Innovative Eco-Technologies to Reduce Emissions in the Manufacturing Processes of Special Wood Products

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Abstract. In the processes of surface treatment of specific wood products, a variety of coatings are used, which even in small-scale production represent the presence of certain hazardous chemicals. Risk substances from the group of volatile organic compounds (VOC) in surface treatment processes of wood products constitute a large number of contaminants that negatively affect both the working and the environment. These are, in particular, still used solvent-based coatings (CN, PUR, PES). The presence of solvents, thinners for consistency and viscosity treatment in coating processes and curing of these coatings a serious environmental risk even in small surface treatment operations in the production of special wood products (sporting goods, musical instruments, artistic and solitary wood articles). To solve the suggested problem, it is necessary to analysed all aspects that could reduce the production of these hazardous chemical substances. We have proposed a variety of eco-technical separation devices: using adsorption technologies with (or without) regeneration of adsorbent for effective capturing of pollutant emissions. Our research has been comparing the effectiveness of capture of pollutants (VOC) in small scale model plant surface treatments of special wood products.

1. Introduction

Currently, increased attention is given to maintaining and improving the quality of life and working environment in accordance with accepted principles of sustainable development. Effective indicators for assessing the state of the working environment are activities associated with the assessment of the environmental impacts of industrial activities and production processes in the context of the health of the population. For prediction and optimal adjustment of technological processes in the wood processing industry in the production of wood products it is necessary to assess the impact of present physical and chemical factors of the working environment in relation to the required quality of the products [1, 10].

The finishing of the surfaces of various materials (wood, metal, plastic, etc.) is one of the most important finishing operations, and the required decorative and protective function is required. At present, the application of coatings with different chemical composition of binders is used in the surface treatment [2, 4]. Organic diluents based on organic solvents are a major environmental problem because they are a significant source of VOC (volatile organic compounds) emissions [3, 10].

Volatile organic compounds (VOC) as risk chemical substances adversely affecting human health levels which are toxicologically: carcinogenic, sensitising, irritant and an allergic effects in acute or chronic exposure is evident in particular in woodworking industry in wood processing: surface finishing, bleaching, gluing, staining, grinding and wood protection [2, 3, 4].
The role of eco-technical devices is to reduce the amount of volatile organic compounds from the coatings so that they do not exceed the established limits and the maximum available concentration of these pollutants and ensure the most effective capture of VOC. The variety of materials to be treated, the finishing methods and coating technologies also influence the final assessment of work and the environment[6, 7, 8, 9]. The implementation of the current regulations concerning the control of emissions of volatile organic compounds of European legislative aims to control and reduce the negative impact of hazardous chemical substances, produced from a variety of industry sectors and their activities (in particular in surface finishing processing of special wood products), in order to ensure the safety and health of the population and workers in the industry [10].

Implementation of the current legislation on the reduction of emissions of volatile organic compounds (VOC) aims to control and reduce the negative impact of these hazardous chemical substances produced from different sectors of industry and activities generating their generation in a coordinated way to ensure the improvement of the health and safety of employees and the general public in the EU while protecting the environment by avoiding air, water and soil contamination. From the point of view of the emission quantification of the sectors involved in the formation of volatile organic compounds, the major producers are the surface treatments of materials and the processes of degreasing the surfaces of the materials with organic solvents. To solve the suggested problem, it is necessary to analyzed all aspects that could reduce the production of these hazardous chemical substances [2, 4, 10]. The proposal of environmentally acceptable method of reducing the occurrence of hazardous substances in surface treatment processes of special wood products is a comprehensive solution to these aspects [5, 6, 7, 8].

2. Experimental part

In our research work [1, 3, 5, 6, 7] we have proposed a variety of eco-technical separation devices: using adsorption technologies (with or without) regeneration of adsorbent for effective capturing of VOC pollutant emissions [8]. Our research has been comparing the effectiveness of capture of pollutants (VOC) in small scale model plant surface treatments of special wood products.

