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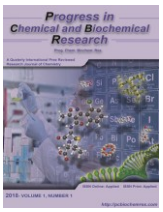

Orginal Research Article

Experimental Study of Carbon Dioxide Absorption in Diethyl Ethanolamine (DEEA) in the Presence of Titanium Dioxide (TiO_2)

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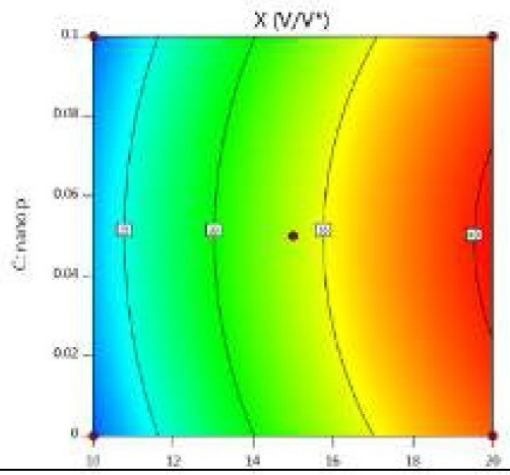
GRAPHICAL ABSTRACT



KEYWORDS

Solubility,
Titanium Dioxide Nanoparticle,
Carbon Dioxide
Diethyl Ethanolamine

ABSTRACT

Fossil fuels are the main source of CO_2 emissions into the atmosphere, which are sources of air pollutants. Environmental research has confirmed that atmospheric CO_2 concentration has risen from 280 ppm in 1800 to 358 ppm in 1994 (an increase of 27.86%). Russia, the United States, China, the rest of the Asian countries, Latin American countries, and African countries accounted for 27, 22, 11, 13, 4, and 3% of the total global CO_2 production, respectively. Various processes based on hydrogen sulfide and other acidic gases such as carbon dioxide, carbon disulfide, mercaptans, and carbonyl sulfide have been introduced for natural gas sweetening. One of these processes involves the use of solvents. In the present research, a device that measures solubility of gases in liquids was employed to measure solubility of CO_2 in solvent DEEA in the presence of TiO_2 at different solvent concentrations (10, 15, 20% w/w), various pressures (5, 10, and 15bar) and different TiO_2 concentrations (0.05 and 0.1% w/w) at ambient temperature. Results showed that solubility increased from 25.8 to 42.4% v/v at constant pressure and without the presence of a nanoparticle in the absence of TiO_2 at solvent concentrations ranging from 10 to 15% w/w. At a constant concentration of the solvent (15% w/w), solubility increased from 31.8 to 36.7% when the pressure was raised from 10 to 15 bar. Moreover, solubility increased from 32.7 to 36.7% v/v at constant solvent concentration (15% w/w) and pressure (15bar) when TiO_2 concentration was raised.

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Introduction

In 1999, Iran with 263 million tons ranked first in CO_2 production in the Middle East (showing a 45.6% increase compared to 1990). Chemical industries in Iran produced 58.4 million tons of the total 263 million tons of this gas [1-4].

Different countries have come up with numerous ways to reduce CO_2 levels as this gas causes accumulation greenhouse gases, increases global temperatures, contributes to sea level rise, and causes droughts and acid rain [5-9].

Many studies have been carried out on increasing CO_2 absorption by using chemical solvents. Specifically, CO_2 absorption by amines is the most common technology employed for this purpose. Since amines of different types have their specific disadvantages when used for CO_2 absorption (e.g. corrosion, low absorptive capacity, high energy requirement for reduction, etc.)[10-16], various studies have been carried out in recent years to upgrade and improve CO_2 absorption by amines. One of these studies is the combination of third type amines with a first or second type amine, the combination of amines with ionic fluids, and the addition of nanoparticles to amines.

Morteza Afkhamipour et al. conducted a laboratory study and modeled CO_2 solubility, density, and viscosity in a 1-Dimethylamino-2-propanol (1DMA2P) solution. The data on equilibrium solubility of CO_2 were predicted using the Deshmukh-Mather thermodynamic model. They also modeled and predicted the experimental data of viscosity based on the Erring conventional transition state theory and using the Eyring–Wilson and the Eyring-NRTL (non-random two liquid) models. Results showed that the Eyring-Wilson model predicted the experimental data of viscosity better than the Eyring-NRTL model [17].

