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Challenges in CO_2 Capture Using Ionic Liquid through Membrane and Absorption Processes

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Abstract: *Global push towards green and clean energy technology has drawn considerable attention to develop new materials and methods for CO_2 capture. In the recent years ionic liquid (ILs) has emerged as a potential candidate to circumvent this problem. The current research with ionic liquid has been mainly focused on synthesis and finding its hydrodynamic properties. And still there is a lot more to be understood for e.g. its toxicity, transport properties etc. before the ILs can be used in large scale application at industrial scale. This paper critically reviews some of aspects of use of ionic liquid in membrane and absorption process.*

Keywords: *Ionic liquid (ILs); CO_2 capture*

1. INTRODUCTION

The atmospheric concentration of CO_2 has increased rapidly primary due to emission of CO_2 from the combustion of fossil fuel since the industrial revolution. The increasing carbon burden has significant implication on the global climate. The long term solution of this problem lies on development of a carbon neutral energy infrastructure. The increasing worldwide demand for the energy and the readily availability of the fossil fuels in particular coal makes it highly likely that fossil fuel combustion will be continued to be a substantial fraction of the energy portfolio for the foreseeable future.

For coal fired power plant and other points source emitters, carbon capture is the most promising method to limiting CO_2 release, but practical carbon capture depends on the discovery of energy efficient means of separating CO_2 from other gaseous components of a flue gas. A typical flue gas from a power plant may contain 15% CO_2 in addition to N_2 as major component along with small amount of O_2 and moisture at near ambient temperature pressure [1]. Separating CO_2 from this stream causes 30% power penalty, using presently available amine absorption technology, far above the theoretical minimum work of separation.

Capturing CO_2 using ionic liquid is a promising option to overcome these drawbacks due to their unique properties like tunability of structure, strong solubility, high thermal stability, capacity and property. However, understanding of research progress on carbon capture with ionic liquids is instrumental for its implementation at the industrial level. This work reviews some of the merits and challenges associated with ionic liquid before its application for CO_2 capture through membrane and absorption processes.

2. CHALLENGES IN CO_2 CAPTURE

Ionic liquid in membrane process: Recent studies suggest that membrane process is an economical option for post combustion CO_2 capture from power plant flue gas [2]. The separation in polymeric membrane is based on the diffusivity of gases. Increase in permeability causes reduction in selectivity due to reduction of diffusivity [3]. Use of ionic liquid of ionic liquid in membrane offers separation based on solubility thus high permeability, therefore significantly high throughput can be achieved without compromising with the selectivity. By tailoring the functionalization of room temperature ionic liquids it is possible to enhance the selectivity for CO_2 which can be exploited in the separation of light gases such CO_2/N_2, CO_2/H_2 etc. (Park et al. 2009) used supported liquid membrane for the separation of acidic gases (CO_2/CH_4 and CO_2/H_2S) mixture at high pressure and reported high selectivity for CO_2 [5]. On the other hand (Bara et al. 2009) reported that SLMs are too thick to withstand high pressure as required in natural gas sweetening process [4].

Can we substitute MEA absorption process? Monoethanolamine MEA is widely used commercially for CO_2 capture from post combustion flue gas; however due to high energy penalty, the process does not meet the goal of removing 90% CO_2 with no more than 35% increase in the cost of electricity as set by the Department of Energy. (Shiflett et al. 2010) modeled ionic liquid, 1-butyl-3-methylimidazolium acetate that can reduce the energy loss by 16%, investment cost by 11% and reduction in equipment foot print by 12% over the MEA process[6]. (Wappel et al. 2009) reported that a solution of 60% ionic liquid and water can save energy upto 16% compared to the 30% MEA solution used for CO_2 capture[7]. (Arshad et al. 2009) reported that the energy requirement with [emim][Tf_2N] and [bmim][Tf_2N] ILs could be 76 to 71 times higher compared to MEA process used for capturing CO_2 from gaseous source at 0.1 bar[8]. This large energy requirement using ILs can be attributed to the low partial pressure of CO_2. (Anthony et al. 2004) showed that the set up used in MEA process can also be implemented for separation using ILs but with some modification. They used absorber filled with IL coated glass beads [9].

Challenges in its use in industry: Before the IL based process can be implemented into industry, it is necessary to have a proper understanding of the dynamics of the system which requires an elaborated model and the transport properties of the IL to be used in the process. The IL based research has been more focused towards hydrodynamics and less on the transport properties and there is still a significant margin before the IL based processes could be transferred from laboratory to industrial scale. Sans these data the scale-up is not only difficult but also the time intensive.

Unlike organic solvents, ILs do not contaminate the environment because of their low pressure and hence low volatility[10, 11, 12]. However, some studies indicate that the presence of fluoride and long alkyl chains in the ILs may exhibit highly toxic behavior [13,14,15]. A detailed study is warranted to understand the toxicity issues of the ILs [16, 17, 18] before it is implemented in a large scale application. Another important drawback of ILs is their high viscosities [19, 20]. The viscosity of [bmim][BF4] (79.5 cP) [20] is reported to be much higher than that of pure monoethanolamine (25 cP) and 30% aqueous MEA solution (2cP).Due to high viscosity the diffusion becomes slow and the equilibrium time increase which limits the rate of absorption. Studies indicate that for NH_2-functionalized ILs, equilibrium can take even 48 h at 303 K. This problem can be overcome by properly adjusting the ratio of anion and cation in the ILs or mixing them with appropriate organic solvents.

Another major drawback is the corrosive nature of the ILs. The presence of halide in the ILs makes them especially corrosive for certain metals and alloys at high temperature [21]. The problem may aggravated if ILs are used as alternate to absorption process in gas sweetening process or CO_2 removal process. Complete addressal of this issue will open pathways for its use in industrial scale.

It should be mentioned that certain ILs have also some inherent drawbacks: (i) Various ILs have been found to be combustible and require careful handling. Abrief exposure (5-7 s) to a flame torch will ignite some ILs, and some of them can be completely consumed by combustion [22] (ii) The higher viscosity of some ILs compared to conventional solvents would increase the pumping and related operating costs, such as reduced mass-transfer rates and poor heat transfer. (iii) Thermal and chemical stability of ILs should be analyzed with caution[23], especially when long thermal stability is required to prevent degradation during the absorption/stripping cycles [24].(iv) Some ILs are highly hygroscopic [25], which dramatically changes their physicochemical properties[26, 27] as well as potentially toxic to aquatic environments[28, 29]. This aquatic toxicity should not be ignored, because it was reported to be equal to or greater than that of many conventional solvents. (v) Their extension to large-scale applications is hindered due to the high prices of most ILs, such as those considered in this work.

3. CONCLUSIONS

Ionic liquid is promising material for CO_2 removal from various point sources emitting CO_2 and other gases. It has great potential to replace the conventional absorption process and it can be effectively used in membrane process as well. However, its transfer from laboratories to large scale industrial application requires adequate knowledge about its hydrodynamic and transport properties. The present available data about ILs are in sufficient to meet the design challenges for scale-up and hence, there is need to push the research in this direction.

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