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Viscosities of Aqueous Solutions of Monoethanolamine (MEA), Diethanolamine (DEA) and N-Methyldiethanolamine (MDEA) at T = (90-150) °C

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ABSTRACT

Aqueous amine viscosities of monoethanolamine (MEA), diethanolamine (DEA) and methyldiethanolamine (MDEA) solutions were examined at a high temperature range from (90 to 150) °C for different concentrations. The measured experimental viscosity data were used to correlate the equation suggested by literatures for aqueous amines. The deviation between experimental viscosities measured in this work and viscosities calculated by regression equation is negligible.

INTRODUCTION

Removal of acid gas impurities such as CO_2, H_2S is of prime importance due to environmental regulations. The most common acid gas absorption methods are running with amine solvents. However, lack of available physical property data gives difficulties in developing calculation models for gas absorption and stripping. A wide variety of alkanolamines such as monoethanolamine (MEA), diethanolamines (DEA), N-Methyldiethanolamine (MDEA) can be used for acid gas absorption. The dynamic viscosity of the amine is one of the most important physical properties related to the amine solvent gas absorption. Therefore, the main interest of this study is focused around dynamic viscosity of the amines. The pure amine viscosities over the temperature range 20 - 150 °C have been reported by DiGuilio et al. [1]. The aqueous amine viscosities up to certain temperature range are already given in the literatures. Aqueous MEA viscosities of high concentration (mass ratio of MEA, $r = M_{amine}/M_{amine+water} = 0.2 - 0.9$) in the range of temperature T = (25 to 80) °C have been reported by Amundsen et. at [2]. Moreover, aqueous DEA viscosity of low concentration (r = 0.1 to 0.3) in the range of temperature T = (20 to 80) °C has been measured by Rinker et al. [3]. Aqueous MDEA solution viscosity of concentration of r = (0.2 to 0.5) in the range of temperature T = (30 to 60) °C has been reported by Li and Lie [4]. This work presents a set of measurements covering completed concentration range (r = 0.1 to 0.9) in the range of temperature T = (90 to 150) °C. The measured viscosity data are used to generate the polynomial for representation of amine viscosities using regression. The polynomial equation given by Teng et al. [5] is used to model the dynamic viscosities of aqueous MEA, DEA and MDEA samples over a temperature range.

EXPERIMENTAL SECTION

This section provides a brief description of sample preparation, sample concentration limits and measurement of performance. Dynamic viscosity was measured using Anton Paar MCR 101 rheometer. Operating pressure is maintained at 5 bars to analyze high temperatures. First, the viscometer is calibrated with petroleum distillate and mineral oil calibration fluid from Paragon Scientific Company. According to the calibration factor, measuring setup was changed to get a high accuracy for measurements. The amine concentration and the supplier are mentioned in the Table 1.

Table 1. Purity of the amines used in experiments.

Amine type	Mass Purity %	Supplier
MEA	99.5	Merck KGaA
DEA	99	Merck Schuchardt OHG
MDEA	98	Merck Schuchardt OHG

The purity of the amines is given in the table in mass basis 99.5, 99 and 98% respectively for MEA, DEA and MDEA. De-gassed distilled water was used to prepare the aqueous amine solution for experimental studies. All the experiments are performed under 5 bar pressure continuously over the temperature range.

RESULTS AND DISCUSSION

Viscosity measurements of this study are categorized into three parts:

- Aqueous MEA viscosity where r = (0.1 to 0.9) in the temperature range T = (90 to 150) °C
- Aqueous DEA viscosity where r = (0.1 to 0.9) in the temperature range T = (90 to 150) °C
- Aqueous MDEA viscosity where r = (0.1 to 0.9) in the temperature range T = (90 to 150) °C

The viscosity measurements of MEA, DEA and MDEA samples are tabulated in the Table 2, 3 and 4, respectively.

Table 2. Viscosities of aqueous MEA solutions (r = 0.1 to 0.9) measured in this work for temperature T = (90 to 150) °C.

