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Effect of taper angle on gas holdup in tapered bubble columns using non-Newtonian pseudoplastic liquids

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Abstract : The effect of taper angle on the gas holdup was investigated in five different taper bubble columns using non-Newtonian pseudoplastic liquids with high clear liquid height to equivalent diameter ratio.

Keywords : Bubble columns; non-Newtonian fluids; Gas hold-up; Taper angle.

INTRODUCTION

Gas–liquid bubble columns are popular and widely used in industry as absorbers, strippers, reactors and fermenters due to absence of any moving parts, simple construction, good mixing and mass transfer capacity, temperature control, minimum maintenance and low capital cost involved. Bubble coalescence, high pressure drop, considerable back mixing in both phases, short residence time of gas and complex hydrodynamics flow patterns are the main disadvantages in the use of bubble column. However, the bubble columns are extensively used in the field of biotechnology, food processing, pharmaceutical processes and waste water treatment. In these field the liquid used are often non-Newtonian in nature. Bubbles in non-Newtonian liquid behave differently than in the Newtonian liquid[1]. The theoretical and experimental studies on bubble flow in non-Newtonian liquids have been reviewed by Chhabra[2]. Only few literatures are available using non-Newtonian liquid in bubble column[3-8]. In view of the importance of non-Newtonian liquids and the advantages accessible by tapered bubble column, the present work has been undertaken for studies of taper angle in batch bubble columns using non-Newtonian liquids.

EXPERIMENTAL DETAILS

A schematic diagram of the experimental setup has been shown in Figure 1. It consists of tapered bubble column, manometers for pressure measurement, distributor plate (D) to distribute the air, compressor (C), pressure gauge (PG), rotameter (R_G) for flow measures and other accessories. The detail setup and fluid used are reported in our earlier paper[9]. The tapered bubble columns were made of thick perspex and square shaped. A perforated plate made of perspex of 50 holes of 0.00227 m hole diameters were used for air distribution and connected with the columns by means of flanges. Detailed dimension of the columns are shown in TABLE 1. Four different SCMC concentrations, 0.2 - 0.8 kg/m^3 were used for the experiment. The SCMC solution is a time-independent pseudoplastic fluid and the power law model describes its rheological behavior. The physical properties of the liquid are shown in TABLE 2. The liquid heights used for the experiments were 1.12m, 1.17m and 1.22m for all columns. The air at a pressure 1kg/cm^2 gauge was introduced into the columns. The experiments were repeated number of times to ensure the reproducibility of the data. The temperature was maintained at atmospheric temperature 30±2^{0}C.

The gas hold up based on liquid bed volume expansion was determined. The overall value of gas hold up ratio was determined from this equation.

$$\varepsilon_g = \frac{V - V_o}{V} \quad (1)$$

where V and V_o are volume of liquid in column with and without gas flow. The diameter of the column is

