Ionic Liquids
The efficiency of ionic liquids in absorbing CO_2 from the atmosphere

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Summary

Ionic liquids are salts that are composed of ions in a liquid state near room temperature. They are generally clear, viscous liquids which are polar and nonvolatile but, most importantly, their intermolecular forces, like their hydrogen bonds, van der Waals bonds, and electrostatic attraction, results in the increase in the solubility of CO_2. This would result in CO_2 being easier to be absorbed in the ionic liquids and the disposal of it due to CO_2 being a soluble gas that is non-polar. The use of ionic liquids in carbon capture and storage, which has been driven by the gravity of climate change, (refer to Figure 3) is a prospective application of ionic liquids as absorbents for use in projects such as carbon capture and sequestration. At the moment, CO_2 capture uses absorption technologies that are mostly amine-based, which are energy intensive and solvent intensive. More specifically, monoethanolamine (MEA) has been used in industrial scales in post combustion carbon capture, as well as in other CO_2 separation. However, amines are corrosive, degrade over time, and require huge industrial facilities. On the other hand, ionic liquids have low vapour pressures which remain low through the substance's thermal decomposition point (typically >300 °C). which simplifies their use and makes them environmentally better alternatives. Additionally, it reduces risk of contamination of the CO_2 gas stream and of any potential leakage into the environment.

