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Modern Technical Solutions for Cleaning, Disinfection and Sterilization

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The article describes a new technical solution for ensuring efficient and inexpensive cleaning, disinfection and sterilization of production facilities and their equipment, based on the principle of generating the use of ozone gas. It describes the technical solution and construction of sterilization and cleaning equipment with ozone gas and the sterilization of small objects, especially textiles contaminated with various viruses, including the Covid-19 virus. The device is designed as energy-saving, structurally simple, with high sterilization and cleaning efficiency. The sterilization device is small in size, mobile and its design enables transportation in the trunk of an ordinary passenger car. The weight of the device is 14 kg. The device's ozone source is an ozone air purifier, mass-produced according to valid EU standards. The power source of the ozone purifier is an electrical source with a voltage of only 230 V and a frequency of 50 Hz. Alternatively, it is possible to use power from a safe mobile source or inverter. The operation of sterilization and cleaning device in a closed, non-ventilated area, does not endanger people's health or damage plants. The description of the construction of a technical sterilization device is focused on a specific type of device, but the stated theoretical results can be equally well used in the electrotechnical, food, medical or pharmaceutical industries and in general wherever there is a need to effectively and efficiently clean and sterilize production objects, their equipment, used materials and all other production aids means and tools.

Keywords: sterilization of manufacturing equipment, energy saving, COVID-19, ozone cleaning, ozone disinfection, ozone generator, mobile devices

1 Introduction

More and more often in industrial production we encounter requirements for a dust-free and sterile working environment. These are usually objects of the electrical engineering industry, where semiconductor components are manufactured. Other such places are food or medicine factories. The requirement of sterility here does not only apply to the work environment, but also to all machinery, materials and work tools used, including production tools. Ensuring the necessary sterility is neither easy nor cheap on a large scale. One of the options for cleaning and sterilizing small and large objects and spaces is ozone cleaning and sterilization. Ozone cleaning has a wide range of applications in the commercial and civil sectors. For over 20 years, it has been successfully used in many areas, especially in the food and medical sectors. Ozone is a natural gas consisting of three oxygen molecules and is commonly found in the stratosphere. In this paper, a new sterilization device and the sterilization process is described. The procedure is based on the oxidative properties of ozone, allowing the removal of pathogens, such as bacteria, viruses, molds, spores and yeasts, from air and water by breaking down their molecular structure and thus causing the destruction of bacteria or deactivation of viruses [1, 2]. In chemical laboratories, ozone serves as an oxidizing agent, especially in organic synthesis and in preparing certain peroxide compounds. It is mainly used for textiles bleaching or water disinfection in industry, where ozonation replaces the common and cheap but less healthful chlorination of drinking water. In the food industry, for disinfection of premises and for the surface preservation of food products. In agriculture, for the surface treatment of vegetables and fruit, in particular, to prevent the growth of molds and yeasts. A mixture of about 10 % liquid ozone and 90 % liquid oxygen was tested during the 1950s as an oxygenator in rocket liquid engines to increase specific impulse. The mixture was highly hazardous and was therefore never used in practice. When in contact with living tissue in adequate concentrations, ozone can heal and circulate the tissue and disinfect it very thoroughly. It is used in medicine, for example, to treat acne, atopic eczema and other skin defects. In recent years, ozone has been used to a limited extent in dentistry and ozone therapy. The effects and use of the above treatments may be debatable, as the safety risks of inappropriate use of ozone directly on the patient and the occurrence of ozone in the work environment may outweigh the potential benefits [3]. The strong oxidative effects of ozone are used in the paper industry to bleach pulp in paper production. Ozone can be prepared relatively easily by a silent electrical discharge in an atmosphere of pure oxygen or air. Using pure oxygen produces a mixture of oxygen and ozone, where the proportion of ozone is usually ten percent [4]. Pure ozone can then be prepared by fractional distillation of this gas mixture.

The advantage of ozone, especially in disinfecting drinking water, is that it inactivates and kills parasitic protozoa even at low doses. At the same time, it oxidises the present organic substances without the formation of carcinogenic trihalomethanes, common with chlorine disinfection. Ozone ranks among the most potent disinfectants and oxidizing agents. It kills commonly occurring bacteria up to 100 times faster than chlorine. It also quickly and reliably kills very resistant species or forms of pathogenic microorganisms that chlorine and other disinfectants are unable to inactivate under acceptable conditions, i.e. acceptable disinfectant concentration and inactivation time [5]. Ozone disinfection occurs by rupture of the cell wall. It is a more effective method than the use of chlorine, which depends on diffusion into the protoplasm of the cell and the passivation of enzymes. An ozone level of 0.4 ppm (parts per million) for four minutes appeared to be sufficient to kill all bacteria, viruses, molds, and fungi.

