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Experimental and correlation study of selected physical properties of aqueous blends of potassium sarcosinate and 2-piperidineethanol as a solvent for CO_2 capture

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ABSTRACT

In this work, physical properties such as density, refractive index, and viscosity of aqueous blends of potassium sarcosinate (K-Sar) and 2-piperidineethanol (2-PE) were measured at temperatures ranging from 298.15 to 333.15 K. Several concentrations of K-Sar and 2-PE blends were prepared in terms of mass fraction (0.04 + 0.16, 0.08 + 0.12, 0.12 + 0.08, 0.16 + 0.04, and 0.20 + 0), respectively. From the results, it was observed that all physical properties data decreases with the rise in temperature of the solution. While, density increases with increase in concentration of K-Sar in the aqueous blended solution, and refractive index and viscosity decrease with increase in K-Sar concentration in the solution. Both density and refractive data were correlated as a function of concentration and temperature using modified form of Graber's equation. However, a modified Vogel–Tamman–Fulcher equation was utilized for correlating the experimental viscosity data of aqueous blend. Experimental density data were used to calculate the coefficient of thermal expansion. It increases marginally with increase in concentration and temperature. Moreover, ANOVA analysis was performed for all the physical properties data.

1. Introduction

CO_2 capture and storage (CCS) is getting popular since CO_2 is considered as a greenhouse gas which can be mitigated and controlled to allow the world to continue fossil fuel consumption (Shaikh et al., 2015). Fossil fuels are the major source of CO_2 emission which is increasing the concentration of CO_2 in the atmosphere (Rao and Rubin, 2002). CO_2 emission from fossil fuels combustion in power generation and various industries is being considered as the primary source which is responsible for about 60% of the total CO_2 emission to the atmosphere (IPCC, 2013). As a result of anthropogenic CO_2 emission, atmospheric concentrations rose by 30% from pre-industrial levels of 280 ppmv (1991) to 390 ppmv (2012) (Kaplan et al., 2013). It is predicted that the CO_2 concentration of the atmosphere will increase from its present value of 390 ppmv to 900 ppmv by the year 2050, primarily as a consequence of fossil fuels use (IPCC, 2013). In view of this, there is a great need to mitigate the problem of CO_2 emission to atmosphere.

Most of CO_2 capture technologies are not considered new since they have been used for the separation of CO_2 from gas mixtures for years ago. Chemical solvents have been used to separate CO_2 from impure natural gases since almost 60 years ago (Anderson and Newell, 2004). Post-combustion, pre-combustion, and oxyfuel are three categories for CO_2 capture,

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but, post combustion has been known as the most mature category among the others (Leung et al., 2014). There are several well-established approaches for effectively capturing CO_2 from post-combustion flue gas streams. These approaches include adsorption, cryogenics separation, membrane separation, and absorption (Rufford et al., 2012). The selection of technology depends on many factors, such as partial pressure of CO_2 in gas streams, extent of CO_2 recovery required, sensitivity to impurities such as acid gases, particulates, operating costs of the process, and many other factors (White et al., 2003). Absorption by chemical solvents has been well-known for capturing CO_2 from low pressure flue gas stream (Rao and Rubin, 2002). Among the technologies mentioned above, it can be concluded that chemical absorption of CO_2 from low pressure diluted flow gas streams is the most effective and economical technology (Leung et al., 2014). Coal-fired power plants are the best candidates for this capture application (Kohl and Nielsen, 1997).

The most commonly used chemical solvents for chemical absorption processes are aqueous alkanolamines (Rao and Rubin, 2002). Today, amines such as monoethanolamine (MEA), diethanolamine (DEA) and methyldiethanolamine (MDEA) are well-known chemical solvents for CO_2 capture (Garg et al., 2016b; Shaikh et al., 2015; Shariff et al., 2016). Regardless of their extensive use for absorption of CO_2, several drawbacks have been identified and reported after comprehensive research of these conventional solvents for CO_2 capture (Shaikh et al., 2015). These drawbacks include low resistance towards oxidative and thermal degradation, highly volatile, and formation of toxic products (Gabrielsen et al., 2007; Gouedard et al., 2012; Mazari et al., 2014; Rochelle, 2012). Therefore, solvents with more favorable characteristics for CO_2 capture are being requested. Only if an energy efficient and environmental safe solvent can be found, the chemical absorption process for CO_2 capture will have the potential for large scale implementation.

