

PROTECTION OF URBAN ATMOSPHERE FROM MOTOR VEHICLES EXHAUST GASES

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Summary: The article is devoted to a topical issue of modern cities concerning clearing of the outdoor air from harmful components of motor vehicles exhaust gases and other sources of air pollution in the most polluted areas of city transport arteries. Technical solutions based on the use of cheap and readily available adsorbent, which reduce the concentration of harmful components in outdoor air by means of installing fixed and mobile street air-conditioners in the places with urban motor-vehicle transport congestions are considered.

Keywords: atmosphere, purification, ecology, exhaust gases

1. INTRODUCTION

In large cities the share of motor-vehicle transport polluting emissions ranges from 70% to 90% of total emissions into the atmosphere (the remaining emissions fall to the share of thermal power plants, boiler stations etc.). Depending on weather conditions, geographic position, the number of motor vehicles, and other factors affecting the atmosphere situations when the concentration of harmful components of exhaust gases in urban atmosphere exceeds health standards in tens and hundreds of times occur in many cities and metropolitan areas. As a result, the composition of the air in large cities and megalopolises contains a significant number of detrimental impurities that cause serious diseases of city dwellers. The exhaust gases of automobile engines contain more than 200

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substances, most of which are toxic. The main components of vehicle exhaust gases are nitrogen (N_2), oxygen (O_2), water vapour (H_2O), carbon oxides (CO_2 and CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), polycyclic (surface-active substances), hydrocarbons, aldehydes, soot, benzopyrene, ozone, etc. However, despite the prohibition of leaded gasoline use, lead content in urban air is quite high. Moreover, exhaust gases, especially from diesel engines, give unpleasant smell to the outdoor air. The role of road transport in the air pollution is caused not only by the quantity of emissions, but also by the fact that the exhaust gases are emitted directly into the surface layer of the atmosphere, where the wind speed is insignificant and gases disperse poorly in contrast to the industrial enterprises and power plants emissions delivered through high chimney stacks. In addition, the bulk of the exhaust pollutants are heavy gases with the specific gravity more than the one of the air that causes them to accumulate in the lower layers of the atmosphere, namely at the level of cars and pedestrians [1, p. 86-90, p. 155]. Along with a high content of harmful components of automobile exhaust gases street air also contains a significant amount of harmful gaseous and suspended particles, presence of which is due to the activities of urban life support systems and industrial enterprises work. An important factor affecting the life and health of urban population (especially in metropolises) is aeroionic state of urban air. It is known that the comfortable state of air environment is determined not only by its temperature, humidity, fluidity and cleanliness, but also by the concentration and composition of aeroions (ionic concentration). Air quality is characterized by the concentration of light aeroions. So, in mountain and resort areas the concentration of light aeroions is up to 2500/cm³, whereas in big cities it does not exceed 200-300/cm³ [2, p. 68-73]. Protection of the ecological state of urban atmosphere is a complex of organizational and technological measures. However, these measures do not include clearing of the outdoor air in the places with the high congestion of motor vehicles. A significant obstacle that does not allow carrying out large-scale activities aimed at the purification of outdoor air from harmful components of exhaust gases is that there are no cheap and available reagents for their implementation.

For the implementation of the measures aimed at the purification of outdoor air from harmful components this paper proposes technical solutions based on the use of granulated blast furnace slags as an adsorbent of harmful components [3]-[5]. For the implementation of these solutions the designs of street air-conditioners for above-ground and underground (fixed and mobile) location have been developed. Granulated blast furnace slag (metallurgical pumice) is a fine-grained material in the form of porous, vitreous or crystalline granules with an average size of 2-8 mm. Slag density depending on its composition is 2.8-3.0 g/cm³, hardness of the grains is 5-8 kg/cm². The chemical composition of the slag, depending on the composition of the original ore and the type of the produced iron, ranges widely; it may contain 30-49% of CaO; 4,5-20% of Al₂O₃; 33-44% of SiO₂; 0.3-0.8% of Fe₂O₃; 1.5-15% of MgO; 0.3-3.0% of MnO [6].

The main characteristics of blast furnace slag are porosity, basicity factor, hydraulic properties, and activity.

The porosity of blast furnace slag P was determined by the formula (1):

$$P = \left(1 - \frac{\rho_v}{\rho_t}\right) \times 100\% \quad (1)$$

where ρ_v is the true specific gravity of the slag, kg/m³;
 ρ_f is the apparent specific gravity of the porous sample, kg/m³;

$$\rho_v = \frac{m}{V} \tag{2}$$

m is the mass of the sample with pores, kg;
 V is the volume of the sample with pores, m³.

