A STUDY OF MULTISTAGE/MULTIFUNCTION COLUMN FOR FINE PARTICLE SEPARATION

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ABSTRACT/EXECUTIVE SUMMARY

Hydrodynamic tests were initiated in this quarter. Gas holdups were measured under different operating conditions. Experimental data show that the multistage column has a uniform gas holdup distributions in different stages. The presence of frother has a significant effect on gas holdups. In addition, when the column is operated continuously, the liquid feed promotes the fluid circulation in the top stage by breaking up stagnant bubbles.

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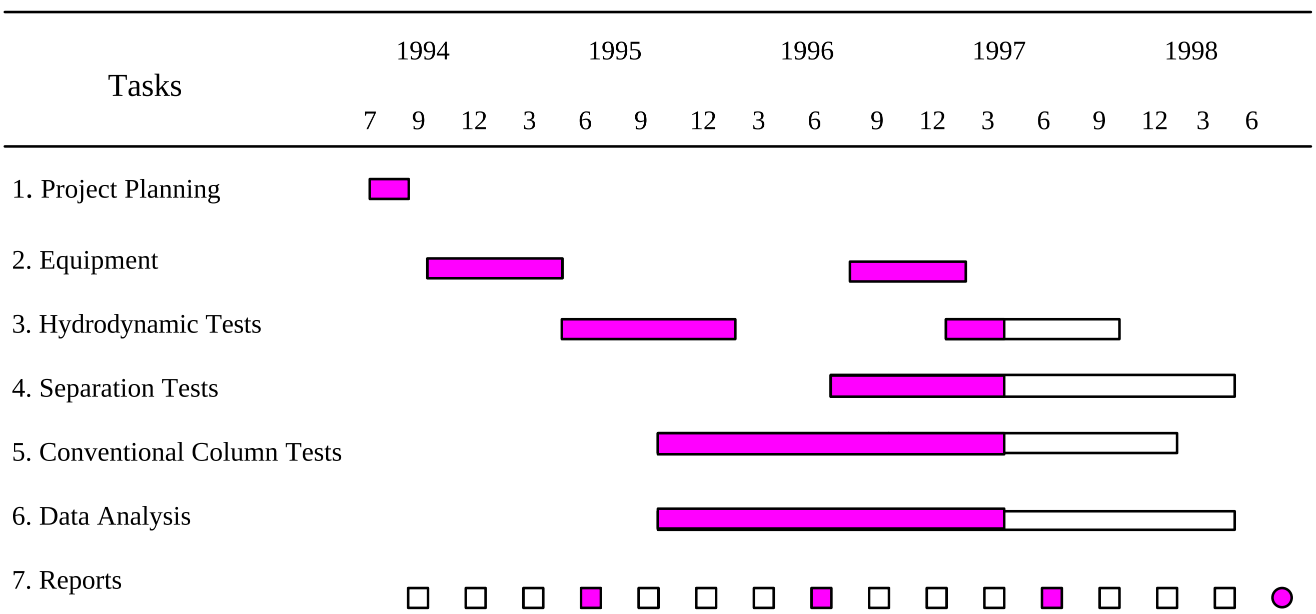
1.0 INTRODUCTION

The overall objective of the research program is to explore the potential application of a new invention involving a multistage column equipped with concentric draft-tubes (hereafter referred to as **the multistage column**) for fine coal cleaning and other fluid/particle separation processes. The research work will identify the design parameters and their effects on the performance of the separation process. The results of this study will provide an engineering basis for further development of this technology in coal cleaning and in the general areas of fluid/particle separation.

In the last quarter, we conducted the gas holdup measurement which is an essential part of the **hydrodynamic experiments** for establishing a process model for engineering design and scale-up. In compliance with DOE grant Amendment No. M003, the project schedule is adjusted. Table 1.1 shows work accomplished to date.

Table 1.1 Project Schedule



Notes: Quarterly Technical Progress Report; Annual Report; Final Report.

2.0 RESULTS AND DISCUSSION

2.1 Task 1: Project Planning

This task was completed in September 1994 [1].

2.2 Task 2: Equipment Design and Construction

The equipment modification was completed in the previous quarter [2].

2.3 Task 3: Hydrodynamic Tests

The objective of this task is to pursue a basic understanding of the hydrodynamic behavior and to characterize the flow and mixing conditions in the multistage separation column. This task was completed in December 1995[3-5] for the previous version of the agitated column for solid-solid separations. The hydrodynamic tests for the newly constructed column for liquid-liquid separation has begun during this quarter.

