CHAPTER-1

INTRODUCTION

Bubble column is frequently used as easy to construct gas-liquid contactor and find applications as chemical reactors [Shah et al.(1982), Rollbusch et al. (2015)], bioreactors [Kantarci et al. (2005)]. Shah et al.(1982) has reviewed several applications of bubble columns as chemical reactions such as chlorination, hydrogenation, absorption, catalytic slurry reactions, coal liquefaction etc. including wastewater applications. In a bubble column a gas is dispersed in forms of bubbles into liquid by sparging it though a distributor. Due to bubble-induced liquid motion, mixing of liquid and gas phases is achieved without having any moving parts. Gentle and uniform mixing in bubble columns makes it suitable as a bioreactor for shear sensitive cell processing [Kantarci et al. (2005)].

Bubble Columns have following advantages:

a. Less maintenance is required due to the absence of moving parts.
b. High heat-transfer rates per unit volume of reactor can be achieved.
c. Solid can be handled without any erosion or plugging problems.
d. Less floor space is occupied and bubble column is less costly.
e. Slow reactions can be carried out due to high liquid residence time. So higher values of effective interfacial areas and overall mass transfer coefficients can be obtained.
f. Simple in construction.

However, considerable back mixing in both phases, liquid and gas, high-pressure drop and bubble coalescence can be disadvantageous.

1.1 Introduction to the Problem:

The performance of bubble columns largely depends upon the size and number of bubbles in the column. The bubble dynamics in the column includes formation of bubbles at nozzles or sparger holes, bubble coalescence and bubble-breakup phenomena after the bubbles leave the sparger and disengaged at the top. At low gas velocity bubble coalescence and bubble-breakup may be absent. Thus bubble-induced turbulence is a complex process. Hydrodynamic parameters used to specify the bubble behaviour are primarily gas holdup, bubble size and shape, bubble velocity. Bubble coalescence and bubble breakup phenomena also influence bubble behaviour [Jasima et al.(2019)]. As all these variables depend on each other, a single correlation cannot be applied to describe gas holdup, transfer coefficients etc. Flow regimes maps have been used to understand different types of bubble column performance under different conditions. Transition from one flow regime to another is characterized by the superficial gas velocity at which the flow regime transition takes place. At low gas velocities uniform bubbling regime is observed. Almost spherical bubbles of uniform size move vertically upwards. Bubble coalescence and bubble-breakup is absent and hence the size of the bubbles which are formed at the sprager remains constant. At high gas velocity, the flow regime change. The bubbles of different sizes are present in the column due to bubble coalescence and bubble-breakup phenomena.

Study of the specific interfacial area, a_i, is important as it is used to estimate volumetric mass-transfer coefficient. Knowledge of bubble size is important as it may be used to estimate interfacial area and mass transfer rate as discussed elsewhere

[Verma (2014), Zhang et al. (2016)]. The average bubble diameter may be estimated from bubble size distribution (BSD) in the column. Bubble size distribution in cases other than uniformly distributed bubble columns can not only be used to measure Sauter-mean bubble diameter, d_{32}, which is useful in estimating a_i, but may also be useful in characterizing flow regimes through statistical analysis. Group of small and large bubbles can easily be identified from the BSD data [Sharaf et el. (2016)]. By using appropriate techniques, experimental values of BSD can be used to estimate d_{32}, gas holdup, ε_g and a_i at different temperature and pressure [Feng et al. (2019)]. These parameters are significantly affected by the height-to-diameter ratio of the column and sparger geometry [Besagni et al. (2018)]. One of the solutions to include the sparger geometry in correlations is to use ratio of column diameter-to-sparger diameter as a dimensionless group [Anastasiou et al. (2013)].

Photographic technique is a direct method of measurement of bubble size but may be used in transparent columns only. The bubble columns may be opaque due to opaque walls, presence of solids, processing of colored materials etc. Chemical methods, based on absorption of specific gases in certain fluids such as absorption of oxygen in sulphite aqueous solutions, are generally used to measure specific interfacial area. This technique can be used in opaque columns also. However, it was pointed out that the chemical method may not give correct value due to Marangoni effect (movement of liquid at the interface due to difference in surface tension) and other factors [Diaz et al. (2008)]. Acoustic technique is based on resonance frequency of the pulsating bubbles [Ryu(1993)]. Therefore, it is not influenced by turbulence. It can also be used in opaque columns. It has already be shown that surface waves are due to local liquid movements and volume pulsations of bubbles influence liquid movements to a long distance[Leighton and Walton (1987). Therefore, acoustic technique can also be used for measurement of bubble size.

