# Absorption of Carbon dioxide in Packed Column

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***Abstract***- The absorption of carbon dioxide into aqueous ammonia solution using packed column was investigated. The volumetric overall mass transfer coefficients ($K_Ga_v$) for $CO_2$ absorption into aqueous ammonia solutions were evaluated over ranges of main operating variables , that is, upto 16kPa partial pressure of $CO_2$, 61-214 $m^3/(m^2.h)$ gas flow rate, 0.75- 3.06 $m^3/(m^2.h)$ liquid flow rate, 2%- 16% ammonia mass fraction, and 20- $50^oC$ temperature. Experimental results show that the mass transfer process in $CO_2$ absorption into aqueous ammonia solution is mainly controlled by the resistance in the liquid phase and the ammonia concentration has a great effect on the overall mass transfer coefficient.

***Keywords***- absorption, volumetric overall mass transfer coefficient, carbon dioxide, aqueous ammonia, packed column.

## I. INTRODUCTION

The global warming caused by increasing emission of carbon dioxide is one of the most serious environmental problems. Carbon dioxide discharged by the consumption of fossil fuel for power and heat production is said to occupy nearly 35% of the amount of discharged $CO_2$ all over the world. Therefore, removal of carbon dioxide from flue gases is a key measure to reduce $CO_2$ emission. Several technologies of $CO_2$ sequestration include chemical solvent absorption methods, adsorption methods, cryogenic methods, separation using membranes and biological fixation, and the $O_2/CO_2$ combustion process. The absorption process is one of the most common industrial technologies today. Chemical solvent absorption methods are considered as a reliable method for reducing $CO_2$ emission from fossil fuel power plants. Among the chemical solvent absorption processes, the monoethanolamine (MEA) scrubbing is widely used in the chemical engineering process of gas purification and carbon dioxide capture. However, the cost to capture $CO_2$ from flue gas of power plants is very high when using MEA scrubbing. It is estimated that the energy penalty from using this method for $CO_2$ capture from coal-fired power plants is about 15% to 35%. Besides, The MEA process suffers the following disadvantages, such as low $CO_2$ loading capacity, high equipment corrosion rate, amine degradation by $SO_2$, $NO_2$, HCL and $O_2$ in the flue gas, and high energy consumption during absorption and regeneration. So, the MEA process requires that the flue gas be clean, which $SO_2$ and $NO_2$ must be removed first.

Some researchers found that ammonia seems to be an alternative and promising absorbent for removing $CO_2$ from flue gas. Aqueous ammonia is not easy to be degraded and the energy input is much lower than MEA process, and the solution does not have a corrosion problem. Three major acid gases, $SO_2$, $NO_2$ and $CO_2$, will be captured in the aqueous ammonia process, which is expected to reduce the total cost and complexity of emission control systems. Yeh and Bai carried out experimental investigation of ammonia and MEA capturing $CO_2$ in a bubble reactor. The tests showed that the NH3 absorbent is superior to MEA absorbent in its capacity to absorb and removal $CO_2$ from flue gas systems. Yeh et al. performed $CO_2$ absorption and regeneration with aqueous ammonia in a semi-continuous flow reactor. It is found that the regeneration energy saving for the aqueous ammonia process is approximately 62% compared with the MEA process. Diao et al. studied the mechanism and kinetics of the reaction between $CO_2$ and $NH_3$ solvent in a sieve-plate tower. Their experimental results showed that the $CO_2$ removal efficiency reaches its highest value at $33^0C$.

The focus in the above literatures seems to lie on the determination of the removal efficiency and absorption capacity, the mass transfer efficiency of carbon dioxide absorption into aqueous ammonia solution rarely reported. The motivation of this paper focuses on the mass transfer performance of the $CO_2$ absorption process using dumped packing and aqueous ammonia solution as the column internal and absorption solvent, respectively. The performance of the packed column was evaluated experimentally under various conditions to revel effects of process parameters, including $CO_2$ partial pressure in gas phase, gas flow rate, flow rate of liquid, concentration of ammonia.

## II. ABSORPTION MECHANISM OF $CO_2$ INTO AQUEOUS AMMONIA SOLUTION

### *A. REACTIONS OF $CO_2$ WITH AMMONIA*

The reaction between aqueous ammonia and carbon dioxide mainly occurred in the liquid phase of the gas-liquid interface, the reactions in the liquid phase of the $CO_2$-ammonia system are given as follows:

$$CO_2\,(g) + 2NH_3\,(aq) \longrightarrow NH_2COONH_4\,(aq), \qquad (1)$$

$$CO_2\,(g) + 2NH_3\,(l) + H_2O\,(l) \longleftrightarrow (NH_4)_2\,CO_3\,(s) \qquad (2)$$

$$CO_2\,(g) + NH_3\,(l) + H_2O\,(l) \longleftrightarrow NH_4HCO_3\,(s) \qquad (3)$$

The reaction (1) is actually composed of the following two steps.

$$CO_2\,(g) + NH_3\,(aq) \longleftrightarrow NH_2COOH\,(aq), \qquad (4)$$

$$NH_3\,(aq) + NH_2COOH\,(aq) \longleftrightarrow NH_4^+(aq) + NH_2COO^{-1}\,(aq) \qquad (5)$$

And then, $NH_2COONH_4$ hydrolyzes in solution instantaneous and generate free ammonia:

$$NH_2COO\text{-}\,(aq) + H_2O\,(l) \longleftrightarrow HCO_3\,(aq) + NH_3\,(aq) \qquad (6)$$

$$NH_3\,(aq) + H_2O\,(l) \longleftrightarrow NH_3\,H_2O\,(aq) \qquad (7)$$

The reaction (4) is very fast and irreversible, and the reaction (5) is instantaneous. The reaction (6) is too slow to influence the rate of the absorption directly. Therefore, the reaction between aqueous ammonia and carbon dioxide is mainly controlled by reaction (4). It is a second- order reaction with first- order for $CO_2$ and $NH_3$ respectively.

