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Experiments and model for the viscosity of carbonated 2-amino -2-methyl-1-propanol and piperazine aqueous solution

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ABSTRACT

The viscosities (η) of carbonated 2-amino-2-methyl-1-propanol (AMP)-piperazine (PZ) aqueous solutions were measured by using a NDJ-1 rotational viscometer, with temperatures ranging from 298.15 K to 323.15 K. The total mass fraction of amines ranged from 0.3 to 0.4. The mass fraction of PZ ranged from 0.05 to 0.10. The Weiland equation was used to correlate the viscosities of both CO_2-unloaded and CO_2-loaded aqueous solutions and the calculated results agreed well with the experiments. The effects of temperature, mass fractions of amines and CO_2 loading (α) on the viscosities of carbonated aqueous solutions were demonstrated on the basis of experiments and calculations.

1. Introduction

Aqueous solutions of amines have been widely used for the removal of CO_2 from a variety of gas streams [1–7]. Among the amine series, the sterically hindered amines, *e.g.*, 2-amino-2-methyl -1-propanol (AMP), is considered to be an attractive solvents for the removal of CO_2 due to its absorption capacity, absorption rate, selectivity and degradation resistance advantages [8–18]. Compared with N-methyldiethanolamine (MDEA), AMP has the same absorption capacity for CO_2 (1 mol of CO_2 per mol of amine) but much higher reaction rate [12]. When the aqueous solutions of AMP are used to absorb CO_2, as AMP only forms bicarbonate and carbonate ions, the regeneration energy costs are relatively low. Adding small amounts of primary and secondary amines to an aqueous solution of AMP is helpful to promote the absorption of CO_2, *e.g.*, Mandal *et al.* [13,14] showed that the addition of small amounts of monoethanolamine (MEA) and diethanolamine (DEA) to an aqueous solution of AMP significantly enhances the rate of absorption of CO_2. For similar relative composition, the rates of absorption of CO_2 in AMP-MEA and AMP-DEA aqueous solutions are higher than those in MDEA-MEA and MDEA-DEA aqueous solutions. Besides MEA or DEA, piperazine (PZ) is also considered to be an effective promoter. It has a greater capacity and higher reaction rates than MEA, *e.g.*, 4.6 mol · L^{-1} PZ aqueous solution has about 75% greater CO_2 capacity than 4.91 mol · L^{-1} MEA aqueous solution, and CO_2 reaction rates for PZ are shown to be 2–3 times faster than MEA [19].

Solution viscosity is important in the mass transfer rate modeling of absorbers and regenerators because these properties significantly affect the liquid film coefficient for mass transfer. Viscosities of both CO_2-unloaded and CO_2-loaded AMP-PZ aqueous solutions are required when designing or simulating an absorption column for CO_2 absorption using AMP -PZ aqueous solutions. So far, there are some experiments concerning the viscosities of aqueous solutions containing AMP and PZ [20–22]. In particular, Murshid *et al.* [20], Samanta and Bandyopadhyay [21] measured the viscosities of aqueous solutions of PZ and aqueous blends of AMP-PZ at temperatures from 298.15 K to 333.15 K. Paul and Mandal [22] measured the viscosities of aqueous blends of AMP-PZ at the temperatures from 288 K to 333 K. Besides experiments, they [20–22] also proposed theoretical models and satisfactorily correlated their experiments as a function of temperature and concentration of amine. However, the experiments and theoretical work for the viscosities of CO_2-unloaded and CO_2-loaded AMP-PZ aqueous solutions are rare.

The main purpose of this work is to investigate the viscosities of carbonated AMP-PZ aqueous solutions experimentally and theoretically, so as to demonstrate the effects of temperature, mass fractions of amines and CO_2 loading on the viscosities. To this end, the viscosities of CO_2-unloaded and CO_2-loaded AMP-PZ aqueous solutions were measured by using a NDJ-1 rotational viscometer, with the temperatures, mass fraction of PZ and CO_2 loading, respectively, ranging from 298.15 K to 323.15 K, 0.05 to 0.10 and 0 to 0.6. The Weiland equation [23] was used to correlate the viscosities of both CO_2-unloaded and CO_2-loaded solutions.

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TABLE 1
Provenance and purity of the samples studied.

