Investigation of viscosity for AEP aqueous solutions

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Abstract. The viscosities (η) of 1-(2-aminoethyl) piperazine (AEP) aqueous solutions were measured by using the digital rotational viscometer. The temperature ranged from 303.2 K to 323.2 K. The mass fractions of AEP ranged from 0.1 to 1. Temperature and mass fraction dependences of η were demonstrated. On the basis of experiments, the viscosity activation energy (Ea) and CO2 diffusion coefficient (D_{CO2}) in AEP aqueous solutions were estimated.

1. Introduction
Carbon dioxide (CO2) is a major greenhouse gas, accounting for 77% of global emissions, much of it from burning fossil fuels and making cement as a by-product [1, 2]. Chemical absorption method is the most widely used in industrial carbon dioxide capture [3]. Among them, the most mature carbon dioxide capture technology is the use of monoethanolamine (MEA) solution for chemical absorption, which has been applied in many industrial processes [4]. Due to the shortcomings of MEA solution such as high requirements for solvent degradation and regeneration energy, the development of new absorbent has become an important research direction and development trend in the field of CO2 capture.

Recently, 1-(2-aminoethyl) piperazine (AEP), a piperazine (PZ) derivative having one primary, one secondary and one tertiary amine group, was suggested as a potential solubility promoter for CO2 capture [5]. It has been demonstrated that AEP takes the advantages of high CO2 absorption capacity, absorption rate and low vapor pressure compared with conventional amines [6]. The knowledge of viscosity is also important for the process design of the chemical absorption process of CO2 capture regeneration in addition to kinetic data, and the measurements can be used to deduce other properties or optimize the design of gas-treating processes. In this work, the viscosities of AEP aqueous solutions were measured with \( w_{AEP} \) ranging from 0.1 to 1 and the temperature ranging from 303.2K to 323.2K. The viscosity activation energy (Ea) and diffusion coefficient corresponding to CO2 (D_{CO2}) in AEP aqueous solutions were calculated and their variations with respect to mass fraction and temperature were analyzed.
2. Experimental section

2.1. Chemical and materials
1-(2-aminoethyl) piperazine (AEP) (C\textsubscript{6}H\textsubscript{15}N\textsubscript{3}, with a mass fraction ≥99%) was purchased from Aladdin Reagent Company in Shanghai. H\textsubscript{2}O (with the resistivity greater than 15MΩ•cm) was obtained from NCEPU (North China Electric Power University).

2.2. Apparatus and experimental procedures
The viscosities of the AEP aqueous solutions were measured by the NDJ-5s rotational viscometer (Shanghai Changji Geological Instrument Company). A HWY-501 thermostatic water bath (uncertainty is ±0.1 K) were used for temperature control. All measurements were performed at 303.2K to 323.2K and atmospheric pressure. The combinations 0# cylindrical rotors of the instrument and proper rotating speed were selected to measure the viscosity ranged from 0 to 100 mPa•s.

3. Results and discussion

3.1. The viscosity of the mixtures with different \textit{w\textsubscript{AEP}}
The viscosities of AEP aqueous solutions were measured, as shown in Table.1. The \textit{w\textsubscript{AEP}} dependence of viscosities of AEP aqueous solutions were displayed in Fig.1. It was found that the viscosity of AEP aqueous solutions exhibited one maximum at \textit{w\textsubscript{AEP}}≈0.7 at a constant temperature. This kind of viscosity variation may be related to the formation of intermolecular hydrogen-bonding [7]. With the increasing of AEP concentration, an intermolecular force from the hydrogen bond formed between AEP and H\textsubscript{2}O increased, which led to an increased viscosity value. When the AEP concentration is high enough, the amount of hydrogen bonding depended on the number of water molecules so that the viscosity value decreased with the decreasing of H\textsubscript{2}O.

![Figure 1. \textit{w\textsubscript{AEP}} dependence of the viscosity of AEP aqueous solutions](image-url)
3.2. Viscosity activation energy

The viscosity activation energy ($E_a$) can be estimated by fitting the temperature dependence of viscosity based on Arrhenius-type expression, which can be expressed as [8]:

$$\ln(\eta) = -\frac{E_a}{RT} + \ln(\eta_\infty)$$  \hspace{1cm} (1)

Where $\eta_\infty$, $E_a$, $R$ and $T$ are the apparent viscosity at infinite temperature, viscosity activation energy, gas constant and temperature, respectively.