2.3.1 Local Gas Holdup Measurement

Gas Holdup is an important parameter affecting the flotation processes. Local gas holdup deference determines the liquid circulation velocity and local interfacial area. In this work, gas holdup is measured in terms of hydrostatic pressure difference using a manometer. U-tube manometer is used to measure the overall gas holdup and an inverted U-tube is employed to measure the local gas holdups in the riser or downcomer. The following equations are used to calculate the overall gas holdup and local gas holdup (6):

$$\varepsilon_{overall} = \frac{H_B - \frac{\rho_m}{\rho_W} H_m - H_W}{H_B} \qquad (2\text{-}1)$$

and

$$\varepsilon_{Local} = \frac{H_m}{H_L} \qquad (2\text{-}2)$$

where H_m denotes the manometer reading; H_B is the liquid surface height; H_L is the distance between two pressure taps; ρ_W and ρ_m are the density of water and indicating fluid receptively. The schematic of manometer setups and the derivations of above equations are explained in Appendix A.

In this work, two pairs of 1/8 inch pressure tabs were inserted 18 inches apart into the each stage. One pair is in the annular region and the other tap through the draft tube. Gas holdups of all three stages are measured.

2.2.2 Results and Discussion on Gas Holdup

The effects of both superficial gas velocity and liquid feed rate on local gas holdups were studied. Since 2-Ethyl-hexanol (2-EH) is used in actual flotation experiments, gas holdup measurements are carried out with and without frother. For each condition, gas holdups in riser and downcomer are measured in all three stages. Experimental results are plotted in Figures 2.1- 2.4.

Experimental results show that, within the operating range, the gas holdups increase linearly with the increase of superficial gas velocity. Linear increase of gas holdups with superficial gas velocity is an indication of bubbly flow. The addition of frother greatly increases the gas holdup. The system with frother is more sensitive to the superficial gas