ADAK S et al. studied CO_2 solubility in an aqueous solution of 2-Diehtylaminoethanol+ Piperazine in the pressure range 0.1-65 kPa and temperature range 303.15-323.15 K. They developed a thermodynamic model that could relate the experimental data to CO_2 solubility extremely well. The experimental data of density were fitted to the Redlich-Kister, Grunberg-Nissan, Gonzalez-Olmos and Iglesias equations and the data on viscosity to the Grunberg-Nissan model. Results of the experiments showed that the DEAE+PZ combination absorbed CO_2 better and in greater quantities than the MDEA+PZ combination [18].

Bikash Kumar Mondal et al. investigated equilibrium solubility and enthalpy of CO_2 absorption in aqueous bis (3-aminopropyl) amine solution and its mixture with MEA, MDEA, AMP, and K_2CO_3. They noticed that the DPTA+K_2CO_3 mixture offered the most favorable loading capacity, enthalpy and viscosity among the mixed solvents. Although solid loading in CO_2 was 0.8 at 40°C, it was accompanied by the high pressure resulting from CO_2 (3kPa) [18, 19].

Helei Liu et al. analyzed CO_2 solubility and absorption rate in aqueous solutions of 1-Diethylamino-2-propanol (1DES2P). They investigated performance of CO_2 absorption in the $1DEA_2P$ solution by taking into account CO_2 equilibrium solubility, absorption rate, and absorption heat, and reported that 1DEA2P could be considered an alternative solvent for CO_2 absorption [20].

Hossein Shahraki et al. studied CO_2 solubility in absorption and desorption processes with the solvent methyl di-ethanolamine (MDEH) activated with Piperazine and reinforced by NPs at 12, 25, 50, and 100 ppm. CO_2 solubility was investigated at 40 and 120°C. The experiments were conducted at CO_2 partial pressure of 0.1-26 atm. They reported that the solvent CO_2 loading was enhanced by almost 37.5% through introducing the NPs at 25 ppm. Therefore, the process in which NPs were added demonstrated a higher productivity and cost-effectiveness [21].

Jiazong Jiang et al. conducted a laboratory study on the effects of NPs on CO_2 absorption by applying aqueous

solutions of MEA and MDEA in a bubble column reactor. They studied the effects of various factors influencing CO_2 absorption including loading solid NPs, NP size and type, total volume flow rate of the mixed gas, and the initial CO_2 mass fraction. Results indicated that most NP types considerably increased CO_2 absorption except for nanoparticles such as SiO_2 NPs. Moreover, CO_2 absorption in MDEA-based Nano fluids varied based on the different NPs following this order: $TiO_2 > MgO > Al_2O_3 > SiO_2$ [22].

Recent research has revealed that solvent DEEA is capable of absorbing CO_2. At certain concentrations, NPs can increase solubility of CO_2 in amine solvents. TiO_2 NPs have desirably increased solubility of CO_2. Therefore, the present study examines discontinuous absorption of CO_2 in DEEA in a laboratory system to measure the volume of CO_2 absorption in solvents. The research variables include solvent concentration, initial pressure, and concentration of TiO_2 NPs. Thermodynamic studies will then be carried out on the data, response surface methodology will be employed in designing the experiments, and results will be analyzed using the Design-Expert software.

In this present study various processes based on hydrogen sulfide and other acidic gases such as carbon dioxide, carbon disulfide, mercaptans, and carbonyl sulfide have been introduced for natural gas sweetening. One of these processes involves the use of solvents. Also a device that measures solubility of gases in liquids will be employed to measure solubility of CO2 in solvent DEEA in the presence of TiO_2 at different solvent concentrations (10, 15, 20% w/w), various pressures (5, 10, and 15bar) and different TiO2 concentrations (0.05 and 0.1% w/w) at ambient temperature.

