Corrosion Study of Carbon Steel in Carbonated BUMEA-2EE Nonaqueous Solution

Fang Liu¹,²,a, Xiaoqian Du³, Lemeng Wang¹,²,b* and Dong Fu ¹, ²

¹ Hebei Key Lab of Power Plant Flue Gas Multi-Pollutants Control, Department of Environmental Science and Engineering, North China Electric Power University, Baoding, 071003, PR China
² School of Environmental Science and Engineering, North China Electric Power University, Baoding, 071003, China
³ China Household Electric Appliance Research Institute, Beijing, 100037, China

aemail: 1347933906@qq.com
bemail: wanglm@ncepu.edu.cn

Abstract—Different effort has been attempted to reduce the equipment corrosion of CO₂ absorption using chemical solvents. In this paper, the corrosion of carbon steel in carbonated 2-(butylamino)ethanol (BUMEA)-2-ethoxyethanol (2EE) non-aqueous solution was studied by using a CHI602E electrochemical analyser. The polarization behaviour and corrosion rate of carbon steel in non-aqueous blends of BUMEA-2EE were investigated. The influence of temperature, the mass fraction of BUMEA (wBUMEA) and CO₂ loading (α) on the corrosion rate were clarified.

1. Introduction

Currently, it is a major technical requirement for achieving carbon peak and carbon neutrality to reduce CO₂ emissions[1]. The alchoolamine-based absorption method has been widely used for CO₂ capture[2,3]. However, the extensive energy penalty during the regeneration process are crucial challenges facing industrial application of conventional amine absorbent[4]. To reduce energy penalty, physical solvents such as alcohol are used as alternatives to water[5]. The non-aqueous blends of amine and physical solvent have gained increasing attention as promising absorbents. It can reduce the heat capacity of solvent thereby reducing the energy consumption of regeneration[6-10].

Recently, 2-(butylamino)ethanol (BUMEA) with higher CO₂ absorption capacity was suggested as a potential absorbent for CO₂ capture. 2-ethoxyethanol (2EE) with higher boiling points also has attracted increasing attention in the CO₂ capture process[11-14]. According to the aforementioned advantages, it is reasonable to expect that both the CO₂ absorption performance and the energy consumption can be considerably improved in BUMEA-2EE non-aqueous solution.

In addition to the extensive energy penalty, the serious corrosion of carbon steel is another disadvantage in the amine-based absorption process, which may damage the operating equipment and lead to a reduction in the process efficiency and increase in operational costs[15,16]. However, studies concerning corrosion behaviour of carbon steel in CO₂-BUMEA-2EE non-aqueous solution are rare, and the effects of temperature, mass fraction of amines and CO₂ loading on corrosion behaviour have
not been well documented so far. The main purpose of this work are to (1) measure the polarization behaviour and corrosion rates of carbon steel in CO₂-BUMEA-2EE non-aqueous solution; (2) demonstrate the effects of temperature, mass fraction of amines and CO₂ loading on corrosion rate.

2. Experimental Section

2.1. Experimental materials
BUMEA (purity ≥98 wt %) and 2EE (purity ≥99 wt %) were purchased from Shanghai Aladdin Biochemical Company. The specimens for corrosion tests were made of carbon steel (AISI 1020). The specimens (10 mm×10 mm×3 mm) were ground, polished and then sealed with resin with an exposed area of 10 mm×10 mm. The specimens were connected with copper wires to make the working electrodes for the electrochemical tests.

2.2. Experimental procedures
The core of the experimental system for corrosion testing consists of an electrochemical workstation (CHI602E, manufactured by Shanghai Chenhua instrument Co., Ltd.), equipped with a thermostat water bath, a corrosion cell and a data recorder. The experimental system and operation procedure has been detailed in our previous works[17].

3. Results and Discussion
The corrosion behaviour of carbon steel in carbonated non-aqueous solutions of BUMEA-2EE were measured. The mass fractions of BUMEA (\(\omega_{\text{BUMEA}}\)) ranged from 0.3 to 0.5. The temperatures ranged from 313.2 K to 343.2 K.

3.1. Effect of temperature on corrosion behaviour
Figs. 1 (a) and (b) show the effects of temperature on the corrosion rate and potentiodynamic polarization curves of carbon steel in CO₂-saturated BUMEA-2EE non-aqueous solutions in the specified conditions, respectively.

Figure 1. Effect of temperature on the corrosion rate and potentiodynamic polarization curves of carbon steel in CO₂-saturated BUMEA-2EE non-aqueous solutions. (b): \(\omega_{\text{BUMEA}}=0.3\). Symbols: experiments from this work. Lines: trend lines.

