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Absorption Characteristics of Ammonia-Water System in the Cylindrical Tube Absorber

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Abstract−Experimental analysis was performed in a cylindrical tube absorber which is considered to be suitable for the bubble mode. Characteristics such as concentration, temperature, and pressure were measured and they reflected the condition of absorber well. The variation of characteristics was conspicuous near the inlet region of the ammonia gas. The ammonia gas and the solution flowed cocurrently and countercurrently and the results were compared.

Key words: Absorption System, Ammonia-water, Cylindrical Tube Absorber, Mass Transfer, Gas Holdup

INTRODUCTION

Due to the ozone depletion problem associated with the use of CFC and HCFC refrigerants, absorption heat pumps and refrigeration systems have gained increasing interest in recent years. More and more, they are regarded not only as environmentally friendly alternatives to CFC based systems, but also as energy efficient heating and cooling technology [Herald et al., 1996].

The absorber, which is a major component in absorption refrigeration systems, greatly affects the overall system performance. Bubble mode has been recommended to enhance heat and mass transfer performance in ammonia-water absorption systems [Christensen et al., 1996]. Falling film modes provide relatively high heat transfer coefficients and are stable during operation. However, falling film modes have wettability problems and need good liquid distributors at the inlet of the liquid flow. Bubble modes provide not only high heat transfer coefficients but also good wettability and mixing between the liquid and the vapor. However, the bubble modes require vapor distribution. Generally, vapor distribution is easier than liquid distribution. Recently, bubble modes were recommended strongly for ammonia-water absorption systems because the low wettability in the falling film modes is critical to the performance of the system [Christensen et al., 1996; Han et al., 1985].

Over the last ten years, ammonia-water bubble mode has been extensively investigated both numerically and analytically [Herbine and Perez-Blanco, 1995; Kang et al., 1997; Yu et al., 2001; Sung, et al., 2000; Tsutsumi et al., 1999; Jang et al., 1999; Hwang et al., 1999; Lim et al., 1999; Noda et al., 2000]. However, few papers have been found concerning the heat and mass transfer analysis of the bubble absorber. Merrill et al. tested three compact bubble absorbers developed for generator-absorber heat exchange absorption cycles (GAX) [Merrill et al., 1998]. Their results show that enhancement techniques are effective in reducing absorber length and increased tube diameters may increase absorber performance.

In the present study, the characteristics of the bubble mode in the cylindrical tube absorber were studied by experiment. The results can be used as fundamental data to design the optimal cylindrical tube absorber.

EXPERIMENT

The schematic diagram of the cylindrical absorber for the bubble mode studies is given in Fig. 1. The cylindrical column is 1 m in height and 0.03 m in diameter. Five sample ports are installed at

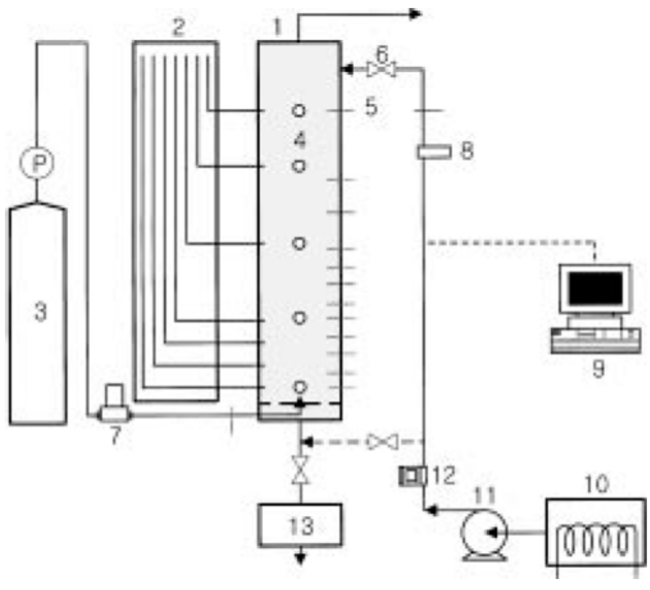

Fig. 1. Experimental absorption system for cylindrical tube absorber.

