THE STUDY OF CO_2 ABSORPTION USING MONOETHANOLAMINE AND SODIUM HYDROXIDE MIXTURE UNDER CONCURRENT FLOW PATTERN

BY

NDUKUBA CHIMERE UKAMAKA
99/8261EH

A PROJECT REPORT SUBMITTED IN FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG) DEGREE IN CHEMICAL ENGINEERING DEPARTMENT, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA NIGER STATE.

NOVEMBER, 2005

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DEPARTMENT OF CHEMICAL ENGINEERING SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA NIGER STATE, NIGERIA.

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i

DECLARATION

I Ndukuba Chimere Ukamaka with matriculation number 99/8261EH of the Department of Chemical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna. Hereby declare that this research project was submitted in partial fulfillment of award of B. Eng. of the Federal University of Technology, Minna and it is solely my work and effort. All references extracted from published and unpublished work are acknowledged in my write up.

Ndukuba Chimere Ukamaka
Name of Student

_____
Signature

_____
Date

CERTIFICATION

This is to certify that this project titled "THE STUDY OF CO_2 ABSORPTION USING MONOETHANOLAMINE AND SODIUM HYDROXIDE MIXTURE UNDER CONCURRENT FLOW PATTERN" was carried out by Ndukuba Chimere Ukamaka under the supervision of Engr. David Agbajelola and submitted to Chemical Engineering Department of Federal University of Technology, Minna in partial fulfillment of the requirement for the award of bachelor of Engineering (B. Eng) degree in chemical engineering.
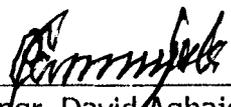
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Engr. David Agbajelola   Signature and Date
Supervisor
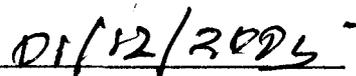
_____   _____
Dr. F. Aberuagba   Signature and Date
Head of Department

_____   _____
External Examiner   Signature and Date

iii

DEDICATION

This project is dedicated to God the Father, God the Son and God the Holy Spirit, for your ever present help in times of need, your faithfulness, your help, your comfort and for the life you gave me.

Also to all Chemical Engineers, Federal University of Technology, Minna, Niger State.

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My heart gratitude to my friends, Mrs. Robert, Mathew, Akin , Joy, Jonathan, Bello, Allor and Janet my association with you all have been a blessing.

Finally, my thanks go to all my classmates.

ABSTRACT

The absorption of CO_2 in monoethanolamine and sodium hydroxide mixture was carried out in a gas absorption column when time increases from 10 minutes to 50 minutes and also when the composition of the absorbent (monoethanolamine and sodium hydroxide) was varied at ratio 1:1, 1:0.66 and 1:0.25 under concurrent flow pattern where the liquid and gas flow in parallel to each other.

Analysis of the solution rich in CO_2 was done by titration using standard 0.5M Hydrochloric acid. The amount of CO_2 absorbed increase substantially as time increases from 10 minutes to 40 minutes. Also the absorptive capability of the absorbent reduced with contact time.

The absorbent composition also affected the amount of CO_2 absorbed. At ratio 1:1 the amount of CO_2 absorbed was lower than that obtained when the ratio was 1:0.25.

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

a = Effective interfacial area until packed column (cm^1)

A = Cross sectional area of tower (m^2)

C_A = Concentration of Gas (gmol./L)

C_{Ai} = Concentration of gas at interface (gmol./L)

C_{AL} = Concentration of gas in bulk of the liquid (gmol./L)

C_{Ac} = Concentration of gas at equilibrium (gmol./L)

C_C = Concentration of feed solvent (Monocthanolamine). (gmol./L)

C_d = Concentration of Monoethanolamine solution. (gmol./L)

H = Height of packing (m)

K_G = Overall gas transfer coefficient

k_G = Gas transfer coefficient

k_L = Liquid transfer coefficient

L_0 = Solvent flow rate (gmole/sec)

MEA = Monoethanolamic solvent

N_A = Rate of gas absorption (gmole/sec)

P_A = Partial pressure of gas (mmHg)

P_{AG} = Partial pressure of gas in gas mixture (mmHg)

P_{Ai} = Partial Pressure Partial of gas at interface (mmHg)

P_{AC} = Partial Pressure Partial of gas at equilibrium

V = Volume of packing (m^3)

Vc = Volume of MEA (m^3)

V_d = Volume of distilled water (m^3)

TABLE OF CONTENTS

CHAPTER THREE

METHODOLOGY AND EXPERIMENT PROCEDURE

CHAPTER FOUR

RESULTS AND DISCUSSION OF RESULT

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

CHAPTER ONE

INTRODUCTION

1.1 Background

Currently, the desire to alleviate the problem of global warming has resulted in the environmental concern over a reduction of green house gases contributing to problem are methane (CH_4), carbon dioxide, nitrous oxide (N_2O) and halogens such as chlorofluorocarbons (CFCs) and hydro fluorocarbons (HFCs) (Doe C. U. S 1999). Among these, CO_2 is the primary contribution to the problem due to its abundance, and is thus a major target for reduction. One such strategy that has received a great deal of attention involves the capture of CO_2 from large point source (such as fossil fuel-fire power plants) and the long term storage underground or in the ocean. To reduce the excessive CO_2 emission, there is great interest in capturing CO_2 and utilizing it as a flooding agent for enhanced oil recovery. Furthermore, the gas has been discovered to have other positive industrial applications in its use as an inert gas for chemical process, as a refrigerant or coolant for storage, a basic raw material in methanol and urea production, also in carbonation of soft drinks, beer, and wine to prevent microbial growth amongst other uses. Therefore to capture CO_2 gas absorption process is employed.

In process engineering, gas absorption is a major operation in which one constituent or constituents are removed from a gas by treatment with a liquid. It is an operation based on interphase mass transfer, which are mostly controlled and monitored by the rate of diffusion of gases and liquid used. This operation is found in many industries for the recovery of valuable products and cleaning of exhaust or vent streams. If necessary the solute can be recovered from the absorbing liquid by distillation and the liquid can be recycled or it can be discarded completely. In some cases, a solute is removed from a liquid by contacting it with a gas. This operation is the reverse of gas absorption and is called desorption or gas stripping. This study deals with the effects of absorbent composition and contact time on absorption of

carbon dioxide (CO_2) in Monoethanolamine and Sodium Hydroxide mixture under cocurrent flow pattern. This system has the advantage that signifies mass transfer, which occurs with the aid of the packing over the entire length of the column (Geankoplis, 1993).

Aqueous Monoethanolamine (MEA) is widely used for removing carbon dioxide (CO_2) from gas streams. It is also used to remove (CO_2) from combustion gases and may receive wide application for abatement of gases. MEA is a relatively strong base with a fast reaction rate, yielding a low CO_2 concentration. NaOH is an ideal absorbent because of its high reactivity with carbon dioxide. As carbon dioxide passes over the NaOH solution reaction occurs with the formation of sodium carbonate. The resulting sodium carbonate remains dissolved in water. An advantage of using caustic soda is that it is regenerable with the presence of calcium hydroxide ($Ca(OH)_2$) (Michigan, 2005).

The development of absorption process has been a continuous process. Many other investigators employed MEA in combination with other additives and experienced an improved absorption while others employed different absorbent flow pattern and variation of process parameters.

A number of investigators have studied the solubility and reaction kinetics of CO_2 in aqueous MEA. Typical absorber tray efficiency is less than 20%. Piperazine (Pz) has been studied as a promoter for Methyldiethanolamine (MDEA), which determine that the rate constant of Pz with CO_2 is one order of magnitude higher than that of MEA with CO_2. Therefore a blend of MEA and Pz should absorb CO_2 faster than MEA alone (Dang, 2001).

This research work is undertaken to investigate the effects of absorbent composition and contact time on absorption of CO_2 in MEA and NaOH mixture under cocurrent flow pattern in a laboratory absorption column.

1.2 Justification of the Study

The studies of CO_2 absorption in Monoethanolamine and Sodium hydroxide mixture will serve to provide information about the mechanism of the process. Such

2

information will serve as a means of improving the efficiency of the absorption process.

1.3 Aim and objectives

The aim of this work is to study the effects of absorbent composition and contact time on absorption of carbon dioxide (CO_2) in MEA and NaOH mixture using cocurrent flow pattern. This will be achieved through the following objectives:

1. Undertaking absorption of carbon dioxide gas from CO_2 – air mixture in MEA and NaOH mixture in a packed tower, in a cocurrent flow of gas and solvent.

2. Investigation of the effects of process parameters (absorbent composition and contact time) on the process.

3. Analysis of data obtained in order to quantify the effectiveness of MEA and NaOH mixture as an absorbent for CO_2 absorption.

CHAPTER TWO

LITERATURE REVIEW

2.1 Gas Absorption

Gas absorption is a mass transfer operation in which a gas mixture is contacted with a liquid to preferentially absorb one or more of the components of the gas steams. In saying the removal of the selected gas components from the gas steam by a suitable liquid or solvent. This operation is on of the major operations of chemical engineering, and its application is found in many industries for the recovery of valuable products and cleaning of exhausts or vent steams. Thus carbon dioxide can be recovered from a steam of flux gas by passing the gas steam into alkanolamine or potassium carbonate solutions, in which the carbondioxide is absorbed while the rest of the gases in the gas steam pass through. Another example can be see in the removal of acetone from an acetone-air mixture, where the acetone is removed via dissolution in water.

Gas absorption can be treated as a physical process, in which there is no chemical reaction occurring and as a chemical process, in which a chemical reaction take place. In the course of achieving this chemical operation it is most imperative to ensure that the desired gas, which is to be absorbed should be brought into intimate contact with the liquid or solvent. In absorption, the gas steam and the suitable solvent are fed from the top of the absorber (the equipment in which the process is carried out). The absorbed gas and liquid leave via the bottom of the absorbers, if necessary the solute can be removed from the absorbing liquid by distillation and the liquid can be recycled or it can be discarded completely (McCabe et al, 1985).

