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TESTING OF THE EFFICIENCY OF MILITARY DEVICES FOR PERSONAL RESPIRATORY PROTECTION IN RELATION TO SUB-MICRON PARTICLES OF BIOLOGICAL AGENTS

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The construction of biological weapons and tactics of its application dictate that dissemination of biological agents on the target has to be in the form of aerosols. The work was done on the effectiveness of filtration Serbian military protective mask M3 under conditions of simulated air contamination by sub-micron particles of biological agents. For this purpose the sodium chloride aerosol is generated in the form of solid aerosol particles, whose granulometric distribution and biological inactivity fulfill qualification for its suitability as a simulator of biological agents. The study was conducted with a focus on determining the filtration efficiency of the combined filter M3 as a vital part of the protective mask M3, with the measurement of filter resistance to air flow. The obtained values of filtration efficiency testing indicate that the protective mask M3 in real terms can successfully protect the user from contamination by biological agents used in aerosol form.

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1. Introduction

The presence of biological agents in the environment is inevitable, whether their origin is natural or the product of human activity. Thanks to technological progress (genetic engineering) the possibility of using biological agents as biological weapons in armed conflicts or through bioterrorism has expanded [1]. By biological weapons (BW) is meant microbes and other biological agents or toxins, whatever their origin and way of obtaining, as well as weapons, equipment and other devices or methods of dissemination designed to use such agents or toxins for hostile intent or during the war, whose possession is not intended to be protective or other peaceful purpose [2].

Biological combat means are divided into those that act on humans (human pathogens), animals (animal pathogens) and plants (plant pathogens). Human pathogens, which according to the EU List of controlled dual-use items and technologies (Regulation 428/2009, Annex I), except for civilian use, have potential application as BO, include [3]:

- 32 viruses - eg. *Ebola virus*,
- 4 Rickettsia - eg. *Coxiella burnetii* (Q fever),
- 15 bacteria - eg. *Yersinia pestis* (plague), *Bacillus anthracis* (антракс)
- 2 fungi – eg. *Coccidioides immitis,*
- 19 toxins - eg. *Botulinum toxin.*

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Since the most likely application of biological combat means will be in the form of aerosols (except in case of diversion), then the known assessments of biological attack effects are related exclusively to biological aerosols. Today it can be produced as a material containing infectious microorganisms in concentrations up to 10 billion per one gram, so its application by aerosol can cause immeasurable epidemiological consequences [2]. For example, the Congressional Office of Technology Assessment (USA) estimated that the aerosolized
release of 100 kg of anthrax spores upwind may cause approximatelly 130 000 to 3 million deaths [4].

In case of occurrence of an epidemic, or pandemic, by using of BO or naturally, it is necessary to maintain high operational capability of the army. First and primary device of formation for personal respiratory protection of each member of the military is a military protective mask. In the use of filtering protective masks human respiratory organs are using outdoor air for breathing, which is purified from harmful gases, vapors and aerosols [5]. Purification is based on the principle of filtration by gas filters, particle filters and the combined filters, in combination with suitable connections for the protection of face and eyes (mask, half-mask).

The Serbian Army is using military protective mask as a device of personal respiratory protection. According to the epidemiological situation in the country and the world, it is necessary to provide the reliability and effectiveness of this device in the phase of prevention and suppression of the spread of possible diseases caused by biological agents. For the civilian population virus protection are usually used disposable masks which provide partial protection. Information on their effectiveness for decreasing the risk of influenza infection in community settings is extremely limited. [6]. The most common is the use of epidemiological masks in which one of the layers is impregnated with nano particles (usually silver-oxide, titanium oxide, gold, etc.) [7,8]. The mechanism of protection is based on a certain amount of impregnated nanoparticles, whose antiviral and antibacterial properties increase the internal filtering efficiency of a particle filter (silver-oxide nanoparticles can destroy more than 650 types of viruses, fungi and bacteria in 6 minutes of contact, eg.) [9, 10]. However, there is no information whether these masks are more suitable for personal respiratory protection of the military population than military protective masks.

In all previous studies of military protective masks, except for positive hypothetical assumptions, there is no experimental proof of its efficiency in protection against biological agents.The aim of this study was to investigate the effectiveness of the latest generation of Serbian military protective masks against the biological agents, because it should enable the combat effectiveness of soldiers in all possible circumstances of sudden biological contamination of the environment.

2. Experimental

Theoretical assumptions of the testing

According to the European standard [11], protective mask is a filtering device for respiratory protection which protects the respiratory organs, eyes and face of the people in case of radiological-chemical-biological (RCB) contamination in the form of gases, vapors and solid and liquid aerosol particles. Mask consists of a facepiece and combined filter.

Combined filters are designed to remove gases, vapors and particles from the air stream that pass through it [12]. It consist of gas filter (active charge of the combined filter) and a particle filter (filter against aerosols) who are placed in a common filterhousing (Fig. 1). Particle filter is located on the inlet side of the combined filter.

