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Impact on Indoor Air of Multifunctional Materials Made with Animal Waste and Agro-Industrial By-Products †

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Abstract: One severe public health problem globally is air pollution, as exposure to air pollutants threatens the health of people everywhere in the world. Agriculture generates waste, the improper disposal of such waste producing adverse environmental effects like air pollution, etc. In this context, our research focused on capitalizing on animal waste (wool) and agro-industrial by-products (sunflower seed husks) as additives in two types of aqueous dispersion finishing/protection products, serving as binders. The paper presents the results from the monitoring of volatile organic compounds (VOCs) emissions of four types of innovative multi-layer finishes made with such types of waste.

Keywords: air pollution; waste capitalization; multifunctional materials

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1. Introduction

Air pollution stands as one of the most critical problems public health faces globally [1–4]. Air pollutants represent a complex combination of gases, solid and liquid particles, suspended in the air [2]. Until now, much focus has been on outdoor air quality [4], with many studies directed towards understanding and improving the conditions of the atmosphere. Exposure to both outdoor and indoor air pollutants pose health risks to individuals of all ages, especially young children who spend extended periods indoors [2]. However, there has been a significant increase in the time spent in indoor spaces by the entire population [2,5]. In this context, indoor air quality is receiving increasing interest. Among the sources of indoor air pollution are indoor finishing products, which usually release volatile organic compounds (VOCs)—a crucial category of pollutants with detrimental effects on human health [6,7]. VOCs are organic compounds with boiling points between 50 and 260 °C, which are used in finishing products for various reasons such as cost-effectiveness (providing relatively inexpensive means to achieve the desired properties of finishing products), appearance (achieving a desired finish), and application consistency (used as solvents to provide a smoother and more consistent application while also evaporating quickly, which helps the finishing product dry and cure faster). An increasing number of studies have shown that VOCs induce health issues, ranging from mild symptoms like irritation in the nose, eyes, and throat to more severe ones like coordination loss, headaches, nausea, and even damage to vital organs such as the kidneys, liver, and central nervous system [7].

Agricultural activities result in the production of waste or by-products [8,9], and the assimilation of these by-products into a circular economy remains inadequate. When not disposed of correctly, this waste can lead to severe environmental consequences, including the contamination of water, soil, and air. Additionally, unchecked fermentation will release methane, which is a potent greenhouse gas, into the atmosphere [9]. Previous research has explored the potential of repurposing animal waste and other agro-industrial by-products for construction materials [10–12]. These studies highlighted several benefits:

improved energy consumption, minimized environmental impact, cost-efficiency, abundant availability, and suitable insulation capabilities [9,10,13–15]. Building upon these findings, our study examines the utilization of animal waste, specifically wool, and agro-industrial residues, like sunflower seed husks, as additives in two different aqueous dispersion finishing/protection products, where they act as binders.

2. Materials and Methods

The paper presents the results from the monitoring of VOC emissions of four types (V2, V3, V4, and V5), of multifunctional materials (finishes/protections) with embedded animal waste and agro-industrial by-products in the closed mode of the experimental stand (emissions test chamber). It should be noted that each of the above-mentioned materials is a distinct composite material, with its own recipe and content of waste and by-products. The multifunctional materials consisted of three layers: a primer followed by two additional layers. Each of these layers contained a mixture of animal waste and agro-industrial by-products. Also, each material contains two main elements: one is the continuous component, with the role of a binder, which consists of one film-forming finishing product based on acrylic resin, denoted as AB1 (acrylic binder, in aqueous dispersion) and, respectively, AB2 (acrylic binder, in aqueous dispersion, containing fungicidal substances that prevent the spread of mold in the paint layer); the second is the discontinuous component, consisting of either a mixture of three fractions of sunflower seed husk (SSH) by-products, with a maximum size of 4, 6, and 8 mm, or a mixture consisting of by-products of 6 mm, 8 mm, and 10 mm fractions, together with waste from sheep's wool. Along with the two primary components mentioned earlier, some multifunctional materials in this study also contained a liquid adhesive based on polymer resin as an additive. The test samples were prepared as follows: each of the four tested materials have been applied on a plasterboard support (resulting different products thickness values), only on faces, not on the sides of the support plates and the edges of the plates were covered with an aluminum foil. The sample of material was placed in the emission testing chamber after six hours from the application of the last layer. Aspects of the samples of multifunctional materials selected for specific measurements regarding the VOCs emissions are shown in Figure 1.

