INTERNATIONAL JOURNAL OF OCCUPATIONAL
SAFETY AND ERGONOMICS (*JOSE*) 2003, VOL. 9, NO. 3, 301–311

Adsorption Air Cleaning From Ozone

Pranas Baltrėnas
Dainius Paliulis
Saulius Vasarevičius
Ramutis Šimaitis

Vilnius Gediminas Technical University, Lithuania

Not much has been written about air cleaning from ozone. The aim of this paper was to demonstrate the possibility of adsorption air cleaning from ozone. The second aim was to investigate the dependence of the efficiency of ozone removal from the air on the height of the adsorber layer and on concentrations of ozone, and to obtain empirical formulas for calculating the efficiency of ozone treatment. Equipment for air cleaning from ozone and nitrogen and sulphur dioxides is suggested.

adsorption ozone air cleaning empirical formulas

1. INTRODUCTION

An electrostatic filter used to clean the air from liquid (oil steam) and solid (welding) aerosols and dust in premises, due to high-level cleaning, operates in a recirculation regime. This is a way to conserve heat in winter, but it causes a problem: The quantity of ozone increases. The particles of pollutants in electrostatic filters get electrified in the field of the coronal gaseous discharge. At the time of discharge, when intensive ionization breaks intermolecular bonds, free atoms of oxygen get formed for a short time. Some of them recombine directly into O_2 molecules, whereas others form ozone O_3.

Correspondence and requests for offprints should be sent to Dainius Paliulis, Environmental Protection Department, Vilnius Gediminas Technical University, Saulėtekio al. 11, 2040 Vilnius, Lithuania. E-mail: <aak@ap.vtu.lt>.

Ozone is unstable and it turns into oxygen comparatively soon. However, in the electrostatic filter, while air ionization is continuously going on, there is no time for ozone to be decomposed, and its concentration is fixed both in the place where the filter is located, and in the exit hole of the filter (Baltrėnas, Bakas, & Kaulakys, 1998). While electrostatic filters remove aerosols from the air, ozone, a very dangerous pollutant, is emitted into the environment.

Chemically, ozone is a very active substance, this meaning its rapid splitting. The greatest permissible concentration of ozone in the air is 0.1 mg/m^3. Ozone as well as ionizing radiation have a mutagenous effect. Theoretically, even the smallest quantity of ozone has this effect.

Ozone that is emitted is usually cleaned by adsorption, whereas in production premises a photochemical method is more frequently used to reduce ozone concentrations. The latter method is based on the decay of ozone due to the influence of ultraviolet rays (Sirota, Skoblikova, & Kchvorostovsky, 1990). There are some studies on the decomposition of ozone with the help of carbon fibrous materials at low temperatures, as well as on the cleaning of ozone with the help of manganese compounds and one or two compounds of alkaline and ground alkaline metals, placed on activated carbon (Rakitskaya, Bandurko, & Litvinskaya, 1993; Method of Removing Ozone, 1983).

In order to properly clean the air from pollutants in working premises, a combined method of air cleaning should be used. Combined air cleaning requires equipment for air cleaning consisting of an electrostatic filter and an adsorber. The adsorber might be used to clean the air from nitrogen oxides, whereas the electrostatic filter to clean the air from solid particles. Therefore to properly clean the air from pollutants, the adsorber, which would clean air from ozone and nitrogen oxides, must be connected to the electrostatic filter. It has been determined that the greater the current flows in the ionizer of the electrostatic filter, the larger the efficiency of cleaning the air from aerosols, but when voltage reaches 15–20 kV, considerably greater amounts of ozone are emitted.

It is very important to evaluate the influence of various factors in the adsorbing block on the efficiency of cleaning the air in it. The main factors that affect air cleaning are filtration velocity, the height of the adsorber layer, and the concentration of the adsorbate. The influence of those factors was investigated during the experiments and empirical dependences were obtained on the basis of the results of this research. This allowed us to calculate precisely the degree of the efficiency of air cleaning, taking into account the magnitude of the aforementioned factors.

In the literature there are data on the dependence of air cleaning efficiency on the height of the adsorber layer, the velocity of the air vortex, and adsorber

concentration. However, there are no mathematical expressions or empirical formulas of those dependences. Neither are there any comprehensive factors with an effect on air cleaning efficiency.

