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Amino silicones solvent advantages to capture CO_2 and improve plant sustainability

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Abstract

Results for novel amino silicone physical properties to capture carbon dioxide (CO_2) were discussed in this article, that also investigated their potential economic benefits versus traditional amine solvents, such as monoethanolamine (MEA). A range of differing amino silicone solvents were tested for density, viscosity, vapor pressure, and heat value. The novel amino silicone solvents showed better results than conventional solvents for CO_2 removal, demonstrating less density, lower vapor pressure, and reduced heat capacity. These advantages were also translated into economic benefits with respect to capital expenditure (CAPEX) and operation expenditure (OPEX).

Keywords: Amino Silicone; Carbon Dioxide; Density; Viscosity; Vapor Pressure; Economic benefits

1. Introduction

Saudi Aramco strives to achieve its ambition for net-zero greenhouse gas emission across its operated facilities by 2050, which complements the Kingdom of Saudi Arabia's aim to reach net-zero emissions by 2060. Numerous efforts by technology leaders were conducted to improve CO_2 capturing technologies over the years. The main proven market scale — for carbon capture and storage (CCS) technologies — is based upon physical and chemical adsorption / absorption pathways. Physical adsorption is based upon solubility of CO_2 into the solution, whereas chemical absorption is mainly based upon chemical reaction/s between the solvent and CO_2. There have been many solvents invented to improve CO_2 capturing within several industries, such as fossil fuel power plants, gas treatment processes, cement production and steel manufacturing. The main well-known constraints for solvents to be addressed are the volume of treated gases, traces of impurities (e.g., NOx and SO_2), solvent stability, energy consumption and capital requirements [2,7].

As chemicals, solvent-based technologies for post-CO_2 combustion have been widely used. This article focuses on comparing conventional amine solvent against novel amino silicone solvents that are yet to be implemented on a commercial scale.

2. Conventional Amine Solvent

Amine solvent-based chemicals have been widely used on a commercial scale in gas treatment processes, to remove CO_2 and H_2S in flue gas post-combustion. The amine solvent reacts with CO_2 to form carbonate salt, which typically absorbs below 60 °C and at ambient pressure [2]. It is a reversible reaction that reproduces CO_2 at 120°C during the regeneration process. The classification of amine solvents is based upon primary amine, secondary amine and tertiary amine.

Amine classification is driven by the number of alkyl group bonds having a nitrogen atom. Figure 1 shows the typical chemical structure for each group.

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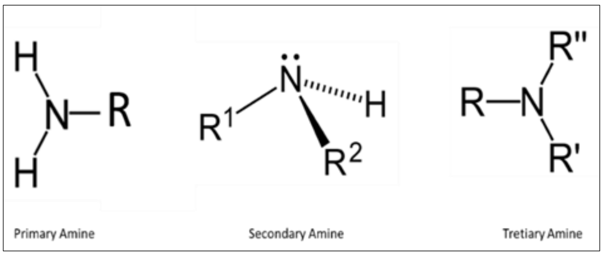


Figure 1 Amine main classification groups

Primary amines such as monoethanolamine (MEA) and diglycolamine (DGA) are the most well-known solvents used on a commercial scale and they provide high reactivity with CO_2. Secondary amines, such as diethanolamine (DEA) and diisopropanolamine (DIPA), are a typical alternative to primary amines. They are more resistant to degradation and possess lower corrosion strength than primary amines. Furthermore, both primary and secondary amines are considered more reactive than tertiary amines.

Main amine solvent issues consist of high-energy consumptions, high corrosion, and degradation in the presence of oxygen and other impurities [2,8].

3. Amino Silicone Novel Solvent Results

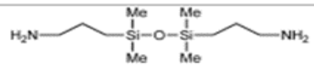
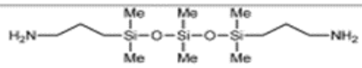
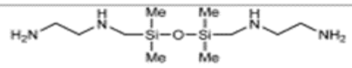
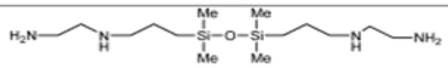
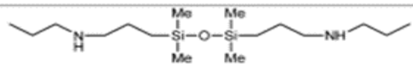
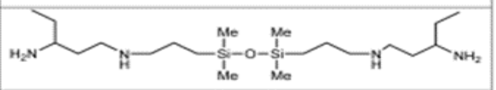
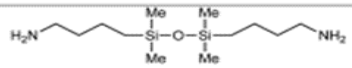
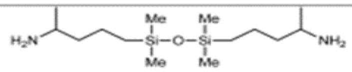
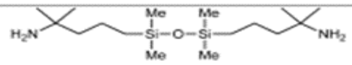
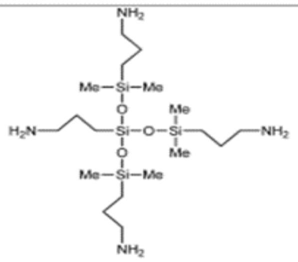
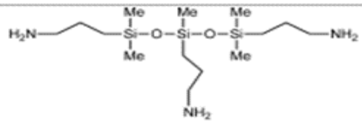
Entry	Designation	Structure
1	GAP-0	
2	GAP-1	
3	GAP-AEAM	
4	GAP-AEAP	
5	GAP-nPr	
6	GAP-Dytek	
7	DAB-0	
8	DAB-Me	
9	DAB-Me$_2$	
10	M'$_3$T'	
11	M'D'M'	

