

## Investigation into the Effect of Electric Field on the Absorption of Carbon Dioxide in a Polar Solvent (Water)

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**Abstract:** The effect of an electric field on the absorption of carbon dioxide in a polar solvent (water) was investigated. After careful analysis of the results obtained, it was established that a divergent electric field does indeed have a desirable effect on the absorption of CO<sub>2</sub> in H<sub>2</sub>O, increasing the amount of CO<sub>2</sub> absorbed by 74% as the voltage applied was increased to 5000 volt at electrode distance of 30cm. The increase in the amount of CO<sub>2</sub> absorbed is thought to be primarily due to the “dielectrophoresis” phenomena resulting from the introduction of the field.

**Key word:** Polar solvent, CO<sub>2</sub>, Dielectrophoresis, electric field, Absorption

### INTRODUCTION

Liquid - gas contacting particularly those involving mass transfer have become very important in the chemical process industries as a result of the significant roles played by the operations in which it is encountered, which range from humidification and dehumidification, gas absorption and desorption, to distillation in its various forms. The purpose of the equipment used for this liquid-gas operation is to provide intimate contact of the two fluids in order to permit inter-phase diffusion of the constituents. The rate of mass transfer is directly dependent upon the interfacial surface exposed between the phases, thus the nature and degree of dispersion of one fluid in the other are of prime importance.<sup>[1]</sup>

This research involves a study of the effect of an electric field on the absorption of carbon dioxide in a polar solvent, representing a typical liquid-gas system in which intimate contacting of the fluids and therefore effective dispersion of one in the other is the objective. However, much of what will be discovered is expected to have some bearing on mass transfer in other liquid-gas contacting systems. Since movement of molecules (in the liquid state) is induced in a non-uniform electric field.<sup>[2]</sup>

#### Background Theory:

**Gas Absorption:** Absorption or gas absorption is a unit operation used in the chemical industry to separate gases by washing or scrubbing a gas mixture with a suitable liquid.

Gas absorption is usually carried out in vertical counter-current columns. The solvent is fed at the top

of the absorber, where as the gas mixture enters from the bottom. The absorbed substance is washed out by the solvent and leaves the absorber at the bottom as a liquid solution. The solvent is often recovered in a subsequent stripping or desorption operation, which is essentially the reverse of absorption. The absorber may be packed, plate or simple spray column. The packed column is a shell filled with packing materials designed to disperse the liquid and bring it into close contact with the rising gas. In plate towers, liquid flows from plate to plate in cascade fashion and gases bubbles through the flowing liquid at each plate through a multitude of dispersers (e.g holes in from plate to plate in cascade fashion and gases bubbles through the flowing liquid at each plate through a multitude of dispersers (e.g. holes in a sieve tray, slits in bubble trap tray) or through a cascade of liquid as in a shower deck tray.

Microfluidic systems rely on many different ways to move small liquid samples about. Those under investigation at present divide loosely into two categories: *closed* and *open* systems. Closed systems consist of tiny channels (~102 to ~103 μm in size) and a variety of pumps, including miniature piezoelectric devices, ion-drag<sup>[3]</sup> electroosmosis<sup>[4]</sup> and electrochemical reactions.<sup>[5]</sup> On the other hand are open systems, which manipulate and transport liquid upon structured surfaces.

Depending on the application, one equipment may be favoured over the other but overall the fundamental physical principles underlying the process of gas desorption are the solubility of the absorbed gas and the rate of mass transfer.<sup>[6]</sup>

**The Role of Dispersion in Mass Transfer:** The mixing or dispersion of one phase in another phase with which the first is immiscible is important in many chemical engineering operations such as heat and mass transfer. Dispersion not only brings about a large increase in the interfacial area available for material or heat transfer but also places the fluids in a state of motion which serves to increase the specific rates of both of the above transfer processes.<sup>[7]</sup>

Dispersions of one fluid in another are produced by injecting one phase into the other as a jet or sheet when surface tension forces cause the later to collapse into a dispersion of drops or bubbles. Fluid dispersions produced in this way may be further reduced in particle size if they are then subjected to shear or turbulent forces as a result of the subsequent flow of the dispersion. Very high rates of fluid flow through orifices can induce dispersion by shear as the particles of the dispersed phase are propelled at high velocity through the continuous phase. High velocities can also be developed for the same purpose by centrifugal force in spinning disk atomizers. A dispersion may be mechanically agitated or sheared by high velocity flow in a conduit to reduce its particle size through the action of turbulence.