2.2 Packings and Packed Tower Design

A common apparatus used in gas absorption and certain other operations is the packed tower, an example of which is shown in Fig 2.1 below
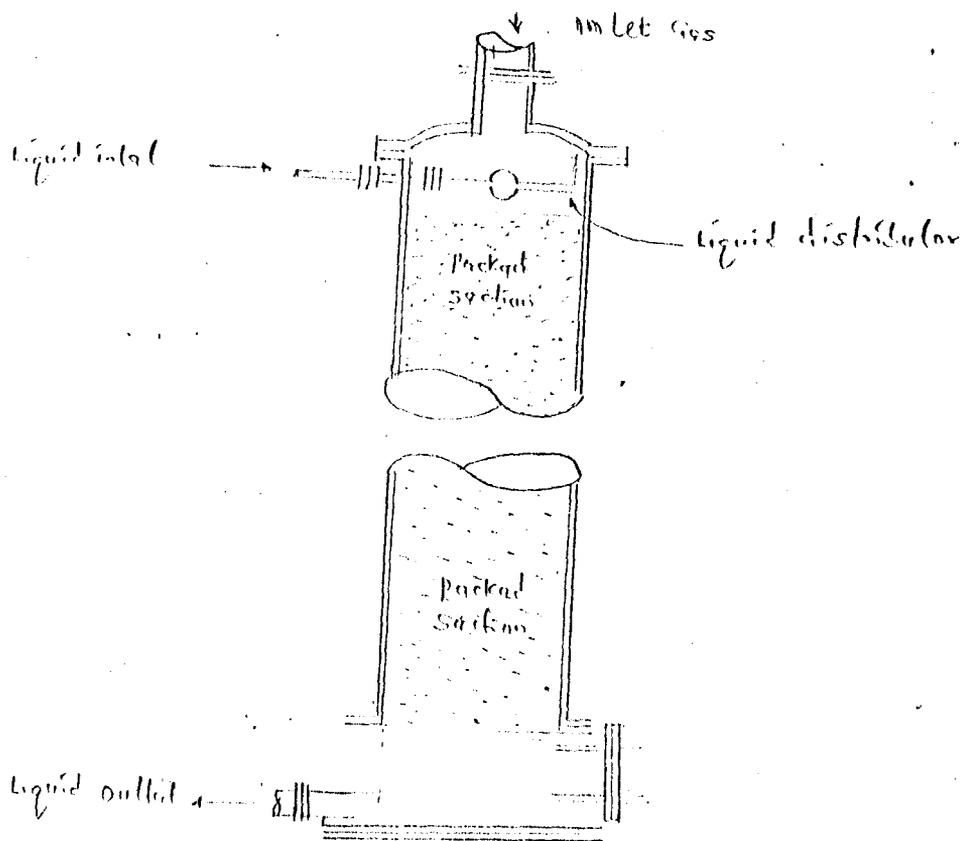
Figure 2.1 Packed Tower.

The device consists of a cylindrical column, or tower, equipped with a gas inlet a liquid inlet at the top with distributing space and a supported mass of inert d shapes called tower packing. The packing support is typically a screen, rupted to give it strength, with a large open area so that flooding does not occur the support. The inlet liquid, which may be pure solvent or a dilute solution of ute in the solvent and which is called the weak liquor, is distributed over the top the packing by the distributor and in ideal operation, uniformly wets the surfaces the packing. The distributor shown in Fig 2.1 is a set of perforated pipes. In large ver, spray nozzles or distributor plates with over flow weir are more common. For ry large towers, up to 9m (30ft) in diameter, Nutter Engineering advertises a plate tributor with individual drip tubes.

e solute-containing gas or the rich gas enters the distributing space from the top d flows downward through the interstices in the packing co currently with the uid. The packing provides a large area of contact between the liquid and gas and ncourages intimate contact between the phases. The solute in the rich gas is bsorbed by the fresh liquid entering the tower. and dilute or clean gas leaves the

5

cked. The liquid is enriched in solute as it flows down the tower, concentrated uid called the strong liquor, leaves the bottom of the tower through the liquid let.

2.1 Contact Between Liquid and Gas.

The requirement of good contact between liquid and gas is the rdest to meet, especially in large towers. Ideally the liquid, once distributed over top of the packing, flows in thin films overall the packing surface all the way wn the tower. Actually, the films tend to grow thicker in some plates and thinner others, so that the liquid collects into small rivulets and flows along localize path rough the packing. Especially at low liquids rates, much of the packing surface y be dry or at best, covered by a stagnant film or liquid. This effect is known as anneling; it is the chief reason for the poor performance of large packed towers.

Channeling is severe in towers filled with stacked packing, which is the in reason why they are not much used. It has less severe in dumped pickings. In wer of moderate size, channeling can be minimized by having the diameter of the wer at least 8 times the packing diameter. If the ratio of tower diameter to packing ameter is less than 8 to 1, the liquid tends to flow out of the packing and down the lls of the column. Even in small towers filled with packing that meet this quirement, however, liquid distribution and channeling have a major effect on lumn performance. In large towers the initial distribution is especially important, t even with good initial condition or distribution, it is necessary to include distributors for the liquid every 5 to 10m in the tower, immediately above each cked section. Improved liquid distribution has made possible the effective use of cked towers as large as 9m (30ft) in diameter.

2.2 Pressure Drop and Limiting Flow Rates.

The Fig 2.2 below shows typical data for the pressure drop in a packed tower.
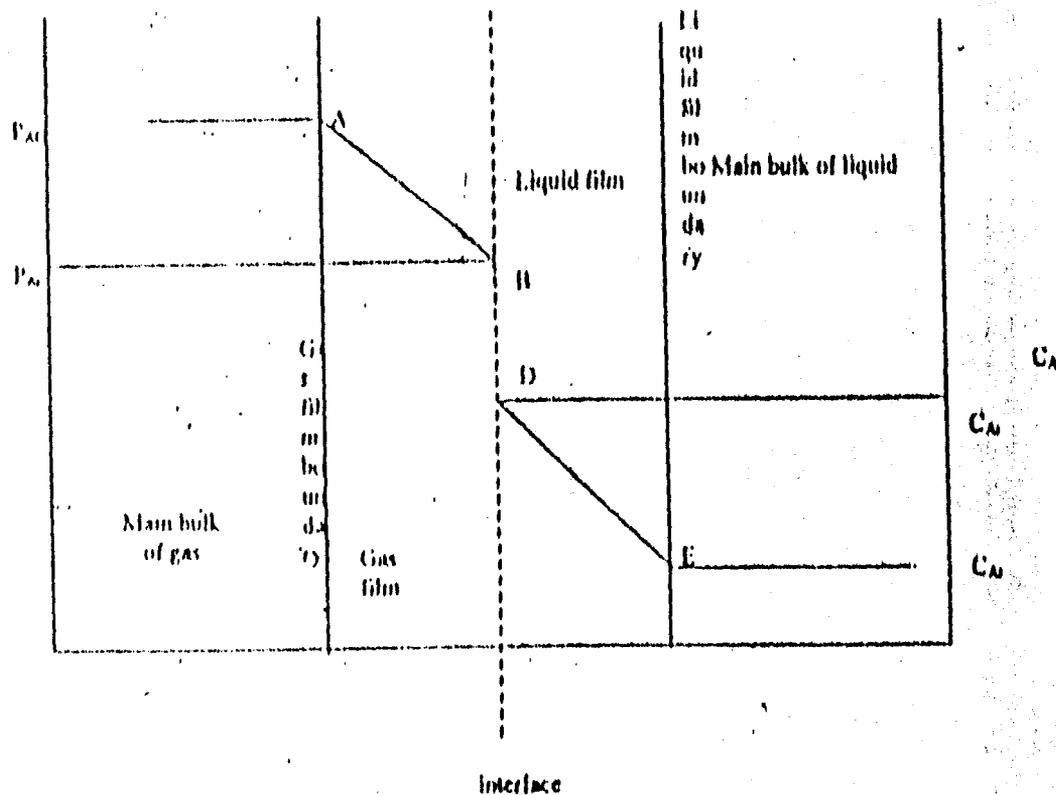
The pressure drop per unit packing depth comes from fluid friction; it is plotted on logarithmic coordinates versus the gas flow rate 'G', expressed in mass of gas per hour unit cross-sectional area, base on the empty tower. Therefore, 'G' is related to the superficial gas velocity by the equation $G = U_o\ell$ where ℓ, is the density of the gas and U_o is the superficial velocity in feet per second. When packing is dry the line so obtained is straight and has a slope of about 1.8. The pressure drop therefore increases with the 1.8 power of the velocity. If the packing is irrigated with constant flow of liquid, the relationship between pressure drop and gas flow rate

7

initially follows a line parallel to that for dry packing. The pressure drop is greater than that in dry parking, because the liquid in the tower reduces the space available for gas flow. The void fraction, however, does not change with gas flow. At moderate gas velocities, the line for irrigated packing gradually becomes steeper, because the gas now impedes the down flowing liquid and the liquid hold up increases with gas rate. The point at which the liquid holdup starts to increase, as judged by change in the slope the pressure drop line, is called the loading point. However, as is evidence from Fig 2.2, it is not easy to get an accurate value for the loading point.

2.3   Principle of Gas Absorption.

The principle of absorption is based on equilibrium, diffusion and mass transfer. Diffusion is the movement, under the influence of a physical stimulus, of an individual component through a mixture. The most common cause of diffusion is concentration gradient of the diffusing component. A concentration gradient tends to move the component in such a direction as to equalize concentrations and destroy the gradient. When the gradient is maintained by constantly supplying the diffusing component to the high-concentration rend of the gradient and removing it at the low-concentration end, the flow of the diffusing component is continuous. This movement is exploited in mass transfer operations. Diffusion can be caused by a pressure gradient, by a temperature gradient or by the application of an external force field. In gas absorption, solute diffuses through the gas phase to the interphase between the phases and through the liquid phase from the interphase. In gas absorption, the diameter of a packed absorption tower depends on the stream of the quantities of gas and liquid handled, their properties, and ratio of one stream to the other. The height of the tower, and hence the total volume of packing, depends on the magnitude of the desired concentration changes and on the rate of mass transfer per unit of packed volume. Calculations of the tower height, therefore, rest on

8

material balances, enthalpy balances, and estimates of driving force and mass transfer coefficients.

2.3.1 Gas and Liquid Flow in Absorption

Flow is one major aspect in absorption system; it is common with the transport of fluid and gas that requires the determination of the pressure drops in any system, measurement of flow rates that has great effects in chemical reactions such as absorption with chemical reaction. We have two types of flow namely; streamline and turbulent flow. In streamline flow, movement across streamline occurs solely as the result of diffusion on a molecular scale and the flow rate is steady. In turbulent flow, the presence of circulating current results in transference of fluid on a larger scale and cyclic fluctuations occur in the flow rate, though the time average rate remain constant.

In absorption column, the gas phase, which may be flowing with a much greater velocity than the liquid, continuously accelerate the liquid, this involving a transfer of energy. If there is no heat transfer to the flowing mixture, the mass rate of flow of each phase will remain substantially constant, though the volumetric flow rates will increase progressively as the gas expands with falling pressure. The mode of flowing of streams can be countercurrent, cocurrent, and cross flow.