To disinfect the air in virus-contaminated areas, commonly manufactured ozone air purifiers can be used conveniently. However, their disadvantage is their insufficient performance when they need to be used quickly and efficiently to sterilize large quantities of material or larger pieces of contaminated material [6].

This article focuses on the constructional adaptation of an ozone air purifier to an ozone sterilizer with sufficient performance for its use as an ozone sterilizer for smaller and larger pieces, especially textile materials contaminated with viruses.

2 Design of the technical solution of the sterilization device

In order to convert a conventional ozone air purifier into an ozone sterilizer, we need to solve the following problems:

- a) To design a sterilization chamber with a suitable geometric shape.
- b) To determine the necessary parameters of the working atmosphere in the sterilization chamber and their values.
- c) Technically ensure the correct values of the required parameters of the working atmosphere sterilization equipment.

Each technical problem can be solved, for example, as described later in the article.

2.1 Design of the technical solution of the sterilization chambre

The constructional design of the ozone sterilizer is based on the regular production of standard air purifiers. To ensure the correct quality of sterilization and cleaning of smaller treated objects, an ozone generator with an output of 5000 $mg \cdot hr^{-1}$ is sufficient. The HE-151 - EU Plug 5 g ozone air purifier is selected from the regular production as the ozone source (Fig. 1). The selection ensures the guaranteed performance of the ozone source, the operational reliability of the tested equipment, and the availability of spare parts. There is no need to deal with electrical safety because it is already approved equipment for operation in the Czech Republic and the EU [3, 4].

The device's dimensions, width and height, are based on the selected type of commercially produced ozone air purifier. The length of the apparatus has been defined, taking into account the maximum possible size of the object to be placed in the luggage compartment of a sedan-type passenger car, so that the apparatus can be comfortably loaded and transported. The width and height are therefore 220 mm x 350 mm and the length 1200 mm (Fig. 2 and Fig. 3). The maximum amount of inserted cleaned fabrics was set at 7.5 kg by an indicative calculation according to [8] and [9]. The time required for complete sterilization of this weight of textile filling should not exceed 6 hours according to [8], [9] or [10]. The working pressure in the sterilization chamber should not exceed 10 percent of ambient atmospheric pressure [9] and [10]. The working temperature in the sterilization chamber should not increase during cleaning and sterilization according to [8], [9] or [10], [16].

Fig. 1 *HE-151 Ozone air purifier – EU Plug 5 g (5000 mg)*

Functions:

- Efficient, low noise, portable, lightweight and easy to maintain.
- High performance oxidation in a compact, robust and simple design.
- The cooler to reduce heat on the ozone plate, ensuring long service life.
- Use of controlled corona discharge technology.
- Stainless steel pre-filter for removal of large particles.
- High quality electronic components.

Specifications:

- Model:HE-151
- Power:80 W
- Input voltage:220-240V/50Hz
- Capacity:80 CFM
- Noise:<40 dB
- Dimensions:205x175x170 mm
- NW / GW: 2.0 kg / 2.8 kg
- Size of a treated area:5000 sq. Ft / 500 sq. M

2.1.1 Application

Effectively removes odours, smoke, pollen, dust, mites, mould; neutralises allergens, destroys bacteria. The device is suitable for home use as an air sterilizer for the environment in the living room, kitchen or bathroom. It can also be used as an air sterilizer and odour eliminator in restaurants or hotel rooms. Industrial use is possible, for example, for sterilizing cars, trains, planes, boats, shops, office buildings, or garages. The proposed equipment is very effective in removing formaldehyde in new houses, hotels, or offices. It helps to preserve fresh food in the refrigerator. It can also be used for the sterilization of children's clothes and toys.

The device is characterized by high ozone production - 5000 mg·hr^{-1}. The airflow rate reaches up to 2.8 m^3·min^{-1}. It is characterized by low energy consumption (80 W) and long service life. There is a special ceramic plate inside the ozone generator with a life span of 5000-6000 hours.