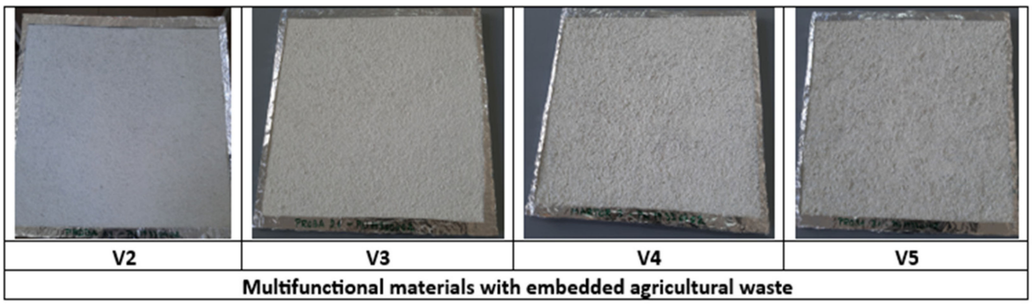


Figure 1. Aspect of multifunctional materials samples with embedded agricultural waste.

The experimental stand used for the monitoring of VOCs emissions has the following dimensions: 4 m length, 3 m width, and 2.5 m height. The walls and ceiling are covered with aluminum foil embossed on both sides, with a thickness of 50 µm, and the floor, with a waterproof vapor barrier membrane, consists of a layer of corrosion-resistant aluminum, tightly fixed between a transparent film of polyester and a reinforced polyethylene film. The experimental stand can operate in three modes: "closed" (using only air recirculation without fresh air intake), "open" (using only the fresh air circulation system), or "mixed" (using both systems simultaneously). Details of the experimental stand are presented in Figure 2.

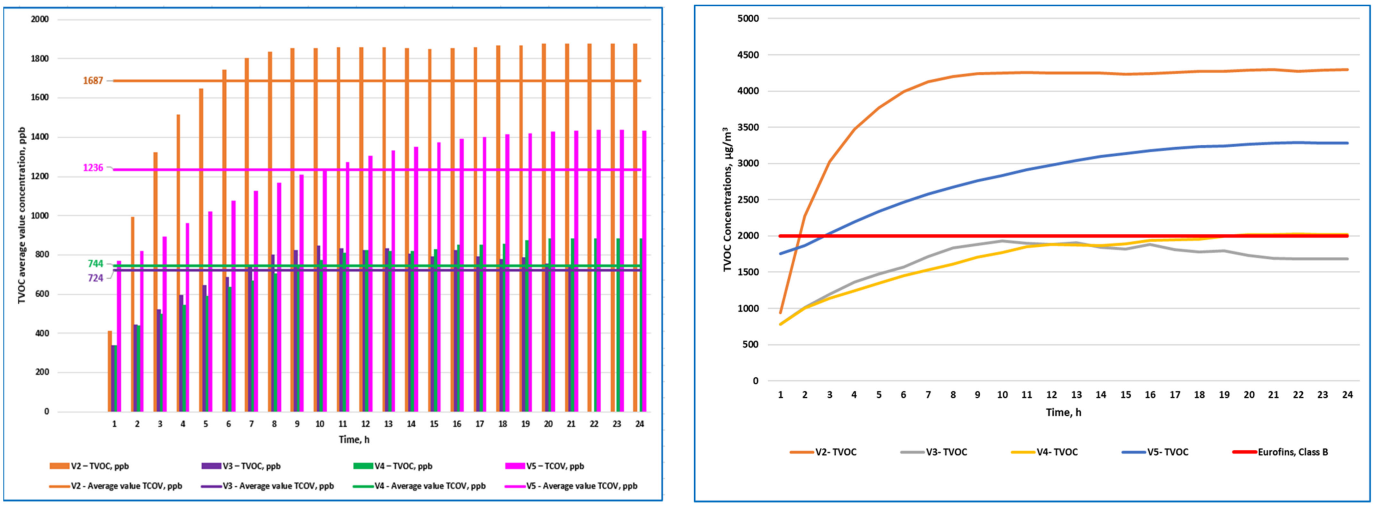
(**a**) (**b**)

Figure 2. Details of experimental stand for the monitoring of VOC emissions: (**a**) the experimental stand; (**b**) the air recirculation installation.