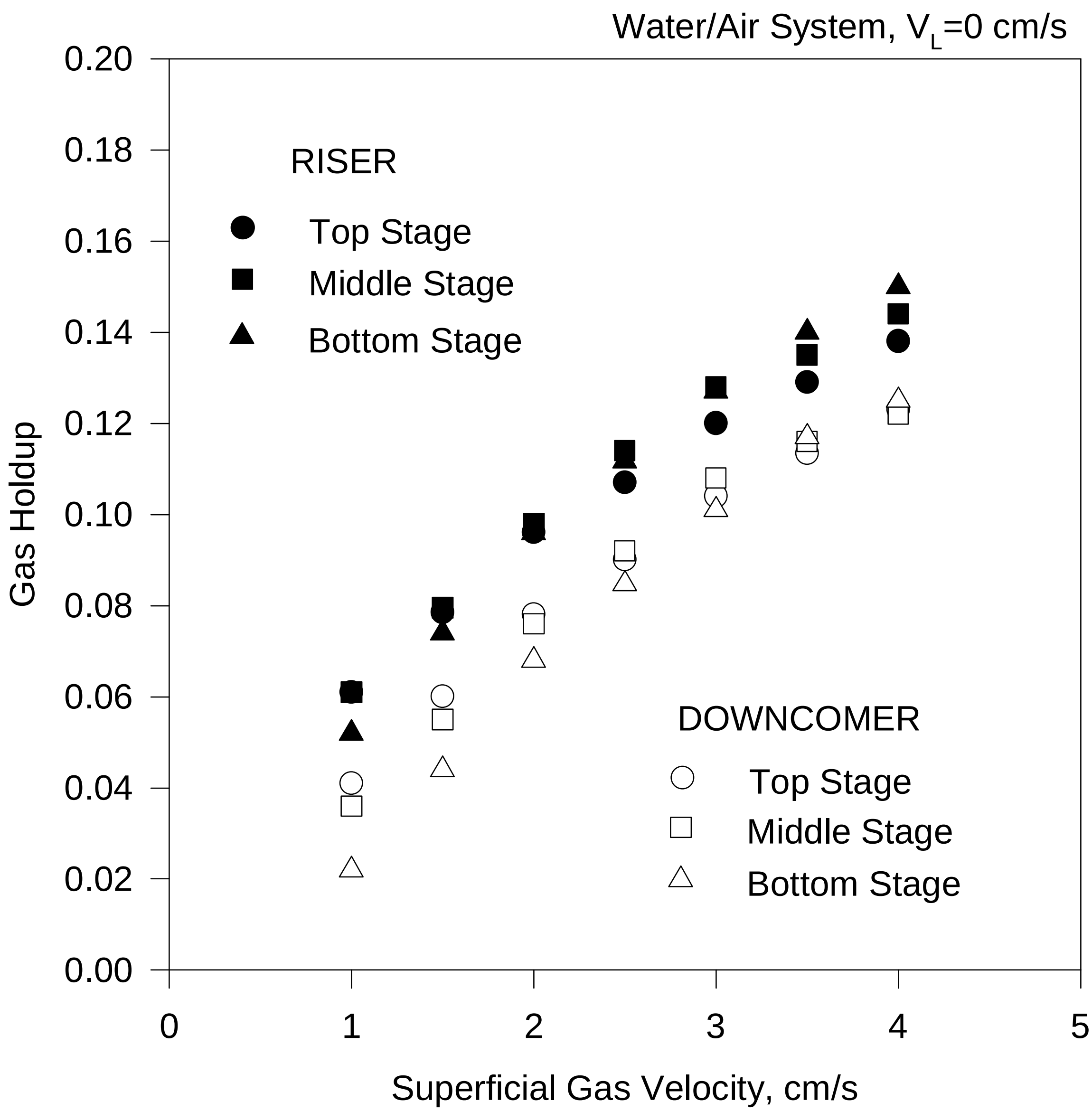


Figure 2.1 Local Gas Holdups in Different Stages (Water/Air, without liquid feeding)

