Penetration Through CE-Marked Respirators - Cut-Based Versus Manikun-Based Method

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PENETRATION THROUGH CE-MARKED RESPIRATORS – CUT-BASED VERSUS MANIKIN-BASED METHOD

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INTRODUCTION

Engineered nanomaterials have been released into the workplaces due to huge progress of nanotechnology in last years. Not only particles in nanometer size range, but also fibers like carbon nanotubes (CNTs) are used in wide range of applications such as electron field emitters, conductive plastics, semiconductor devices and medical devices (Endo et al., 2008; Wang et al., 2011; Chen et al., 2014). Furthermore, workers in some industries may be exposed continually to dust of various size and composition during extraction and grinding in mining (Vrins and Hofschreuder, 1988) or demolition, concrete cutting, surface grinding and sanding processes in constructions (Flanagan et al., 2003). Compared to ingestion or absorption through the skin, inhalation is considered as the main route of entry of nanoparticles (<100 nm) to the respiratory system.

Inexpensive and preventive protection of workers from exposure to hazardous aerosol particles is to be wearing filtering respiratory devices recommended by many organizations worldwide. Filtering facepiece respirators (FFR) are widely used against harmful respirable aerosol particles to protect the user if worn properly.

There are well-known standards describing how to perform the testing of filter efficiency, such as EN 1822 for HEPA and ULPA filters; EN 143 and 149 for respirators. The personal protective equipments (PPE) placed within the european market has to be certified by European Norm (EN) and marked with "Conformité Européen" (CE) mark indicating European Community (EC) conformity, according to Personal Protective Equipment directive (89/686/EEC). The PPE has to be tested according European legislation based on EN 13274-7:2008, Determination of particle filter penetration, which uses for testing of the respirator penetration non-neutralized polydisperse 1% solution of sodium chloride and paraffin oil at flow rate of 95 lpm. The NaCl particles are supposed to be generated as a polydisperse aerosol having particle size range approximately 40-1200 nm (MMD ~600 nm). In the case of paraffin oil the resulting size distribution is supposed to be log-normal with MMD of 400 nm and GSD of 1.82. The MMD of generated aerosol is usually supposed to be close to Most Penetrating Particle Size (MPPS) through the filtration material.

This work presents size-resolved penetration testing of 13 commercially available filtering facepieces (FFP1, FFP2 and FFP3 filtering classes) on pieces of filtration material (47 mm in diameter) cut from various FFRs (referred as cut-based). Second objective of this work was to measure the size-resolved penetration of 9 complete FFRs (selected from identical filtering facepieces as in the first case) placed on the manikin (refered as manikin-based). The results obtained by these two methods were compared and the real MPPS of all FFRs obtained by both methods were estimated.

EXPERIMENTAL SETUP

The filter testing system used in this study was developed in the Laboratory of Aerosol Chemistry and Physics (LACP) of the Institute of Chemical Process Fundamentals (ICPF), v.v.i., Czech Academy of Sciences (CAS). The whole system basically consists of three main parts: particle generation system, filter holder including the flow control through the measured material and the detectors (see Fig. 1). The LACP filter testing system was similar for both measurement methods - cut-based and manikin-based measurements. The only difference was in the filter holder part (simple filter holder for cut-based measurements was replaced by sealed box with manikin) and additional valve for cleaning the box with manikin. The whole set-up is described in details elsewhere e.g. Zíková et al. (2015).

