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Hygric properties of hemp bio-insulations with differing compositions

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HIGHLIGHTS

- We examined the key hygric properties of five hemp insulations.
- There were considerable variations in the hygric properties of the insulations.
- Insulations with more monolayer sorption area showed higher adsorption capacity.
- The insulation materials exhibited 'Excellent' and 'Good' moisture buffer value.
- The data can be used as inputs in hygrothermal simulation software.

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ABSTRACT

The paper presents the results of a laboratory investigation on the hygric properties of five hemp insulation materials commercially available in the UK. The hemp fibre content varies between 30% and 95% in the total fibre content of the insulation materials examined. The adsorption–desorption isotherm, moisture buffer value, vapour diffusion resistance factor and water absorption coefficient were determined for the insulation materials investigated. The results showed that the hygric properties of the hemp insulation materials could vary widely depending on the constituents and fibrous structure. The considerable differences noted in the hygric properties of the insulation materials examined could potentially influence their hygrothermal performance as part of a building thermal envelope.

1. Introduction

Use of sustainable materials is becoming an integral part of the construction process in response to the concerns over resource depletion and global warming. As such, sustainability and efficiency are becoming key criteria for selecting thermal insulation materials [1]. Hemp insulation is a plant-based, renewable and carbon-negative thermal insulation material. Among the bio-based thermal insulation materials, hemp insulation is of particular importance in the UK. Hemp is a high yield and low input crop with the additional advantages of being a break crop in cereal rotations. Other benefits include weed control and less field operation. Compared to the conventional mineral and petrochemical based thermal insulation materials like stone wool, glass fibre and expanded polystyrene (EPS) insulations, hemp insulation is a relatively new product. Hence, limited information is available on the hygric and thermal properties of hemp insulations. The effects of hygric properties of insulation materials on the hygrothermal performance of building envelopes are manifold. Moisture can effect heat flux, heat capacity, condensation, mould growth and structural integrity [2]. If the key hygric and thermal properties of the insulations are known, the data can then be assessed individually or can be used in numerical simulation software to study the hygrothermal performance of the materials in building envelope for given hygrothermal boundary conditions. Thus, for example, it can be determined whether a vapour barrier is required in a thermal envelope or how long it will take for a wet insulation to dry out.

This paper characterises five types of hemp insulation materials available in the UK market in terms of the following key hygric properties: adsorption–desorption isotherm, moisture buffer value (MBV), vapour diffusion resistance factor (μ value) and water absorption coefficient (A value). The moisture buffer value

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represents the materials' relative humidity management capacity in adjacent spaces. The other three parameters (adsorption–desorption isotherm, vapour diffusion resistance factor and water absorption coefficient) can be used in hygrothermal and biohygrothermal simulation software to study the hygrothermal performance and mould growth potential of the insulation materials in various building envelopes and climatic conditions.

2. Theory

2.1. Adsorption–desorption isotherm

Adsorption is the increase in the concentration of a dissolved substance at the interface of a condensed and a liquid or a gaseous phase due to the operation of surface forces [3]. An adsorption isotherm is the constant temperature relationship between the amounts of adsorbate accumulated by the unit quantity of adsorbent in equilibrium condition in a range of partial pressure [4]. An adsorption isotherm can be divided into three distinct regions in relation to water storage functions (Fig. 1).

At lower relative humidity, 0–15% according to Hill, Norton and Newman [6] and 5–35% according to Collet et al. [7], water molecules are adsorbed in a monolayer (solid solution) on to the internal surfaces of the cell wall. Multi-molecular layers of water are formed on the cell wall micro-capillaries at a relative humidity varying between 15% and 70%, while capillary condensation occurs at further higher relative humidity ranges. Area covered by 0% to 95–98% relative humidity is defined as hygroscopic region. Adsorption isotherms, in subcritical temperature, are classified by the International Union of Pure and Applied Chemistry (IUPAC) into six distinct types [8], as shown in Fig. 2.