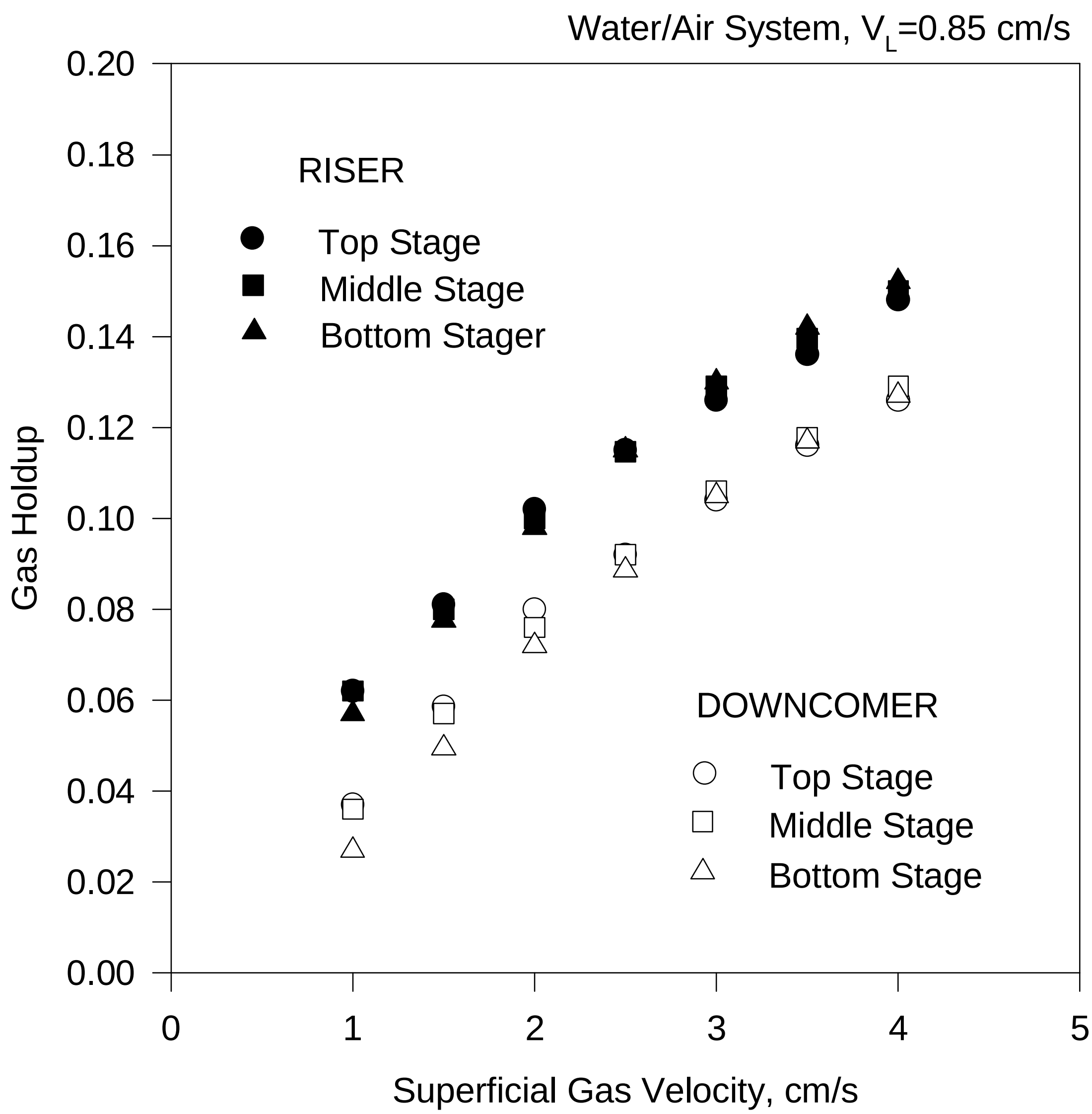


Figure 2.2 Local Gas Holdups in Different Stages (Water/Air, with liquid feeding)