Table 1 Structures of amino silicones

As highlighted above, conventional amine-based solvents (such as MEA) have several drawbacks for increasing energy consumptions, high volatility and poor stability. For example, using MEA will increase the cost of energy and decrease plant efficiency when used in power plan process [3]. As amino silicone-based solvents have been recently examined as an emerging, novel alternative, this offsets a degree of drawbacks previously mentioned. Several amino silicone solvents were analyzed, and such results are highlighted in this article. Table 1 shows the differing types of analyzed amino silicone solvents, that were obtained from commercial sources and synthesized to examine impact on selected properties. It is also worth noting that amino silicone-based solvents do not contain water, unlike as in a traditional MEA solution, which also significantly distinguishes these solvents, as portrayed within results obtained below.

As thermo-physical properties are important for designing novel processes, this article covers the main aspects of amino silicone solvents that are related to viscosity, vapor pressure and heat capacity, as reported by Perry et al. [4].

3.1. Density Results

The amino silicone solvent's density was measured in comparison to MEA. As shown in Figure 2, the novel solvent's density was lower than MEA density. This, of course, is an important aspect that can positively influence operating cost.

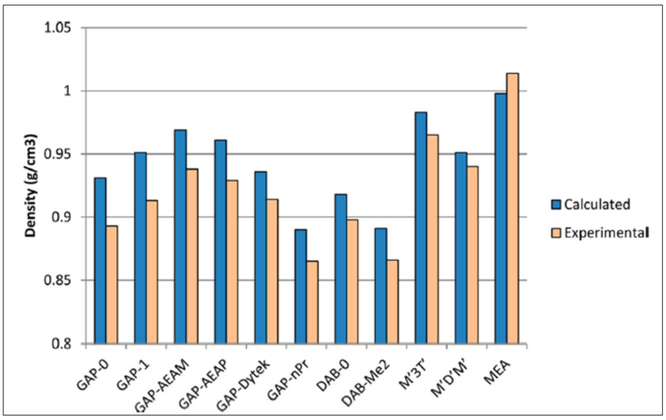


Figure 2 Comparing amino silicone solvent density versus MEA.

3.2. Viscosity Results

Depicted in Figure 3, the viscosity of amino silicone decreases with increasing temperature, which is also impacted by solvent molecular weight [4]. Viscosity can have an impact on process hydraulics and equipment sizing, which is to be considered during the designing phase.

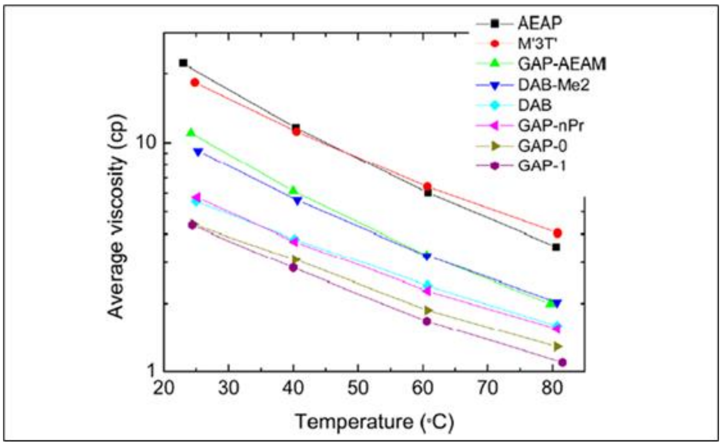


Figure 3 Viscosity of amino silicone as a function of temperature.

3.3. Vapor pressure results

The amino silicone solvent has a lower vapor pressure than conventional MEA solvent, as seen in Figure 4 [4]. Having a lower vapor pressure can also improve the separation process versus typical MEA.