Theory

As is well known, CO_2 absorption into an amine solution combines both physical and chemical absorptions. In order to obtain theCO2equilibrium solubility, the concentration of CO2in the aqueous solution needs to be calculated.

An equation of state (EOS) is required to perform calculations related to solubility, for which the present study employed the Peng-Robinson EOS (1). The parameters of this equation, proposed in 1967 by Peng-Robinson, are obtained by using the critical properties and the acentric factor [23].

$$P=\frac{RT}{v-b}-\frac{a}{v(v+b)+b(v-b)} \quad (1)$$

The EOS must be rewritten in terms of the compressibility coefficient Z to perform the calculations. Equation 2 is obtained in terms of Z by using the Peng-Robinson EOS.

$$Z^3-(1-B)Z^2+(A-2B-3B)Z-(AB-B^2-B^3)=0 \quad (2)$$

$$A=\frac{a\alpha P}{R^2T^2} \quad (3)$$

$$B=\frac{BP}{RT} \quad (4)$$

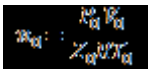
$$a=0.457235\frac{(RT_C)^2}{P_C} \quad (5)$$

$$b=0.077796\frac{RT_C}{P_C} \quad (6)$$

$$\alpha=[1+(0.37464+1.54226\omega-0.26992\omega^2)(1+T_r^{0.5})]^2 \quad (7)$$

$$T_r=\frac{T}{T_C} \quad (8)$$

In the above equations, V is the molar volume, T_C and P_C are the temperature and pressure at the critical point, respectively, R denotes the gas constant, and ω is the acentric factor. By solving Equation 2 in vapor-liquid equilibrium calculations, the largest obtained value for Z is used for the vapor phase and the smallest for the liquid phase. Using the values of Z obtained at the initial and equilibrium (final) temperature and pressure, the numbers of the initial and final (equilibrium) moles are determined from Equations 9 and 10: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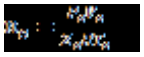
(10)

$$\Delta n=n_0-n_e \quad (11)$$

$$x = \frac{Mole\ Absorber}{Solvent\ kg} \quad (12)$$

$$x = \frac{[illegible]}{[illegible]} \quad (13)$$

Equation 12 defines solubility in terms of the number of carbon moles in CO_2 per kilogram of the solvent. To calculate the number of moles of solute for CO_2 dissolved in the solvent, the volumetric method is employed using Equation 13, in which the standard volume is calculated from the following equation:

$$V_{STP} = \frac{nRT}{P} \quad (14)$$

In Equation 14, the volume of the carbon dioxide gas is calculated under standard conditions (pressure of 1 atm and temperature of 25°C).

Experimental

The experiments were performed using a stainless-steel jacketed reactor (SS-316) with an internal volume of 296 cm^3 and a pressure endurance of 200 bars. The internal vessel was equipped with four valves with a pressure endurance of 6000 psi, of which two were ball valves used to inject the solution and drain the water/gas mixture the test, and two were needle valves, one of which was used for gas injection, and the other for connecting to the gas chromatograph and gas sampling. There is also a gas loading chamber with a volume of 1820 cm3, which is fitted with two ball valves for gas injection and another for discharging into the reactor. A platinum temperature sensor (Pt-100) with a precision of ±0.1 K was used to measure the reactor internal temperature. The tank pressure was measured with a BD sensor with a precision of about 0.01 MPa. A swing mixer was used for to proper mixing in the hydrate formation main tank, and a pump was used to create vacuum inside the cell. The apparatus used in this study is schematically shown in Fig. 1.

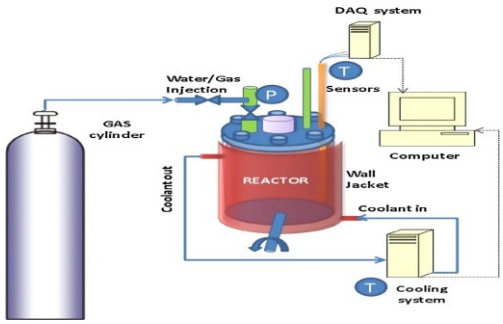

Fig 1. Schematic view of the apparatus

Material

Materials used in this work include: Carbon dioxide gas was purchased from the Arvand Industrial Company of gases and with a purity of 99.99%. The carbon dioxide gas capsule is 50 liters in volume and has an initial pressure of 5 MPa. Nanoparticle of titanium dioxide as a suspended particle in a solvent and an effect on adsorption in some experiments with TiO_2 chemical formula from Nano Pasargad New Co., Diethyl ethanolamine (2-DEEA) with a purity of 99.99% from the Swiss Folka Company with the chemical formula $C_6H_{15}NO$ and demineralized (DM) Water for solution preparation. Made from industrial companies[9, 24-30].

