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Assessing the indoor CO₂ adsorption capacity of earthen materials: A novel experimental methodology

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Abstract. This study examines the effectiveness of natural plasters, and in particular clay-based plasters, in improving indoor air quality by measuring their CO₂ adsorption capacity. The experimental approach consists, at first, to characterise the interactions between the material and CO₂ to better predict its behaviour under real conditions. The results for a clay-based plaster show that it has the potential to buffer CO₂ through physisorption of CO₂ on clay minerals. This research provides the first protocol for determining the adsorption capacity of indoor CO₂ concentrations of coating materials already known for their good hygrothermal properties, which is the case of clay-based or bio-based materials.

Keywords: Indoor air quality, clay-based plasters, CO₂ adsorption, Hygrothermal properties

1 Introduction

Indoor air quality (IAQ) is a growing concern in modern society, with people spending more time indoors than ever before[1][2]. Poor IAQ can have significant health effects, including respiratory problems, headaches and allergies. The use of bio- and geo-based materials in construction has been proposed as a solution to improve IAQ, as they are known to have lower emissions of volatile organic compounds than conventional building materials [3][4]. They are also known for their good hygrothermal properties, helping to regulate indoor humidity[5]. The microstructure and surface activity of the constituents favouring the moisture adsorption may also have the potential to regulate indoor pollutant concentrations. However, there is currently no protocol to measure this potential, making it difficult to evaluate its effectiveness.

This research aims to help fill this gap by developing an experimental methodology to characterise the CO₂ adsorption capacity of building materials at the microscale. This methodology will be of particular interest for bio- and geo-based

materials, which are known for their hygroscopic properties. CO_2 was chosen as the study gas to develop the experimental protocol because it is present in significant amounts in indoor environments and is a common indicator of IAQ [6]. However, it is important to note that the experimental protocol developed in this study could potentially be applied to other gas compounds present in indoor air, opening the way to a more comprehensive evaluation of the ability of bio- and geo-based materials to improve indoor air quality.

This presentation discusses the experimental approach of measuring the CO_2 adsorption capacity and provides a case study of a clay-based plaster.

2 Experimental Approach

The approach involves characterising the interactions between the material and the gaseous pollutant of interest, in this case CO_2 . The nature of these interactions can help to determine whether the pollutant can be retained and later released. The experiment uses a TG-DSC apparatus capable of measuring mass and heat flux changes associated with one or more reactions. Several devices are used upstream of the apparatus to create an atmosphere similar to indoor air, including a gas mixer to control the CO_2 concentration and a wet gas generator to control humidity and temperature. The gas mixture is introduced into the TG-DSC apparatus for simultaneous thermogravimetric and differential scanning calorimetric measurements.

The test procedure for measuring CO_2 adsorption capacity consists of fixing external parameters such as temperature and humidity, while varying the CO_2 concentration. The material's response to changing CO_2 concentrations is then studied under these controlled conditions. By applying successive concentration steps followed by a return to zero, the effects of varying CO_2 concentrations on the material can be analyzed systematically.

The results of the experiment are analysed as follows:

1. The shape of the TG curve indicates whether the process is reversible, partially reversible, or irreversible. This allows for an initial distinction between physical interactions, which are more reversible, and chemical interactions, which are more irreversible.
2. The equilibrium mass determination provides the maximum retention capacity of the material for the given conditions.
3. The direction of the heat flow peak indicates whether the reaction is endothermic or exothermic, and by combining mass measurement and heat release values, the associated enthalpy can be calculated.
4. To calculate the enthalpy, we integrate the 95% of the signal and divide by the corresponding mass. The comparison of the calculated value with known values for the assumed process allows for the validation of the assumptions regarding the nature of interactions.

3 Case study on clay-based plaster

For this study, we decided to focus on clay-based plasters. The material introduced in the TG-DSC apparatus is approximately 60 mg of natural earth sieved at 80 μm . After a stabilisation phase, concentration steps are applied for a humidity set at 0%RH and temperature of 35°C. The protocol consist of 5 hours of exposition to 5000 ppm of CO₂ and 5 hours of exposition to a free-CO₂ air.

