1.1 HISTORICAL PERSPECTIVE

The first description of the use of fluidization was by the German philosopher-scientist Georgius Agricola in his book De Re Metallica (1556, Latin), to upgrade run-of-mine ores. In more recent times the first industrial application of fluidization was for the gasification of brown coal in the Winkler coal gasification process in 1922. The first unit was a 2 m diameter and 13 m tall fluidized bed that produced some 2000 m$^3$/h gas which was subsequently improved to 5.5 m diameter and 23 m tall bed processing some 700 tons/day of coal.

The major impetus for fluidization came with the advent of the fluidized catalytic cracker in 1942, since then the growth of fluidization technologies has been steep and uninterrupted. Fluidized bed reactor technologies have been immensely successful in the commercial production of acrylonitrile (Sohio process, 1969) and the synthesis of polyolefin’s (Unipol process, 1984). Fluidized bed reactors have also been used commercially for the production of ethylene oxide, ethylene dichloride, maleic anhydride and Fischer-Tropsch synthesis.

In 1940’s Dorr-Oliver used the fluidized bed technique successfully for roasting of sulfide ores and since then almost all new roasters have been fluidized beds. In addition to these applications the fluidized beds have also been used in coking technologies, gasification, combustion and waste treatment technologies. Fluidized bed drying, granulation and coating operations find wide spread applications in the pharmaceutical sector. Currently, most of the processes that are being developed for the industrial production of carbon nano tubes use a fluidized bed.

1.2 GAS-SOLID FLUIDIZATION

Most of the applications of fluidized beds involve gas as the fluidizing media. Gas-solid fluidization is distinctly different from fluidization using liquid media. Liquid-solid
fluidization is more orderly and homogeneous while Gas–solid fluidization – called aggregative fluidization- is largely chaotic in nature.

Numerous structures / patterns are observed in Gas–solid fluidization. These structures are often transient and they emerge under different parametric set of conditions. Different fluidization regimes are encountered in Gas-solid fluidized beds depending upon the gas velocities. With increasing gas velocities the state of the bed transits from fixed bed to particulate fluidization to bubbling fluidization leading to slugging in some cases, to turbulent fluidization, fast fluidization and eventually pneumatic conveying as shown in Fig.1.1 (Grace 1990).

![Fluidization regimes](image)

**Fig. 1.1 Fluidization regimes encountered with increasing gas velocities.**

The presence of bubbles and slugs in the bed is a unique feature of Gas–solid fluidization. There are merits and demerits of having bubbles formed in the beds. The high degree of mixing of the bed solids is primarily attributed to the vertical movement of particles with the bubbles this gives rise to excellent heat transfer properties of the bed. On the other hand the gas flowing within the bubbles have little contact with the bed solids, this bypassing effect severely restricts the extent of Gas-solid reaction that could be achieved. Hence, a generation of investigators have focused their attention on the understanding of the process of bubble formation, bubble dynamics, bubble growth, bubble coalescence and splitting using the tools and methods available at their disposal.
1.3 Research Objectives

In spite of the effort and the huge amount of work put up in this area over a period of five decades, the knowledge base on fluidization is still far from complete. The information derived from experiments is often uncertain and the numerous correlations developed for the estimation of design parameters are at the best approximate, it is difficult to state something conclusive on the fluidized beds. It is this uncertainty that motivates numerous workers even today, to investigate Gas-solid fluidization with new and more sophisticated tools and techniques developed particularly to meet this end.

This work was primarily undertaken to generate data on the bubbling fluidized beds, over a range of particles having different particle sizes and densities as well as the variation of design and operating parameters using non-intrusive and intrusive techniques. Digital video imaging was the discrete non-intrusive technique used. The other non-intrusive continuous measurement technique was the optical imaging technique, while absolute pressure measurement was the intrusive technique adopted in this investigation.

Data so obtained were suitably analyzed using appropriate analytical techniques such as statistical analysis, probability distribution of bubble chord lengths, frequency analysis, FFT, state space analysis, decomposition of power spectral density etc to qualitatively and quantitatively discern the hydrodynamic features of Gas-solid fluidized beds.

1.4 Outline of the Thesis

Chapter 2 ‘Literature survey’ focuses on the conceptual understanding of bubbling fluidized bed, prediction of bubble diameters and bubble rise velocity and other aspects of design interest such as bubble coalescence and splitting. Measurement techniques and tools used by various investigators are surveyed and the relative effectiveness of these techniques are established.

Chapter 3 ‘Materials and methods’ discusses the rationale of selecting 2-D fluidized beds in this investigation. It details the experimental set-up including the gas distributor, the
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particles used in this study and their characterization. The determination of minimum fluidization velocity for each particle system is discussed and tabulated.

Chapter 4 ‘Digital imaging of two-dimensional fluidized beds’ details out, the digital video imaging technique used, the experimental procedure, technique of frame generation and processing, measurement of bubble sizes and the estimation of bubble diameters. The data obtained using digital video imaging technique was suitably used to address the following:

- Effect of various parameters on bubble sizes.
- Range of bubble sizes observed at particular location of the bed and the effect of parameters on the size range.
- Statistical analysis of bubble shapes. Effect of various parameters on bubble shapes
- To check the efficacy of bubble size prediction correlations.
- Determination of bubble rise velocity and check the efficacy of correlations.
- Effect of various parameters on bed expansion.
- Evaluation of bubble density and the effect of parameters on bubble density.
- To identify the various mechanisms of bubble coalescence and bubble splitting
- Slug and cavity formation in fluidized beds

Chapter 5 ‘Imaging of 2-Dimensional fluidized beds with optical fiber probes’ presents a new tool for imaging fluidized beds. The detailed experimental set up including the electronic components and the data acquisition system used are discussed. The procedure of data filtering and data analysis are specified. The data obtained from the optical imaging technique was used to suitably address the following:

- Determination of bubble frequency and the effect of various parameters on bubble frequency.
- Evaluation of bubble size distribution and the effect of parameters such as excess gas velocity, static bed height, sensor location and bed thickness on the bubble size distribution.
- Analysis of bubble shape and the identification of a bubble shape by comparison of the probability distribution function (PDF) of the experimental chord lengths with the PDF generated for various bubble shapes likely to exist in the bed.

Chapter 6 ‘Pressure fluctuation analysis of 2-Dimensional fluidized beds’ discusses the experimental procedure, acquisition of data and the establishment of the pressure time
series. Using the pressure time series data, frequency domain analysis yields only qualitative results, while the state space analysis of the pressure time series yields a quantitative estimate of the velocity of the transition from bubbling to turbulent. The effect of height, particle size and density on the transition velocity from bubbling to turbulent was evaluated. From an analysis of absolute pressure time series the effect of measurement location and excess gas velocity on pressure fluctuations was discerned.

The pressure signals were also decomposed into the coherent part and the incoherent part. The standard deviation of the incoherent pressure fluctuations were calculated by the Parseval’s theorem. The diameter of the bubble was in turn estimated from the incoherent standard deviation. The bubble sizes obtained for sand, glass bead and resin particles using the pressure fluctuation analysis were compared with the bubble sizes obtained under identical conditions by the digital imaging technique and the results were found to be in fair agreement.

Chapter 7 summarizes the main conclusions of the thesis and also highlights the scope and opportunities for future research on bubbling Gas-solid fluidized beds.