These techniques are used to produce high interfacial areas in contacting immiscible fluids for mass-transfer operations such as distillation, gas absorption, spray drying, and liquid-liquid extraction. The dissolution and crystallization of solids in liquids is facilitated by suspending solid particles in a fluid stream as a dispersion of high interfacial area while solids in gas dispersions are used in several catalytic gas reactions and in the combustion of solid fuels. The mixing or inter-dispersion of immiscible phases is thus an important and common operation designed to produce high interfacial area for mass transfer, chemical reaction or both.

In gas-liquid contacting, plate columns employ the principle of dispersion through orifices and the vapour flow rate is generally high enough to secure a thorough agitation of the liquid phase at the same time as a large interfacial area is produced.

Some principles of efficient contacting in continuous dispersed-phase flow may be seen by consideration of the relationship:

$$a = \frac{6H}{D_p} \quad (1)$$

- $a$  = interfacial area per unit volume of mixed phases

- $H$  = fractional volumetric hold-up of dispersed phase, and
- $D_p$  = equivalent, mean spherical diameter of one drop or bubble of the dispersed phase

**The Movement of Molecules in Non-uniform Electric Fields:** The movement of suspensoid particles relative to that of the solvent resulting from polarization forces produced by an inhomogenous electric field is defined as "dielectrophoresis". It is analogous to the related phenomenon of "electrophoresis", in which motion of suspensoid particles is produced by the action of an electrostatic field on charged panicles.

The term "dielectrophoresis" was however introduced by Pohl<sup>[8]</sup> to describe the movement of polar molecules in non-uniform electric fields.<sup>8</sup> Dielectrophonesis does not require ionized particles but rather depends on asymmetrical induction and attraction of displacement charges within the particles and further that the resultant motions be different for solvent and solutes. Migration in either alternating or direct current fields is observed to take place.<sup>[9]</sup>

When the polarizability of the suspensoid is greater than the solvent, the asymmetric field forces accelerate the suspensoid particles more than the solvent, giving rise to an increased concentration of the suspensoid near the center of high field strength. The suspensoid particles are then more prone to collision and coagulation.

**Dielectrophoresis of Water:** The electromechanical response of water resting atop the planar electrodes when voltage is applied is well-understood.<sup>[10]</sup> The electrodes create a non-uniform electric field, and the DEP force attracts the water, or any polarizable liquid, into regions where this field is strongest.

**Theory:** When an electric dipole is placed in a uniform electric field it experiences a torque, which tends to orient it in a direction anti-parallel to the field direction, there is however no resultant translational motion. If the field is non-uniform one pole of the dipole will be in a stronger field than the other; accordingly the force on it will be greater than on the other pole and a net translational force result.<sup>[2]</sup>

Assuming that the applied is non-uniform in the  $z$ -direction and decreasing with increasing  $z$ , the net translational force  $f$ , acting on the dipole moment  $m$  is

$$f = m \frac{dF}{dz} \quad (2)^{[11]}$$

where F is the electric field intensity operating at the site of molecule.