On the other hand, reactions (2) and (3) are reversible, with ammonium carbonate ($(NH_4)_2CO_3$) or bicarbonate ($NH_4HCO_3$) as the products. The forward reactions are dominant at room temperature. The backward reactions occur at temperatures of around 38-60$^0$C

### *B. HYDRATION OF $CO_2$ IN AQUEOUS SOLUTION*

The ammonia solution show weakly alkaline, thus, the hydration of $CO_2$ in aqueous solutions would occur in the liquid phase, the reactions are as follows:

$$CO_2 + H_2O \longleftrightarrow HCO_3^- + H^+ \qquad (8)$$

$$CO_2 + OH^- \longleftrightarrow HCO_3^- \qquad (9)$$

The contribution of reaction (8) to the overall reaction rate is very small as the reaction has a very low rate constant and may usually be neglected.

### *C. REACTION RATE FOR $CO_2$ ABSORPTION INTO AQUEOUS AMMONIA SOLUTION*

Based on all considerations concerning the various reactions with $CO_2$ in aqueous ammonia, the reacton rate for $CO_2$ absorption into ammonia solution mainly controlled by the reactions are given in Eq.(4) and Eq.(9). The reaction rate for $CO_2$ absorption into aqueous ammonia solution can be described as follows.

$$r_{CO2\text{-}NH3} = k_2\,[NH_3]\,[CO_2] \qquad (10)$$

$$r_{CO2\text{-}OH\text{-}} = k_{OH\text{-}}[OH^-][CO_2] \qquad (11)$$

The overall reaction rate can be described as:

$$r_{ov} = r_{CO2\text{-}NH3} + r_{CO2\text{-}OH\text{-}} = k_2\,[NH_3][CO_2] + k_{OH\text{-}}\,[OH^-]\,[CO_2] \qquad (12)$$

Where the values for rate constant $k_2$ for reaction between $CO_2$ and ammonia is about 300 L/ (mol.s) in 20$^o$C. The kinetic rate constant $k_{OH\text{-}}$ can be described in terms of temperature.

$$\lg (k_{OH-}) = 13.635\text{-}2895/T$$

The value of $k_{OH-}$ equals to 5747.9 $m^3$/(kmol.s) when the temperature is 20$^o$C. The hydroxyl ion concentration and the pH value of aqueous ammonia are estimated by the following relations:

$$[OH^-] = \sqrt{Kb[NH3]} \quad (14)$$

$$pH = -\log_{10}[H^+] = -\log_{10} \frac{KW}{[OH-]} \quad (15)$$

Where $K_b$ represents the ionization equilibrium constant of the aqueous ammonia and the value of $K_b$ is $1.710\times10^{-5}$ at 20$^o$C. The $K_w$ is the dissociation constant of water which responds to changes in temperature, and the value of $K_w$ equals to $10^{-14}$ in room temperature.

The calculated kinetic data for absorption of $CO_2$ into aqueous ammonia at 20$^o$C are given in Table 1. The value of $k_{OH-}[OH^-]$ is much smaller than that of $k_2[NH_3]$ as the reaction has a very low hydroxyl ion concentration. The contribution of reaction (6) to the overall reaction rate is less than 7%. Thus, the reaction rate between $CO_2$ and ammonia solution is mainly controlled by reaction (4) and the action of $CO_2$ with $OH^-$ ion can be neglected.

Then, the overall reaction rate can be approximately described as:

$$r_{ov} = r_{CO2\text{-}NH3} + r_{CO2\text{-}OH-} = k_2 [NH_3][CO_2] \quad (16)$$

The reaction between $NH_3$ and $CO_2$ is very fast , and the $CO_2$ concentration in liquid phase can be assumed to be zero in the fast pseudo-first-order reaction regime.

In order to verify whether the absorption of $CO_2$ into aqueous ammonia occurs in the fast pseudo-first-order reaction regime ($1<< Ha << \beta_i$ or $2 < Ha < \frac{\beta i}{2}$), some chemical kinetic parameters of the reaction between $NH_3$ and $CO_2$ are discussed according to Higbie penetration theory.

Where

$$\beta_1 = \sqrt{\frac{Dco2L}{DNH3L}} + \frac{[NH3]}{Z[CO2i]}\sqrt{\frac{DNH3L}{Dco2L}} \quad (17)$$

The diffusivities of $CO_2$ and $NH_3$ will be taken as equal to simplify the argument for they are only about 20% different in fact. As the value of the mole concentration of ammonia is bigger than 1.16kmol/$m^3$ and the partial pressure of $CO_2$ is less than 15kPa, the value of $\beta_1$ is satisfied $\beta_1 > 100$.

