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Investigation of diagnostic methods of protective efficiency of dust respiratory protective devices

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Abstract
It was established that the harmonised standards, which are based on unlike research methods, are used for protective efficiency determination. It was determined that in European Standards regardless different testing methods, the acceptable penetration rate regulations are accepted as identical while the testing conditions vary, especially particles diameters, which size effects the penetration rate to a great extent. Obtained results allow prediction of dust respirator protective effect period by the permissible breathing resistance value when operating at the plant.
Key words: PROTECTIVE EFFICIENCY, PENETRATION RATE, DUST RESPIRATOR, BREATHING RESISTANCE

Relevance

In accordance with "Confirmation of Compliance Act of Ukraine", the use of dust respirator, which has undergone compliance assessment procedure confirmed by documents, in production is allowed. In accordance with the demand of GOST 12.4.041:2006 "Respiratory filter protective device. General specifications (GOST 12.4.041-2001)", the main respiratory filter protective devices function is ensuring of breathing air purification from harmful agents to the level, which is not higher than maximum concentration limit. While the use of poor quality dust respirators causes the increasing of occupation diseases such as dust bronchitis and dust diseases. Thus, the workers respiratory organs reliable protection is the relevant objective, which solution depends on many components. However, from our point of view, the main of them is the ensuring of respirators quality permanent and reliable monitoring at production site; this function was assigned on testing laboratories. It is evidence that the quality level of respirators, which the consumer will receive, depends on testing accuracy. The use of objective control methods, which ensure the sequence and reproducibility of measurement results, is the essential component of this process. It is necessary to know methods permissible errors boundary for rate determination accuracy.

The RPD evaluation problem is deepened by aiming at international cooperation, which requires the unification of approaches to products quality determination and national standards of different countries harmonization. It caused the introduction of new harmonized standards in the territory of Ukraine in 2004. But in fact, there was no harmonization. Inasmuch as the poor translations of European standards appeared without national producer interests considering, hence it became necessary to reequip the testing laboratories by the expansive imported equipment. There is no such equipment in the list of metrological certification and this violates GOST1.5-2004 requirements.

At the same time it should be noted that the RPD production and testing base, which allows turning out of high quality products, has been created in our country. The decision on transition to test methods accepted international standards must be grounded. It would be necessary to conduct products comparative researches for all the testing methods and introduce the correlation coefficient. Thus, there is problem of respirators quality rate evaluation determined by different standards requirements.

In this regard, some work was carried out but definite results were not obtained. Some authors say about methods equivalence while another about their substantial difference. For example, in paper [1], the tests on sodium chloride test-aerosol of dust half-masks of N95 protection index (classification by American standards) were conducted. It was established that their penetration rate was not more than 5%. It allowed maintaining that obtained results are similar to DOP-test, which uses dioctyl phthalate monodisperse aerosol. However, other researches of protective respirator efficiency of P100 index (classification by American standards) showed insignificant penetration rate (about 0.03%) of sodium chloride particles with a diameter of 0,5 – 1,5 microns while for monodisperse aerosols with a diameter of 0,3 micron, the penetration rate is about 1% [2]. In some papers, the most penetrated particles of sodium chloride in the range of 0,5 - 10 microns were determined [3]. Another researcher obtained the highest penetration rate for 0,4 – 0,5 micron particles with different materials. It is interesting that neutral charged particles show more penetration than charged ones [5].

Researches methods

As we can see, there is no definite result. So let us try to investigate the respirator protective efficiency by monodisperse and polydisperse aerosols with the aim of correlation coefficient establishment. The respirator protective efficiency is determined by protection coefficient (C_p), the ratio of harmful substances concentration reduction of respirator. It is determined by formula [6]

$$C_p = \frac{100}{C}, \%$$

where C – general penetration rate, which is determined by experiment.

The general penetration rate C (%) expresses disperse particles quantas, which penetrated through RPD or its elements and is the function of one or several coefficients named below:

filter penetration rate;

obturation line inleak rate;

expiratory valve penetration rate.

The following standards can be used for determination of rates mentioned above: GOST EN 143-2002 “Respiratory protective devices. Particle filters. Requirements, testing, marking”, or GOST 12.4.156-75 “Occupational safety standards system. Industrial filtering gas masks and respirators. Nephelometric method for determination of all-service canisters penetration coefficient of oil mist”, and GOST EN 140-2004 “Respiratory protective devices. Half masks and quarter masks. Requirements, testing, marking”, or GOST12.4.157-75 “Occupational safety standards system. Industrial filtering gas masks and respirators. Nephelometric methods for determination of penetration coefficient of oil mist under the face part”. Table 1 shows the RPD protective properties requirements in Ukraine and EU regulations.

