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INTERCOMPARISON STUDY FOR CAPABILITY OF PM_{10} AND $PM_{2.5}$ CAPTURE BY FILTER MATERIALS USED IN SELECTED FACE MASKS

Abstract
Due to often excess of the daily limit value for PM_{10} particles in the air, it is common to use anti-dust masks by citizens of big cities in Poland. This paper reports an intercomparison study on efficiency of filter materials used in popular face masks in range of capture PM_{10} and $PM_{2.5}$ fractions. The tests were carried out in Krakow in the winter season for five different filters and in addition for a three- or six-layer medical mask. The measurements were conducted in outdoor conditions using referential dust sampler with PM_{10} or $PM_{2.5}$ inlet heads. The filtration efficiency were evaluated by weighting method with consideration of two filtration stages (the first stage was the tested filter and the second stage was the final filter made of glass microfiber). Obtained efficiencies for PM_{10} and $PM_{2.5}$ capture by filters from typical anti-dust masks were similar and included in range respectively 84.6–98.0 and 82.9–97.9%, whereas in case of tested medical masks they were significantly lesser and equal respectively 33.3–72.0 and 34.9–54.5% depending on number of layers. Using appropriate anti-dust face masks can reduce concentration of suspended particles in inhaled air by significant value. It is not recommended to use ordinary medical masks in this purpose.

Keywords
anti-dust masks, filtering efficiency, $PM_{2.5}$, PM_{10}, personal exposure reduction

1. INTRODUCTION

Air quality in many European countries leave a lot to be desired [1]. The air which provides existence of highly developed living forms on Earth and in key means decides about quality of life and health of humanity and plants, became receiver and medium of toxic substances

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mainly due to presence of suspended particles and their adsorptive capabilities. This issue is especially important in heavily urbanized areas because of high density of population and in most cases, higher levels of air pollution. Situation like that is observable, i.a., in many of large Polish cities [2–12]. In this cities there are relatively often noticeable over-normative concentrations of suspended particulate matter such as PM_{10} and $PM_{2.5}$ (the fraction of particles with an aerodynamic diameter up to respectively 10 and 2.5 μm) in ambient air, especially in the winter season. This situation is caused by many factors, among many of them the most frequently mentioned one is excessive emission of fine dust from domestic heating boilers and stoves, but significant part belongs to primary and secondary dust emissions from road transport and air emissions form industrial plants. In addition there is observed an effect of pollutant concentrations increase in ambient air being intensified in winter months, when thickness of mixing layer is being reduced, and vertical air flows are considerably undermined, what is being noticed, i.a. in Krakow (Southern Poland) [13, 14].

Meanwhile there is observed growing public awareness of citizens in bigger cities, whose under self-protection from air pollutions more often reach for face masks with anti-dust filters, called also anti-smog masks (especially when they include layer of activated carbon). Nowadays Polish market offers plentiful scope of face masks and removable filters of different types in wide price range, and their efficiency is defined by certificates and producers declarations. Tests presented in this research were carried out to intercompare the filtration efficiencies of filter materials used in selected face masks in range of differences in capture capabilities of PM_{10} and $PM_{2.5}$ fractions in conditions approximated to actual (aspirating ambient air with particles after separation dust fractions larger than tested). In addition medical face masks were tested, which despite of different original purpose, was considered in research due to low price and, as a consequence, high popularity in use. Research were carried out in Krakow in the winter period, when high concentrations of PM_{10} and $PM_{2.5}$ in air are observed. This conditions present~~s~~ the most often situation when this kind of mask are used.

There are studies evaluating efficiencies of anti-dust face masks and/or estimating health benefits as a result of their usage [15–21]. Nevertheless this work is based on rarely seen method, using specially prepared filter materials as a preliminary filters in referential suspended dust sampler $PM_{10}/PM_{2.5}$ and weight analyze to evaluate the mass of dust retained and passed through the tested material (without testing the effectiveness of the entire face mask resulting from its possible leak). Similar methodology was used in the work [22], but presented in mentioned work results pertain only to filtration efficiency for $PM_{2.5}$ fraction, including smaller number of tested filters and partly different anti-dust masks e.g. high-efficiency half masks commonly used in construction works and industrial plants.

On the other hand, some results of initial tests on the filtration efficiency of selected materials used in popular face anti-dust masks with regard to total suspended particles (TSP) were presented in the paper [23]. These tests were carried out in laboratory conditions in a well ventilated room without pre-selection of dimensional particulate matter fractions and included, among others, three-layer medical face masks. The TSP retention efficiency for this type of filter material was obtained at 67–79%. In this paper, the filtration efficiency of this material was evaluated in relation to the PM_{10} and $PM_{2.5}$ fractions for the case of single and double medical masks corresponding respectively to three and six filtration layers.