The Hatta number Ha is expressed as:

$$Ha = \sqrt{k2[NH3]Dco2L}/k_L \quad (18)$$

The mass transfer coefficient in the liquid phase is expressed as:

$$k_L = 2\sqrt{\frac{Dco2L}{\pi tc}} \quad (19)$$

Thus,

$$Ha = \sqrt{\frac{\pi}{4} tck2[NH3]} \quad (20)$$

Where $t_c$ is the contact time (given in seconds). In this study, the gas-liquid contact time is much bigger than 0.03s and less than 20s. Thus, the relationship of $1<< Ha << \beta_1$ can be satisfied. Therefore, the absorption of $CO_2$ into ammonia occurs in the fast pseudo-first-order reaction regime where the enhancement factor β equals to the Ha, and the carbon dioxide is completely exhausted in the liquid film, so the equilibrium mole fraction of $CO_2$ in the liquid phase (y*) can be assumed to be zero.

## III. DETERMINATION OF OVERALL MASS TRANSFER COEFFICIENT.

### *A. TRADITIONAL TWO-FILM THEORY*

The absorption of $CO_2$ into aqueous ammonia is a gas-liquid reaction. According to the two-film model, a thin gas film exists on one side of the interface and a thin liquid film exists on the other side with the controlling factors being molecular diffusion through each of the films. In case of chemical absorption, the overall mass transfer coefficient is based on the individual gas, liquid-phase mass transfer coefficients and the enhancement factor β.

$$\frac{1}{KG} = \frac{1}{kG} + \frac{H}{\beta \mathrm{kL}} \qquad (21)$$

In a gas-absorption apparatus such as packed column, the effective gas-liquid interfacial area ($a_v$) is considered as another important parameter in mass transfer process in addition to the mass transfer coefficients. Transfer unit theory has been used for a number of years to design absorption columns, and it is in this theory where the $K_G a_v$ appears in engineering design. Therefore, it is more practical to determine the volumetric overall mass transfer coefficients ($K_G a_v$):

$$\frac{1}{KGav} = \frac{1}{kGav} + \frac{H}{\beta \mathrm{kLav}} \qquad (22)$$

Apparently, the overall coefficient $K_G a_v$ can be directly determined from Eq. (22). However, this approach is not extensively used because experimental determinations of the individual mass transfer coefficients involve the use of extremely difficult techniques. In experiments, it is convenient to measure the mole fraction of $CO_2$ at the top and bottom of the packed column and the overall mass transfer coefficient can be determined based on the measured $CO_2$ concentration.

### *B. DETERMINATION OF OVERALL MASS TRANSFER COEFFICIENT ACCORDING TO THE MEASURED $CO_2$ CONCENTRATIONS AT THE TOP AND BOTTOM OF THE PACKED COLUMN.*

The overall mass transfer coefficient is affected by three main factors; there are the interfacial area between gas phase and liquid phase, the resistance in the gas phase and the resistance in the liquid phase. In the derivation of overall mass transfer coefficient, it is assumed that the liquid flow rate is unchanged. So, the interfacial area between gas phase and liquid phase is unchanged. Then, the overall mass transfer coefficient is unchanged about the interfacial area between gas phase and liquid phase. In the process of absorption, the total gas flow rate is constantly changing due to $CO_2$ absorption into aqueous ammonia solution. However, the variation of total gas flow rate along the height of the tower is little as the mole fraction of the inert gas of nitrogen in gas steam is above 85%. Therefore, there is a slight effect of gas flow rate on the total mass transfer resistance. Besides, as the liquid flow rate, the concentration of ammonia solution and the inlet $CO_2$ loading of the solution are regarded as unchanged, and the amount of aqueous ammonia solution is very sufficient in the whole absorption process. Thus, it is considered that the overall mass transfer coefficient would not be significant changed along the height of the tower.

Then, considering an element of column with height *dh*, due to the inert gas flow rate is constant along the height of the tower, the mass balance can be given as follows:

$$dm_A = \Omega G_B dY = N_A .\ a_v .\ \Omega .\ dh. \qquad (23)$$

And:

$$G_B dY = K_G\ P\ a_v\ (y\text{-}y^*).\ dh. \qquad (24)$$

Where $m_A$ represents the amount of carbon dioxide absorbed per unit time in kmol/h, Y is the mole ratio of component A, *h* is column height in m, $G_B$ is inert gas flow rate in kmol/$m^2$.h, y is the mole fraction of component A in gas stream.

From Eq. (24), the element of column *dh* can be determined as:

$$dh = \frac{GB}{KGPaV} \frac{dY}{(y - y*)} \qquad (25)$$

When used for chemical absorption, y* in Eq. (25) is assumed to be zero since the chemical reaction is fast. Thus, Eqn (25) can be expressed as:

$$dh = \frac{GB}{KGPaV}\frac{dY}{y}, \qquad (26)$$

And

$$\mathrm{Y} = \frac{Y}{1+Y} \qquad (27)$$

Therefore,

$$\int_0^h dh = \frac{GB}{KGPav}\int_{Y2}^{Y1} dY/(\frac{Y}{(1+Y)}) = \frac{GB}{KGPav}\int_{Y2}^{Y1}(1+Y)/Y\ \mathrm{dY}, \qquad (28)$$