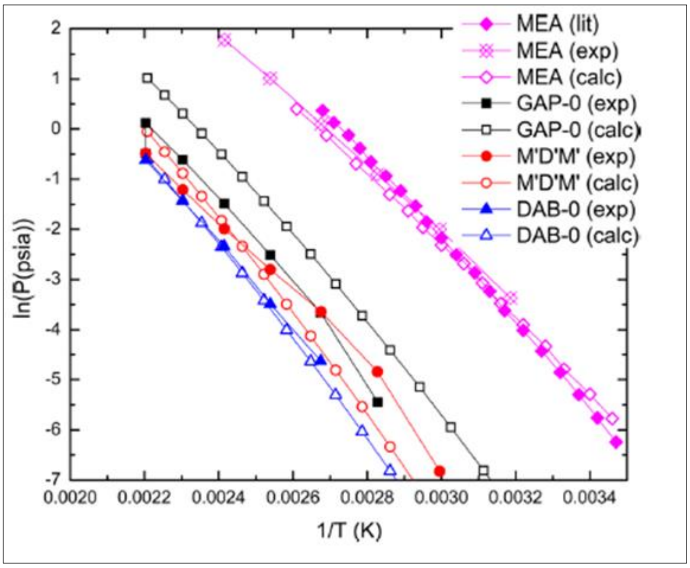


Figure 4 Comparison between experimental and calculated vapor pressure, and amino silicone solvent versus MEA.

3.4. Heat capacity results

The heat capacity was measured for amino silicone solvents, having a mean value ranging between 2 and 2.3 J/g CO_2 at 40 °C. The conventional solution of MEA heat capacity was approximately 4 J/g CO_2 at 42°C. This is an important aspect for the desorption process, as amino silicone-based solvent will require lower energy compared to MEA [4].

4. High Level amino silicone Techno Economics Results

The selected amino silicone solvent used in this analysis was based upon amino silicone solvent at 60/40 mixture with other chemicals (3-aminopropyl end-capped polydimethylsiloxane, with tri-ethylene glycol (TEG) as a co-solvent). This was compared against a conventional MEA solution. The economics-based evaluation outcome was derived from Aspen model simulation and piloting analysis; amino silicone-based solvent normalized cost was \$46 / ton CO_2, compared to \$60 / ton CO_2 when MEA was used. Figure 5 further illustrates the breakdown of cost reduction.

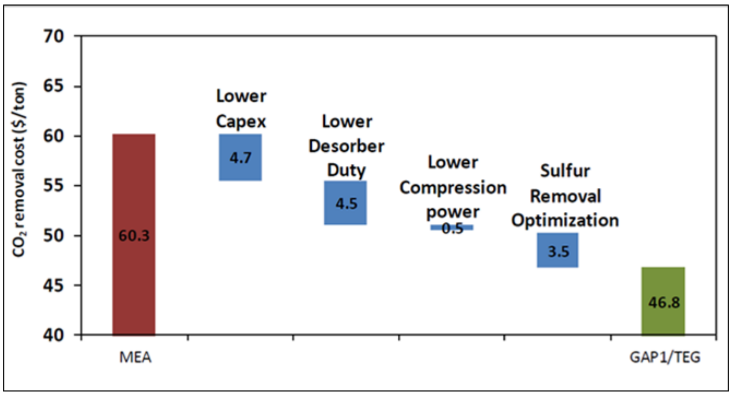


Figure 5 Amino silicone based-solvent saving breakdown versus traditional MEA solution.

The major contributors to CAPEX reduction, as highlighted (\$4.7/ ton CO_2), were driven by a larger working capacity, increased thermal stability allowing regeneration at higher temperatures, and lower vapor pressure. Thus, equipment sizing was reduced; for example, lower vapor pressure allows for regeneration steps (separation of solvent from CO_2)

to be conducted in stirred tanks instead of packed-bed columns, as in MEA solvent processes. Further CAPEX savings can be obtained if the solvent system is changed to carbon steel, since it is believed that an amino silicone solvent is less corrosive than a MEA solvent process [9].

The major contributors to reduced desorber duty ($4.5 / ton CO_2) are lower heat capacity and reduced sensible heat requirements versus MEA. Furthermore, lower compression is related to amino silicone higher thermal stability, allowing for desorption at a higher temperature and pressure, ultimately leading to reduce compressor size. In addition, amino silicone has lower solvent-loss, since it is more thermally stable than MEA solution – driving savings of $3.5 / ton CO_2, which enables more flexibility to modify operating conditions, and also improves sulfur removal [6].

5. Conclusion

Physical properties were tested for amino silicone-based solvents, and promising results were obtained. The main advantages found versus conventional amine solvents were low density, low vapor pressure, low heat capacity, and high thermal stability. These distinguished physical properties were the drivers to significantly improve capital and operation cost of CO_2 capturing and regeneration process. The amino silicone solvent process showed an overall CAPEX reduction up to 10 - 20% versus conventional MEA solvent process. Further CAPEX reduction can be obtained if process material is replaced onto carbon steel. This requires additional investigations, since amino silicone is less corrosive than conventional amine solvents. Further scale-up pilot analyses need to be conducted, in order to validate the highlighted results on a larger scale, whereas cost of amino silicone solvent also needs to be investigated further. Lowering the cost of CO_2 capturing is becoming a vital aspect for designing novel facilities, as more novel regulations call for enhancing plants' sustainability and reduce greenhouse gases. Consequently, amino silicone solvents are potential candidates to substitute the current conventional MEA solvent, thus facilitating CAPEX reduction and improving plant efficiency.

Compliance with ethical standards

Acknowledgments

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