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A Performance Evaluation and Inter-laboratory Comparison of Community Face Coverings Media in the Context of COVID-19 Pandemic

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ABSTRACT

During the recent pandemic of SARS-CoV-2, and as a reaction to the worldwide shortage of surgical masks, several countries have introduced new types of masks named "community face coverings" (CoFC). To ensure the quality of such devices and their relevance to slow down the virus spreading, a quick reaction of the certification organisms was necessary to fix the minimal acceptable performances requirements. Moreover, many laboratories involved in the aerosol research field have been asked to perform tests in a quick time according to (CEN, 2020) proposed by the European committee for standardization. This specification imposes a minimal air permeability of 96 L m^{-2} s^{-1} for a 100 Pa pressure drop and a minimal filtration efficiency of 70% for 3 μm diameter particles.

In the present article, an intercomparison of efficiencies and permeabilities measured by 3 laboratories has been performed. Results are in good agreement considering the heterogeneity of the material samples (within 27% in terms of filtration efficiency and less than 20% in terms of permeability).

On this basis, an analysis of 233 materials made of woven, non-woven and mixed fibrous material has been done in terms of filtration efficiency and air permeability. For some of them, measurements have been performed for 0.2 μm, 1 μm and 3 μm particle diameters. As expected, no deterministic correlation could be determined to link these efficiencies to the permeability of the considered samples. However, a trend could be identified for woven and mixed materials with an increase of filtration efficiency when the air permeability decreases.

The same exercise has been conducted to link the filtration efficiency measured at 3 μm to the one for lower diameters.

Finally, a discussion on the kind of material that is the most relevant to manufacture CoFC supported by spectral filtration efficiency values (from 0.02 μm to 3 μm) is proposed.

Keywords: Respirator mask, inter-comparison, Filtration efficiency, Fibrous material

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1 INTRODUCTION

According to the World Health Organization, disease transmission can occur due to the transport of the infectious agent by aerosolized droplets (https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions). In their review, Gralton *et al.* (2011) concluded that particles generated by respiratory activities range from 10 nm to 500 μm. Since the size range of the particles emitted strongly varies and

might also be influenced by their ageing (among others the drying of the droplets), their diameter (including droplets and eventual dry residues) can be assumed as mainly smaller than 5 μm (Papineni and Rosenthal, 1997; Morawska *et al.*, 2009; Johnson *et al.*, 2011; Asadi *et al.*, 2019). Furthermore, Lindsley *et al.* (2010) collected cough-generated particles produced by individuals with influenza like symptoms and concluded that the virus was present in the droplets, whatever their size. More recently and to the specific case of SARS-CoV-2, van Doremalen *et al.*, 2020) observed that this coronavirus remained viable and infectious in aerosol during at least 3 hours (duration of the experiments under laboratory conditions). Fears *et al.* (2020) have even shown that this virus remains viable in aerosol phase after droplet drying. Considering the size of corona type viruses such as SARS-CoV-2 (i.e., within 60–140 nm by several authors (Kim *et al.*, 2020; Park *et al.*, 2020; Ren *et al.*, 2020)), a dispersion of an active virus beyond the advised social distance of 1 meter, as reported by Asadi *et al.* (2020), cannot be excluded and is still in debate in the scientific community (Abkarian *et al.*, 2020). This huge debate, supported by a limited number of case studies under realistic conditions and contradictory conclusions (Faridi *et al.*, 2020; Liu *et al.*, 2020; Santarpia *et al.*, 2020) highlights the need for well characterized respiratory protection devices for a broad particle size range.

Due to the worldwide shortage of surgical masks, several countries have introduced new types of masks named "community face coverings" (CoFC, (Konda *et al.*, 2020; Pei *et al.*, 2020; Zhao *et al.*, 2020; Clapp *et al.*, 2021)). In that context, the European commission identified the urgent need for a harmonised and consistent degree of safety in such CoFC. Main idea was to allow industrial but also the general public to manufacture and distribute such masks with a dedicated characterization in terms of air permeability and filtration efficiency. In link with the French CoFC AFNOR guide (AFNOR, 2020), the European committee for standardization has developed a new CEN workshop agreement on CoFC (CEN, 2020) presenting manufacturing guides and testing protocol in link with public and private laboratories to conduct such tests. These specifications have been considered to design and produce masks by actors who are not generally involved in the filtration industry. Do-It-Yourself (DIY) tutorials were also largely diffused over social networks. In both cases, woven, non-woven and a mix of both types of medium have been used without any consideration regarding the real performances in terms of filtration. Moreover, even if an harmonized approach was developed ((CEN, 2020), Annex D), no precise requirements concerning the experimental protocol in terms of aerosol composition, size polydispersity, instrumentation and overall test bench design are specified. In face of all attempts conducted by these new manufacturers and to improve the specifications proposed at the European level, statistical performances analysis of media composing CoFC tested by different laboratories need to be conducted. Furthermore, inter-laboratory comparisons need to be organised for filtration efficiency and air permeability prior to this discussion.