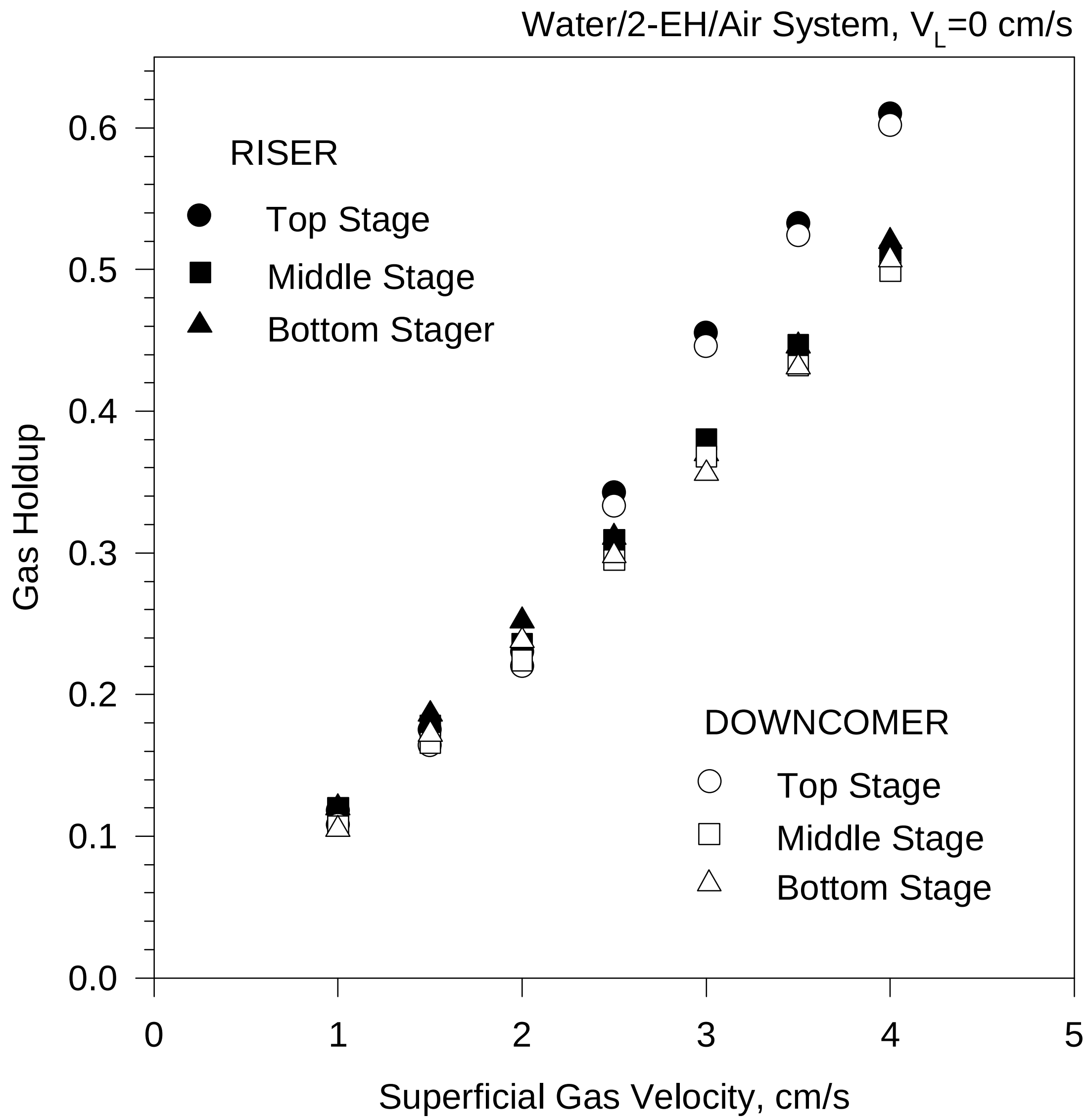


Figure 2.3 Local Gas Holdups in Different Stages (Water/2-EH/Air, without liquid feeding)