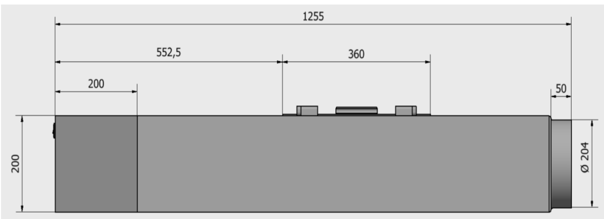

***Fig. 2** General dimensions of the proposed ozone cleaning device – side view*

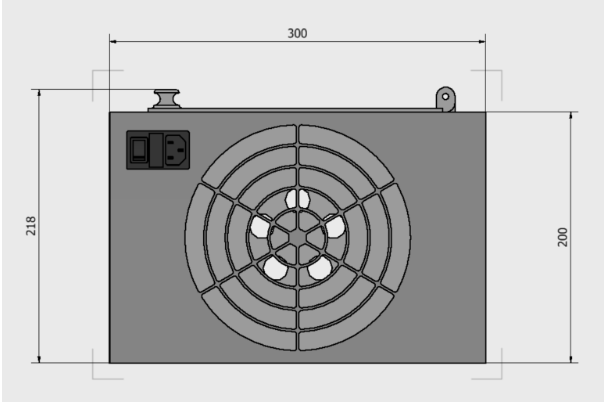

***Fig. 3** General dimensions of the proposed ozone cleaning device - front view*

Ozone generators are working on the principle of high-voltage discharge. They prepare ozone in a so-called discharge element, through which the working medium - air or pure oxygen - passes, and the discharge takes place. The discharged energy splits part of the oxygen molecules into atomic oxygen, which combines with the oxygen molecule to form the trivalent ozone molecule O_3. The capacity of an ozone generator is usually given in g or kg O_3 hr^{-1}. Another important figure is the concentration of ozone in the gas leaving the ozone generator, usually given as a weight percentage. The concentration of ozone dissolved in the treated medium is generally given in ppm, mg·m^{-3} or μg·m^{-3}. For various applications, it is recommended to indicate the concentration value as well as the reaction time - the time the treated medium is exposed to the effective dose. An important figure for the operation of an ozone generator is the energy consumed per g or kg of ozone produced, i.e. kW·g^{-1} or kW·kg^{-1} O_3. For calculations of the ozone concentration produced by the proposed HE-151 unit, the calculated airflow rate is 0.0378 m^3·s^{-1}, with a production of 5000 mg·hr^{-1}. The corresponding ozone concentration is then 36.8 mg·m^{-3}. The proposed unit assumes in the first stage a simple flow of the air-ozone mixture of the above concentration through the cleaned material. By the construction and layout of the unit, the airflow will be slowed down as the pressure in the unit increases slightly. The present ozone will enter into chemical oxidation-reduction interactions with the contamination on the material itself and probably, in the case of textiles, partially also with the carrying material. The mechanism will reduce the concentration of ozone in the cleaning unit, but with respect to written above, the remaining ozone must be removed from the air leaving the cleaning unit. The ozone molecule is very reactive and therefore very unstable [10]. These properties can be exploited for the disposal of residual ozone. Our constructional design uses capture on absorbers followed by catalytic decomposition for ozone destruction [11], [15] (see Table 1).

Tab. 1 *Impact of temperature on the half-life of ozone in air and water*

AIR		Dissolved in water (Ph 7)	
Temperature (°C)	Half-life	Temperature (°C)	Half-life
-50	3 months	15	30 min.
-35	18 days	20	20 min.
-25	8 days	25	15 min.
20	3 days	30	12 min.
120	1,5 hours	35	8 min.
250	1,5 seconds	------	-------

With respect to the amount of air passing through the unit under consideration, thermal ozone destruction would be very energy-intensive and, given the design limitations of the unit, impractical. Therefore, it is not further considered [12]. Absorbents, such as activated carbon, molecular sieves, silica gel or aluminum oxide, act as a strong catalyst supporting the ozone decomposition already at room temperature. For the practical destruction of residual ozone, we consider activated carbon absorption to be the most appropriate method, where ozone is trapped over a large surface area of 500-1000 $m^2 \cdot g^{-1}$ and decomposed back into molecular oxygen, which leaves the atmosphere with the air stream. The technical solution considered is to route the gas from the cleaning unit into a 50 of liter plastic container, where the gas inlet is brought to the bottom of the container. The inlet pipe to the container is provided with a suitable deflector - a simple manifold, above which a second bottom, consisting of a stainless steel or plastic screen, is placed. On top of the sieve is placed an absorbent layer of activated carbon in the amount of 1.5-2 kg, which is again covered from above with a stainless steel or plastic sieve to fix the absorbent layer [13]. The deflector-gas distributor ensures even distribution of the purified gas under the absorption layer and uniform flow through this layer. The filtered air is discharged through a plastic pipe routed through the sealed lid of the absorption vessel. For safety reasons, a vapour vent to the outside atmosphere is connected to the pipe.

