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Inquiries into the measurement of vapour permeability of permeable materials

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HIGHLIGHTS

- Measurement of vapour permeability with cup method.
- Application to three very permeable insulating materials: rockwool, polyurethane, under-roof screen.
- Influence of boundary conditions on the diffusion resistance.
- Values of apparent and real vapour permeability depending on the boundary conditions of test.

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ABSTRACT

This paper focuses on the measurement of the apparent vapour permeability of three different insulating materials: rockwool, polyurethane (PUR), and under-roof screen, by means of the cup method. The objective is to determine the influence of different test parameters on the superficial exchanges that affect the methodology of the vapour diffusivity determination. The parameters that are varied are: thickness and area of the specimen, thickness of the air gap at the lower surface of the specimen, air velocity, cup height, and hygrometry inside and outside the cup. Recommendations are then given for measuring the vapour diffusivity of very permeable materials with such a method.

1. Introduction

The research reported in this paper is part of the "MACHA 2" project, financed by the French National Research Agency. The main objective is to better understand mass transfers through building envelopes in order to control heat transfers. The first part of the project showed that tools for coupled mass and heat transfer simulation are very efficient in revealing and explaining the different mechanisms that influence mass transfer inside the building envelope components. However, these simulations do not always match the experimental results, on the one hand because of the complexity of the codes used for simulation and, on the other, because they require very precise material characteristics.

One of the most important parameters needed to characterise the mass transfer of building materials is the vapour permeability, also called vapour diffusivity or vapour diffusion. Various methods are used to measure this parameter, mainly gravimetric methods and gas analyses [1–7]. The literature shows that, in general, for the same material, the different measurements give relatively scattered results [8–10]. The cup method, as described in standard NF-EN-ISO 12752 [2] is one of the most widely used methods to measure the vapour permeability of building materials. Although it is quite easy to implement, the results obtained with this method need thorough analysis because it is very sensitive to the test conditions [10,11].

For this reason, the second part of the project focused on the measurement of vapour permeability with the cup method in order to determine the influence of the different test parameters on the superficial exchanges. It concentrated particularly on permeable materials, which are most concerned by the impact of the boundary conditions. The parameters studied were: the thickness and the area of the specimen, the thickness of the air gap at the lower surface of the specimen, the air velocity, the cup height, and the hygrometry inside and outside the cup. Five humidity levels (0.3%, 33%, 55%, 76% and 93%) were chosen, for both the

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Nomenclature

Symbol	Meaning, Unit
ρ	bulk density, kg/m^3
λ	thermal conductivity, W m^{-1} K^{-1}
μ	diffusion resistance factor, –
π	vapour permeability, s
$\vec{g}_v$	vapour flux density, kg/(m^{2}s)
h_m	vapour mass exchange coefficient, s/m
RH	relative humidity (p_v/p_{sat}), –
p_v	partial vapour pressure, Pa
p_{sat}	saturated vapour pressure, Pa
R_S	surface diffusive vapour resistance, m/s
R_D	apparent vapour diffusive resistance, m/s
th	thickness, m

Subscripts and superscripts	Meaning
air	air
mat	solid material
v	water vapour

inner and outer parts of the cup (RH_{in}/RH_{out} pairs).The experiments were carried out at a temperature of 23 °C. The impact of air diffusion through tested material will be the subject of another paper.

This study of parameter variability led to a campaign of 141 tests, shared between two laboratories: CSTB (Scientific and Technical Centre for Building) and LMDC (Laboratoire Matériaux et Durabilité des Constructions) with common measurements on some specimens to evaluate the differences in experimental equipment. CSTB used a climatic chamber with ventilation at the rear through 3 grids (at the top, in the middle and at the bottom). LMDC chose a climatic chamber configuration that allowed two specimens to be placed so as to be subjected to the same air velocity and two other specimens to be placed farther away, where the air velocity was lower.

In this paper, the results of these tests are presented and analysed in order to give some recommendations for the use of the cup method in the determination of vapour permeability of very permeable materials.

2. Theoretical background of the cup method

2.1. Measuring protocol

The permeability of a material defines its ability to let gas pass through it under the action of a pressure difference between its two opposite faces. In the case where the gas is water vapour, the permeability represents the ratio of the amount of water vapour that passes through a material per unit of thickness and time, and per unit of vapour pressure difference prevailing between the two sides of the material [12]. This magnitude depends on the physical characteristics of the material, such as the pore diameter or the geometry of voids [1,13–16].

The measurement of the vapour permeability of materials by the cup method, although apparently simple, implies a large number of interacting physical phenomena that need to be analysed if the results are to be validated [17,18].

Based on standard NF-EN-ISO 12752 [2], this gravimetric steady-state test involved sealing a sample, of thickness th_{mat}, above a test cup containing saline solution to impose the humidity level (Fig. 1). The whole system was placed in a temperature- and humidity-controlled climatic chamber so that the material was situated between two environments with different partial vapour pressures: pv_1 outside the cup and pv_2 inside. A layer of air was present inside the cup (Fig. 1).

Due to the partial vapour pressure difference between the inner part of the cup and the climatic chamber, water vapour flow caused a variation in the mass of the cup (uptake or loss). Periodic weighing of the assembly allowed the density of mass flux g_v to be found when the steady state was reached.

In the steady-state, the apparent water vapour permeability π_{app} [s] is given by the relation:

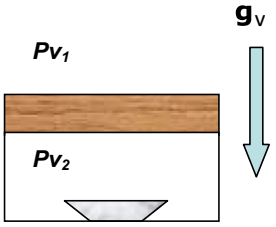

Fig. 1. Cup method: mass flux g_v due to vapour pressure gradient.

$$g_v = -\pi_{app}\frac{p_{v1}-p_{v2}}{th_{mat}}\,[s] \quad (1)$$

As no specific prescription is given in NF-EN-ISO 12752, measurements depend mainly on the climatic chambers and the materials used by each laboratory. Nevertheless, some recommendations are given:

- The air velocity inside the climatic chamber should be between 0.02 and 0.3 m/s. However, for very permeable materials, it is recommended to accelerate the air up to 2 m/s;
- The air gap between the saturated solution and the lower face of the specimen must be 15 ± 5 mm;
- The exposed area should be greater than 0.05 m^2, otherwise at least 3 specimens must be tested.

2.2. Theoretical basis for surface resistance and transfer mechanisms

Actually, the material is not subjected to the vapour pressure gradient (pv_1–pv_2) but to (pv_{1S}–pv_{2S}), where pv_{1S} and pv_{2S} are the vapour pressures at the surfaces of the material (Fig. 2).

(pv_1 – pv_{1S}) is conditioned by the convective, and so the mass, exchange conditions between the external surroundings and the material, while (pv_{2S}–pv_2) is conditioned by the air gap resistance and so the vapour pressure gradient imposed by the saline solution inside the cup and the inner surface of the specimen [19–22].

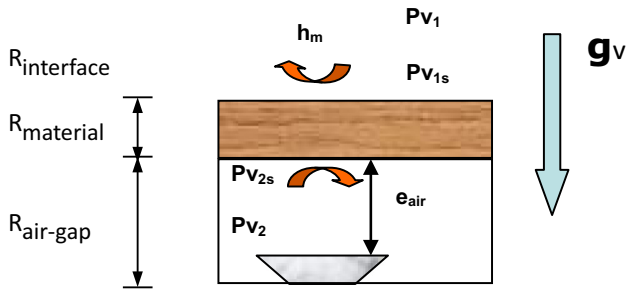

Fig. 2. Cup method: mass flux g_v due to vapour pressure and diffusion resistance due to air gap, material and external environment.