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Carbon Dioxide Absorption By 1-Butyl-3-Methyl-Imidazolium Tetraflouroborate [Bmim][BF_4]

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Abstract

The main objective of this thesis is to study the reduction of carbon dioxide emissions into the atmosphere as it leads to higher temperatures, increased pollution, health problems, smog and acid rain. In this work, the ionic liquid, such as 1-butyl-3-methyl-imidazolium tetrafluoroborate [Bmim] [BF4] was used at a concentration of (0-3) mol/L and a temperature of (25-40) degrees Celsius. The ionic liquid is mixed with alkanolamines such as (MEA) (4 mol/L) and water to increase the absorption efficiency. 10 ml of aqueous solution (IL + MEA + j,absorber cell (50ml), water bath and CO_2 analyzer. The central composite design (CCD) method was applied to reduce the number of experiments needed to improve operating conditions. In absorption experiments, the effect of temperature of the solution (25-40)˚C, the concentration of the solvent (0-3) mole/l and absorption time (60-120 min) were investigated to determine the optimum operating conditions on the performance of absorption process. In addition, the absorption rate of CO_2 were calculated. The experimental data have shown that The best conditions for obtaining the highest absorption rate were at a temperature of 40°C, a concentration of 1.5 mol/L and an absorption time of 90 min, with an absorption rate of approximately 0.077 mol/kg/min and absorption efficiency for solution ([Bmim][BF4], MEA and water) 88%.

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1. Introduction

Pollution has increased over the previous century as a result of industrialization and population growth. Apart from contamination of water and soil, which has a negative effect on the ecosystem, air pollution is the most important concern in the environmental debate [1]. Carbon dioxide (CO_2) is one of the most prevalent waste gases emitted by industries, industrial plants, and vehicles [2]. The most serious issue with carbon dioxide is the greenhouse effect, which causes rising temperatures. More than 60% of global warming is attributed to carbon dioxide [3]. CO_2 concentrations are presently approximately 400 parts per million, according to scientific estimations, a significant increase from pre-industrial values of fewer than 300 parts per million [4]. The Intergovernmental Panel on Climate Change (IPCC) predicts a 1.9°C increase in global temperature by 2100, implying that lowering CO_2 levels is critical for humans and all other life on the planet [5]. Health issues, urban smog, and acid rain are just a few of the major consequences of CO_2 pollution. For lowering total CO_2 in the atmosphere, several options are offered. The first option is to replace fossil fuels with non-carbon energy sources like wind, solar, and biomass, which necessitates a switch to non-fossil fuels (e.g. renewable energy and hydrogen). The second alternative is to improve energy efficiency in order to reduce greenhouse gas emissions per unit of energy consumed, which requires efficient energy use. The third alternative (CCS) [6] is carbon sequestration and storage.

Ionic liquids (ILs), for example, have been proposed as promising CO_2 capture possibilities. In 1914, Paul Walden created the first IL (ethyl ammonium nitrate), although he had no idea that over a century later, ILs would become a major scientific topic [7]. In actuality, ILs as creative fluids have only recently gained a lot of attention. The number of SCI articles published on ILs has increased at an exponential rate, from a few in 1996 to over 5000 in 2016, considerably surpassing the annual growth rates of other important research topics. This suggests that an increasing number of scholars are working on this fascinating topic, resulting in a multitude of findings. A multidisciplinary study encompassing chemistry, materials science, chemical engineering, and environmental science is being conducted on ILs. Some essential fundamental viewpoints have begun to vary from the initial principles as more knowledge regarding the core of ILs becomes available [8].

Ionic liquids (ILs) at room temperature have lately been suggested as a possible CO_2 capture candidate. The effects of SO2 and O_2 on CO_2 capture were investigated using an aqueous amine solution mixed with IL in an absorption-desorption loop system in this work. The feed gas was chosen as a gas mixture containing CO_2, O_2, SO_2, and N_2 in the composition range of flue gas from a coal-fired power plant following flue gas desulfurization. By reducing the saturated vapour pressure of the mixed absorbent, it was discovered that adding hydrophilic IL of 1-butyl-3-methylimidazolium tetrafluoroborate ([Bmim][BF4]) to a monoethanolamine (MEA) aqueous solution reduced MEA and water losses. Because carbonate, which was produced by MEA reacting with CO_2, was insoluble in [hmim][Tf2N] at the absorber working temperature of 323 K, the MEA loss for 30 wt% MEA + 70 wt% [hmim][Tf2N] increased considerably with the system running [9].