2.1 Proposal for reducing of VOC risk substances in wood surface treatment operations

To effectively address the issue of reducing hazardous substances in surface treatment operations, it is necessary to assess all aspects that would reduce the production of these hazardous pollutants. It is problematic to balance and effectively reduce VOC in small operators of surface treatment lines, who are not legally obliged to monitor and balance emissions of these substances and to address the issue of reducing volatile organic compounds by implementing effective measures to the extent that large, medium air pollutants within the meaning of the European VOC Directive and subsequent applicable laws and decrees [10]. Especially for small operators of wood material surface treatment, it is problematic to balance the actual consumption of coatings and thus lead the agenda on fugitive emissions and the reduction plan to contain these substances. The problem is all the more serious that most of these plants have no eco-installations installed to capture them. The share of small woodworking operators with the subsequent coating is in comparison with the large almost 60% [3].

Methods for reducing risk substances categorized as VOC are variable using dry processes of adsorption, catalytic desorption, and ternary degradation. Wet techniques include: adsorption, condensation, ozonization, biofiltration and using effective filters.

Given the timeliness of the need to design efficient and economical eco-technical solutions for the reduction of hazardous substances for small surface treatment operations of special wood products in which the separating devices are not installed, we have devoted their main attention [8]. The result is an eco-technical design of a complex device for the separation of gaseous and solid pollutants for small surface treatment operations.
It has been proposed two different variants of the eco-technical separation equipment [1, 3, 5, 6, 7]:
  - Variant A: Operation of wood treatment with adsorbent installation without adsorbent regeneration;
  - Variant B: Operation of wood treatment with adsorbent installation in the form effective filters.

2.2 Proposal for reducing of VOC risk substances in wood surface treatment operations - variant A
We have proposed a model variant (A) for the operation of the surface treatment of special wood products using adsorption technology for the separation and subsequent capture of VOC emissions from coating technology processes on different binder bases (solvent and waterborne coatings). Adsorption medium was selected as granular activated carbon (GAC) [8]. In this variant, filters for VOC capture were not used.

2.3 Proposal for reducing of VOC risk substances in wood surface treatment operations - variant B
We have also progressed in our research with the B variant; we have proposed a model variant for the operation of the surface treatment of special wood products using adsorption technology for the separation and subsequent capture of VOC emissions from coating technology processes on different binder bases (solvent and waterborne coatings). On the basis of our previous research, we have designed and prepared porous bicomponent polymer blended fibers as innovative filters for the effective capture of hazardous substances - VOC from surface treatment processes of wood composite materials [1, 3, 5, 6, 7].

3. Results and discussion
When designing model - variant A, the adsorption principle of separating these pollutants was applied to capture VOC risk substances. The adsorption medium was granulated activated carbon (GAC), installed in the patron boxes that are used up to their full adsorption capacity.

Based on our previous work [1, 3, 5, 6, 7], we found that from the perspective of recalculated economic costs, it is a good option not to use a desorption method for the elimination of entrapped VOCs but to apply catalytic thermal degradation of the saturated adsorption medium to the presence of hazardous chemicals as hazardous pollutants and this adsorption medium constitutes hazardous waste.

Figure 1 is a visualization of adsorbent medium – granulated active carbon (GAC) that is part of a comprehensive eco-design for VOC separation and capture in technological coating processes, when finishing surfaces in surface treatment processes of special wood products. A comprehensive variant A design is shown in Figure 2. Figure 3 shows a plan view of the model operation of the surface treatment of special wood products - variant A.

Figure 1. Visualization of adsorbent medium – granulated active carbon (GAC)
Figure 2. Schematic proposal separators equipment in operation surface finishing of special wood products without regeneration of adsorbent using GAC– variant A [3, 5, 8]
1–jalousie I, 2–drainage pipe from recuperates, 3- heat exchanger (recuperator), 4 - supply pipe, 5–jalousie II, 6–GAC, 7-connecting pipes, 8-fan, 9–nonwoven fabric, 10-metalgrid, 11- drainage pipe

Figure 3. Plan view of the model operation of surface treatment of wood products – variant A [3, 8]

Our solution pre effective capture of VOC is based on the assumption that the sorption on a solid bedrock of active coal - it is a device with fixed ballast layer of granular activated carbon the grates with a thickness of 100 to 500 mm. Discontinuous work, the saturation of coal adsorbed VOC signal must be interrupted and active load either replaced or regenerated. Discontinuous work, the saturation of coal adsorbed VOC signal must be interrupted and active load either replaced or regenerated. Exchange workload is laborious and lengthy recovery can be designed as automated [3, 8, 9].