And

$$h = \frac{GB}{KGPav}\left[\ \ln\frac{Y1}{Y2}\right] + (\ \mathrm{Y}_1\text{-}\mathrm{Y}_2\ )] \qquad (29)$$

Then, the expression of $K_Ga_v$ can be obtained as follows:

$$K_Ga_v = \frac{GB}{Ph}\left[\ \ln\frac{Y1}{Y2}\right] + (\ \mathrm{Y}_1\text{-}\mathrm{Y}_2\ )] \qquad (30)$$

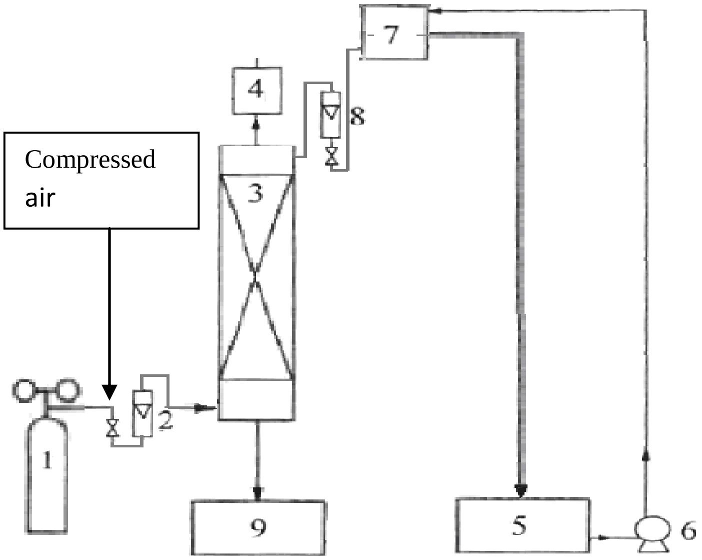
In this paper, the $CO_2$ concentration at the top and bottom of the column was measured and used for evaluating the $K_Ga_v$ value in accordance with Eq. (30).

## IV. EXPERIMENTAL SETUP

The schematic diagram of the experimental setup is shown in Figure 1. The packed column was made of stainless steel with 0.6 m high and 0.1 m inside diameter. The packing height of the reactor was 400mm, and the filler of the packed column was ceramic Raschig ring with 8mm diameter. The void fraction of packing layer is 0.64 ($m^3/m^3$) and the specific surface area is about 570($m^2/m^3$).

In order to control the reaction temperature, experiments were carried out under water bath conditions. The water bath was kept at constant temperature by temperature controller and an electric heater, and also, the aqueous ammonia solution and inlet artificial flue gas of $CO_2$ and nitrogen mixture were kept at same temperature with heater. The simulated flue gas was mixed using two mass flow controllers with an accuracy of ∓ 1.0% S.P. which controlled the flow rates of $CO_2$ and nitrogen, respectively, and the mixture gas passed through the packed column from its bottom to the top. When the mixture gas reached a steady state, the heated aqueous ammonia solution was then pumped at a given flow rate to the column top. So, the mixture gas and the aqueous ammonia solution were in counter flow pattern, it is beneficial to make $CO_2$ and aqueous ammonia contact and react thoroughly. The $CO_2$ concentration at the top of the column was determined by an infrared gas analyzer with an accuracy of ∓ 2% of the full-scale reading. Each absorption experiment was operated until the concentration of $CO_2$ in the gas phase reached a steady-state condition. All experiments were carried out under atmospheric pressure. Details of the operating conditions are shown in Table 2.

In order to validate the repeatability of the experimental system, one test case has been repeated three times, the experimental results show that the standard deviation of the $CO_2$ concentration at the top of the packed column is 0.14%,this indicates that the experiment system has a good repeatability.



1. $CO_2$ cylinder
2. Flow meter
3. Packed column
4. Outlet gas
5. Feed tank
6. Pump
7. Head tank
8. Valve
9. Product tank

Figure.1:- Experimental setup

## V. RESULTS AND DISCUSSION

The effects of different operating and design parameters on $K_G a_v$ including $CO_2$ partial pressure, total gas flow rates, volume flow rate of aqueous ammonia solution, aqueous ammonia concentration, and reaction temperature were investigated.

### *A. EFFECT OF $CO_2$ PARTIAL PRESSURE*

The effect of $CO_2$ partial pressure on the overall $K_G a_v$ value of $CO_2$ absorption using aqueous ammonia solution was shown in Figure 2. The $K_G a_v$ value decreases slightly as the $CO_2$ partial pressure increases. Such behavior also reported by Aroonwilas et al. using AMP aqueous solution to absorb $CO_2$ in columns packed with structured packing. According to two-film theory, the mass-transfer resistance of the gas phase will decrease with the increasing $CO_2$ partial pressure. Logically, an increase in the $CO_2$ partial pressure allows more $CO_2$ molecules to travel from gas bulk to the gas-liquid interface, which would result in higher mass transfer performance. On the other hand, the rate of gas absorption is not exclusively dependent upon the mass transfer phenomenon in the gas phase. The mass transfer behavior in the liquid phase also plays an important role. And diffusion of solvent molecules in the liquid phase is restricted in comparison with that of $CO_2$ from the gas phase to the gas-liquid interface. Thus, mass transfer process of $CO_2$ absorption into aqueous ammonia solution is mainly controlled by the resistance of the liquid phase.