1.2 Carbon Dioxide Capture Technologies

Many technologies have been developed to absorb CO_2 and reduce its emissions into the environment. The most important technologies used are cryogenic process, adsorption technique, membrane technique and absorption method [10].

1.2.1 Absorption Technology

For more than a few decades, absorption technology has been the commercial technique for CO_2 capture. CO_2 absorption can take place either physically or chemically.

There is no reaction between the solvent and the absorbed solute in the physical absorption process (CO_2). The Henrry's law governs the transfer of CO_2 from gas to solvent, therefore absorption is influenced by pressure and temperature. When the CO_2 partial pressure is high and the temperature is low, the solubility of CO_2 in the solvent

increases. The output solution is then forced through a succession of flash towers at various pressures. CO_2 is released as a result of the flash process [11]. Many solvents are utilized in this process, including union carbide selexol (selexol process), methanol (rectisol process), and propylene carbonate (propylene carbonate process) (flour process). Selexol process is used union carbide selexol (dimethylether polyethylene) as solvent since 1969 to sweeting the natural gas in order to absorbe carbon dioxide and hydrogen sulfide. Rectisol process is widely used in natural gas plants to remove carbon dioxide and it is used the methanol as a solvent because of its high vapor pressure, does not form the spume, does not erosion problems and degradation of the solvent. Flour process is used to CO_2 absorption at higher partial pressure $>$ 4.137 bar and it used propylene carbonate as solvent. In general, the physical absorption process has several disadvantages are more low-cost at high pressure, need for cooling of the lean seloxe solution [12].

1.3 Aims of the Work

The primary objectives of this study are listed below:

- Investigate the behavior of ionic liquids and their effect on CO_2 capturing from synthetic gas mixture.
- Quantify the effect of variables such as solvent temperature, solvent concentration and absorption time on the capture of carbon dioxide during the absorption process.
- Identify the best operating conditions for CO_2 capturing.

4. Materials and Methods

4.1 Chemicals

The ionic liquid 1-butyl 3-methylimidazolium tetrafluoro[Bmim] [BF4] was imported from China. The basic properties of [Bmim] [BF4] are summarized in Table 1 [13]. Monoethanol and water were mixed with the ionic liquid to increase the absorption efficiency.

Table 1: Basic characteristics of [Bmim][BF4]

Property	Detalis
Short name	[bmim][BF_4]
Molecular Formula	$C_8H_{15}BF_4N_2$
Molecular Weight	226.02
Purity	≥98%
Melting Point	-71.0° C
Poling Point	100° C
Flash Point	288° C not applicable
Density	1.21 g/cm^3 at 20° C
pH Value	5 (H_2O 20° C)
Vapor Pressure	<9.375×10-5 mmHg
Water	≤ 1.0 %
Storage	below +30°C

4.2 Equipments

The equipment used in this work are listed in Table 2.

TABLE 2: List of tools and devices used in this work.

No.	Equipment	Source
1	Bottles CO_2 & N_2	Biladi plant for gases/Iraq
2	Pressure gauge (0-50)bar	Visto/ German
3	Needle Valve	Visto/ German
4	Flow meters/Air(0-150)ml/min	Flutech / China
5	Water bath	England
6	Absorber cell (50ml) (It is a glass cell that contains two holes, one for gas input and one for gas removal	China
7	Analyzer (vol.%)	Atmocheck DOUBLE O_2/CO_2/ U.S.A

4.3 Absorption Process

An aqueous solution (IL + MEA + Water) of 10 mL was applied and heated to the desired temperature (25-40)˚C using a water bath at a specified concentration. The gas mixture (15% CO_2 and 85% N_2) was allowed to contact the solution to absorb carbon dioxide. Gas flow rates were controlled by calibrated flow meters. The operating conditions of the absorption process are atmospheric pressure and the flow rate of a gas mixture of 133 mL/min (20 mL/min for CO_2 and 113 mL/min for N_2). The gas exists of the cell uptake was analyzed by a carbon dioxide analyzer every five minutes to find out the saturation of the solvent (the solvent does not absorb more carbon dioxide). The run time (60 - 120) min was taken during the period in which there is a marked change in the carbon dioxide concentration which is measured with a carbon dioxide analyzer. Figures (1) and (2) show the schematic diagram and photo of the experimental setup for the absorption process used in this work.

