
Studying the Influence of a Filter Box Design on Respirator Resistance to Breathing

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ABSTRACT

Work safety, including respiratory protection, is one of the priorities in modern industries. Thus, the objective of the paper is to study the influence of a filter box design on the air purifying respirator efficiency. Dust holding capacity of filters was determined with dust concentration of about 500 mg/m³ until the ultimate drop of pressure of 500 Pa was reached (according to DSTU requirements EN 143 for filters of Protection rating 2). The following devices were used: AFA VP-10 filters with a diameter of about 36 mm, VLO 200 laboratory balance, an electronic stop-watch timer of HS43 type; the drop of pressure at filter boxes was controlled by using an MKV-250 compensated micromanometer.

It has been established that the design of filter boxes influences the pressure drop of a respirator because of non-use of filter surface (formation of dead zones where the air does not flow) thereby increasing resistance to breathing and decreasing dust holding capacity and protective effect.

The results of laboratory tests showed that the initial breathing resistance of a filter box with a truncated cone is almost 25% lower than that of other boxes, at the same time dust holding capacity and protective effect duration doubled with dust concentration in the air being 500 mg/m³.

Based on the conducted research, it is possible to define rational parameters of filter boxes which will provide air filtration over the whole filtering surface, decreasing initial pressure drop while breathing and increasing protective effect duration.

Keywords: respirator, filter, filter box, drop of pressure.

INTRODUCTION

To provide high quality dust protection, it is necessary to try to apply respirators with low breathing resistance which feature slight impact on workers' functional state. Otherwise, they will not be used during the whole working shift. Thus, research on the issues of improving ergonomic parameters of air purifying respirators is topical.

The resistance value of air purifying respirators depends on the design of filters and filter boxes. The most widely used filters are pleated ones since they are characterized by a considerably large filtering surface including, for example, MSA Safety *Advantage* filters or 3M 6035 P3R filters. The filter boxes are connected to an elastomeric half mask by means of special clamping (bayonet fastening, threading or flange mounting). The size of the outlet port of the box is 27 to 35 mm. The difference between the areas of the inlet and outlet of the filter box results in additional resistance caused by abrupt narrowing of airflow and possible exclusion of part of the filter from the filtration process. This, particularly, can be experienced when the outlet port is placed asymmetrically.

Over recent years there have been undertaken a considerable number of studies dedicated to efficiency of various filter elements. Thus, works by H.C. Wang (Wang et al., 2007) and A.W. Richardson (Richardson et al., 2006) examined properties of filters capturing nanoparticles. Their studies resulted in recommendations on improvement of filter design as well as in providing a required diameter and packing density of fibers. Other researchers headed by L. Boskovic determined work peculiarities for various mechanisms of capturing aerosol particles (Boskovic et al., 2007). This allowed obtaining recommendations on the size of filter areas with which any given particles will be best captured. There are certain research studies on evaluating the effect of air humidity on filter efficiency (Kim et al., 2006). Furthermore, a number of works present results of testing protective properties of filters after being affected by various negative factors including ionizing radiation, their isopropanol and industrial aerosol treatment (Janssen et al., 2003; Janssen et al., 2003). The authors determined that in most cases current filters which completed certification testing are quite reliable and preserve their efficiency throughout the warranty period specified by manufacturers.

However, the works have never considered the research on evaluation of the effect of filter box design on respirator efficiency. Even the works studying the influence of drops of pressure on air purifying respirators depending on air consumption, its humidity, temperature, do not point out which share refers to the filter and which applies to the filter box. Dealing with this issue is important since it will allow finding solutions to decrease breathing resistance (Golinko et al., 2016). The research was conducted to define the influence of the filter box design (namely the outlet port placement) on breathing resistance with dust settling on the filter surface.