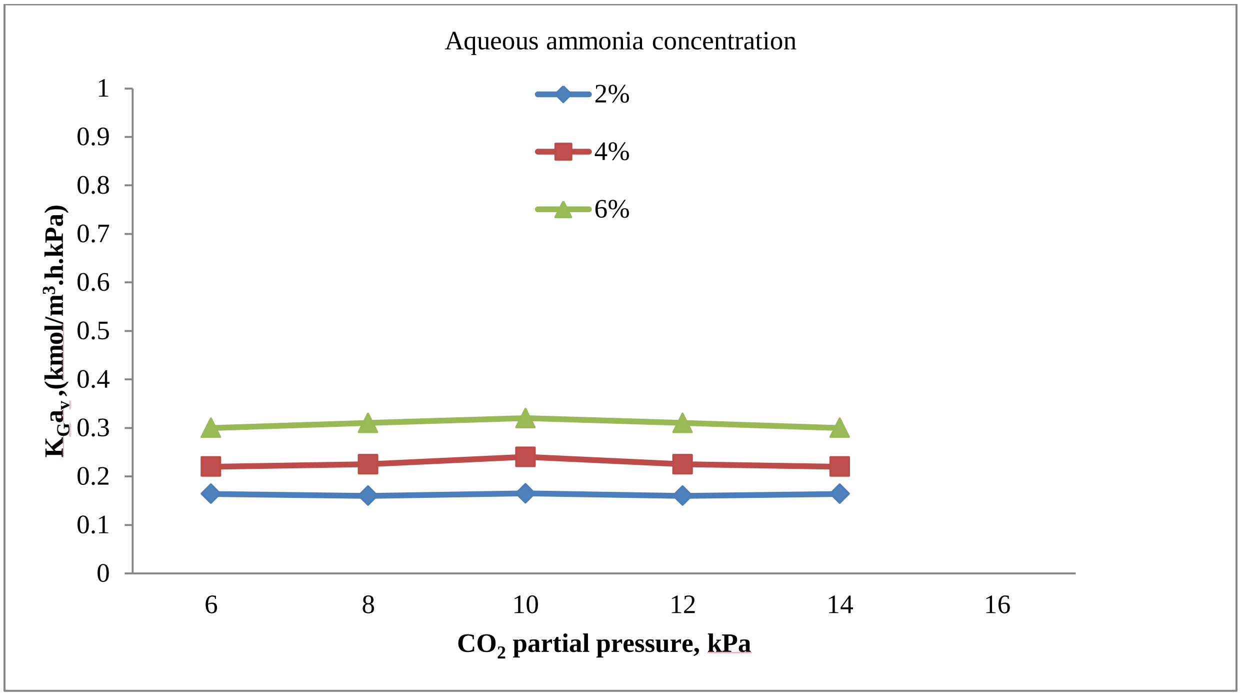


Figure 2: Effect of $CO_2$ partial pressure on overall mass transfer coefficient

### *B. EFFECT OF LIQUID FLOW RATE*

Figure 3 shows the effect of liquid flow rate on the overall mass transfer coefficient. It is found that an increase in the liquid flow rate results in an increase in $K_Ga_v$ value. Previous studies on $CO_2$ absorption in rotating packed bed, spray tower and membrane contactor have also revealed a similar trend of increasing $K_Ga_v$ with increasing liquid flow rate. With the liquid flow rate increasing, more liquid would be spread on the packing surface, and this leads to an increase in the interfacial area per unit volume ($a_v$). Besides, the higher liquid flow rate leads to a higher liquid-side mass transfer coefficient ($k_L$) in the case of liquid phase controlled mass transfer. According to Eq. (22), both of the increases in $k_L$ and $a_v$ lead to a higher $K_Ga_v$ value.