2.3.2 Conditions of Absorption Between Solvent and Gas

In the course of two phases being brought into intimate contact, equilibrium is eventually reached. Thus a solvent in contact with a particular gas evaporates until the gas is saturated with the vapour of the solvent, and the solvent absorbs the gas until it becomes saturated with the individual gases. As a rule in any mixture of gases, the extent to which each gas is absorbed is determined by its partial pressure. At a given temperature and pressure, each gas exerts a definite partial pressure. Three types of gases may be considered from this aspect: a very soluble gas, for

instance carbon dioxide, a moderately soluble gas such as sulphur dioxide, and a slightly soluble gas, like oxygen. It has been discovered that a slightly soluble gas requires a much higher partial pressure of the gas in contact with the liquid to give a solution of a given concentration. Conversely a very soluble gas at given concentration is obtained at a lower partial pressure in the vapour phase.

For dilute concentrations of most gases, and over a wide range for some gases, the equilibrium relationship is given by Henry's law, which can be stated mathematically as:

$P_A = {}^*C_A$ .... (2.1)

Where P_A is the partial pressure of the component A in the gas phase, C_A is the concentration of the component in the liquid phase, and. is Henry's constant (Warren L., McCabe, Julian C. Smith).

2.3.3 Mechanism of Absorption

The process of gas absorption is seen explicitly in the two- film theory. According to this theory, material is transferred in the bulk of the phases by conventional currents, and the concentration differences are regarded as negligible though with exception in the vicinity of the interface between the phases. On either side of this interface, it is also supposed that the currents die out and there's the existence of a thin film of fluid through which the transfer is affected solely by molecular diffusion. The film is slightly thicker than the laminar sub layer, because it offers a resistance equivalent to that of the whole boundary layer.

According to Fick's law ($N_A = -D (dC_A/dy)$ .... (2.2)

Where N_A is the molar flux of A (moles per unit area per unit time),

C_A is the concentration of A (moles of A per unit volume)

D is the diffusivity or diffusion coefficient,

y is the distance in the direction of transfer (Richardson & Coulson).

the rate of transfer by diffusion is proportional to the concentration gradient and to the area of interface over which the diffusion is occurring, though this law is limited to where the concentration of the absorbed component is low.

From Fick's law, integrating the equation,

$$N_A (Y_2 - Y_1 J) = -D (C_{A1} - C_{A2}) \dots\dots\dots\dots\dots\dots\dots\dots (2.3)$$

$$N_A = \frac{D (C_{A1} - C_{A2})}{(y_2 - y_1)}$$

Where $D/(y_2 - y_1) = k_L$ is a mass transfer coefficient with the driving force expressed as a difference in molar concentration, therefore

$$N_A = k_L (C_{A1} - C_{A2}) \dots\dots\dots\dots\dots\dots\dots\dots\dots (2.4)$$

At high concentrations bulk flow occurs and high transfer rate; Stefan's law governs this situation.

This law shows explicitly that the absorption of a gas consisting of a soluble and of course insoluble component is a problem of mass transfer, which is encountered at the interface. The direction of transfer of material across the interface is not dependant solely on the concentration difference but also on the equilibrium relationship between the two phases. Thus for a mixture of carbon dioxide or acetone and air, which is in equilibrium with an aqueous solution, the

concentration in the water is as many times greater than that in air. There exists a very big concentration gradient across the interface; though this is not the controlling factor in the mass transfer, as it is assumed that no resistance exists at the interface. The rate of diffusion of the gas is basically the controlling factor as all resistance is considered to lie. The change in concentration of a component through a gas and liquid phase is illustrated in Fig 2.0 shown below:

P_A(Y-axis) = Partial pressure of soluble gas

C_A (X-axis) = Molar concentration of soluble A in liquid

Fig 2.0. Concentration profile for absorbed component A

P_{AG} represents the partial pressure in the bulk of the gas phase and P_{AI} the partial pressure at the interface. C_{AL} is the concentration in the bulk of the liquid phase and C_{AI} the concentration at the interface.

In accordance to the theory, the concentrations at the interface' are at equilibrium, and the resistance to transfer is centered in the thin films on either side of the interface.

2.3.4 Gas Absorption Associated with Chemical Reaction

Gas absorption can be treated as either a physical or chemical process. In a situation in which the gas on absorption reacts chemically with the component in the liquid phase, such process is regarded as chemical gas absorption. Thus in the absorption of carbon dioxide by caustic soda, the carbon dioxide reacts directly with the caustic soda, and the process of mass transfer is thus made more complicated. Again when carbon dioxide is absorbed in ethanolamine solution, there is direct chemical reaction between the amine and the gas. In these processes the conditions in the gas phase is similarly to that of physical absorption processes, but in the liquid phase there exists a liquid zone, followed by a reaction zone.

This can be clearly illustrated by assuming a gas A which is absorbed from a mixture by a liquid or solvent B, according to the equation: A + B → AB. As the gas approaches the liquid interface, it dissolves and reacts at once with B, forming a product AB that diffuses towards the main body of the liquid. The concentration of B at the interface reduces very rapidly and this naturally results

in the diffusion of B from the bulk of the liquid phase to the interface. Since the chemical reaction is very rapid, B is removed very quickly, thus giving way for A to diffuse through the liquid film before meeting B. Thus a zone of reaction is formed between A and B which moves away from the gas-liquid interface, taking up position towards the bulk of the liquid. The final position of the reaction zone will be such that the rate of diffusion of A from the gas-liquid interface will be equal to the rate of diffusion of B from the main body of the liquid (Sharma M. M., 1966).

12

The concentration profile for this process is illustrated in Fig 2.2, where the concentrations are shown as ordinates and the position of the plane relative to interface as abscissa. In the diagram, the plane of the interface between the gas and liquid is shown by U, the reaction zone by R and the outer boundary liquid film by S. it can thus be postulated that A diffuses through the gas film as a result of driving force P_{AG} - P_{Ai} and diffuses to the reaction zone as a result of driving force C_{Ai} in the liquid phase, while the component B diffuses from the main body of the liquid phase to the reaction zone under a driving force q, and a non-volatile product AS diffuses back to the main bulk of the liquid a driving force m-n.
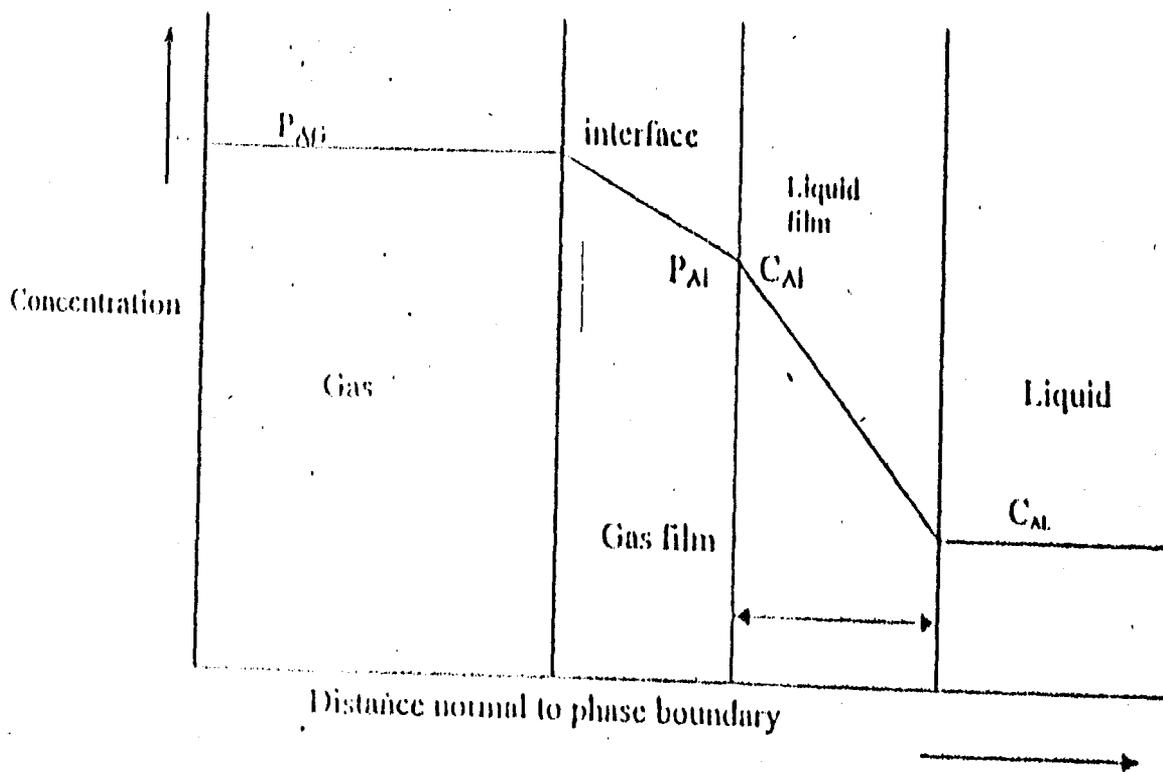
Fig. 2.2 (a) Concentration profile for absorption without chemical reaction.

For transfer in the gas phase: $N'_A = k_G (P_{AG} - P_{Ai})$................ (2.5)

and in the liquid phase: $N'_A = k_L (C_{Ai} - C_{AL})$........................ (2.6)

The effect of the chemical! reaction is to accelerate the removal of A from the interface, and supposing that it is now r times as great then:

$N''_A = r k_L (C_{Ai} - C_{AL})$.. ...(2.7)

13
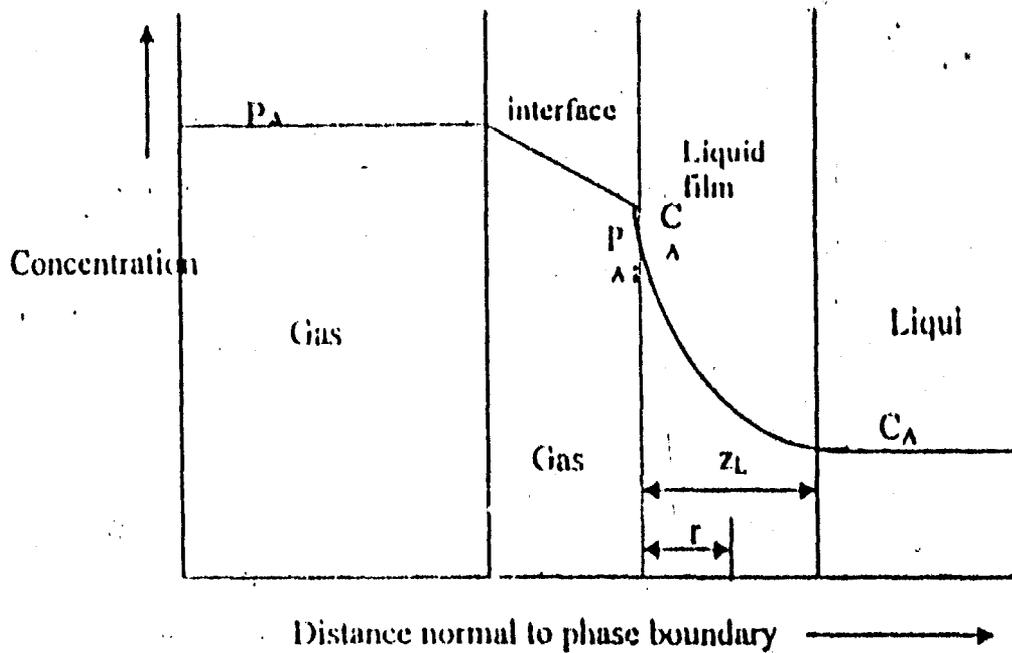
Fig. 2.2 (b) Concentration profile for absorption with chemical reaction.

