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# Hydrodynamics of Packed Bed Column: Study of the Column for the Absorption of $CO_2$ in Water and its Efficiency

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## Abstract

Hydrodynamics and rate of absorption of gas into liquid contribute much in the overall efficiency of the absorption column which are widely used in the food industry, oil refineries, power plants and in the coal fired stations to control the pollution of air. It is noted that the range of possible air flow rates decreases as long as water flow rate goes to increase unless onset of the flooding of the column happen. Absorption of the carbon dioxide through solvent was carried out on the laboratory scale absorption column. By the motion of water, the dynamics of column was noted. Pressure differential was measured at the three tapings provided at three points of the column. Actually pressure differential was measured as a function of air flow rate for each water flow rate measured.

**Keywords:** Hydrodynamics; Absorption; Packed column; Efficiency; Pressure differential; Flow rate; Flooding; $CO_2$

## Introduction

Control of air pollution refers to control the unwanted materials like VoC's, SOX, NOX, CO, soot and particulates. Packed towers are used to scrub the unwanted materials from the gas stream with the help of liquid which could be water. Packed towers work on the principal of increasing liquid solubility, alkalinity and reducing the vapor pressure to enhance the absorption of acidic gases. In order to carry out the absorption process effectively, the area of contact between two fluids should be large and both phases should be in vigorous motion. Enough time should be given to establish the equilibrium [1-3]. Fluid mechanics, Chemical reaction kinetics and molecular diffusion are the phenomena involved during this contact. The main purposes involve in this study is to make the process economical and safer. Thickness, velocity, inclination of packed material and saturation of the liquid with gas does not affect the absorption process [3]. Agitation is carried out naturally by the turbulence of the flow of liquid but what is the type of this mixing process is still unknown certainly. In the stagnant film, the dissolved molecules of the gas can only pass through molecular diffusion. Surface renewal models supposed that the parts of liquid surface are from time to time replaced by the fresh liquid brought up by the bulk of the layer [1]. With the increment of concentration of the liquid, rate of absorption falls off while with the generation of new surface this rate increases. Surface renewal models suppose that every element of the liquid is exposed to the gas for the same length of time before being replaced by the fresh liquid and chance of replacement is independent of time [1]. Apparently, hydrodynamics and rate of absorption of gas into liquid are the two major factors which take major role in the overall efficiency of the absorption column. Absorption reaction can produce some new products like weak carbonic acid giving the change to the indicator color according to the following stoichiometric formula [3].

$$CO_2\,(aq)+H_2O\,(l) \rightleftharpoons H+(aq)+HCO_3-(aq)$$

## Industrial use of absorption column for air pollution control

In industry, packed towers are used for separation processes like absorption, stripping and distillation. Most of its applications are in the food processing industries [1]. During the hydrogenation of oils in food processing industries, hydrogen gas is bubbled through oil making the unsaturated bonds harder than normal in the presence of catalyst. Carbonation of beverages involves the absorption of carbon dioxide into beverage during the release of pressure [4]. Steam stripping of fats and oils involve desorption of unwanted particles of fats with steam. This is used in the deodorizing of natural gas before blending them into food products such as margarine and unwanted flavors stripping from the cream before the butter formation. Beside food industry, these are used in oil refineries, steel mills, cement plants, and power stations to control the elimination of contaminants such as particulates, aerosols, vapors and gases. Examples of some plants are asphalt and concrete batch plants, coal burning power plants [2]. Examples of pollutants involve the sulphur compounds like oxides of sulphur, hydrogen sulphide, and hydrochloric acid, ammonia and other gases that can be absorbed into water and can be neutralized with the help of appropriate reagent [2]. Carbon absorbers are used to purify the fluent gases from the steel mills, refineries, power plants to remove the volatile organic compounds [5] (Figure 1).

