The impact on indoor air of bio-based insulation materials: effect of humidity and potential mould growth

Ana Maria TOBON[1*], Yves ANDRES[1], and Nadine LOCOGE[2]

1 IMT ATLANTIQUE
4 rue Alfred Kastler
44300 Nantes, France
**Corresponding author:*
Ana-Maria.TOBON@imt-atlantique.fr

2 IMT LILLE DOUAI
941 rue Charles Bourseul
59508 Douai, France

ABSTRACT

Bio-based insulation materials represent an alternative to petro-based materials which may contribute to enhance buildings energy efficiency. Nevertheless, these material must respond to indoor air quality requirements and prove their resistance to moulds. In this study, VOCs emissions of a wood fibre board were characterised at 50% and 85% of relative humidity (RH) as well as its potential to mould growth. Relative humidity variation impacted significantly some VOCs emissions and colonies from *Aspergillus niger* developed onto the material. This results can contribute to the different questions concerning the use of this type of materials to isolate buildings.

KEYWORDS

Bio-based insulation materials, relative humidity, mould growth, VOCs emissions

1 INTRODUCTION

The use of bio-based insulation materials has become an interesting alternative to enhance buildings energy efficiency. These materials made of natural or recycled biomass, present good environmental and technical performances which have contributed to their increase in the construction market. In France, they must also respond to the sanitary requirements concerning indoor air quality (volatile organic compounds or VOC emissions). In the research performed by Maskell et al. 2015, total VOC emissions (TVOC) from cellulose flakes, wool, hemp fibre, wood fibre and hemp lime were analysed, showing low emission rates of TVOC which generally decreased or remained stable within the 28 days of the test. For some of the characterised VOCs including formaldehyde, the higher concentrations were produced by the wood fibre. In 2016, the French environment and energy management agency (ADEME) performed a study in order to compare the COVs emissions of bio-based construction materials used in French buildings. The analysed materials included paintings, insulation boards, doors and windows, presented low VOCs emissions rates as their homologous mineral or petro-based ones. The characterisation of these materials and their related emissions is important and will eventually allow for their further development.

Apart from the nature and the chemical composition, climatic conditions can also determine materials emissions (Koivula et a. 2005). Relative humidity (RH) is one of the environmental factors that affect emissions behaviours of formaldehyde from building materials. Experimental studies in emission chambers showed that concentrations as well as emissions rates increase when increasing RH (Huang et al. 2010). Lin et al. 2009 observed that the emission rate and chamber concentration of toluene, n-butyl acetate, ethylbenzene, and m,p-xylene increased when RH increased from 50% to 80%.

When RH increases, potential mould growth may happen in bio-based insulation materials. As moulds colonize a material, volatile organic compounds (VOC) and mycotoxins can be emitted from their metabolism during the biodegradation of the substrate, affecting the indoor air quality and inhabitants' health (Joblin, 2011). So, Bio-based insulation materials must also prove their resistance to moulds.

The objectives of this research project are to characterise VOCs emissions from bio-based insulation materials, to analyse the effect of relative humidity on the emissions behaviour and to assess materials potentiality to mould growth.

2 MATERIALS AND METHODS

2.1 Tested materials

In France, wood and cellulose are the two more frequently used raw products to produce bio-based insulation materials. In 2011, 69% of the bio-based boards produced corresponded to wood fiber boards (DREAL, 2015). In this study, VOC emissions of an insulation bio-based board were assessed. The material is composed of 90% wood fibre and 10% thermo-fusible binder fibers (recycled polyester) (figure 1).

.

Figure1. Insulation bio-based board made of wood fibre

2.2 VOC emissions experimental setup, sampling and analysis

A CLIMPAQ (Chamber for Laboratory Investigations of Materials, Pollution and Air Quality) (figure 2) chamber was used to analyse VOC emissions from the materials.

The tests were performed using two different values of relative humidity (RH), 50% and 85%. In the first instance, the objective was to assess the material following the French regulation for construction materials (ISO 16000 series) (50%RH), and then to analyse the effect of humidity on the emissions behaviour (85%).

The tested specimen (20 cm x 20 cm) was introduced in the chamber at 23°C and 50% HR during 28 days, and then the RH was increased to 85%.

Samples were collected on days 28 (50%) and 3 days after the humidity was increased for the first test and Samplings were performed 5, 13, 21 and 28 for the second test into sample tubes containing tenax TA adsorbent and DNPH (for aldehydes) by pumping purified air through the chambers.