2. MATERIALS AND METHODS

Studies were carried out for popular face mask filters used by citizens of Krakow. To the group of tested filter materials belong more expensive filters using HEPA class or additional activated carbon layer, as well as cheap mask used mainly by medical personnel to retain biological aerosols. General view of individual types of used filters shows Figure 1, and Table 1 presents their characteristics.

Tested materials also outstand with shape, way of usage/installation in mask, size and thickness of the filter. Mentioned physical attributes have no direct influence on filtration materials properties, but significantly determine effect resulting from usage of filters, i.e. by precise adherence to face, simple and comfortable usage. These attributes were not considered in the present research, and filters were rated just and only by filtration efficiency in relation to individual particulate matter fractions in specified conditions of dusty air aspiration.

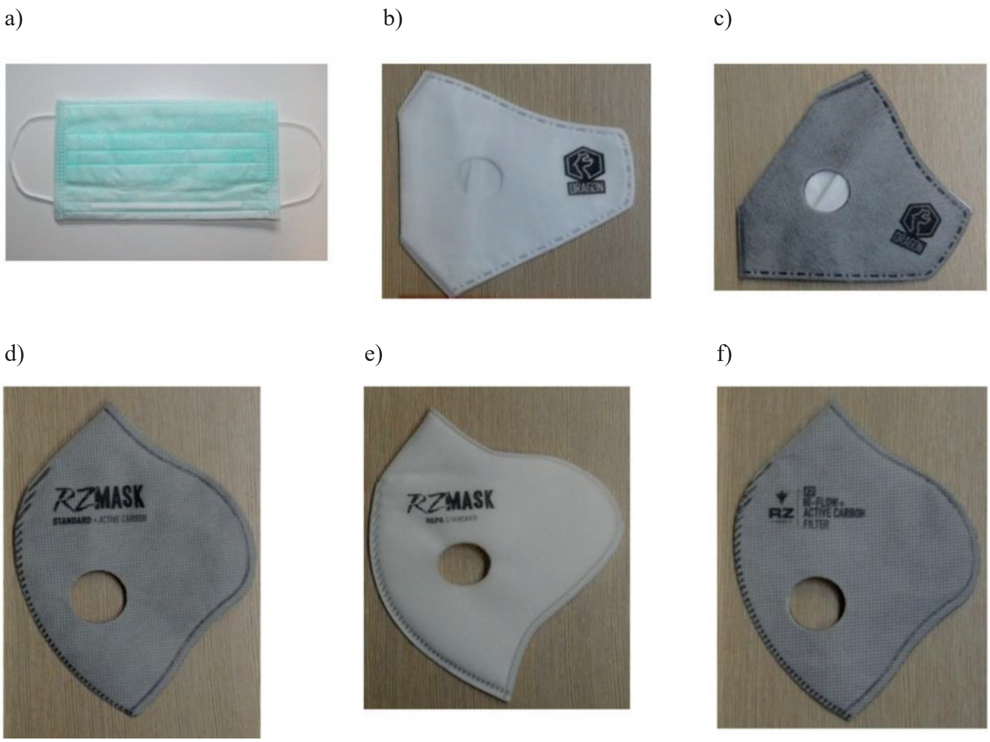

Fig. 1. Filters used in the research: a) medical mask (MM); b) dragon standard (DS); c) dragon with activated carbon (DC); d) RZ mask F1; e) RZ mask F2; f) RZ mask F3

Research of filtration efficiency for individual filter materials was carried out in the winter half year in Krakow (from November 2017 to April 2018), simulating intensive usage conditions.

In this purpose some quantity of ambient air were run through each of tested filter materials (the first stage of filtration) with constant velocity and the mass of particles unretained on the tested filter was evaluated by using a highly efficient glass microfiber filter Whatman GF/A with diameter 47 mm as the final filter (the second stage of filtration). The air aspiration was carried out in outdoor conditions on the roof of fifth floor building with using referential dust sampler type LVS-3 (Atmoservice) with removable PM_{10} or $PM_{2.5}$ inlet heads (capturing dust fractions above 10 or 2.5 µm and passing through fractions PM_{10} or $PM_{2.5}$) that comply with EN 12341:2014.