**Figure 1:** Rashing rings.

## Theoretical background

According to Fick's law, the diffusion of component A into Component B in a binary mixture can be represented by the following mathematical formula in the one directional diffusion, especially in the z direction (Figure 2).

$$J_A = -D_{AB}\frac{dC_A}{dz}$$

**Figure 2:** Mathematical formula in the one directional diffusion.

Concentration gradient is the driving force that enhances the diffusion. So at a pressure of 101.32 Kpa, the diffusivity of carbon dioxide is 0.202 $cm^2$/ sec (Figure 3).

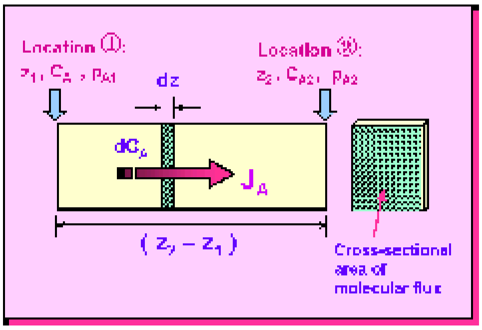



**Figure 3:** Concentration gradient enhances the diffusion.

## Methods

### Hydrodynamic test

Hydrodynamics of packed tower is noted by observing the pressure differential as a function of air flow rate against each water flow rate. It is observed that the range of possible air flow rates is going to decrease as far as the flow rate of water increase [6]. This happened due to the onset of flooding of the column. As according to the observed values, the onset of flooding reached earlier as long as the flow rate of water increased from 2.5 to 4.5 (l/m). Experimental apparatus was consisted of 75 mm diameter high column containing two lengths of rashing rings such that three tapings for pressure measurement instruments and sampling points of gas were provided while that gas was carrying the carbon dioxide gas. Flow rates of inlet and outlet water were measured and flow rate of carbon dioxide and inlet and outlet air stream was also measured. It was noted that after each flow rate of water, appearance of column was changed (Figure 4).