1. Absorber	8. Cartridge heater
2. Manometer	9. Data acquisition system
3. NH_3 bomb	10. Heating tank
4. Sampling port	11. Solution pump
5. Thermocouple	12. Flow meter
6. Valve	13. Neutralization tank
7. Mass flow controller	

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0.2 m intervals axially and twelve thermocouples are set to measure the behavior of mass transfer and the thermal state of inner experimental column. Also, seven manometers are equipped to measure the pressure profile. The cylindrical column made of acrylic resin is transparent, so the state of bubble flow can be observed. In the experiments, flow rate of ammonia gas was 1-9 L/min and the inlet liquid concentration was selected as 20-30 weight%. Ammonia gas flowed upward, while ammonia solution flowed both upward and downward.

ANALYSIS

The absorption rate is expressed as the following equations by using the overall mass transfer coefficients, K [McCabe et al., 1993; Kim et al., 2001; Choi, 2001; Tsutsumi et al., 1999; Park, 1999].

$$m_{abs} = K\rho A_{abs}\Delta x_{lm,l} \tag{1}$$

$$\Delta x_{lm,l} = \frac{[x_{in}^{eq} - x_{in}] - [x_{out}^{eq} - x_{out}]}{\ln[(x_{in}^{eq} - x_{in})/(x_{out}^{eq} - x_{out})]} \tag{2}$$

The physical properties needed to determine the coefficients were referred to literature [Reid et al., 1986; KDB].

Gas holdup, which is defined as the volume ratio of gas phase in the binary mixture, is an important parameter for characterizing the absorption performance of the absorber. The gas holdup influences the interfacial area between the liquid and the gas and thus determines the mass transfer rates during the absorption process [Clift et al., 1978; Fukuji, 1999; Yamashita et al., 1999; Choi et al., 1992; Mok et al., 1990; Ide et al., 1999; Kim et al., 1990; Park et al., 2000]. The gas holdup can be obtained indirectly from the pressure variation:

$$P_0 - P_1 = \rho_1 g Z_1 = \rho_l g Z_1 \tag{3}$$

$$P_0 - P_2 = \rho_2 g Z_2 = \varepsilon_l \rho_l g Z_2 \tag{4}$$

where subscript 0 is standard position, 1 is initial value when only solution flowed, and 2 is final value when the gas flowed with the solution.

Dividing Eq. (3) by Eq. (4) and arranging yields

$$\varepsilon_g = \frac{\Delta P}{P_1 - P_0} \tag{5}$$

RESULTS AND DISCUSSION

1. Effect of Gas Flow Rate on Concentration Profile

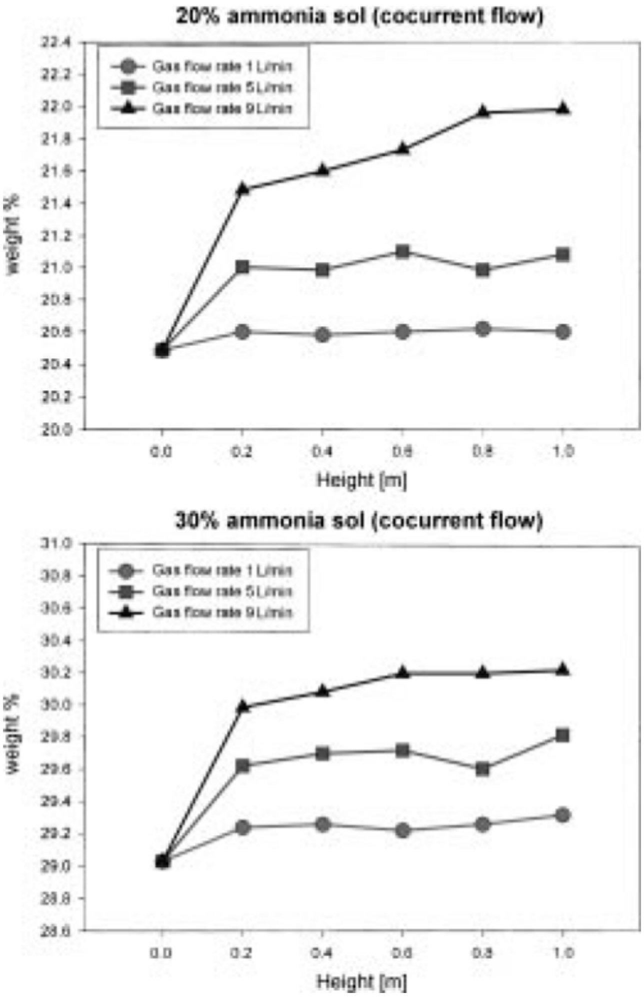

Fig. 2. The effect of gas flow rate on concentration profile (cocurrent).

