CHAPTER-3

EXPERIMENTAL SETUP AND PROCEDURES

CHAPTER-3

EXPERIMENTAL SETUP AND PROCEDURES

Experimental setup and procedure to study the effect of bubble properties on gas liquid mass transfer in bubble column have been presented in this chapter. The algorithm for estimation of expanded bed height, foam layer thickness, entry region width, auto correlation coefficient, bubble size distribution, Sauter-mean bubble diameter, bubble aspect ratio and specific interfacial area of bubbles from videos are also presented.

3.1 Experimental Set-Up

Schematic diagram of present experimental setup is given in Figure 3.1. It consisted of a rectangular column with 0.37m height, 0.2m width and 0.02m depth. The set-up was made of Perspex sheet. Two walls facing the camera for photographic study were made of glass to avoid erosion of the wall and facilitate easy cleaning.

Air was sparged through a distributor to provide uniform bubbling. The sparger consisted of a perforated plate having 200 holes of 0.0015 m diameter. Over it 0.005 m glass beads were filled up to a height of 0.05 m. A 200 mesh of SS (0.00074 Nominal Sieve Opening) was placed over the beads. The glass beads between perforated plate and wire mesh acted as calming section. The bubble column consisted of a conical bottom below the perforated plate. A drain was provided to remove the liquid collected during startup and shutdown of the operation. The entire column was supported on an aluminium stand.

The gas was supplied using a compressor. A rotameter was provided for gas flow rate measurement.

Light sources (100 watt bulbs) were placed behind the rear wall which was covered with a translucent plastic sheet to diffuse the light resulting in almost uniform illumination.

Nikon (J4 model) camera was mounted on a stand in front of the wall at a height equal to centre of the column and at a distance of 1.5 m from it. After some prearrangements of camera position, backlight illumination of the column and use of a regulated power supply resulted in similar illumination in all the frames. To achieve this, the set-up was surrounded by walls to avoid reflections from the column walls. The camera was synchronized to record at a rate of 120 & 400 fps.

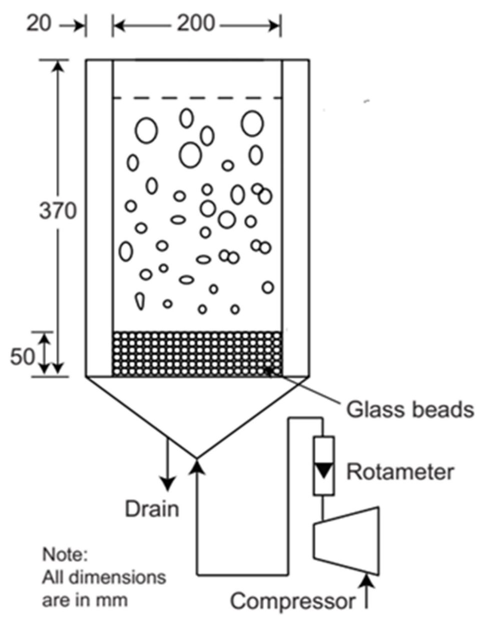

Figure 3.1: Experimental Set-up for bubble column

3.2 Physical Properties of the System

Experiments were conducted with distilled water and aqueous solutions of Carboxy Methyl Cellulose (CMC) as liquid phase and air as gas phase. CMC was used to study the applicability of image processing technique in non-Newtonian solution. Physical properties of these solutions at 30 ^{o}C are presented in in Table 3.1 and 3.2.

Table 3.1: Physical Properties of the Distilled water

Liquid	Density $kg\ m^{-3}$	Surface Tension $N\ m^{-1}$	Viscosity $kg\ m^{-1}\ s^{-1}$
Distilled water	996	72.0	0.000894

Table 3.2: Physical Properties of the CMC solution

Conc. (wt% CMC in water) at 30°C	Density, $kg\ m^{-3}$	Surface Tension $N\ m^{-1}$	K	n
0.5	998	70.0	0.456	0.23
1.0	999	69.1	0.268	0.26
2.0	997	65.3	0.193	0.28
3.0	995	64.1	0.158	0.25

3.3 Experimental Procedure

Air from the compressor was supplied through the empty bubble column, and the required flow rate was maintained using the rotameter for 15 to 20 minutes to achieve steady state conditions. This rotameter reading was used to estimate superficial gas velocity, U_g. The amount of water was estimated to achieve a particular static bed height. After achieving steady state conditions, required amount of water was poured into the column from top.