Permanently polar molecules, under the influence of the field tend to align themselves anti-parallel with the field direction. If the field, F is acting upon polar and non-polar molecules comprising a solution, the translational force on polar and non-polar molecules is given as

$$f_p = M_p \frac{dF}{dz} = (\alpha L(x) + \alpha_p F) \frac{dF}{dz} \quad (3)$$

$$f_n = M_n \frac{dF}{dz} = (\alpha_n F) \frac{dF}{dz} \quad (4)$$

Where the subscripts p and n indicate polar and non-polar molecules respectively  $\alpha$  is the mean polarity of the molecules

### MATERIALS AND METHODS

The research was carried out in two phases viz:

**Phase 1:** The experimental glassware absorption column was washed thoroughly with distilled water, and allowed to dry. 100ml of distilled water was measured out using a measuring cylinder after which the water was transferred into the experimental absorption column. The column was clipped to a clamp stand and a temporary line in form of a rubber tube was run from the filled CO<sub>2</sub> cylinder to the column. All other outlets from the column were then sealed using a rubber bung, while making provision for the passage of unabsorbed CO<sub>2</sub> out of the column to avoid building of pressure within.

An experimental absorption run was carried out by bubbling CO<sub>2</sub> through the water in the column at a constant flow rate for sometime. The resulting carbonic acid solution was collected in beaker and immediately analyzed after agitation by swirling.

A stopwatch was used to determine the exact duration of the absorption, which was kept constant at five (5) minutes; and the flow rate was kept constant by maintaining the gas regulator (valve) at a fixed position.

**Phase 2:** The same procedure was followed as in phase 1 up to the point of connecting the column to the CO<sub>2</sub> cylinder, and then an electric field was introduced into the column before the outlets from the column were sealed as in phase 1. Experimental absorption runs were again carried out at a constant flow rate and for a specified time while varying the applied voltage as follows: 500V, 1000V, 3500V, 4000V and 5000V respectively.

The voltage parameter was varied so as to be able to establish the trend of variation of the absorption process resulting from the introduction of the electric field. On completion of each run, the resulting carbonic acid solution was collected and immediately analyzed while another run was in progress. In both phases of the experiment; the same time duration for absorption and flow rate were maintained. This was vital for any reasonable comparison to be made between phase I and phase II .

The flow rate was kept rather low in order to obtain a measurable effect.

**Introduction of Electric Field:** The electric field was introduced by inserting two (2) copper wire electrodes, which, were connected to a high voltage power supply unit into the experimental absorption column. The two electrodes were suspended horizontally at the top and bottom of the column respectively.

The high voltage power supply unit was connected to a variable transformer, which was connected to a direct current power supply course (220V). The variable transformer was used to vary the applied voltage.

**Determination of the Amount of Carbonic Acid Formed:** The absorption of CO<sub>2</sub> in H<sub>2</sub>O was followed by a chemical reaction which yields carbonic acid (H<sub>2</sub>CO<sub>3</sub>) see Equation 5. Therefore as a measure of the amount of the acid that was formed; the correlation was determined by the method of back titration in which the samples collected from each run were titrated with a standard sodium hydroxide solution.



**Determination of the Amount of Carbon Dioxide Absorbed:** From the stoichiometric equation given in Equation (5), one mole of carbon dioxide gas reacts with one mole of water to give one mole of carbonic acid. Therefore, if the number of moles of carbonic acid formed is known than we can calculate the amount (mass) of carbon dioxide formed using the formulae:

$$\text{Mass} = \text{number of moles} \times \text{molar mass.} \quad (6)$$

The molar concentration of H<sub>2</sub>CO<sub>3</sub> determined in accordance with Equation (6) is given as:

$$\text{Molarity of } H_2CO_3 = \frac{\text{Number of moles of } H_2CO_3}{\text{Volume of of } H_2CO_3 \text{ used}} \quad (7)$$

**Table 1:** Titration results for the standardization of NaOH solution.

Titration	1	2	3
Final burette reading (cm <sup>3</sup> )	2.5	4.9	7.4
Initial burette reading (cm <sup>3</sup> )	0.0	2.5	4.9
Volume (cm <sup>3</sup> )	2.5	2.4	2.5