2.3.5 Rate of Gas Absorption

In the course of a steady process of gas absorption, the rate of mass transfer of gas from the gas phase to the liquid phase can be expressed by the general equation in which a gas component 'A' is being absorbed into a particular solvent. The equation can be stated as follows:

$$N_A = k_G (P_{AG} - P_{AI}) = K_L (C_{AI} - C_{AL}) \quad ....(2.8)$$

Where N_A is the rate of gas absorption, P_{AG} is the partial pressure in bulk of the gas, C_{AL} is the concentration in the bulk of the liquid, and P_{AI} and C_{AI} are the partial pressure and concentration at the interface, where equilibrium is assumed to exist. K_G and k_L are the gas and liquid coefficients, which can only be obtained in very special circumstances, as these values require measurement of the concentrations at the interface. Thus the overall coefficients are used and these are denoted as K_G and K_L, which are the overall gas and liquid coefficient respectively. Inserting these into equation (2) it becomes;

$$N_A = K_G (P_{AG} - P_{AC}) = K_L.(C_{Ae} - C_{AL}.) \quad .... (2.9)$$

In the course of this project work, in order to exhibit an improved rate of CO_2 absorption in monoethanolamine and sodium Hydroxide the overall gas coefficient will be evaluated. The familiar equation used for a packed absorption column is:

$$N_A = K_G V (^\wedge PA)Im \quad\text{.............................. (2.10)}$$

Where V is volume of the packed column and can also be expressed as;

$$V = aAH \quad\text{.................... (2.11)}$$

Where a is the effective interface area per unit packed column, A is the cross sectional area of the tower and H is the packing height.

$(^\wedge PA)Im$ is the log mean driving force, which can also be expressed as

$$(^\wedge PA)Im = In \quad \frac{Pi/Po}{(Pi- Po)} \quad\text{........................ (2.12)}$$

Where Pi and Po are the pressure of CO_2 entering and leaving the tower respectively.' Then putting equations (2.11) and (2.12) into (2.10), the following equation is obtained:

$$N_A = K_G (aAH) \times In \quad \frac{Pi/Po}{(Pi - Po)} \quad\text{... (2.13)}$$

Then making K_G the subject of formula in equation (7), the equation. obtained is:

$$K_G = \frac{N_A}{aAH} \times In \frac{Pi/Po}{(Pi - Po)} \quad\text{... (2.14)}$$

2.3.6 Diffusion through a stagnant gas

The process of absorption may be regarded as the diffusion of a soluble gas A into a liquid. The molecules of A have to diffuse through a stagnant gas film and then through a stagnant liquid film before entering the main bulk of liquid.

The absorption of a gas consisting of a soluble component A and an insoluble component B is a problem of mass transfer through a stationary gas.

In industrial processes, the 'film thickness is not known, so the rate equation:

15

$N'_A = k_G (P_{A1} - P_{A2})$.. (2.15) is used as the gas film transfer coefficient for absorption and is a direct measure of the rate of absorption per unit of interface with a driving force of unit partial pressure difference.

2.3.7 Diffusion in the liquid phase

The rate of diffusion in the liquids is much slower than in the gases, and mixtures of liquids may take a long time to reach equilibrium unless agitated. This is partly due to the much closer spacing of the molecules as a result of which the molecular attractions are more important.

At present, there is no theoretical basis for the rate of diffusion in liquids comparable with the kinetics theory for gases: the basic equation is taken as similar to that for gases that are for dilute concentrations:

$N'_A = -DL \, dC_A/dz$... (2.16)

Since the film thickness is rarely known, therefore,

$N'_A = k_L (C_{A1} - C_{A2})$...(2.17)

Where k_L is the liquid film transfer coefficient, which is usually expressed in m/s.

2.4 Carbon Dioxide Gas

The chemical compound carbon dioxide, or CO_2, is an atmospheric gas composed of one carbon and two oxygen atoms. Carbon Dioxide thus is one of the two oxides of carbon; it is a colourless, odourless, slightly toxic and slightly pungent acid-tasting gas, sometimes called carbonic acid gas, the molecule of which consists of one atom of carbon joined to two atoms of oxygen (CO_2). Carbon dioxide is a small but important constituent of air. Its typical concentration is about 0.03% or 300 ppm. The carbon dioxide, which is present in the atmosphere, is produced by respiration and by combustion. However, it has a short residence time in this phase, as it is both consumed by plants during photosynthesis.

16

At normal temperatures and pressures, carbon dioxide is a colou.rless gas, with a slightly pungent odor at high concentrations. When compressed and cooled to the proper temperature, the gas turns into a liquid. The liquid in turn can be converted into solid dry ice. The dry ice, on absorbing heat, returns to its natural gaseous state.

Exhaled air contains about carbon dioxide. Carbon dioxide is a by-product of cellular metabolism that is eliminated by the lungs (Wikipedia Encyclopedia).

2.4.1 Properties of Carbon dioxide

2.4.1.1 Physical Properties

a. Carbon dioxide is a colourless, odourless gas, its density at 298K is 1.98 kg/m^3 , about 1.5 times that of air. It has a weight of 44gram/mol.

b. Carbon dioxide is soluble in water, ethanol and acetone.

c. Carbon dioxide has a melting point of -55°C and a boiling point of -78.5$^{\text{O}}$C at high pressures of 216k and 197k respectively.

d. Carbon dioxide gas turns damp blue litmus paper pink.

e. Carbon dioxide can be reduced to a liquid and solid form by intense pressure. At standard pressure, it is never liquid: it directly passes between the gaseous and solid phase at -78$^{\text{O}}$C in a process called sublimation (Wikipedia Encyclopedia).

2.4.1.2 Chemical Properties

i. Carbon dioxide has a chemical formula of CO_2 and is a linear covalent molecule.

ii. The carbon dioxide molecule O=C=O contains two and has a linear shape. It has no electrical dipole.

iii. Carbon dioxide is an acidic oxide and reacts with water to give carbonic acid.

$$CO_2 + H_2O \rightarrow H_2CO_3 \dots\dots\dots\dots\dots\dots\dots\dots\dots(2.18)$$

iv. Carbon dioxide reacts with alkalis to give carbonates and bicarbonates. The carbonic acid in turn dissociates partly to form bicarbonate and carbonate ions.

$$CO_2 + NaOH \rightarrow; NaHCO_3 \quad \text{..} \quad (2.19)$$

$$NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O \text{..........................} (2.20)$$
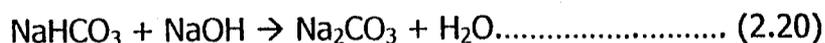
v. Carbon dioxide is reduced to carbon monoxide when passed over red-hot carbon.

$$CO_2 + C \rightarrow 2CO_2 \quad \text{....................}(2.21)$$

2.4.2 Synthesis of Carbon dioxide Gas

Methods of preparation of Carbon dioxide gas can either be via laboratory synthesis or industrial production.

2.2.4 Applications of Carbon Gas.

Carbon dioxide is a versatile material, being valued by various users for its reactivity, inertness and coldness.

❖ **Chemicals, Pharmaceuticals and Petroleum:**

Large quantities are used as raw material in the chemical process industries, especially for methanol and urea production.

Carbon dioxide is used to prime oil wells for oil extraction and maintain pressure within a formation. When CO_2 is pumped into an oil well, it is partially dissolved into the oil, rendering it less viscous, so that the oil can be extracted more easily from the bedrock. Considerably more oil can be extracted through this process.

❖ **Food and Beverages:**

Liquid or solid carbon dioxide is used for quick freezing, surface freezing, chilling and refrigeration in the transport of foods. In cryogenic tunnel and spiral freezers, high pressure liquid CO_2 is injected through nozzles that convert it to a mixture of CO_2 gas and dry ice "snow" that covers the surface of the food product. As it sublimates (goes directly from solid to gas states) refrigeration is transferred to the product.

Carbon dioxide gas is used to carbonate soft drinks, beers and wine and to prevent fungal and bacterial growth.

It is used as an inert "blanket", as a product-dispensing propellant and an extraction agent. It can also be used to displace air during canning.

❖ Multi-Industry Uses:

Carbon dioxide in solid and in liquid form is used for refrigeration and cooling. It is used as an inert gas in chemical processes, in the storage of carbon powder and in fire extinguishers.

❖ Health Care:

Carbon dioxide is used as an additive to oxygen for medical use as a respiration stimulant.

❖ Other Uses

Carbon dioxide extinguishes flames, and some fire extinguisher contains pressured liquid carbon dioxide. Life jackets often contain capsules of pressured liquid carbon dioxide used for quick inflation.

2.5 Monoethanolamine

Monoethanolamine (MEA) is a colourless, hygroscopic and moderately viscous liquid with a mild ammoniacal odour. The chemical compound belongs to the family of organic compounds known as the Alkanolamines, which also include diethanolamine, and triethanolamine amongst others. Monoethanolamine combine the properties of amines and alcohols, thus they exhibit the unique capability of undergoing reactions common to both groups. As amines, they are mildly alkaline and react with acids to form salts or soaps. As alcohols, they are hygroscopic and can be esterified. The chemical structure of Monoethanolamine is $H_2NCH_2CH_2OHNH_2$.

Monoethanolamine find uses in such diverse areas as gas sweetening, 'where they serve as lubricant and scouring agents; detergent and specialty cleaner formulations, in which they are used to form various amine salts and, to control pH;

and in a host of other applications including concrete admixtures, pharmaceuticals, personal care products, agricultural chemicals, photographic emulsions, and more (Mather A. E., 1995) .