2.2 Determination of the necessary parameter values of the working atmosphere in the sterilization chamber

The goal of calculating the parameters of the working atmosphere is to determine the unknown values of the parameters of the atmosphere at the output of the ozone generator and the gas pressure in the ozone chamber. The unknown values of the parameters at the output of the ozone generator are the velocity of the output air stream v_1 (m · s $^{-1}$), the output pressure p_1 (Pa) and the output temperature T_1 (°K). The unknown value of the atmosphere parameter inside the chamber is the gas pressure in the chamber p (Pa).

Calculation of parameters values inside the ozone sterilizer chamber

The aim of calculating the atmosphere parameters inside the ozone sterilizer chamber is to determine the actual values of selected parameters. These are temperature T, pressure p, and flow velocity of the ozone atmosphere v1 inside the chamber. When calculating the parameters of the atmosphere inside the sterilizer, it is necessary to consider that larger metal container, filled with a known volume of air and ozone, is connected to the output from the sterilization chamber. The output is made by several holes of precise diameter. The air is drawn in from the outside atmosphere, and the ventilator that blows the air into the chamber is a single-stage axial fan with adiabatic compression. We assume that the pressure change is small. However, even such a ventilator has a very steep volume/pressure ratio characteristic. For a ventilator, we know the volume flow for zero pressure gradient. For our case, we will assume approximately half of this volume flow. This is only an approximation to the actual situation, but it is reasonable and acceptable. Ozone from the generator is added to the blown air, but its volume concentration is insignificant compared to the blown air. The effect of ozone is neglected; only the air is considered. The outlet of the sterilizer container consists of five 20 mm diameter holes. It is situated in the external atmosphere or a catalyst with insignificant pneumatic resistance. Therefore, it is again an adiabatic expansion. A scheme of the gas flow is shown in Fig. 4.

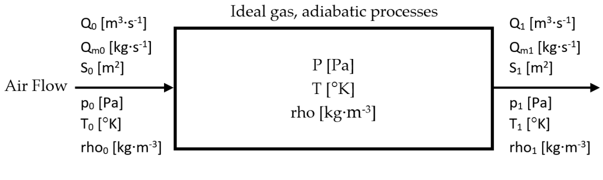

Fig. 4 *Schematic illustration of the airflow through the device and pressure conditions*

Known parameters of the inlet atmosphere:

- Inlet airflow volumeQ_0 = 0.0189 m3·s-1 (80 CFM)
- Inlet mass airflowQ_{m0} = 0.0232 kg·s-1
- Inlet flow areaS_0 = 0.0314 m2 (200 mm circular diameter)
- Inlet airflow velocityv_0 = 0.602 m·s-1
- Inlet pressurep_0 = 101325 Pa
- Inlet temperatureT_0 = 293.15 °K (20 °C)
- Inlet air densityϱ_0 = 1.225 kg·m-3

Known parameters of the atmosphere at the outlet:

At the outlet, we only know the air's volume, mass flow, and density. The outlet values are equal to the inlet ones.

- Outlet airflow volumeQ_1 = 0.0189 m·s-1
- Outlet mass airflowQ_{m1} = 0.0232 kg·s-1
- Outlet flow area S_1 = 0.00157 m2 (five 20 mm diameter holes)
- Outlet airflow velocity v_1 = ? m·s-1
- Outlet pressurep_1 = ? Pa
- Outlet temperature T_1 = ? °K
- Outlet air densityϱ_1 = 1.225 kg·m-3

Atmosphere parameters inside the chamber:

- Gas pressure inside the chamber$p$ = ? Pa
- Gas temperature inside the chamber$T = T_0$ = 293.15 °K
- Gas density inside the chamberϱ = 1.225 kg·m-3

2.2.1 Applied assumptions

A suitable physical model must be chosen for the solution. In this case, the following assumptions are applied:

- Air is replaced by a non-viscous gas.
- The pressure proportions are assumed to be low, and the gas will realistically behave as incompressible (density does not change).
- We assume a constant volume and mass flow of the working mixture of air and ozone produced by the ventilator.

2.2.2 Outlet parameters

The condition inside the container is given by a function of the inlet and outlet parameters.

First, the inlet parameters must be determined. The limiting conditions for the calculation are as follows: The installation is adiabatic, there is no heat transfer. Mechanically, the installation is without mechanical energy change, so the process inside the does not affect the total gas energy, and its influence does not need to be considered. The outlet data can be calculated directly from the inlet ones.