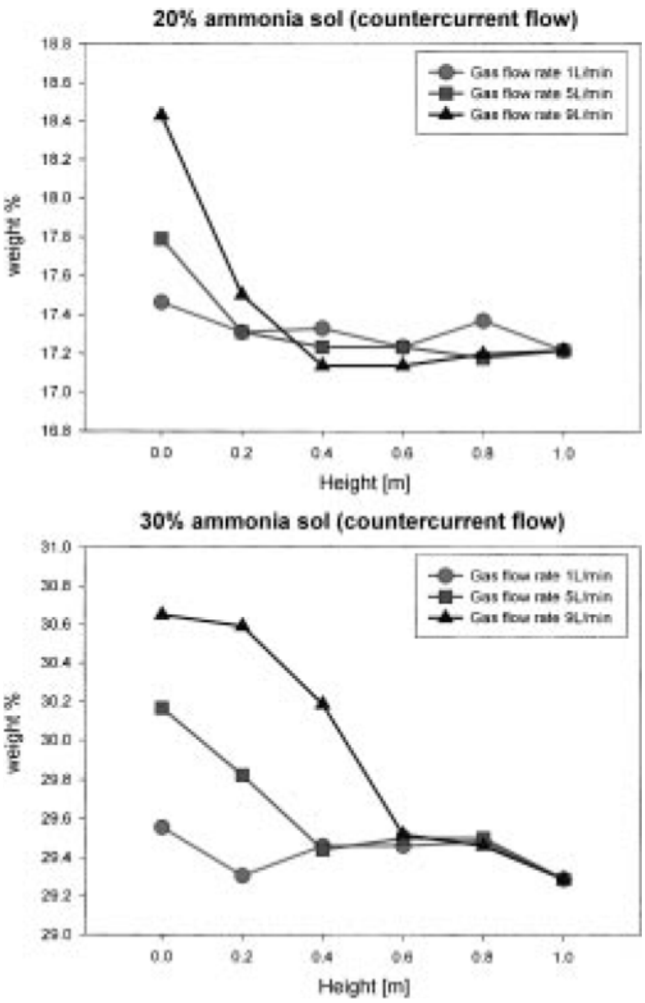

Fig. 3. The effect of gas flow rate on concentration profile (countercurrent).

Fig. 2 shows the effect of the gas flow rate on the concentration profile when the gas and the solution flows are cocurrent. At low gas flow rate, the concentration of solution is almost same above 0.2 m. At high gas flow rate, the concentration of solution increases with increasing height of absorber. Most of the ammonia gas was absorbed immediately after injection at low gas flow rate. However, as gas flow rate increased, the remaining gas which was not absorbed increased.

Fig. 3 shows the effect of the gas flow rate on the concentration profile when the gas and the solution flows are countercurrent. Contrary to cocurrent flow, the concentration of solution increases with decreasing height of absorber. Similar to cocurrent flow, the concentration of ammonia is almost same above 0.2 m at low gas flow rate. At high gas flow rate, compared to low gas flow rate, the un-absorbed gas increased so that the length of absorber which was needed to absorb gas was increased. It is because as the amount of input gas increased, the capacity of solution that can absorb the gas decreased. The un-absorbed gas was gradually absorbed as it flowed upward. As can be seen in Fig. 3, the un-absorbed gas was more in the 30% ammonia solution than in the 20% ammonia solution.

2. Effect of Gas Flow Rate on Temperature Profile

Fig. 4 shows the effect of the gas flow rate on the temperature profile when the gas and the solution flows are cocurrent. The temperature rose rapidly as soon as the gas flowed in, and then it increased a little or remained constant.