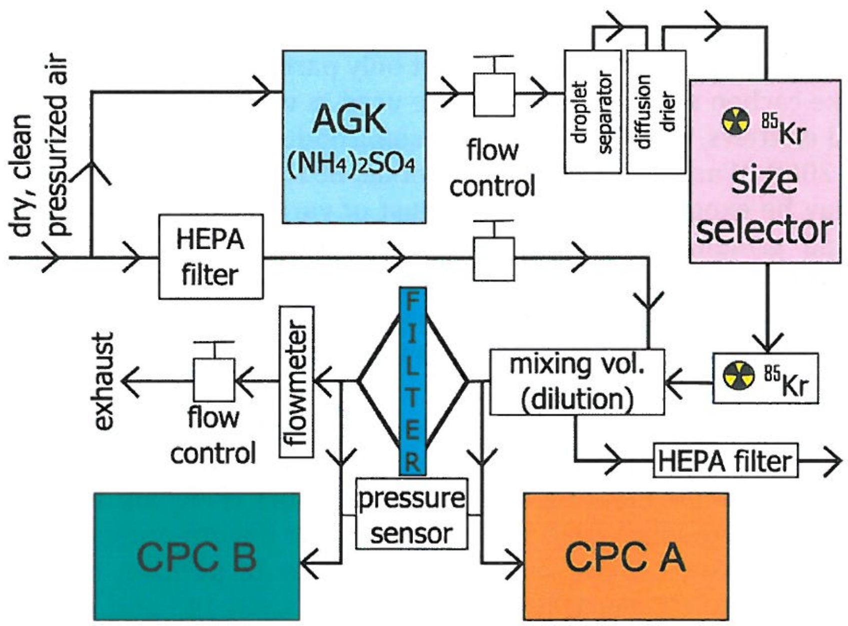

Fig. 1: Setup of the LACP filter testing system for cut-based penetration measurement.

TESTED MATERIALS

Within the presented study thirteen CE-marked commercially available FFRs (see Tab. 1) of five different brands were selected (3M, Refil, Moldex, Europa Safety and Segre) from all three protection classes FFP1 (3 respirators), FFP2 (4 respirators) and FFP3 (6 respirators). Two representative pieces of filtering material with diameter of 47 mm were cut from each FFR as received (i.e. without any conditioning). These samples were used for measurement of penetration of cut-based filtration material. In the case manikin-based measurements nine out of the thirteen FFRs of four different brands (3M, Refil, Moldex and Segre) were selected (see. Tab. 1). The measurements on all the FFRs were repeated to check the reproducibility of the measurement method. Moreover, for all the measurements 2 pieces of the FFR of the same type were measured to check for the inhomogeneity between the two identical pieces as well as the variability within one piece of FFR.

Tab. 1: List of FFRs used for the measurements using both methods - cut-based and manikin-based size resolved penetration; grayed FFRs were used for both methods; all of the FFRs are made out of polypropylene.

FFR test number	FFR	Protection class	Certification
1	Refil 511	FFP1	CE 1024
2	Moldex 3505	FFP3	CE 0121
3	3M 9312+	FFP1	CE 0086
4	RespAir C	FFP3	CE 0086
5	Refil 831	FFP2	CE 1024
6	3M 8835	FFP3	CE 0086
7	Moldex 3405	FFP3	CE 0121
8	Segre CN P3	FFP3	CE 0194
9	Moldex 2405+	FFP2	CE 0121
10	3M 9310	FFP1	CE 0086
11	3M 9322	FFP2	CE 0086
12	Refil 731	FFP2	CE 1024
13	Segre CN P3 V	FFP3	CE 0194

RESULTS AND CONCLUSIONS

In the case of cut-based penetration measurements, differences in penetrations were found not only between two identical respirators, but as well between two filters from the same piece of respirator. The real MPPS was found to be between 30 and 60 nm and corresponding maximum pentration between 0.05 and 20 % for all cut-based FFRs (see Tab. 2 and Fig. 2). In the case of manikin-based penetration measurements, the real MPPS was found to be between 25 and 65 nm and the corresponding maximum penetration between 0.09 and 18 % (see Tab. 2 and Fig. 3). Detailed tests revealed that penetration levels increased when the respirator was not sealed around the face of the manikin and reached up to ~50% so the real protection level provided by these filtering facepieces may be even lower if the respirator does not have a perfect fit.