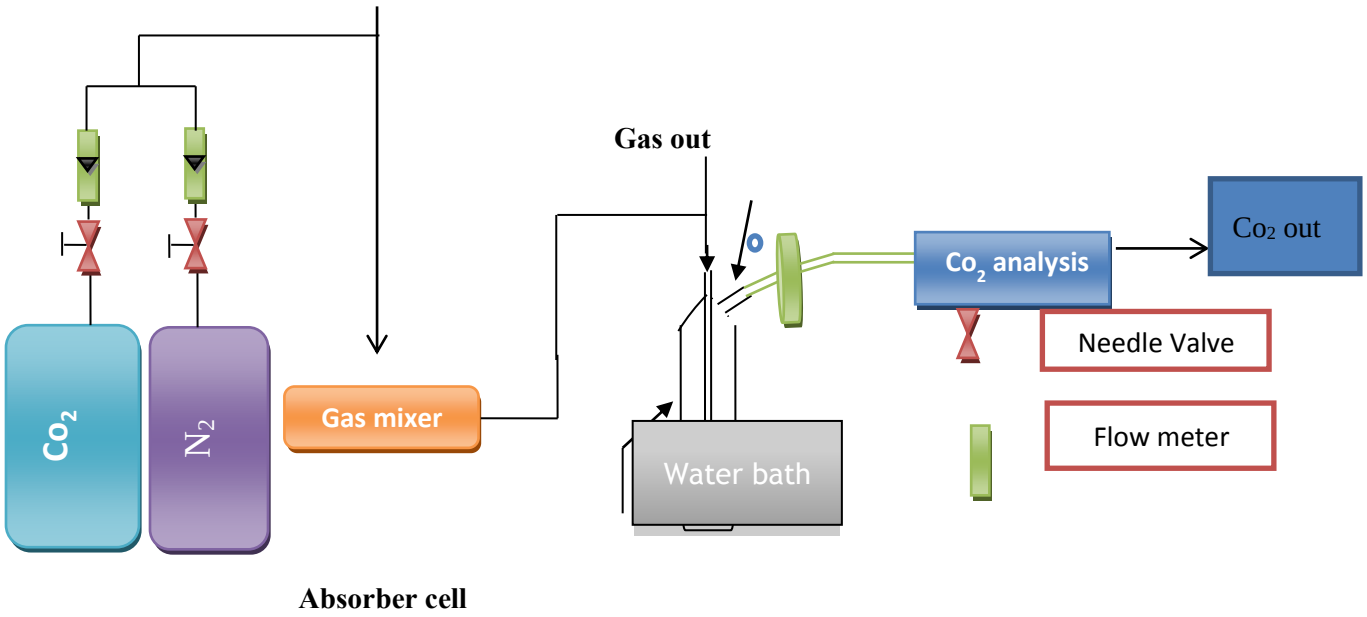

Figure 1. The schematic diagram of the experimental setup.

Figure 2. Photograph of the whole experimental setup.

4.4 Design of experiments

To investigate factors affecting the treatment process, RSM (Response Surface Methodology) and statistical experiment design approaches have grown popular [14,15]. 3-level factorial design, central composite design (CCD) [16,17], Box–Behnken design (BBD) [18], and D-optimal design [19] are examples of RSM designs. When compared to the other types of Response Surface Method (RSM) designs, the central composite design requires the fewest testing [20]. A response surface technique design is Central Composite Design (CCD). The CCD enables for the quantification of significant components and reactive factors, which is an advantage of this design. It also works to uncover the effect's nonlinear nature and to identify the ideal collection of experimental conditions for achieving the greatest outcome. While the CCD covers the same experimental area as the standard array design utilized in the primary study, it does so in a different way, it does so in a different way, it is less expensive and requires fewer tests in terms of cost. The Design Expert 11 version was utilized in this project. CCD design points

can be divided into three categories: The center points (0, 0) are positioned in the middle of the response and are also used to calculate curvature. Axial points ((+, 0), (0, +), (-, 0), (0, -) are found They are also used to estimate coefficients at a distance from the central point. Points based on the factorial ((-1, -1), (+1, -1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (+1, +1), (According to Expert, these points should be used to evaluate linear terminology coefficients and two-way interactions 2016) [14].