Results

In this work, the solubility of carbon dioxide in DEEA solution was measured with/without of titanium dioxide nanoparticle with various concentrations and pressures, so the experimental results are presented in this section.

Investigation of carbon dioxide solubility using the Peng-Robinson equation

To study the actual solubility behavior of CO_2 in DEEA, its solubility was calculated and investigated by using the Peng-Robinson EOS. Results obtained from these calculations are presented in Table 1.

Table 1. Solubility of carbon dioxide using the Peng-Robinson equation

RUN	*Solvent(AMIN)*	*Nano particle*	*P_0*	*V(STP)*	*X*
1	*20*	*0*	*9*	*4239.28*	*42.39*
2	*15*	*0*	*13.5*	*3265.69*	*32.66*
3	*15*	*0*	*4.5*	*3242.89*	*32.43*
4	*10*	*0*	*9*	*2581.36*	*25.81*
5	*20*	*0.05*	*13.5*	*4434.28*	*44.34*
6	*20*	*0.05*	*4.5*	*4150.51*	*41.51*
7	*15*	*0.05*	*9*	*3764.54*	*37.65*
8	*10*	*0.05*	*13.5*	*2640.63*	*26.41*
9	*10*	*0.05*	*4.5*	*2282.96*	*22.83*
10	*20*	*0.1*	*9*	*4135.96*	*41.36*
11	*15*	*0.1*	*13.5*	*3668.65*	*36.69*
12	*15*	*0.1*	*4.5*	*3178.92*	*31.79*
13	*10*	*0.1*	*9*	*2506.68*	*25.07*

As shown in Table 1, in the absence of the NPs, solubility of CO_2 in water improves with increases in the concentration of the amine solvent, increasing further if NPs are added to the solution. Changes in solubility in the presence of the NPs and the solvent are now further studied and interpreted by using the Figures.

The effect of different parameters on solubility

In Figures 1-6, effects of each parameter (pressure, NP, and solvent) are presented individually or in combination according to what was stated in **Table 1.**

Fig. 2 indicates effects of pressure on solubility. Effects of pressure on solubility at NP concentration of 0.05% w/w and solvent concentration of 15% w/w show that solubility of CO_2 is less affected by pressure compared to the solvent type. The reason for this is that higher pressures at constant temperature increase the partial pressure (the pressure exerted on each part of this mixture).

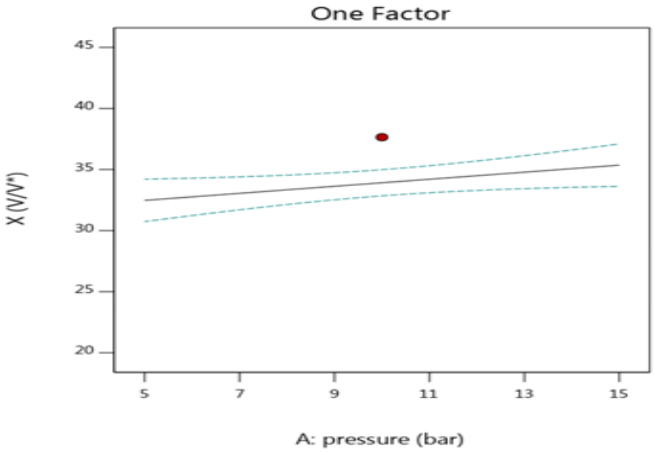

Fig 2. The effect of pressure on solubility

Consequently, further gas compression takes place, a larger number of molecules enter the liquid phase, and solubility increases.