For each of tested filters dust sampler was working with normalized for this type of samplers (according to EN 12341:2014) air suction velocity of approx. 2.3 m^3/h and actual in a given period particulate matter concentration in the air. The aspiration time equaled from 24 to 48 hours and depended on the type of tested filter and PM_{10} or $PM_{2.5}$ air concentrations that occurred in day before particular test. In case when the filter materials had predictably higher efficiency and when suspended particulate matter concentrations in air were low, the time was extended to collect more mass of particles on tested and final filters.

Table 1. Characteristics of filter materials used in the research

No.	Mask brand	Filter type	Mask / filter symbol	Filter description, efficiency declared by the manufacturer
1	Romed	medical mask	MM	filtration material consist of 3 layers of hypoallergenic non-woven fabric, filters up to 98% of biological aerosols
2	Dragon	standard	DS	N99 filter, declared efficiency 99.4% for $PM_{2.5}$*
3		activated carbon	DC	N99 filter with activated carbon layer inside, filters up to 99.4% of $PM_{2.5}$*
4	RZ Mask	F1	RZF1	filter with activated carbon layer inside, declared efficiency up to 99.9% particles > 0.1 µm
5		F2	RZF2	HEPA type filter, filters up to 97% of particulate matters > 0.1 µm
6		F3	RZF3	HEPA and activated carbon layer, filters up to 97% of particulate matters > 0.1 µm

* examined by Central Institute for Labour Protection – National Research Institute in Poland

The procedure of preparing tested filter materials included cutting out discs with diameter of approx. 47 mm from filters, drying them in laboratory dryer in 105°C for at least two hours and cooling down in desiccator to ambient air temperature. Changes of filters masses result from particulate matter collection on them were evaluated with laboratory scale Sartorius CP64 with weighing accuracy of 0.0001 g.

Obtained masses in weighing process were used to calculate capture efficiency of particles for each of tested filters by using following equation:

$$\eta = \frac{m_1}{m_1 + m_2} \cdot 100\%$$

where:

m_1 – mass of particles retained on the tested filter [g],

m_2 – mass of particles retained on the final filter [g].

The filtration efficiency was additionally evaluated in the context of the possibility of reducing the concentrations of PM10 in the inhaled air to the permissible level determined for the averaging time of 24 hours [23] with the assumed initial concentration.

3. RESULTS AND DISCUSSION

Obtained in carried research average, minimum and maximum values of filtration efficiency for individual types of filter materials are presented in Table 2 (capturing PM_{10} fractions) and in Table 3 (capturing $PM_{2.5}$ fractions). In case of the filter cut from medical mask, there were tested both single three-layer filter (MM) and two filters put on each other making summarily six-layer filter (MMx2). Therefore it was possible to check potential filtration efficiency of this masks in situation, when two medical masks were used at once. Considering using procedure of drying filter materials, average values of PM_{10} and $PM_{2.5}$ inlet concentrations showed in Tables 2 and 3 pertain only to non-volatile particles (unable to evaporate in temperature 105°C).

Table 2. The results of measurements of tested filter efficiencies for PM_{10} fraction

No.	Mask / filter symbol	Number of tested filters	Total volume of aspirated air [m³]	Total sampling time [h]	Average PM_{10} inlet concentration [μg/m³]	$PM_{2.5}$ filtration efficiency (η) [%]	
						average	range
1	MM	2	109.0	48	22.0	40.0	33.3–46.7
2	MM×2	1	54.5	24	91.8	72.0	–
3	DS	5	440.8	167	33.8	91.3	86.2–97.2
4	DC	3	383.4	168	40.7	92.4	90.3–94.3
5	RZF1	3	164.3	72	73.8	95.8	95.0–96.5
6	RZF2	3	164.7	72	71.7	88.5	84.6–91.5
7	RZF3	3	205.5	90	64.2	97.6	97.3–98.0

As the carried research show, the filters used in typical anti-dust face masks (DS, DC, RZF1, RZF2 and RZF3) retain from 83 to 98% of PM_{10} and $PM_{2.5}$ suspended particles and the highest efficiency in this range (not less than 95%) showed filters RZF1 and RZF3, which in addition were enriched in activated carbon layer. Whereas three-layer medical mask (MM) is characterized by low capture efficiency of PM_{10} and $PM_{2.5}$ fractions, that varies between 33 and 47%.