Examining and estimating coefficients from statistically prepared experiments by comparing experimental data to response functions, The optimization approach [18] includes phases such as anticipating the response of the developed model and verifying the model's suitability. Table 3 shows the effects of three parameters affecting the rate of carbon dioxide absorption: solution temperature (X1), solvent concentration (X2), and absorption time (X3).

TABLE 3: The experimental results of Central Composite Design (CCD)

		Factor 1	**Factor 2**	**Factor 3**	**Response 1**
Std.	Run	A:Temp. X1	B:Conc. X2	C: Time X3	Absorption rate
		˚C	mol/l	min	
1	17	25	0	60	0.0866
2	20	40	0	60	0.0875
3	6	25	3	60	0.0755
4	7	40	3	60	0.0807
5	3	25	0	120	0.06
6	18	40	0	120	0.0839
7	16	25	3	120	0.0197
8	19	40	3	120	0.0292
9	12	25	1.5	90	0.06
10	10	40	1.5	90	0.0759
11	13	32.5	0	90	0.0875
12	15	32.5	3	90	0.0369
13	14	32.5	1.5	60	0.081

14	4	32.5	1.5	120	0.0241
15	2	32.5	1.5	90	0.0673
16	11	32.5	1.5	90	0.0673
17	8	32.5	1.5	90	0.0673
18	9	32.5	1.5	90	0.0673
19	1	32.5	1.5	90	0.0673
20	5	32.5	1.5	90	0.0673

The experimental results were correlated with a second order polynomial as described below

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 \quad (1)$$

Where Y is the expected response, b0 denotes the model constant, and X1, X2, and X3 are independent variants. The linear coefficients are b1, b2, and b3; the interaction coefficients are b12, b13, and b23; and the quadratic coefficients are b11, b22, and b33. In this work, CCD was used to design 20 trials (Table 3), and all of the experiments were examined using analysis of variance (ANOVA). To measure the correctness of the relevant model, the coefficient of determination and its adjusted value were utilized.. The F-test was also used to confirm the relevance of the linear and quadratic terms. In addition, the p-value is used to identify the final subset of variables.

5. Results and discussion

As indicated in Table 3, many tests were conducted under various experimental settings using Central Composite Design (CCD). The following operating parameters were used to attain a complete absorption rate: temperature 40°C, concentration 1.5 mol/l, and absorption time 90 minutes.

The coefficients were determined using a regression analysis based on the experimental data in Table 3 that were associated to quadratic response functions. With the calculated coefficients, After 90 minutes of absorption time, Equation (1) gives reaction functions to the percentage of absorption rate (Y).

$$Y = +0.0648 + 0.0055X_1 - 0.0163X_2 - 0.0194X_3 - 0.0013X_1X_2 + 0.0034X_1X_3 - 0.0096X_2X_3 + 0.0069X_1^2 + 0.0012X_2^2 - 0.0085X_3^2 \quad (1)$$

($R^2 = 0.93$)

The absorption rate at the experimental sites was predicted using Equation (1). The response function predictions obtained are consistent with the experimental results. The ANOVA test was employed to measure the fit quality. The results of the ANOVA test based on the absorption rate are presented in Table 4. The model has been determined to be significant based on the F-value of absorption rate 14.74 presented in Table 4. The model conditions are also significant if the p-value is less than 0.05. The temperature of the solution, concentration, and absorption time all had a significant impact on CO_2 absorption.

TABLE 4: ANOVA test for the response function Y (absorption rate)

Source	Sum of Squares	Df	Mean Square	F-value	p-value
Model	0.0079	9	0.0009	14.74	0.0001
A-Temp.	0.0003	1	0.0003	5.19	0.0460
B-Conc.	0.0027	1	0.0027	45.17	< 0.0001
C-Time	0.0038	1	0.0038	63.85	< 0.0001
AB	0.0000	1	0.0000	0.2154	0.6525
AC	0.0001	1	0.0001	1.57	0.2381
BC	0.0007	1	0.0007	12.55	0.0053
A^2	0.0001	1	0.0001	2.24	0.1657
B^2	3.871E-06	1	3.871E-06	0.0654	0.8033
C^2	0.0002	1	0.0002	3.33	0.0981
Residual	0.0006	10	0.0001		
Lack of Fit	0.0006	5	0.0001		
Pure Error	0.0000	5	0.0000		
Cor Total	0.0084	19			

