Recovery of Ammonia Solutions From Fertilizer Industry Wastewater by Air Stripping Using Jet Bubble Column

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ABSTRACT

Jet bubble column is one of the methods that can be applied to reduce levels of ammonia solutions from a fertilizer industry wastewater. This study intends to evaluate the entrainment of gas volumetric flow rate, mass transfer, and ammonia removal efficiency. Process variables studied include effluent concentration (90-300 mg/L), the liquid volumetric flow rate (10-50 L/min), and nozzle diameter (8-12.7 mm). It was found that the liquid volumetric flow rate and nozzle diameter affects the volumetric rate of gas entrainment. The volumetric flow rate of gas entrainment can result in a significant effect on ammonia removal, while the ammonia concentration and volumetric flow rate of the liquid did not produce significant effects on ammonia removal. The overall volumetric mass transfer coefficients (K_La) have been calculated from obtained model and it was determined that increasing volumetric flow rate of gas entrainment have a very significant effect on K_La.

Keyword: jet bubble column, air entrainment, air stripping

1. INTRODUCTION

Ammonia conducted in natural or industrial water waste will be a big problem toward environmental life. When it is wasted by neglecting the waste management process, even a small number of ammonia does give a negative impact to the environmental life. This is due to the waste containing ammonia is hard to be processed biologically. The ammonia processing contained in waste water can be conducted physically, chemically or combination of some methods such as adsorption, chemical precipitation, filtration membrane, reverse osmosis, ion transfer, air stripping, chlorination breakpoint and biological nitrification [1]. A removal attempt of ammonia content in wastewater containing high level of pH by using aeration process is one common process to use. This operation is conducted in stripping tower by using large amount of air into it. A stripping tower is fulfilled with materials to enlarge its contact surface. However, it also has a weakness, that is, deposit of iron and magnesium oxide occurring to the materials. This deposit will cause the decrease of mass transfer. A low temperature of the process occurring in the stripping tower also results lower removal efficiency. Temperature, pH, air flow, liquid volumetric flow rate, and reactor configuration is one central parameter influencing the efficiency of ammonia removal can be increased by increasing the temperature and air flow rate [1]. In addition to the stripping tower, the process of ammonia removal with air stripping can also be conducted through aerocyclone reactor [2] and jet loop reactor [1].

Table.1. Attributes of common G/L contactors [6]

Contactor	$k_L.a$, 1/s	a, m^2/m^3	ε_G	V_R m^3	ε_V kW/m^3
Bubble column excluding jet (loop)	0.005-0.01	~20	< 0.2	0.002-300	0.01-1
Spray column	0.0007-0.015	10-100	> 0.8	-	-
Packed column, countercurrent	0.005-0.02	~200	> 0.95	0.005-300	0.01-0.2
Plate column	0.01-0.05	100-400	> 0.8	0.005-300	0.01-0.2
Pipe/tube	0.01-0.7	50-2,000	0.05-0.95	-	0.1-100
Mechanically agitated tank	0.02-2.2	~200	< 0.1	0.002-100	0.5-4
Jet (loop)	0.01-2.2	200-2,000	< 0.5	0.02-100	0.8-90
Tubular/venturi ejector and motionless mixer	0.1-3	1,000-7,000	~0.5	< 10	10-700

Air stripping process might need a low cost and simple equipment design which is commonly used for ammonia removal from wastewater, and the high level of ammonia removal can be reached through this process [2]. The process of ammonia removal using jet bubble column is very efficient for type of contact equipment in between gas and liquid phase. This is shown in coefficient value of mass transfer which is reached. For jet ejector, the coefficient value of mass transfer is 0.1-3/second which goes beyond the bubble column (0.05-0.01/second) and the stirring tank (0.02-2.2/second). The advantages of jet bubble column are in its simple design, practical in use and maintenance, small column need, small size of dispersed bubble diameter, specific large space of phase, gaining a very big coefficient of mass transfer compared to another type of conventional bubble [3,4,5,6]. Besides, the compound formed by phase of gas-liquid which is caused by liquid collision hitting stagnant liquid inside the column, the collision will form a horn-like hole by which the air is absorbed and trapped in the slit of the hole. The collision allows to form eddy currents [7,8], thus a stirrer is not necessarily needed. The function of this eddy currents depends on diameter of downcomer pipe that will be designed. In Table 1, it is shown a typical comparison of k_La, ε_G, V_R (the volume of column) and ε_V (Energy released per volume unit) in any kind of gas-liquid equipment [6].