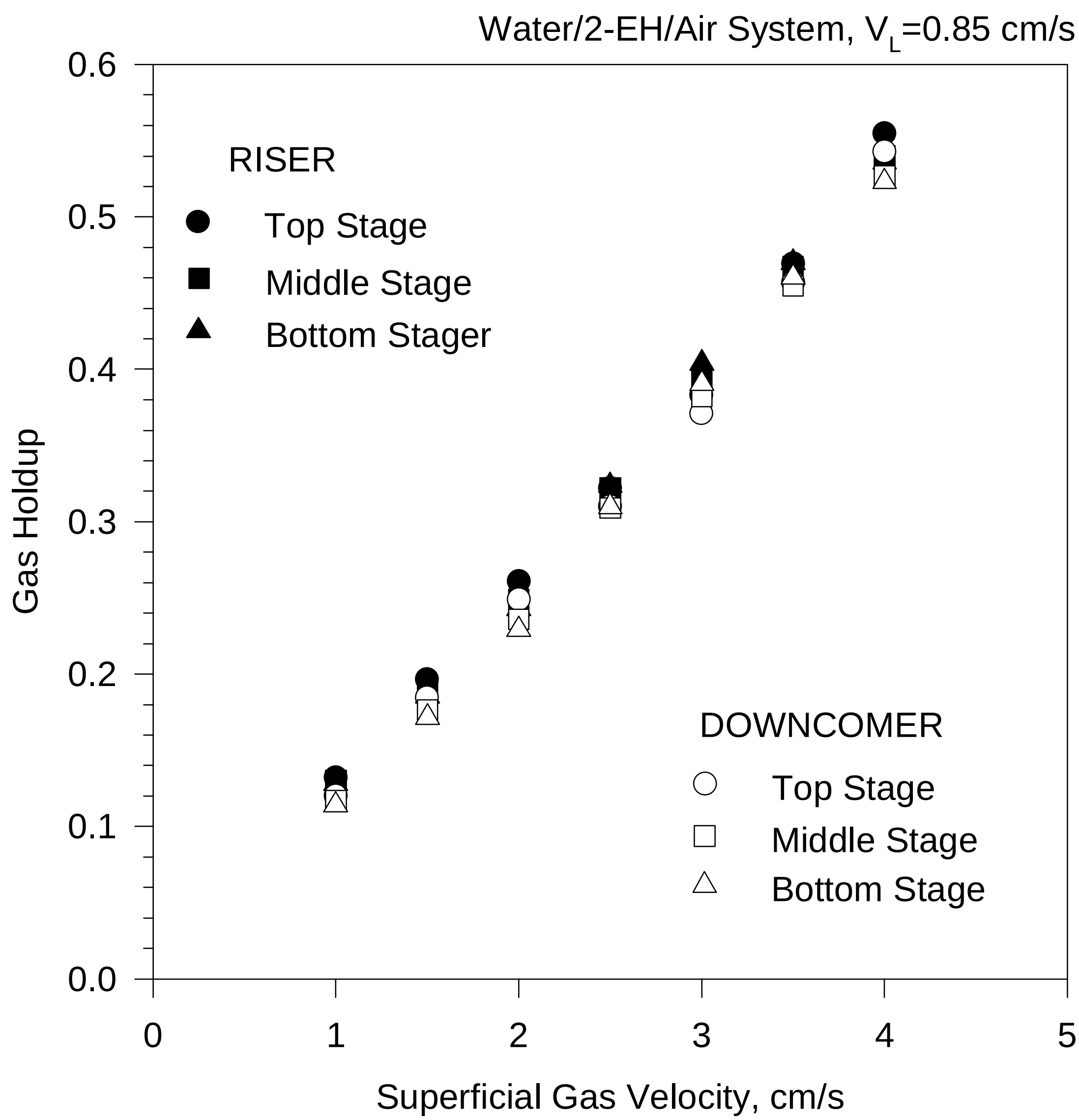


Figure 2.4 Local Gas Holdups in Different Stages (Water/2-EH/Air, with liquid feeding)

velocity. It is also evident that the riser gas holdup is always greater than the downcomer holdup whereby the loop flow is induced.

In general, the gas holdups in all three stages are quite comparable, resulting in relatively uniform axial holdup distribution compared to bubble columns and single stage Air-Loop-Reactors (ALRs)[7]. Nevertheless, the gas holdups differences between stages are still noticeable, especially at higher gas flow rate and in the presence of frother. As in bubble columns and ALRs, the gas holdup at the column top is usually greater than that at the bottom, near gas sparger. This is due to the fact that gas bubbles undertake an isothermal expansion during their rising. However, gas holdup also depends on the local coalesce/breakup conditions which may promote or hinder the bubble growth. In pure water system, the coalesce is dominant. The big bubbles in the top stages leave the dispersion very rapidly and result in reduced gas residence time, consequently reduced gas holdup[8]. Therefore, the gas holdup in the top stage is slightly smaller than that of bottom. On the other hand, with the presence of the frother, bubble coalescence is not as significant in the top stage due to reduced surface tension. At high gas velocity (> 3cm/s), the gas holdup is over 50% where individual rising of the bubbles is replaced by a sophisticated bubble collision and rising behavior. The liquid circulation becomes poor because the gas holdup in the downcomer is too high. Under this condition, bubbles are stable and stagnant. Consequently, the gas holdup is higher in the top than in the other stages.

It is found that in all cases the gas holdup difference between riser and downcomer in bottom stage is slightly higher that in the top, which corresponds to the observation that liquid circulation is faster in the bottom stage than in the top one. Also, the riser-downcomer gas holdup difference is larger in the water/air system than in the frother/air/water systems where the downcomer gas holdup is high because bubbles are small and readily entrained downward by the liquid. All these observations need to be confirmed by measuring the liquid circulation velocities in the next quarter.

The effect of liquid feed rate was also examined. A downward superficial liquid velocity was superimposed on the flow of the fluid. Experimental results indicate that the feed of liquid from top help break the stagnant bubbles and improve liquid circulation. Also, the gas holdup and other hydrodynamic behavior becomes visually similar in all three stages. This is expected to benefit the flotation performance.

As described above, the gas holdup is an important parameter used to examine hydrodynamic behavior of the column. Many factors, including mean bubble sizes, surface tension, liquid velocity, etc, interact with each other. The interrelationships between these factors are complicated[(9)]. Therefore, further investigation on liquid circulation velocity and bubble sizes are needed to establish a hydrodynamic model.

2.4 Task 4: Separation Tests

No separation test was performed in this reporting period.

2.5 Task 5: Conventional Column Tests

No conventional column test was conducted in this quarter

2.6 Task 6: Data Analysis

Experimental results were analyzed and discussed qualitatively in section 2.3. Mathematical treatments will be presented upon the completion of the hydrodynamic tests.

3.0 CONCLUSION AND WORK FORECAST

In this quarter, efforts were mainly devoted to the measurement of local gas holdups. Experimental results can be summarized as below:

1. Gas holdups increase linearly, in most cases, with the superficial gas velocities. This is the feature of two phase bubbly flow;
2. Gas holdups are greatly improved by the addition of frother (2-EH);
3. Gas holdup differences between riser and downcomer is lager in pure water system than the frother/water system.
4. The liquid feed from column top help break up the big stagnant bubbles and improves the liquid circulation in the top stages.

Research work to be continued in the next quarter will include the following: under the current column geometry,

1. Examine overall gas holdups and back check with the local gas holdup data.
2. Measure the liquid circulation velocities using conductivity tracer method.