Furthermore due to the adsorption of intermolecular - Van der Waals forces occur on the surface of the activated carbon from the oxidative polymerization or other chemical reactions, but which are irreversible and disrupt the process and damage the sorbent therefore, it is necessary to monitoring the saturation and capacity of GAC in the patron boxes by calculating the total amount of exchanged air in the working area of the surface treatment for the various designs of eco-technical equipment.
for the capture of VOC of hazardous substances generated during paint coating processes and the finishing of the surfaces of special wood products [3, 5, 6, 9].

Figure 4 shows the schematic proposal separators equipment in operation surface finishing of special wood products without regeneration of adsorbent using effective innovative bi-component polymeric filters - variant B [3, 8].

![Figure 4](image-url)

**Figure 4.** Schematic proposal separators equipment in operation surface finishing of special wood products without regeneration of adsorbent using effective innovative filters - variant B [3, 8] 1-heat exchanger (recuperator) 2–injection fan, 3- evacuate fan I, 4 - jalousie, 5– exhaust pipe I, 6–innovative porous bicomponent filters, 7–work table, 8–active box with GAC, 9–exhaust pipe II, 10–deployed tank, 11- sheet metal

An important element of the proposed eco-technical separation devices are filters for the capture of aerosol particles of VOC forming during the application of individual layers of coatings in the process of surface treatment of wood materials. It also occurs in the technological processes and in the fine-grinding operations of the individual layers of painted films on the surfaces of the wood products, so it is necessary to remove solid particulate matter (particle size about 10 μm) to achieve high quality coatings and achieve a separation below 5 mg.m-3 [3, 9].

Textile filters are especially used for dust separation systems on the partition, but using for capture of risk substances (VOC). The quality of the filtration partition essentially influences the filtration efficiency, in particular the filtration separation, as well as operating care, pressure loss, wear and thus the life of the filter pad including the filtration operation economy [1, 6, 7, 9].

Separation of textile filters typically reaches 99.9%, top quality filters reach 99.99% separability, making them the most efficient mechanical dust separators. The very development in the use of new types of synthetic materials allows for high separation even under demanding operating conditions at lower economic costs compared to, for example, with glass, respectively PTFE filters [3, 9].
The main research task at present is to design and prepare multifunctional filters that can efficiently capture not only dusty aerosol particles but also hazardous substances - VOC pollutants [4]. For this reason, our work, which follows on from our previous research activities [1, 3, 5, 6, 7] deals with the subject matter and implements the acquired knowledge from the field of development of special bi-component polymer fibre composite materials also in the design of eco-technical equipment for conditions of small operations of surface treatment of special wood products. Designed by us and experimentally prepared filter fibre materials should ensure separation of aerosols of solid pollutants and hazardous substances (VOC) up to 3 mg.m\(^{-3}\) of exhausted air from operations of surface treatment of special wood products, which represents higher than 99.99% separation.

The study of the preparation of bi-component fibres, as well as the evaluation of morphological structure, rheological characteristics and utility properties, were devoted to our research work [1, 3, 5, 6, 7]. We used the separation of mixed fibre components not only for the evaluation of the phase structure but also for the preparation of polyamides 6 modified. Since microfibers based materials are used not only as filter materials but also for sound-insulating purposes, we considered the assessment of the specific surface of the surface formations as a priority qualitative criterion for their industrial application [7, 11, 12].

Using a mercury porosimetry method based on mercury overpressure in the pooled material we evaluated the specific surface area and the pore distribution in a constant volume of fibres. We compared the sample prepared from blended bi-component fibres PP/PA\(_{60/40}\) with sample of polyamide microfibers obtained by extraction of blended fibres, a standard of comparison was a sample of unmodified polypropylene [3, 6 7]. From the pore distribution curves for individual evaluated fibers - experimentally prepared microfibers and commercially produced synthetic fibers, specific surface values were calculated, the results reported are shown in Table 1.

| Sample       | Specific surface of fibres (m\(^2\)/g) |
|--------------|----------------------------------------|
| PP\(^a\)     | 4.68                                   |
| PA6\(^a\)    | 3.98                                   |
| PP/PA6 60/40 \(^b\) | 4.91                                   |
| microfibres\(^b\) | 30.91                                  |