The form of jet (loop) has a coefficient of transfer in the range of rentang 0,01-2,2 s^{-1}, specific surface area between phases (a) 200-2000 m^2/m^3, *holdup* of gas phase < 0,5, volume of column (V_R) is at range of 0,02-100 m^3, and energy released In per volume unit (ε_V) is at the range of 10-700 kW/m^3. While the range of coefficient value of mass transfer for tubular and jet type has a very high value compared to another type of equipment. If the value of k_La at the jet type equipment then it will be more excellent than the tubular type. This 'superiority' has a very significant difference. Moreover, if it is compared to jet bubble column without jet loop, then the value gap between the two jet equipment is too far particularly in the coefficient value of mass transfer or its in-between phase area [3,4,5]. Therefore, in the essence, this study will provide a combination of jet (loop) and bubble column design with new phenomena/ concept called as jet bubble column.

This study is divided into some sub-studies of the volumetric flow rate of gas entrainment, the overall volumetric mass transfer coefficients (K_La), and ammonia removal efficiency.

2. MATERIAL AND METHODS

2.1 Experiments

Chemical materials used in stripper column with the jet bubble is fertilizer industry wastewater, PIM Ltd. The scheme of equipment series is shown in Fig. 1. The jet bubble column consists of column (outer tube) and downcomer (inner tube) made from acrylic cylinder having diameter of each 100cm and 36cm with 2mm thickness and 80cm height. The upper part of column is linked with acrylic box with size of 50cm x 20cm. Firstly, the wastewater is filled into the column with the volume of 12L, the wastewater is then flowed by using a pump. Liquid circulation rate is adjusted with the setting of valve-1. The gas entrainment occurs due to some liquid coming out from nozzle in a jet speed which hits the stagnant liquid contained in the column. The volumetric flow rate of gas being adsorbed into the column (Q_g) is measured by using flowmeter. Sample were taken from the outlet acrylic box of the jet bubble column followed by ammonia through Nessler Reagent ($HgCl_2$-KI-KOH Spectrophomety at 420 nm according to the standards of PIM Ltd).

Variable of process condition is conducted in variation, such as a effluent concentration (C_{l0}) at 90-300 mg/L, nozzle diameter (D_n) at 8mm, 10mm, 12mm, dan 12.7 mm, and the liquid volumetric flow rate (Q_l).

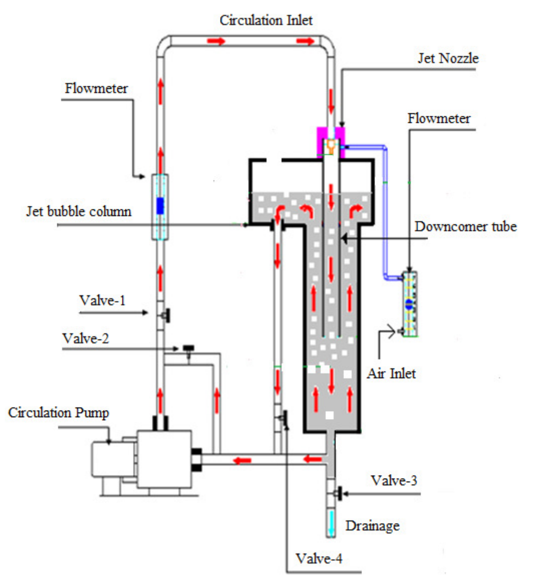

Fig. 1. The flow diagram of the experimental setup

2.2. Calculation of mass transfer coeficient and efficiency of ammonia removal.

For the air stripping system, mass transfer of volatile compound A in the water occurring in unit of batch stripping has been derived into an equation [1,2]. The equation can be seen as follows:

$$-\ln\left(\frac{C_{l_t}}{C_{l_0}}\right) = \frac{Q_g He}{V_l}\left(1-\exp\left(-\frac{K_L a V_l}{He Q_g}\right)\right)t \qquad (1)$$

Where C_{l0} and C_{lt} are the effluent concentrations at the beginning and at any time (mg/L). He is the dimensionless Henry's constant; K_La is the overall volumetric mass transfer coefficient based on liquid phases (min^{-1}); V_l is the total volume of liquid (L) Q_g is the volumetric flow rate of gas entrainment; and t is the stripping time.

