Study of the possibility of using a sorption mesh to clean the air from formaldehyde

E A Zemtsova[1], and *E A* Gornostaeva[1*]

[1]Vyatka State University, 36, Moskovskaya St., Kirov, 610000, Russia

Abstract. The paper considered the possibility of purifying air from formaldehyde by using a carbon sorbent (powder activated carbon) applied in the form of a spray on polymeric mesh. It was shown that the adsorption capacity of the system was 0.69±0.01 cm^3/g, and the degree of regeneration of the sorption material reached 37 %, which indicates about of promising this method.

1 Introduction

At present, the level of atmospheric pollution, namely, the surface air layer of most Russian cities often exceeds permissible sanitary and hygienic standards. The most dangerous and polluting substances in the atmosphere are exhaust gases from automobile transport and emissions from thermal power plants, and they account for more than half of all harmful emissions. They contain highly toxic and mutagenic substances in their composition [1-3].

The development of the industrial sector of the economy of cities, their urbanization, leads to the fact that almost 80 % of the population spends most of their lives indoors [4]. Tendencies to remote format of work of office employees, increase of use of remote technologies also contribute to increase of time spent in enclosed spaces. At the same time, indoor concentrations of pollutants can be significantly higher than in the atmospheric air, which can cause the development of various diseases. According to the WHO, more than half of all deaths caused by air pollution are attributable to indoor air pollution. More detailed study of the effect of pollutants on humans, knowledge of the course and development of diseases, has shown that indoor air pollution can cause the growth of respiratory, cardiovascular diseases, lead to the appearance of cancer [5].

But high concentrations of pollutants in indoor air can be associated not only with direct sources of emissions (automobile transport, industrial facilities, thermal power plants), but also with indirect, such as building materials, furniture, household appliances, etc. Researches of last years show that among organic pollutants of premises representatives of the simplest hydrocarbons of aromatic series (benzene, toluene, xylenes), terpenes (limonene, pinene) and carbonyl compounds (formaldehyde, acetaldehyde) are found [6].

Formaldehyde, a gas with a pungent odor that irritates the mucous membranes of the respiratory tract and eyes. Therefore, reducing the presence of formaldehyde in the air is a promising task. Chronic exposure can affect the nervous system, including impairment of

* Corresponding author: ea_gornostaeva@vyatsu.ru

memory, concentration and sleep. In acute poisoning causes irritation of the mucous membranes of the eyes, runny nose and dry throat, the appearance of pain and a feeling of pressure in the chest. It also causes coughing and shortness of breath, which intensify at night [7].

There are many ways to purify exhaust gases from formaldehyde. Among them sorption purification technologies and methods of thermal and photocatalytic neutralization are the most widespread [8, 9]. At the same time, it is the sorption methods of purification of gaseous substances, due to the assumption of the content of any initial impurities in the gas (absorption) and the sufficiency of purification depth (adsorption) that are most applicable [10].

Implementation of absorption methods of cleaning from the organic component of gaseous pollutants requires the use of aqueous solutions of caustic soda, soda ash and some other agents, exhibiting basic properties and allowing to achieve a high degree of purification [7].

Such adsorbents as activated carbon, natural and synthetic zeolites, porous glasses, natural clay materials [9] and other types of natural sorbents, including those of plant origin (plant biomass, etc.) exhibit relatively high sorption capacity with respect to formaldehyde vapor [11].

There are also more specific approaches to reduce the concentration of formaldehyde in exhaust gas emissions into the atmosphere. In particular, the method of redox enzymatic oxidation with the use of plant juices is used, which effectively reduces the concentration of pollutants, especially those of organic nature, in the atmospheric air [12].

Almost all of the above-mentioned approaches are implemented for indoor air purification. At the same time, the cleaning elements are integrated either in ventilation systems [13] or in window openings [9] or in portable portable devices, which are widely available on the market.

One of these methods is sorption. Thus, for adsorption of formaldehyde vapor, nanaporous aluminosilicate sorbents of various structures are used [14]. There is a method of air purification that involves passing air through a biologically active adsorbent, as which a mixture of zeolite with ammonia-containing sawdust is used [15]. Sorption materials based on high silica zeolite are known, which also showed a high degree of purification from formaldehyde [16]. In our case, for local purification of atmospheric air from formaldehyde it was proposed to use sorption nets (mosquito nets for windows), covered with carbon sorbent. Activated carbon is a highly porous hydrophobic sorbent with a contact surface area reaching 1500 m^2/g [17]. It detains alcohols better than water in itself due to its molecular polarizability. The use of this material is promising because it is not toxic, not poisonous, it can be repeatedly regenerated [18].