Figure 1 shows the results of the experiment:

1. Firstly, in part (a) we can see the mass gain associated with the concentration step from 0 ppm to 5000 ppm and then back to 0 ppm. The reversibility of the reaction is indicative of physical interactions such as physisorption.
2. The CO₂ retention capacity Q (in mg of CO₂ captured within the material per kg of material) of the sample is calculated from the relative mass variation of the sample after and before the exposure step. According to the curves, $Q = 142$ mg/kg at 5000 ppm 35°C and 0%RH.
3. Then in part (b) we can see the associated heat flow peak. Here the flow is exothermic as it is directed upwards, confirming the possibility of adsorption, which is known to be exothermic.
4. Finally, part (c) shows the integration zone from which the enthalpy is calculated. The result of 60 kJ/mol for adsorption enthalpy is quite large compared to the usual values for physisorption (between 0 and 20 kJ/mol and up to 40 kJ/mol in some case), but too small to be chemisorption (more than 100 kJ/mol). It can therefore be concluded that some adsorption sites are very energetic and contribute to increasing the adsorption enthalpy value. There are therefore sites with a strong affinity for CO₂ in the material.

4 Conclusion

In conclusion, this study has demonstrated the potential of bio-based materials, particularly clay-based plasters, to adsorb CO₂. Through a novel experimental approach, we have characterized the interactions between a raw earth and CO₂, providing insight into its behavior under real-world conditions. Our findings suggest that clay-based plasters are able to effectively buffer CO₂ through the physisorption of the gas on their clay minerals surfaces. Importantly, this research has established a protocol for measuring the CO₂ adsorption capacity of other bio and geo-based coating materials, such as raw earth or fibers. This work underline the need to consider the impact of building materials on indoor air quality and highlights the potential for sustainable, bio-based materials to support healthy indoor environments. Future studies should explore the long-term effects of these materials on indoor air quality and human health and the impact of external condition such as humidity and temperature.

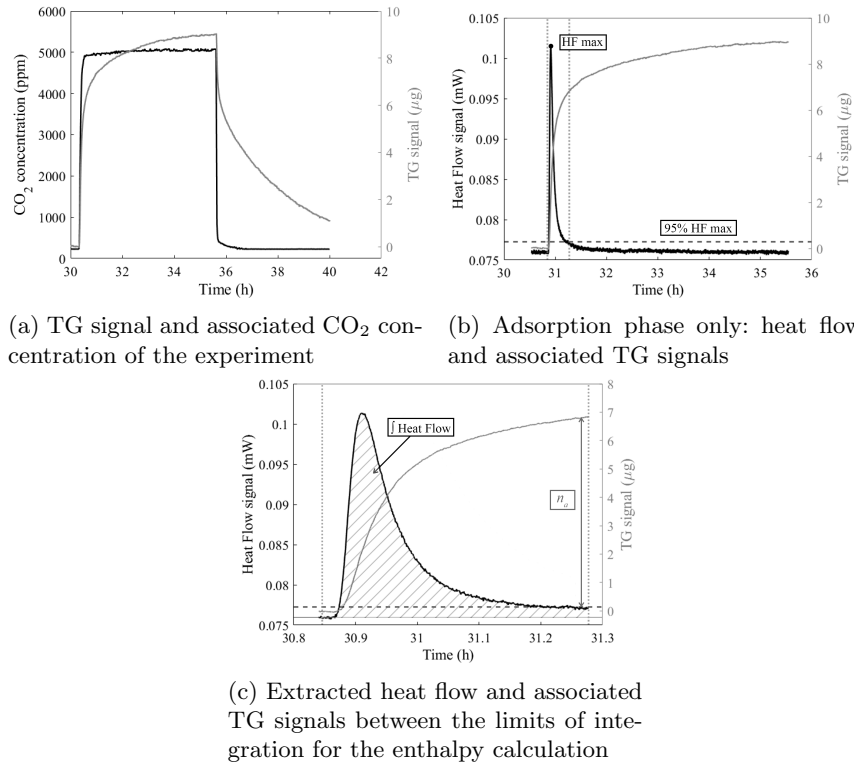


Fig. 1: Results of the experiments and analysis methodology

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