When $K_L aV_l / HeQ_g << 1$, then the Eq. (1) will be:

$$-\ln\left(\frac{C_{i_t}}{C_{i_0}}\right) = K_L a.t \qquad (2)$$

To calculate the efficiency of ammonia removal can use the following equation:

$$Efficiency\,(\%) = \frac{C_{i_0} - C_{i_t}}{C_{i_0}} \qquad (3)$$

3. RESULTS

3.1. Volumetric flow rate of gas entrainment

Gas entrainment is an absorbed gas coming from momentum energy of liquid jet. The data of gas flow absorbed is gained from flowmeter measuring equipment.

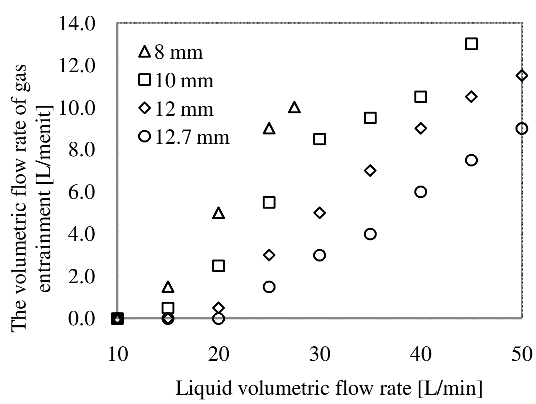

Fig. 2. Effect of liquid volumetric flow rate toward any size of nozzle diameter

From Fig. 2. it is gained increases slightly with increasing the liquid volumetric flow rate. In contrast, the smaller the size of nozzle diameter will result the higher volumetric flow rate of gas entrainment. This is caused by a bigger momentum energy inflowing of which the result of the increase of the liquid volumetric flow rate and the size of nozzle diameter which is getting smaller. Consequently, it results the depth of penetration bigger in the downcomer column. In addition, it can increase the rotation flow get more intensive which then makes the gas entrainment into downcomer column bigger [4].

3.2. Effect of initial effluent concentration

The effect of initial effluent concentration on efficiency of ammonia removal is shown in Fig. 3. Initial concentration changing in the range of 105-195 mg/L. Nozzle diameter, liquid volumetric flow rate, volumetric rate of gas entrainment, and temperature where kept constant at 12 mm. 50L/min, 11.5 L/min and 30^{o}C. The mass transfer coefficients under different initial effluent concentration could be obtained using Eq. (2), i.e. plotting $-\ln\left(C_{l_t}/C_{l_0}\right)$ vs. stripping time (t min) and making a liniear regression between $-\ln\left(C_{l_t}/C_{l_0}\right)$ and stripping time (t min), could get the mass transfer coefficients (K_La) shown in Fig. 4.

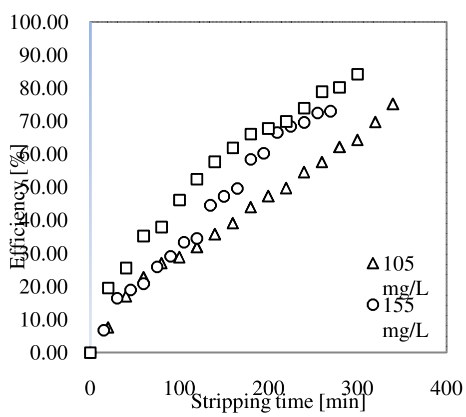

Fig. 3. Effect of initial effluent concentration on the efficiency of ammonia removal. The condition of experiment is at D_n=12mm, Q_l=50 L/min, Q_g=11.5 L/min, dan T = 30^{o}C

It was observed that K_La is not significantly effected by initial effluent concentration, i.e. while initial effluent concentration varied from 105-195 mg/L, K_La varied from 0.004-0.006 min^{-1}. This can be explained that the ammonia removal operation is mainly controlled by diffusion through gas film. The higher the concentration, the bigger the air stripping rate. Increasing ammonia concentration can increase the driving force of mass transfer, leading to a higher rate of ammonia removal [2]. Similar result can be observed in the literatur [1,2].