Comparing the two measurement methods, the cut-based mesurements in the filter holder and the manikin-based measurements of respirators in the experimental chamber are in good agreement and a significant correlation of R^2=0.90 was obtained. Generally, for almost all of the tested FFRs the penetration measured on cut piece of filtration material exhibited lower values than in the case of the whole FFR measured on the manikin face. This could be given by several facts. First, the cut-based filter measurements (with effective diameter 42.54 mm and corresponding effective filter area 14.27 cm^2) were challenged with the flow of 9 lpm with corresponding face velocity equal to 10.56 cm/s, which is equivalent to 95 lpm aerosol flow at assumed 150 cm^2 of effective filter area for the respirator in the case of manikin-based measurements. During the manikin-based measurements we used 95 lpm aerosol flow at assumed uniform 150 cm^2 of effective filter area for all the respirators which in reality may vary from respirator to respirator as well as the respirator style (flat fold or cup shaped, with/without exhaling valve) and this could cause the discrepancy in the percentage penetration results.

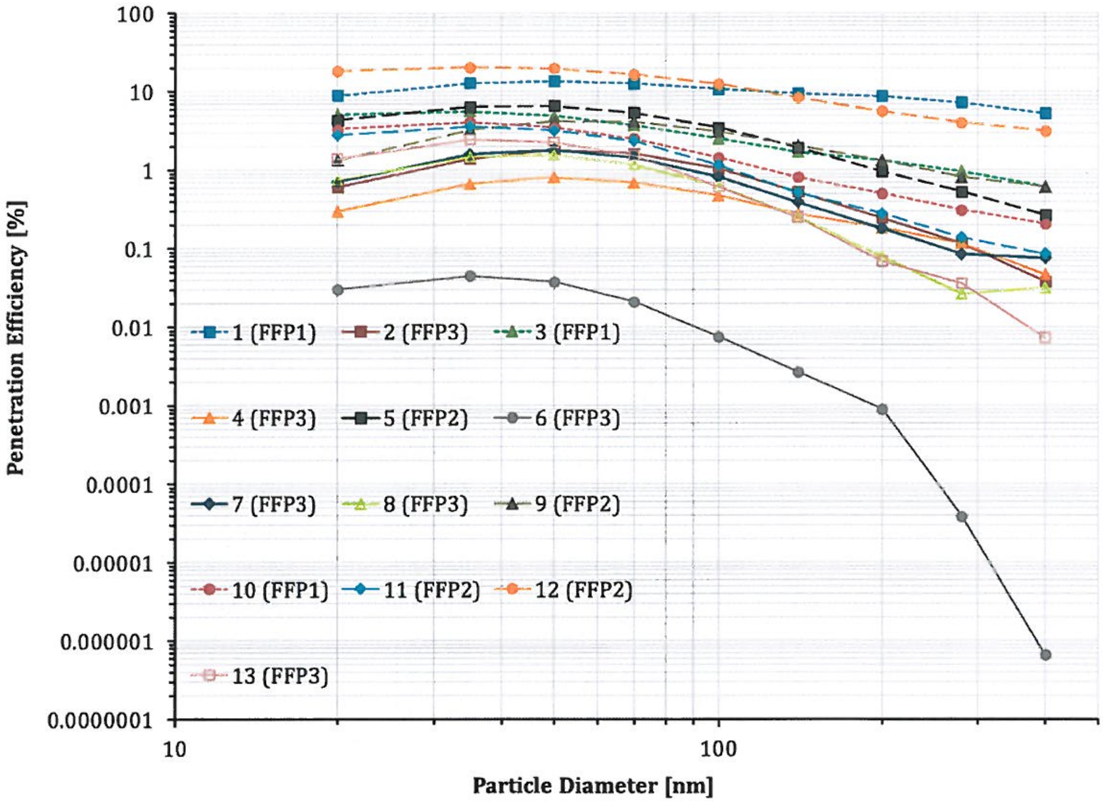

Fig. 2: Average size-resolved penetration of FFRs for cut-based measurement method.