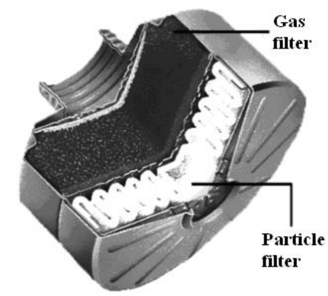

Fig. 1. Combined filter.

The gas filter is used for protection from harmful gases and vapors, without the simultaneous occurrence of particles. The mechanism of protection is based on the removal of pollutants and gases from the inhaled air by physical binding (adsorption) or chemical reaction (chemisorption or catalytic oxidation) on the filter material with a large internal specific surface (commonly used adsorbent is activated carbon). Gas filters are not effective for protection against particles [12].

Particle filter is designed to provide respiratory protection against radioactive aerosols, aerosols of highly chemical substances and biological agents [11]. It is made of filtration material fibrous structure. Fibers can be made of natural or artificial raw materials. With the development of nanotechnologies manufacturing of particle filter is upraised on a very high level. Filtration materials of today possess opportunities for filtration of micron and sub-micron particles [13,14]. According to their different abilities to keep particles, particle filters are classified into classes [15]:

- P1 (for solid particles) - low filtration efficiency (≥80 %),
- P2 (for solid and liquid particles) - medium filtration efficiency (≥94 %),
- P3 (for solid and liquid particles) - high filtration efficiency (≥99,95 %).

The order is consistent with the increasing filtration efficiency. This division also applies to the particle filters that are an integral part of the combined filters.

One of the key parameters for assessing the effectiveness of protective masks is the monitoring of contaminant aerosol penetration through the filter. Since the experiments with real contaminants in the laboratory is a high-risk activity, in practice is applied the test method of generated aerosols of some non-toxic agent which simulate the presence of contamination in the air [15].

Tested samples

Testing was performed on samples of the combined filter M3, as a vital part of a protective mask M3, which is produced by "Trayal" Corporation from Krusevac. Particle filter within the combined filter M3 is type of ULPA filters (manufacturer company Bernard Dumass SAS, France), which is on the basis of glass fibers. Taking representative samples was carried out by random selection of the required number of pieces individually packed filters [16].

Test procedure

Test procedure is set up in accordance with European and national standards [12,16]. Filters are balanced before testing with air relative humidity (80$\pm$3)% at a temperature (23$\pm$1) ^{0}C to constant mass. Testing was performed by the test aerosol brought into the test chamber (pipe), on which is hermetically connected test filter. Solid test aerosol of total flow 30 dm^3/min is generated by spraying an aqueous solution of sodium chloride, the mass concentration of 1%, using a Collison type generator (the air is supplied to diffuser under pressure of at least 3.45 bar; on exit of the nozzle, aerosol is mixed with dry air flow of 82 dm^3/min; water evaporates during mixing with dry air, so it is obtained dried aerosol with solid sodium chloride particles). Particle size distribution of aerosols of sodium chloride was determined by electrical aerosol analyzer (EAA-3030, Company TSI, USA). Concentration of generated aerosol is measured before and after the test filter by Type 1100 Sodium Flame Photometer (manufacturer Moores (Wallisdown)

LTD., UK). Initial penetration is measured after 3 minutes after the test's start, as the average response of the instrument in an interval of 30 ± 3 s. Precise determination is possible in the area of 0.0001% to 100% penetration through a filter. The resistance of the test filter to air flow is measured by differential meter pressure drop in front of and behind the filter.

Apparatus used for testing the penetration of sodium chloride aerosol is shown in Fig. 2 as described in the literature [15].

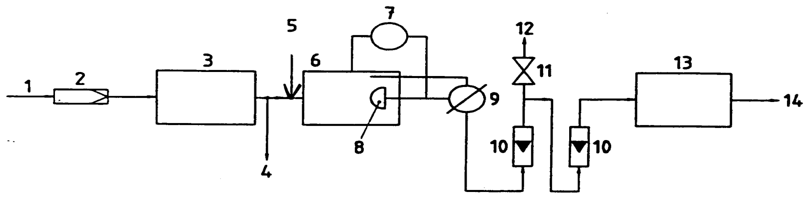

Fig. 2. Apparatus for testing the filtration efficiency of combined filter with *sodium chloride aerosol: 1 - compressed air, 2 - air filter, 3 - test aerosol generator, 4 - valve (*vent), *5 - clean air flow 82* dm^3/min, *6 - test chamber, 7 - meter pressure drop, 8 - combined filter for testing, 9 - the three-*pointed *tap, 10 – flowmeters, 11 -valves to maintain the flow, 12 – outlet, 13 - flame photometer, 14 – outlet.*

Calculation

Penetration of particles through the tested filter (P) is calculated by the formula:

$$P(\%) = \frac{C_2}{C_1} 100$$

C_1 – concentration of sodium chloride aerosol in front of tested filter,

C_2 – concentration of sodium chloride aerosol after tested filter.

