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High Pressure Rheology and Viscosity of Monoethanolamine with n-Methyl-2-Pyrrolidone and Water Hybrid Solvent

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Abstract

In this work, the rheology of a solvent which consisted of monoethanolamine (MEA) as well as water and n-methyl-2-pyrrolidone (NMP) (weight ratio 20:40:40) was studied at gauge pressure up to 5MPa and temperature range from 303.15 to 333.15 K. The flow chart showed positive linear relationship between shear stress and shear rate for the solvent at all temperature and pressure conditions tested. This trend was consistent with the behaviour of a Newtonian fluid. The dynamic viscosity of MEA-NMP hybrid solvent at temperature from 303.15 to 333.15 K and gauge pressure from (0.1 to 5) MPa was calculated from the rheology data measured.

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1. Introduction

CO₂ removal is an essential process in sweetening of natural gas from underground reservoir. Natural gas generally contains a large quantity of methane along with heavier hydrocarbons such as ethane, propane, isobutene, normal butane and considerable amount of CO₂ [1]. CO₂ must be removed from natural gas as CO₂ is highly corrosive with presence of moisture (water) and rapidly destroys pipelines and equipment. It also reduces the heating value of a natural gas stream and wastes pipeline capacity [2].

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Amine systems have been widely used for many years to remove entrained CO₂ in raw natural gas [3, 4]. One of the advantages of amine systems is low hydrocarbon loss, besides being able to meet the low CO₂ specification required in processed natural gas [5].

Chemical absorption is one of the most efficient technologies for CO₂ removal from various industrial gas streams. This technology employs the chemical solvents which are reactive with CO₂ [6]. Chemical solvents are usually diluted in water before usage in order to reduce the chemical's corrosiveness. Among the solvents available, the most widely used solvent in industrial process for capturing CO₂ is MEA [7, 8].

In recent years, there are growing research on hybrid solvents such as combination of propylene carbonate with methyl diethanolamine (MDEA) or diisopropanolamine (DIPA) [9, 10], polyethylene oxide with diethanolamine (DEA) [11], methanol with DEA or MEA [12-14] and n-methyl-2-pyrrolidone with 2-amino-2-methyl-1-propanol (AMP) or MEA [15, 16].

Hybrid solvent, which consists of both physical and chemical solvents, has the potential to minimize the weakness of each solvent whilst simultaneously offer the opportunity to formulate the solvent according to the high pressure offshore field or onshore gas received condition [17]. Hybrid solvent is expected to provide fine cleanup at high CO₂ partial pressure [18]. N-Methyl-2-Pyrrolidone (NMP) is the physical solvent used in the Purisol process due to its attractive properties of low vapour pressure, low viscosity and high CO₂ absorption capacity [19]. Despite MEA solvent being widely used for commercial application, data on its hybrid solution with NMP are not much available in open literature.

In this work, the rheology of a solvent which consisted of MEA as well as water and NMP was studied at gauge pressure up to 5MPa and temperature range from (303.15 to 333.15) K. The weight ratio of MEA:NMP:H₂O selected for this hybrid solution study was 20:40:40. This would provide further understanding on the physical properties of the hybrid solvent at high pressure conditions.

2. Materials and Method

MEA (99%) and NMP (99%) used in this study were purchased from Acros Organics. The chemicals were used without further purification. Double distilled water was used to prepare the hybrid solvent for this work.

The rheology and dynamic viscosity of MEA-NMP-water hybrid solution was measured using MCR 302 Anton Paar double gap rheometer. The diagram of the double gap cell is shown in Fig. 1. The first gap was the measurement difference between R₁ and R₂ while the second gap was the measurement difference between R₃ and R₄. The rheometer was calibrated using calibration fluid APN26 from Paragon Scientific Ltd.

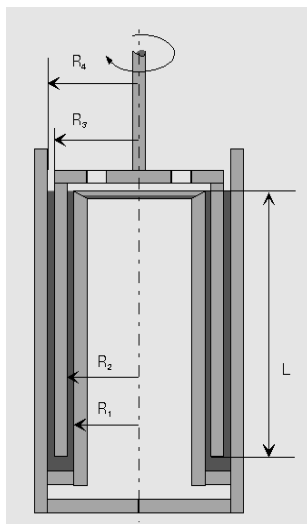


Fig. 1. Double gap cell used in this study

Temperature control was achieved by circulating water from water bath Anton Paar Viscotherm VT2 to the rheometer setup at (303.15, 313.15, 323.15 and 333.15) K. The high pressure rheometer system was achieved by applying pressurized nitrogen gas to the setup at 0.1 MPa, 1 MPa, 3 MPa and 5 MPa.