METHODS

To conduct the research, three types of widely-used cylindrical filter boxes were made; their sizes are given in Figure 1. All the boxes had similar outlet with a size of 33 mm. They were equipped with polypropylene pleated filters which corresponded to Protection rating 2 according to EN 143. The air flow resistance of the filters with flow rate of 95 l/m was defined by placing them into a special pipe whose diameter was the same as the diameter of the filter. Dust holding capacity of filter boxes with filters was determined on a special testing device (Figure 2) which corresponds to the requirements of EN 143. The cross-section area of the testing chamber was 0.42 m². Dolomite dust concentration was maintained to be 500±50 mg/m³. Dusting time was defined when the filter boxes reached the ultimate drop of pressure of 500 Pa (according to the requirements of EN 143 for Protection rating 2 filters). By means of Ejector 3 and Compressor 1 with flow rate of 60m³/h, the dolomite dust was brought into Testing chamber 13 from Generator 10 through Diffusor 4 and Dust distributor 11. The diffusor and distributor provided uniform

distribution of dust and air flow throughout the height of the chamber of the testing device construction. The air consumption in the chamber was controlled using Airflow meter 6. With the purpose of removing dust from the chamber and protecting the environment, Air exhauster 7 with Cyclone separator 5 were installed.

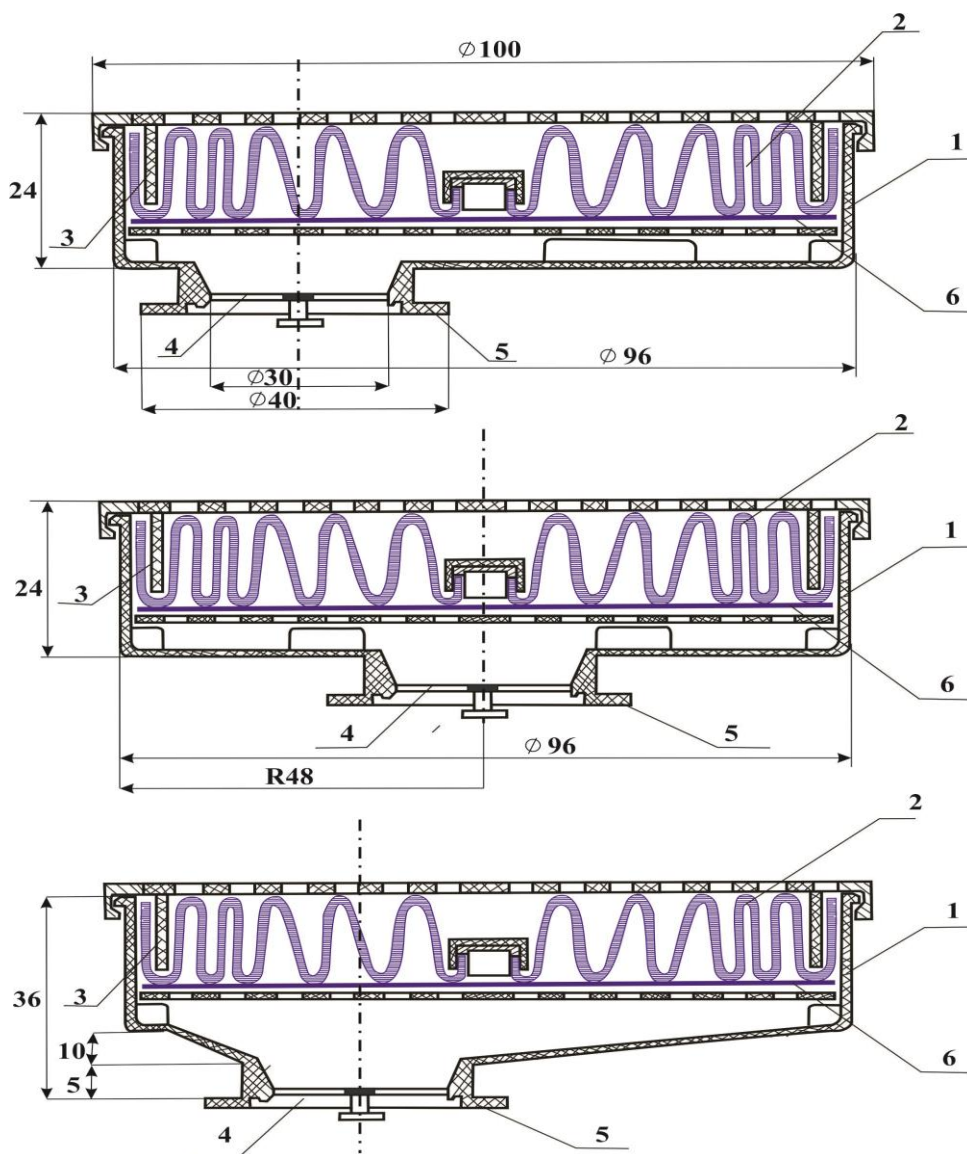


Figure 1. Designs of filter boxes for testing with different placement of the outlet port: 1 – the body of a box; 2 – filter element; 3 – the cover of a box with a clamping element of a filter; 4 – an inhalation valve; 5 – attachment flange for a filter box; 6 – mesh screen.

