Johnston PM, M.E.Sc., "The Effects of Distributor Design on the Hydrodynamics within the Entrance Region of a Cocurrent Downflow Circulating Fluidized Bed (Downer) Reactor", The University of Western Ontario, March 1998 (co-supervisor: HI de Lasa).

Abstract

The effects of the gas and solids distributor design and operating conditions on the flow structure development and acceleration in the entrance region of a 9.3 m tall and 0.1 m i.d. gas-solid downflow reactor were studied using FCC particles.

The three distributors were designed as internals of the 0.2 m distributor shell so that modifications were more easily facilitated. Distributor #1, with 37 uniformly spaced 12.7 mm i.d solids feed tubes that were each centered within an air feed hole of 16.7 mm i.d., provided an even flow of solids through each of the solids feed tubes and uniform air distribution through each of the 2 mm gaps. Distributor #2, with 7 solids feed tubes of 25.4 mm i.d. and 12 air holes of 12.7 mm i.d. in the annular region near the wall, provided an even flow of solids through each of the solids feed tubes but less uniform solids distribution over the column cross-section and non-uniform air distribution along the wall. Distributor #3, with 7 coaxial solids and gas nozzles, provided excellent gas-solids contacting from high velocity nozzles that rapidly dispersed over the column cross-section.

Separate optical fiber probe systems were used to measure the local solids holdup and particle velocities at numerous positions along the column length. A unique iterative procedure is described for the calibration of the solids holdup sensor within a miniature downer system. Pressure transducers were used to measure the pressure gradient along the column.

The fully developed radial profiles of solids holdup were very uniform with a peak density near a normalized radial position of 0.8. The fully developed radial profiles of particle velocity were uniform with higher values in the core that decrease in a 'parabolic' fashion towards the column wall. The radial profiles of solids flux, determined as a product of the velocity and holdup measurements, were characteristically similar to the holdup profiles with a peak near a normalized radial position of 0.8 because the velocity profiles were relatively uniform. The shapes of the holdup and velocity profiles tended to be affected by neither the gas velocity nor the solids circulation rate in the developed region.

Particles accelerated very rapidly upon entering the downer, due to the combined forces of gravity and drag in the first acceleration region. The magnitude of acceleration is reduced when the particle velocity exceeds the gas velocity, leaving only the gravity as the acceleration force in the second acceleration region. Down the column, the flow enters the constant velocity region when the gas drag eventually balances the gravity. The resulting axial profiles of solids holdup and particle velocity changed greatly in the top 1 to 2 m of the column and then more slowly as they approached stable values in the developed region. This result describes the 3 section axial flow structure described by Wang et al. (1992); however, this study also found that the axial profiles of pressure gradient can only be used to clearly demarcate the section boundaries when the wall friction and gas nozzle pressure effects can be neglected. Moreover, the axial changes within the

downer were quite simple as compared to the variable and complex axial profiles that have been found within the riser.

The operating conditions affected the hydrodynamics within the entrance region of the downer in a different manner than within the riser. Increasing the superficial gas velocity did not seem to affect the flow development length nor the shapes of the radial profiles in the developing region; however, it did increase the acceleration length because the "final" particle velocity was raised. Increasing the solids circulation rate tended to increase the flow development length because particles must disperse under increased friction; however, it did not seem to have any effect on particle acceleration. For all cases, the flow could be considered developed no more than 5 m from the distributor.

Distributor #1 led to longer flow structure (solids holdup, particle velocity, and solids flux) development lengths and particle acceleration lengths because approximately 50 % of the solids were distributed along the wall and the air was not injected in order to enhance contacting. Distributor #2 led to shorter flow development and acceleration lengths for 2 fundamental reasons: The solids were pre-accelerated in the larger diameter solids feed tubes; and, the solids were distributed away from the column wall and the air was distributed near the wall so that the solids-wall friction seemed to be reduced. Distributor #3 led to more rapid solids acceleration and flow development as compared to Distributor #1 because the high velocity nozzles greatly increased the gas-solids contacting and dispersion. As compared to Distributor #2, acceleration and flow development was slower because the air expanded from each nozzle and probably also carried solids to the wall region so that friction was enhanced.

This study proposes that the distributor design may be the critical consideration in order to optimize the downer reactor. An efficient distributor design will provide the rapid gas-solids contacting, flow development, and particle acceleration that is required to facilitate the cracking reactions within this short contact time reactor.