Beyond the question of the relevancy of the testing methods proposed by different laboratories, the present article aims to bring additional recommendations to identify the most relevant medium for manufacturing efficient and comfortable filtering mask.

The objectives of this study are first to perform a comparison of measurement protocols applied by laboratories involved in the testing phase of CoFC during the pandemic crisis. As a second step, present study aims to propose a statistical analysis and discussion of filtration performances of materials proposed as candidates for manufacturing CoFC.

2 MATERIAL AND METHODS

2.1 Air Permeability

In link with CoFC specifications, only the filter medium composing the masks has to be characterized. The first test defined is related to the filter medium « breathing performance ». This test could be performed according to different measurement protocols (AFNOR, 2020; CEN, 2020). Nevertheless, for the inter-laboratory comparison purpose, the same protocol has been considered as a reference for each laboratory. The "breathing performance" was then characterized by measuring the air permeability (air flow passing through a known medium surface when a pressure drop of 100 Pa is applied between both sides of the medium) which must be higher than 96 L m^{-2} s^{-1}.

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2.2 Filtration Efficiency

Dealing with filtration performances, the fractional efficiency, defined as the specific efficiency associated to a given particle size, is calculated as follows:

$$E_N\left(d_p\right)=1-\frac{C_{N,down}\left(d_p\right)}{C_{N,up}\left(d_p\right)} \quad (1)$$

where $C_{N,down}$ and $C_{N,up}$ are respectively the particle number concentrations downstream and upstream of the mask sample. The particle considered for measured filtration efficiency is fixed at 3 μm according to studies related to human emitted droplets. According to CWA 17553:2020 specifications (CEN, 2020), a filtration velocity of 6 ± 1 cm s^{-1} was used from human expelled air flowrate and CoFC filtration surface. Under these conditions, and for CoFC performances validation, the filtration efficiency measured at 3 μm should reach a minimal value of 70% or 90% in order to classify each tested CoFC in two categories. One must notice that the diameter considered in CEN or AFNOR specifications is not imposed, then it is crucial to clearly specify, within each measurement report, the equivalent diameter of 3 μm considered for the analysis of the filtration efficiency.

2.3 Inter-laboratory Comparison

To investigate potential influence of the aerosol type (nature, composition), test bench design and measurement protocols, on filtration efficiencies, an inter-laboratory comparison has been conducted to quantify potential discrepancies between several testing laboratories. For this purpose, three different laboratories were involved, i.e., LRGP from Université de Lorraine, IRSN and LNE reported hereafter as Lab 1, Lab 2 and Lab 3.

Additional information on filtration test benches are available in supplementary information and Table 1 summarizes the experimental conditions. All test benches are based on pneumatic dispersion of aqueous solutions. As particles source, liquid DEHS droplets were used by Lab 1 while Lab 2 and Lab 3 respectively considered solid sodium chloride and polystyrene latex sphere particles. Two measurement strategies were assumed, a first one based on a main pipe with aerosol samplings upstream and downstream filter holder containing tested samples (Lab 1), a second one (Lab 2 and Lab 3) based on 2 parallel pipes and 2 identical filter holder (one containing the tested sample and a second empty one).

Significantly different measurement cycles were considered to cover a wide range of testing conditions. The filtration velocities were considered by each laboratory in agreement with CoFC specifications (6 cm s^{-1} ± 1 cm s^{-1}, CWA 17553:2020). The slight discrepancy reported for the filtration velocities used by the three laboratories will be discussed in the experimental results section but was not expected to have an impact on the accuracy of filtration efficiencies measurements within the considered range.

Ten different woven media, tested as potential CoFC filtering media and presenting wide range of air permeability (120–1200 L m^{-2} s^{-1}) and filtration efficiency (20–97%), were considered for this inter-laboratory comparison. Pieces of each sample, large enough to perform at least two measurements of filtration efficiency and air permeability, were prepared and distributed to each

Table 1. Experimental conditions for each laboratory involved in filtration efficiency measurements.