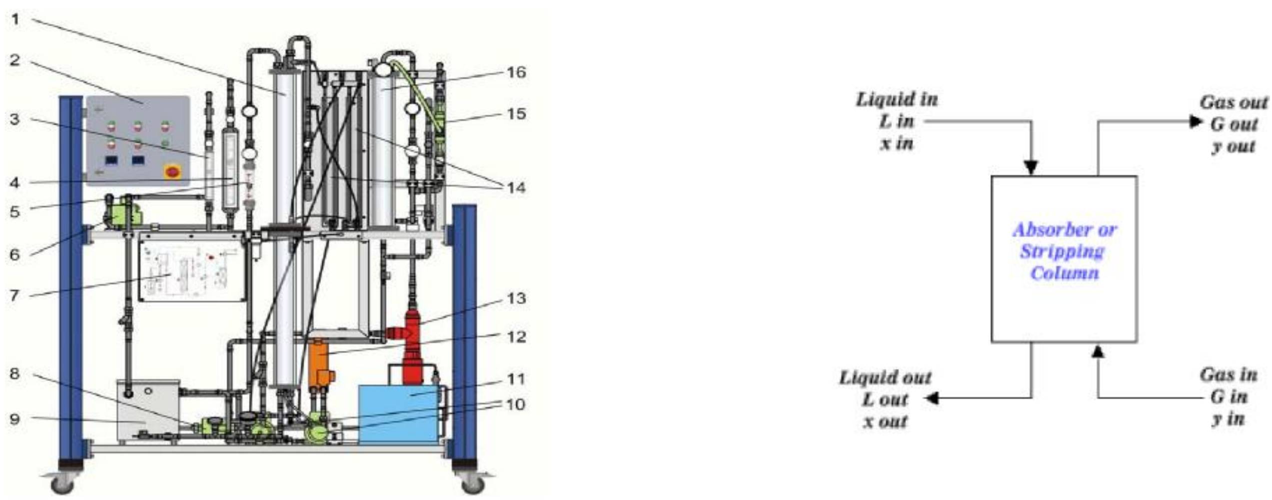



**Figure 4:** General packed column arrangement.

## Results

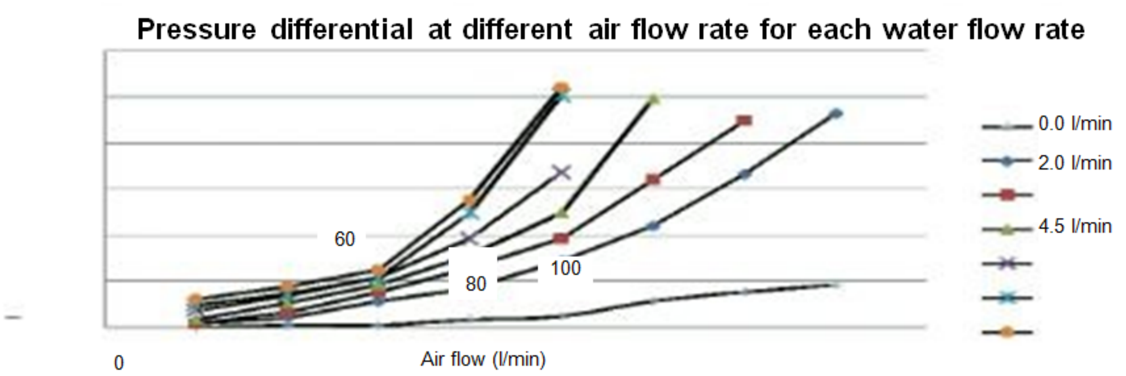
### Pressure differential (mm water)

| Air Flow (l/min) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Water flow (l/m in) | | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 175 |
| | 0 | 0/0 | -1/1 | -1/1 | -4/ 4 | -6/6 | -14/ 14 | -19/ 19 | -23/23 | -25/25 |
| | 2 | -2/2 | -5/5 | -14/ 14 | -21/21 | -36/36 | -55/55 | -83/83 | -116/ 116 | |
| | 2.5 | -2/2 | -8/8 | -19/19 | -32/32 | -48/ 48 | -80/ 80 | -112/112 | Flood | |
| | 3 | -4/ 4 | -13/13 | -23/23 | -39/39 | -62/62 | -124/ 124 | Flood | - | |
| | 3.5 | -9/9 | -17/17 | -27/27 | -48/48 | -84/ 84 | Flood | - | - | |
| | 4 | -12/1 2 | -18/18 | -27/27 | -62/62 | -126/126 | Flood | - | - | |
| | 4.5 | -15/1 5 | -22/22 | -31/31 | -69/69 | -130/130 | Flood | - | - | |

**Table 1:** Pressure Differential between air flow and water flow.

| Air Flow (l/min) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 175 |
| | 0 | 0 | 2 | 2 | 8 | 12 | 28 | 38 | 46 | 50 |
| | 2 | 4 | 10 | 28 | 42 | 72 | 110 | 166 | 232 | |
| Water flow (l/m in) | 2.5 | 4 | 16 | 36 | 64 | 96 | 160 | 224 | Flood | |
| | 3 | 8 | 26 | 46 | 78 | 124 | 248 | Flood | - | |
| | 3.5 | 18 | 34 | 54 | 96 | 168 | Flood | - | - | |
| | 4 | 24 | 36 | 54 | 124 | 252 | Flood | - | - | |
| | 4.5 | 30 | 44 | 62 | 138 | 260 | Flood | - | - | |

**Table 2:** Pressure Differential between air flow and water flow.




**Graph 1:** Pressure differential at different air flow rate for each water flow rate Determination of Rate of $CO_2$ absorption.

