*Journal of Industrial Technology 9 (1), 2000, 55-61*

# GAS HOLDUP IN GAS-LIQUID OSCILLATORY FLOW IN A BAFFLED TUBE

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***RINGKASAN:*** *Gas tertahan telah di kaji di dalam aliran berayun gas-cecair di dalam turus sesekat. Kesan parameter-parameter seperti kadar alir gas, frekuensi ayunan, kadar alir cecair dan kelikatan ke atas gas tertahan telah dikaji. Hasil yang di perolehi dari kajian ini menunjukkan gas tertahan meningkat dengan peningkatan kadar alir gas dan frekuensi ayunan. Kadar alir cecair pula didapati tidak mempengaruhi gas tertahan. Walaubagaimanapun gas tertahan menurun dengan peningkatan kelikatan cecair.*

**ABSTRACT:** An experimental investigation of gas holdup in a gas-liquid oscillatory flow was carried out in a baffled tube. The effects of gas flow rate, oscillation frequency, liquid flow rate and liquid viscosity on gas holdup were investigated. The gas holdup was found to increase with gas flow rate and oscillation rate, unaffected by liquid flow rate and decrease with liquid viscosity.

**KEYWORDS:** Baffled tube, gas holdup, mixing, oscillatory flow

## INTRODUCTION

Various types of gas liquid contacting devices have successfully been used in chemical and biochemical processes. Oscillatory flow in baffled columns has been reported in numerous publications as very promising for gas-liquid contacting (Hewgill *et al.,* 1993; Mackley, 1987 and Mackley, 1991). Liquid flow in a baffled tube responds non-linearly to oscillations producing at certain conditions, vortices at edges of baffles and consequently chaotic flow or oscillatory flow mixing in between baffles. Fluid mixing is enhanced in the space between baffles due to formation and disruption of these vortices. Oscillatory flow in a baffled tube can be characterised by the oscillatory Reynolds number, $Re_o$.

$$\mathrm{Re}_o = \frac{\rho \omega x_o D}{\mu} \tag{1}$$

Efficient mixing is obtained at $Re_o$ greater than 150 (Roberts and Mackley, 1995). Ni and Gough (1997) reported a modification on the definition of oscillatory Reynolds number to account for variation of inner diameter of baffle, $D_o$;

$$\mathrm{Re}_o = \frac{\rho \omega x_o D}{\mu}\left(\frac{D}{D_o}\right) \tag{2}$$

Another dimensionless number that is used to characterise oscillatory flow is the Strouhal number, St.

$$St = \frac{D_o}{\pi x_o} \tag{3}$$

St represents the ratio of orifice diameter to oscillation amplitude

This paper presents the results collected from gas holdup investigation of gas-liquid oscillatory flow in a baffled tube. Gas holdup is defined as the volume fraction occupied by the gas in a vessel. The definition of gas holdup is given in the following equation.

$$\varepsilon = \frac{V_g}{V_g + V_L} \tag{4}$$

## MATERIAL AND METHODS

A schematic diagram of the experimental apparatus is shown in Figure 1. The experiments were conducted in a glass column of 1335 mm height and 50 mm diameter. The column has 18 baffle plates made of stainless steel and connected to the driver by two vertical tie rods. The diameter of the baffle plate is 45 mm and each plate has a central hole of 13 mm diameter. The column is operated at a fixed amplitude of 20 mm.

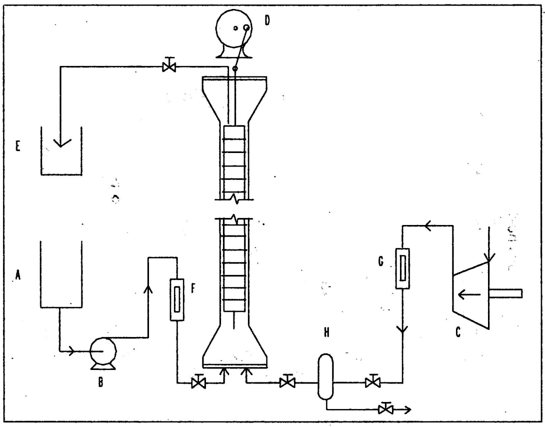


***Figure 1.*** *Schematic diagram of experimental apparatus*

Compressed air is used as the dispersed phase and water, CMC solutions, cooking oil and kerosene are used as the continuous phase. The continuous and dispersed phases flow concurrently upward through the baffle plates to the expanded top where the liquid is channelled to an overflow tank and air released to the atmosphere. The gas holdup is measured as the difference in liquid level under gassed and ungassed conditions. A summary of the range of the operating conditions is presented in Table 1.

**Table 1.** Range of operating conditions

| No. | Variable | Range |
|---|---|---|
| 1. | Liquid flow rate | 0.0017 - 0.0067 L/s |
| 2. | Gas flow rate | 0.083 - 0.5 L/s |
| 3. | Oscillation frequency | 0.5 - 3.0 rps |
| 4. | Liquid viscosity | 2.0 - 32.0 mPa-s |

## RESULTS AND DISCUSSION

The effect of gas flow rate on gas holdup is shown in Figure 2. The gas holdup increases with increasing gas flow rate. At higher gas flow rate, an increase in the number of gas bubbles was observed, thus occupying more volume in the column and displacing out the liquid, giving a greater gas holdup. This suggests that the effect of increasing gas rate is to reduce the residence time of the liquid phase. At higher gas flow rates, besides the formation of more bubbles, the increase in gas holdup is caused by a higher drag to gas flow through the plate holes. The effects of superficial velocity of water on gas holdup is illustrated in Figure 3. As anticipated, liquid flow rates has practically negligible effect on gas holdup.