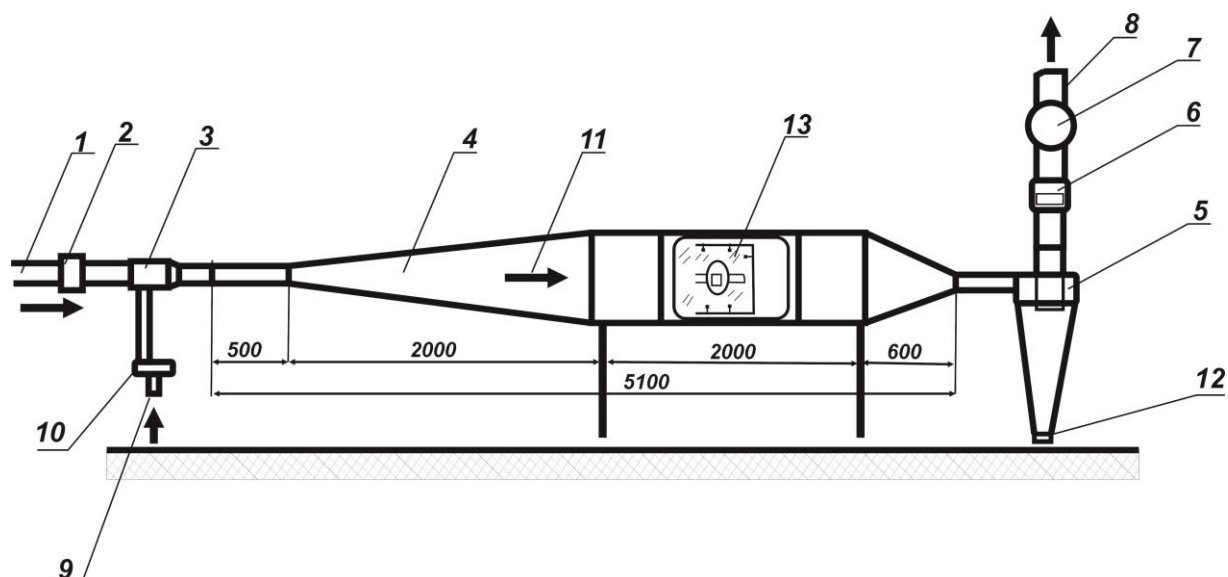


Figure 2. General view of the testing device: 1, 9 – air pressure supply; 2 – forced air purifying pre-filter; 3 – ejector; 4 – diffusor; 5 – cyclone separator; 6 – airflow meter; 7 – air exhauster; 8 – outlet fitting; 10 – dust generator; 11 – dust distributor; 12 – damper valve of a respirator; 13 – testing chamber.

The filter box with a filter was installed in the testing chamber, and a micromanometer was attached to it to control airflow resistance. Through the filter, a constant volume of air with consumption of 95 dm³/min. was drawn by using an aspirator. The dust concentration was estimated with a sampling instrument with an analytical filter AFA which was placed in the middle of the chamber near the tested sample. The sampling was performed with flow rate of 2 l/min. The dust concentration in the chamber was determined by the formula

$$C = \frac{10^3(m_2 - m_1)}{Qt}$$

where m_1 is the weight of the AFA filter, mg; m_2 is the weight of the AFA filter with the dust after sampling, mg; Q is the air consumption, dm³/min.; t is the time of air sampling, min.