	LRGP (Lab1)	IRSN (Lab2)	LNE (Lab3)
Test aerosol	DEHS (liquid)	NaCl (solid)	PSL (solid)
Filtration velocity (cm s^{-1})	5.6	5.3	5.7
Sample area (cm^2)	28.3	10.2	10.7
Configuration	1 main pipe with samplings upstream and downstream of the filter holder with sample	2 parallel paths (P1: empty filter holder P2: filter holder with sample)	2 parallel paths (P1: continuous pipe P2: filter holder with sample)
Upstream 3 μm particles number concentration	300 part cm^{-3}	300 part cm^{-3}	500 part cm^{-3}

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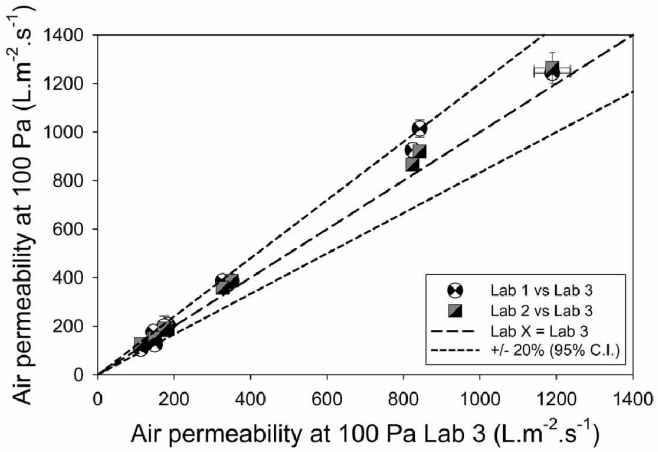


Fig. 1. Inter-laboratory comparison of air permeability measured by Labs 1, 2 and 3.

laboratory involved in this study. For this work, the French national laboratory for metrology and testing (LNE) was defined as the reference laboratory.

3 RESULTS

3.1 Inter-laboratory Comparison

3.1.1 Air permeability

Fig. 1 shows the inter-laboratory comparison results between Labs 1, 2 and 3 in terms of permeability at 100 Pa. With a 95% confidence interval, a good agreement was obtained below 20% between the air permeability measured for Lab 1 and Lab 2 versus Lab 3 considered as a reference. Since such measurement is relatively simple to perform and uses a limited amount of robust measurement devices, these results are associated to a low experimental dispersion ((AFNOR, 2020), method 4 described in EN-ISO 9237; https://www.iso.org/standard/16869.html). The discrepancies between the air permeability values are then mainly driven by the heterogeneity of the considered samples (reported in Fig. 1 through error bars obtained from three different measurements carried out on each CoFC medium).

3.1.2 Filtration efficiency

Fig. 2 presents the comparison between filtration efficiency measurements for a particle diameter of 3 µm reported by the three laboratories involved in this exercise. In this framework, the measurements uncertainties evaluation, reported in Fig. 1 as x-axis error bars, has been performed by LNE (Lab 3) according to the law of uncertainty propagation described in the Guide

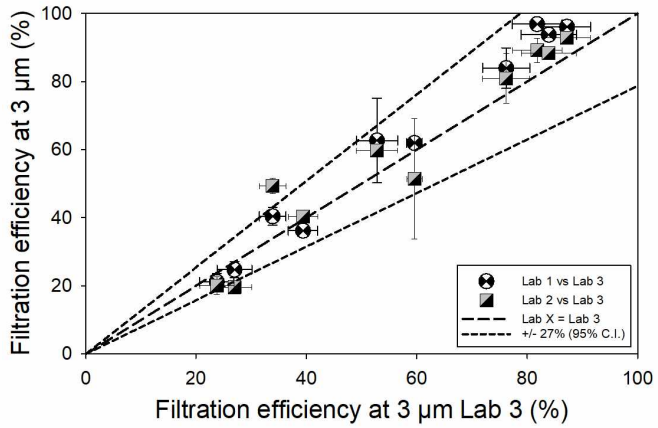


Fig. 2. Inter-laboratory comparison of filtration efficiencies measured by Labs 1, 2 and 3.