Average volume of HCl used = 2.47cm<sup>3</sup>

**Table 2:** Titration results for the absorption of CO<sub>2</sub> in H<sub>2</sub>O without electric field.

Titration	1	2	3
Final burette reading (cm <sup>3</sup> )	8.6	15.6	22.4
Initial burette reading (cm <sup>3</sup> )	1.6	8.6	15.6
Volume (cm <sup>3</sup> )	7.0	7.0	6.8

Average volume of NaOH used = 6.93cm<sup>3</sup>

It follows that, No. of moles of H<sub>2</sub>CO<sub>3</sub> formed = molarity of H<sub>2</sub>CO<sub>3</sub> x volume of H<sub>2</sub>CO<sub>3</sub> used. Therefore, it means that: Mass of CO<sub>2</sub> absorbed = molarity of H<sub>2</sub>CO<sub>3</sub> x vol. of H<sub>2</sub>CO<sub>3</sub> used x molar mass of H<sub>2</sub>CO<sub>3</sub>,..... (8)

**Preparation and Standardization of 0.02M Sodium Hydroxide Solution:** 0.4g of NaOH pellets was dissolved in 500ml of distilled water in a volumetric flask and stirred vigorously with a glass rod. With the aid of a 25cm<sup>3</sup> of the NaOH solution was measured into a 150ml conical flask. The sample was then titrated against a 0.2M hydrochloric acid solution (which was placed in the burette) using 3 drops of phenolphthalein indicator until a colourless end point was reached.



The molarity of the NaOH solution was then calculated as follows:

$$M_B = \frac{M_A V_A}{V_B} \times \frac{n_B}{n_A} \quad (10)$$

Where

- M<sub>B</sub> = Molarity of base
- M<sub>A</sub> = Molarity of standard acid solution (0.02M)
- V<sub>A</sub> = Volume of standard used (read from the burette)
- V<sub>B</sub> = Volume of base (25cm<sup>3</sup>)
- n<sub>B</sub>/n<sub>A</sub> = mole ratio of base to acid obtained from stoichiometry

**Titration of Sample:**

Equation of reaction:



25cm<sup>3</sup> of sample (carbonic acid) was pipetted into a conical flask after which 3 drops of phenolphthalein indicator were added. Titration was then carried out using the NaOH solution in the burette until a pink end point was received. During titration, the conical flask containing the sample was swirled to provide a form of mixing. Also the tip of the burette was lowered well into the flask to minimize the loss of NaOH.

The concentration of carbonic acid was calculated using Equation 10 as appropriate.

**RESULTS AND DISCUSSION**

From Table 3 above, the amount of carbon dioxide absorbed were calculated as presented in the appendix. The graph of carbon dioxide absorbed and the corresponding voltage applied across the field are presented in the Table 4 below from which Figure 1 was then plotted.

The results of this work as can be seen from the graph of Figure 1 clearly indicate that the divergent electric field has a desired effect on the amount of CO<sub>2</sub> absorbed, the amount increases with the applied voltage. The field however, showed no effect until an applied voltage of 500V.

The increase in the amount of carbon dioxide absorbed is not unconnected with the increased dispersion resulting from the introduction of the field. The increased dispersion of course brings about an increase in the interfaces area available for mass transfer.