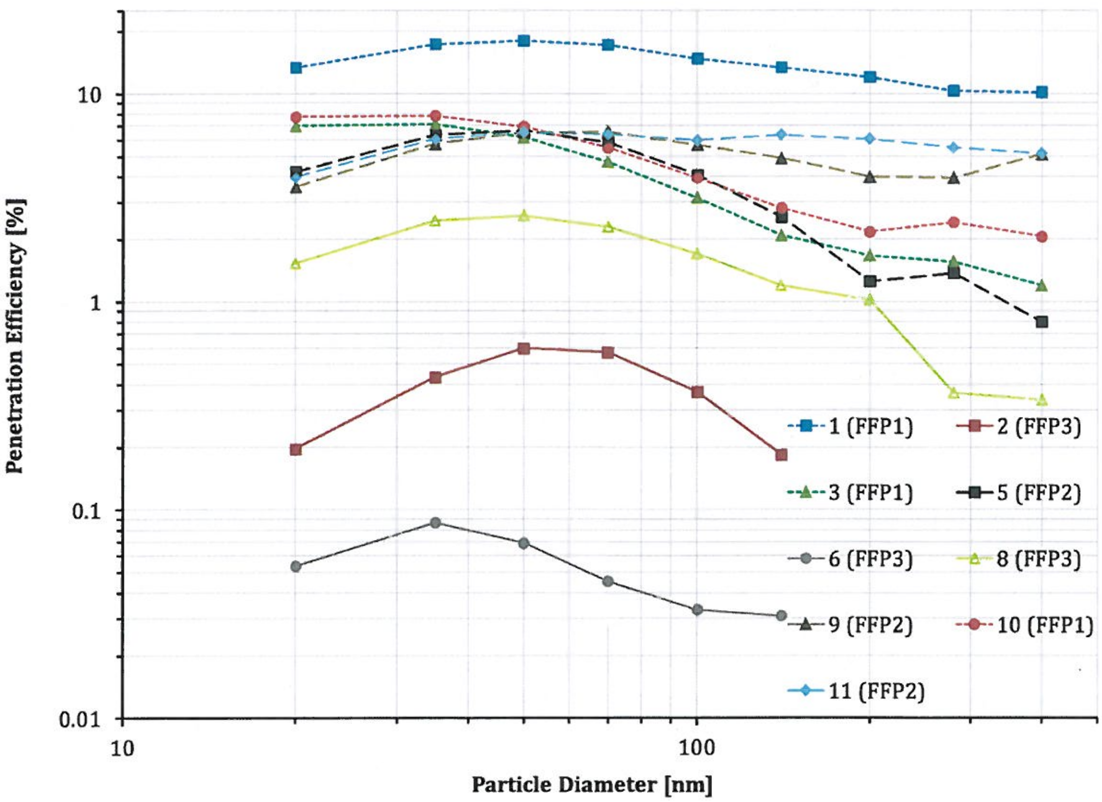

Fig. 3: Average size-resolved penetration of FFRs for manikin-based measurement method.

Tab. 2: Results obtained from size-resolved penetration measurements using both methods - cut-based and manikin-based size resolved penetration; grayed FFRs were used for both methods.

FFR test number	Cut-based penetration		Manikin-based penetration	
	MPPS [nm]	Pressure drop [kPa]	MPPS [nm]	Pressure drop [kPa]
1	57.8	0.07	52.8	0.07
2	52.4	0.15	54.7	0.12
3	28.1	0.07	25.0	0.08
4	43.3	0.21		
5	42.5	0.11	44.4	0.12
6	36.7	0.23	36.0	0.15
7	46.5	0.15		
8	43.8	0.21	48.1	0.17
9	58.7	0.18	64.4	0.15
10	32.5	0.08	26.5	0.06
11	32.7	0.12	43.0	0.10
12	40.4	0.04		
13	38.8	0.19		

Second, during the filter measurements the homogeneity of the material was determined by measuring four filters cut out from two identical FFRs and the results suggest rather non-homogenous distribution of the filtering material in some respirators. And this inhomogeneity within the FFR could cause some shortcuts for the particles penetrating the material of the respirator thus enhancing the measured penetration.

Furthermore, the results obtained during this work show that the standard filter testing methods are based on misleading assumption possibly leading to overestimating of the FFR performance (taking into account the suggested MPPS at 200 - 300 nm by EU norms compared to real ones - all bellow 100 nm and use of polydisperse versus monodisperse aerosol). Therefore, such a study could serve also as a basis for improvements in the filtration efficiency standard method, which seems to give insufficient and in some perspectives limited or even misleading information.

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