With p-values less than 0.05, X1, X2, X3, X12, X22, and X32 were identified as essential model parameters. According to the results of the ANOVA test on CO_2 removal efficiency, With a p-value less than 0.05, the variations X2, X3, X22, and X32 were essential model terms. The influence of influencing factors on the absorption rate is shown in Figure(3-a, b, and c).

Figure.(3-a) depicts the impact of both the temperature and concentration on the absorption rate. With increasing temperature and decreasing concentration of ionic solvent [Bmim] [BF4], the absorption rate increase. The ability of the exothermic CO_2 absorption thermodynamics system to induce reversible responses was attributed to this [21]. And the size of the available cavities in [Bmim][BF4] is insufficient to hold a CO_2 molecule. When CO_2 is introduced, the $[BF4]^-$ anions are reorganized by a tiny angular displacement, which has no effect on the radial distribution functions, to generate larger voids that can store CO_2 molecules [22]. At a temperature of 32.5˚C and concentration of 3 mol/l the absorption rate is 0.0369 mol/kg.min, but at a temperature of 40 ˚C and a concentration of 1.5mol/l, the absorption rate is 0.0795 mol/kg.min.

Figure.(3-b) depicts the impact of both the temperature and time on absorption rate The absorption rate increases with decreasing time and with increasing temperature at constant concentration. An increase in temperature may result in lower physical solubility, and therefore there should be a balance between reaction kinetic and physical solubility when temperature is a variable [23]. At a temperature of 32.5˚C and after a time of 120 minutes, the absorption rate is 0.0241 mol/kg.min, but when the temperature is increased to 40˚C and the concentration is stable, and after 90 minutes, the absorption rate is 0.0759 mol/kg.min.

Furthermore, Figure.(3-c) demonstrates the effect of both concentration and time on the rate of absorption. The absorption rate decreases with increasing time and increasing concentration with a constant temperature. This is because of two factors, the heat of the reaction increases as the concentration rises, causing the temperature to rise. As a result, the pressure of CO_2 vapor in the solution rises [22]. Second, for an equivalent acid-gas/amine mole ratio, the vapor pressure of acid-gas over the highly concentrated solution would be greater. Furthermore, raising the solvent concentration increases viscosity, which in many circumstances hampers the liquid's capacity to spread and reduces mass transfer [24]. At a concentration of 1.5mol/l and after 90 minutes, the absorption rate is 0.06 mol/kg.min, but at a concentration of 3mol/l and after 120 minutes and with constant temperature, the absorption rate is 0.0197 mol/kg.min