The initial mass of the AFA VP-10 filters with a diameter of about 36 mm (produced by OOO Spetskhipostach-D) before and after studying with deposit dust was determined using analytical balance VLO 200 (produced by GOSMETR, 0.1 mg). The time was controlled with an electronic stopwatch of HS43 type (produced by Q&Q Company, within the accuracy of 1 s). The pressure drop at the filter boxes was checked with MKV 250 compensated micromanometer (manufactured by OOO NVF Standart-M, Ukraine) and was estimated by the formula.

$$R = (n_i - n_0)K_1,$$

where n_i is micromanometer reading, Pa; n_0 is the initial resistance of the measuring system, Pa; K_1 is a temperature and atmosphere pressure correction factor.

Every filter box was fitted with 3 filters and an average pressure drop value was estimated. In general, 168 test values were obtained. Based on the results, measurement uncertainty was determined with $P < 0.05$ according to Evaluation of measurement data – Guide to the expression of uncertainty in measurement. – JCGM 100:2008.

RESULTS AND DISCUSSION

As a result of the conducted research, the dependence of pressure differences on the duration of filter dusting (Figure 3) was determined as well as the value of dust holding capacity of filters (Table I) which was defined at the end of the testing.

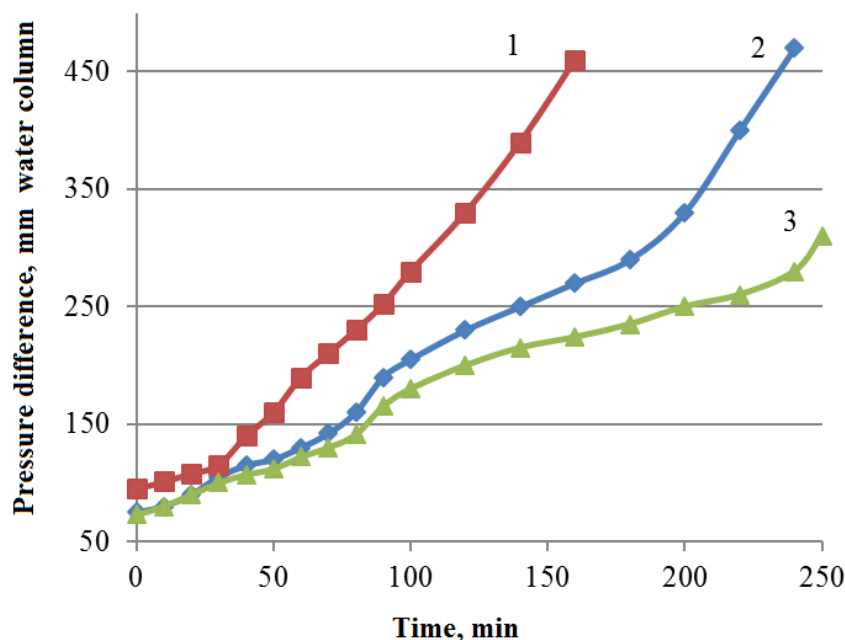


Figure 3. . Dependence of pressure differences on time of dusting: Type 1, 2, 3 of the filter box, correspondingly.

Table I. The Results of Studying Filter Boxes

Determined factors	Filter boxes		
	Type 1	Type 2	Type 3
Initial pressure drop at the filter without a box, Pa with air consumption of 95 dm ³ /min	71.2±3.5	72.3±3.6	70.5±3.5
Initial pressure drop at the filter box with a filter, Pa with air consumption of 95 dm ³ /min	103.2±4.1	98.8±3.9	75.4±3.7
Dust holding capacity, g, featuring air consumption of 95 dm ³ /min and reaching the final breathing resistance of 500 Pa with dust concentration in the testing chamber being 500 mg/m ³	5.5±0.1	7.3±0.1	10.2±0.1
Time of dusting, min	160	240	300

The analysis of the obtained data showed that the placement of the outlet port of a filter box influences the main factors of air purifying respirators: breathing resistance, dust holding capacity, time of dusting (protective effect duration). Filter boxes with a central opening feature additional overall resistance to airflow which is almost 10 % lower than that of filter boxes with a shifted outlet port (See Table I). This is explained by the decreasing area of a dead zone where air hardly flows.

To reach the outlet port shifted off-center, the air flow is to overcome the resistance of a number of pleats placed on its way, since hitting the back plate the air moves back. The farther the air stream is from the outlet port, the higher resistance it has to overcome. The filter box with a central opening features a less prominent phenomenon. Outer airstreams are to cover a shorter distance to the outlet with a larger area involved in filtration processes.