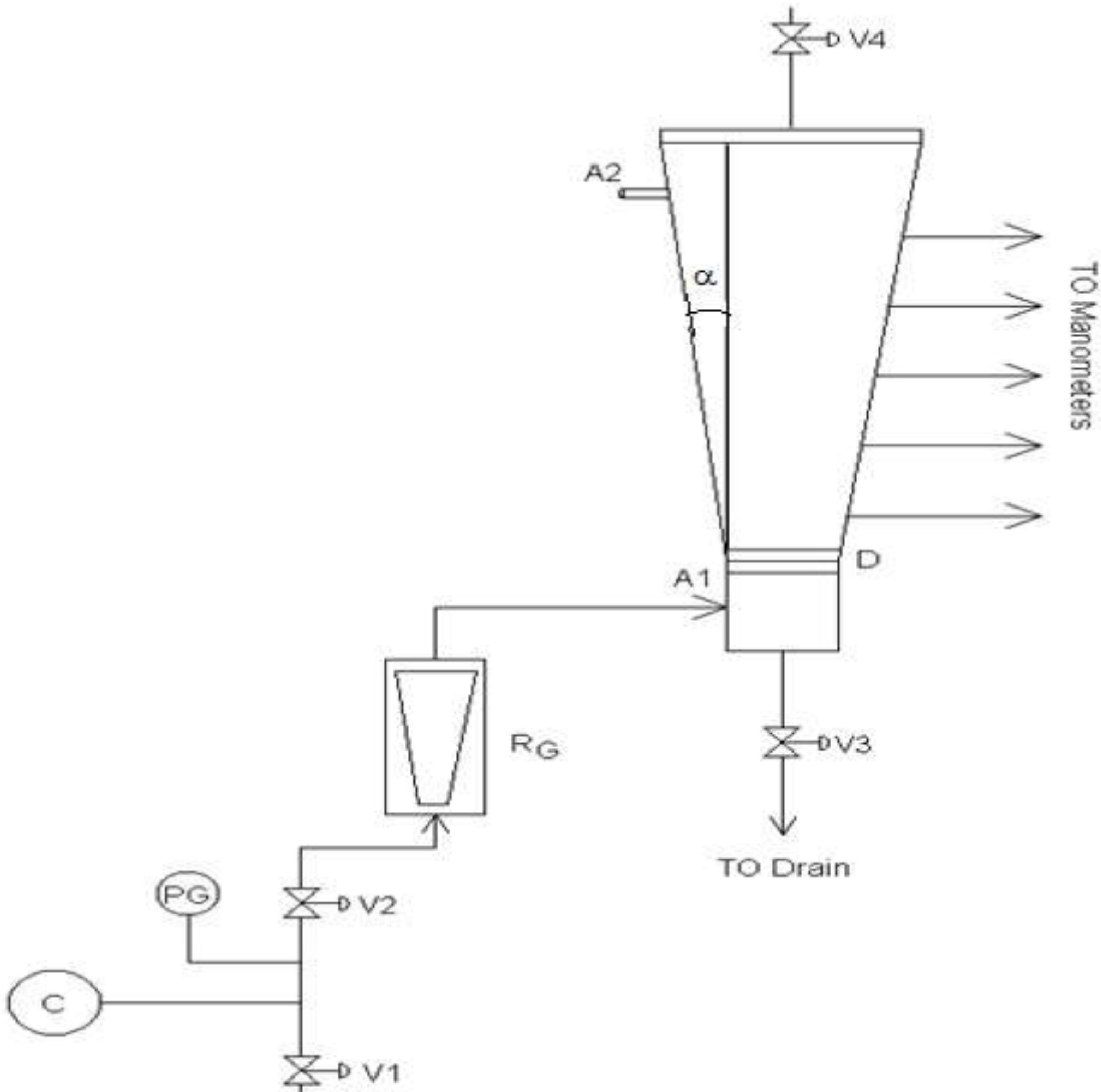

Figure 1 : Schematic diagram of experimental setup; A1: Air inlet; A2: Air outlet; Manometers; D: Distributor; C: Compressor; PG: pressure Gauge; R_G: Rotameter for gas; V1-V4: Control valves, α : taper angle.

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TABLE 1 : Dimension of bubble columns

Characteristic parameters	Tapered Bubble Column-1	Tapered Bubble Column-2	Tapered Bubble Column-3	Tapered Bubble Column-4	Tapered Bubble Column-5
Thickness of Perspex sheet, m	0.0127	0.0127	0.0127	0.0127	0.0127
Height of column, m	1.83	1.83	1.83	1.83	1.83
Top plate area, m^2	0.0762×0.0762	0.1016×0.1016	0.1397×0.1397	0.2281×0.2281	0.3468×0.3468
Bottom plate area, m^2	0.0508×0.0508	0.0508×0.0508	0.0508×0.0508	0.0508×0.0508	0.0508×0.0508
Equivalent diameter, m	$0.0605 \le D_c \le 0.0614$	$0.0692 \le D_c \le 0.0710$	$0.0851 \le D_c \le 0.0868$	$0.0991 \le D_c \le 0.102$	$0.1352 \le D_c \le 0.1442$
Hole diameter of the air inlet and outlet, m	0.0127	0.0127	0.0127	0.0127	0.0127
Taper angle, α (deg)	0.44	0.86	1.5	3.0	5.0
Hole diameter of different sieve plates used, m	0.00277	0.00277	0.00277	0.00277	0.00277
Hole number of sieve plate	50	50	50	50	50
Manometer tapping : distance from the air distributor plate, m					
Taping no. 1, m	0.0508	0.0508	0.0508	0.0508	0.0508
Taping no. 2, m	0.2032	0.2032	0.2032	0.2032	0.2032
Taping no. 3, m	0.3556	0.3556	0.3556	0.3556	0.3556
Taping no. 4, m	0.5080	0.5080	0.5080	0.5080	0.5080
Taping no. 5, m	0.6604	0.6604	0.6604	0.6604	0.6604
Taping no. 6, m	0.8128	0.8128	0.8128	0.8128	0.8128
Taping no. 7, m	1.0050	1.0050	1.0050	1.0050	1.0050
Taping no. 8, m	1.1500	1.1500	1.1500	1.1500	1.1500