Table 3. The results of measurements of tested filter efficiencies for PM2.5 fraction

No.	Mask / filter symbol	Number of tested filters	Total volume of aspirated air [m³]	Total sampling time [h]	Average PM_{10} inlet concentration [μg/m³]	$PM_{2.5}$ filtration efficiency (η) [%]	
						average	range
1	MM	3	164.1	72	35.7	36.6	34.9–37.5
2	MM×2	1	61.6	27	44.6	54.5	–
3	DS	3	202.8	89	20.7	90.8	84.2–96.3
4	DC	5	383.0	168	33.2	92.1	86.2–96.4
5	RZF1	3	202.5	89	56.4	96.5	95.6–97.9
6	RZF2	3	219.2	96	35.0	89.5	82.9–93.7
7	RZF3	3	207.7	91	52.5	96.3	95.5–97.2

Average efficiencies in range of capturing PM_{10} and $PM_{2.5}$ fractions for each type of filter material were usually similar, except of the case, when double medical mask (MM×2) was used. A filter obtained in that way, consisted of six layers, was characterized with significantly less capturing efficiency of $PM_{2.5}$ than PM_{10}. Considering the fact, that medical masks (MM) have no dedicated filter for capture of fine suspended particulate matter, and that they have especially low price (about 0.11 euro/pcs), obtained average efficiency on the level of approx. 40% for PM_{10} fraction and of approx. 37% for $PM_{2.5}$ fraction is a huge surprise. Using double medical masks allows to significant increase of this efficiency, especially in relation to PM_{10} fraction, however it is still not much higher than 70%.

The research regarding DS and DC Dragon filters was basically carried out in less PM_{10} and $PM_{2.5}$ concentrations in sucked air, than it took place in case of RZ Mask filters. It could have possible influence on obtained results, because the dust collecting on filters makes additional filtration layer, causing increase of filtration efficiency in time function. This situation was not always possible to predict and compensate by extending aspiration time.

The effectiveness of fine particle collection obtained for typical filter materials used in the analyzed anti-dust masks is lower than the values given by the manufacturers of these masks (Tab. 1). However, these filters should ensure a significant reduction in PM_{10} and $PM_{2.5}$ concentration in the inhaled air during their proper use. In case of, for example, PM_{10} concentration in the air at a very high level of 300 μg/m³ (6-times exceeding the daily limit in European Union countries [24]), reduction of this concentration to the permissible level of 50 μg/m³ requires filtration efficiency of these particles at least 84%. Actual efficiencies in the order of 90–98% guarantee in this case reaching the concentration of particles in the inhaled air of 6–30 μg/m³. At lower initial concentration, the particulate matter level in the air obtained at the exit of the filter should be correspondingly smaller.

If the usual medical masks are used for the same purpose, reaching a PM_{10} concentration in the inhaled air of 50 μg/m^3 is possible at an inlet PM_{10} concentration of at most 80 μg/m^3 (in the case of a three-layer mask) or 175 μg/m^3 (in the case of a six-layer mask). Replacing typical anti-dust masks with medical masks is therefore not recommended because they do not guarantee high efficiency in collecting fine particles.

4. CONCLUSIONS

Using anti-dust face masks with high efficiency filters allows to even 50-fold reduction of PM_{10} and $PM_{2.5}$ concentration in inhaled air, but this reduction is usually at slightly lower level (range of 30–40 times). This means that at the time of very high instantaneous concentration of PM_{10}, e.g. on level 300 μg/m^3,such type of masks should let their users to inhale air with PM_{10} concentration below 10 μg/m^3. Unfortunately, simple medical masks available in pharmacies cannot be used for this purpose, even if two of them are used at the same time. These masks are not designed for effective capture of fine solid particles, especially the respirable dust ($PM_{2.5}$). In the case of other examined filter materials, there were no significant differences in capturing PM_{10} and $PM_{2.5}$ fractions. Slightly higher extent of capturing that two fractions is characterized by filters which include additional activated carbon layer, but more significant in that case is quality of selected anti-dust filter (e.g., using HEPA type filter), than presence of activated carbon.

Weighting method, used in this research, of defining the capture efficiency of PM_{10} and $PM_{2.5}$ fractions by filters used in anti-dust masks appears to be appropriate to evaluate extent of reduction the exposure to mentioned particles. At some level, obtained filtration efficiency could be affected with actual concentration of PM_{10} and $PM_{2.5}$ in air, which were not equal on the individual days when the measurements were taken. It is then desirable to continue initiated research in order to test analyzed filter materials in both higher and lower values of suspended particulate matter concentration in air and evaluation of the impact of this concentration, captured particle load and aspiration time on filtration efficiency.

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