In the continuity equation, we assume incompressible flow, so Q is constant. The flow velocity of the atmosphere with ozone v_1 in the sterilization chamber and at the outlet will then be:

$$Q_m = Q \cdot \rho; \quad Q = v_1 \cdot S_1 \quad \rightarrow \quad v_1 = Q_m S_1 \cdot \rho \tag{1}$$

$$v_1 = \frac{0.0232}{0.00157 \cdot 1.225} = 12.0\ \mathrm{m} \cdot s^{-1} \tag{2}$$

Where:
Q_m…Mass flow (g·s-1),
v_1…Outlet airflow velocity (m·s-1),
S_1…Inlet flow area (m2),
ϱ…Air density (kg·m-3).

Energy equation: the gas energy equation at the inlet and outlet (in the form of mass flows) can be constructed from the following components: internal gas energy + kinetic gas energy + positional energy + mechanical pressure energy. The total inlet and outlet energy must be equal:

$$Q_{m_0} \cdot \left(u_0 + \left(\frac{1}{2}\right) \cdot v_0^2 + g \cdot h_0\right) + p_0 \cdot Q_0 = Q_{m_1} \cdot \left(u_1 + \left(\frac{1}{2}\right) \cdot v_1^2 + g \cdot h_1\right) + p_1 \cdot Q_1 \tag{3}$$

Where:
Q_m…Mass flow (g·s-1),
Q…Volume flow (m3·s-1),
u_0…Internal energy (J),
v_1…Outlet airflow velocity (m·s-1),
g…Gravitational acceleration (m·s-2),
h…Height of the flow surface (m),
p…Air pressure (Pa),
Q…Flow volume (m3·s-1).

Since the device is small and the height of the inlet h_0 and outlet h_1 of the flow area is the same, the positional energy can be neglected and not further considered:

$$g \cdot h_0 = g \cdot h_1 = 0 \tag{4}$$

The mass airflow at the inlet Q_{m0} is equal to Q_{m1} at the outlet (mass is neither created nor lost, it does not accumulate in the system but flows continuously and steadily):

$$Q_m = Q_0 \cdot \rho_0 = Q_1 \cdot \rho_1 \tag{5}$$

The internal energy of a gas u is represented by the difference between the enthalpy of the gas i and the pressure energy of the gas p/ϱ.

$$u = i - \frac{p}{\rho}; \quad i = c_p \cdot T \quad \rightarrow \quad u = c_p \cdot T - \frac{p}{\rho} \tag{6}$$

By substitution we obtain:

$$Q_0 \cdot \rho_0 \cdot \left(c_p \cdot T_0 - \frac{p_0}{\rho_0} + \left(\frac{1}{2}\right) \cdot v_0^2\right) + p_0 \cdot Q_0 = Q_1 \cdot \rho_1 \cdot \left(c_p \cdot T_1 - \frac{p_1}{\rho_1} + \left(\frac{1}{2}\right) \cdot v_1^2\right) + p_1 \cdot Q_1 \quad (7)$$

Where:
Q_0…Inlet airflow volume ($m^3 \cdot s^{-1}$),
Q_1…Outlet airflow volume ($m^3 \cdot s^{-1}$),
ϱ_0…Inlet air density ($kg \cdot m^{-3}$),
ϱ_1…Outlet air density ($kg \cdot m^{-3}$),
c_p…Specific heat capacity of gas ($J \cdot °K^{-1} \cdot Kg^{-1}$),
p_0…Inlet pressure (Pa),
p_1…Outlet pressure (Pa),
v_0…Inlet airflow velocity ($m \cdot s^{-1}$),
v_1…Outlet airflow velocity ($m \cdot s^{-1}$),
T_0…Inlet air temperature (°K),
T_1…Outlet air temperature (°K).

By further calculation, we conclude that the total energy of the gas is the sum of enthalpy and kinetic energy only.

$$c_p \cdot T_0 + \left(\frac{1}{2}\right) \cdot v_0^2 = c_p \cdot T_1 + \left(\frac{1}{2}\right) \cdot v_1^2 \quad (8)$$

At this point, it is possible to express the outlet temperature T_1.