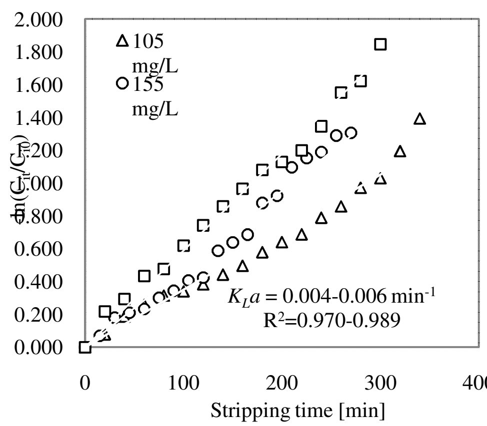

Fig. 4. Effect of initial effluent concentration on K_La. The condition of experiment is at D_n=12mm, Q_l=50 L/min, Q_g=11.5 L/min, dan T=30^{o}C

3.3. Effect of liquid volumetric flow rate

To determine the effect of liquid volumetric flow rate toward the efficiency of ammonia removal, in this experiment it was conducted various liquid volumetric flow rate (25, 35, 40 dan 50 L/min) and nozzle diameter (8, 10, 12, 12.7 mm) by keeping the condition of temperature, initial effluent concentration, volumetric flow rate of gas entrainment, and pH was constant at 30^{o}C, 180 mg/L, 11.5 L/min, and 11.37. The effect of liquid volumetric flow rate on the efficiency of ammonia removal and K_La is shown in Fig. 5 and 6. The two figures show that the effect of increase of liquid volumetric flow rate has little effect on ammonia removal efficiency, and did not increase of the mass transfer coefficient. This illustrates that the increase of the liquid volumetric flow rate cannot obviously increase the contact area of the two phases and reduce the mass transfer resistance [2].

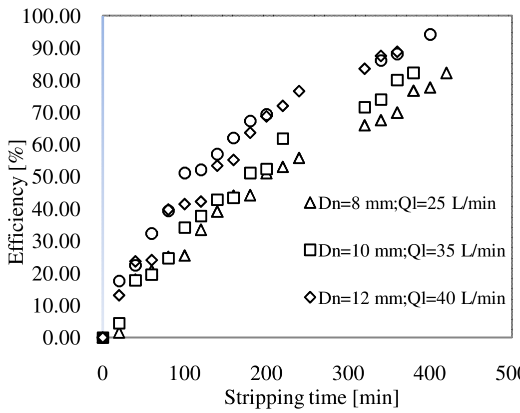

Fig. 5. Effect of liquid volumetric flow rate on air stripping of ammonia. The condition of experiment is at C_{l0}=180 mg/L, Q_g=11,5 L/min, pH=11.37, dan T=30^{o}C

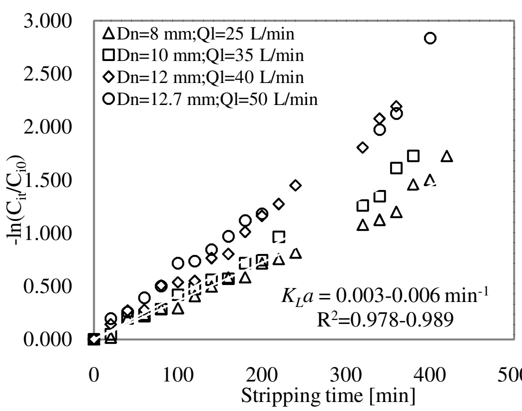

Fig. 6. Effect of liquid volumetric flow rate on the mass transfer coefficient of ammonia removal. The condition of experiment is at C_{l0}=180 mg/L, Q_g=11.5 L/min, dan pH=11.37, dan T=30^{o}C.

3.4. Effect of volumetric flow rate of gas entrainment

The effect of volumeric flow rate of gas entrainment, Q_g,, on stripping air efficiency and on the volumetric mass transfer coefficient of ammonia removal is shown in Fig. 7 and 8. In this experiment, it is conducted in various volumetric flow rate of gas entrainment (6, 9, 10.5 L/min) and nozzle diameter (10, 12, 12.7 mm) by keeping the initial effluent concentration, liquid volumetric flow rate, temperature and pH constant at 92 mg/L, 40 L/min, 30^{o}C, and 10,45. From Fig. 7 and 8, it is found that efficiency of ammonia removal and K_La is getting higher along with the bigger volumetric flow rate of gas entrainment and the smaller the nozzle diameter. K_La increased with increasing volumetric flow rate of gas entrainment.