Chemical	CAS No.	Mass fraction purity	Molar mass	Density/(g · cm^{-3}) (293.15 K)
PZ Huaxin	110-85-0	0.995	86.14	0.8760
AMP Huaxin	124-68-5	0.995	89.14	0.9172

2. Experimental

2.1. Materials

AMP and PZ were purchased from the Huaxin Chemical Co. The provenance and sample purity are shown in table 1. They were used without further purification. Aqueous solutions of AMP-PZ were prepared by adding doubly distilled water. The uncertainty of the electronic balance is ±0.1 mg.

2.2. Apparatus and procedure

The carbonated AMP-PZ aqueous solutions were prepared according to the methods mentioned in the work of Weiland *et al.* [23], Amundsen *et al.* [24], and our previous work [25–27]: CO_2-unloaded AMP -PZ aqueous solutions were put into a volumetric flask immersed in the thermostatic bath with a built-in stirrer for uniform temperature distribution. CO_2 from a high-pressure tank was inlet into the volumetric flask at certain temperatures (CO_2 pressure is atmosphere). Once the carbonated solution was prepared, varying proportions of the unloaded and loaded solutions were mixed together to produce a set of samples having a fixed ratios of AMP /PZ -to-water, but with varying CO_2 loading. The CO_2 loading is defined as $\alpha = n_{CO_2}/(n_{AMP} + n_{PZ})$, in which n_{CO_2} is the mole of loaded CO_2, n_{AMP} and n_{PZ} are, respectively, the moles of AMP and PZ in the unloaded aqueous solutions. The uncertainty of CO_2 loading is less than 2% [23–27].

TABLE 2
Viscosities η [a] (mPa · s) of carbonated AMP-PZ aqueous solutions under different mass fractions of AMP (w_1) and PZ (w_2), and different CO_2 loadings α (mol CO_2 per mol amines).

w_1/w_2	α/(mol CO_2 per mol amines)	η/mPa · s			
		T = 298.15 K	303. 15 K	313. 15 K	323. 15 K
0.25/0.05	0	3.92	3.31	2.43	1.87
	0.10	5.63	4.87	4.63	3.50
	0.20	6.09	5.05	4.84	3.84
	0.30	6.25	5.54	4.93	4.03
	0.40	6.68	6.03	4.99	4.23
	0.50	7.19	6.28	5.51	4.90
	0.60	7.84	6.39	5.86	5.42
0.30/0.05	0	4.83	4.01	3.18	2.75
	0.10	6.42	6.05	5.00	3.92
	0.20	6.91	6.71	5.78	4.16
	0.30	7.78	7.32	6.51	5.03
	0.40	8.48	7.89	6.80	5.94
	0.50	9.04	7.94	7.09	6.31
	0.60	9.92	8.54	7.86	6.75
0.35/0.05	0	6.08	5.14	4.22	3.35
	0.10	8.27	7.99	6.91	5.35
	0.20	9.54	8.76	7.34	5.77
	0.30	10.12	9.44	7.84	6.48
	0.40	10.56	9.76	8.23	7.06
	0.50	11.24	10.28	8.63	7.66
	0.60	12.18	10.86	9.26	8.28
0.20/0.10	0	3.93	3.47	2.50	1.99
	0.10	6.80	6.06	4.83	4.12
	0.20	6.98	6.25	5.24	4.40
	0.30	7.23	6.34	5.37	4.54
	0.40	7.46	6.64	5.68	4.63
	0.50	7.82	7.06	5.99	4.82
	0.60	8.35	7.63	6.24	5.24
0.25/0.10	0	5.38	4.73	3.82	3.08
	0.10	7.56	7.41	5.85	4.34
	0.20	7.95	7.73	6.25	4.56
	0.30	8.46	7.99	6.67	4.94
	0.40	8.68	8.38	7.08	5.47
	0.50	9.26	8.74	7.41	5.73
	0.60	9.62	8.94	7.78	6.56
0.30/0.10	0	7.31	6.54	5.21	3.96
	0.10	8.57	7.90	7.06	5.31
	0.20	9.09	8.68	7.35	5.39
	0.30	9.45	9.02	7.86	6.10
	0.40	10.42	9.99	8.19	6.79
	0.50	11.35	10.96	8.75	7.11
	0.60	12.85	12.22	9.89	7.82

[a] Standard uncertainties σ are $\sigma(T)$ = ±0.05 K; (w) = ±0.0001; $\sigma(\alpha)$ = ±0.02 mol CO_2 per mol amines; σ (η) = ±0.01 mPa · s.