like state by suspension in a gas stream. Fluidization is widely applied in chemical and physical operations for its intrinsic advantages: ease of solids handling, favorable mass and heat transfer, temperature uniformity, ease of temperature control etc. However, it also has distinct disadvantages such as inefficient gas–solids contacting caused by bubbles/voids, non-uniform residence times of gas and solids, loss of solids by entrainment, wear of surfaces, and attrition of particles.

Various methods have been investigated to improve the performance of fluidization systems. Among these, internal baffles are often suitable when good gas–solids contacting and low axial backmixing of gas and solids are needed, as in chemical reactors requiring high selectivity of intermediate products, solids drying and continuous gas adsorption. Adding simple internal baffles is a relatively low-cost measure to improve the performance (conversion and selectivity) of fluidized bed reactors (Jin et al., 1982; Kwauk, 1996). Reviews on the effects of baffles in fluidized beds have been provided by Harrison and Grace (1971) and Jin et al. (2003). Except for traditional experimental approaches, CFD modeling was also employed in recent years to study the complex hydrodynamics in baffled fluidized beds (Gao et al., 2008a,b).

Among the various types of internal baffles, louver baffles have already been studied and applied in industrial applications, e.g. for synthesis of phthalic anhydride (Kwauk, 1996). Louver baffles consist of a bundle of inclined surfaces, with the simplest form of louver baffle shown in Fig. 1. The inclined surfaces can guide the gas and solids phases to create a horizontal velocity component, which is effective in breaking bubbles and hence strengthening gas–solids contacting. In addition, axial backmixing of both gas and solids is suppressed by the restricted flow area in the baffle layer. There are three main geometric parameters of louver baffles as defined in Fig. 1(b): (a) height of baffle, h_b, (b) pitch of inclined vanes, d_v, and (c) inclination angle of vanes, θ_v. In large fluidized-bed columns, four or more bundles of different vane orientations may exist in a single layer of louver baffles, creating one or more turns of annular gas flow in the cross-section of the bed, as in the single-turn and multi-turn louver-baffle arrangements seen in Figs. 2(a) and (b).

The performance of louver baffles was summarized by Jin et al. (2003). Jin et al. (1982) studied the effect of louver baffles on bubble

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behavior by photography. Louver baffles were reported to be able to control, break-up and renew bubbles, thereby substantially improving gas–solids contacting at relatively low gas velocities, but they also had a detrimental effect on fluidization because of the appearance of a thick air "cushion" below the baffles at high gas velocities. Chen et al. (1983) studied the effect of louver baffles on the expansion of a fluidized bed of Group B particles. Kong (1993) found that louvers in both the dense bed and freeboard can decrease solids carryover, with the baffles in freeboard being more effective. Yang et al. (1991) studied the effect of louver baffles on the transition from the bubbling to the turbulent flow regime in a fluidized bed. Kwauk (1996) summarized the empirical design guidelines for louver baffles in industrial fluidized beds. Recently, Zhang et al. (2008) compared the gas backmixing properties in a baffle-free fluidized bed and baffled fluidized beds with louver baffles of different structural parameters and arrangements. The results demonstrated that louver baffles can greatly suppress gas backmixing and decrease the axial gas dispersion coefficients.

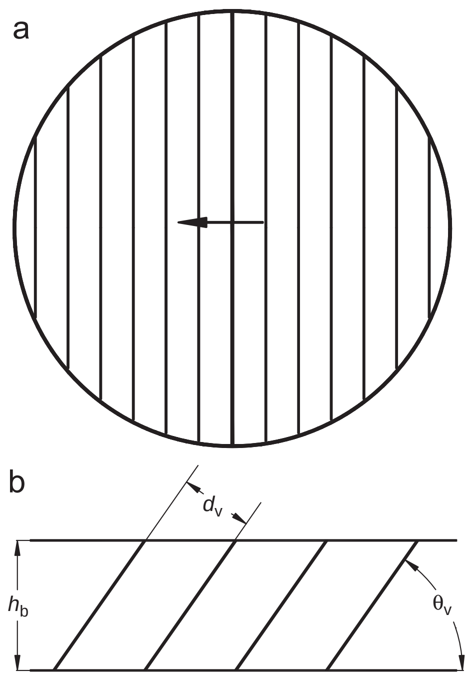

Fig. 1. Schematic of louver baffles. (a) Top view, and (b) sectional view (part).