Absorption analysis equipment is used to determine the rate of absorption of carbon dioxide into water [7] (Tables 1 and 2). It consist of two globes on the left side of the panel which are used to fill the caustic soda (NaOH) having sight tube on the right side to see the level which should retain at the level of '0' approximately such that extra unwanted caustic soda can be drain off through drain tube by using

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flask. So in this experiment, 1 molar caustic soda solution was filled with the gloves and goggles weared hands. Molar fraction of carbon dioxide entering and leaving into the absorption column was determined. For up to 15 minutes, the system should be allowed to stable just after entering the air into the absorption column through the compressor so that its flow rate is measured and taken out through the sampling point S2. At this point, every valve other than T1 was closed. Flush the sample lines.

## Readings and calculations

For ideal gases: Molar fraction=volume fraction

$CO_2$ content of gas samples (Tables 3-5)

F1=F$CO_2$=flow rate of carbon dioxide;

F2=Fair=flow rate of air;

F3=F$H_2O$=flow rate of water;

V1=initial volume of air;

V2 (in)=volume of inlet air;

V2 (out)=volume of outlet air;

Flow rate of water=6 l/min.

| | **Readings at inlet** | | | **Calculations** | | |
|---|---|---|---|---|---|---|
| | F1 ($CO_2$) | F2 (air) | V1 (ml) | V2 ml | F3/F2+F3 | V2/V1=Y1 |
| **l/min** | 6 | 30 | 20 | 6.6 | 0.166 | 0.33 |
| **l/sec** | 0.1 | 0.5 | - | - | - | - |

**Table 3:** Readings at inlet.

| | **Readings at outlet** | | | **Calculations** | | |
|---|---|---|---|---|---|---|
| | F1( $CO_2$) | F 2( air) | V1 (ml) | V2 ml | F3/F2+F3 | V2/V1=Y0(ml) |
| **l/min** | 6 | 30 | 20 | 4.5 | 0.166 | 0.225 |
| **l/sec** | 0.1 | 0.5 | - | - | - | - |

**Table 4:** Readings at outlet.

| **$CO_2$ in sample** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **input** | 0.2 | 0.8 | 2.2 | 2.8 | 3.5 | 4.9 | 5.4 | 5.3 | 5.9 | 6.4 | 6.5 | 6.6 | 6.6 |
| **output** | 0.1 | 1.1 | 1.7 | 2.7 | 3 | 3.7 | 4.3 | 4.4 | 4.4 | 4.5 | 4.4 | 4.5 | 4.5 |

**Table 5:** Input and output of $CO_2$ in the sample.

Volume fraction of carbon dioxide in gas stream at inlet=(v2/v1) 1=y1= 0.33 ml.

Volume fraction of carbon dioxide in gas stream at outlet=(v2/v1) out=yo=0.225 ml.

Y1=0.33 ml.

Yo=0.225 ml

F3/F2+F3=0.166 l/sec

If Fa is litters/sec of carbon dioxide absorbed between bottom and top then

Fa=(Y1–Y1)(F2+F3)/(1-Y0)

Fa=(0.000105)(0.6)/(.99977)

Fa=0.00006301 l/sec

Therefore the amount of carbon dioxide absorbed in the liquid water in the absorption column is 6.301 × 10-5 l/sec (Table 5).

# Discussion

For mass transfer operations packed towers are widely used to carry out the gas absorption [8]. The process chemistry involves as solute being transferred between a gas and a liquid phase by contacting the gas and the liquid. The gas absorbs into the liquid based on its solubility.

In case of this experiment, two tests were performed. The hydrodynamics of the packed tower have been investigated. The rate of absorption of $CO_2$ in water has been measured.

According to the literature for a packed column to have correct fluids dynamic operation should have the following; In the form of a film, the liquid should be sliding along the packing surface and Covering the widest possible packing surface whereas; gas showing a continuous phase should be rising through the packing surface [9].

The first test performed the air pressure differential across the column has been measured as a function of air flow rate at different flow rates of water up to a maximum of 5 liters/min. A Graph (Graph 1) has then plotted from the results obtained. Initially the pressure differential has been measured at different air flow rates (l/min) with 0 (l/min) water flow rate. Followed this, the pressure differential has been measured again at the same values of the air flow rate, however with an increased flow rate of water (l/min) in each run. This has showed that when there is no water flowing through the column there was a maximum range of possible air flow rates and it has the least pressure differential across the column.