The effect of the height of the adsorber layer and adsorbate concentration on natural zeolite, silica gel, and activated carbon was investigated.

The purpose of the research was an analysis of the efficiency of adsorption air cleaning from ozone emitted from a working mobile electrostatic filter.

During the experiment the following parameters were subject to changes: ozone concentration, the height of the adsorber layer, and the velocity of the air vortex, when natural zeolite, silica gel, and activated carbon were used as adsorbents. After investigating the dependence of the efficiency of ozone removal from the air on the height of the adsorber layer and ozone concentrations, empirical formulas for calculating the efficiency of ozone treatment were proposed.

2. METHODS

During the experiment the environmental conditions were as follows: p = 739–745 mmHg (985.25–993.25 hPa), temperature T = 19–24 °C, relative air humidity D = 45–49%.

The main instruments used were as follows:

1. Thermometer, measuring range T = –20–200 °C, error 0.5 °C;
2. Psychrometer, measuring range D = 10–100%, error 10%;
3. Barometer, measuring range P = 610–790 mmHg (813.27–1053.25 hPa), error 0.8 mmHg (1.07 hPa);
4. Meter of velocity TESTO-452 (Testoterm, Germany), measuring range v = 0.4–60 m/s, error 0.4 m/s;
5. A meter of ozone concentration, an ML8810 ozone analyzer (Teledyne Monitor Labs, USA), measuring limits C = 0–1.0 ppm, error 0.001 ppm.
6. Pressure meter TESTO-452, measuring range P = 0–10 hPa, error 0.10 hPa.

The concentration was recalculated from ppm to mg/m^3 using the following formula:

$$1 \text{ ppm} = P \bullet 273 \bullet M/22.4 \bullet (T + 273) \bullet 760 \text{ mg/m}^3, \quad (1)$$

where P—atmospheric pressure (Pa); T—ambient temperature (°C); M—molar mass of the substance (g/mol).

Research was carried out with a mobile electrostatic filter (produced at the Vilnius Gediminas Technical University, Lithuania) used as a source of ozone. It was also used as experimental equipment for adsorption air cleaning. This equipment for air cleaning consisted of a metal two-part air duct with a diameter of 9.5 cm and height of 2 m. It had a cassette filled with a certain amount of the adsorbent. Air polluted with ozone came from below and ozone was adsorbed in the cassette with the adsorbent. Clean air went up and left the filter through a hole at the top.

The investigation was conducted using natural zeolite of grey or yellowish colour shaped like granules of irregular form with a diameter d = 6 mm and bulk density γ = 0.890 g/cm^3, from a zeolite-bed in Sokirnica (the Ukraine), d = 3 mm KCM grade silica gel, yellow round granules, bulk density γ = 0.831 g/cm^3. It was activated with CKT grade carbon, with granule length l = 1.5–2 mm, width b = about 0.5 mm, bulk density γ = 0.400 g/cm^3 (Russian product TY No. D2GY-937-66).

Experiments were conducted with adsorbent layers L = 3.5, 7.0, and 10.5 cm in height. Adsorbents were prepared for air cleaning with a regeneration process. Regeneration was carried out with 8-hr heating in nitrogen atmosphere. Natural zeolite was regenerated at 290–300 ºC, silica gel KCM was regenerated at 190–200 ºC, and CKT carbon was regenerated at 105–115 ºC. Adsorbents were cooled for 4 hrs in a desiccator filled with $CaCl_2$ at room temperature after the regeneration stage. Sieves with cell diameters of 5 and 7 mm were used to separate 6-mm diameter zeolite. Sieves with cell diameters of 2 and 4 mm were used to separate 3-mm diameter silica gel. Activated carbon separation was not carried out because its grains were highly homogenous.

Air stream velocity was regulated by changing the position of the hood. Average air stream velocity fluctuated up to 5%.

Ozone concentration was changed by changing the voltage of the ionizer. The voltage of the ionizer was 13 KV when ozone concentration was 0.035 mg/m^3, 15 KV when ozone concentration was 0.075 mg/m^3, and 16 KV when ozone concentration was 0.115 mg/m^3. Average ozone concentration fluctuated up to 10%.