4.0 REFERENCES

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APPENDIX

DERIVATION OF EQUATIONS FOR GAS HOLDUP CALCULATION

A-1 Overall Gas Holdup

The manometer setup of overall gas holdup measurement is shown in Figure A-1. The overall gas holdup is obtained by solving the following force balance equations.

Fluid statics gives

$$P_1 = P_0 + \rho_m H_M g \tag{A-1}$$

$$P_2 = P_0 + \rho_D H_D g - \rho_W H_W g \tag{A-2}$$

where P_0 is the atmospheric pressure.

Since the air pocket is sealed in the connecting tubing, we have

$$P_1 = P_2 \tag{A-3}$$

Therefore,

$$\rho_m H_m g = \rho_D H_B g - \rho_W H_W g \tag{A-4}$$

$$\rho_m H_m = \rho_D H_B - \rho_W H_W \tag{A-5}$$

Based on the definition of gas holdup, the density of the dispersion can be expressed as

$$r_D = r_W(1 - e_{Overall}) \qquad \text{(A-5)}$$

The substitution of equation (A-5) into equation (A-3) leads to

$$r_m H_m = r_W(1 - e_{Overall})H_B - r_W H_W \qquad \text{(A-6)}$$

The rearrangement of the above equation yields

$$e_{Overall} = \frac{H_B - \frac{r_m}{r_W} H_m - H_W}{H_B} \qquad \text{(A-7)}$$

which is the desired equation.