Proceeding with the test, as the water flow rate has set to 2 (l/min), the pressure differential has increased as compared to when there was no water flow rate and has given a value to a maximum air flow rate of 160 (l/min). At a water flow rate of 2.5 (l/min), similarly the pressure differential has increased comparatively to previous water flow rate and at this stage flooding has occurred in the column.

Flooding point is a point at which there is a sheer increase in the pressure drop. Flooding occurs at a point when there is high liquid flow rate that restricts the flow of the gas in the counter current direction due to the high liquid hold up, hence occupying a major portion of the tower cross section and flooding occurs [10].

Furthermore, the results showed that by increasing the water flow rate each time, there was a significant increase in the pressure difference and flooding occurs in column at an earlier stage as compared to it occurred at lower water flow rates.

The highest pressure differential occurred at a water flow rate of 4.5 (l/min).

The second test has been performed to measure the rate of $CO_2$ absorption in water. For ideal gases the volume fraction=mole fraction. Therefore, following this the samples of $CO_2$ taken from the inlet to the absorption column should give the same value of $CO_2$ fraction as indicated by the inlet flow meters which is given by the relationship; V2/V1=Y1 =F3/(F2+F3).

However form the values calculated (Y1=0.33) and [F3/(F2+F3)=0.166], hence they are not equal. Therefore due to the diluting effect of $CO_2$ the absorption rate of $CO_2$ in NaOH was found not proportional to C.

## Conclusions

It can be concluded that for mass transfer operations, packed towers are widely used to carry out the gas absorption.

Pressure difference across the column depends on the flow rate of air and water.

When there is no water flowing through the column there was a maximum range of possible air flow rates and it has the least pressure differential across the column.

With an increase in the flow rate of water, there is a significant increase in the pressure differential.

Flooding occurs in the column at a water flow rate of 2.5 (l/min) and air flow rate of 160 (l/min).

However with an increasing water flow rate, the flooding tends to occur at a lower value of air flow rate.

The solubility of $CO_2$ has not occurred according to the expected value, which might be due to the diluting effect of $CO_2$ in $CO_2$.

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## References

1. Lee KR, Hwang ST (1989) Gas absorption with wetted-wick column. Korean Journal of Chemical Engineering 6: 259-269.
2. Packed Column Design (2009) Available from: http://www.cheresources.com/packcolzz.shtml Accessed on: January 16, 2011.
3. Sowerby AM (2011) Packed Tower Gas Absorption, Laboratory Manual . School of Process Environment and Materials Engineering, University of Leeds, UK.
4. Shoaf MD, Basile PA (1984) Reactant/gas separation means for beverage carbonation device. US Patent 4,475,448.
5. Baker FS, Miller CE, Repik AJ, Tolles ED (1992) Activated carbon. Kirk-Othmer Encyclopedia of Chemical Technology.
6. Dankworth DC, Sundaresan S (1989) A macroscopic model for countercurrent gas-liquid flow in packed columns. AIChE journal 35: 1282-1292.
7. Al-Hindi M, Azizi F (2018) Absorption and desorption of carbon dioxide in several water types. The Canadian Journal of Chemical Engineering 96: 274-284.
8. Olutoye MA, Mohammed A (2006) Modelling of a gas-absorption packed column for carbon dioxide-sodium hydroxide system. AU JT 10: 132-140.
9. Ruiz Salmon I, Cambier N, Luis Alconero P (2018) CO2 Capture by Alkaline Solution for Carbonate Production: A Comparison between a Packed Column and a Membrane Contactor. Applied Sciences 8: 996.
10. Charpentier JC (1981) Mass-transfer rates in gas-liquid absorbers and reactors. InAdvances in chemical engineering. Academic Press 11: 1-133.