The c_p value represents the specific heat capacity of the gas for dry air at a temperature of 293 °*K*.

$$c_P = 1010 \ \frac{J}{kg \cdot K} \quad (9)$$

$$T_1 = T_0 + \frac{1}{c_p} \cdot \left(\frac{1}{2}\right) \cdot (v_0^2 - v_1^2) \quad (10)$$

$$T_1 = 293.15 + \frac{1}{1010} \cdot \left(\frac{1}{2}\right) \cdot (0.602^2 - 12^2) = 293.08 \,°K \quad (11)$$

The outlet air pressure p_1 is calculated using the gas state equation. In this case, the inlet and outlet air density values are the same $\varrho_0 = \varrho_1$:

$$\frac{p_0}{\rho_0} = R \cdot T_0 = \frac{p_1}{\rho_1} = R \cdot T_1 \quad (12)$$

$$p_1 = p_0 \cdot \frac{T_1}{T_0} = 101325 \cdot \frac{293.08}{293.15} = 101300 \ Pa \quad (13)$$

Where:
R…Ideal gas constant ($J \cdot °K^{-1} \cdot mol^{-1}$).
Calculated outlet parameter values:

- Outlet airflow volume$Q_1 = 0.0189 \ m^3 \cdot s^{-1}$
- Outlet mass airflow$Q_{m1} = 0.0232 \ kg \cdot s^{-1}$
- Outlet flow area $S_1 = 0.00157 \ m^2$ (five 20 mm diameter holes))
- Outlet airflow velocity $v_1 = 12 \ m \cdot s^{-1}$
- Outlet pressure $p_1 = 101300$ Pa
- Outlet temperature $T_1 = 293.08$ °K
- Outlet air density $\varrho_1 = 1.225 \ kg \cdot m^{-3}$

Calculation of parameter values inside the chamber:

- We apply the Saint Vénant-Wantzel equation to determine the ideal gas flow rate from the nozzle.

Calculation of pressure *p* inside the chamber:

$$p = p_1 \cdot \left(1 - \frac{1}{T_1} \cdot \frac{\kappa - 1}{\kappa \cdot R} \cdot \frac{1}{2} \cdot v_1^2\right)^{\frac{-\kappa}{\kappa - 1}} \quad (14)$$

$$p = 101300 \cdot \left(1 - \frac{1}{293.08} \cdot \frac{1.4 - 1}{1.4 \cdot 8.314} \cdot \frac{1}{2} \cdot 12^2\right)^{\frac{-1.4}{1.4-1}} = 104373 \ Pa \quad (15)$$

Calculated atmosphere parameter inside the chamber:

- Gas pressure inside the chambre $p = 104373$ Pa

The results of the calculations of the unknown values of the atmospheric parameters at the output of the ozone generator are the velocity of the output air stream $v_1 = 12 \ m \cdot s^{-1}$, the output pressure $p_1 = 101300$ Pa and the output temperature $T_1 = 293.08$ °K.

The value of gas pressure inside the chamber $p = 104373$ Pa.

2.2.3 Possible reasons for the inaccuracies of the results calculation

Four limiting assumptions were used in the theoretical calculations of the chamber atmosphere parameters, which are reflected in the real error of the calculations. The first is the assumption of a non-viscous gas. This assumption has a significant effect on the calculation error.

The calculation of the values of the atmosphere parameters in the non-viscous state is not affected by the shape and number of outlet openings. However, the actual gas in the viscous condition is affected. Five smaller outlets have a significantly greater resistance to flow than one large outlet, even if it is the same cross-sectional area as the sum of all five. However, the calculation used does not take this into account. The effect on the result of the calculation is that the actual pressure inside the chamber will be slightly higher. The difference shall be in the range of percentages.

The second important assumption is the pressure-volume characteristic of the fan used. A simple axial fan has a very steep pressure-volume characteristic. However, the fan's actual characteristic is unknown, so it was estimated. Counter-pressure could be 1/2 of the nominal volume of non-pressure mode. It probably represents the most significant effect on the result accuracy.

The third assumption is the incompressibility of the gas at such small pressure gradients. This assumption holds very well, the pressure differences are minimal.

The fourth assumption is that the ozone generator adds only a fraction of the volume of the fan and is not considered. A suitable and recommended solution would be an experiment to verify the occurrence of a significant error. This experiment was performed at the end of the sterilizer development.

2.2.3 Device material

The housing material can be chosen in terms of chemical resistance either PVC-U, stainless steel or, given the required low weight of the experimental unit, aluminium sheet (possibly anodized). Small parts can be produced either by 3D printing as described below or by a combination of a basic structure made of aluminium sheet combined with parts (fittings, seals, couplings) made of PVC-U, PVDF or PTFE. To a limited extent, sealing with silicone in parts with lower ozone concentration in the treated air can also be considered, but obviously a lower lifetime has to be assumed. However, this can only be confirmed or refuted by test operation.

The recommended procedure for realizing the prototype construction is to design and print the structure on a 3D printer with PETG material. The experimental piece was made of paper cardboard, which met the requirement of testing cleaning in five cycles. Material containing rubber is not recommended. In the chemical reaction between ozone and rubber, the rubber degrades to its ultimate destruction, which could result in a crash of the device.