2.5.1 Properties of Monoethanolamine.

Monoethanolamine exhibits properties which enable the compound to be utilized in a broad range of applications. Typical properties of monoethanolamine are shown in the following text:

i.   The molecular weight is 61.08g.

ii.   Monoethanolamine is a colourless, hygroscopic compound.

iii.   Apparent specific gravity at $20/20^0C$ is 1.017.

iv.   Boiling point of Monoethanolamine is 172°C.

v.   Vapour pressure at 20^0C is 1.017

vi.   Freezing point is 10.5^0C

vii.   The compound is completely soluble in water, and in some organic solvents such as acetone and benzene.

viii.   Absolute viscosity at 20°C, is 24cP (Dang H. Y., 2001)

2.5.2 Characteristics of Monoethanolamine as a Good Gas Absorbent

i.   Mass-transfer (Kinetics)

CO$_2$ absorption with a chemically reacting solvent involves mass transfer with chemical reaction. The role of the chemical reaction is to speed up the mass transfer rate as well as to provide greater solvent loading capacity at lower CO$_2$ partial pressure conditions. The reaction between dissolved CO$_2$ and monoethanolamine is reversible and proceeds through a series of reactions. In general, the chemical reaction proceeds forwards in the absorption direction under low temperature and high partial pressure conditions and reverses in the desorption (regeneration) direction under high temperature and low partial pressure conditions. Ideally, higher reaction rate constants for both the forward and the reverse reactions are favorable;

this will allow the absorption and regeneration to be accomplished within as short a time period. The forward reaction is exothermic while the reverse reaction is endothermic (Tontwachuthikul P., 1998).

ii.   Solvent Working Capacity

Monoethanolamine exhibits a high equilibrium loading of carbon dioxide gas, and thus indicating a good regenerating capacity. This also shows that the solvent requires a lower solvent circulation rate, which enhances the rate of gas absorption, and thus is a good solvent for the process of CO_2 absorption.

iii. Solvent Corrosiveness

Monoethanolamine from its characteristics exhibits a low level of corrosiveness and thus generally, the use of highly concentrated monoethanolamine solutions for CO_2 absorption can lower the energy required for solution regeneration, and thus consequently reduce the effect of corroding the absorber or reactor (Tontwachuthikul P., 1998).

2.5.3 Applications of Monoethanolamine

❖ **Monoethanolamines for Gas Sweetening**

Monoethanolamine is commonly used for treating synthesis gas streams formed in ammonia, hydrogen, carbon monoxide, and flue gas facilities. Carbon dioxide is the principal contaminant that is removed.

❖ **Monoethanolamine for detergents, specialty cleaners and personal care products**

Monoethanolamine is used in heavy-duty liquid laundry detergents because it provides a unique combination of beneficial property and performance qualities.

❖ **Monoethanolamines for textiles**

Monoethanolamines are also used as dye auxiliaries.

❖ **Other Monoethanolamine applications**

Some other areas in which Monoethanolnmine are utilized include as follows:

i. It is used as a pH control agent in the formulation of packaging and printing inks.

ii. It is used in the manufacture of flexible and rigid urethane foams

iii. Salts of monoethanolamine are used in the production of herbicides and intermediates in the agricultural sector.

iv. It also functions as an intermediate for the manufacture of adhesives and rubber chemicals (Hitika H., 1977).

2.6 Absorption of CO_2 gas in Monoethanolamine

Aqueous monoethanolamine (MEA) is widely used for removing carbon dioxide (CO_2) from natural gas streams and refinery process streams. It is also used to remove CO_2 from combustion gases and may receive wide application for abatement of greenhouse gases. MEA is a relative strong base with a fast reaction rate, yielding a low CO_2 concentration. Primary amines such as monoethanolamine dominantly produce carbonate (Sharma M. M., 1965).

Based on current technologies, the gas absorption with a chemical reaction process using amine is considered to be the most cost effective and has the best proven operability record. However, the cost of absorption using conventional solvents such as aqueous solutions of monoethanolamine (MEA) is still relatively high. A major reason for the high cost is that the conventional solvents introduce a variety of practical problems including:

(i) A high energy consumption for the solvent regeneration.

(ii) A high rate of corrosion of the process equipment.

(iii) A fast evaporation rate causing high solvent losses (Bavebek O., 1999).

(iv)   A high rate of degradation in the presence of oxygen. All these problems translate into high capital and operating costs.

One way to reduce the process cost is the use of better solvents in the CO_2 separation process. These solvents should have higher CO_2 Absorption capacity as well as faster CO_2 Absorption rates, thus the addition of sodium hydroxide, which serves a positive purpose of reducing the problem of regeneration of monoethanolamine in the process of absorption, and also enhances the rate of absorption of CO_2 gas into the solvent via reduction of resistance to mass transfer of CO_2 gas to the solvent. The reaction mechanism between monoethanolamine and CO_2 gas, using a blend sodium. Hydroxide as promoter will be of a magnitude higher than that of MEA with CO_2. Therefore a mixture of MEA and sodium hydroxide should absorb CO_2 faster than MEA alone.

In addition, it has been also generally adopted that the reaction of CO_2 with primary alkanolamines like monoethanolaminc, with a blend of another base can be described by the zwitterions mechanism; the general consensus for the reaction is the formation of zwitterions intermediate, rather than one-step carbonate formation. As CO_2 passes over MEA solution the following reactions occurs;

$$HOCH_2\,CH_2NH_2 + H_2O + CO_2 \rightarrow HO\,CH_2\,CH_2NH_3\,HCO_3$$
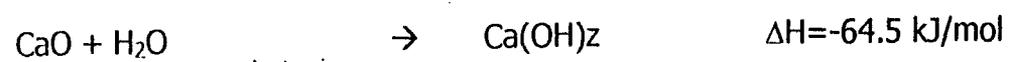
2.7   NaOH as an Absorbent

Using NaOH, also known as caustic soda, as the absorbent in the CO_2 removal process. NaOH is an ideal absorbent because of its high reactivity with carbon dioxide. As carbon dioxide passes over the NaOH solution the following reaction occurs.

$$NaOH + CO_2 \rightarrow NaHCO_3 \; \Delta H = -171.8 \; kJ/mol$$

The resulting sodium carbonate remains dissolved in water. An advantage to using caustic soda is that it is regenerable with the presence of calcium hydroxide $(Ca(OH)_2)$. The following reactions take place in the regeneration process of NaOH.

23

$$Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3 \quad \Delta H = 57.1 \text{ kJ/mol}$$

$$CaCO_3 \rightarrow CaO + CO_2 \quad \Delta H = 179.\text{lkllmol}$$

$$CaO + H_2O \rightarrow Ca(OH)z \quad \Delta H = -64.5 \text{ kJ/mol}$$
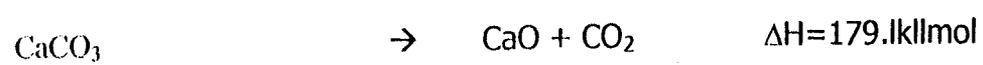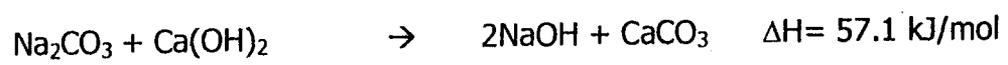
Calcium hydroxide helps regenerate the NaOH solution when the NaOH's capacity is reached. In order for this to happen, calcium oxide (CaO) is added to the solution. The CaO reacts with water to form $Ca(OH)_2$, the end result is that more NaOH.

CHAPTER THREE

METHODOLOGY AND EXPERIMENT PROCEDURE

3.1 Methodology

The experiment was carried out in a packed tower of a cocurrent flow pattern between the gas and the liquid.

The device consist of a cylindrical column, or tower, equipped with the gas inlet and distributing space at the top; a liquid inlet and distributor at the top; gas and liquid outlets at the bottom; and a supported mass of inlet solid shapes called tower packing.

The liquid entering the top of the column was a mixture of Monoethanolamine and Sodium Hydroxide solution, the distributor distributes this liquid over the top of the packing. The gas stream enters the distributing space from the top too and flow downwards through the interstices in the packing with liquid. This is called a cocurrent packed tower where the gas flows in the same direction with liquid at the same time solute of the gas stream is absorbed by the liquid. The liquid is enriched in solute as it flows down the tower and become concentrated liquid and leaves the bottom of the tower through the liquid outlets.

3.2 Equipment

In carrying out the laboratory analysis in this project work, the following equipments were used:

i. Gas-liquid Absorption Column

Description: The gas liquid absorption column consists of a 75mm diameter column in which there are two lengths of Raschig ring packing material. Pressure tapings are provided at the base, center and top of the column to determine pressure drop across the column. Sampling points are also provided for gas at the some three points. The liquid outlet stream and feed solution are also equipped with sampling

25

points. Suitable manometric measurement is included. The apparatus is deigned to absorb carbon dioxide/air mixture into aqueous solution flowing down the column.