The techniques for measurement of bubble size using a probe are capable of measuring local values of bubble size and number [Buchholz and Schügerl (1979)]. Probe techniques, in general, do not provide total number of bubbles at a particular time. Optical probes works in a clear liquid, conductivity probes require sufficient ions in the solution.

A comparative study among photographic, acoustic inverted funnel method showed that that acoustic method is as accurate as photographic method [Vazquez et al. (2005)]. It is not essential to use industrial hydrophones, but piezo-electric element can be used to get accurate estimates of bubble size. The processing of acoustic signal is faster than image analysis in case of photographic technique [Vazquez et al. (2005)].

Applications of acoustic techniques in chemical engineering processes have been reviewed by Boyd and Varley (2001). Unlike probe methods, acoustic technique can be used in any liquids. It can be used in opaque columns also where photographic column cannot be used. However, acoustic technique has few disadvantages also. It does not provide any information about the bubble shape. However, few shortcomings have to be addressed. Acoustic signals may include noise. Bubble breakup, bubble coalescence, fluctuating top layer of the column produces acoustic signals which are also measured and need to be filtered.

Though, a hydrophone captures acoustic signal in the entire column, however, it requires the signal to be measured for some time so that the obtained time-series can be converted to frequency domain. Local bubble size distribution measurement using this technique does not seem to be reported in literature.

In a study using acoustic technique in a stirred tank, it was observed that acoustic signals and volumetric mass-transfer coefficient are inter-related though no quantitative relationship was proposed [Usry et al. (1987)]. I was pointed out that there is a possibility of using the acoustic signals to monitor the mass-transfer process. However, no significant methodology has been reported in literature.

Use of acoustic method for estimation of BSD was described by Al-Masery et al. (2005). Later, it was used to study the effect of antifoam agents on hydrodynamics and bubble behavior in bubble columns [Al-Masery and Ali (2006)]. Improvement of the acoustic technique used to get estimates of the average bubble size and its distribution was felt [Al-Masery et al. (2005)].

1.2 Aims and Objectives:

From the above discussion it is clear that acoustic technique to measure bubble properties, identification of flow regimes and get some idea of mass transfer coefficient. There is a possibility to improve the available methodology for analysis of acoustic signal received from such measurements. Acoustic method has not been used to measure local values of bubble properties. Such measurements might reveal the changing bubble properties while the bubbles move up, away from sparger.

The present work is aimed at use of acoustic technique for measurement of bubble size locally i.e. in the sparger region, in the middle portion of the bubble column and near the top where foam layer may be present. From BSD, Sauter-mean bubble diameter, d_{32}, and specific interfacial area, a_i, may be estimated. The effect of fluid properties on BSD, d_{32} and a_i will be studied. The objective of the present study is as following:

1. To validate and develop the acoustic technique for local measurement of acoustic signals and extracting features related to bubble size.
2. To measure bubble size distribution in a bubble column using this technique at different distance from the distributor plate i.e near the sparger and at different height.
3. To estimate Sauter-mean bubble diameter. d_{32}, and interfacial area, a_i. from BSD and to study effect of superficial gas velocity, U_g, static bed height, H_s, distance above distributor plate, Z, and fluid properties (only low viscosity fluids) on d_{32} and a_i.
4. To compare the results with some of the work reported in literature.
5. To estimate statistical parameters e.g. mean, variance, coefficient of skewness and kurtosis from BSD and to study effect of various variables on these parameters.
6. To experimentally measure mass-transfer rate and understand the relationship of volumetric mass-transfer coefficient in terms of a_i and other parameters.

1.3 Organisation of the Thesis:

The organisation of this thesis is as following:

The Literature relevant to the present problem is presented in Chapter-2. It covers the topics related to hydrodynamics of the bubble column, techniques to measure bubble behaviour and details of acoustic technique.

Details of experimental setup, properties of the systems used, experimental procedure to perform the experiment and to analyse the acoustic data are presented in Chapter-3.

The variation of BSD, d_{32} , gas holdup and a_i with superficial gas velocity, static bed height and height above the distributor plate is presented in under the heading of 'Results and Discussion' in Chapter-4. Estimation of statistical parameters are also presented in this chapter. Results of the mass-transfer studies are also presented.

Conclusions based on present findings and suggestion for future are presented in Chapter-5.

All the data on BSD, estimated values of the parameters are given in appendices. It also included essential 'MATLAB' code.