It can be seen from Fig.1 (a) that the corrosion rate increases significantly by increasing temperature. For example, the corrosion rate of carbon steel in the absorption solution increases from 0.0394 mpy to 0.1230 mpy at \(\omega_{\text{BUMEA}}=0.3\) and temperature ranged from 313.2 K to 343.2 K. Generally, the changes in temperature will affect the balance of chemical reactions. The chemical equilibrium constant increases with the increase of solution temperature. In order to maintain the equilibrium of the reaction, more metals will be dissolved in the solution to generate electrons required for the reduction of the oxidant, thereby increasing the corrosion rate.

As seen in the Fig.1 (b), the anodic current density increases significantly with the increase of temperature, and cathodic current density changes little with increasing temperature. Generally, the
cathodic and anodic current densities respectively refer to the metal dissolution rate and oxidant reduction rate. The increasing temperature tends to increase both the cathodic and anodic current densities, which may result in an increase in both the metal dissolution rate and oxidant reduction rate, and the corrosion process can consequently be accelerated.

3.2. Effect of $w_{\text{BUMEA}}$ on corrosion behaviour

Figs. 2 (a) and (b) show the effects of mass fraction of BUMEA on the corrosion rate and potentiodynamic polarization curves of carbon steel in CO$_2$-saturated BUMEA-2EE non-aqueous solutions in the specified conditions, respectively.

![Figure 2](image)

Figure 2. Effect of mass fraction of BUMEA on the corrosion rate and potentiodynamic polarization curves of carbon steel in CO$_2$-saturated BUMEA-2EE non-aqueous solutions. (b): $T=343.2K$.

Symbols: experiments from this work. Lines: trend lines.

It can be seen from Fig.2 (a) that the corrosion rate increases significantly by increasing $w_{\text{BUMEA}}$. For example, the corrosion rate of carbon steel in the absorption solution increases from 0.0349 mpy to 0.1762 mpy at $T=313.2K$ and $w_{\text{BUMEA}}$ ranged from 0.3 to 0.5. Fig.2 (b) shows that the corrosion polarization curves of carbon steel in saturated non-aqueous solution gradually shifts to the right with the increase of $w_{\text{BUMEA}}$ under the constant temperature. with an increasing $w_{\text{BUMEA}}$ in solution, both the cathodic and anodic current densities increased. The acceleration of the corrosion process is due to the increase of the metal dissolution rate and oxidant reduction rate arising from the increase in carbamate content.

3.3. Effect of CO$_2$ loading on corrosion behaviour

Fig.3 (a) and (b) show the effects of CO$_2$ loading on the corrosion rate and potentiodynamic polarization curves of carbon steel in BUMEA-2EE non-aqueous solutions.

![Figure 3](image)

Figure 3. Effect of mass fraction of CO$_2$ loading on the corrosion rate and potentiodynamic polarization curves of carbon steel in BUMEA-2EE non-aqueous solutions. (b): $w_{\text{BUMEA}}=0.5$. $T=328.2K$. Symbols: experiments from this work. Lines: trend lines.
Fig. 3 (a) indicates that the corrosion rate increases significantly with increasing CO\(_2\) loading. For example, the corrosion rate of carbon steel in the absorption solution increases from 0.0351 mpy to 0.1752 mpy at T=313.2K and CO\(_2\) loading ranged from 0.1 to 0.4. As seen in the Fig. 3 (b), with the increase of CO\(_2\) loading from 0.1 to 0.4, the corrosion polarization curves of carbon steel in BUMEA-2EE absorption solution gradually drifts upward to the right and the \(E_{\text{corr}}\) from -0.295V to -0.038V. In general, increasing the CO\(_2\) loading results in higher amounts of carbamates, there are more ions participate in the reduction reaction of the cathode and the corrosion intensifies, thus resulting in a higher corrosion rate.

4. Conclusion

In this work, the corrosion of carbon steel in BUMEA-2EE non-aqueous solutions were investigated. The effects of temperature, \(w_{\text{BUMEA}}\) and CO\(_2\) loading on the corrosion rate were demonstrated. The results show that:

1. Corrosion rate of carbon steel of BUMEA-2EE non-aqueous solutions increased with increasing temperature, \(w_{\text{BUMEA}}\) and CO\(_2\) loading.

2. The increase of solution temperature, \(w_{\text{BUMEA}}\) and CO\(_2\) loading will lead to the increase of anode current density and cathode current density. Dissolution of metals and reduction of oxidizer will accelerate the corrosion process and making the corrosion of carbon steel more severe.

3. The novel BUMEA-2EE non-aqueous solutions could be considered a promising candidate for CO\(_2\) capture with a low energy penalty and low-corrosion behavior. The absorption performance of BUMEA-2EE non-aqueous solutions would be investigated in the future.

Acknowledgments

The authors thank the National Natural Science Foundation of China (No. 51776072) and the Natural Science Foundation of Hebei Province (No. E2020502044) for their financial support.

References

[1] Zhang, L.Y., Sun, N.N., Wang, M.Q., Wu, T., Wei, W., Pang, C.H. (2021) The integration of hydrogenation and carbon capture utilisation and storage technology: A potential low-carbon approach to chemical synthesis in China. International Journal of Energy Research.