TABLE 2 : Physical properties of the liquids

Concentration Kg/m^3	Flow behavior Index n	Consistency index K (Ns^n/m^2)	Density ρ_l (Kg/m^3)	Surface tension σ_l (N/m)
0.2	0.9013	0.0142	1001.69	0.07834
0.4	0.7443	0.1222	1002.13	0.08003
0.6	0.6605	0.3416	1002.87	0.08142
0.8	0.6015	0.7112	1003.83	0.08320

calculated by calculating the equivalent diameter of the base and at the gas-liquid interface, then calculates the log mean diameter for the column.

RESULTS AND DISCUSSION

Bubble characteristics and flow regime

At very low air flow rate the homogeneous flow region observed. With increasing air flow rate the bubbles are close together allowing coalescence leading to the formation of larger bubbles. When the bubbles are sufficiently large and the concentration of SCMC solution is high enough, the bubble appear to be cups at its lower end. Similar results are also observed by other researchers[10,11]. These large bubbles rises in the centre of the column, carrying considerable amount of liquid and many small bubbles in their wake. Once the large bubbles reach the liquid surface, the small bubble in the wake are entrained by the liquid down flow and are swept downward at the sides of the column.

The flow pattern in the tapered bubble column consists of two zones, central zone and annular region. In the central zone most of the bubble rises and whereas the bubble breakup and downward flow occurs in the annular region[12]. At high gas flow rate the bubbles burst at the surface causing ejection of fines of liquid droplets and inward dipping in the annular region.

Effect of taper angle

Figures 2-3 show the effect of taper angle on the holdup. It is clear from the figures that as the taper angle decrease the holdup increases. At lower taper angle back mixing is more and at higher taper angle the liquid at near the wall in the top portion of the column is remain unaffected. i.e., stagnant and hence holdup decreases. Increasing the taper angle the cross sectional area particularly in the upper zone increases which