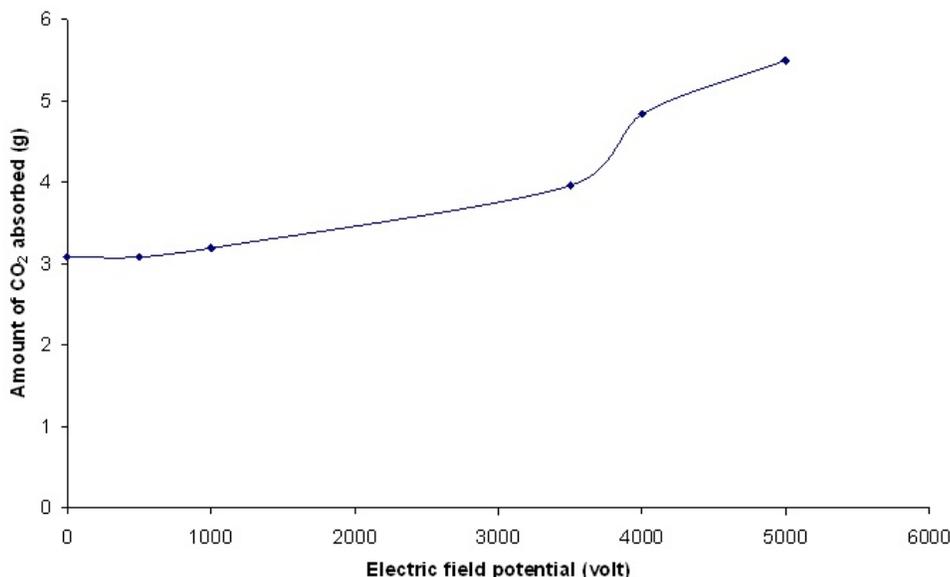
It is likely that non-uniform electric field induced motion of molecules toward the region of high field density thereby triggering some form of mixing and hence increased the rate of mass transfer. The fact that polar molecules move faster in field than non-polar molecules further enhancing the agitation.

Ion type migration (electrophoresis and electrolysis) are highly unlikely since distilled water contains no ions and therefore will not conduct electricity, even though electrolyte migration of ions occur as a result of the resulting carbonic acid, but to a limited and negligible extent since the acid is weak and very much diluted by water, thus the increase in the amount of CO<sub>2</sub> absorbed may be largely attributed to the "dielectrophoresis phenomena.

Overall, the increase in the amount of CO<sub>2</sub> absorbed as the applied voltage is increased is initially not very strongly pronounced but then increases sharply between 3500 and 4000V and remains less strongly pronounced up to 5000V. This seems to suggest the presence of secondary phenomena.

**Table 3:** Titration results for the absorption of CO<sub>2</sub> in H<sub>2</sub>O in the presence of an electric field.

Titration	500 volt			1000 volt			3500 volt			4000 volt			5000 volt		
Final burette reading cm <sup>3</sup>	6.8	7.0	6.9	7.2	14.4	7.2	8.8	9.0	9.0	11.0	22.1	33.2	12.6	25.1	37.6
Initial burette reading cm <sup>3</sup>	0.0	0.0	0.0	0.0	7.2	0.0	0.0	0.0	0.0	0.0	11.0	22.1	0.0	12.6	25.1
Volume cm <sup>3</sup>	6.8	7.0	6.9	7.2	7.2	7.2	8.8	9.0	9.0	11.0	11.1	11.1	12.6	12.5	12.5
Average vol. cm <sup>3</sup>	6.9			7.2			8.93			11.07			12.53		



**Fig. 1:** Graph of amount of CO<sub>2</sub> absorbed in the presence of electric field.

**Table 4:** Electric field potential supplied with corresponding amount of CO<sub>2</sub> absorbed

Electric field potential (volt)	Amount of CO <sub>2</sub> absorbed (g)
0	3.08
500	3.08
1000	3.19
3500	3.96
4000	4.84
5000	5.50

**Conclusion:** At the end of the experiment, within the limit of experimental error, the following conclusion can be drawn

- The amount of CO<sub>2</sub> absorbed in the absence of electric field was found to be 3.08g.
- The amount of CO<sub>2</sub> absorbed in the presence of 500, 1000, 3500, 4000 and 500V of electric field were found to be 3.08, 3.19, 3.96, 4.84 and 5.50g.

From this result, it can be deduce that increase in electric field from (500volt to 5000volt) causes an increase in absorption of CO<sub>2</sub> in water.