The effect of nanoparticle concentration on solubility

Fig. 3 shows the effects of NPs on the solubility of CO_2 at pressure of 10 bar and solvent concentration of 15% w/w. As shown in this Figure, the effects of the NPs are negligible compared to those of the other two parameters (pressure and solvent). In the beginning, as soon as the gas is absorbed by the Nano fluid, the stable NPs break up the gas bubbles into smaller ones and the mass transfer area increases. Therefore, solubility of small gas bubbles increases eventually, leading to increased total absorption by the Nano fluids.

The effect of amine solution concentration on solubility

Fig. 4 displays effects of the solvent on carbon dioxide solubility at pressure of 10 bar and NP concentration of

0.05% w/w. It shows that the solute greatly influences solubility of CO_2 compared to the other two parameters (pressure and NPs). We can say that the amine solution decreases the surface tension of the solvent.

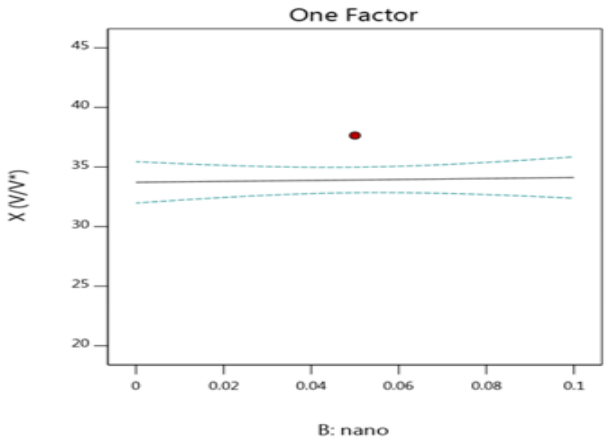

Fig. 3. The effect of nanoparticle concentration on solubility

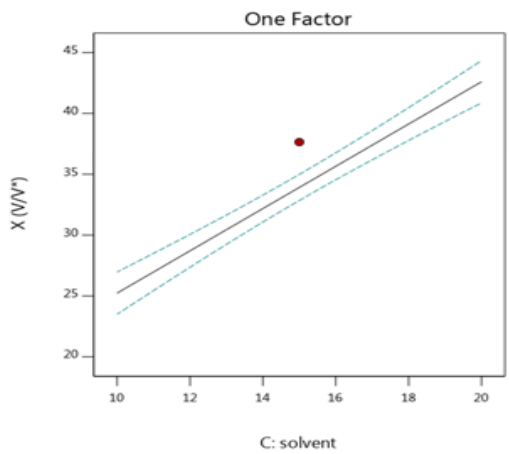

Fig 4. The effect of amine solution concentration on solubility

In other words, accumulation of the amine solution at the interface between immiscible fluids can reduce surface tension. This decreases mass-transfer resistance at the surface, facilitating the penetration of gas CO_2. As a result, the kinetic behavior is improved leading to higher solubility of gas CO_2 in the solvent.

Fig, 5 presents simultaneous effects of pressure and NP concentration on solubility of CO_2. This Figure shows that, at the constant solvent concentration of 15%w/w, a combination of pressure in the 5-15 bar range and NP concentration in the 0-0.1% w/w range does not significantly affect solubility of CO_2.