Temp	Concentration (r)								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
T/°C	η/mPa·s								
90	0.441	0.554	0.669	0.824	1.091	1.344	1.673	2.010	2.462
100	0.372	0.500	0.574	0.706	0.898	1.085	1.293	1.651	1.897
110	0.327	0.471	0.540	0.584	0.758	0.898	1.048	1.325	1.522
120	0.305	0.441	0.489	0.518	0.656	0.743	0.881	1.093	1.257
130	0.268	0.389	0.449	0.486	0.564	0.629	0.741	0.913	1.030
140	0.245	0.360	0.423	0.444	0.512	0.559	0.637	0.775	0.862
150	0.210	0.325	0.405	0.413	0.484	0.512	0.568	0.638	0.684

Table 3. Viscosities of aqueous DEA solutions (r = 0.1 to 0.9) measured in this work for temperature T = (90 to 150) °C.

Temp	Concentration (r)								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
T/°C	η/mPa·s								
90	0.447	0.568	0.724	0.971	1.565	2.328	3.692	6.159	10.059
100	0.413	0.491	0.602	0.882	1.353	1.829	2.840	4.449	6.994
110	0.366	0.449	0.533	0.769	1.157	1.511	2.269	3.409	5.164
120	0.327	0.411	0.487	0.663	0.999	1.270	1.856	2.689	3.921
130	0.297	0.371	0.449	0.577	0.874	1.088	1.538	2.154	3.074
140	0.255	0.349	0.412	0.520	0.754	0.934	1.320	1.757	2.439
150	0.216	0.306	0.368	0.465	0.648	0.826	1.120	1.428	1.869

Table 4. Viscosities of aqueous MDEA solutions (r = 0.1 to 0.9) measured in this work for temperature T = (90 to 150) °C.

Temp	Concentration (r)								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
T/°C	η/mPa·s								
90	0.463	0.543	0.739	0.985	1.398	1.953	2.802	3.803	5.082
100	0.431	0.488	0.594	0.805	1.127	1.535	2.145	2.797	3.685
110	0.400	0.448	0.518	0.680	0.948	1.263	1.719	2.172	2.825
120	0.362	0.417	0.469	0.599	0.816	1.058	1.403	1.726	2.226
130	0.323	0.377	0.427	0.532	0.702	0.941	1.170	1.403	1.776
140	0.294	0.335	0.408	0.487	0.600	0.755	0.987	1.158	1.457
150	0.246	0.302	0.364	0.442	0.512	0.621	0.831	0.938	1.213

Viscosities of MEA, DEA and MDEA decrease with the increasing of operating temperature, and increase with the increasing of amine concentration. Some of the viscosity data variations with temperature are given in the Figure 1, 2 and 3 for MEA, DEA and MDEA respectively. Figures are drawn for temperature range from (90 to 150) °C for every case.

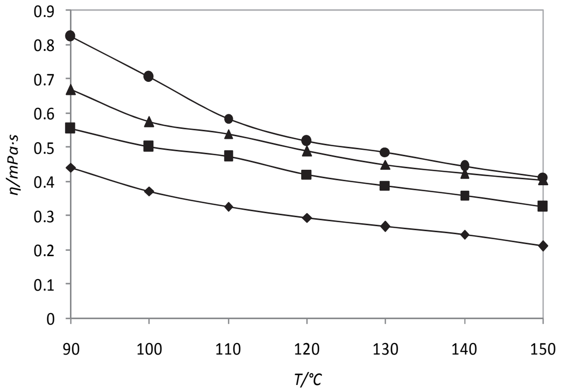

Figure 1. Aqueous MEA viscosity as a function of temperature. Symbols refer to concentration of amine (mass basis), ♦, 10%; ■, 20%; ▲, 30%; ●, 40%.

