THE DEVELOPMENT OF NATURAL SUSTAINABLE MATERIALS FOR CO_2 CAPTURE

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Intro:

The aim of this project is to investigate if advanced porous metal-organic frameworks, MOFs, with exceptional CO_2 capture abilities can be synthesised from natural organic materials and abundant, sustainably sourced metals.

The use of CO_2 capture materials is a very exciting development in science today due to the need to drastically reduce the amount of greenhouse gases such as CO_2 in the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC), a 4-fold decrease in CO_2 emissions is required in the coming decades to successfully stabilise the CO_2 concentrations by 2100 to reach a stabilising benchmark concentration of 550 ppmV. However modest reductions of CO_2 emissions will only delay the increase of CO_2 levels in the atmosphere. Negative emission technologies are required to decrease these atmospheric CO_2 concentrations and meet the promises of the Paris Climate accord. Unfortunately many proposed carbon capture technologies are not economically viable and are not sustainable and associated with large intrinsic carbon footprints.

Metal-organic frameworks, MOFs, consist of metal ions or clusters of metal ions that are linked by organic carbon-based molecules to form extended 3D network structures with unprecedented porosity. The large number of pores in these materials leads to their affinity for gas capture, whereby small gas molecules can be stored in the pores of the structures.

MOFs are proving to be very effective in selective gas capture, i.e. they can adsorb CO_2 from mixtures of gases and even directly from the air, due to their large inner surface areas and porosity. Importantly, the size of these pores can be tuned, and their chemical properties are able to be modified. The ability of MOFs to release captured CO_2 at very low energy cost, and their ability to carry out CO_2 capture even in the presence of water sets them apart from the other competitive carbon capture technologies. While MOFs are highly efficient in carbon capture and release, there is still a considerable carbon footprint currently associated with their synthesis.

This proposed research project will aim to use natural organic materials such as naturally occurring sugars and amino acids, and abundant metals like iron, silicon, manganese and copper to synthesise advanced MOFs for CO_2 capture. Through the synthesis and testing of a variety of sustainable MOFs, this project will determine whether effective CO_2 capturing materials can be manufactured without the environmental costs.

Methodology:

1: Literature review.(week 1).

I will spend the first week of the project analysing literature to define benchmark characteristics for CO_2 capture performances of MOFs. Based on initial evaluations, I believe that particularly amine-functionalised carbohydrates and amino acids can give rise to exceptional CO_2 capture characteristics. However, these have never been exploited for these applications. The reading will consist of research papers to define and specify the synthetic methodologies. An investigation into which metals will be the most sustainable to create the MOFs will be carried out through analysis of the literature. The sustainability of all reagents will be evaluated by taking into account their price, abundance and carbon footprint of sourcing them.

2:Synthesis (weeks 2-4)

The MOFs will be synthesised in small quantities. The natural organic materials will require a high nitrogen-content, therefore some of the materials will undergo functionalization reactions to achieve this. In order to create MOFs capable of carrying out carbon capture successfully, the number of pores in the material needs to be maximised. This will be accomplished by carrying out a syntheses at elevated temperature in closed reaction vials that will link the organic molecules to a number of various metal centres.

3:Characterisation of materials. (weeks 3-6)

Characterisation techniques will include:

a) X-ray crystallography - by preparing single crystals, the precise molecular structure can be determined through X-ray diffraction.
b) The structural analyses may also include electron microscopy techniques.
c) NMR spectroscopy (nuclear magnetic resonance spectroscopy) - using radiofrequency radiation on the materials in a magnetic field to further analyse the structure.
d) Thermogravimetric analysis - investigating the thermal stability of the materials. The hydrolytic stability under neutral, basic and acidic conditions will be investigated.

4:Gas adsorption tests(weeks 5-6)

The ability of the MOF materials to absorb CO_2 will be determined through volumetric gas adsorption studies. “Breakthrough” study, involving flowing air through a column of MOFs, will determine their CO_2 adsorption performance (through measuring the CO_2 concentration at the column outlet).

5:Analysis (week 6)

The materials will be evaluated and those with promising abilities to capture CO_2 along with a minimum carbon footprint synthesis method, will be further analysed to determine if there will be room for modifications to improve its performance in further experiments.

The expected result of this research will give new, sustainably produced, natural materials to be used in CO_2 capture. These results have the possibility to be developed and analysed further in my "leadership in action project", the following year, in collaboration with the engineers at the University of Mons. This project is designed to interface with my skills and allows me to work on a societal, important subject area with potential high impact and will gain me the opportunity for career development in research.

Covid-19 considerations:

While restrictions due to Covid-19 will cause concern, the School of Chemistry has measures in place to minimise the spread of Covid-19 while also keeping the materials laboratory operational. The project will be undertaken in the later half of the summer to allow for the number of Covid-19 cases to reduce and for more vaccines to be administered. Under the current level 5 restrictions, the research group is split into pods and currently a maximum of 12 people are allowed in the lab space, ensuring social distancing while allowing research to continue. Only essential synthesis and analysis is carried out in the lab. Prof. Schmitt and the School of Chemistry can guarantee that there will be space for me to carry out this project, even under the highest restrictions, should they still be in place this summer, while also keeping myself and others at a low risk of contracting the virus.