Fig. 3.1 A Schematic Diagram of Gas Absorption Column System
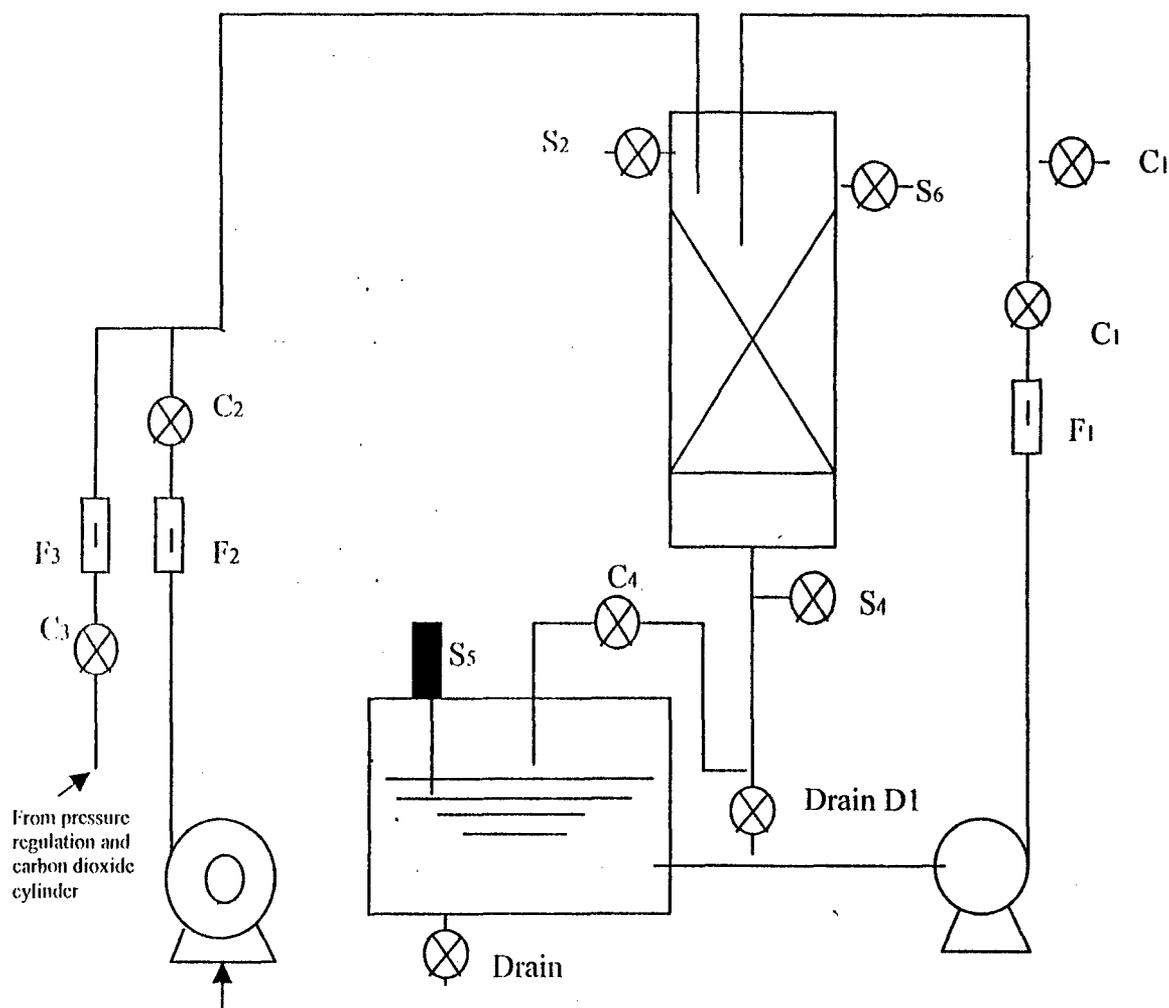
ii. Syringe

Description/Use: This was used in the course of caring out the solution analysis, basically for titiating the mixture of MEA and NaOH solution containing CO_2 with the hydrochloric acid.

iii. Measuring Cylinder

Description/Use: a measuring cylinder was used basically for measuring the volume of the feed and outlet solution.

iv. Stop watch

Description/Use: This was used to measure lime, as the experiment was carried out at intervals.

v. Weighing Balance

Description/Use: A digital weighing balance was used for carrying out weights of samples in the course of the experiment.

vi. Conical Flask

Description/Use: This was used in the course of titration, which was carried out during analysis of rich lye.

vii. Gas cylinder

Description/Use: This equipment holds the CO_2 gas, which is the raw material for the absorption process.

viii. Jerican.

ix. Bucket.

x. Wash bottle.

xi. Beaker.

3.3   Chemicals/ Materials

i. Monoethanolamine(0.1M)

ii. Sodium Hydroxide (0.1M)

iii. Methyl Orange Indicator

iv. Phenolphthalein Indicator

v. 0.5M Hydrochloric acid

vi. Carbon dioxide gas

vii. Distilled water.

3.4 Experimental Procedure.

The experimental procedures involved in this project work is splitted into three parts.

i.   Preparation of the feed solvent, that is the mixture of
        Monoethanolamine and Sodium Hydroxide solution.

ii.   Absorption of Carbon-dioxide gas into the mixture of Monoethanolamine and Sodium Hydroxide solution.

iii.   Analyses of the solution containing carbon dioxide.

3.4.1 Preparation of Monoethanolamine and Sodium Hydroxide mixture.

The liquid was prepared via mixing of 0.1M of both MEA and NaOH solution but by varying their composition.

3.4.2 Absorption Process in the Column.

In this section of the experimental procedure, Carbon dioxide gas was absorbed in Monoethanolamine and Sodium Hydroxide mixture. The set up for carrying out this experiment is shown in Fig 3.1, and the following procedures were taken in carrying this out:

i.   First the reservoir at the base of the column was filled with 20litres of mixture of monoethanolamine and sodium Hydroxide solution (of desired composition).

ii.   Then with the gas flow control valves C_2 and C_3 closed, the liquid pump was started and the flow of mixture of MEA and NaOH solution was adjusted to the desired flow rate. The solution was allowed to circulate in order to ensure that the column reached equilibrium with the temperature of the MEA solution.

iii.   The compressor was started and the valve C_2 was adjusted to give an air flow rate of 20liters/min on the flow meter F_2.

iv.   Then the pressure regulating valve on the carbon-dioxide cylinder was carefully opened and the valve C_3 was adjusted to give a flow rate of 6 liters/min on the flow meter F_3.

v.   After 10 minutes of steady operation, samples were taken at an interval of 10 minutes simultaneously from sump tank (S_4) and liquid outlet (S_5), these samples were later analyzed.

28

3.4.3 Analysis of Liquid Solution Containing Co_2 Gas.

The solution containing absorbed CO_2 gas, sampled from the liquid outlet at the bottom of the column and the sump tank were analyzed with the sole intent of obtaining the amount of CO_2 absorbed in the solution of MEA and NaOH mixture.

To carry out the analysis, the following equipment were used; conical flasks, syringe and measuring cylinder.

Reagents used were 0.5M Hydrochloric acid, Phenolphthalein and Methyl Orange indicator.

The following procedures were undertaken in the course of carrying out this analysis.

i.   Samples of liquid were collected from the absorption column at interval of 10 minutes, from the liquid outlet and sump tank simultaneously. These samples were placed in two separate conical flasks marked S_4 and S_5 for easy identification.

ii.   To the flask marked, two drops of phenolphthalein indicator was added to acquire purple colour in the solution and then titrated with acid until there was a colour change indicating the end point of the reaction. The volume of acid added to neutralize the solution was noted and recorded as V_p.

iii.   Two drops of methyl orange solution was added to the solution in flask S_4 and S_5 and also titrated with acid until there was a colour change indicating the end point of reaction. The amount of acid added to neutralize the solution was noted and recorded as V_m. Therefore the total volume of acid used for complete neutralization of the solution is given by $V_p - V_m$ which is represented by V.

The concentration of solution rich in CO_2 and the amount of CO_2 absorbed were calculated as follows:

The concentration of the solution rich in CO_2 is obtained by the equation

$$CN = (V \times 0.5)/50 \quad ....(3.1)$$

And the amount of CO_2 absorbed is calculated by this equation

$$\text{Liquid flow rate} \times (CN_{out} - CN_{in}) \quad ....(3.2)$$

Where,

CN_{out} is the concentration of the liquid collected from the liquid outlet (S_5). CN_{in} is the concentration collected from the sump tank (S_4).

3.5 Precautions

The following precautions were taken while running the experiment

i.   It was ensured that there were no leakages of the tubes used, to avoid error in calculating the amount of CO_2.

ii.   The various solvent used were carefully measured to avoid error due to Parallax.

iii.   The airflow rate was monitored and readjusted during the experiment as It has a tendency to drift.

iv.   It was ensured that samples were gradually titrated with Hydrogen Chloride to avoid values exceeding the end point.

CHAPTER FOUR

RESULTS AND DISCUSSION OF RESULTS

4.1 Results

The Results of the experiment are tabulated below:

Table 4.1: Effect of Contact Time on the Amount of CO_2 Absorbed for Ratio 1:1 of MEA and NaOH.

Contact Time (Min)	Concentration of $NaHCO_3$ + $HOC_2NH_3HCO_3$		Amount of CO_2 absorbed (gmol)
	S_4(in)	S_5 (out)	
10	0.026	0.079	0.0053
20	0.044	0.132	0.0088
30	0.054	0.162	0.0108
40	0.059	0.177	0.0118
50	0.062	0.188	0.0125

Table 4:2 Effect of Contact Time on the Amount of CO_2 Absorbed for Ratio 1:0.66 of MEA and NaOH.

Contact Time (Min)	Concentration of $NaHCO_3$ + $HOC_2H_4NH_3HCO_3$		Amount of CO_2 absorbed (gmol)
	S_1 (in)	S_5 (out)	
10	0.030	0.073	0.007
20	0.054	0.163	0.0109
30	0.065	0.196	0.0131
40	0.069	0.208	0.0139
50	0.07	0.216	0.0144

Table 4:3 Effects of Contact Time and on the Amount of CO_2 for Ratio 1:0.25 of MEA and NaOH.

Contact Time (Min)	Concentration of $NaHCO_3$ + $HOC_2NH_3HCO_3$		Amount of CO_2 absorbed (gmol)
	S_4(in)	S_5 (out)	
10	0.041	0.121	0.0081
20	0.060	0.181	0.0121
30	0.071	0.214	0.0143
40	0.075	0.220	0.015
50	0.077	0.233	0.0155

Table 4.4: Comparison of Effects of Contact Time and Absorbent Composition on Absorption of CO_2.

Contact Time (Min)	Amount of CO_2 Absorbed (g mol)		
	1:1	1:0.66	1:0.25
10	0.0053	0.007	0.0081
20	0.0088	0.0109	0.0121
30	0.0108	0.0131	0.043
40	0.0118	0.0139	0.015
50	0.0125	0.0144	0.0155

4.2   Discussion of Results

The effect of the altered parameters on CO_2 absorption is discussed as follows:

The experimental results of this project are as shown in Table 4.1 to 4.3. These tables confirmed the amount of CO_2 absorbed at different composition of Monoethanolamine (MEA) and Sodium hydroxide (NaoH) mixture at contact time of 10 to 50 minutes. For instance, in Table 4:1, when the time is 10 minutes the amount of CO_2 absorbed was found to be 0.053gmol while as the time increases to 20 minutes amount of CO_2 absorbed increase to 0.008gmol, as time increases to 40 minutes there was a substantial increase in the amount of CO_2 absorbed but when the time gets to 50 minutes there was no substantial increase in the amount of CO_2 absorbed. The same principle is applicable to Table 4.2 and 4.3.

In Table 4.2, the amount of CO_2 absorbed when the composition of Monoethanolamine and Sodium Hydroxide was in the ratio 1:66 (i.e 60% MEA and 40% NaoH) are shown. The result revealed that the amount of CO_2 are higher than that of ratio 1:1 of MEA and NaoH respectively. For instance, the amount of CO_2 absorbed at contact time of 10 minute is found to be 0.007gmol. While 0.0109, 0.0131, 0.0139 and 0.0133 of CO_2 are absorbed respectively for contact time of 20, 30, 40 and 50 minutes. This shows that the more the composition of Monoethanolamine in the absorption mixture the more the amount of CO_2 absorbed.