After measuring ion concentration in front of and behind the filter the efficiency of air cleaning was calculated. Each measurement was repeated five times. Figure 1 is a schematic diagram of the experiment. The speed of airflow movement was measured at five cross-section points, repeating measurements five times according to methods described in Standard No. LAND 27-98/M-07 (Standardization Department of Lithuania, 1998). The air with ozone, generated in the ionizer (3) and drawn by a ventilator (7), came

through a mesh (4). It then went through an exit air duct (6) and passed through an adsorbent cassette (10).

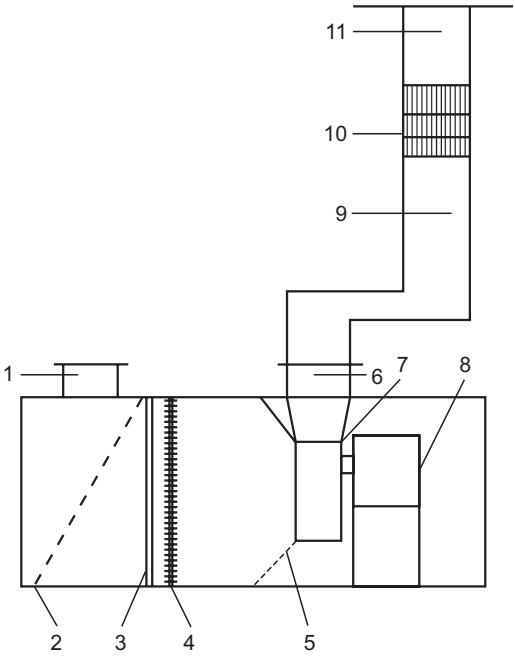

Figure 1. A schematic diagram of the experiment. *Notes.* 1—entrance air duct; 2—air flow guide; 3—ionizer; 4—mesh; 5—cylindrical casing; 6—exit air duct; 7—ventilator; 8—electric engine; 9—concentration and speed measurement point in front of the adsorbent cassette; 10—adsorbent cassette; 11—concentration and speed measurement point behind the adsorbent cassette.

Measurement of ozone concentration (C) was based on ultraviolet radiation (UV) adsorption measurements. Airflow speed was v = 1.2–2.2 m/s.

The electrostatic filter was the source of ozone. Ozone concentration was changed by changing the voltage of the ionizer. Ozone concentration was measured in ppm and recalculated into mg/m^3. The height of the adsorbent layer was changed by changing the cassette.

3. EXPERIMENT AND ANALYSIS

Removal of ozone from the air was studied by using activated carbon, silica gel, and natural zeolite as adsorbents. Figures 2–4 show the dependence of the efficiency of air cleaning from ozone on ozone concentration for silica gel, activated carbon, and zeolite.

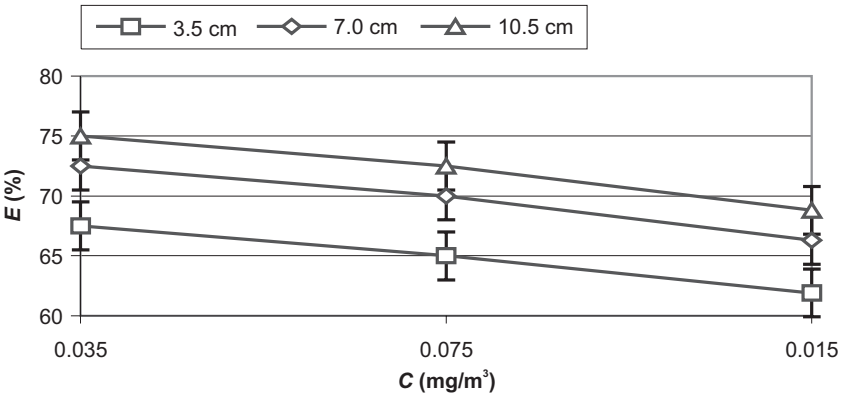

Figure 2. Dependence of the efficiency of air cleaning from ozone on ozone concentration, with natural zeolite used as the adsorbent, at different heights of the layer, v = 2.2 m/s.

Figure 2 provides the dependence of the efficiency of ozone removal from the air on ozone concentration, at different heights of the layer, with natural zeolite being used as the adsorbent. Cleaning was least efficient when zeolite was used for adsorption air cleaning from ozone. This can be explained by the fact that its granules are larger than those of the other adsorbents, whereas its own surface is the smallest. The figure shows that with the increase of ozone concentration the degree of cleaning decreased.

