Water vapor properties of two hemp wools manufactured with different treatments

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ABSTRACT

Hemp wools are environmentally friendly materials that are used for thermal insulation of building. These fibrous materials are the places of moisture transfer and storage that impact on thermal performances of the material. In this work, two kinds of hemp wool are studied: hemp wool with an organic binder (called HW1) and hemp-cotton wool with a polyester binder (called HW2). The investigations are based on water vapor sorption and on water vapor permeability measurements. The two kinds of hemp wool show similar sorption isotherm with quite high values of water content. The water vapor permeability is quite high too.

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1. Introduction

In a context of sustainable development, environmental awareness induces to save energy and resources. The use of thermal insulation in building walls contributes to reduce energy needs while the use of renewable raw materials prevents extinction of resources [1,2]. Hemp fibers are suitable for insulations due to their thermal properties and some ecological features, i.e. biodegradability [3]. Nowadays, the European market of insulation materials is still characterized by the domination of inorganic fibrous materials and organic foamy materials [4]. Environmental and public health aspects play an increasing role. Insulation materials have to improve their performance, but they also have to be adaptive, friendly to the construction site personnel and cost effective. However, hemp fibers as a natural resource have a risk for microbial and other contaminants, and their quality should be monitored regularly. Careful procedures during harvesting, processing, manufacturing, building and maintenance of buildings are required in order to avoid the risk of negative effects (i.e. molding) caused by moisture and free water. So, additives are added along the fibers. Like all materials showing open porosity, hemp wools store and transfer moisture. This moisture may reduce the thermal performance of the insulation and may alter the chemical composition of the material (molding in humid conditions). More, simultaneous heat and mass transfer and storage may lead to water

condensation. This condensation damages the insulation and the structure of the building walls. To prevent this, a vapor barrier can be used. The need of vapor barrier may be studied thanks to a numerical simulation. If the dew point appears, one should use a vapor barrier. To do such numerical study, hydric properties of the materials are needed as input. Also, this paper presents hydric characterization of two kinds of hemp wools. One is made with an organic binder (called HW1) and the other one is made with a polyester binder (called HW2). The experimental study investigates water vapor sorption isotherm and water vapor permeability. The sorption curves are then compared and fitted with BET and GAB models in order to calculate the specific surface area of the material. More, results are compared with hydric properties of mineral wools.

2. Theory

2.1. Water vapor sorption

2.1.1. Generality

Materials that show open porosity adsorb surrounding gas. The water vapor sorption isotherm relates the water content of the material to the ambient relative humidity at constant temperature. In the lower half of the range of relative humidity ($0.05 < \varphi < 0.35$–0.40), molecules are strongly sorbed in a monomolecular layer. With increasing relative humidity, molecules are sorbed in multimolecular layers. Lastly, capillary condensation appears at higher relative humidity (Fig. 1).

The amount of gas adsorbed by physisorption (monolayer, multilayer and capillary condensation) depends on the surface area

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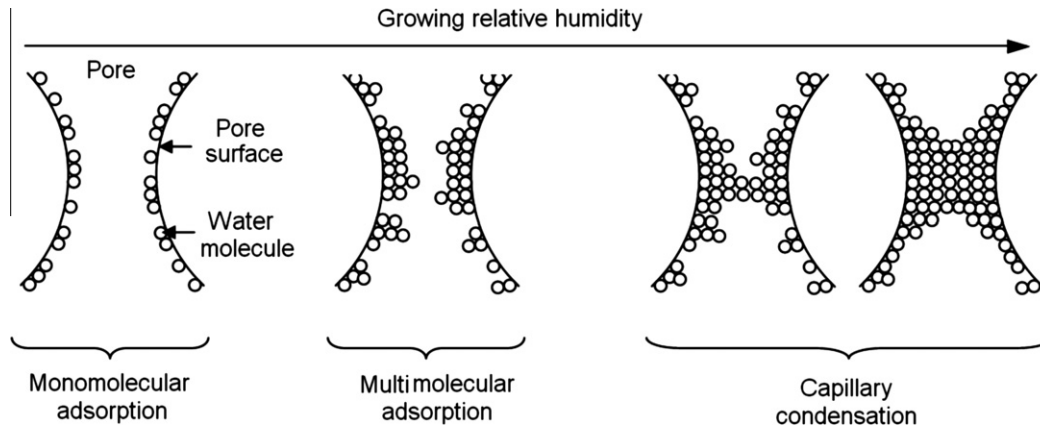
Fig. 1. Physisorption.

and on the porous structure of the material. The IUPAC [5] gives a classification of physisorption isotherms in six types (Fig. 2) with reference to pore size.