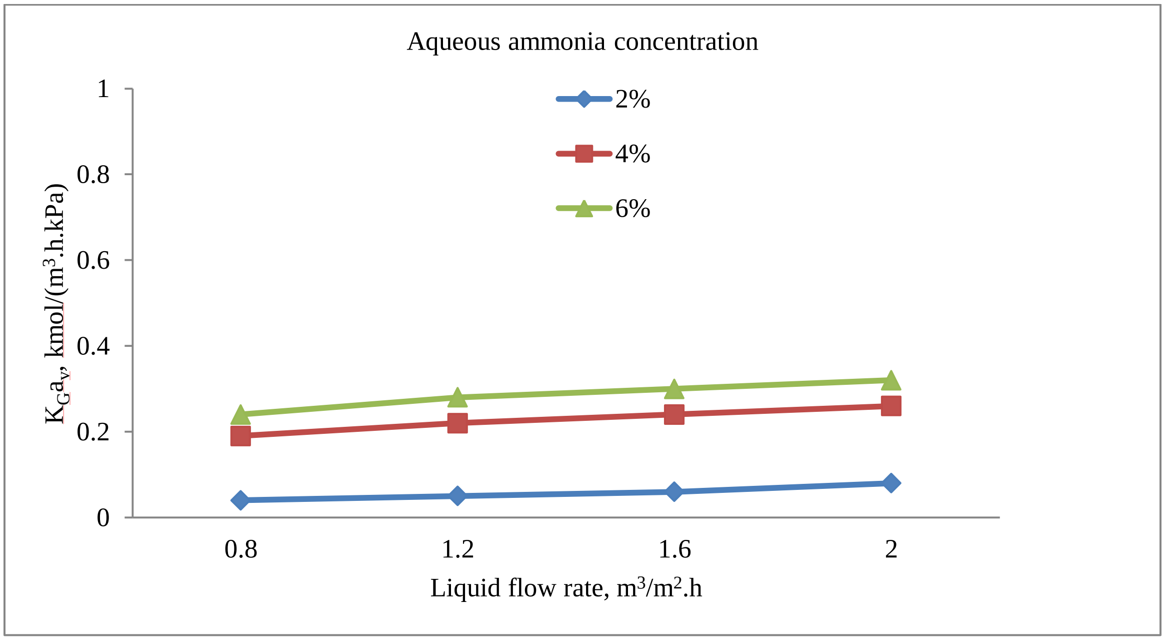


Figure 3: Effect of liquid flow rate on overall mass transfer coefficient

### C. *EFFECT OF GAS FLOW RATE*

Gas flow rate has an effect on the absorption performance in the packed column. Increase in the gas flow rate leads to a higher $K_Ga_v$ value especially when the ammonia concentration is high. As shown in the Figure 4, the gas flow rate has little effect on the overall mass transfer coefficient when the ammonia concentration is 2%. When the ammonia concentration increased to the values of 6% and 8%, the effect of gas flow rate on the overall mass transfer coefficient becomes apparent. This phenomenon indicates that the overall $CO_2$ absorption rate is not only dependent upon the gas flow rate, it is also dependent upon the availability of the reactive in the liquid. When the ammonia concentration is low, the enhancement factor $\beta$ would be small, which leads to higher value of the resistance in the liquid phase ( $\frac{H}{\beta kL}$ ). Thus, the resistance in the gas phase can be negligible. So, the overall mass transfer coefficient is not dependent upon the gas flow rate when the ammonia concentration is low. Whereas, the resistance in the liquid phase ( $\frac{H}{\beta kL}$ ) decreased with increasing concentration of ammonia, the impact of the resistance in the gas phase becomes increasingly significant. Previous $CO_2$ absorption studies in spray scrubber and rotating packed bed have also revealed a similar trend of increasing $K_Ga_v$ with increasing gas flow rate, but generally more rapidly.