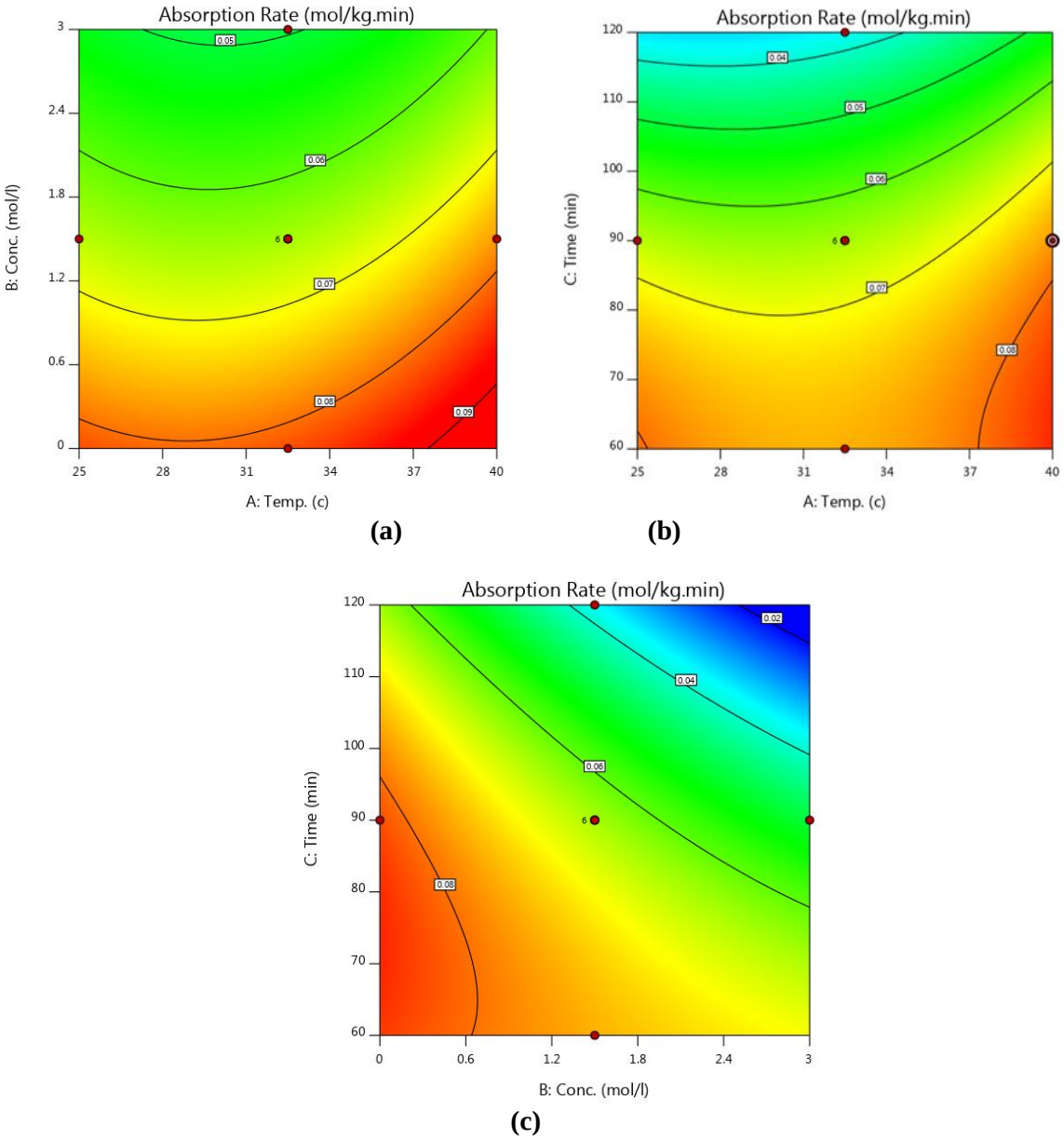

Figure 3. 3D response surface and contour plots: interactive effects of (a) Temperature and Concentration (b) Temperature and Time (c) Concentration and Time.

6. Optimization Choices

Response optimization helps identify the optimal factors that will give rise to an optimal response. The three factors were evaluated in this work to get the values that will give the maximum value of absorption rate. The essential objective of this study is to discover the best-operating conditions (temperature, concentration and absorption time) that give the highest absorption. Obtaining the optimal operating conditions as shown in Fig. (4) and Table (5), where the temperature, concentration of solvent and absorption time is 40 ˚C, 1.5 mol/l, 90 min for [Bmim][BF4], these values are economically good in comparison with other researchers and after these conditions the absorption efficiency decreases.

Table 5: optimal operating conditions

	Temp.	Conc.	Time	CO_2 outlet	Absorption Rate	CO_2 Loading	Absorption Capacity	Diffusivity	Solubility	
1	40.000	1.500	90.000	1.533	0.077	7.120	313.313	6.147×10^{-11}	0.068	Selected
2	32.500	1.500	60.000	1.833	0.076	4.151	182.625	4.5×10^{-11}	0.022	
3	25.000	1.500	90.000	3.353	0.066	5.964	262.501	3.033×10^{-11}	0.023	
4	40.000	0.000	60.000	0.606	0.094	5.850	257.395	4.576×10^{-11}	0.125	
5	25.000	3.000	60.000	1.614	0.076	4.784	210.557	3.033×10^{-11}	0.033	
6	40.000	0.000	120.000	1.514	0.081	9.615	423.052	4.576×10^{-11}	0.125	
7	25.000	3.000	120.000	12.934	0.011	1.559	68.616	3.033×10^{-11}	0.033	
8	32.500	1.500	120.000	8.553	0.037	4.420	194.484	4.5×10^{-11}	0.022	
9	32.500	3.000	90.000	6.393	0.050	4.305	189.410	4.5×10^{-11}	0.041	
10	40.000	3.000	60.000	1.294	0.078	4.659	204.986	6.147×10^{-11}	0.055	