Type 1 corresponds to Langmuir isotherm describing monolayer adsorption on microporous (pore widths below 2 nm) adsorbent. Type 2 describes adsorption on macroporous adsorbent with adsorbent–adsorbate interaction. There is initial formation of monolayer and subsequent formation of multilayer. Type 3 describes multilayer isotherm on macroporous absorbent with week adsorbent–adsorbate interaction. Type 4 and 5 represent adsorption isotherm with hysteresis. Capillary condensation occurs in mesopores (pore widths from 2 to 50 nm) in these two types. Type 6 includes steps that occur due to phase transition of adsorbed molecular layer or due to adsorption on different faces of crystalline solids.

2.2. Moisture buffering

Moisture buffer capacity is a property by which hygroscopic materials in touch with surrounding air adsorb and desorb moisture to create equilibrium with the relative humidity of the surrounding space. Moisture buffering capacity can be used for moderating the humidity fluctuations in internal spaces. Several quantitative methods are available to determine and represent moisture buffering capacity such as the method developed by the Organisation for Testing in the Nordic Countries (NORDTEST) [9], Japanese Standards [10], ISO standard [11] and the method proposed by Padfield [12]. Among them, NORDTEST method is mostly used in the European context. The three ways of representing moisture buffering capacity described by NORDTEST method are explained in Sections 2.2.1–2.2.3.

2.2.1. Moisture effusivity

Moisture effusivity (b_m) is the measure of the ability of the material to exchange moisture with its surroundings when the surface of the material is exposed to sudden change in humidity. The equation for moisture effusivity is:

$$b_m = \sqrt{\frac{\delta_p \cdot \rho_0 \cdot \left(\frac{\partial u}{\partial \varphi}\right)}{P_s}} \tag{1}$$

where b_m is the moisture effusivity [kg/(m^2 Pa s$^{1/2}$)], δ_p is the vapour permeability [kg/(m s Pa)], ρ_0 is the dry density of the material (kg/m^3), u is the moisture content (kg/kg), φ is the relative humidity (–), P_s is the saturation vapour pressure (Pa).

2.2.2. Ideal moisture buffer value

The most common step change function for moisture buffering is to expose the surface to 75% relative humidity for 8 h and to 33% relative humidity for 16 h in each testing cycle. The equation for the relationship between surface moisture flux and time is:

$$G(t) = \int_0^t g(t)dt = b_m \cdot \Delta P \cdot h(\alpha) \cdot \sqrt{\frac{t_p}{\pi}} \tag{2}$$

where $G(t)$ is the accumulated moisture uptake (kg/m^2) and the corresponding moisture release during a time period t_p, $g(t)$ is the moisture flux over the surface at time t and $h(\alpha)$ can be expressed by the following equation:

$$h(\alpha) = \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{\sin^2(n\pi\alpha)}{n^{3/2}} \approx 2.252[\alpha(1-\alpha)]^{0.535} \tag{3}$$

where α is the fraction of the time period when moisture load is high. In this case the value of $\alpha = 1/3$ and $h(\alpha) = 1.007$ and therefore Eq. (2) becomes:

$$G(t) \approx 0.568 \cdot b_m \cdot P_s \cdot \sqrt{t_p} \tag{4}$$

The value (MBV_{ideal}) is determined by dividing Eq. (4) by the change in relative humidity, as follows:

$$MBV_{ideal} \approx \frac{G(t)}{\Delta RH} = 0.568 \cdot b_m \cdot P_s \cdot \sqrt{t_p} \tag{5}$$

where ΔRH is the change of relative humidity (%). MBV_{ideal} is measured in [kg/(m^2 %RH)].

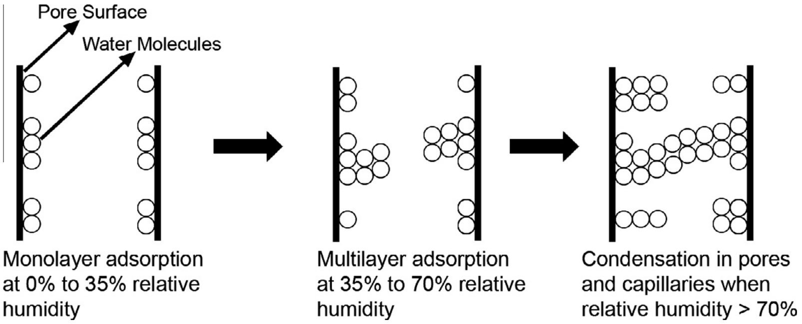

Fig. 1. Physisorption, adopted from Osborne [5].