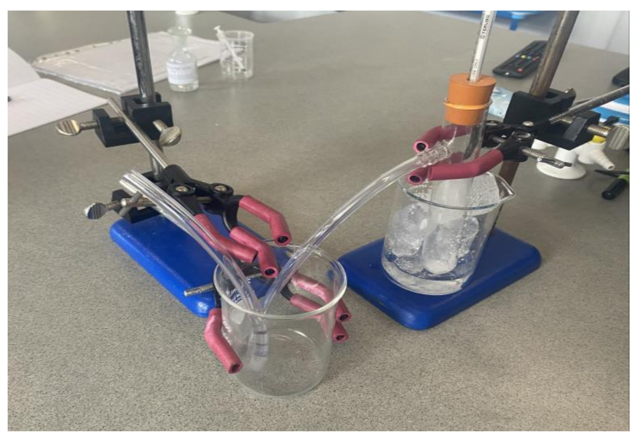

Figure 1 Showing the calibration process of the U-Tube monometer

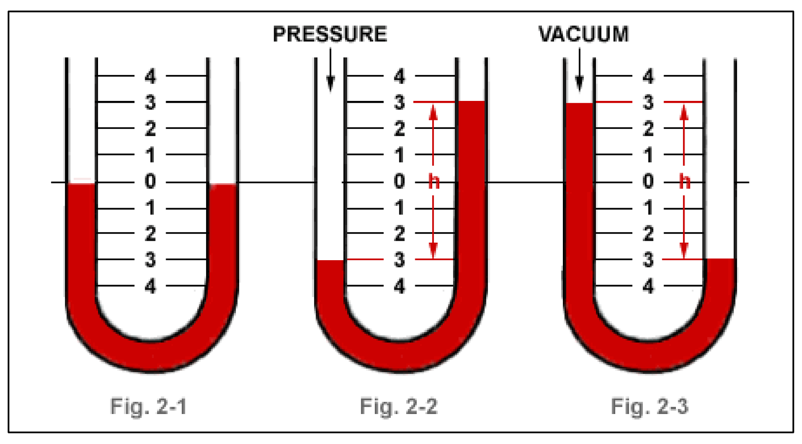

Figure 2 Showing the apparatus setup

Research aims

We wanted to test how much CO_2 would be absorbed in the ionic liquid 1-butyl-3-methylimidazolium chloride (BMIM-Cl) to find out the efficacy of ionic liquids in carbon capture. This aims to investigate a more efficient and environmentally friendly alternative for carbon capture and storage. Rather than using geo-sequestration which involves the pumping of CO_2 underground, this research aims to investigate the use of ionic liquids for absorbing CO_2 directly from the atmosphere. This approach offers a potentially more sustainable and efficient solution for addressing CO_2 emissions through discarding of the gas instead of simply transporting it somewhere else. By exploring the properties of ionic liquids in absorbing CO_2, we find that they are highly effective as two-dimensional ionic liquids have a molecular structure that allow for higher rates of CO_2 to be absorbed due to its strong basicity. Figures 1 and 2 show our method in which we carried this experiment out. The apparatus used proved to be advantageous as it facilitated the investigation of absorbance properties of ionic liquids while effectively preventing any gas leakage, which was a challenge encountered by the previous group during their investigation. The use of BMIM-Cl was a pragmatic choice due to it being easy to synthesise and the fact that it is also reasonably safe to handle in a school lab, rather than a specialist academic lab. As well as this, previous investigations had investigated the solubility of CO_2 in BMIM-Cl and stated that while it can absorb CO_2, it isn't the best ionic liquid for absorbing the gas.

Experimental method

To test the effectiveness of BMIM-Cl as a solvent for CO_2, we set up a U-tube manometer, which was connected to a side-arm boiling tube. Our aim was to generate a fixed volume of CO_2 gas in the side-arm boiling tube, inject the BMIM-Cl into the boiling tube, then measure how long it took for the liquid position in the manometer to return to its original position. This showed us how quickly the CO_2 gas dissolved into the BMIM-Cl.

First, we calibrated the manometer using known volumes of air. We marked the U-tube with these values so we could tell how much the CO_2 was displacing the solvent. We originally planned to use distilled water in the manometer, however we found that due to its cohesive properties it would adhere to the walls of the tube due to the high surface tension of water, which made it difficult to record valid readings. We then decided to try washing up liquid; however, this resulted in bubbles, and it was also very viscous. We then trialled the use of a mixture of $2cm^3$ washing up liquid and $40cm^3$ ethanol, which resulted in a solution with lower surface tension than pure water, allowing for smoother movement of the solvent through the U-tube and no bubbles which gave us more valid manometer readings.

We also required CO_2 for our experiment. We originally generated this using 0.6g glacial ethanoic acid and 0.53g sodium carbonate, however after trials, the acid was changed to concentrated HCl, which was easier to manage. Once the acid and carbonate were mixed in the boiling tube, we waited 57 seconds until the boiling tube was completely full of CO_2 before replacing the bung and using a syringe to add specific volumes of BMIM-Cl. We then watched the ethanol/washing up liquid mixture in the U-tube get displaced due to the added volume of CO_2 and BMIM-Cl mixture, then fall as the CO_2 dissolved in the ionic liquid. We ensured when carrying out the experiment that the boiling tube with the CO_2 stayed at constant temperature by placing it in an ice bath, to avoid expansion and reduction of the gas.

We made the decision to conduct this experiment using CO_2 due to the elevated concentration of CO_2 in our atmosphere. It is considered one of the primary gases responsible for global warming and has a detrimental effect on the planet, so we decided to gather research into the efficiency of ionic liquids in its absorption; especially significant as if this technique were to be implemented globally, this could have an immense effect on the rising CO_2 levels, and we could be one step closer to combatting climate change.