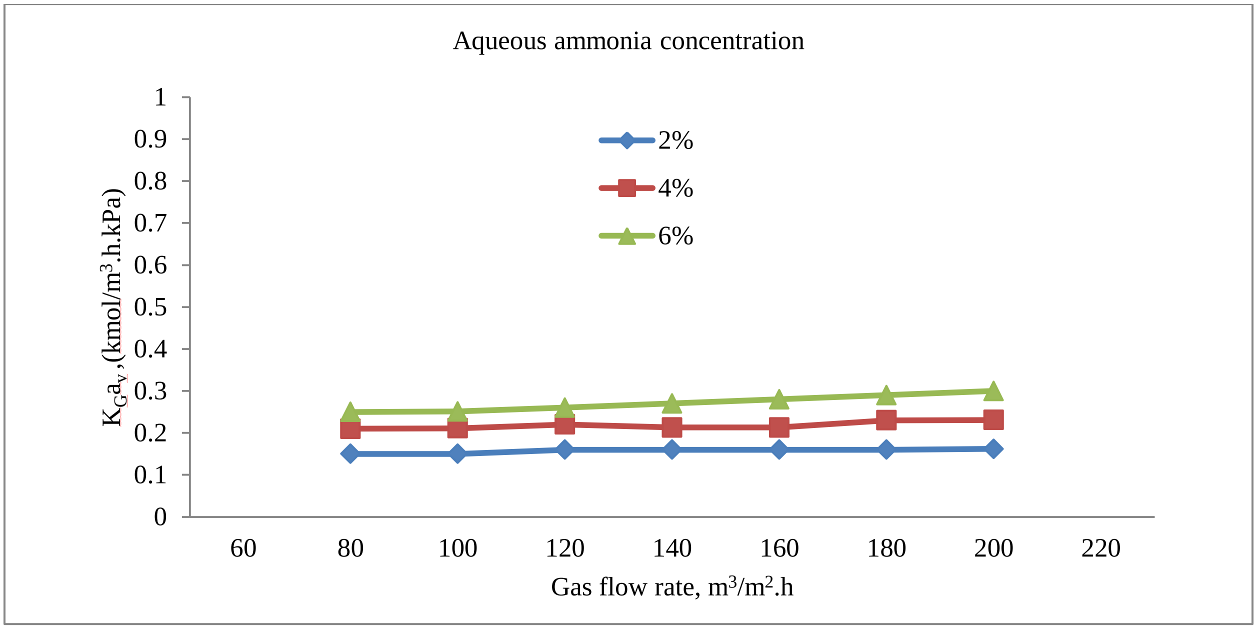


Figure 4: Effect of gas flow rate on overall mass transfer coefficient

### D. *EFFECT OF AQUEOUS AMMONIA CONCENTRATION*

Figure 5 shows the effect of mass fraction of aqueous ammonia on the overall mass transfer coefficient. The aqueous ammonia concentration obviously has an impact on the absorption performance. As shown in Figure 5, an increase in the solvent concentration induces a higher $K_Ga_v$ value. When the mass fraction of ammonia increases from 2% to 16%, the $K_Ga_v$ value increases from nearly 0.1 kmol/($m^3$.h.kPa) to 0.6 kmol/ ( $m^3$.h.kPa). However, the finding that the $K_Ga_v$ increasing as the ammonia concentration increasing differs from what has been normally observed about $CO_2$ absorption into MEA in the packed column and membrane contactor. Previous research shows that the mass transfer coefficient decreases with MEA concentration increasing beyond 5.0 mol/L in packed column. The reduction in the $K_Ga_v$ results from an increase in the viscosity of the liquid solution which causes the rate of molecular diffusion to reduce. The increasing viscosity also tends to cause a reduction in the effective interfacial area between gas and liquid in the packed column. However, the increasing $K_Ga_v$ of the packed column due to the increasing ammonia concentration seems to show that the effect of ammonia concentration on the liquid viscosity is less than the effect of MEA concentration.

Viscosity of aqueous ammonia solution was calculated with correlation given by Frank et al.

$$\mu^{NH3\text{-}sol} = (0.67 + 0.78\, x_{NH3}) \times 10^{-6} \exp\left(\frac{17900}{RT}\right) \quad (31)$$

Where $\mu^{NH3\text{-}sol}$ represents the viscosity of aqueous ammonia solution and $x_{NH3}$ represents the molar solute fraction of $NH_3$ in aqueous ammonia solution. The viscosity of aqueous ammonia solution increasing from 2% to 16%, which has a little effect on the effective interfacial area between gas and liquid in the packed column.

Diffusivity of $CO_2$ in aqueous ammonia solution was estimated by applying the modified Stokes-Einstein equation as follows:

$$D_{co2}^{NH3\text{-}sol} = D_{co2}^{H2O} \, ( \mu^{H2O}/\mu^{NH3\text{-}sol})^{0.8} \qquad (32)$$

Where $D_{co2}^{NH3\text{-}sol}$ and $D_{co2}^{H2O}$ represent the diffusivity of $CO_2$ in aqueous ammonia solution and water, respectively. From this equation, the viscosity of aqueous ammonia solution decreases only 15.7% when the mass fraction of ammonia increasing from 2% to 16%. Thus, the increasing of ammonia concentration has a little effect on the rate of molecular diffusion.

The increasing concentration yields a amount of the active ammonia available to diffuse toward the gas-liquid interface and react with $CO_2$. This will greatly promote the enhancement factor increase, which leads to a higher $K_Ga_v$ value from Eq. (22).

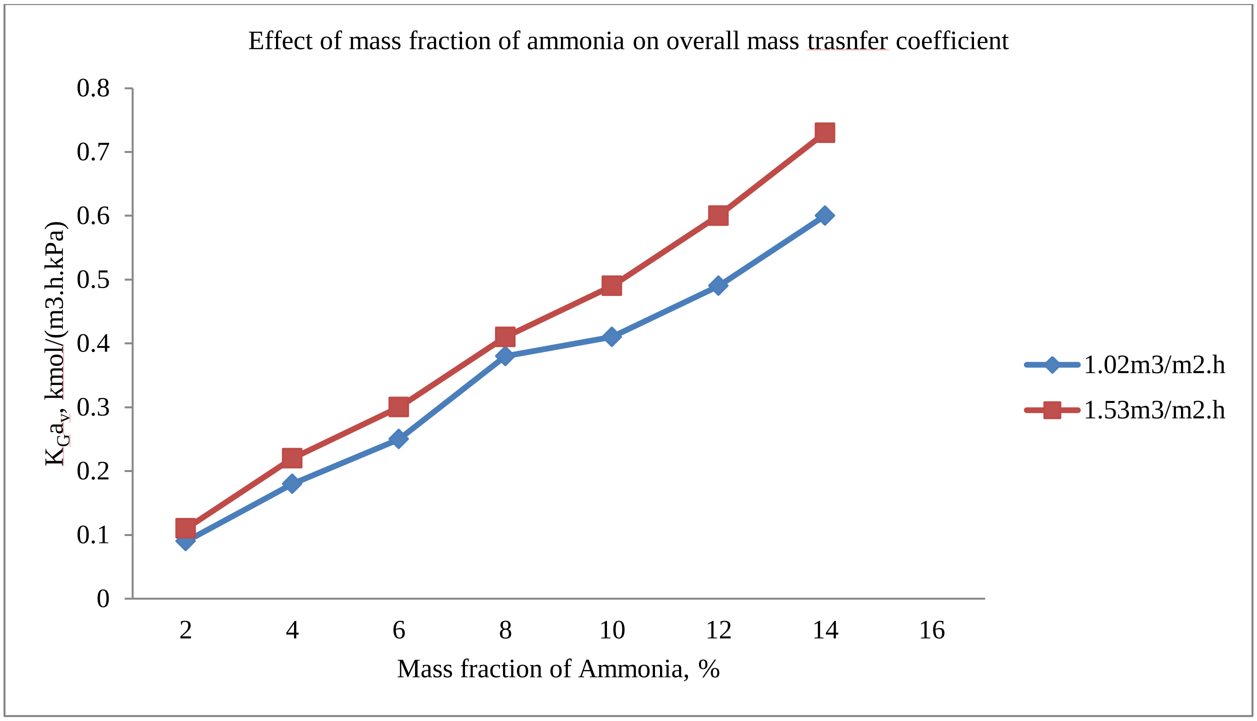


Figure 5: Effect of mass fraction of ammonia on overall mass transfer coefficient