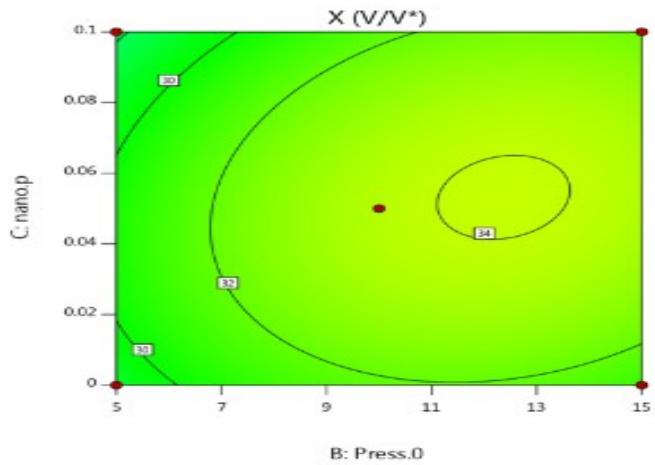

Fig. 5. The simultaneous effect of pressure and nanoparticles on solubility

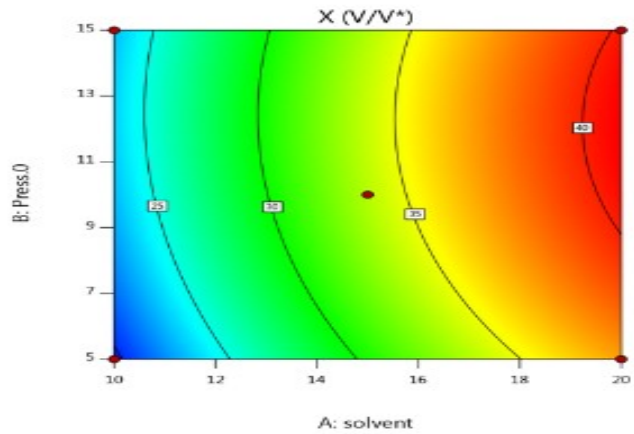

Fig. 6. The simultaneous effect of pressure and solvent on solubility

Figure 6 displays that, at NP concentration of 0.05% w/w, the greatest effect on solubility is observed at solvent

concentrations higher than 15% w/w and pressure in the 5-15 bar range.

Fig. 7 shows that, at the pressure of 10 bar, the simultaneous use of the NP concentration range 0-0.1% w/w and the solvent concentration higher than 15% w/w results in the highest solubility percentage.

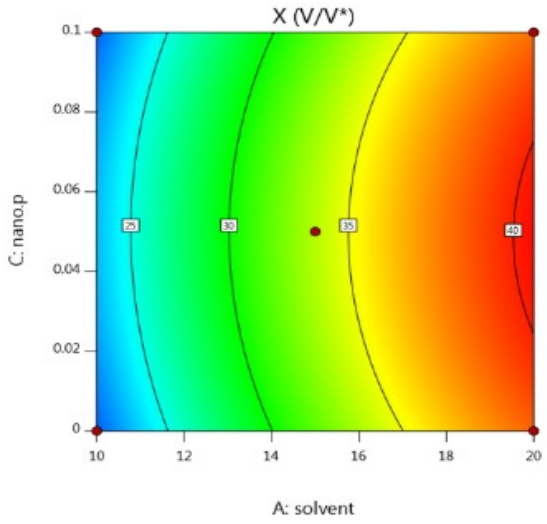

Fig 7. The simultaneous effect of solution and nanoparticles on solubility

Conclusion

In the present research, solubility of CO_2 in DEEA in both absence and presence of TiO_2 NPs was studied. The following results were obtained:

All experiments were conducted at a constant temperature. Therefore, effects of temperature were not taken into account in any of the results. In general, the experiments were carried out in 13 stages and at 3 different pressures (5, 10, and 15 bar) to study the degree of solubility of CO_2 in DEEA at concentrations of 10, 15, and 20% w/w of the solvent in both presence and absence of TiO_2 NPs with a concentration range of 0-0.1% w/w. Results indicated that, at constant pressure, increases in the concentration of the DEEA solution increased solubility of CO_2, but increases in the concentrations of the NPs did not considerably change solubility. At constant concentration of the DEEA solution, increases in the pressure of the system improved solubility of CO_2. Moreover, the performed analyses of the Figures produced by the Design Expert-11 software suggested that the DEEA solution was a more influential factor of solubility.