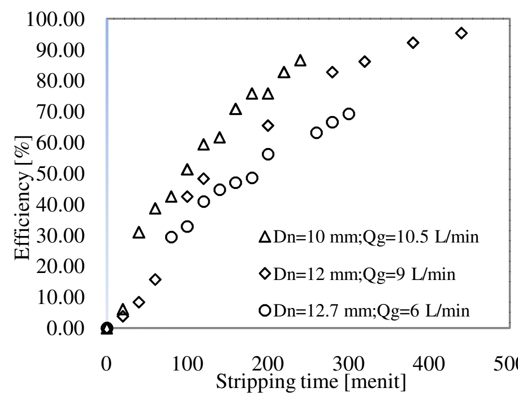

Fig. 7. Effect of volumetric flow rate of gas entrainment on the efficiency of ammonia removal. The condition of experiment is at C_{l0} = 91.6 mg/L, Q_l = 40L/min, pH = 10.5, and T = 30^{o}C.

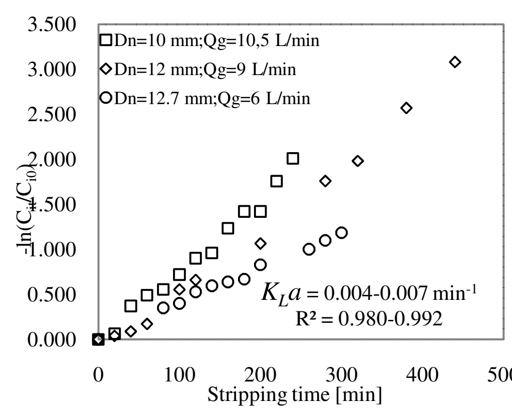

Fig. 8. Effect of volumetric flow rate of gas entrainment on mass transfer coefficient of ammonia removal. The condition of experiment is at C_{l0}=91.6 mg/L, Q_l=40 L/min, pH=10.5, and T=30^{o}C.

K_La value shown in Fig. 8 vary in 0.004-0.007 min^{-1}. This is due to the smaller nozzle diameter with also increases the volumetric flow rate of gas entrainment producees decrease the size of gas bubbles dispersed in the liquid of JBC. It is show and increases gas holdup [1,2]. This case causes to increased gas entrainment and gas-liquid interfacial area, thus increasing efficiency of ammonia removal as well as the K_La.

ammonia in an aqueous solution, ensuring the air stripping of ammonia [2]. The value of mass transfer coefficient gained by adding NaOH (pH=11.75) into waste water in 0.009 min^{-1}, efficiency of amonia removal is 95% with stripping time of 4 hours 30 minutes. While the coefficient value of mass transfer obtained

Table.2. The comparison of air comsumption and K_La of the air stripping in different

Equipments	Experimental conditions V_L (L)	Q_G (L/min)	T (°C)	Air consumption (L/min)/Liquid (L)	K_La (h^{-1})	Reference
Jet Loop Reactor	9	50	20	5.5	0.63	Degermency *et al.* 2012
Stirer tank	0.05	4.8	16	96.0	0.48	Basakcilardan *et al.*2007 in Degermency *et al.* 2012
Packed tower	1000	25.000	15	25.0	0.42	Le *et al.* 2006 in Degermency *et al.* 2012
Aerocyclone	10	66	15	6.6	0.78	Quan *et al.*2009
Jet Bubble Column	12	10.5	30	0.875	0.57	This work

3.5. Effect of pH

The effect of increasing NaOH into wastewater up to pH standard of 11.75 conducted by keeping constant nozzle diameter, initial effluent concentration, liquid volumetric flow rate and temperature at 10 mm, 243 mg/L, 40 L/min, dan 30°C is shown in Fig. 9 and 10.

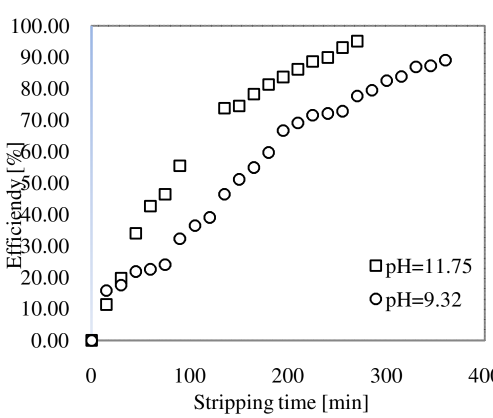

Fig. 9. Effect of pH increase on the efficiency of ammonia removal. The condition of experiment is at Dn=10mm, C_{l0}=243 mg/L, Q_l=40L/min, dan T=30°C.