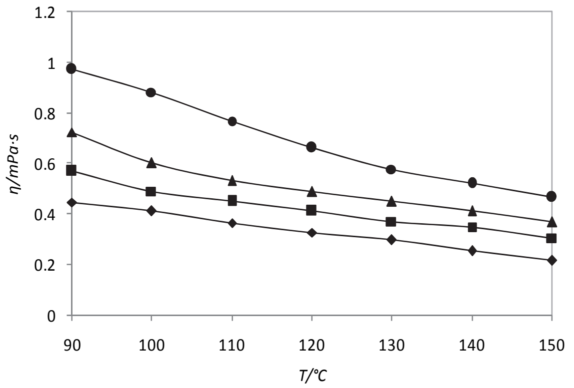

Figure 2. Aqueous DEA viscosity as a function of temperature. Symbols refer to concentration of amine (mass basis), ♦, 10%; ■, 20%; ▲, 30%; ●, 40%.

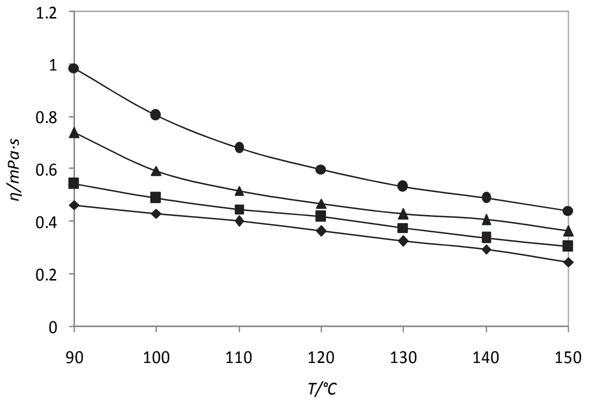

Figure 3. Aqueous DEA viscosity as a function of temperature. Symbols refer to concentration of amine (mass basis), ♦, 10%; ■, 20%; ▲, 30%; ●, 40%.

As can be seen from Figure 1, 2 and 3, viscosity of the amine are decreasing with the increase of temperature.

Viscosity measurements of the MEA, DEA and MDEA solutions with r = 0.1 to 0.9 are used to model the equation that is representing aqueous amine viscosity. The equation 1 is suggested by Teng et al. for estimation of aqueous amine viscosities.

$$\ln[\eta/(\mathrm{mPa.s})] = \ln\eta_0 + \sum_{0}^{m} a_k \mathrm{x}^{\mathrm{k}} \qquad (1)$$

In this equation, η represents the viscosity of the binary solution while η_o is the viscosity of pure water, and x the mole fraction of the amines. Pure water viscosity is measured for the complete temperature range. Measured viscosity data for different temperatures are separately used to develop the constant values that are required for this equation. Calculated polynomial coefficients which are given by the regression of equation 1 is indicated by a_k in Table 5. Deviation of calculated versus measured aqueous amines' viscosities are calculated as average absolute deviation (AAD) and tabulated in the same table.

Table 5. Coefficients of the polynomial of the binary solutions between MEA, DEA and MDEA and water at different temperatures.