The trend of CO_2 absorbed shows that the amount CO_2 absorbed increases as time increases and as composition of MEA is higher than that of NaOH. For instance when the contact time was 40 minute, for ratio 1:0.60 of MEA and NaoH, the amount of CO_2 absorbed was found to be 0.0139gmol while that of contact time of 50 minutes, for the same ratio was found to be 0.0144gmol.

The Comparison between the amount of CO_2 absorbed at different compositions of MEA and NaOH are shown in table 4.4. The observation from the results show that the amount of CO_2 absorbed per unit time increases. This

observation was more pronounced for ratio 1:0.25 which indicated that the amount of CO_2 was rapidly absorbed.

The pattern for the amount of CO_2 absorbed using different compositions of MEA and NaOH as the absorbent are depicted by Figure 4.1 to 4.3.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the results obtained in the course of conduction of close study of effects of absorbent composition and contact time on absorption of CO_2 in Monoethanolamine and sodium hydroxide mixture, the following conclusions were obtained.

There was a substantial increase in the amount CO_2 absorbed within the time of 10 minutes to 40 minutes. As time increases to 50 minutes, CO_2 was absorbed but not in a substantial amount. Therefore it is more economical to carry out CO_2 absorption process within the time of 10 minutes to time 40 minutes.

Increase in composition of one of the absorbent also enhances the amount of CO_2 absorbed. This can be seen clearly from the results obtained in this project work.

5.2 Recommendation

For further study of CO_2 absorption in Monoethanolamine and Sodium Hydroxide mixture under cocurrent flow pattern, the following recommendations are necessary:

    i.   The percentage of Sodium Hydroxide should be higher than that of Monoethanolamine to see the effect such would have on the absorption process.

    ii.   The gas flow rate should also be varied and the effects of such change on the process studied.

Another absorbent should be blended with the mixture to see the effects such would have on absorption process.

To calculate the concentration of $NaHCO_3 + HOC_2H_4NH_3HCO_3$

The following formula was used.

$$\text{Concentration} = \frac{V \times 0.5M}{50 \times 1}$$

Where V is the volume difference between the little value when phenolpthallin was

used and little value when methylorange was used.

i.e. $V = Vp - Vm$

Where Vp is the litre value when phenolpthalin was used.

0.5M = was used concentration of Hcl

50ml = volume of the sample

Concentration of $NaHCO_3 + HOC_2H_4NH_3HCO_3$ in the inlet stream

(S4) for ratio 1:1 of MEA and NaOH

$(Cin)_{10} = \dfrac{(3.9 - 1.3) \times 0.5}{50} = 0.026$

$(Cin)_{20} = \dfrac{(6.6 - 2.2) \times 0.5}{50} = 0.044$

$(Cin)_{30} = \dfrac{(8.1 - 2.7) \times 0.5}{50} = 0.054$

$(Cin)_{40} = \dfrac{8.8 - 2.9) \times 0.5 \times 0.5}{50} \quad 0.059$

$(Cin)_{50} = \dfrac{(9.3 - 3.1) \times 0.5}{50} = 0.062$

Concentration of $NaHCO_3 + HOC_2H_4NH_3HCO_3$ in the outlet stream (S5) for ratio 1:1 of

MEA and NaOH and NaoH respectively.

$(Cout)w = \dfrac{(11.8 - 3.9) \times 0.5}{50} = 0.079$

$(Cout)20 = \dfrac{(198 - 6.6) \times 0.5}{50} = 0.0132$

$(Cout)30 = \dfrac{(24.3 - 8.1) \times 0.5}{50} = 0.162$

$(Cout)40 = \dfrac{(26.5 - 8.8) \times 0.5}{} = 0.177$

$$(Cout)\ 50 \quad = \quad \frac{(28.2 - 9.4) \times 0.5}{50} \quad = \quad 0.188$$

The quantity of CO_2 absorbed for ratio 1:1 of MEA and NaOH .

CO_2 (absorbed) = (Cout – Cin) x liquid flow rate = 60 litre/min = 0.1 litre/sec.

$(CO_2$ absorbed$)_{10}$ = (0.079 – 0.026) x 0.1 = 0.0053

$(CO_2$ absorbed$)_{20}$ = (0.132 – 0.044) x 0.1 = 0.088

$(CO_2$ absorbed$)_{30}$ = (0.162 - 0.054) x 0.1 = 0.0108

$(CO_2$ absorbed$)_{40}$ = (0.177 – 0.059) x 0.1 = 0.0118

$(CO_2$ absorbed$)_{50}$ = (0.188 – 0.062) x 0.1 = 0.0125

Concentration of $NaHCO_3$ + $HOC_2H_4NH_3HCO_3$ in the inlet stream (S4) for ratio 1:0.66

of MEA and NaOH.

$$(CIN)_{10} \qquad \frac{(4.5 - 1.5) \times 0.5}{50} \quad = \quad 0.030$$

$$(CIN)_{20} \qquad \frac{(8.1 - 2.7) \times 0.5}{50} \quad = \quad 0.054$$

$$(CIN)_{30} \qquad \frac{(9.7 - 3.3) \times 0.5}{50} \quad = \quad 0.065$$

$$(CIN)_{40} \qquad \frac{10.3 - 3.4) \times 0.5}{50} \quad = \quad 0.069$$

$$(CIN)_{50} \qquad \frac{(10.5 - 3.5) \times 0.5}{50} \quad = \quad 0.07$$

Concentration of $NaHCO_3$ $HOC_2H_4NH_3HCO_3$ in the outlet stream (S5) for ratio 1:0.66 of

MEA and NaoH.

$$(Cout)_{10} \quad = \quad \frac{(10.9 - 3.6) \times 0.5}{50} \quad = \quad 0.073$$

$$(Cout)_{20} \quad = \quad \frac{(24.4 - 8.1) \times 0.5}{50} \quad = \quad 0.163$$

$$(Cout)_{30} \quad = \quad \frac{(29.4 - 9.8) \times 0.5}{50} \quad = \quad 0.196$$

$$(Cout)_{40} \quad = \quad \frac{(31.2 - 10.4) \times 0.5}{50} \quad = \quad 0.208$$

$$(Cout)_{50} \quad = \quad \frac{(32.4 - 10.6) \times 0.5}{50} \quad = \quad 0.216$$

The quantity of CO_2 absorbed for ratio 1:0.66 of MEA and NaOH.

CO_2 (absorbed) = (Cout − Cin) x liquid flow rate

$(CO_2$ absorbed$)_{10}$ = (0.073 − 0.030) x 0.1 = 0.007

$(CO_2$ absorbed$)_{20}$ = (0.163 − 0.054) x 0.1 = 0.0109

$(CO_2$ absorbed$)_{30}$ = (0.196 − 0.065) x 0.1 = 0.0131

$(CO_2$ absorbed$)_{40}$ = (0.208 − 0.069) x 0.1 = 0.0139

$(CO_2$ absorbed$)_{50}$ = (0.216 − 0.07) x 0.1 = 0.155

Concentration of $NaHCO_3$ + $HOC_2H_4NH_3HCO_3$ in the inlet stream (s_4) for ratio 1:0.25 of MEA and NaOH.

$$(C_{IN})_{10} = \frac{(6.1 - 2.0) \times 0.5}{50} = 0.041$$

$$(C_{IN})_{20} = \frac{(9 - 3.0) \times 0.5}{50} = 0.060$$

$$(C_{IN})_{30} = \frac{(10.6 - 3.5) \times 0.5}{50} = 0.071$$

$$(C_{IN})_{40} = \frac{(11.2 - 3.7) \times 0.5}{50} = 0.075$$

$$(C_{IN})_{50} = \frac{(11.5 - 3.9) \times 0.5}{50} = 0.077$$

Concentration of $NaHCO_3$ + $HOC_2H_4NH_3HCO_3$ in the outlet stream (s_4) for ratio 1:0.25 of MEA and NaOH.

$$(C_{OUT})_{10} = \frac{(18.1 - 6.0) \times 0.5}{50} = 0.121$$

$$(C_{OUT})_{20} = \frac{(27.1 - 9.0) \times 0.5}{50} = 0.181$$

$$(C_{OUT})_{30} = \frac{(32.1 - 10.7) \times 0.5}{50} = 0.214$$

$(C_{OUT})_{40} = \dfrac{(33.0 - 11.0) \times 0.5}{50} = 0.220$

$(C_{OUT})_{50} = \dfrac{(34.9 - 11.6) \times 0.5}{50} = 0.233$

The quantity of CO_2 absorbed for ratio 1:0.25 of MEA and NaOH.