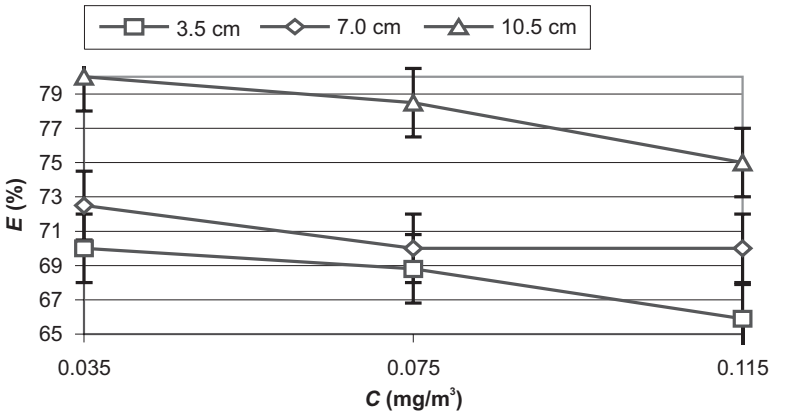

Figure 3. Dependence of the efficiency of ozone removal from the air on ozone concentration, at different heights of the layer, with silica gel used as the adsorbent, at different heights of the layer, v = 2.2 m/s.

Figure 3 provides the dependence of the efficiency of ozone removal from the air on ozone concentration, at different heights of the layer, with silica gel

used as the adsorbent. Using silica gel for adsorption air cleaning from ozone, intermediate efficiency of cleaning was obtained as opposed to the other two adsorbents. This can be explained by the fact that both the size of its granules and its own surface is of intermediate size in comparison with the other adsorbents.

The figure shows that with an increase in ozone concentration, the degree of cleaning decreased. While investigating the effect of concentration on the efficiency of ozone removal from the air, it turned out that all adsorbents clean the air better when ozone concentration is lower. If ozone concentration C = 0.035 and 0.075 mg/m^3, the efficiency of cleaning was similar, and if C = 0.115 mg/m^3, air cleaning efficiency was lower.

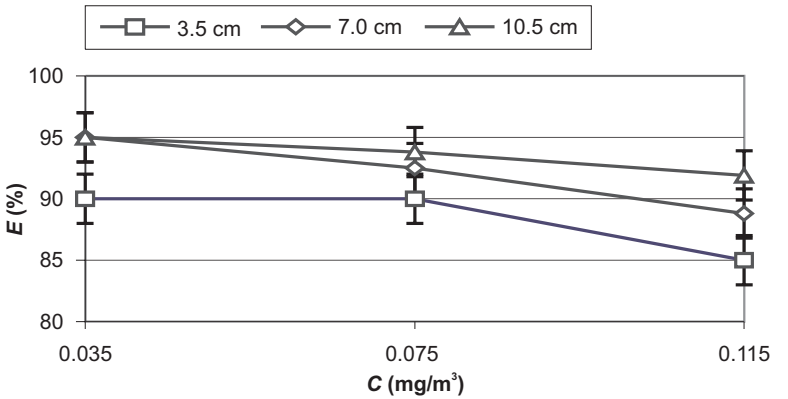

Figure 4. Dependence of the efficiency of ozone removal from the air on ozone concentration, at different heights of the layer, with activated carbon used as the adsorbent, at different heights of the layer, v = 2.2 m/s.

Figure 4 presents the dependence of the efficiency of ozone removal from the air on ozone concentration, at different heights of the layer, with activated carbon used as an adsorbent. The use of activated carbon for adsorption air cleaning from ozone provides the highest efficiency of cleaning in comparison with the other two adsorbents. This can be explained by the fact that its granules are smaller than those of the other adsorbents and in addition it has a well-developed microporous structure, which predetermines the high level of cleaning.

If silica gel was used as an adsorbent, with an increase in the height of the layer from L = 3.5 to 10.5 cm, cleaning efficiency increased from 70 to 80% (when ozone concentration was C = 0.035 mg/m^3) and from 69 to 77.5% (when ozone concentration was C = 0.075 mg/m^3), as well as from 60 to 67.6% (when ozone concentration was C = 0.115 mg/m^3).