T/°C	*amine*	a_0	a_1	a_2	a_3	a_4	a_5	a_6	*AAD*
90	MEA	0.3453	3.4619	-14.4202	119.735	-371.1737	491.5896	-236.6139	0.01
	DEA	0.3329	4.7260	-42.4504	386.9422	-1167.1	1636.8	-855.6841	0.08
	MDEA	0.4736	-2.0905	62.9991	-294.7465	824.7204	-1134.7	583.5687	0.05
100	MEA	0.2133	6.6914	-60.1462	373.9031	-1103	1511.5	-771.5124	0.07
	DEA	0.5515	-7.1398	114.4023	-527.9142	1313.4	-155.8	703.7359	0.01
	MDEA	0.4736	-2.7278	53.5302	-224.9534	580.7206	-776.2963	398.1262	0.03
110	MEA	0.0593	11.8655	-126.6862	711.4526	-1944.9	2520.9	-1234.4	0.01
	DEA	0.4640	-5.1285	87.4062	-400.6163	984.6645	-1163.5	524.2393	0.04
	MDEA	0.4218	-1.3781	28.1658	-84.6120	184.8714	-254.0793	139.4344	0.02
120	MEA	0.076	10.0953	-103.0506	550.3446	-1451.0	1834.4	-882.9911	0.03
	DEA	0.3682	-2.4144	51.1804	-219.4658	519.5077	-597.8328	263.3452	0.01
	MDEA	0.3525	0.1449	8.8563	3.3596	-38.5952	30.3710	2.8030	0.01
130	MEA	0.0838	7.6582	-65.7286	310.5228	-755.703	910.0895	-426.188	0.02
	DEA	0.2493	2.0840	-16.9533	174.7263	-570.5933	804.8258	-412.6446	0.03
	MDEA	0.2419	3.5695	-39.5729	282.2498	-823.4096	1066.2	-508.7170	0.02
140	MEA	0.0557	7.8983	-69.9447	333.3806	-822.4012	1002.1	-473.0645	0.01
	DEA	0.2139	1.3075	7.3841	-33.8689	120.9994	-198.3091	114.2200	0.02
	MDEA	0.2840	-0.3376	24.4690	-151.0273	477.3292	-703.2198	379.2793	0.002
150	MEA	0.0195	7.7825	-64.9183	293.5027	-696.1422	819.678	-375.6467	0.01
	DEA	0.1375	3.0216	-16.0308	92.3158	-217.8615	229.5957	-89.6132	0.01
	MDEA	0.2395	-0.6921	36.9316	-263.3742	853.1105	-1245.5	662.3318	0.005

Predicted viscosity values of the fitted correlation and the experimental data are in good agreement with negligible deviation.

EVALUATION OF EXPERIMENTAL UNCERTAINTIES

The uncertainty of the viscosity measurements of MEA, DEA and MDEA aqueous amines arises as a combination of the uncertainty of the temperature measurements, sample preparation and measuring instrument uncertainties.

The temperature accuracy, U(T), which is related to rheometer temperature controller, is given as ±0.3K. The maximum viscosity gradient against the temperature, $\Delta\eta/\Delta T$, is calculated as 0.040 $\mathrm{mPa\cdot s\cdot K^{-1}}$. The corresponding uncertainty in η, $(\Delta\eta/\Delta T)\cdot\Delta T$, is then estimated as ±0.0120 mPa·s. The uncertainties of the sample preparation were found by calculating the error values (difference between the expected value and measured value r) of the prepared sample. The mass ratio uncertainty ±0.004, U(r), and the viscosity gradient $(\Delta\eta/\Delta r)$ with 0.05 mPa·s are used for calculating the uncertainty of sample preparation. The resulting uncertainty in the sample preparation is calculated as, $(\Delta\eta/\Delta r).\Delta r$, ±0.00020. The rheometer accuracy is given as ± 0.002 mPa·s. The overall uncertainty of η, $U(\eta)$, is calculated by combining the partial uncertainties reported in this section with root sum of square method. The value is calculated as ±0.0122 mPa·s. The combined expanded uncertainty of the viscosity, $U_c(\eta)$, is calculated as ±0.024 mPa·s (level of confidence 0.95). The combined expanded uncertainty, suggested by symbol Uc, is obtained by multiplying overall uncertainty, $U(\eta)$, by a coverage factor, suggested symbol k. Typically, k is assumed to be 2 with the level of confidence 0.95.

CONCLUSION

The viscosity of MEA, DEA, and MDEA were measured at a temperature range from (90 to 150) °C for aqueous amines. Aqueous amine viscosities were measured for a mass fraction range 0.10 to 0.90. As the temperature increase, viscosity of aqueous amine solutions decreases. Moreover, the viscosity of aqueous amine solutions increases as the mass fraction of amine increase for a given temperature. The equation suggested by Teng et al. is used for estimation of aqueous amine viscosities. The required coefficient for the suggested equation is generated by regression. The deviation of regression values and measured values are calculated for all three aqueous amines.

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