The explanation suggested is proved by viewing the described phenomena in SolidWorks service pack where models were designed according to sizes of the natural samples (Figure 4).

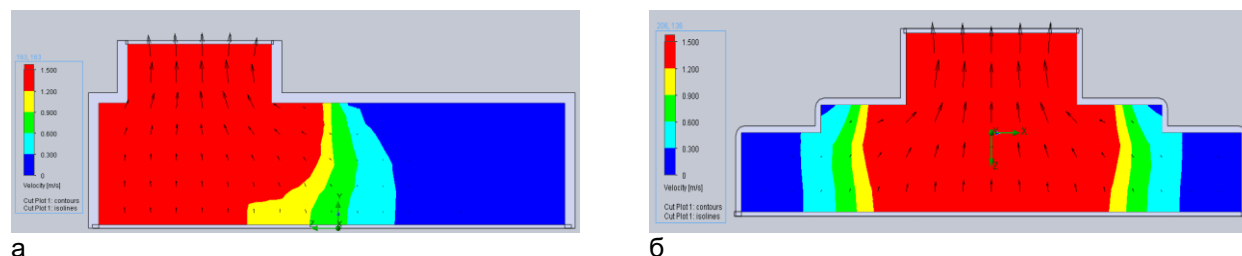


Figure 4. Air motion in filter boxes: Type 1 (a); Type 2 (b).

The least additional resistance was recorded for the filter box with a truncated cone-shaped back cover. This is explained by relatively uniform flotation of the air stream at filter surface compared to other designs. The cone of this filter box provides gradual speed leveling of the airflow on its way to the outlet port with an inhaling valve. Thus, with dust accumulation the filter resistance to the airflow does not increase as much as that of other type boxes.

Decreasing initial resistance and uniform flotation of the air stream at filter functional surface provides increasing dust holding capacity and service term. The results of the study show that dust holding capacity has almost doubled compared to boxes with a shifted outlet port.

CONCLUSIONS

It has been determined that the designs of Type 1 and Type 2 filter boxes influence pressure differences of the respirator due to non-use of considerable surface area of respirators (formation of dead zones where the air does not flow); this results in increasing breathing resistance and decreasing dust holding capacity and protective effect duration. Designs of filter boxes with the backplate made in shape of a truncated cone provide the use of the whole working surface of a filter throughout the filtration process. The results of the laboratory testing of air purifying respirators show that the initial breathing resistance of the filter box with a truncated cone is almost by 25% lower than that of other boxes. At the same time, dust-holding capacity and respiratory-protection period have increased almost twofold with 500 mg/m³ of dust concentration in the air

REFERENCES

- Wang J, Chen DR and Pui DYH (2007) *Modeling of filtration efficiency of nanoparticles in standard filter media*. J Nanopart Res 9, 109–115.
- Richardson AW, Eshbaugh JP, Hofacre KC and Gardner PD (2006) Respirator filter efficiency testing against particulate and biological aerosols under moderate to high flow rates. U.S. Army Edgewood Chemical Biological Center Report for Contract No. SP0700-00-D-3180, Task No. 335, ECBC-CR-085.
- Boskovic L, Agranovski IE and Braddock RD (2007) *Filtration of nanosized particles with different shape on oil coated fibres*. J Aerosol Sci 38, 1220–1229.
- Kim CS, Bao L, Okuyama K, Shimada M, Niinuma H (2006) *Filtration efficiency of a fibrous filter for nanoparticles*. J Nanopart Res 8, 215–221.
- Janssen LL, Bidwell JO, Mullins HE, Nelson TJ. (2003) Efficiency of degraded electret filters, Part I: laboratory testing against NaCl and DOP before and after exposure to workplace aerosols. *J. Int. Soc. Resp. Prot.*, 20:71-80
- Janssen LL, Bidwell JO, Mullins HE, Nelson TJ. (2003) Efficiency of degraded electret filters, Part II: Field Testing Against Workplace Aerosols. *J. Int. Soc. Resp. Prot.*, 20: 81-90
- Golinko VI, Cheberyachko Yul., Cheberyachko SI. and Naumov NN. (2016) Respiratory protection of workers of mining enterprises, *Metallurgical and Mining Industry*, 111-116 (in Ukrainian).