Nomenclature

P, bar	pressure
T, K	Temperature
R, j. mole. k	universal gas constant
v, m^3	volume
Z,	Compressibility factor
T_C, K	Critical temperature
P_C, bar	Critical pressure
T_r,	Reduced temperature
n_0, mole	Initial moles
n_e, mole	Secondary moles
P_0, bar	Initial pressure
P_e, bar	Secondary pressure
v_0, m^3	Initial volume
v_e, m^3	Secondary volume
T_o, K	Initial temperature
T_e, K	Secondary temperature
a,b, A,B	Constant
V_{STP}, m^3	Standard volume
ω	Acentric factor

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References:

[1] S. Singto, T. Supap, R. Idem, P. Tontiwachwuthikul and S. Tantayanon, The effect of chemical structure of newly synthesized tertiary amines used for the post combustion capture process on carbon dioxide (CO2): Kinetics of CO2 absorption using the stopped-flow apparatus and regeneration, and heat input of CO2 regeneration. *Energy Procedia*, 114 (2017) 852-859.

[2] S. Singto, T. Supap, R. Idem, P. Tontiwachwuthikul, S. Tantayanon, M.J. Al-Marri and A. Benamor, Synthesis of new amines for enhanced carbon dioxide (CO2) capture performance: The effect of chemical structure on equilibrium solubility, cyclic capacity, kinetics of absorption and regeneration, and heats of absorption and regeneration. *Separation and Purification Technology*, 167 (2016) 97-107.

[3] A. Samimi, S. Zarinabadi, A.H. Shahbazi Kootenaei, A. Azimi and M. Mirzaei, Kinetic Overview of Catalytic Reforming Units (Fixed and Continuous Reforming). *Chemical Methodologies*, 4 (2019) 852-864.

[4] A. Samimi, S. Zarinabadi, S. Kotanaei, A. Hossein, A. Azimi and M. Mirzaei, Use of data mining in the corrosion classification of pipelines in catalytic reforming units (CRU). *Iranian Chemical Communication*, 7 (2019) 681-691.

[5] E.S. Rubin, H. Mantripragada, A. Marks, P. Versteeg and J. Kitchin, The outlook for improved carbon capture technology. *Progress in energy and combustion science*, 38 (2012) 630-671.

[6] P. Tontiwachwuthikul and R. Idem, Recent progress and new developments in post-combustion carbon-capture technology with reactive solvents. *Future Medicine*, 2 (2013) 261-263.

[7] A. Dey, S.K. Dash and B. Mandal, Equilibrium CO2 solubility and thermophysical properties of aqueous blends of 1-(2-aminoethyl) piperazine and N-methyldiethanolamine. *Fluid Phase Equilibria*, 463 (2018) 91-105.

[8] M.W. Arshad, P.L. Fosbøl, N. von Solms, H.F. Svendsen and K. Thomsen, Equilibrium solubility of CO2 in alkanolamines. *Energy Procedia*, 51 (2014) 217-223.

[9] N.F.N.A. Samat, R.B. Yusoff, M.K. Aroua, A. Ramalingam and M.A. Kassim, Solubility of CO2 in aqueous 2-amino-1, 3-propanediol (Serinol) at elevated pressures. *Journal of Molecular Liquids*, 277 (2019) 207-216.

[10] D. Fu, H. Hao and F. Liu, Experiment and model for the viscosity of carbonated 2-amino-2-methyl-1-propanol-monoethanolamine and 2-amino-2-methyl-1-propanol-diethanolamine aqueous solution. *Journal of Molecular Liquids*, 188 (2013) 37-41.

[11] A. Ahmady, M.A. Hashim and M.K. Aroua, Kinetics of Carbon Dioxide absorption into aqueous MDEA+[bmim][BF4] solutions from 303 to 333 K. *Chemical engineering journal*, 200 (2012) 317-328.

[12] J.M. Navaza, D. Gómez-Díaz and M.D. La Rubia, Removal process of CO2 using MDEA aqueous solutions in a bubble column reactor. *Chemical Engineering Journal*, 146 (2009) 184-188.

[13] D. Mohammadnazar and A. Samimi, Nessacities of Studying HSE Management Position and Role in Iran Oil Industry. *Journal of Chemical Reviews*, 1 (2019) 252-259.

[14] H. Guo, L. Hui and S. Shen, Monoethanolamine+ 2-methoxyethanol mixtures for CO2 capture: Density, viscosity and CO2 solubility. *The Journal of Chemical Thermodynamics*, 132 (2019) 155-163.