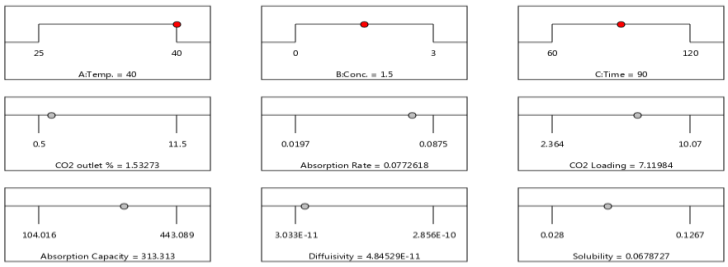

Figure 4. Process Optimization for the CO_2 removal by using absorption process for [Bmim][BF4]

Conclusions

The absorption method was used to determine total CO_2 removal. The effect of independent variables on CO_2 absorption rate, such as temperature, concentration, and time, was investigated. Temperature and concentration were shown to be the most influential factors on absorption rate. It may be deduced that higher temperatures are required for higher absorption rates at lower concentrations of solvent, however increasing the concentration of solvent with increasing time at constant temperature also results in a high absorption rate. The best conditions for obtaining the highest rate of absorption are (temperature 40˚C, concentration 1.5 mol/l and absorption time 90 min) the absorption rate is 0.077 mol/kg.min.

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Conflict of Interest: The authors declare that they have no conflict of interest.

References

[1] Aghaie, M. Rezaei, and N. Zendehboudi, S, " A systematic review on CO_2 capture with ionic liquids: Current status and future prospects," Renew Sustain. Energy Rev., 96, 502–525, 2018.

[2] Ahmad, M. Masohan, A. and Sawhney, S, "Alkanolmonoamines as activators for the hot potash process for CO_2 capture", Asian journal of chemistry, 26, 975, 2014.

[3] Al-Dahri, T. AbdulRazak, A. A. Khalaf, I. H. and Rohani, S, et al., "Response surface modeling of the removal of methyl orange dye from its aqueous solution using two types of zeolite synthesized from coal fly ash," Materials Express , (3), 234-244, 2018.

[4] Budhathoki, J. K. Shah and E. J. Maginn, " Molecular Simulation Study of the Solubility, Diusivity and Permselectivity of Pure and Binary Mixtures of CO_2 and CH_4 in the Ionic Liquid 1-n-Butyl-3-methylimidazolium bis(triuoromethylsulfonyl)imide," Ind. Eng. Chem.Res. 54, 8821-8828, 2015.

[5] Cao, B. B., Du, J. Y., Liu, S. Y., Zhu, X., Sun, X. J., Sun, H. T., et al., "Carbon dioxide capture by amino-functionalized ionic liquids: DFT based theoretical analysis substantiated by FT-IR investigation," RSC Adv., 6, 10462–10470. doi: 10.1039/C5RA23959A, 2016.

[6] J. Su, Q. Yang, J.F. Teo, T.S. Chung, et al., "Cellulose acetate nanofiltration hollow fiber membranes for forward osmosis processes," J. Membr. Sci. 355 , 36–44. Doi, 2010.

[7] Garcia, M. KnuutilA, H. K., Gu, S, et al., " Determination of kinetics of CO_2 absorption in unloaded and loaded DEEA+ MAPA blend," Energy procedia. 114, 1772-1784, 2017.

[8] Ghaedi, M. Mazaheri, H. Khodadoust, S. Hajati, S., Purkait, M. K., et al., "Application of central composite design for simultaneous removal of methylene blue and Pb2+ ions by walnut wood activated carbon," Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 135, 479-490, 2015.

[9] Khan, A. A. Halder, G. and Saha, A., "Experimental investigation of sorption characteristics of capturing carbon dioxide into piperazine activated aqueous 2-amino-2-methyl-1-propanol solution in a packed column, International journal of greenhouse gas control, 44, 217-226, 2016.