Standards GOST EN 143-2002 and GOST EN 140-2004 provide aerosols penetration research by methods of using of sodium chloride, paraffinic oil and sulphur hexafluoride. Their nature is that prepared mixture in generator (sodium chloride spray equipment, or bubbling type - paraffinic oil for test-aerosol) with known test-aerosol concentration (2% solution) and with a certain speed (100 l/min) runs into a test chamber where respirator is located (Fig. 1). Using the special equipment, the mask air is sucked at a speed of 95 l/min, this air gets into the analyzer for particles concentration determining (for sodium chloride - flame photometer, for paraffin oil - integrated photometer, for sulphur hexafluoride - infrared spectroscopy measurement analyzer). As a result, the penetration rate is calculated as ratio of test-aerosol concentrations before and after RPD. It should be noted that these methods provide obtaining of polydisperse aerosols within the range from 0,02 to 2 microns with an average diameter of 0.6 microns for sodium chloride and 0.4 microns for paraffin oil.

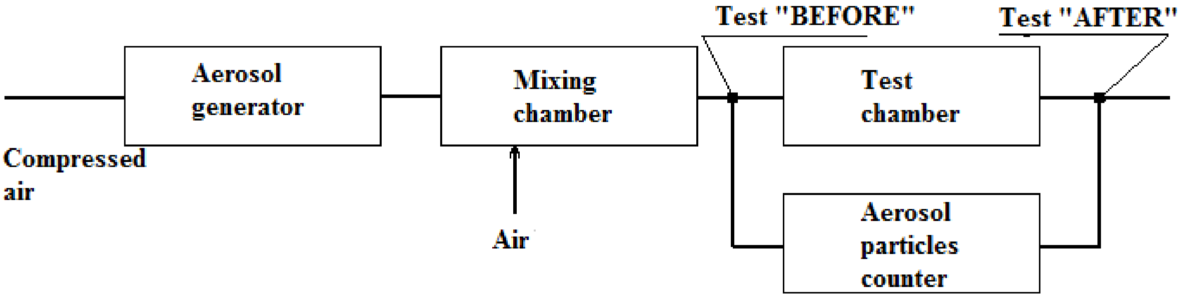

Figure 1. Basic diagram of respirator testing by test-aerosols

Table 1. Test-aerosol penetration rate requirements

Index	Protection rating					
	Low		Medium		High	
	UA	EU	UA	EU	UA	EU
Filter penetration rate	< 10	20	< 1	6	< 0,1	0,05
Obturation line inleak rate	> 10	25	1 - 10	11	< 1,0	5

Note:
1. Protection rate in Ukraine is determined by GOST 12.4.041-2001.
2. Protection rate in the countries of the European commonwealth is determined according to EN 149.
3. The requirements in Ukraine are similar to the requirements of EN 149 from 1st October 2004.

According to GOST 12.4.156-75 and GOST 12.4.157-75, the turbine oil is used as test-aerosol. The method is similar to above mentioned, but formed oil aerosol is monodisperse with particles diameter of 0,28 – 0,32 micron, and the optical photometer is used for concentration determining. Table 2 shows the testing conditions by above mentioned test-aerosols.

The researches results

Several identical dust filters elements of RPA-TD respirators made of polypropylene from one batch at production site RPE “Standart” were taken for conducted analysis examination and correlation coefficient determination between penetration rate values of different testing methods. Test-aerosol testing was conducted in special laboratory accredited with the National Accreditation Agency of Ukraine (certificate 2T127 from 22 September, 2008) in accordance with above mentioned standards. Five samples were used for each experiment. The results are shown in Table 3.