[15] I. Adeyemi, M.R. Abu-Zahra and I. Alnashef, Experimental study of the solubility of CO2 in novel amine based deep eutectic solvents. *Energy Procedia*, 105 (2017) 1394-1400.

[16] M. Xiao, H. Liu, H. Gao and Z. Liang, CO2 absorption with aqueous tertiary amine solutions: Equilibrium solubility and thermodynamic modeling. *The Journal of Chemical Thermodynamics*, 122 (2018) 170-182.

[17] M. Afkhamipour and M. Mofarahi, A modeling-optimization framework for assessment of CO2 absorption capacity by novel amine solutions: 1DMA2P, 1DEA2P, DEEA, and DEAB. *Journal of Cleaner Production*, 171 (2018) 234-249.

[18] A. Samimi, S. Zarinabadi, A.H. Shahbazi Kootenaei, A. Azimi and M. Mirzaei, Considering different kinds of gasoline unit catalysts. *Journal of Medicinal and Chemical Sciences*, 3 (2020) 79-94.

[19] B.K. Mondal, S.S. Bandyopadhyay and A.N. Samanta, Equilibrium solubility and enthalpy of CO2 absorption in aqueous bis (3-aminopropyl) amine and its mixture with MEA, MDEA, AMP and K2CO3. *Chemical Engineering Science*, 170 (2017) 58-67.

[20] H. Liu, M. Xiao, Z. Liang and P. Tontiwachwuthikul, The analysis of solubility, absorption kinetics of CO2 absorption into aqueous 1-diethylamino-2-propanol solution. *AIChE Journal*, 63 (2017) 2694-2704.

[21] H. Shahraki, J. Sadeghi, F. Shahraki and D. Kalhori, Investigation on CO2 solubility in aqueous amine solution of MDEA/PZ with SiO2 nanoparticles additive as novel solvent. *J Chem Eng Process Technol*, 7 (2016) 37-43.

[22] J. Jiang, B. Zhao, Y. Zhuo and S. Wang, Experimental study of CO2 absorption in aqueous MEA and MDEA solutions enhanced by nanoparticles. *International Journal of greenhouse gas control*, 29 (2014) 135-141.

[23] T. Sema, A. Naami, K. Fu, G. Chen, Z. Liang, R. Idem and P. Tontiwachwuthikul, Comprehensive mass transfer and reaction kinetics studies of a novel reactive 4-diethylamino-2-butanol solvent for capturing CO2. *Chemical Engineering Science*, 100 (2013) 183-194.

[24] A. Bozorgian and M. Ghazinezhad, A Case Study on Causes of Scale Formation-Induced Damage in Boiler Tubes. *J Biochem Tech*, special issue (2018) 149-153.

[25] S. Adak and M. Kundu, Vapor–liquid equilibrium and physicochemical properties of novel aqueous blends of (2-Diethylaminoethanol+ Piperazine) for CO2 appropriation. *Journal of Chemical & Engineering Data*, 62 (2017) 1937-1947.

[26] A. Bozorgian, Z. Arab Aboosadi, A. Mohammadi, B. Honarvar and A. Azimi, Optimization of determination of CO2 gas hydrates surface tension in the presence of non-ionic surfactants and TBAC. *Eurasian Chemical Communications*, 2 (2020) 420-426.

[27] J. Mashhadizadeh, A. Bozorgian and A. Azimi, Investigation of the kinetics of formation of Clatrit-like dual hydrates TBAC in the presence of CTAB. *Eurasian Chemical Communications*, 2 (2020) 536-547.

[28] S. Yang, A. Arvanitis, Z. Cao, X. Sun and J. Dong, Synthesis of silicalite membrane with an aluminum-containing surface for controlled modification of zeolitic pore entries for enhanced gas separation. *Processes*, 6 (2018) 13.

[29] M. Zhang, L. Deng, D. Xiang, B. Cao, S.S. Hosseini and P. Li, Approaches to Suppress CO2-Induced Plasticization of Polyimide Membranes in Gas Separation Applications. *Processes*, 7 (2019) 51.

[30] S.A. Stern, Polymers for gas separations: the next decade. *Journal of Membrane Science*, 94 (1994) 1-65.

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