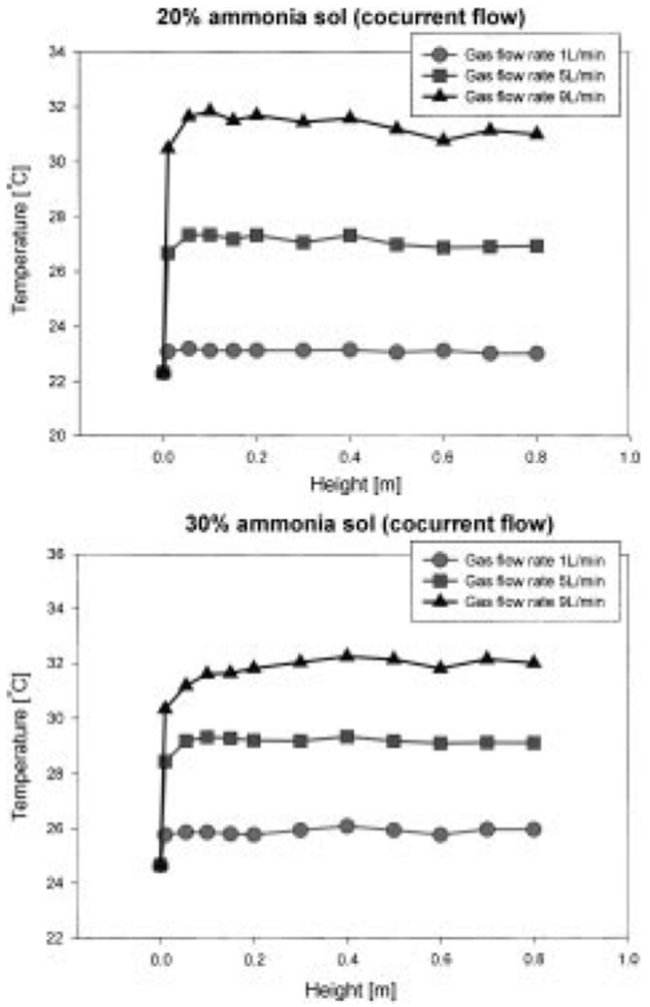

Fig. 4. The effect of gas flow rate on temperature profile (cocurrent).

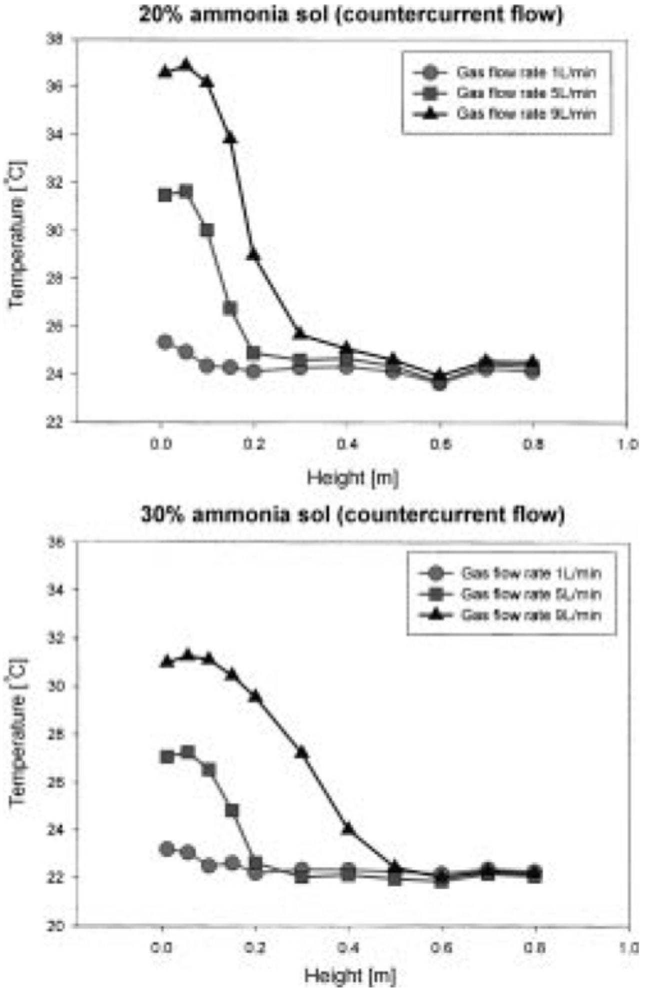

Fig. 5. The effect of gas flow rate on temperature profile (countercurrent).

Fig. 5 shows the effect of the gas flow rate on the temperature profile when the gas and the solution flows are countercurrent. The temperature of solution was practically constant due to the solution flow: near the top of absorber. It increased from the middle of the absorber to the bottom of the absorber where the gas flowed in. The region where the temperature variation occurred was larger at the higher gas flow rate and in the solution of higher concentration. It means that the ammonia gas is not absorbed well on the condition of high gas flow rate and high concentration solution.