[10] Lee, T. B., Oh, S., Gohndrone, T. R., Morales-Collazo, O., Seo, S., Brennecke, J. F., et al., "CO_2 chemistry of phenolate-based ionic liquids," J. Phys. Chem. B 120, 1509–1517. doi: 10.1021/acs.jpcb.5b06934, 2016.

[11] Yu, B.; Li, L.; Yu, H.; Maeder, M.; Puxty, G.; Yang, Q.; Feron, P.; Conway, W.; Chen, Z., et al., "Insights into the Chemical Mechanism for CO_2(aq) and H+ in Aqueous Diamine Solutions—An Experimental Stopped-Flow Kinetic and 1H/13C NMR Study of Aqueous Solutions of N,N-Dimethylethylenediamine for Postcombustion CO_2 Capture. Environ, Sci. Technol., ,52, 916–926, 2018.

[12] Dheyaa Jumaah, "Natural Gas in Iraq, " Currently and Future prospects :A Review. https://doi.org/10.36909/jer.11989. 2020

[13] Yang, "Long-term accumulation and low toxicity of single-walled carbon nanotubes in intravenously exposed mice,' 2016.

[14] E. Balanosky, F. Herrera and J. Kiwi, "Optimization in design, testing and construction of reactors by use of statistical modeling of the reaction variables, energy input and reaction time." Studied in Surface Science and Catalysis, vol. 130, Elsevier, Amsterdam, pp. 2765– 2770. Available: https://doi.org/10.1016/S0167-2991(00)80889-7. 2020

[15] Zhang X, Bao D, Huang Y, Dong H, Zhang X, Zhang S., et al., "Gas–liquid mass-transfer properties in CO_2 absorption system with ionic liquids," AICHE J, 60: 2929–2939, 2014.

[16] Zhang, F., Heldebrant, D. J., Mathias, P. M., Koech, P., Bhakta, M., Freeman, C. J., Bearden, M. D. & Zwoster, A. et al., " Bench-scale testing and process performance projections of CO_2 capture by CO_2–binding organic liquids (CO2BOLs) with and without polarity-swing-assisted regeneration," Energy & fuels, 30, 1192-1203, 2016.

[17] Zhao, S., Tian, X. Z., Liu, J. N., Ren, Y. L., and Wang, J. J., et al., " A theoretical investigation on the adsorption of CO_2, N_2, O_2 and H2 in 1-buty-3-methylimidazolium heptafluorobutyrate ionic liquid. Comput. Theor," Chem.1052, 12–16. doi: 10.1021/jp205830d, 2015.

[18] Yu, C.-H., Huang, C.-H., Tan, C.-S., et al., "A review of CO_2 capture by absorption and adsorption," Aerosol air qual. res, 12, 745-769, 2012.

[19] A. Boza, Y. De la Cruz, G. Jordan, U. Jauregui-Haza, et al., "A. Aleman, and I. Caraballo, "Statistical optimization of a sustained-release matrix tablet of lobenzarit disodium Drug Develop," Ind. Pharm, Vol. 26, pp.1303-1307, 2020.

[20] M.Ahmadi, F.Vahabzadeh, B.Bonakdarpour, E.Mofarrah, M.Mehranian, et al., "Application of the central composite design and response surface methodology to the advanced treatment of olive oil processing wastewater using Fenton's peroxidation," Journal of Hazardous Materials, vol.123, no.1-3, pp.187-195, 2015.

[21] Notz R, Asprion N, Clausen I, Hasse H., etal., "Selection and pilot plant tests of new absorbents for post-combustion carbon dioxide capture," Chem Eng Res Des; 85: 510–515, 2017.

[22] Setameteekul A, Aroonwilas A. and Veawab A. "Statistical factorial design analysis for parametric interaction and empirical correlations of CO_2 absorption performance in MEA and blended MEA/MDEA processes," Sep Purif Technol; 64: 16–25, 2018.

[23] Brennecke and Joan F. Maginn, "Edward J. Ionic liquids: Innovative fluids for chemical processing" 2016.

[24] Thee, H. Nicholas, N. J., Smith, K. H., Da silva, G., Kentish, S. E., Stevens, G. W., et al., " A kinetic study of CO_2 capture with potassium carbonate solutions promoted with various amino acids: glycine, sarcosine and proline," International journal of greenhouse gas control, 20, 212-222, 2014.