### *E. EFFECT OF TEMPERATURE*

Temperature is an important parameter influencing reaction kinetics. The reaction of $CO_2$ absorption into aqueous ammonia solution is reversible, the forward reactions are dominant at room temperature, the backward reactions occur at temperatures of around $38^o$-$60^o$. As shown in Figure 6, increasing the temperature in the packed column from $20^oC$ to $50^oC$ results in shifting the $K_Ga_v$ value. The $K_Ga_v$ value increases with temperature when the temperature of the water bath is lower than $40^o$. Such behavior is attributable to the nature of CO2 absorption kinetics, the second-order reaction rate constant $k_2$ of $CO_2$-ammonia system increases with the reaction temperature, those are beneficial to enhance the absorption rate. Whereas, the $K_Ga_v$ value decreases with the increasing temperature when the temperature of water bath is higher than $40^o$. The chemical reaction between the $CO_2$ and ammonia system at this point shifts from the forward reaction to the reverse controlling mechanism. A similar trend has been reported by Aroonwilas et al. for the absorption of $CO_2$ into MEA solution in columns with structured packing. In general, the change of the $K_Ga_v$ value is small when the temperature in the packed column from $20^oC$ to $50^oC$. From the principle of molecular dynamics, diffusion coefficient and rate-constant of reaction increase with increasing temperature; those are beneficial to enhance the mass transfer. However, the $CO_2$ solubility coefficient decreases with increasing temperature which gives rise to an increase of the resistance in the liquid phase.

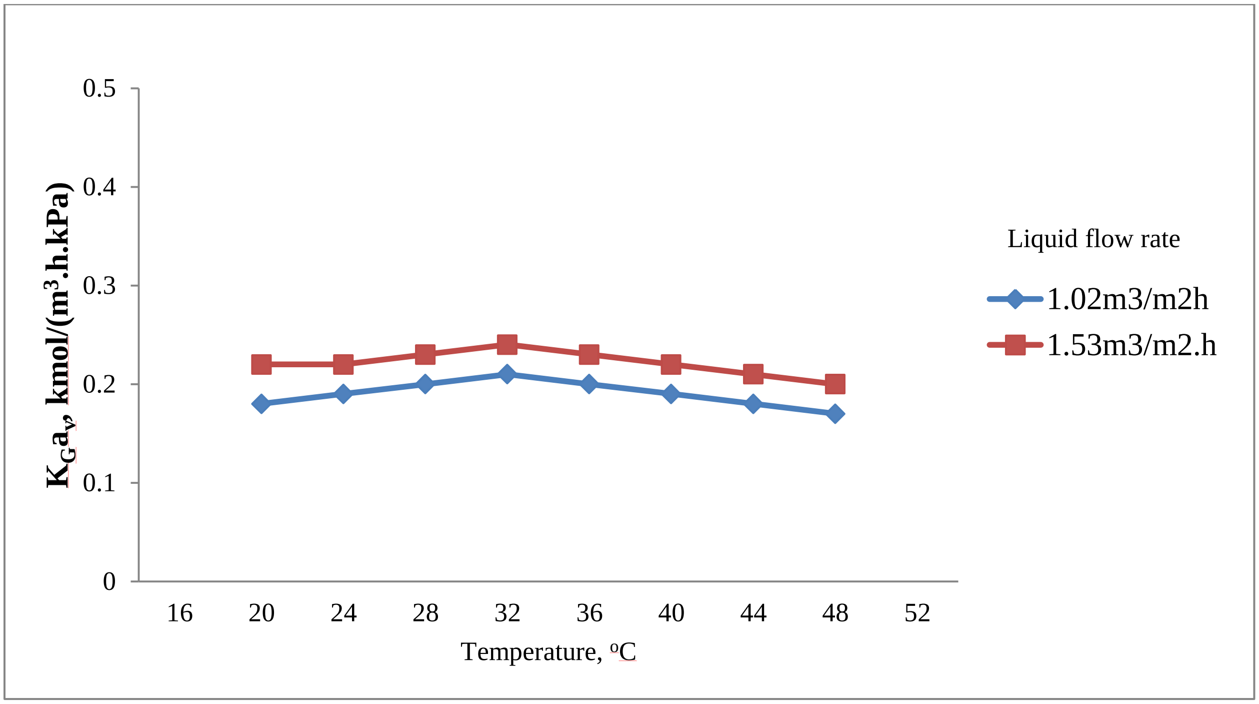


Figure 6: Effect of temperature on overall mass transfer coefficient

## VI. CONCLUSIONS

The overall mass transfer coefficients for $CO_2$ absorption into aqueous ammonia in a packed column were investigated. The following major conclusions can be drawn from this work.

(1) The overall mass transfer coefficient ($K_Ga_v$) was measured according to the $CO_2$ concentrations at the top and bottom of the packed column.

(2) Experimental results show that the mass transfer process in $CO_2$ absorption into aqueous ammonia solution is mainly controlled by the resistance in the liquid phase and the aqueous ammonia concentration has a great effect on the overall mass transfer coefficient.

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