3. Effect of Gas Flow Rate on Pressure Variation Profile and Gas Holdup

Fig. 6 and Fig. 7 show the effect of the gas flow rate on the profile of gas holdup, ε_g, when the gas and the solution flows are cocurrent and countercurrent, respectively. The gas holdup was obtained from the measured pressure profile. The gas holdup decreased with the increasing length of the absorber, and had the similar decreasing trend with the pressure variation. The gas holdup was higher on the condition of high gas flow rate and high concentration solution. The absorber can be divided into two regions by the slope of

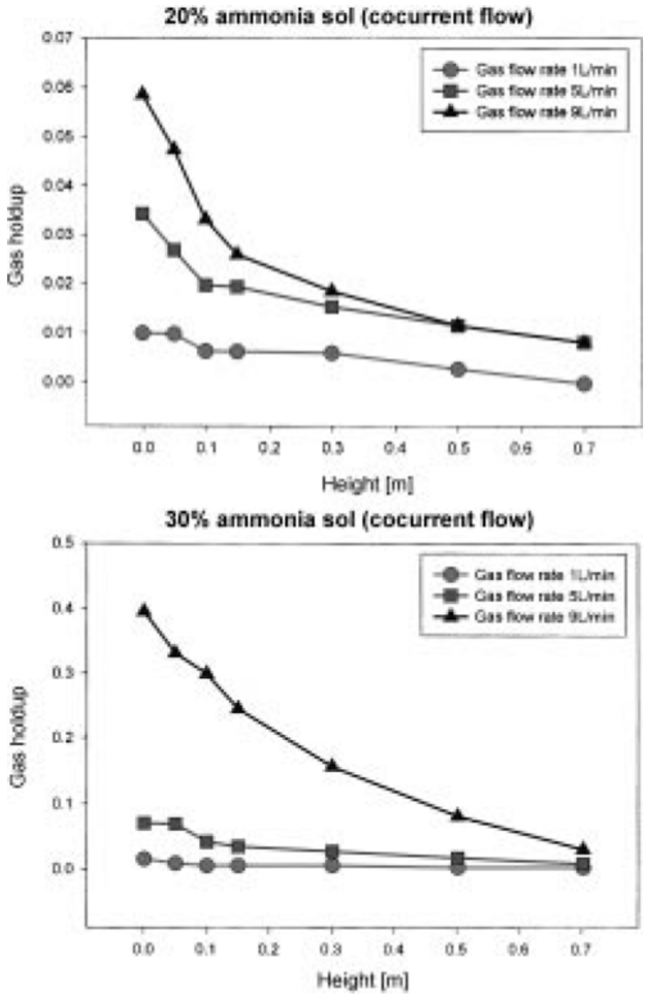

Fig. 6. The effect of gas flow rate on gas holdup profile (cocurrent).

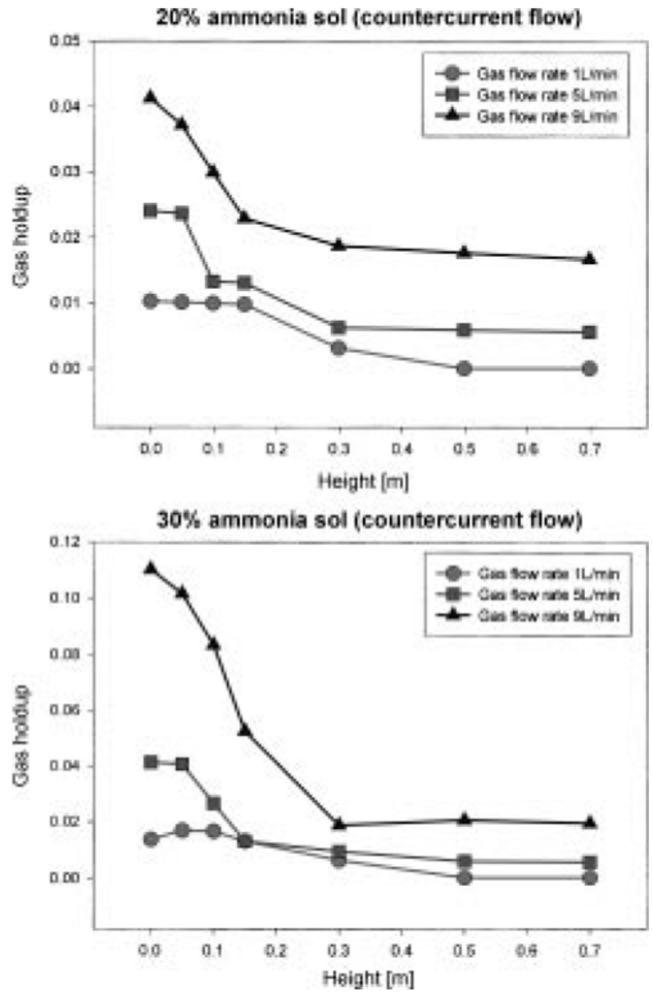

Fig. 7. The effect of gas flow rate on gas holdup profile (countercurrent).

