In this chapter the characteristics of fluidized gas-solid suspensions are described, and the basic designs of fluidized bed reactors are sketched. Several modeling approaches that have been applied to described these units are outlined.

The term fluidization has been used in the literature to refer to dense-phase and lean-phase systems, as well as circulation systems involving fast fluidization, pneumatic transport or moving beds [56, 82]. The broad field of fluidization engineering thus deals with all these modes of contacting, but the two major groups of fluidized bed reactors are the dense phase and lean-phase reactors. Among the dense phase reactors, the bubbling bed reactor design is most common. The lean-phase flow regimes are employed in circulating bed reactors. The first industrial applications of the fluidized bed technology considered gasification of coal and the chemical fluid catalytic cracking (FCC) process. Today, the FCC process and circulating fluidized bed combustion (CFBC) are the major technologies for circulating fluidized beds.

Moving packed beds normally consist of a stack of catalyst particles inside a tube thus resembling a fixed bed. In a moving packed bed reactor, as distinct from fixed bed, the gravity force is generally utilized to shift the catalyst from top to bottom. However, other arrangements like upwards, horizontal and inclined beds exist as well. Therefore, the moving bed reactors have many of the same properties as fixed beds, but allow continuous regeneration of deactivated catalyst and lower pressure drop. Large scale operations of moving beds can thus be employed for rapidly deactivated catalysts [82]. Temperature gradients caused by extreme exothermic/endothermic reactions can also be minimized with appropriate solid circulation. Nevertheless, very little is known about the hydrodynamics, mixing, and transport characteristics of moving bed reactors. Moving beds are thus not considered further in this book.
10.1 Solids Classification

When gas is passed through a bed of solid particles, various types of flow regime are observed. Operating conditions, solid flux, gas flux and system configuration and the solid particle properties (e.g., mean size, size distribution, shape, density, and restitution coefficient) are factors that affect the prevailing flow regime. Geldart [49] investigated the behavior of solid particles of various sizes and densities fluidized by gases. From this study a four group classification of solids was proposed to categorize the bed behavior based on particle density and particle size:

- **Group A**: Solid particles having a small mean size $30 < d_p < 100 \, \mu m$ [52, 142] and/or low particle density $< \sim 1.4g/cm^3$. These solids fluidize easily, with smooth fluidization at low gas velocities and bubbling/turbulent fluidization at higher gas velocities. Typical examples of this class of solid particles are catalysts used for fluid catalytic cracking (FCC) processes.

- **Group B**: Most solid particles of mean size $100 \mu m < d_p < 800 \mu m$ [52] and density in the range $1.4g/cm^3 < \rho_s < 4g/cm^3$. These solids fluidize vigorously with formation of bubbles that may grow in size. Sand particles are representative for this group of solids.

- **Group C**: This class of solids includes very fine and cohesive powders. For most cases $d_p < \sim 20 \mu m$ [52]. With these particles normal fluidation is extremely difficult because inter-particle forces are greater than those resulting from the action of gas. Cement, face powder, flour, and starch are representative for this group of solids.

- **Group D**: These solid particles are large $d_p > \sim 1mm$ [52] and/or dense, and spoutable. Large exploding bubbles or severe channeling may occur in fluidization of this type of solids. Drying grains and peas, roasting coffee beans, gasifying coals, and some roasting metal ores are representative for these solids.

Apart from density and particle size, several other solid properties, including angularity, surface roughness and composition may also significantly affect the quality of fluidization. However, in many cases Geldart’s classification chart is still a useful starting point to examine fluidization quality of a specific gas-solid system.

10.2 Fluidization Regimes for Gas-Solid Suspension Flow

Most gas-solid systems experience a range of flow regimes as the gas velocity is increased. Several important gas-solid fluidization regimes for the chemical process industry are sketched in Fig 10.1. In dense fluidized beds regions of low solid density may be created. These gas pockets or voids are frequently referred to as bubbles.