3. Results and Discussion

The shear stress, τ , of the hybrid solvent was measured as the shear rate, γ , of the rheometer was varied from 100 to 1000 s^{-1} . The flow chart for MEA-NMP hybrid solvent at temperature of 303.15 K, 313.15 K, 323.15 K and 333.15 K for gauge pressure of 0.1 MPa, 1 MPa, 3 MPa and 5 MPa is shown in Fig. 2. The flow chart showed positive linear relationship between shear stress and shear rate for the solvent at all temperature and pressure conditions tested. This trend is consistent with the behaviour of a Newtonian fluid. With the shear stress linearly proportional to the shear rate, viscosity, η , of the solvent was calculated using equation 1.

$$\eta = \frac{\tau}{\gamma} \quad (1)$$

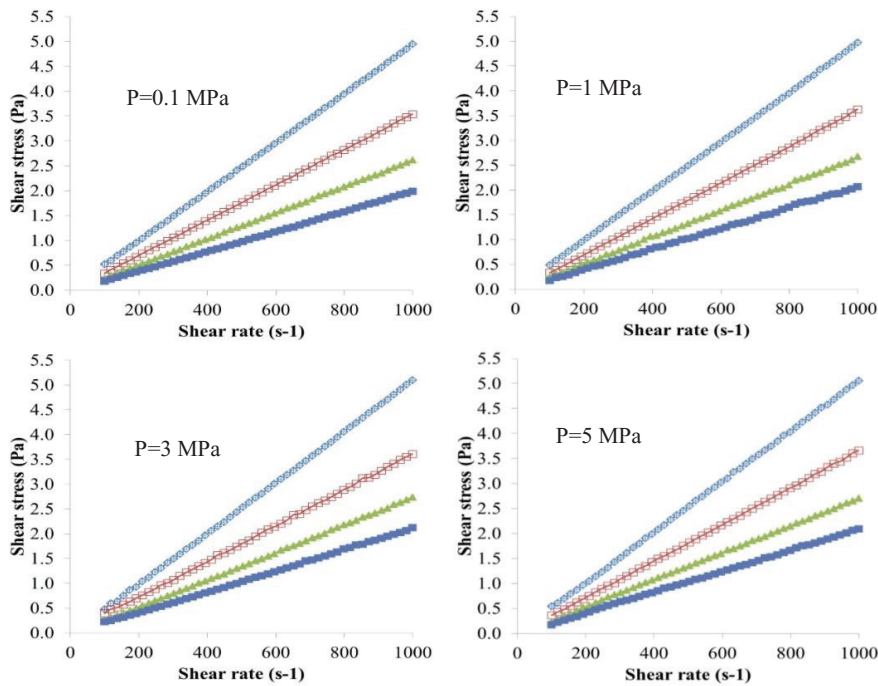


Fig. 2. Flow chart for MEA-NMP hybrid solvent at different temperature (K): \diamond , 303.15; \square , 313.15; \blacktriangle , 323.15; \blacksquare , 333.15

The viscosity data of MEA-NMP hybrid solvent at temperature from (303.15 to 333.15)K and gauge pressure from (0.1 to 5) MPa are listed in Table 1.

Table 1. Viscosity, η (mPa.s), of MEA-NMP hybrid solvent at temperature from (303.15 to 333.15)K and gauge pressure from (0.1 to 5) MPa.

Pressure (MPa)	Temperature (K)			
	303.15	313.15	323.15	333.15

0.1	4.94	3.53	2.6	1.96
1	4.95	3.58	2.66	2.05
3	5.06	3.6	2.7	2.07
5	5.07	3.63	2.7	2.08

The viscosity data was transformed into a graphical form in Fig. 3. It was observed that the viscosity decreases with an increase in temperature. This could occur because with the rise in temperature the internal resistance of molecules decreases, hence allowing the solution molecules to flow easily and thereby reduced the viscosity of the solution [6].

However, the increase of pressure appeared to have smaller impact on the viscosity of solution. The viscosity of solution increased by only 2.5% when pressure was increased by approximately 50 times from 0.1 MPa to 5 MPa at temperature of 303.15 K. The increment percentage was higher with increase of temperature as it was observed that the viscosity decreased by 3%, 4% and 6% for temperature of 313.15 K, 323.15 K and 333.15 K respectively.