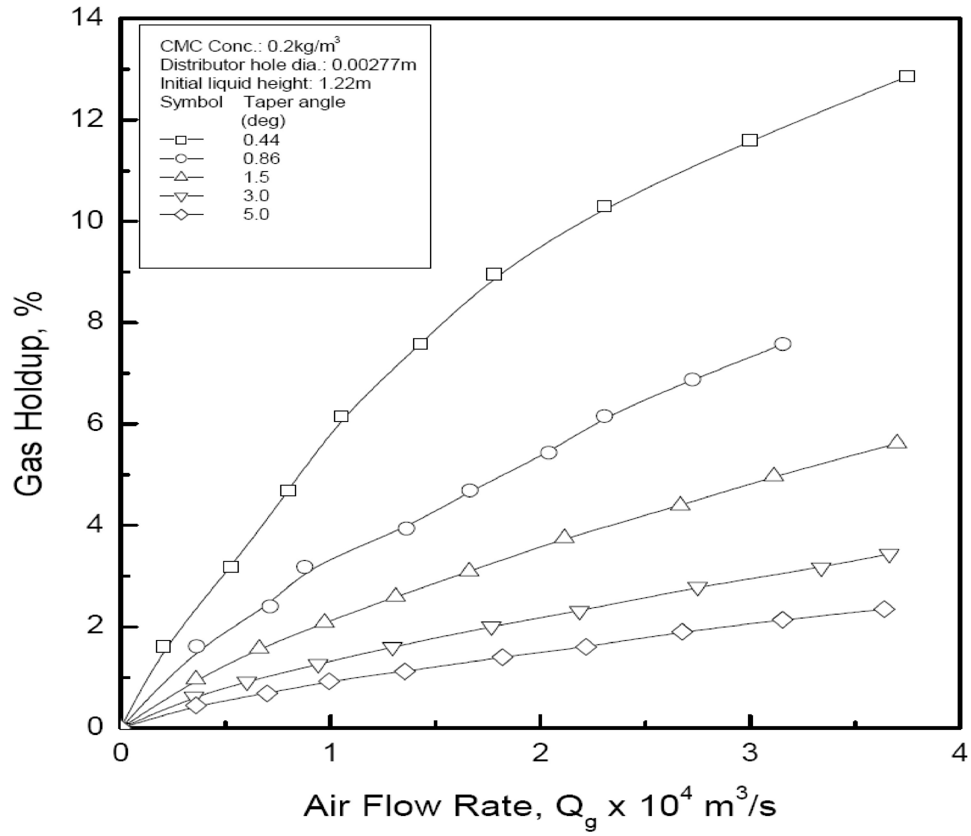

Figure 2 : Variation of gas holdup with gas flow rate at different taper angle

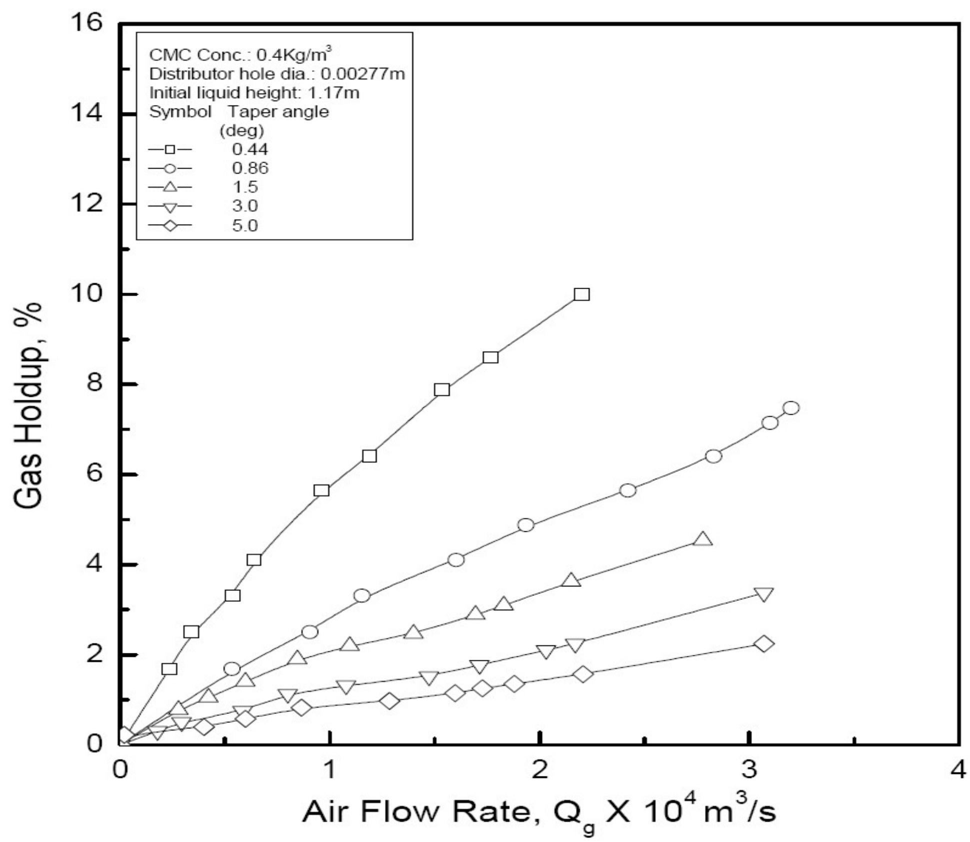

Figure 3 : Variation of gas holdup with gas flow rate at different taper angle

minimizes the transition of flow pattern and also reduce the coalescence. In the case small taper angled bubble column the coalescence of bubbles are more, large sized bubble having higher rise velocity and followed by small sized bubbles. Few of these small sized bubbles are recirculated through the annular region and are responsible for higher holdup and frictional pressure drop. Whereas for higher taper angled bubble column the rate of recirculation is low due higher cross-sectional area in the upper zone and the existence of the stagnant liquid layer in the wall. Hence, the gas holdup is higher for lower taper angled bubble column.

CONCLUSION

The gas holdup has been measured in five different taper bubble columns with different taper angle using non-Newtonian liquids. The gas holdup is higher for lower taper angle.

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