The measurement of VOC emissions, in ppb, was performed using a direct detection method and the portable data-logging detector IQ-610 probe [16–18] (Gray Wolf Sensing Solutions, Shelton, CT, USA), in the range 20–20,000 ppb, with a resolution of 1 ppb. The operating principle is based on electronic detection via a photo-ionization detector (PID) sensor. The equipment was calibrated before the measurements. The sampling interval for the VOC concentrations was one minute, and the total recording period was 24 h.

3. Results and Discussion

The recorded results in the experimental program for monitoring emissions from the tested multifunctional materials, at minute intervals, were averaged at an hourly level. Their processing in the form of diagrams is shown in Figure 3.



(**a**) (**b**)

Figure 3. Obtained results for the monitoring of VOC emissions: (**a**) in ppb, average values and time variation; (**b**) comparative analysis with the value of 2000 µg/m^3.

The time variation and the average values (in ppb) of the total volatile organic compounds concentration (TVOC) emitted by the tested materials in the air recirculation mode of the emission test chamber (without fresh air supply) over 24 h of monitoring are represented in Figure 3a. The average values of the TVOC concentrations for the monitored materials ranged between 724 ppb (1661 µg/m^3 in isobutylene units) for the V3 product and 1687 ppb (3871 μg/m^3 in isobutylene units) for the V2 product. The trend over time initially rises, but after a certain period specific to each material, it levels off to a plateau. From the analysis of the obtained results, a greater volatility of the AB1 binder is observed, compared to that of the AB2 binder, which results in higher TCOV concentration values recorded for the V2 and V5 structures. The series V5 > V4 > V3 is probably partly influenced by the quantities of AB2 binder required for embedding the SSH by-products mixture. The highest monitored values were for the V2 product (1687 ppb) and for the V5 product (1236 ppb–2836 μg/m^3 in isobutylene units) as a result of the multiple interactions between the composition of the binder, the characteristics of the additives (nature, size, quantity) of the applied composite materials, and, implicitly, the structure of the multilayer systems generated by the embedded animal waste and agro-industrial by-products. When comparing V3 and V4, emissions are higher for V4, likely due to the adhesive's presence. In V4, the amount of vegetal waste added is both larger in size and quantity than in V3.

Figure 3b shows the comparative analysis of the obtained results, in μg/m^3, with the value of 2000 μg/m^3 being, according to www.eurofins.com, the limit of class B, one of the pollutant emission classes for construction products. From this point of view, it can be concluded that materials V3 and V4, monitored in the first 24 h from the application, are put into class B, with emission values of 1500 and 2000 μg m^{-3}.

4. Conclusions

Air quality and the current potential health risk it poses play a crucial role in people's physical, mental, and social well-being. Therefore, reducing air pollution not only saves millions of lives, but also prevents the damage caused by air pollution to human well-being. Widely used in buildings, aqueous dispersion paints are significant sources of VOCs, a key indoor air pollutant. To mitigate the impact of VOCs on the environment and health, scientists suggest incorporating various natural waste products and by-products. The tested multifunctional materials, made with natural waste and by-products of vegetal and animal origin, present a positive contribution to the modification of indoor air quality parameters by reducing TVOC emissions in the compositions where a binder with a lower volatility is used. Also, the fact that the modification does not only depend on the amounts of added waste and by-products but also on the type and quantity of the binder in each studied material is outlined.

Considering the importance of a healthy indoor environment in which to spend our lives, it is necessary that, when designing different types of materials for indoor use, they are also evaluated from the point of view of pollutant emissions, in such a way as to have the lowest impact on our health.

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