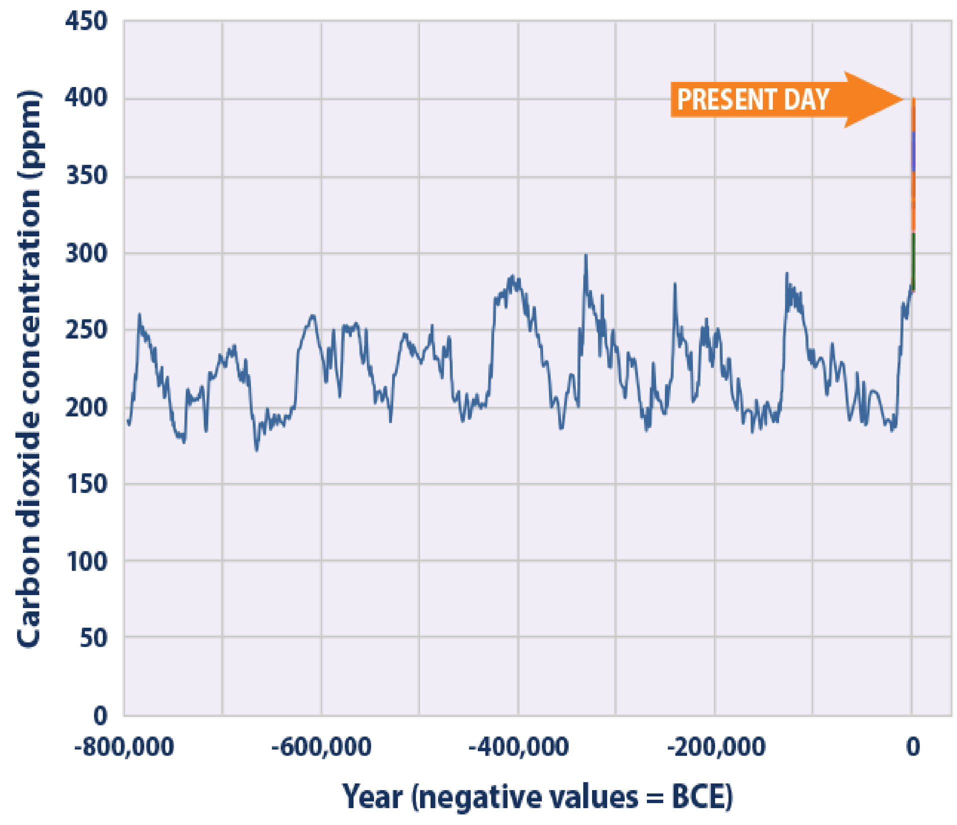

Figure 3 Showing the concentration of CO_2 in the atmosphere

Based on our research, we found that ionic liquids exhibit exceptional gas absorption properties and therefore have great potential for mitigating CO_2 levels both in the atmosphere and underground. Figure 4 shows the ionic liquid used in this research.

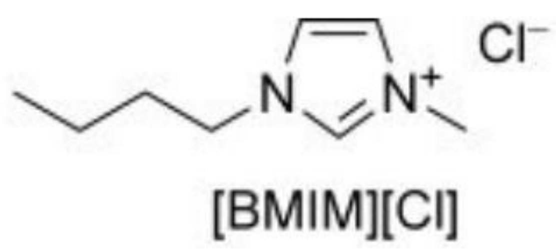

Figure 4 – The ionic liquid: BMBM Cl

Results

Our results suggest that a larger volume of BMIM-Cl dissolves the fixed volume of CO_2 gas more quickly. This supports the hypothesis that the ionic liquid BMIM-Cl is an effective solvent for CO_2. Due to many trials and modifications being needed to get our method to work and yield valid results, we did not have sufficient time to carry out repeated tests or test a wider range of volumes of BMIM-Cl.

Volume of BMIM-Cl used (cm^3)	Time for monometer to return to original position (s)
0.3	270
0.4	102
0.5	N/A

Figure 5 Showing the results from the experiment

Analysis & conclusions

A 2023 experiment (Ali, Ahmed, Dixons 6th Form) investigating this same theory found that the rate of absorption of CO_2 was slower than expected. To refine their method, they reported that they would consider other factors such as increasing room temperature and pressure which would increase the absorption of CO_2 if they were to redo the experiment. although this would be costly so we could not implement this idea in our own experiments. They report that combining BMIM-Cl with water to lower the viscosity would increase CO_2 absorption. Also, they identified that they had issues with the apparatus they used (like leakages). Therefore, we redesigned the test equipment to reduce leakage of CO_2 during the experiment by keeping the system sealed and at ambient pressure.

Moving forward, it would be important to consider the use of a less complicated apparatus as assembling the apparatus was inefficient and there wasn't enough time for the production of conclusive results.

Further tests should also be done to gather more data and create a larger set of results which would validate our findings and create a more stable conclusion. From our findings we can see that as the volume of BMIM-Cl increased, the time for displacement decreased which shows that the ionic liquid is effective in absorbing CO_2. If the results for increased volumes of BMIM-Cl (e.g. 0.5, 0.6, $0.7cm^3$, etc.) continued to show this trend, we could assume that BMIM-Cl is efficient in absorbing CO_2. However, if the time taken for displacement decreased as the volume of BMIM-Cl increased, we could assume that the ionic liquid is not effective in absorbing CO_2 from the atmosphere.

Acknowledgements

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