In the search of new solvents for the chemical absorption process, the majority of studies centers on amino acid salt solutions (Garg et al., 2016a, 2016c; Holst et al., 2008; Kumar et al., 2001; Portugal et al., 2007; Shaikh et al., 2014). CO_2 absorption using amino acids is a bio-mimetic approach to CO_2 capture, due to its similarity to CO_2 binding by proteins such as for example hemoglobin (Mathews et al., 2000). Aqueous alkaline salts of amino acids, usually potassium salts but also sodium and lithium salts, are considered alternatives to currently used alkanolamines (Aronu et al., 2010; Garg et al., 2016c). Amino acids have the same functional group as present in the alkanolamines, and thus they behave similarly towards CO_2 in flue gas (Aziz et al., 2016; Majchrowicz and Brilman, 2012; Portugal et al., 2009). Compared to alkanolamines, amino acid salt solutions are considered to be having low volatility and higher resistance towards thermal and oxidative degradation (Kumar et al., 2003a). In addition, they are expected to be environmental friendly as they do not form any toxic intermediates (Jockenhövel et al., 2009). When absorbing CO_2 into amino acid salt solutions, precipitation of the reaction products might occur (Hook, 1997; Kumar et al., 2003a; Majchrowicz et al., 2009). The appearance of solids offers interesting advantages as well as drawbacks. The main negative aspects are the possible plugging and fouling of the gas–liquid contactors and heat-transfer surfaces (Kumar et al., 2003a). Advantages are explained by the fact that precipitation of the reaction products, decreases their concentration in the liquid phase, which shifts the reaction towards the formation of more products, thereby increasing the CO_2 absorption by the solvent (Mazinani et al., 2015). Depending on the chemical nature of the precipitation, there are possibilities for the (temporary) storage of CO_2, and thereby new process opportunities (Majchrowicz et al., 2009). According to literature, the precipitate can be amino acid itself (Kumar et al., 2003b), but it can consist of carbonate species as well which was reported by Hook (1997). Moreover, it has been shown that as a result of such precipitation the CO_2 equilibrium partial pressure over the resulting slurry will remain (approximately) constant for a certain solution loading. This gave a possibility of higher loadings of the solvent, which has benefits for both the solvent circulation and thermal energy requirement for solvent regeneration (Majchrowicz et al., 2009). The occurrence of precipitation is challenging and adaption of equipment and process design is needed in order to handle the slurry and proper benefit from its formation (Brouwer et al., 2005).

One such amino acid salt that has a potential for CO_2 capture is potassium sarcosinate (K-Sar) (Ma'mun, 2014). Previous studies by Aronu et al. (2013) and Ma'mun and Kim (2013) showed that aqueous K-Sar has higher absorption rate and high CO_2 loading as compared to aqueous MEA. In addition to this, aqueous K-Sar solutions showed precipitation behavior at higher CO_2 loadings (Ma'mun and Kim, 2013). Moreover, it is probable to attain several other characteristics of aqueous K-Sar solution by blending promoter or activator for enhancing the CO_2 absorption (Kang et al., 2013; Lu et al., 2010; Shaikh et al., 2015). One such promoter is 2-piperidineethanol (2-PE). It is a secondary amine consisting of naphthenic ring and amino groups. Previous studies showed that it has higher absorption rate, higher absorption capacity, and degradation resistance flexibility as compared to conventional amine solvents (Paul and Mandal, 2006). As per the knowledge of the authors, no studies have been found on the blended system of aqueous K-Sar and 2-PE.

Therefore, new formulations of aqueous K-Sar and 2-PE have been prepared. An economical and efficient process design will be more feasible if accurate data on the physical properties of blended system is present in the simulators. Physical properties are very important, since these properties can play a significant role in designing an efficient gas treating process plant (Lu et al., 2011; Murshid et al., 2011a, 2011c; Shaikh et al., 2015). Density and viscosity of the solutions are necessary in modeling the absorber and regenerator because these properties affect the hydrodynamics and mass transfer coefficients (Rinker et al., 1995). Also, these properties are required to estimate other properties such as diffusivity and reaction rate constants (Song et al., 1996). Refractive index is an elemental physical property, and can be applied for a component's identification, concentration determination, and purity confirmation (Murshid et al., 2011a; Tseng and Thompson, 1964). The goal of this work is to provide a database of selected physical property's data for the studied solvents at different temperatures and concentrations. Moreover, the effect of temperature and concentration on each physical properties have been assessed.

Thus, selected physical properties such as density, refractive index, and viscosity of aqueous blends of K-Sar and 2-PE have been studied and reported at temperatures ranging from 298.15 to 333.15 K. Various concentrations (0.04 + 0.16, 0.08 + 0.12, 0.12 + 0.08, 0.16 + 0.04, and 0.20 + 0.00 mass fractions) of aqueous K-Sar and 2-PE blends were prepared. Additionally, each physical property data have been correlated with empirical correlations as a function of both temperature