While investigating the effect of the height of the adsorbent layer on the efficiency of cleaning from ozone, it was established that with an increase in the height of the adsorbent layer from L = 3.5 to 10.5 cm, the efficiency of cleaning increased as follows: If activated carbon was the adsorbent, the efficiency of cleaning increased from 90 to 95% (when ozone concentration was C = 0.035 mg/m^3) and from 90 to 93.5% (when ozone concentration was C = 0.075 mg/m^3), as well as from 80 to 84.5% (when ozone concentration was C = 0.115 mg/m^3). If zeolite was used as an adsorbent, with an increase in the height of the adsorbent layer from L = 3.5 to 10.5 cm, cleaning efficiency increased from 68 to 75% (when ozone concentration was C = 0.035 mg/m^3) and from 65 to 72.5% (when ozone concentration was C = 0.075 mg/m^3), as well as from 58 to 63.2% (when ozone concentration was C = 0.115 mg/m^3).

The filter cleaned most effectively when the adsorbent layer height L = 10.5 cm. This was predetermined by the fact that the time of contact between the adsorber and the air cleaned had to be longer, as it determined fuller adsorption of ozone. The aerodynamic resistance with an increase in the height of the adsorbent layer from L = 3.5 cm to 10.5 cm increased from 64 to 152 Pa.

A 10.5-cm-high adsorbent layer was used, as with an increase in the adsorbent layer, aerodynamic resistance increased. Therefore it was not reasonable to increase the height of the adsorbent layer, and it was better to change the adsorbent more frequently and to regenerate it.

Research was carried out to find out how much time it took for ozone to split in closed premises. The volume of the room was V = 40 m^3, with no ventilation in the room. Ozone concentration decreased from C = 0.079 to 0.004 mg/m^3 within 23 min, when the source of ozone was switched off. Changes in the efficiency of ozone cleaning depending on time were studied. Within 4 hrs, while using the adsorbent layer of the least height L = 3.5 cm, the efficiency of cleaning almost did not change. An adsorbent with a greater height of the layer made it possible to use the adsorbent for a longer time. It is possible to draw a conclusion that the adsorbent can be used longer, that is, until hopping is achieved.

Figure 5 illustrates the dependence of the efficiency of the removal of ozone from the air on air flow speed, if the adsorbent layer height L = 10.5 cm, ozone concentration C = 0.035 mg/m^3 for zeolite, silica gel, and activated carbon.

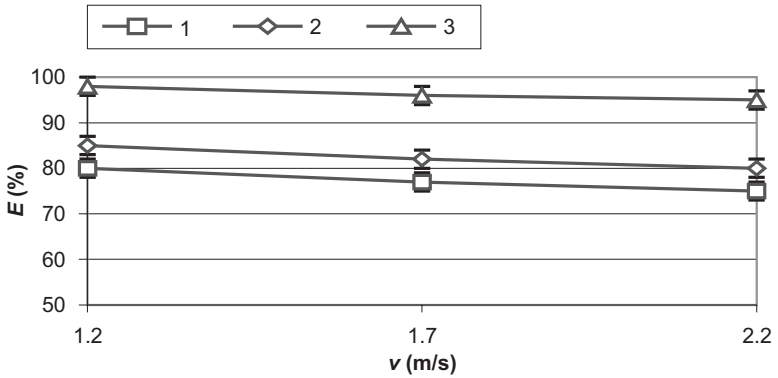

Figure 5. The dependence of the efficiency of the removal of ozone from the air on airflow speed, *L* = 10.5 cm, *C* = 0.035 mg/m^3. *Notes.* 1—zeolite; 2—silica gel; 3—activated carbon.

As is seen in Figure 5, with an increase in airflow speed, the efficiency of ozone removal from the air decreased, but this reduction was insignificant.

Equation 2 is the empirical expression of the interdependence of the efficiency of cleaning, the height of the adsorbent layer, and ozone concentration:

$$E = k_1 + k_2 L_1 + k_3 C + k_4 v; \quad (2)$$

where E—cleaning efficiency (%), L—height of the adsorbent layer (cm), C—ozone concentration (mg/m^3), v—air stream velocity (m/s); k_1, k_2, k_3, k_4—empirical ratios.