The sample volume was determined by measuring [7]. We obtained that the average porosity of the slag used was 60%. The pore size ranged from 1.0mm to 0.1mm, which corresponds to macropores.

Slag basicity factor is the characteristic of the activity of metallurgical slags and their stability during lime dissolution. It is determined as the ratio of the content of basic oxides in the slag to the content of acidic ones. When $B_f < 1$, the slags are considered to be acidic and are not affected by lime dissolution; when $B_f > 1$, the slags are considered to be basic and are prone to lime dissolution. The basicity factor was determined by the formula (3):

$$M_0 = \frac{CaO + MgO}{SiO_2 + Al_2O_3} \tag{3}$$

Since harmful impurities (SO_x, CO_x, NO_x) have acidic properties in exhaust gases, blast furnace slag with basicity factor $B_f > 1$ should be used in the process of their purification. The hydraulic properties of blast furnace slag are measured using quality factor (Q), which is determined by the formula (4, 5):

when the content of magnesium oxide is less than 10%:

$$Q = \frac{CaO + Al_2O_3 + MgO}{SiO_2 + TiO_2} \tag{4}$$

when the content of magnesium oxide is more than 10%:

$$Q = \frac{CaO + Al_2O_3 + 10}{SiO_2 + TiO_2 + (MgO - 10)} \tag{5}$$

Table 1 Grades of Blast Furnace Slag

Factor	Grade Standard		
	1	2	3
Quality factor, not less than	1.65	1.45	1.20
The content of aluminium oxide (Al ₂ O ₃), %, not less than	8.0	7.5	No limitation
The content of magnesium oxide (MgO), %, not more than	15.0	15.0	15.0
The content of titanium dioxide (TiO ₂), %, not more than	4.0	4.0	4.0
The content of manganese (II) oxide (MnO), %, not more than	2.0	3.0	4.0

where Q is the quality factor; CaO , Al_2O_3 , MgO , SiO_2 , TiO_2 are the contents of the oxides in the blast furnace slag in % on weight basis.

The activity of slag (the averaged value of the compressive strength of the hardened samples from fine-grained slag and water at 28 days) is $7 \text{ kgf} / \text{cm}^2$.

Depending on the quality factor and the chemical composition blast furnace slags are divided into three grades (classes) (Table 1) [8]:

Blast furnace slag of the 1st grade produced by Novolipetsk Steel (NLMK Group, Russia) was used for the experiment. Some of its characteristics were specified directly while preparing the experiment. The experimental results for the adsorption of nitrogen oxides (NO_x), carbon oxides (CO_2 and CO) from the flue gases of heat generators show that the degree of purification for nitrogen oxides reaches 50-55%; for carbon dioxide it is 20-25%; for carbon monoxide it is 15-20%. The experiments on the purification of exhaust gases of the internal combustion engine (with the same flow rate of exhaust gases and with the increased amount of the adsorbent) show similar results for the degree of purification for nitrogen oxides and carbon oxides, but for sulfur oxides (SO_x) the degree of purification is 55-60%. The obvious advantages of blast furnace slag (metallurgical pumice) over other known adsorbents are:

- 1) the content of basic oxides (CaO , MgO , FeO) in blast furnace slag and the presence of acidic oxides (CO , CO_2 , NO_x) in exhaust gases, which contribute to active processes of chemisorption;

- 2) no of by-products of the reaction during effective lifetime of the adsorbent;

- 3) blast furnace slag sanitary safety resulting from the technology of granulated blast furnace slag manufacturing (iron smelting is carried out at high temperatures);

- 4) longevity due to high mechanical strength; no cracking and dust formation;

- 5) simple technology of use and substitution of spent adsorbent for fresh;

- 6) low market price of the blast furnace slag compared to other adsorbents

(the average price of 1t of granulated slag is 650 rubles (about \$11.6); the average price of 1t of activated carbon is 70,000 rubles (about \$1, 241.5). Characteristic features of the composition of the outdoor air in which ozone is found alongside with harmful components of exhaust gases of motor vehicles and also high solubility of carbon dioxide in water in comparison with the other components of air are used in the proposed technical solutions. This ensures a high rate of the reaction of oxidation of CO to CO_2 , NO to NO_2 , and SO_2 to SO_3 in the presence of ozone, which then dissolve readily in water to form HNO_3 and H_2SO_4 [9, p. 316, 275], [6, p. 348]. Thus, in view of the well-developed porous structure and a high value of basicity factor, which give metallurgical pumice its basic properties [10, p. 423], [11, p. 163], adsorption of substances having acidic properties, including harmful components of exhaust gases of motor vehicles (NO_x , SO_x , CO_x) takes place on the surface of its granules. The principle of the operation of the proposed outdoor air-conditioners can be seen in Fig. 1 where an example of a mobile street air-conditioner is given. The purification of the outdoor air from harmful components of exhaust gases of motor vehicles and dust goes as follows. At first, mobile street air-conditioner (MSC) is carried on a truck chassis, or on a trailer (movable platform 24), placed at the edge of the traffic way and the pedestrian area of the busiest streets in such a way that the inlet 10 was turned towards the traffic way, and the outlet 13 was turned towards the pedestrian area; MSC should be connected to all communications (electricity, water supply and