If lubricants are to be used in the equipment, fluorocarbon lubricants with good ozone resistance should be used. Conventional lubricants must not come into a contact with ozone at any time.

2.2.4 Verification of theoretical calculations by measuring of ozone

In order to obtain relevant work results and verify the results of theoretical calculations, it is always necessary to compare the results of the theoretical solution with the results of experimental measurements. Residual ozone was measured to verify the safety of operation in closed spaces, in this case. As described above, ozone acts on bioflora and biofauna as a strong oxidant and can be harmful to humans in higher concentrations.

The measurement was carried out in a room with dimensions of 5 m x 4 m x 2.5 m at a room temperature of 22 °C and normal atmospheric pressure. The length of the cleaning and measuring was 8 hours. The data collection was in ten repetitions in three places in the room. Data collection was always carried out at the outlet of the air from the device.

Tab. 2 *Measured residual ozone values*

measurement n^o	0.3 m [mg O_3.m^{-3}] 40 minutes	0.5 m [mg O_3.m^{-3}] 40 minutes	1 m [mg O_3.m^{-3}] 40 minutes
1	0.09	0.09	0.08
2	0.1	0.09	0.08
3	0.09	0.08	0.09
4	0.09	0.09	0.08
5	0.1	0.09	0.08
6	0.09	0.08	0.08
7	0.09	0.09	0.08
8	0.1	0.09	0.09
9	0.1	0.09	0.08
10	0.09	0.08	0.08
arith. average	0.094	0.084	0.082
maximum	0.1	0.09	0.09
arithmetic average of all measurements			0.08766
maximum measured value of all measurements			0.1

The Trotec OZ-ONE handheld device was used to measure ozone (Fig. 5). The first measurement was made at a distance in 0.3 m from the air outlet of the device. The second measurement was made at a distance in 0.5 m from the air outlet of the device. The third measurement was made a distance in 1 m from the air outlet from the device. The measurement was always carried out for 40 minutes. They are given the measured values from the ten described measurements in the table no 2. The measured values are given in units of mg $O_3.m^{-3}$ (milligram of ozone per cubic meter of air).

As already mentioned, ozone is a very strong oxidizing agent that reacts very quickly with all organic substances, including human tissues. In connection with the safety of operation of ozonation technologies, it is necessary to realize that ozone is very dangerous as a gas. Even at lower concentrations, respiratory tract irritation occurs, and at higher concentrations, even human life is at risk.

***Fig. 5** Concentrated ozone meter Trotec OZ-ONE [14]*

The limit concentrations of ozone for the working environment are as follows:

- PEL (permissible exposure limit) = 0.1 mg $O_3.m^{-3}$ i.e. 0.05 ppm, 24-hour exposure
- NPK (highest permissible concentration) = 0.2 mg $O_3.m^{-3}$, i.e. 0.1 ppm, 8-hour exposure [2]

The maximum measured value from all measurements was 0.1 mg $O_3.m^{-3}$, as it follows from the measurement results shown in Tab. 2. The average value from three series of measurements was 0.094 mg $O_3.m^{-3}$, which is well below the highest permissible concentration of 0.2 mg $O_3.m^{-3}$. The maximum measured value from all measurements was 0.1 mg $O_3.m^{-3}$. The limit concentration of ozone in the room was not exceeded in any of the measurements. Residual ozone measurements have shown that the device is completely safe for use in a closed room.

2.3 Technical provision of the required parameters of the sterilization device

The basis for the proposed construction of the cleaning and sterilization device is a commercially produced ozone air purifier with sufficient ozone production. Its output is 5000 $mg \cdot h^{-1}$ of ozone gas in the working chamber of the sterilizer with the ability to achieve air flow at a speed of v = 2.8 $m^3 \cdot min^1$. The selected air purifier was supplemented with a sterilization chamber, which forms a space for inserting cleaned objects. The weight of cleaned textiles can be up to 7.5 kg. The working pressure in the sterilization chamber is only 3% higher than the ambient atmospheric pressure. The ozone flow through the sterilization chamber is v = 0,602 $m \cdot s^{-1}$. The working pressure p = 104373 Pa and the atmospheric flow rate Q = 0.0189 $m \cdot s^{-1}$ in the chamber ensure that the required amount of ppm is sufficient for the complete destruction of bacteria even at the maximum weight of the disinfected fabric. During cleaning and disinfection, the working temperature in the sterilization chamber does not increase. The values of the parameters of the outlet air velocity v_1 = 12 m s^{-1}, the outlet pressure p_1 = 101300 Pa, the outlet temperature T_1 = 293.08 °K and the gas pressure in the chamber p = 104373 Pa. The parameters of working atmosphere in the sterilization chamber gained by theoretical calculations were verified at the end of device development by using of experimental measuring. The energy-saving source of the sterilization device is made from a commonly available electrical source used in the EU, i.e. 230 V and 50 Hz. Alternatively, it is possible to use power from a secure mobile source or inverter. The dimensions of the sterilization device are 200 x 300 x 1255 mm. They enable convenient transportation of the device in a passenger car. The sterilization device is also supplemented with an effective filter system that reliably neutralizes the generated and used ozone. The device is completely safe even for use in a closed room.