$(CO_2 \text{absorbed}) = (C_{OUT} - C_{IN}) \times$ liquid flow rate

$(CO_2 \text{absorbed})_{10} = (0.121 - 0.041) \times 0.1 = 0.0081$

$(CO_2 \text{absorbed})_{20} = (0.181 - 0.060) \times 0.1 = 0.0121$

$(CO_2 \text{absorbed})_{30} = (0.214 - 0.071) \times 0.1 = 0.0143$

$(CO_2 \text{absorbed})_{40} = (0.220 - 0.075) \times 0.1 = 0.015$

$(CO_2 \text{absorbed})_{50} = (0.233 - 0.077) \times 0.1 = 0.0155$

0.0125
0.0118
0.0113
0.0108
0.010
0.0088
0.0053
0.005

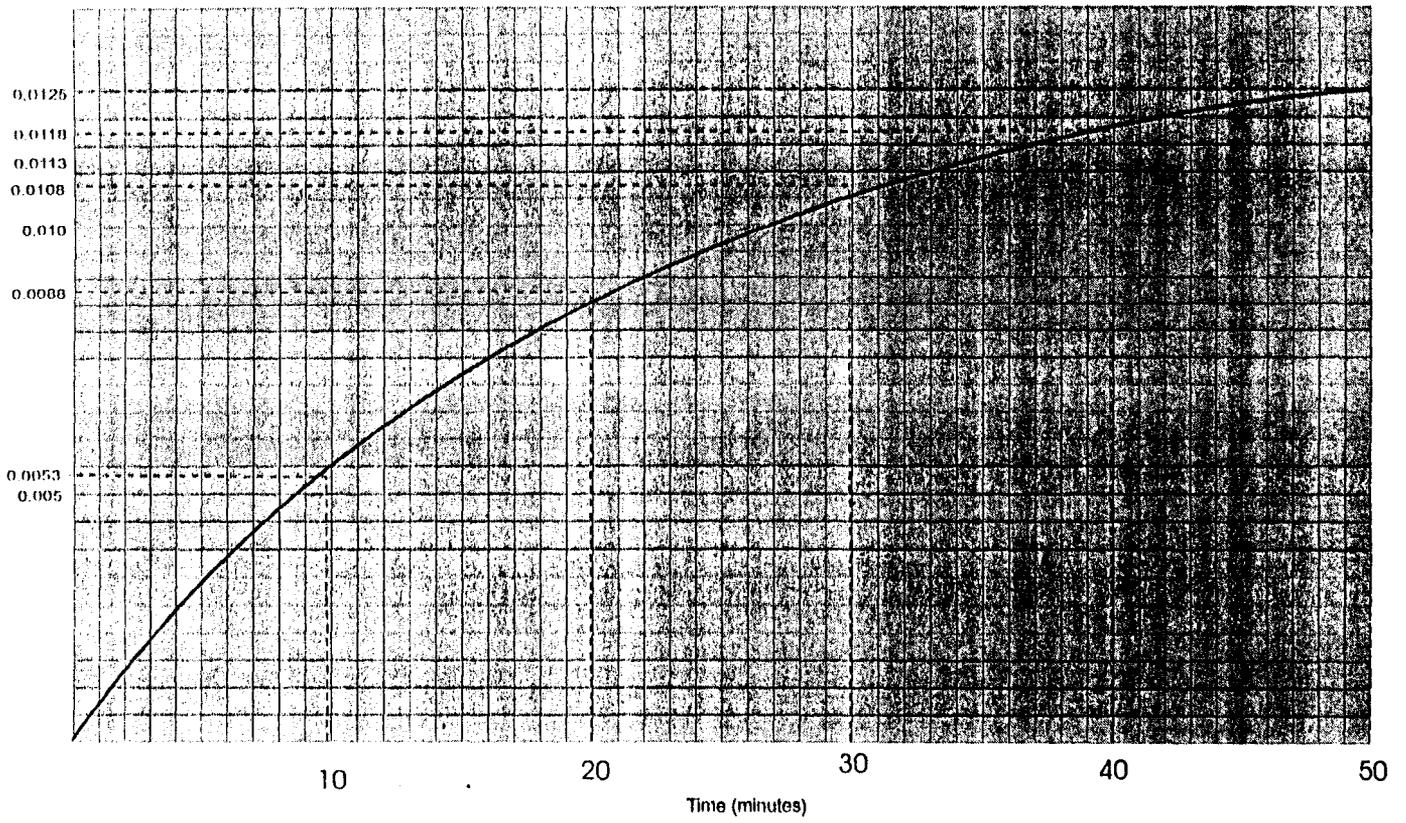10   20   30   40   50

Time (minutes)

Fig. 4.1 Effect of Contact Time on the amount of CO_2 absorbed for ratio 1:1 of MEA and NaOH
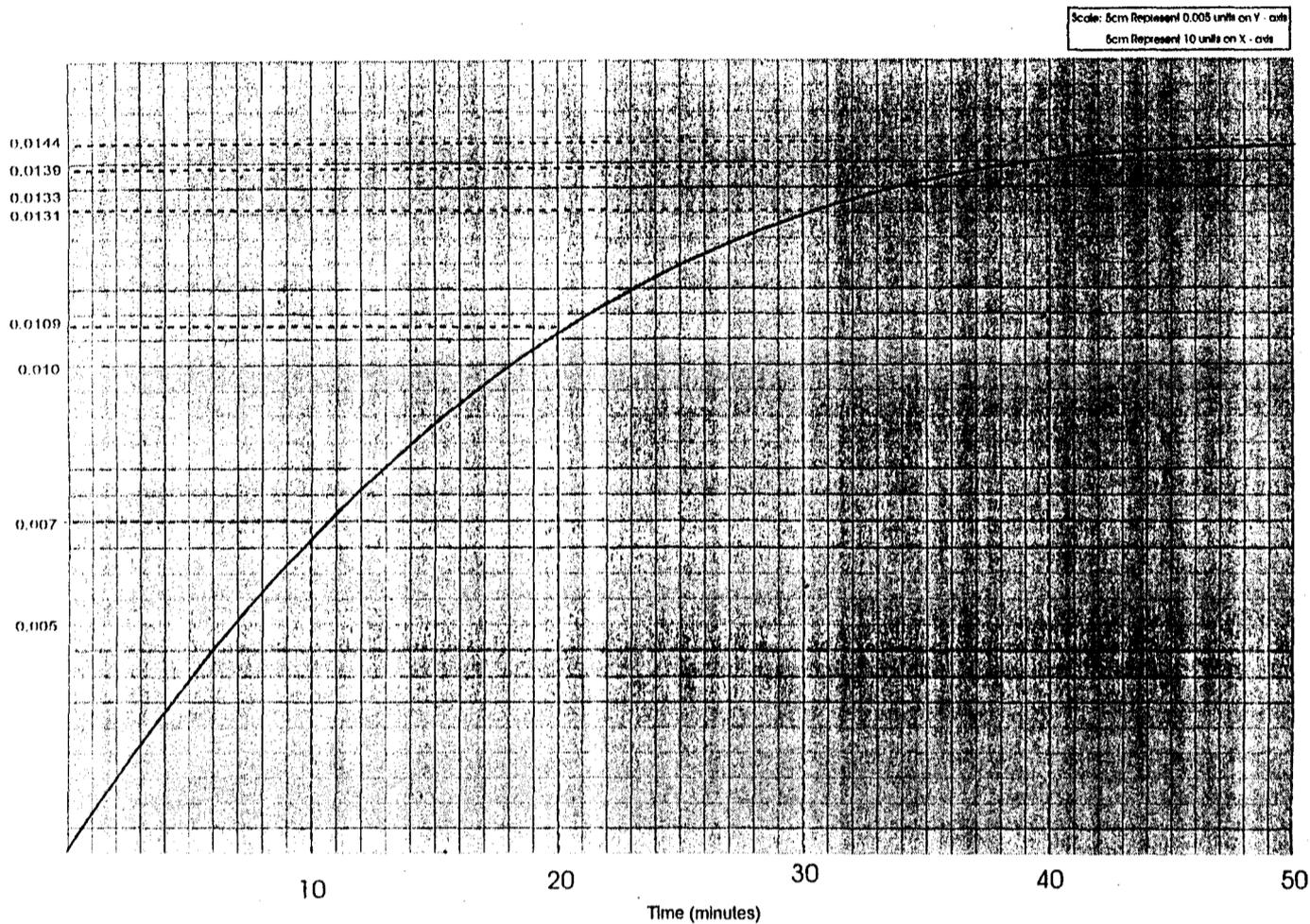
42

Fig. 4.2 Effect of Contact Time on the amount of CO_2 absorbed for ratio 1:0.66 of MEA and NaOH
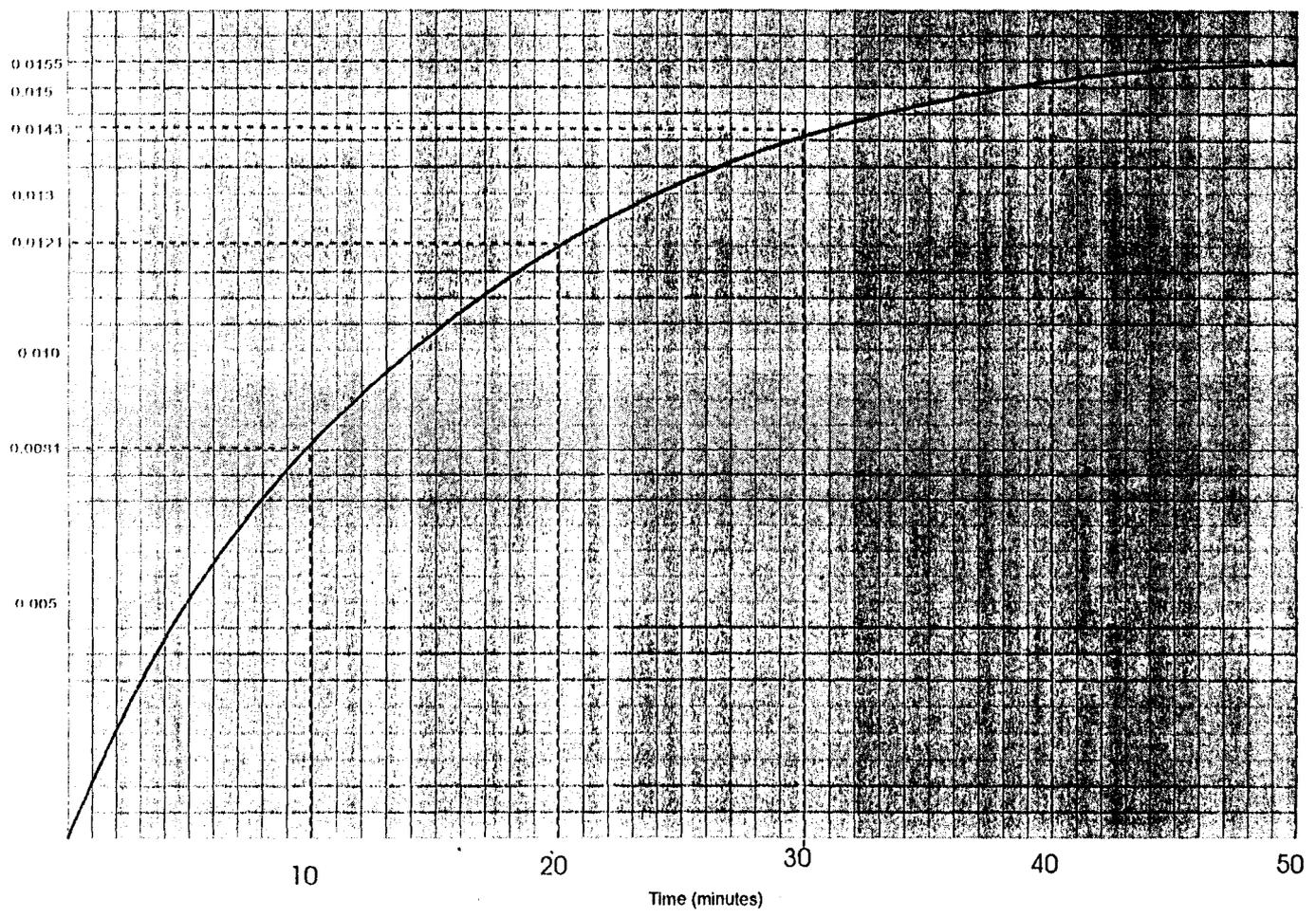
Fig. 4.3 Effect of Contact Time on the amount of CO_2 absorbed for ratio 1:0.25 of MEA and NaOH

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