Table 2. Test-aerosols testing methods and conditions

Test-aerosols	Sodium chloride	Paraffin oil	Oil fog
Air flow rate	95 l/min	95 l/min	30 l/min
Particles diameter	0,6 micron (mass median)	0,4 micron (Stokes diameter)	0,28 – 0,32 micron (mass)
Aerosol concentration before testing	8±4 mg/m^3	20±5 mg/m^3	250±50 mg/m^3
Concentration measuring means	Flame photometer (C = 0,001 – 100 %)	Integrated photometer (C = 0,003 – 100 %)	Photoelectric nephelometer FAN-A
Exposure time	30 s in 3 min after the beginning of testing		1 min in 10 – 15 s after OF flow

Penetration rate calculating formula	$C = \frac{C_1}{C_2}$, where C_1 – sodium chloride concentration after filtering; C_2 – sodium chloride concentration before filtering	$C = \frac{I_2 - I_0}{I_1 - I_0}$, where I_2 – photometer index after filtering ; I_1 – photometer index before filtering; I_0 – photometer background indices	$C = \frac{F - F_c}{F_0}$, where F – photometer luminous flux after filtering; F_c – background light scattering; F_0 – photometer luminous flux before filtering

Table 3. RPD samples test results

Tested sample	Test-aerosol penetration rate						
	Sodium chloride			Paraffin oil			Oil fog
	After supply	After temperature impact	After mechanical impact	After supply	After temperature impact	After mechanical impact	
Filter RPA-TD made of “Eleflen"	0,08 ± 0,03	1,44 ± 0,17	0,084 ± 0,024	0,24 ± 0,06	3,54 ± 0,52	0,26 ± 0,05	0,75 ± 0,02
Respirator Lepestok (with checker filing)	0,093 ± 0,05	-	0,096 ± 0,05	0,19 ± 0,07	-	0.9 ±	0,38 ±0,03

It is interesting that acceptable penetration rates regulations are accepted as identical (Table 1) when testing according to any method regardless different testing methods in European standards. However, studying the distribution spectra of test-aerosol particles noted in the regulations, we can see:

NaCl size range is from 0,04 micron to 1 micron with their maximum number of 0,6 – 0,8 micron fraction;

paraffin oil particles size range is 0,06 - 2 microns with their maximum number of 0,3 – 0,4 micron fraction;

oil fog test-aerosol particles distribution is in the range of 0,28 – 0,32 micron.

It is known that the most penetrating aerosols size is in the range of 0,2 to 0,4 micron depending on the filter thickness, fiber diameter, their packing density and filtering rate. At that case, NaCl aerosol particles will be filtered out more than paraffin oil particles due to their particles size of up to 0,1 micron. At that, it is necessary to consider that 2 microns particles mass is several times larger than 1 micron particles ($m = \frac{4}{3}\rho\pi R^3$, where ρ – particles density; R – particles radius) [7]. Consequently, testing results by these methods can vary due to concentration determining by mass method. Thus, one and the same filter may be significantly lower when NaCl testing and larger in size than paraffin oil, and at the same time, much larger by test-aerosol than oil fog.

From the experiments results, we can establish the testing methods correlation coefficient. It should be noted that its value will depend on the filter material type. Thus, the test-aerosols penetration rates for paraffin oil and NaCl can be determined by known value of oil fog penetration rate by formulas given in Table 4.

Table 4. Coefficients determination formulas

Material of RPD	Sodium chloride		Paraffin oil	
	After supply and mechanical impact	After temperature impact	After supply and mechanical impact	After temperature impact
“Eleflen”	$C_{NaCl} = 0{,}15C_{OF}$	$C_{NaCl} = \frac{C_{OF}}{0{,}5}$	$C_{PO} = 0{,}3C_{OF}$	$C_{PO} = \frac{C_{OF}}{0{,}2}$

FPP	$C_{NaCl} = 0{,}25C_{OF}$	-	$C_{PO} = 0{,}5C_{OF}$	-

Conclusions

The harmonised standards GOST EN 143-2002, GOST EN 140-2004, and domestic standards GOST 12.4.156-75, GOST 2.4.157-75 based on different testing methods are used for RPD protective properties determination. This causes the variations of obtained results and inability of their repeatability. The determination of test-aerosols filtering efficiency of NaCl and paraffin oil is suggested in harmonised standards, i.e. the determination of filter material ability to entrap liquid and solid aerosols. However, regardless different testing methods, European standards acceptable penetration rates regulations are accepted as identical while the testing conditions vary, especially particles diameters, which size effects the penetration rate to a great extent. It violates GOST1,5 – 2003 requirements.

From our point of view, it is necessary to leave the test-aerosol oil fog testing as it is monodisperse. It provides particles dispersion quick control, which is absence in European methods. An additional point is that laboratories can be equipped by domestic equipment instead imported. It has severe requirements to RPD quality control comparing with other methods.

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