3 Discussion

The content of the article is a description of the structural design of the sterilization and cleaning device, supplemented by theoretical calculations of the parameters of the working ozone atmosphere. The article further describes the construction of a functional model and the successful experimental verification of sterilization and cleaning function of the newly designed and manufactured sterilization device. They are new information that a completely new sterilization and cleaning device has been designed and assembled, capable of cleaning and sterilizing all small objects made of various materials, except rubber in the article.

It can be operated in an enclosed space without negative impact on the health of people, animals or degradation of materials other than rubber. The device is portable. It works economically with alternating mains voltage 230 V / 110 V and 50 Hz / 60 Hz. As an alternative power source, a voltage converter from 12 V (car socket) to 230 V with a nominal power of 180 W or a generator with the same minimum power can be used.

It is new in the article from the point of view of theory, the parameters of the working ozone atmosphere have been determined and quantified. They describe the environment that must be created for sterilization and cleaning to function properly in the device. This device is based on the use of the sterilizing and cleaning properties and capabilities of ozone gas.

New and beneficial for practice is the information on the implementation of the structural design, assembly and successful experimental verification of the function of a new sterilization and cleaning device, the basis of which is a commonly produced ozone air purifier. The described sterilizing and cleaning equipment is simple in design, energy-saving, highly efficient, reliable, small in size, mobile and absolutely safe to operate even in enclosed spaces.

The described method of cleaning and sterilization using ozone is very effective, safe and at the same time cheap. It can be used as described in the article for cleaning and sterilizing small objects. Another option is to use it for cleaning and sterilizing all the equipment, equipment and tools of the electrotechnical, pharmaceutical, health industry or, for example, the food and beverage processing industry. Using this method, it is possible to sterilize individual small objects as well as entire production halls. As a cleaning and sterilization method, it is a universal method.

4 Conclusion

The content of the article is a description of the structural design, production and testing of a functional model of a new sterilization and cleaning device. The goal of the design and production of the device was to design and manufacture a sterilization and cleaning device that is structurally simple, inexpensive, energy-saving and maximally efficient. The device should be small in size, light in weight and mobile. The novelty of the design lies in the simplicity of the technical and structural solution. It is based on the using of a commonly produced ozone air purifier, which is integrated together with a simple sterilization chamber and a filter system of a new design, into one functional unit.

The article describes a theoretical solution where the parameters of the working environment are determined and quantified. They are mainly the required level of working pressure and working temperature or the flow of ozone through the chamber. A suitable technical solution for a newly designed device is also described here.

The design of the device is based on the sterilizing and cleaning properties of ozone, capable of cleaning and sterilizing small objects, especially textiles contaminated with various viruses, including the Covid-19 virus. The article describes the proposal of the overall technical solution. Choosing the appropriate type of ozone air purifier as an ozone source. The dimensions of the sterilization chamber and the construction of the filter part, assembled into a single unit of sterilization and cleaning equipment. The device's ozone source is a cheap, commonly produced, ozone air purifier. The energy source of the air cleaner is a common, economical, electrical source with a voltage of 230 V. Alternatively, it is possible to use power from a safe 12 V automotive source.

The practical benefits of the content of the article also include the published finding that the weight of the maximum load of 7.5 kg and the time of 8 hours required for the sterilization of textiles at the maximum load were confirmed experimentally. It was confirmed, the cleaning and sterilization in a closed, non-ventilated space does not harm people's health or harms plants, when verifying the sterilization and cleaning function of the device, by experimental measurement.

It would be appropriate to focus on determining the required values of the parameters of the working ozone atmosphere in the field of theory in future research. It will be necessary to determine required output of ozone production of a larger air purifier and determine the new dimensions of the sterilization chamber for sterilizing and cleaning larger objects weighing at least 50 kg for the possibility of next and better practical use, in the future.

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