The interdependence of filtration efficiency, the height of the adsorbent layer, ozone concentrations, and air stream velocity for silica gel is given in Equation 3 (d = 3 mm, L = 3.5–10.5 cm, v = 1.2–2.2 m/s, C_{O3} = 0.035–0.115 mg/m^3):

$$E = 73.075 + 1.529\,L - 51.25\,C - 5.0\,v. \quad (3)$$

The value of coefficient r for this empirical formula is .917. The interdependence of filtration efficiency, the height of the adsorbent layer, ozone concentrations, and air stream velocity for activated carbon are given in Equation 4 (d = 1.5–2 mm, L = 3.5–10.5 cm, v = 2.2 m/s, C_{O3} = 0.035–0.115 mg/m^3):

$$E = 96.521 + 0.724\,L - 62.5\,C - 5.0\,v. \quad (4)$$

The value of coefficient r for this empirical formula is .905, which shows this empirical formula describes experimental data well enough.

The interdependence of filtration efficiency, the height of the adsorbent layer, ozone concentrations, and air stram velocity for natural zeolite is given (d = 6 mm, L = 3.5–10.5 cm, v = 1.2–2.2 m/s, C_{O3} = 0.035–0.115 mg/m^3):

$$E = 72.302 + 1.071\,L - 70\,C - 5.0\,v. \tag{5}$$

The value of coefficient r for this empirical formula is .910, which shows this empirical formula describes experimental data well enough.

It is possible to draw a conclusion that an empirical formula for calculating the dependence of the efficiency of ozone removal from the air on the height of the adsorbent layer and concentration was determined for natural zeolite, activated carbon, and silica gel.

It is possible to distinguish the following reasons why ozone concentration decreases during the removal of ozone from the air: ozone adsorption, spontaneous zone splitting, and ozone reaction with a metal surface. The contribution of all of those reasons to the reduction of ozone concentration is the same. The main reason for the reduction of ozone concentration is its adsorption, but it is difficult to evaluate its quantitative effect on the reduction of concentration. Experimental results were statistically processed.

Upon studying the effect of the nature of the adsorbent on the efficiency of air cleaning, it was established that activated carbon was the best adsorbent. This can be explained by the fact that activated carbon has the best-developed microporous structure, predetermining the high level of treatment. For air cleaning from welding aerosol it is possible to use combined air treatment, in which the air is cleaned not only from dust (aerosols), but also from nitrogen (sulphur) oxides, by removing the latter by adsorption. Here the role of ozone is ambiguous: It oxidizes NO to NO_2, which is chemically more active than NO and more easily adsorbed, and it oxidizes SO_2 to SO_3, which if mixed with water forms sulphuric acid. Being very aggressive, sulphuric trioxide disintegrates zeolite, which is frequently used as an adsorbent for the adsorption of sulphuric dioxides, and thus a negative impact of ozone manifests itself.

Adsorption air cleaning can be used for air treatment from welding aerosols, as together with nitrogen oxides it makes it possible to clean the air from ozone as well.

4. CONCLUSIONS

1. For air cleaning from aerosols, electrostatic filters are used most frequently, with extra ozone emitted from them. To clean the air a combined air cleaning method with an electrostatic filter and an adsorber for ozone removal from the air is applied.
2. During the experiment it was proved that the efficiency of air cleaning from ozone depends on its concentration, with whose increase the degree of cleaning decreases, as the adsorbent cannot absorb a greater amount of ozone.
3. The efficiency of ozone removal from the air is predetermined by the height of the adsorbent layer, on which the time of the contact of the adsorbent and the air under treatment depends. With an increase in the height of the adsorbent layer, the degree of air cleaning increases, with a simultaneous increase in aerodynamic resistance.
4. Of adsorbents used in experiments activated carbon, with its greatest surface, is the most effective adsorbent of ozone.
5. An empirical formula was determined for calculating the dependence of the efficiency of ozone removal from the air on the height of the adsorbent layer and the concentration for natural zeolite, activated carbon, and silica gel.
6. With an increase in the velocity of airflow the efficiency of air cleaning from ozone decreases, but this reduction is insignificant and does not have a considerable effect on the efficiency of ozone removal.

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