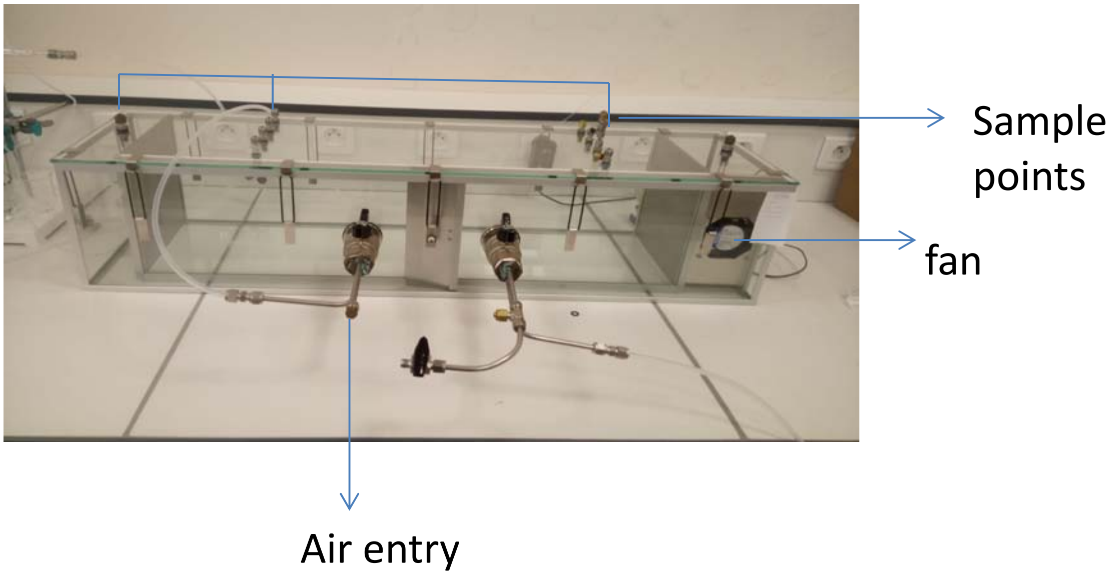

Figure 2. CLIMPAQ chamber

2.3 Mould development experimental setup and analysis

A 105L glass chamber (figure 3) was used to assess microbial development onto the tested insulation board. The materials were cut into test specimens of 15cm x 4cm x 15cm that were preconditioned at 19±1°C and 89, 5±2%RH for two weeks. Simultaneously, an *Aspergillus niger* strain obtained from a mould contaminated indoor environment was grown separately on DRBC agar medium at 25±2°C and 90±3 %RH. Test specimens were artificially contaminated by a dry aerosol of $5x10^3$ spores per cm^2 and incubated at 19±1°C and 89, 5±2% RH for two weeks. Visual assessment was performed according to the following rating classes: 0, no visible mould growth to naked eye or magnification x50; and 1, visible mould growth to naked eye or magnification x50. To quantify fungal development, a $4cm^2$ square of graph paper (figure 4) was posed on different parts of the surface of the test specimens and pictures were taken to count the colonies on the images. The counting allows the calculation of the number of colonies developed per cm^2.

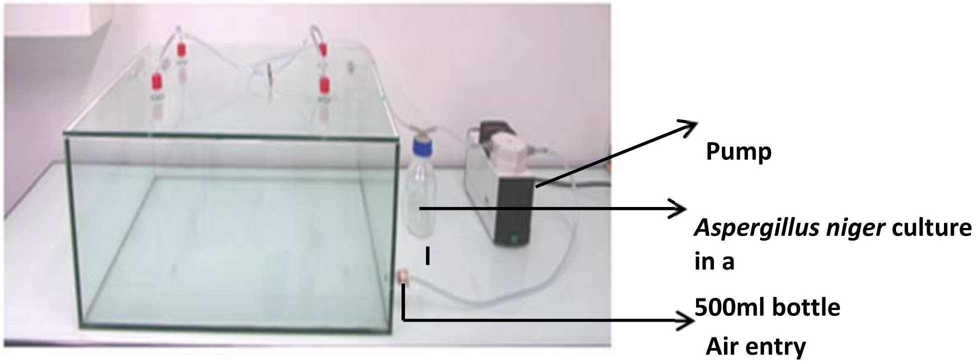

Figure 3 Glass chamber to asses mould growth

Figure 4. 4cm^2 square of graph paper to quantify mould colonies

3 RESULTS AND DISCUSSION

3.1 Effect of relative humidity on VOCs emissions

Two tests were performed to analyse VOCs emissions from material 1(wood-fibre board). Concentrations of some of the compounds (table 1) showed an important effect of humidity variation as they increased significantly in both tests, while another group of compounds concentrations stayed relatively constant (table 2) and some others showed no test reproducibility (table 3).