In those two figures, the pH (11-12) which gets higher lead to a higher efficiency of ammonia removal and mass transfer coeficient. This is caused when the pH is 11-12, the ammonium nitrogen is almost all converted into molecular

without addition of NaOH (pH=9.32) is 0.006, efficiency of ammonia removal is 94.8% with stripping time of 7 hours. This is still far beyond to compare with traditional stripping tank which needs 24 hours. It is getting smaller that the large of contact between gas-liquid phase and holdip phase of gas incresing [1].

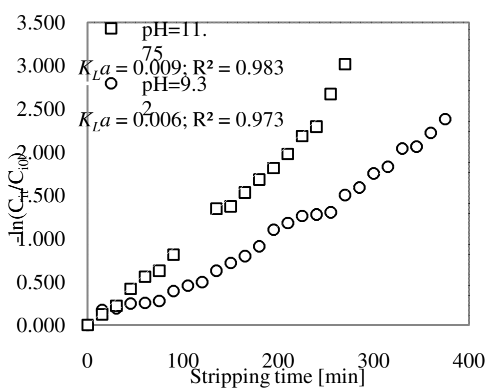

Fig. 10. Effect of pH increase on mass transfer coefficient of ammonia removal. The condition of experiment is at Dn=10mm, C_{l0}=243 mg/L, Q_l=40L/min, dan T=30°C.

4. CONCLUSION

3.6. Comparison between this study and stirrer tank, packed tower, aerocyclone reactor and JLR.

Table 2 shows the comparison of mass transfer coefficient of this study and other types of contact equipment. It shows that the coefficient of mass transfer of jet bubble column is higher than that of stirrer tank and packed tower. The coefficient value of jet bubble column mass transfer is lower than one of jet loop reactor and aeorocylone, however the consumption of air per liquid that is needed by jet bubble column is much smaller than the two equipment need. it means that the energy consumption needed by jet bubble column is much lowerer than that of jet loop reactor or aerocyclone.

The following conclusions from the present study can be drawn :

- Jet bubble column which is the present paper design is worth operating in terms of mass transfer aspect.
- The volumetric rate of gas entrainment (Q_g) will get bigger positively correlating with the bigger liquid volumetric flow rate (Q_l) and in contrast result a smaller nozzle diameter (D_n).
- It was founded from the result that the most effective parameters on the eficiency of amonia removal is the volumetric rate of gas entrainment. Liquid volumetric flow rate and initial effluent concentration of ammonia were found to be less effective on the efficiency.
- The coefficient value of mass transfer (K_La) will get higher along with the higher volumetric rate of gas entrainment (Q_g).

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REFERENCES

[1] Degermency N, Nuri AO, Yildiz E. 2012. Ammonia Removal By Air Stripping In Semi-Batch Jet Loop Reactor. *J. Ind. Eng. Chem.*,18, 399-404.

[2] Quan X, Wang F, Zhao Q, Zhao T, Xiang J. 2009. Air stripping of ammonia in a water-sparge aerocyclone column. *J. Hazard. Mat*, 170, 983-988

[3] Setiadi, Hantizen, Nita TH, Bambang HS, Heru S, Supramono D. 2009. Kemampuan kolom gelembung pancaran (*jet bubble column*) Untuk Mereduksi Kandungan gas CO_2. Departemen Teknik Kimia Universitas Indonesia.

[4] Setiadi, Nugroho DH. 2007. Studi Hidrodinamika dan Kinetika Absorbsi CO_2 kolom gelembung pancaran (*jet bubble column*). Prosiding Seminar Nasional Rekayasa Kimia dan Proses, ISSN : 1411-4216.

[5] Ide M, Uchiyama H, Ishikura T. 2001. Mass Transfer Characteristics In Gas Bubble Dispersed Phase Generated By Pluging Jet Containing Small Solute Bubble. *Chem.Eng.Sci*.,56, 6225-6231.

[6] Lee Sheng-Yi, Pang Tsui Y. 1998. Succed at Gas/Liquid Contacting. *J.Am.Inst.of. Chem.Eng.*

[7] Ito A, Yamagiwa K, Tajima K, Yoshida M, Ohkawa A. 2000. Maximum Penetration Dept of Air Bubble Entrained by vertical Liquid Jet. *J. Chem. Eng. Japan*, vol. 33, No. 6, hal. 898-900.

[8] Havelka P *Et al*. 2000. Hydrodynamic and Mass Transfer Characteristics Of Ejector Loop Reactor. *Chem.Eng.Sci.*, 55, 535-549.