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Water Vapour Adsorption on Moisture Buffering Building Materials

Gloria J. Lo [a*]

[a] *Civil and Environmental Engineering & Mechanical and Aerospace Engineering, University of Strathclyde, Glasgow, UK*

Abstract

Moisture buffering in buildings relies on the passive adsorption of water vapour at high relative humidity by hygroscopic materials and the release of that vapour when humidity falls. Understanding the material properties and processes that guide the isotherm behaviour, enables the effective use of materials in construction to modulate indoor humidity fluctuations. Filling in the material characterisation data gap for heterogeneous materials commonly used in the construction industry provides an improved basis for modelling and effective specification. This research can transform the way we build our homes and improve our ability to deal with dampness and indoor air quality without relying on mechanical ventilation systems.

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Keywords: Hygroscopic materials; moisture buffering; isotherm; dynamic vapour sorption; adsorption; water vapour; microstructure; heterogeneous materials; material performance; retrofit; sustainable construction

Nomenclature

n	number of molecules adsorbed
n_m	number of molecules at monolayer coverage
C	partition function for water molecule, associated with clear monolayer determination
k	additional correctional parameter for multilayer interaction, particularly suited to heterogeneous materials
p/p_0	partial pressure, of water vapour in this case.

1. Introduction/Background

We spend on average over 90% of our time indoors, therefore indoor environment has a direct relationship with our health and well-being. Current construction practices promote condensation and mould growth or rely heavily on mechanical ventilation systems to regulate indoor relative humidity (RH). It is estimated that we generate 10-12kg of moisture/day/household [1].

Moisture buffering is a known phenomenon and tested for some materials in humidities imitating diurnal indoor cycles [2-3], however with changes in building use pattern the cyclical models maybe less applicable. Layered compositions in construction, each with unknown vapour penetration depths for the given humidity variation and potential pore blocking between layers, all of which have had limited testing [4-5], with the underlying hygroscopic drivers unexplored.

1.1. Aims and Objectives

Hygroscopic behaviour i.e. the ability to adsorb and re-release water vapour benignly without degradation of materials is driven by vapour pressure (RH), specific surface area, pore size and distribution, particle size, chemical composition, temperature, and ventilation rates. The contribution of material characteristics and microstructure to this hygroscopic flow path and process is complex.

A multiscale investigation is necessary, to understand the relationship between material microstructure and the effects of adsorption, diffusion, capillary condensation and hysteresis, then embed that knowledge within the overall process of moisture buffering on the macroscale. This study contributes to missing data and proposes more accurate building performance evaluation, exploring models from different disciplines between soil physics, building physics and engineering to explain the combined sorption and diffusion behaviour [6]

2. Methodology

2.1. Understanding Material Performance - Accurate Quantifiable Results for Heterogeneous Materials

Accurate measurement of water adsorption at constant temperature and changing RH ranging from 0-90% using dynamic vapour sorption (DVS) instrument was carried out for a range of building materials, chosen for their supposed hygroscopic performance previously unmeasured and compared with commonly used wall finish materials. These include wood fibreboard, clay boards, plasterboards, clay plasters, gypsum plaster, lime plasters, and a range of paints.

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[*] Corresponding author. +44 7786 326 409 glo.lo@strath.ac.uk

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To understand why and how the materials behave in response to different RHs, these materials have been subjected to a range of tests: nitrogen and krypton BET tests for specific surface area determination; scanning electron microscopy (SEM) for qualitative observations on structure, with energy dispersive X-ray (EDX) elemental mapping; X-ray diffraction (XRD)for crystalline phase identification; mercury intrusion porosimetry (MIP) for pore size distribution; helium pycnometry for total pore volume and solid density; Archimedes method for bulk density; total organic content (TOC) for organic component analysis; cup test for permeability. In search of a better-controlled RH environment, a novel permeability test method was established [7].

2.2. Isotherm Models Exploration and Choice

Isotherm models chart the amount of water adsorbed, first in a monolayer and then in multilayers, then exhibit vapour film flow characteristics before the pores are finally filled. Building materials tend to be macroporous, with pore widths greater than 50nm, and have Type II reversible isotherms with H3 hysteresis loops under IUPAC definitions [8]. This broadly describes all the materials under test, therefore vapour capillary condensation is rare until above 90% RH.

In mapping the adsorption data to isotherm models, several were investigated including BET (Brunauer-Emmer-Teller) as the golden standard for monolayer determination, FHH (Frenkle-Halsey-Hill) is a model often ascribed to structured heterogeneous materials and fits well with multilayer region of the isotherm, and GAB the model often used for food industry fits well with organic materials. This latter model fits the heterogeneous construction materials very well with a relatively low number of parameters.

The GAB formula is:

$$\frac{n}{n_m} = \frac{C \cdot k \cdot (p/p_0)}{(1-k(p/p_0)) \cdot (1-k(p/p_0)+C \cdot k \cdot (p/p_0))}$$

A good model would accurately describe the material behaviour over the full range of RHs and predict accurately the material performance in modelling or simulation.

3. Results and Discussion

The water vapour adsorption data collected for these materials, allow detailed analysis and comparison of their performance. The study of the microstructure of heterogeneous materials is complicated, as scientific experiments are mostly established for homogeneous single-phased samples or carefully controlled structured materials.

Observations show that there is a marked improvement in overall sorption capacity where cellulosic materials are present. There is also a direct relationship between specific surface area and adsorption capacity. The chemical composition influences adsorption at specific RHs. The interlinked parameters of porosity, permeability and tortuosity are still under investigation. Comparing the overall adsorption capacity of the samples when subjected to the maximum RH 90%, wood fibre board adsorbed most moisture per mass (19.7%) followed closely by historic lime plaster sample (18.8%). At the other end of the scale, as expected moisture resistant plasterboard performs to its designed purpose and takes on 0.5% of its own weight in moisture, followed closely by normal plasterboard at 1.1%. (Other materials tested and experimental results not reported in this abstract).

Despite the difficulties in isolating causal-effect relationships in heterogeneous materials, the results of this study will enable quantifiable modulation of indoor humidity by internal finish materials.

4. Conclusion

Combining the material characteristic and performance knowledge with moisture buffering and building performance simulation, the influence of micro-scale water vapour processes towards modulation of indoor humidity can be established. This is especially useful in retrofit and conservation scenarios, in dealing with dampness and internal moisture issues, while making minimal changes for maximum effect.

If the passive measures for modulating indoor humidity can be implemented successfully, there could be energy savings to mechanical systems and long-term amelioration of energy demand.

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