\(^a\)commercially produced fibers, \(^b\)experimentally prepared

From the results in Tab. 1, it is clear that in pure polypropylene as well as mixed bicomponent fibers there are pores in a relatively narrow distribution practically up to 50 nm. Pores originated as a manifestation of structural defects in the surface of the fiber. This is also related to the low specific surface area of 4.91 m\(^2\)/g. The specific surface value is 30.91 m\(^2\)/g and represents about 6.6 times the specific surface area of the mixed and homopolymeric polypropylene fiber. It is clear from this that separated microfibers are an innovative separating material for the preparation of effective filters, the separation of dust aerosols and hazardous chemicals - VOC.

In our research, we designed and evaluated the effectiveness of the capture of individual ecotechnical equipment for different variants of solvent-based and water-dilutable coatings after the design of 2 complete variants of eco-technical devices for efficient trapping of harmful chemicals VOC for small operations of surface treatments of special wood products. The table 2 shows assessment of investment costs, the average efficiency capture of VOC and estimate VOC emission capture from coatings for proposed variants of eco-technological equipment for small surface treatment of special wood products.
Table 2. Assessment of investment costs, the average efficiency capture of VOC and estimate VOC emission capture from coatings for proposed variants of eco-technological equipment for small surface treatment of special wood products

| Sample  | The average efficiency capture of VOC (%)<sup>1</sup> | Estimate of VOC emissions capture from coatings (kg/year)<sup>2</sup> | Investment Cost (EUR) |
|---------|--------------------------------------------------|-------------------------------------------------|-----------------------|
| Variant A | 92.0 | 591.4 | 38.900 |
|          | II.b** | 421.3 |          |
| Variant B | 99.99 | 1218.7 | 44.800 |
|          | II.b** | 756.4 |          |

<sup>1</sup> – the average VOC emission capture efficiency was calculated from the measurement quantitative VOC content in the inlet and outgoing flow of circulating air in the wood treatment technological equipment

<sup>2</sup> – estimate of VOC emission capture from coatings were calculated from the average annual consumption of coatings and fugitive emissions

I.a* – solvent based coatings

II.b** – water diluent coatings

From the data presented, it is obvious that variant B - with the application of the inventive and experimentally prepared innovative filters in the form of fibrous porous polymeric fibrous materials showed a higher efficiency compared to variant A - without the use of filters with GAC application only. Even with another evaluated characteristic - the VOC capture estimation, Variant B showed better separation efficiency compared to Variant A. The investment costs of the B variant are higher, but given the previous environmental characteristics of the proposed eco-technical devices, this variant is suggested as optimal.

4. Conclusions

In our research work we have proposed a variety of eco-technical separation devices: using adsorption technologies (with or without) regeneration of adsorbent for effective capturing of VOC pollutant emissions. Our research has been comparing the effectiveness of capture of pollutants (VOC) in small scale model plant surface treatments of special wood products.

In the experimental part of our contribution, our research activities focused on the design, preparation and subsequent application of mixed bi-component microfiber as an innovative and perspective filter materials based on our previous published work [1, 3, 5, 6, 7].

It is clear from the results of mercury porosimetry [5, 6] that microfibers with a significant increase in their specific surface due to the conditioned conditions of their preparation in the spinning process are progressive material compared to conventional synthetic fibres used in the manufacture of filters and can be assumed to have high separation efficiency as well excellent resistance to the demanding operating conditions of eco-technical equipment installed in small surface treatment operations.

From the comparison of the proposed eco-technical equipment, it is clear that the innovative bi-component fibres filtering materials have shown a quantitatively larger capture of the VOC volume in surface treatment processes of special wood products and with an efficiency of 99.99% being an environmentally acceptable method of capturing hazardous VOCs in surface treatment comparison with the classical adsorptive technological methods of separating these pollutants.

Acknowledgment

The article was created for financial support and as a result of the solution of the internal grant project No. 8110IGS201818 "Creating professional studies as a tool for innovation and development of pedagogical activities" at the The Institute of Technology and Business in České Budějovice, Czech Republic.
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