sewer system). MSC may be used being on the movable platform 24 or may be taken from the platform 24, and installed on a special support (not shown in Fig. 1). MSC can be almost completely autonomous: power supply for fans and a pump can be provided by automobile electric generator and water can be brought in water lorries. In this case, only connection to the sewer system (through storm sewer system 25 or sewer manhole) should be provided. Outdoor air is sucked by the forced draft fan 12 through the grille 11 and the inlet pipe 10 into the air washer 8 where its indraft velocity drops rapidly; then the air moves upwards and, in cross-flow along the whole height of the air washer 8 it contacts with the particles of water coming from the nozzles of the spraying device 18, where it is humidified and partially cooled. The water, the amount of which is determined by the specified amount of absorbed harmful components from the outdoor air and its moisture content, is fed to the spraying device 18 by the feed pump 23 through the branch pipe 4 and delivery pipe line 17 with the open feedwater valve and closed flushing valve (these valves are not shown in Fig. 1).

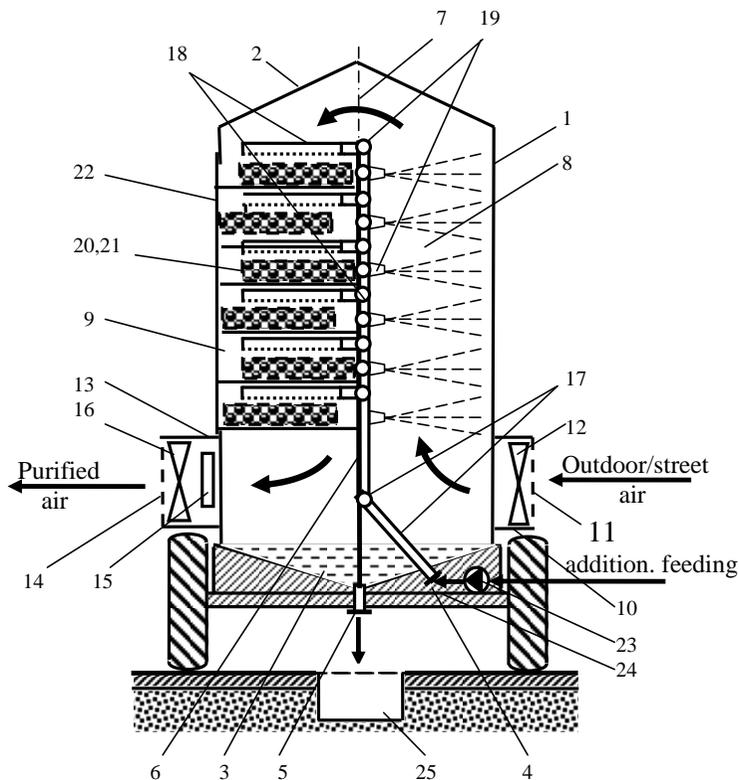


Figure 1. Mobile street air-conditioner: 1 – casing; 2 – roof; 3 – pot; 4,5 – branch pipes; 6 – skimming baffle; 7 – port; 8 – air washer; 9 – purifying compartment; 10 – inlet pipe; 11 – grille; 12 – forced draft fan; 13 – outlet pipe; 14 – grille; 15 – air ionizer; 16 – induced draft fan; 17 – delivery pipe line; 18 – spraying device; 19 – washing device; 20 – detachable perforated basket; 21 – metallurgical pumice granules; 22 – vertical door; 23 – feed pump; 24 – movable platform; 25 – storm sewer system.