2 Materials and methods

A window mosquito net with a standard cell side of 1.2×1.2 mm was used for the experiments. To fix the sorbent - powder activated carbon of OU-A brand - to the mesh, a polymeric adhesive base based on polyurethanes mixed with toluene was used. The use of the adhesive component of the composition based on polyurethanes is justified by their good adhesive properties, high wear resistance, frost resistance and low water absorption. The ratio of glue to solvent was 1:5. A sorbent was added to the adhesive base in a 1:3 ratio, after which the resulting composition was transferred to a sprayer. Application of the mixture to the surface of the mesh was carried out by aerosol spraying with a trigger sprayer. The mixture was sprayed on the mosquito net in one layer on one side.

For evaluate the effectiveness of the proposed solution the method of determining the adsorption capacity of the sorbent in static conditions by condensed formaldehyde vapor

[17] was used. The method is based on determining the value of total saturation of the sorbent by adsorbate vapor under standard test conditions (at 23±4 °C). For this purpose, 200 ml of technical formalin of FM brand was poured on the bottom of a 2-liter desiccator (liquid level should be 10 mm lower than the used support), and a porcelain support was put on it to fix a grid. Exposure time was 18 h. At the end of the experiment, the efficiency of formaldehyde adsorption was determined by the change in the mass of the grid. The adsorption capacity was calculated by the formula 1:

$$A=m/(M\cdot d), \tag{1}$$

Where *m* - the mass of adsorbate absorbed, g; *M* - mass of dry sample, g; *d* - density of adsorbate, g/cm^3 (for formaldehyde = 1.08 g/cm^3).

Desorption of formaldehyde vapors (D, %) after the end of the experiment was also evaluated. For this purpose, the change in mass of samples after 30 minutes of contaminated mesh samples exposure under normal conditions was determined.

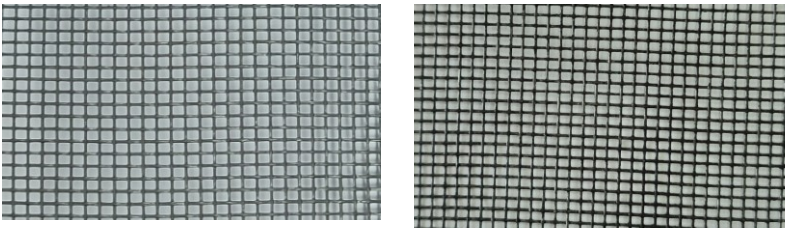
After that, regeneration of the sorption material was carried out. For desorption of impurities the adsorbent can be heated, evacuated, purged with an inert gas, displacing impurities with a more easily adsorbed substance, for example, water vapor [19].

For this purpose, after determining the adsorption capacity, the samples were treated with water steam for 20 minutes. Steam cleaning in this work was performed in a water bath, with samples of the contaminated mesh placed at a distance of 10 cm from the surface of the boiling water mirror. Steam cleaning was carried out in a water bath. The degree of adsorbate extraction was determined as the ratio of the difference in mass of the samples before the experiment and after the treatment to the initial mass of the adsorbate vapor absorbed.

3 Results

It was found that the aerosol spraying method fixed an average of 2.78 ±0.67 g of activated carbon per 1 m^2 of the mosquito net.

With this method of application it is not possible to achieve a uniform distribution of the sorbent on all the available surface of the mosquito net (Figure 1).



a b

Fig. 1. Samples of the mosquito net: a - without sorbent, b - with sorbent.

The results of determining the sorption capacity are presented in Table 1.

Sorption refers to a reversible process in which the substance absorbed by the sorbent can be transferred back into the environment. The rate of the desorption process depends on the concentration of the substance in the atmospheric air and on the surface of the sorbent.

Table 2 shows the results of determining the degree of formaldehyde extraction from the sorption mesh using water vapor.

Table 1. Determination of the adsorption capacity of the sorption mesh.

Experience number	Adsorption system	m, g	M, g	A, cm^3/g	D, %
1	Sorption mesh	0.1596	0.2309	0.85	1.70
2		0.1347	0.2568	0.64	0.65
3		0.0958	0.1589	0.74	1.71
4		0.0550	0.1307	0.52	0.32
5		0.0889	0.1581	0.69	1.70
6		0.0805	0.1702	0.58	1.72
7		0.0978	0.1464	0.82	2.51
8	Mesh without adhesives and sorbent	0	0	0	0
9	Mesh with adhesive and without sorbent	0.0215	0.0571	0.46	0.02

Table 2. Extraction of formaldehyde from the sorption mesh using water vapor.

Experience number	Weight of the polluted sample, g	Weight of the sample after water vapor cleaning, g	Weight difference of samples, g	Mass of adsorbed formaldehyde in the contaminated sample, g	Degree of formaldehyde extraction from the sorbent, %
1	4.8411	4.8094	0.0317	0.1568	20.21
2	4.3964	4.2889	0.0402	0.1075	37.40
3	4.6224	4.6166	0.0058	0.0182	31.87
4	4.7184	4.7012	0.0172	0.0548	31.40
5	4.7775	4.7464	0.0311	0.0874	35.56
6	4.5772	4.5567	0.0205	0.0791	25.92
7	4.6393	4.6215	0.0178	0.0953	18.62

4 Discussion

The obtained data show that mosquito nets with activated carbon on them effectively absorb formaldehyde vapors. On average, the value of adsorption capacity of such a system is 0.69±0.01 cm^3/g, which agrees with the typical indicators of the sorption capacity of activated carbons in relation to gaseous pollutants [20]. It should be noted that the adhesive backing is also able to retain a small number of vapors, while partially reducing the sorption capacity of the coal itself. This is due to a decrease in the size of the active surface of the sorbent.