Camera was switched on to record video at 120 or 400 fps for 3 seconds. All recordings were made at 120 fps while studying the expanded bed height and thickness of foam layer. Measurements for bubble characteristics the recordings were made at 400fps. Such recordings were made at several superficial gas velocity and for different static bed height. Same procedure was followed for different CMC concentration solutions also. The properties of the liquids used are presented in Table 3.1 and 3.2.

Later the videos were processed using an image processing algorithm written in MATLAB.

3.4 Image Analysis Algorithm

The image processing algorithm written in MATLAB to identify different regions of gas-liquid dispersion and for calculation of theoretical gas holdup consisted of the following steps.

1. A frame from video captured at 120 fps was extracted and cropped to contain active test section only.
2. Range filtering was applied to characterize regions of image by their texture content. Statistical measure as range provides information about the local variability of the intensity values of pixels in an image.
3. Filtered image was converted to grayscale image.
4. Background noise was minimized. Salt-pepper noise was removed with the help of nonlinear digital filtering technique known as median filtration.
5. Enhancement of the image was carried out by adjusting the image contrast.
6. Histogram equalization of the image was performed to enhance the contrast of images by transforming the values in an intensity image.
7. Threshold was applied to the image.
8. Obtained image was converted into binary image.

The enhanced image was analysed to identify entrance region, foam layer and expanded bed height, H_e and measure them. The image processing algorithm written in MATLAB for measurement of bubble characteristics consisted of the following steps. Effect of these steps is shown in Figure 3.2.

1. A frame from video captured at 400 fps was extracted and cropped to contain entire gas-liquid dispersion.
2. Cropped image was converted to grayscale image by applying range filtering.

3. Contrast limited adaptive histogram equalization of the image was performed to enhance the contrast of images by transforming the values in an intensity image.
4. Obtained image was divided into twenty parts, i.e., seven rows and four columns.
5. On each section modified watershed technique was applied.
6. Divided images were reconstructed to get original image.

An average over 60 successive frames were taken. Contour was plotted over original image to verify the correctness of the algorithm. The enhanced image was analysed to measure bubble size and its shape using MATLAB's 'regionprop' function. Information about each bubble obtained and stored in an Excel file are major axis, *b*, and minor axis, *c*, of all individual bubbles in the frame.

From the major axis and minor axis of all bubbles following was estimated

1. Volume occupied by bubbles, $V_G = \sum_{N_b} \frac{1}{6} f_{b,i} \left(\pi d_{b,i}^3 \right)$ (3.1)
2. Gas hold up, $\varepsilon = V_G / \left(V_G + V_L \right)$ where volume of liquid is $V_L = H_s A_c$ (3.2)
3. Volume average bubble diameter: Considering bubbles as oblate ellipsoids with *b* = major axis and *c* = minor axis, average bubble diameter, d_b, is obtained as $d_b = \left(bc^2 \right)^{1/3}$
4. Bubble size distribution, *BSD*: Bubbles were counted in different class of bubbles, separated by 0.001 m. Bubbles with $d_b < 0.002$m were considered in one class. The number of bubbles in each class, N_b, is given in Tables A1 to A10 in Annexure-I.
5. Sauter-mean bubble diameter, d_{32}, is estimated from $d_{32} = \sum_i d_i^3 \Big/ \sum_i d_i^2$
6. Specific interfacial area, a_i, is estimated from $a_i = 6\varepsilon / d_{32}$
7. Aspect ratio, *E* is estimated as *E=c/b*

The least count estimated from image-size is size of 1 pixel i.e. 0.0015m in case of 120 fps and 0.001 m in case of 400 fps. At low fps video were captured for longer duration so that dynamics behaviour of dynamic behaviour of gas holdup, foam layer thickness and entrance region thickness is based on large number of images for each run. Extraction of bubble size from image capturing at 120 fps was inappropriate. Therefore, bubbles sizes were estimated from video taken at 400 fps.

The technique was validated by comparing the visual results with the estimated values. Pixel density validation is clear from Figure 4.1 (actual bed height is to the scale). Estimated bubble sizes were validated with that measured in individual images.

3.5 Detection of Expanded Bed Height

For detection of expanded bed height the binary image was used. It consisted of only black and white pixels. The white pixels corresponding to gas have the value 1 and the black pixels corresponding to water have the value 0. The pixel density at any height above the distributor plate, *H*, is defined as ratio of sum of all pixel values to the number of pixels at *H*. The top layer of the air-dispersion is not exactly horizontal. Since the same is changing with time, an average value of the top surface requires capturing the image. Using pixel average method allows us to study dynamic behaviour of top surface. The results are presented in Chapter-4.