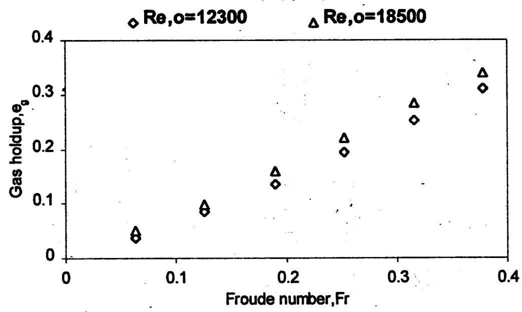


***Figure 2.*** *The effect of gas flow rate on gas holdup*

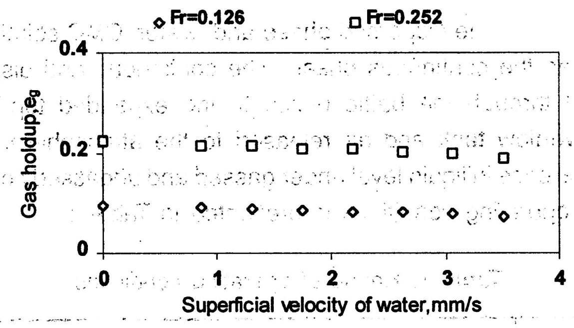


***Figure 3.*** *The effect of superficial velocity of water on gas holdup*

Figure 4 illustrates the effect of oscillation frequency on gas holdup. The gas holdup is found to increase with oscillation frequency. The gas bubbles that flow upward are broken into smaller size bubbles due to the oscillation of the baffle plates. Smaller bubbles have lower rising velocity and remain longer in the column. As a result greater gas holdup is observed.

Figure 5 shows that the gas holdup decreases with liquid viscosity. At higher viscosity, more stable gas bubbles are formed and greater energy is required to breakup the bubble into smaller size. Larger bubbles with higher rise velocity are formed in a liquid with higher viscosity. As a result less volume is occupied by the gas in the column and lower gas holdup value is observed for more viscous liquids.

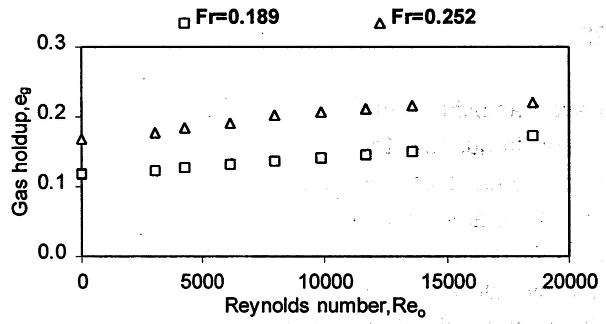


***Figure 4.*** *The effect of oscillation rate on gas holdup*

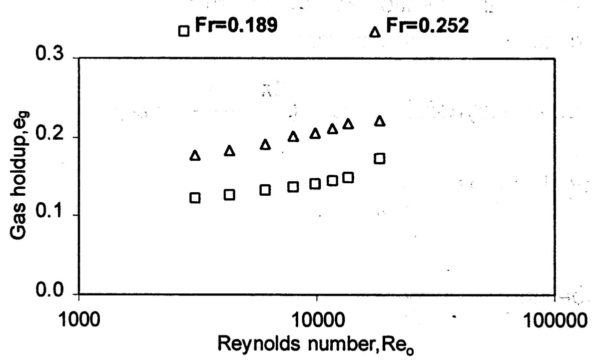


***Figure 5.*** *The effect of liquid viscosity on gas holdup*

## CONCLUSION

Gas holdup in gas-liquid oscillatory flow in a baffled tube was found to increase with gas flow rate and oscillation rate. The increase of gas holdup was mainly due to bubble size reduction as a result of turbulence, leading to lower rise velocity. Gas holdup was also found to decrease with liquid viscosity. At higher viscosity, more stable larger bubbles are formed which has higher rise velocity. The gas holdup in gas-liquid oscillatory flow is unaffected by liquid velocity.

## NOMENCLATURE

| | |
|---|---|
| A | Oscillation amplitude, mm |
| f | Oscillation frequency, 1/s |
| D | Column internal diameter, mm |
| $D_p$ | Baffle outer diameter, mm |
| $D_o$ | Baffle inner diameter, mm |
| h | Column overall height, mm |
| g | Gravitational acceleration, mm/s$^2$ |
| $Q_g$ | Gas flow rate, l/s |
| $Q_L$ | Water flow rate, l/s |
| $U_g$ | Superficial gas velocity, mm/s |
| H | Height of active section of column, mm |
| $x_o$ | Centre to pick amplitude, mm |
| $Re_o$ | Oscillatory Reynolds number $\left(\frac{2\pi f x_o \rho D}{\mu}(D/D_o)\right)$ |
| St | Strouhal number $\left(\frac{D_o}{\pi x_o}\right)$ |
| Fr | Froude number $\left(\frac{U_g}{(Dg)^{1/2}}\right)$ |
| ρ | Liquid density, kg/m$^3$ |
| ε | Gas holdup |
| ω | Angular frequency (2πf), rad./s |
| μ | Liquid viscosity, mPa-s |

## ACKNOWLEDGEMENT

The authors would like to thank the Ministry of Science, Technology and the Environment and Universiti Kebangsaan Malaysia for funding this research.

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