However, previous studies on louver baffles were usually focused on some specific aspects. Operating conditions, bed scales and particle properties differed in these studies, leading to a lack of systematic understanding of the effect of louver baffles in fluidized beds. The aim of this study is to investigate the effect of standard louver baffles, as recommended by Kwauk (1996), on the hydrodynamics and gas mixing of a fluidized bed of catalyst particles over a wide range of operating conditions. Another aim is to identify drawbacks in standard louver baffles for future structural improvements and potential applications such as in bubbling FCC strippers and turbulent FCC regenerators.

2. Experimental set-up and measurement techniques

2.1. Experimental set-up

A schematic of the experimental set-up is shown in Fig. 3. The main component was a column of cross-section 500×30 mm and height 6 m, made of plexiglass. This "two-dimensional" (2-D) design provided direct views of the internal flow behavior of gas and solids in the bed. The column consisted of six sections of height 1 m, connected by flanges. Four 500 mm×360 mm detachable back covers were mounted in the bottom two sections, facilitating the installation and replacement of baffles. The gas distributor was an 11-hole perforated plate of 1.44% open area. Two-stage external cyclones captured particles entrained in the discharge gas flow and returned them to the dense bed via standpipes to maintain a constant solids inventory in the column.

Ambient air was introduced by a roots blower to fluidize the particles. Equilibrium FCC particles of mean diameter 78 μm and density 1500 kg/m^3 were the bed solids. The static bed height was maintained at 1.28 m in all experiments. The superficial gas velocity ranged from 0.2 to 1.1 m/s, covering both the bubbling and turbulent flow regimes.

2.2. Louver baffles in this study

For industrial fluidized bed reactors with multilayer louver baffles, according to the guideline of Kwauk (1996), the distance between adjacent layers of louver baffles is often in the range of 0.4–0.6 m, large enough that each layer of baffles functions independently, without being affected by adjacent layers. Therefore, it is reasonable to study a single layer of baffles to simulate the effect of multiple-layer louver baffles in industrial fluidized bed reactors.

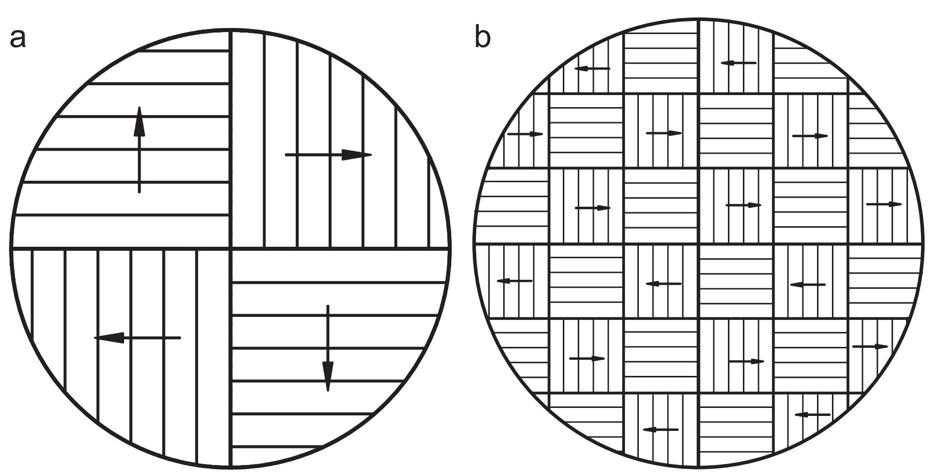

Fig. 2. Single-turn and multi-turn louver-baffle plates. (a) Single-turn louver-baffle plate, and (b) multiple-turn louver-baffle plate.