[2] Zhang, J.F., Agar, D.W., Zhang, X.H., Geuzebroek, F. (2011) CO\(_2\) Absorption in biphasic solvents with enhanced low temperature solvent regeneration. In: 10th International Conference on Greenhouse Gas Control Technologies. Amsterdam, Netherlands. 4: 67-74.

[3] Xiao, M., Liu, H., Idem, R., et al. (2016) A study of structure-activity relationships of Commercial tertiary amines for post-combustion CO\(_2\) capture. Applied Energy, 184: 219-229.

[4] Lin, P.H., Wong, D.S.H. (2014) Carbon dioxide capture and regeneration with amine/alcohol/water blends. International Journal of Greenhouse Gas Control, 26: 69-75.

[5] Bai, H., Yeh, A.C. (1997) Removal of CO\(_2\) Greenhouse Gas by Ammonia Scrubbing. Industrial and Engineering Chemistry Research, 36: 2490-2493.

[6] Kang, M.K., Cho, J.H., Lee, J.H., Lee, S.S., Oh, K.J. (2017) Kinetic Reaction Characteristics of Quasi-Aqueous and Nonaqueous Sorbents for CO\(_2\) Absorption Using MEA/H\(_2\)O/Ethylene Glycol. Energy Fuels, 31:8383-8391.

[7] Barzagli, F., Lai, S., Mani, F., Stoppioni, P.(2014) Novel Non-aqueous Amine Solvents for Biogas Upgrading. Energy Fuels, 28:5252-5258.

[8] Barzagli, F., Mani, F., Peruzzini, M. (2016) A Comparative Study of the CO\(_2\) Absorption in Some Solvent-Free Alkanolamines and in Aqueous Monoethanolamine (MEA). Environmental Science & Technology, 50: 7239-7246.

[9] Chen, S.M., Chen, S.Y., Fei, X.Y., Zhang, Y.C., Qin, L. (2015) Solubility and Characterization of CO\(_2\) in 40 mass % N-Ethylmonoethanolamine Solutions: Explorations for an Efficient Nonaqueous Solution. Industrial & Engineering Chemistry Research, 54: 7212-7218.

[10] Chen, S.M., Chen, S.Y., Zhang, Y.C., Qin, L., Guo, C., Chen, J.(2016) Species distribution of CO\(_2\)
absorption/desorption in aqueous and non-aqueous N-ethylmonoethanolamine solutions. International Journal Greenhouse Gas Control, 47: 151-158.

[11] Olyaei, E., Hafizi, A., Rahimpour, M.R. (2021) Low energy phase change CO₂ absorption using water-lean mixtures of glycine amino acid: Effect of co-solvent. Journal of Molecular Liquids, 336, 116286.

[12] Pokorny, V., Stejfa, V., Pavlicek, J., Klajmon, M., Fulem, M., Ruzicka, K. (2021) Vapor Pressures and Thermophysical Properties of Dimethoxyethane, 1,2-Dimethoxyethane, 2-Methoxyethanol, and 2-Ethoxyethanol: Data Reconciliation and Perturbed-Chain Statistical Associating Fluid Theory Modeling. Journal of Chemical and Engineering Date, 66: 2640-2654.

[13] Dong, Y., Yin, X., Cao, Y.P., Shen, S.F. (2021) Densities and viscosities for water-lean ternary mixtures of 2-butoxyethanol with monoethanolamine, 2-(methylamino)ethano 2-(ethylamino)ethanol or 2-(butylamino)ethanol from 293.15 to 353.15 K. Journal of Molecular Liquids, 323, 115079.

[14] Hwang, S.J., Kim, J., Kim, H., Lee, K.S. (2017) Solubility of Carbon Dioxide in Aqueous Solutions of Three Secondary Amines: 2-(Butylamino)ethanol, 2-(Isopropylamino)ethanol, and 2-(Ethylamino)ethanol Secondary Alkanolamine Solutions. Journal of Chemical and Engineering Date, 62: 2428-2435.

[15] Zhou, X.B., Li, X.L., Wei, J.W., Fan, Y.M., Liao, L., Wang, H.Q. (2020) Novel Nonaqueous Liquid-Liquid Biphasic Solvent for Energy-Efficient Carbon Dioxide Capture with Low Corrosivity. Environmental science & Technology., 54: 16138-13146.

[16] Gunasekaran, P., Veawab, A., Aroonwilas, A. (2013) Corrosivity of Single and Blended Amines in CO₂ Capture Process. In: International Conference on Greenhouse Gas Technologies (GHGT). Kyoto, JAPAN. 2094-2099.

[17] Xie, J.L., Zhang, L., Fu, D., Zhu, H.T. (2019) CO₂ Capture Process and Corrosion of Carbon Steel in [Bmim][Lys]-K₂CO₃ Aqueous Solutions. International Journal of Electrochemical Science, 14: 634-650.