The values of $E_a$, as shown in Table 1, ranged from 14.68 kJ•mol$^{-1}$ to 53.98 kJ•mol$^{-1}$. Maximum in $E_a$ was observed in AEP aqueous solutions. It was found that a higher viscosity indicated a larger $E_a$.

| $w_{AEP}$ | 303.2K | 313.2K | 323.2K | $E_a$(kJ•mol$^{-1}$) |
|-----------|--------|--------|--------|---------------------|
| 0.1       | 1.32   | 1.12   | 0.92   | 14.68               |
| 0.2       | 2.18   | 1.74   | 1.39   | 18.32               |
| 0.3       | 4.44   | 3.23   | 2.46   | 24.06               |
| 0.4       | 9.79   | 6.41   | 4.38   | 32.76               |
| 0.5       | 25.06  | 13.93  | 8.38   | 44.63               |
| 0.6       | 54.26  | 27.83  | 15.20  | 51.83               |
| 0.7       | 81.50  | 40.30  | 21.66  | 53.98               |
| 0.8       | 68.93  | 35.40  | 19.20  | 52.06               |
| 0.9       | 34.23  | 18.65  | 11.35  | 44.99               |
| 1         | 9.59   | 6.62   | 4.73   | 28.79               |

Table 1. The viscosity of AEP aqueous solution at different $w_{AEP}$

![Figure 2. Semi-logarithmic Arrhenius-like plots of the mixtures at different temperature](image-url)
3.3. Diffusivity of CO\(_2\) in AEP aqueous solutions

The diffusivity of CO\(_2\) \((D_{CO2})\) in AEP aqueous solutions can be calculated by Equation (2) \([9, 10]\).

\[
D_{CO2} = D_w \left(\frac{\eta_w}{\eta}\right)^{0.8}
\]

\[
D_w = 2.35 \times 10^{-6} \exp \left(-\frac{2119}{T}\right)
\]

Where \(D_w\), \(\eta_w\) and \(\eta\) are the diffusivity of CO\(_2\) in pure water, the water viscosity at the different temperature and the mixtures viscosity in Table 1, respectively. \(D_w\), as a function of temperature according to Equation (3) \([10]\), can be calculated and \(\eta_w\) can be attained from literature \([11]\).

The value of \(D_{CO2}\) in AEP aqueous solutions were calculated and tabulated in Table 2. The variation of \(D_{CO2}\) with increasing \(w_{AEP}\) was similar to that of viscosity, which indicated that a higher viscosity may induce a lower \(D_{CO2}\) in the solution, thus hinders the absorption.

Table 2. The diffusion coefficients of CO\(_2\) in AEP aqueous solutions

| \(w_{AEP}\) | 303.2K | 313.2K | 323.2K |
|---|---|---|---|
| 0.1 | 1.45 | 1.76 | 2.20 |
| 0.2 | 0.97 | 1.24 | 1.58 |
| 0.3 | 0.55 | 0.75 | 1.00 |
| 0.4 | 0.29 | 0.44 | 0.63 |
| 0.5 | 0.14 | 0.23 | 0.38 |
| 0.6 | 0.07 | 0.14 | 0.23 |
| 0.7 | 0.05 | 0.10 | 0.18 |
| 0.8 | 0.06 | 0.11 | 0.19 |
| 0.9 | 0.11 | 0.19 | 0.30 |
| 1.0 | 0.30 | 0.43 | 0.60 |

4. Conclusion

The viscosities of AEP aqueous solutions were measured. Temperature and mass fraction dependences of \(\eta\) were demonstrated. The viscosity activation energy and CO\(_2\) diffusion coefficient was estimated based on the viscosities. Our results show that:

1. Viscosities of AEP aqueous solutions increased firstly and then decreased with increasing \(w_{AEP}\). Maximum in viscosity was observed in AEP aqueous solutions.

2. The variations of \(E_a\) and \(D_{CO2}\) with increasing \(w_{AEP}\) are similar to that of viscosity. A higher viscosity means a larger \(E_a\) and a lower \(D_{CO2}\) in the solution.

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