At the same time with the above described process, in the air washer 8 water captures dust and soot particles and interfacial contact of spray water and air occurs; these result in the absorption of carbon dioxide (CO_2) by water, chemical interaction between nitrogen oxides (NO_x), sulfur oxides (SO_x), ozone (O_3), oxygen (O_2), water (H_2O) in gas and liquid phases, chemisorption of resulting nitrogen dioxide (NO_2) and sulfur trioxide (SO_3) with water to form nitric (HNO_3) and sulfuric (H_2SO_4) acids. The resulting acidified water saturated with carbon dioxide and mechanical impurities flows into the pot 3 and then together with the dirt through the branch pipe 5 into the storm sewer system 25; after that the mixture of fresh and acidified water is again fed by the feed pump 23 through the branch pipe 4 to the air washer 8. Purified from carbon dioxide and from some portion of oxides of nitrogen and sulfur, dust and soot, humidified and partially cooled outdoor air with acidified water particles goes from the air washer 8 through the port 7 to the purifying compartment 9; then it goes downwards through the detachable perforated baskets 20 filled with the pumice granules 21 made of basic metallurgical slags, the diameters of granules range from 20 mm to 40 mm (the diameter of the granules 21 was specified according to the conditions of providing the minimum aerodynamic drag of the purifying compartment 9 and the standard list of granule sizes for metallurgical pumice). Adsorbed from outside air oxides of nitrogen and sulfur have high reactivity in the pores of the granules 21 due to their interaction with the surface of the adsorbent i.e. the surface of slag pumice granules [10, p. 298], and, therefore, they oxidize with oxygen at a rate greater than during the gas phase with the formation of NO_2 and SO_3 which are easily soluble in water; NO_2 and SO_3 , in turn, react with the acidified water particles remaining in the pores of the granules 21 to form the corresponding acids HNO_3 and H_2SO_4 . In addition, fine particles (dust, soot etc.) settle on the surface and in the pores of the granules 21; as a result, purified and dried air when passing through the air ionizer 15 is enriched with light air ions and with the help of the induced draft fan 16 is fed through the outlet 13 and distribution grille 14 to the pedestrian side of the street.

When the pumice granules 21 in the perforated baskets 20 lose their activity they are subjected to regeneration directly in the air conditioner, which is carried out when the vehicular flow is the lowest (for example, at night). The process of regeneration includes washing the granules 21 from dust, soot and acidified water containing carbon, sulfur and nitrogen oxides. Washing is carried out by supplying feed water through the washing device 19 into the purifying compartment 9. The amount of wash water and washing time is set up by test. Pumice granules 21 are completely replaced once per season.

As a source of water supplied to the air washer 8 to absorb carbon dioxide in large amounts, it is possible to use water from groundwater pumping stations for underground railway (providing that it does not contain harmful impurities) or water brought in water lorries; acidified water discharged through the branch pipe 5 into wastewater disposal system, due to the high content of carbon dioxide will facilitate the process of photosynthesis [12, p. 210] on the irrigation fields of municipal wastewater treatment plants.

The height of the street air conditioner is determined by the area of maximum air pollution of the outdoor air and the allowable dimensions of cargoes transported by motor vehicles; the height mark of the inlet 10 and the outlet 13 pipes is at the height of the working zone of a standing person taking into account the angle of the expansion of the air current flowing from the distribution grille 14. The square of cross-section area, the number and capacity size of the perforated baskets 20, the porosity, size and number of the pumice

granules 21, the capacity and performance of the fans 12 and 16, the ionizer 15, the feed pump 23, the capacity size of the pot 3, the absorbing capacity of the purifying compartment 9, the amount of water for spraying in the air washer 8 and for the recirculation are determined by air capacity, air pollution and the required degree of its purification. It is recommended to produce street air-conditioner in the form of standard sections (Fig. 1 shows one section of a street air-conditioner), each of which can operate independently, which makes it possible to increase or decrease the performance of the entire system, depending on the environmental situation in the street.

Thus, the proposed mobile street air-conditioner makes it possible to purify outdoor air from harmful components of exhaust gases of motor-vehicle transport without using expensive and hazardous chemicals, to automate the processes of spraying and washing, and to move the air-conditioner quickly to the most polluted places.

2. CONCLUSION

1. A cheap and affordable type of adsorbent – granulated blast furnace slag (metallurgical pumice) is proposed to carry out the purification of urban outdoor air from harmful components of exhaust gases of motor vehicles.

2. The main physical characteristics of granulated blast furnace slags and the experimental data on their absorbing capacity for harmful components (nitrogen oxides, sulfur oxides, carbon oxides) of exhaust gases of motor vehicles are presented.

3. Engineering solutions (designs of fixed located on the ground, underground street air-conditioners, mobile street air-conditioners) for the implementation of the processes of the purification of urban outdoor air from the exhaust gases of motor vehicles are proposed.

4. The proposed design of street air-conditioners makes it possible to purify outdoor air from harmful components of exhaust gases of motor-vehicle transport without using expensive and hazardous chemicals, to improve its quality by increasing the content of light aeroions in it and to dispose removed harmful components.

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