3. Results and Discussion

Using European and national standards regarding respiratory protection [12,15,16,17], it was conducted filtration efficiency testing of protective mask M3 at contamination of air by biological agents. Also, it was analyzed its suitability for use, which is conditioned by appropriate resistance to the flow of contaminated air.

All tested samples of the combined filter M3 are composed of a ULPA filter - based glass fibers, whose diameters are on a sub-micron range. According to its technical characteristics of the filtration, this type of filter is in the class P3 particle filter.

It is known that different simulators of chemical, biological and radioactive agents are used for testing the protection effectivness of protective masks. The decision on the use of solid sodium chloride aerosols to simulate biological aerosols in this study was made on the basis of comparing their physical properties.

Aerosols of biological agents are polydispersed systems with particles of different sizes and shapes [18]. Size of virus particles (virions) are from 0.015 to 0.3 μm [19], while bacterial cell can be a length of 0.3 to 20 μm and a diameter of 0.5 to 2 μm [20].

For conducted testing, polydispersed aerosol of sodium chloride was successfully generated in the form of solid aerosol particles. The results of determining particle size distribution of aerosols of sodium chloride by electrical aerosol analyzer are shown in Table 1.

Table 1. Parameters of size distribution particle of generated aerosols from 1% NaCl solution

Particle diameter d_p (μm)	Concentration C_0 (mg/m^3)	Particle median by weight MMD (μm)	Particle median per number NMD (μm)	Geometric deviation σg
0,02 – 2,0	8	0,40	0,03	2,53

Pursuant to the displayed, solid aerosol of sodium chloride is suitable as a simulator of biological aerosols because the size distribution of generated particles of sodium chloride correspond to aerosols of biological agents.

Results of testing the filtration efficiency of combined filter protective mask M3 are shown in Table 2.

Table 2. Resistance values of the combined filter M3 and penetration values of sodium chloride aerosol by air flow of 30 dm^3 /min

		Total resistance of the filter air flow of 30 dm^3/min (Pa)	Aerosol penetration NaCl *P* (%)	Filtration efficiency (%)
Ordinal number of sample	1.	110	0,0005	99,9995
	2.	120	0,0005	99,9995
	3.	120	0,0004	99,9996
	4.	120	0,0005	99,9995
	5.	120	0,0007	99,9993
	6.	110	0,0005	99,9995
	7.	110	0,0005	99,9995
	8.	120	0,0007	99,9993
	9.	115	0,0008	99,9992
	10.	110	0,0008	99,9992
Mean value		**115,5**	**0,00059**	**99,99941**

Obtained mean value of total resistance of all tested samples by flow air of 30 dm^3/min is 115.5 Pa, that is 11.15% less than the maximum allowed total resistance of combined filters wich is 130 Pa. Even all the individual measured values of total resistance for all samples are less than defined 130 Pa, so that the combined filter M3 fully satisfies the quality requirements defined in this standard [17]. By comparison, the fact that the limit of the total resistance of independent particle filter class P3 is 120 Pa (a condition set out in EN 143:2000) [15], only confirms the quality of combined filter samples, because the measured values for each of them are less or equal to a given limit value. In accordance with displayed, the obtained values of the total filter resistance result positive assessment of the suitability of the protective mask M3 for actual use by users.

The results of the tested samples efficiency filtration at air flow of 30 dm^3/min are very high, extremely homogeneous (standard deviation is 0,000145). The resulting mean efficiency filtration is 99.99941%, which is at least five times higher filtration efficiency than the required filtration efficiency defined by standard SORS 8829/04 [17] (the penetration of aerosols is 0.00059%, which is five times less than 3.0×10^{-3} %, which is the limit value). Compared to the standard set for the particle filter class P3 (a condition set out in EN 143:2000) [15], which defines the maximum value of the filter leakage through of 0.05%, the penetration of aerosols through the tested combined filters is over eighty times less. At the same measured value of leakage of each filter individually is smaller in relation to a given standard. In accordance with the above, the obtained values of the efficiency filtration combined filter M3 shows that millitary protective mask M3 in the real conditiones effectively protects the user from contamination by biological agents used in form of solid aerosols.

4. Conclusion

Based on theoretical considerations and experimental results obtained in this work, it can be concluded that millitary protective mask M3 is physiologically suitable for use in real conditions. It is effective device for protection in case of user exposure to contamination by biological agents through the respiratory organs. Filtration efficiency of combined filter M3 is much higher efficiency as compared to the requirements set forth by standards for combined filter and for particle filters. The assumption of the reliability of protective masks M3 for undertaking of prevention measures and combat the spread of these types of respiratory disease in military environment is fully confirmed.

When considering new directions for the development of respiratory care devices in the military, the experience applied in the development of protective nanomasks dedicated for civilian populations should be considered. Based on the antimicrobial properties of nanoparticles (silver oxide, titanium oxide), by impregnation procedure of nanoparticles to a particle filter of combined filter protective mask, improving of the filtration efficiency of biological agents aerosols could be achieved. Further investigations on these matters are warranted, as well as as well as establishing which one of them is most suitable for use in the military devices of respiratory protection.

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