The change in formaldehyde concentration in the tests of the mesh without sorbent material, but with adhesive applied to its surface, is probably due to the curing process of the polyurethane base [21].

It was found that the degree of hot-steam cleaning of the sorption nets averaged 29 %, which is somewhat lower than possible for this method. The low percentage of regeneration is explained by the complexity of desorption from meso- and micropores of coals [4].The low percentage of regeneration is explained by the complexity of desorption from meso- and micropores of coals [13]. This indicates a low regeneration potential of the sorption grid and low efficiency of hot-steam cleaning.

5 Conclusion

Increased content of pollutants in the indoor air, which is a consequence not only of emissions into the atmosphere of combustion products and industrial enterprises, but also emitted by household items, affects the comfort of stay in them, and, of course, their state of health. In view of the increase in the time people spend in enclosed spaces, the issue of improving indoor air quality is acute.

Based on the results obtained, it is clear that the proposed alternative solution for local purification of atmospheric air in urban areas with the use of sorption nets, which can be built into window frames, filters, ventilation ducts, is a fairly promising direction, due to its simplicity, ease of operation, the possibility of regeneration and low cost.

References

1. A.M. Surovov, A.G. Bubnov, Modern High Technologies, Regional Application, **2**, 87-94 (2012)
2. K.I. Trifonov, A.V. Kuznetsova, S.V. Afanasyev, O. S. Roschenko, Izvestia of Samara Scientific Center of the Russian Academy of Sciences, **1**, **16**, 1862-1865 (2014)
3. I.S. Khalikov, Ecological Chemistry, **6**, **28**, 307-317 (2019)
4. N.H. Baymatova, Development of technologies for cleaning air and industrial emissions using carbon-containing adsorbents PhD Thesis (Al-Farabi Kazakh University, Almaty, 2016)
5. World Health Organization, Air pollution, https://www.who.int/
6. D.A. Sarigiannis, S.P. Karakitsios, A. Gotti, I.L. Liakos, A.Katsoyiannis, Environment International, **4**, **37**, 743-765 (2011)
7. N.B. Lazarev, Harmful Substances in Industry, Organic Substances (Khimiya, Leningrad, 1976)
8. S. Tu, Y. Chen, X. Zhang, J. Yao, Y. Wu, H. Wu, J. Zhang, J. Wang, B. Mu, Z. Li, Q. Xia, Applied Catalysis A: General, **611** (2021)
9. M.M. Shebedya, K.S. Chumarova, Photocatalytic method of air purification, in Proceedings of the International Youth Scientific Conference "XXIV TUPOLEV SCIENCE (School of Young Scientists)", Volume III, Kazan, Russia (2019)
10. B.J. Safarov, S.B. Usmonov, A.R. Khafizov, B.N. Sirozhov, Technical Sciences, **11**, 5-11 (2022)
11. N.A. Khodosova, Reduction of formaldehyde concentration in the environment by aluminosilicate sorbents PhD Thesis (Ivanovo, 2009)
12. O.A. Zhigalsky, V.O. Skapkareva, Modern Science-Intensive Technologies, **12**, **2**, 199-203 (2014)
13. N.A. Litvinova, V.N. Azarov, Scientific Journal of Construction and Architecture, **65**, 55-68 (2022)
14. L.I. Belchinskaya, N.A. Khodosova, L.A. Bityutskaya, Protection of Metals and Physical Chemistry of Surfaces, **2**, **45**, 218-221 (2009)
15. Scientific Electronic Library, Method to Purify Air of Harmful Substances, https://www.elibrary.ru/item.asp?id=37694261 (2010)
16. A.S. Panasyugin, V.A. Lomonosov, O.L. Smorygo, Litiyo and Metallurgiya, **2**,**75**, 19-25 (2014)
17. N.V. Keltsev, Fundamentals of Adsorption Technology (Khimiya, Moscow, 1984)

18. M.M. Dubinin, Porous Structure and Adsorption Properties of Active (Khimiya, Moscow, 1965)
19. V.L. Bokov, A.V. Lushchik, Fundamentals of Environmental Safety (Sonat, Simferopol, 1998)
20. Technical Bulletin Choosing an Adsorption System for VOC: Carbon, Zeolite or Polymers? (U.S. Environmental Protection Agency, North Carolina, 1999)
21. K.N. Aleksandrov, K.I. Freudheim, V.I. Alekseenko, V.A. Mikhailov, Polyurethanes in the production of artificial materials for clothing and footwear (Light Industry, Moscow, 1977)