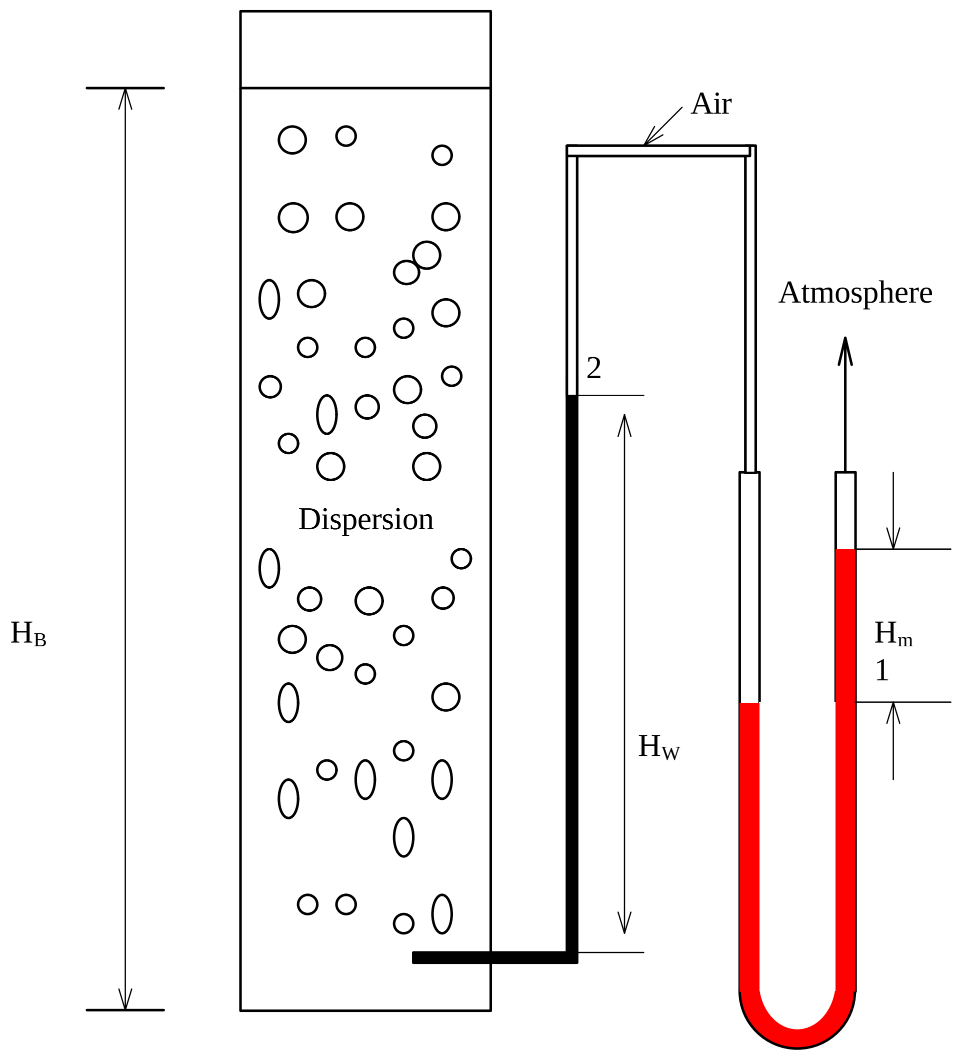

Figure A-1 The manometer Setup for Overall Gas Holdup Measurement

A-2 Local Mean Gas Holdup

The local mean gas holdup is measured by an inverted manometer arrangement which is depicted in Figure A-2. If P_1 and P_2 are the pressures of the two locations along the column respectively, the fluid statics gives

$$P_1 = P_A + \rho_M H_l g \tag{A-8}$$

$$P_2 = P_A + \rho_M H_r g \tag{A-9}$$

where P_A is the pressure of the air sealed in the manometer; H_l and H_r are the liquid levels in the left leg and right leg of the manometer, respectively.

$$\Delta P = P_2 - P_1 = \rho_D H_L g = \rho_m (H_r - H_l) g \tag{A-10}$$

From Figure A-2

$$H_r - H_l = H_L - H_m \tag{A-11}$$

The substitution of equation A-11 in equation A-10 gives

$$\rho_D H_L = \rho_m (H_L - H_m) \tag{A-12}$$

Again, substitute equation (A-5) in (A-12),

$$\varepsilon_{local} = 1 - \frac{\rho_m H_L - \rho_m H_m}{\rho_W H_L} \tag{A-13}$$

In this case, the indicator in the manometer is just the liquid in the column, so

$$\rho_m = \rho_W \tag{A-14}$$

Therefore, equation (A-13) becomes the desired form

$$\varepsilon_{local} = \frac{H_m}{H_L} \tag{A-15}$$

The validity of equations (a-7) and (a-15) is based on the assumption that the dynamic component of the measured pressure and the frictional losses are negligible.

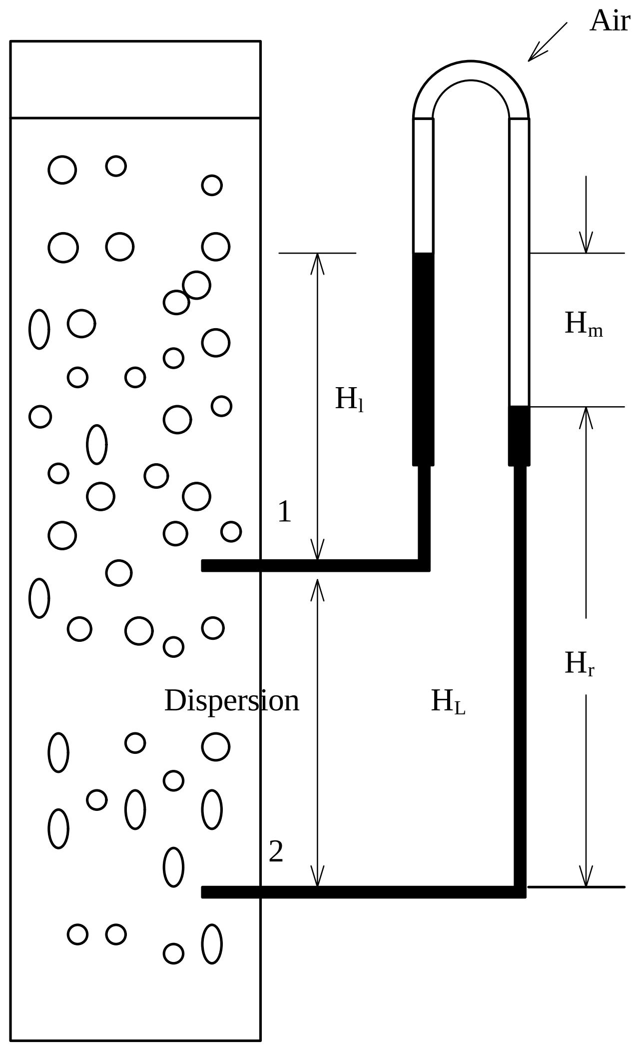

Figure A-2 The manometer Setup for Local Mean Gas Holdup Measurement