2.1.2. Sorption models – specific surface area

Several models have been developed to describe sorption curve. The BET theory [6] gives the isotherm equation for multilayer adsorption by generalization of Langmuir's treatment for monomolecular layer (Table 1) (Eq. (1)). Independently, Guggenheim [7], Anderson [8,9] and De Boer [10] have developed the GAB model (Table 1) (Eq. (2)). These models relate the water content to the specific surface area of the material. Despite they are physically valid when there is not capillary condensation, the GAB model covers a wide range of relative humidity ($0.05 < \varphi < 0.8–0.9$)
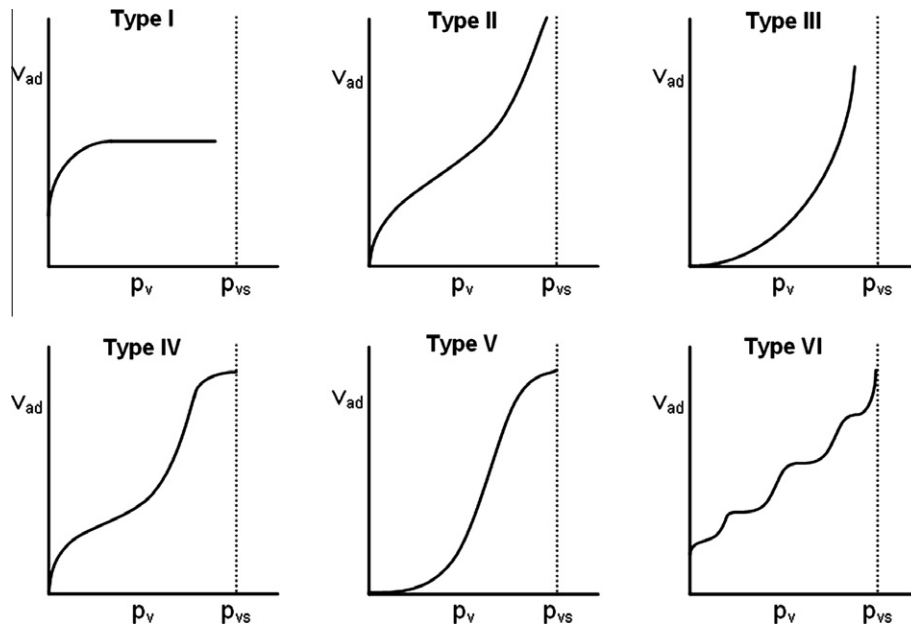

Fig. 2. Physisorption isotherm (IUPAC classification).

Table 1
Adsorption models.

Model	BET		GAB	
Equation	$\frac{w}{w_{mB}} = \frac{C_B \varphi}{(1-\varphi)(1-\varphi+C_B\varphi)}$	(1)	$\frac{w}{w_{mG}} = \frac{C_G k \varphi}{(1-k\varphi)(1-k\varphi+C_G k\varphi)}$	(2)
Linearized equation	$F(\text{BET}) = \frac{\varphi}{(1-\varphi)w} = \frac{1}{w_{mB}C_B} + \frac{C_B-1}{w_{mB}C_B}\varphi$	(3)	$F(\text{GAB}) = \frac{\varphi}{(1-k\varphi)w} = \frac{1}{kC_G w_{mG}} + \frac{C_G-1}{C_G w_{mG}}\varphi$	(4)
Parameters	w_{mB}; $C_B = \exp\left(\frac{E_a-E_L}{R.T}\right)$		w_{mG}; $C_G = \exp\left(\frac{E_a-E_m}{R.T}\right)$; $k = \exp\left(\frac{E_L-E_m}{R.T}\right)$	
Slope at origin	$C_B \cdot w_{mB}$		$C_G \cdot k \cdot w_{mG}$	
$\varphi (w_m)$	$\varphi_{mB} = \frac{1}{1+\sqrt{C_B}}$		$\varphi_{mG} = \frac{1}{k(1+\sqrt{C_G})}$	
$w_{max} (\varphi = 100\%)$	∞		$w_{max} = \frac{C_G k}{(1-k)(1-k+C_G k)}w_m$	

Where w_{mB} or w_{mG} is the moisture content when the adsorbent surface area is covered with a complete unimolecular layer, $\varphi = \frac{p_v}{p_{vs}}$ is the relative humidity, p_v and p_{vs} are the pressure and the saturation pressure of water vapor, E_a is the heat of adsorption (binding energy considered between the first layer of adsorbed molecules and the adsorbent), E_L is the heat of liquefaction (binding energy considered for the second and consecutive layers), E_m is a binding energy different from E_L for all molecular layers.