In the first test, the sampling was done 3 days after the change on relative humidity and in the second one, 5 days after. So maybe samplings were performed at two different times of the desorption kinetics and this may explain differences of both tests. More sampling at 85% were performed in the second test in order to understand emissions desorption kinetics.

Tableau 1.Major VOCs emitted at 50% and 85% of RH (two tests performed). Humidity variation significantly affected concentrations.

	Test 1		Test 2	
Compound	Cexp (µg/m3) J28 - 50%RH Wall scenario	Cexp (µg/m3) J31 - 85%RH Wall scenario	Cexp (µg/m3) J28 - 50%RH Wall scenario	Cexp (µg/m3) J35 - 85%RH Wall scenario
Acetaldehyde	5,6	23,8	7,4	14,0
Acetic acid	7,4	46,0	4,4	9,7
2 pentylfuran	<LD	8,7	<LD	0,33

Tableau 2. Major VOCs emitted at 50% and 85% of RH (two tests performed). Concentrations stayed relatively stable during the tests.

	Test 1		Test 2	
Compound	Cexp (µg/m3) J28 - 50%RH Wall scenario	Cexp (µg/m3) J31 - 85%RH Wall scenario	Cexp (µg/m3) J28 - 50%RH Wall scenario	Cexp (µg/m3) J35 - 85%RH Wall scenario
Ethylbenzene	0,03	0,55	0,04	0,07
Styrene	0,04	0,24	<LD	0,21
Formaldehyde	11,77	14,70	13,84	13,68

Tableau 3. Major VOCs emitted at 50% and 85% of RH (two tests performed). Results of some emissions are not reproducible.

	Test 1		Test 2	
Compound	Cexp (µg/m3) J28 - 50%RH Wall scenario	Cexp (µg/m3) J31 - 85%RH Wall scenario	Cexp (µg/m3) J28 - 50%RH Wall scenario	Cexp (µg/m3) J35 - 85%RH Wall scenario
Toluene	0,11	1,17	0,10	0,20
2 Butoxyethanol	<LD	0,15	0,02	<LD
Propanone	3,90	1,7	4,5	7,65
Hexanal	2,03	18,1	1,2	1,77

3.2 Large time range emissions at 85% of relative humidity

As differences were seen concerning the sampling after humidity variation, major VOCs were analysed by sampling at different times at 85% of RH, in order to analyse the emissions kinetics and different emissions behaviours were observed (figure 5). Huang et al. (2010)reported an important increase of formaldehyde when humidity passed from 50% to 85%. In this study, relative humidity has not an important effect over this compound, the concentration stays more or less stable during the whole test. Nevertheless, other compounds as acetaldehyde, propanone, acetic acid, nonanal and 5 methylfurfural are significantly affected by relative humidity variation. Concentrations strongly increased with humidity variation and then stabilise at almost the level of emission at 50%. O-cymene, limonene, 4 terpineol and alpha terpineol are not emitted at 50% of RH but appeared when the conditions vary, showing that humidity can generate other emissions from the material. This mechanism may be due to the competition between water and the VOC molecules for the adsorption sites of wooden flooring, which changes partition coefficients of VOCs between wood and air.

Also, water molecules would tend to be adsorbed on the hydrophilic sites of wood, so when RH increases, more VOCs would be desorbed from these sites (Lin et al. 2009).

In order to better analyse the results obtained and to interpret new ones, other tests are planned to be performed: first, a Karl Fischer test to evaluate the moisture content of the materials, second, a BET (Brunauer, Emmett et Teller) test to analyse the adsorption capacity of the materials and third, a short term range of RH samplings and VOCs concentrations to the emissions kinetics.