gas holdup. The slope is steep in the lower part of the absorber and it is gentle in the higher part. It is because the ammonia gas remained in the lower part and the pressure varied sharply as the gas was absorbed. After the gas was absorbed, the pressure variation became flat. Pressure variation means the difference between the pressure when only the solution flowed and the pressure when the gas flowed together. The region where the ammonia gas was mainly absorbed could be known by the pressure variation or the gas holdup.

Optimum height of absorber can be obtained by analyzing concentration, temperature and gas holdup. It is approximately 0.4 m and 0.6 m, when the gas flow rate is 9 L/min and the concentration of input solution is 20% and 30%, respectively.

4. Comparison of Mass Transfer Coefficients

Table 1. Results of mass transfer coefficient

		Mass transfer coefficient at 20% input solution [m^3/min]		
Gas flow rate [L/min]		1	5	9
Plate type absorber	Falling film mode	$1.185 \cdot 10^{-3}$	$1.942 \cdot 10^{-2}$	$3.815 \cdot 10^{-2}$
	Bubble mode	$7.131 \cdot 10^{-3}$	$2.885 \cdot 10^{-2}$	$5.760 \cdot 10^{-2}$
Cylindrical tube absorber	Cocurrent flow	$1.627 \cdot 10^{-2}$	$3.018 \cdot 10^{-2}$	$8.728 \cdot 10^{-2}$
	Countercurrent flow	$1.564 \cdot 10^{-2}$	$3.275 \cdot 10^{-2}$	$5.910 \cdot 10^{-2}$
		Mass transfer coefficient at 30% input solution [m^3/min]		
Gas flow rate [L/min]		1	5	9
Plate type absorber	Falling film mode	$9.257 \cdot 10^{-3}$	$4.712 \cdot 10^{-2}$	$9.334 \cdot 10^{-2}$
	Bubble mode	$4.110 \cdot 10^{-2}$	$8.664 \cdot 10^{-2}$	$1.655 \cdot 10^{-1}$
Cylindrical tube absorber	Cocurrent flow	$1.839 \cdot 10^{-1}$	$2.234 \cdot 10^{-1}$	$2.581 \cdot 10^{-1}$
	Countercurrent flow	$7.468 \cdot 10^{-2}$	$1.546 \cdot 10^{-1}$	$2.228 \cdot 10^{-1}$

Table 1 summarizes the results of mass transfer coefficient when the concentration of input solution was 20% and 30%. The results of plate type absorber are from the former study [Lee et al., 2000]. The mode of cylindrical tube absorber was the bubble mode both in the cocurrent and in the countercurrent flow. This table shows that the mass transfer coefficients in the bubble mode were greater than those in the falling film mode. In particular, the mass transfer performance in the cylindrical tube absorber was excellent. The results both in the cocurrent and in the countercurrent flow were much the same compared with the results in the plate type absorber.

CONCLUSIONS

For the further understanding of bubble mode, the characteristics of bubble mode in the cylindrical tube were studied. The absorption and complex flow behavior in multiphase flow systems were interpreted by analyzing state variables such as concentration, temperature, and gas holdup. The following conclusions were drawn from the present experimental studies:

1. As the gas flow rate increased, the concentration, temperature and gas holdup of solution increased.
2. When the gas and the solution were cocurrent, the concentration and temperature of solution increased with increasing height of absorber. However, when countercurrent, the concentration and temperature of solution increased with decreasing height of absorber.
3. For the gas holdup, in the lower part of the absorber the slope was steep and in the higher part the slope was gentle.
4. Optimum height of absorber can be obtained to analyze concentration, temperature and gas holdup in the absorber.

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NOMENCLATURE

A : area [m^2]
g : gravitational acceleration [m/s^2]
K : overall mass transfer coefficient [m/min]
m : mass flow rate [kg/min]
P : pressure [mmHg]
x : concentration [weight %]
Z : height [m]

Greek Letters

ρ : density [kg/m^3]
ε : holdup

Superscript

eq : equilibrium

Subscripts

abs : absorption
g : gas
in : input
l : liquid
lm : log mean
out : output

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