**Appendix:**

**Calculations:**

A) Molarity of standard NaOH prepared

- Given; Volume of base used = 25cm<sup>3</sup>
- Average volume of acid used = 2.47cm<sup>3</sup> (from

Table 1)

- Molarity of acid = 0.2 M
- From Equation (9) and (10)

• Molarity of NaOH =

$$\frac{M_A V_A}{V_B} = \frac{0.2 \times 2.47}{25} = 0.01998 = 0.2M$$

- 0.01998 M = 0.02 M

B) Amount of carbonic Acid Formed

i) 0.0volt Electric Field

- Average volume of NaOH used, V<sub>B</sub> = 6.93 cm<sup>3</sup> (From Table 2)

- Volume of carbonic acid used, V<sub>A</sub> = 25cm<sup>3</sup>
- Molarity of NaOH, M<sub>B</sub> = .02 M
- Molarity of H<sub>2</sub>CO<sub>3</sub> M<sub>A</sub> = ?
- From Equation (10) and (11)

- $M_A = \frac{M_B V_B}{V_A} \times \frac{1}{2} = \frac{0.2 \times 6.93}{25 \times 2} = 0.0028M$

ii) For 500volt electric field

$$V_B = 6.9 \text{ cm}^3 \quad V_A = 25 \text{ cm}^3 \quad M_B = 0.02 \text{ M}$$

$$M_A = \frac{0.2 \times 6.9}{25 \times 2} = 0.0028M$$

iii) For 1000volt electric field

$$V_B = 7.2 \text{ cm}^3 \quad V = 25 \text{ cm}^3 \quad M_B = 0.02M$$

$$M_A = \frac{0.2 \times 6.9}{25 \times 2} = 0.29M$$

iv) For 3500volt electric field

$$V_B = 8.93 \text{ cm}^3 \quad V = 25 \text{ cm}^3 \quad M_B = 0.02M$$

$$M_A = \frac{0.2 \times 8.93}{25 \times 2} = 0.0036M$$

v) For 4000volt electric field

$$V_B = 11.07 \text{ cm}^3 \quad V_A = 25 \text{ cm}^3 \quad M_B = 0.02M$$

$$M_A = \frac{0.2 \times 11.07}{25 \times 2} = 0.0044M$$

vi) For 5000volt electric field

$$V_B = 12.53 \text{ cm}^3 \quad V_A = 25 \text{ cm}^3 \quad M_B = 0.02M$$

$$M_A = \frac{0.2 \times 12.53}{25 \times 2} = 0.005M$$

C) Amount of carbon-dioxide absorbed

- Volume of carbonic acid = 25cm<sup>3</sup>
- Molar mass of CO<sub>2</sub> = 44g

i) For 0.0volt electric field

- Molarity of H<sub>2</sub>CO<sub>3</sub> = 0.0028 M
- From equation (8)
- Mass of CO<sub>2</sub> absorbed - 0.0028 x 25 x 44 = 3.08g

ii) For 500volt electric field

- Molarity of H<sub>2</sub>CO<sub>3</sub> = 0.0028M
- Mass of CO<sub>2</sub> absorbed - 0.0028 x 25 x 44 = 3.08g

iii) For 1000volt electric field

- Molarity of H<sub>2</sub>CO<sub>3</sub> = 0.0029M
- Mass of CO<sub>2</sub> absorbed = 0.0029 x 25 x 44 = 3.19g

iv) For 3500volt electric field

- Molarity of H<sub>2</sub>CO<sub>3</sub> - 0.0036M
- Mass of CO<sub>2</sub> absorbed = 0.0036 x 25 x 44

v) For 4000volt electric field

- Molarity of H<sub>2</sub>CO<sub>3</sub> = 0.0044M
- Mass of CO<sub>2</sub> absorbed = 0.0044 x 25 x 44 = 4.84g

vi) For 5000volt electric field

- Molarity of H<sub>2</sub>CO<sub>3</sub> = 0.005M
- Mass of CO<sub>2</sub> absorbed = 0.005 x 25 x 44 = 5.50g

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