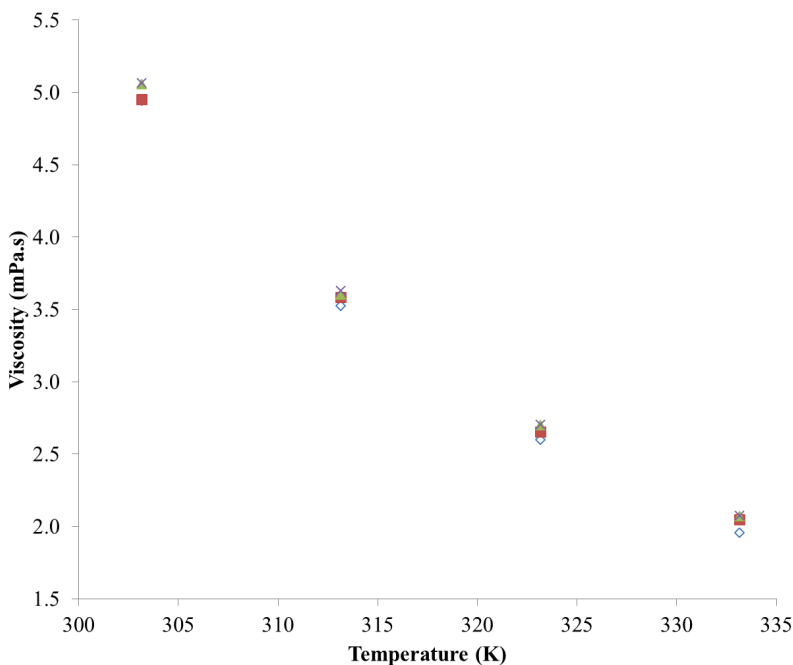


Fig. 3. Plot of calculated values of viscosity versus temperature at different pressure (MPa): ◇, 0.1; ■, 1; ▲, 3; ×, 5

The viscosity data for the tested MEA-NMP hybrid solvent were fitted using Curve Fitting function in Matlab R2013a software. The best fit was exponential function. Therefore, following exponential equation (2) was used to fit the viscosity data.

$$\eta = B_0 \exp(B_1 \cdot T) \quad (2)$$

Where η is the viscosity (mPa.s), B_0 and B_1 are the correlation coefficients and T is the temperature (K). The fitting equation parameters are listed in Table 2 with standard deviations (SD) calculated using equation 3.

$$SD = \left[\frac{\sum_i^n (x_{exp} - x_{calc})^2}{n} \right]^{0.5} \quad (3)$$

where n is the number of experimental data points, X_{exp} and X_{calc} are experimental and calculated values, respectively.

Table 2. Fitting parameters of equation 2 and SD for viscosity ($\eta/\text{mPa}\cdot\text{s}$) of MEA-NMP hybrid solvent

Pressure (MPa)	B_0	B_1	R^2	SD
0.1	68254.31	-0.03147	0.9987	0.0419
1	46054.33	-0.03017	0.9981	0.0471
3	54099.79	-0.03063	0.9969	0.0617
5	53384.42	-0.03058	0.9974	0.0549

Fig. 4 shows the comparison of experimental and predicted viscosity values. Based on Table 2, the R^2 value of the predicted viscosity data obtained from the exponential fitting equation for each pressure condition tested was more than 0.99. This indicated that the predicted data are in good relation with the experimental data, therefore, can be used for viscosity prediction of the studied system.

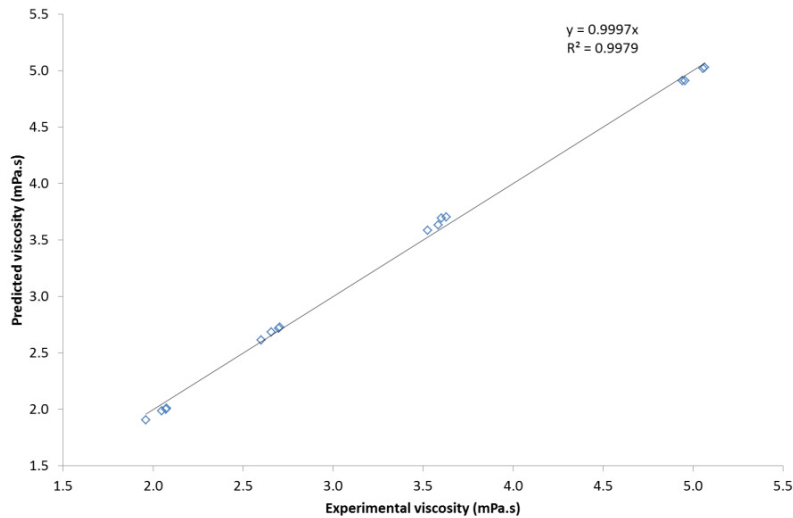


Fig. 4. Comparison between experimental values versus predicted values of viscosity for MEA-NMP hybrid solvent

4. Conclusion

The rheology behaviour of MEA with NMP and water hybrid solvent at weight ratio of (20:40:40) were measured at a range of temperatures from (303.15 to 333.15) K and pressure from (0.1 to 5) MPa. The flow chart showed positive linear relationship between shear stress and shear rate for the solvent at all temperature and pressure conditions tested, hence, consistent with the behaviour of a Newtonian fluid. Viscosity of the hybrid solvent was calculated from rheology data. The viscosity decreased with increase of temperature. There was only slight increase of viscosity with increase of pressure. The viscosity data at different pressure condition were correlated by mathematical fitting equations of least-squares in order to calculate the predicted data. There is a good agreement between the experimental and predicted data based on the deviations calculated between both sets of data. Hence, the developed correlation can be used satisfactorily for viscosity prediction in future CO_2 removal system design calculations.

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