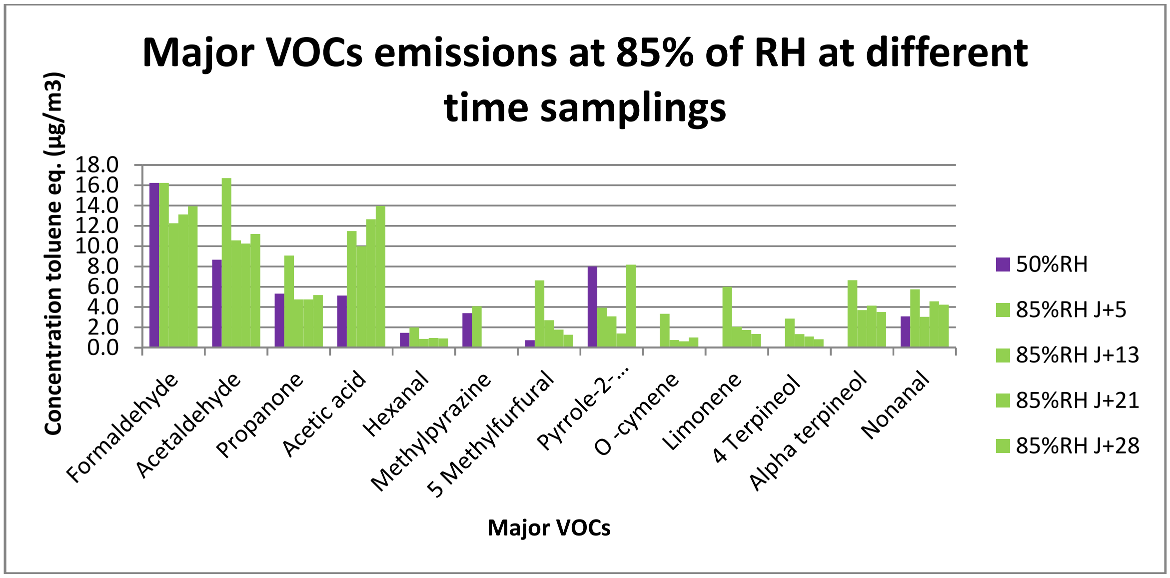

Figure 5. Major VOCs emitted at 85% at different time samplings

3.2 Mould development

After two weeks of incubation at 19±1°C and 89, 5±2% of RH, 7.9 ±2 colonies/cm^2 of *Aspergillus niger* developed onto the material, showing that this insulation board is not resistant to mould growth in such conditions. Figure 6 shows the colonies developing onto the material. Different characteristics of bio-based insulation materials may promote mould development, first, their hygrothermal behaviour can be an advantage for indoor humidity regulation but, if water vapour transfer is altered somehow, humidity accumulated within the material may generate a favourable environment for conidia development. Second, raw material as wood may respond to nutritive needs of microorganisms and third, there is a potential contribution of microorganisms from the native material (Koivula et al. 2005).

Figure 6. Colonies d'*Aspergillus niger* onto the material

4 ACKNOWLEDGEMENTS

We acknowledge the French Agency for the Environment and Energy Management (ADEME) and the Pays de la Loire region (France) for their financial support.

5 REFERENCES

C.C. Lin, K.P. Yu, P. Zhao, G.W.M. Lee, (2009) *Evaluation of impact factors on VOC emissions and concentrations from wooden flooring based on chamber tests*, Build. Environ. 44 (2009) 525- 533.

Huang, Ruth, Oleg V. Pyankov, Bofu Yu, and Igor E. Agranovski (2010) *Inactivation of Fungal Spores Collected on Fibrous Filters by Melaleuca Alternifolia (Tea Tree Oil).* Aerosol Science and Technology 44(4): 262–268.

Koivula, Minna, Hanna-Riitta Kymäläinen, Jari Virta, et al.(2005)*Emissions from Thermal Insulations—Part 2: Evaluation of Emissions from Organic and Inorganic Insulations.* Building and Environment 40(6): 803–814.

Jelle, B. P. (2011). *Energy and Buildings*, *43*(10), 2549–2563

Lamouile, J., Le Bayon, I., Draghi, M., Roger, M., Pompeo, C., Gabille, M., … Kutnik, M. (2016). In: IAQVEC *9th International Conference on Indoor Air Quality Ventilation and Energy Conservation in Buildings*. Seoul, Korea

Le Bayon, I., Draghi, M., Gabille, M., Prégnac, M., Lamouille, J., Jequel, M., … Kutnik, M. (2015). In: First International Conference on Bio-based Building Materials.
Lechtenbohmer, S., & Schuring, A. (2011). *Energy Efficiency*, (4), 257–70.

Lelievre, D., Colinart, T., & Glouannec, P. (2014). *Energy and Buildings*, *84*, 617–627.

Pacheco-Torgal, F. (2014). *Construction and Building Materials*, *51*, 151–162.
Sterflinger, K., Ettenauer, J., & Piñar, G. (2013). *Energy Procedia*, *40*, 499–506.