for Uncertainty Measurements (GUM, JCGM 100:2008; https://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf), while errors bars reported in y-axis on Fig. 2 for Labs 1 and 2 only represent the standard deviation associated to the mean values of filtration efficiency. Lab 3 (LNE) has been also considered as a reference since this laboratory used monodispersed and calibrated polystyrene latex sphere PSL (Duke Thermos, 4203A geometric diameter of 3μm corresponding, assuming perfect spherical shape and a PSL density, as reported by the manufacturer, of 1.05 g cm^{-3} to an aerodynamic diameter of 3.07 μm) as the aerosol source for measuring 3 μm filtration efficiencies. Compared to air permeability, the filtration efficiency is associated to the highest experimental uncertainty and standard deviation (error bars in x-axis and y-axis in Fig. 2, respectively). This larger dispersion is not solely due to the heterogeneity of the test media but also to more complex experimental procedure and devices (mainly the Aerodynamic particle sizer TSI 3321 used by all laboratories involved in the intercomparison) used to determine this parameter (Pfeifer *et al.*, 2016). The stability of aerosol number concentration, aerosol sampling devices and APS counting efficiency (Armendariz and Leith, 2002; Volckens and Peters, 2005) are identified as experimental dispersion sources. Nevertheless, with a 95% confidence interval, a good agreement below 27% was observed between the filtration efficiency measured at 3 μm reported by Labs 1 and 2 versus the reference Lab 3. This agreement highlights the relevance of test benches and measurement protocols considered by Lab 1 and Lab 2, even for polydispersed aerosols composed by liquid oil droplets (Lab 1) and solid sodium chloride particles (Lab 2) and slightly different filtration velocities (from 5.3 to 5.7 cm s^{-1}). Considering this good agreement, a further discussion in this paper will be carried out by merging the experimental results reported by Labs 1 and 2 without any distinction.

3.2 CoFC Raw Performances

To support the choice of the most relevant media for designing CoFC, 160 woven, 33 non-woven and 40 mixed materials were characterized following the previously qualified protocol. These media were retrieved from the textile industry but also from municipalities or associations aiming to produce and distribute CoFC at a local or national level. Selection of tested materials was conducted without any criteria on their composition or structure (woven, non-woven or mixed) and was only motivated by the agreement of media, as submitted by manufacturers, with the specifications proposed within French CoFC AFNOR guide (AFNOR, 2020) and CEN workshop agreement on CoFC (CEN, 2020). No systematic characterisation of the fibrous structure (in terms of fibers diameters and packing density) has been performed on the different tested media. As an illustration, scanning electron microscopy (SEM) pictures are presented in Fig. 3 for woven (a) and a non-woven (b) media. The fibre used are quite comparable for the different media, (approximately from 1 to several tenth of micrometres), nevertheless, and as expected, the main difference lies in the organisation of the fibres. One must also notice on Fig. 3(b) that some non-woven and mixed materials might be composed of very different kinds of fibres.

Fig. 4 presents distributions of (a) air permeability and (b) filtration efficiency at 3 μm and (c) 1 μm aerodynamic diameters over the whole set of tested media. The detailed results for

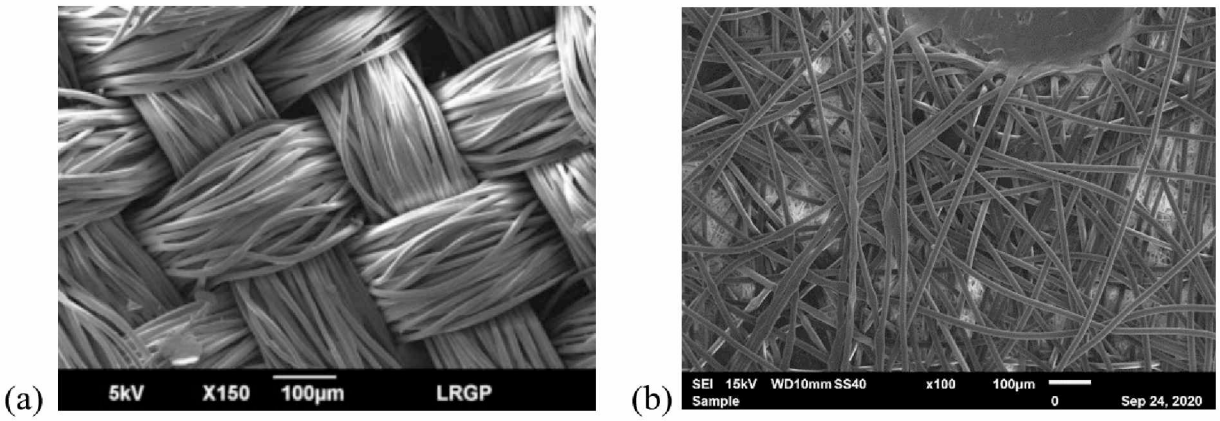


Fig. 3. SEM pictures of (a) a woven and (b) a non-woven media.

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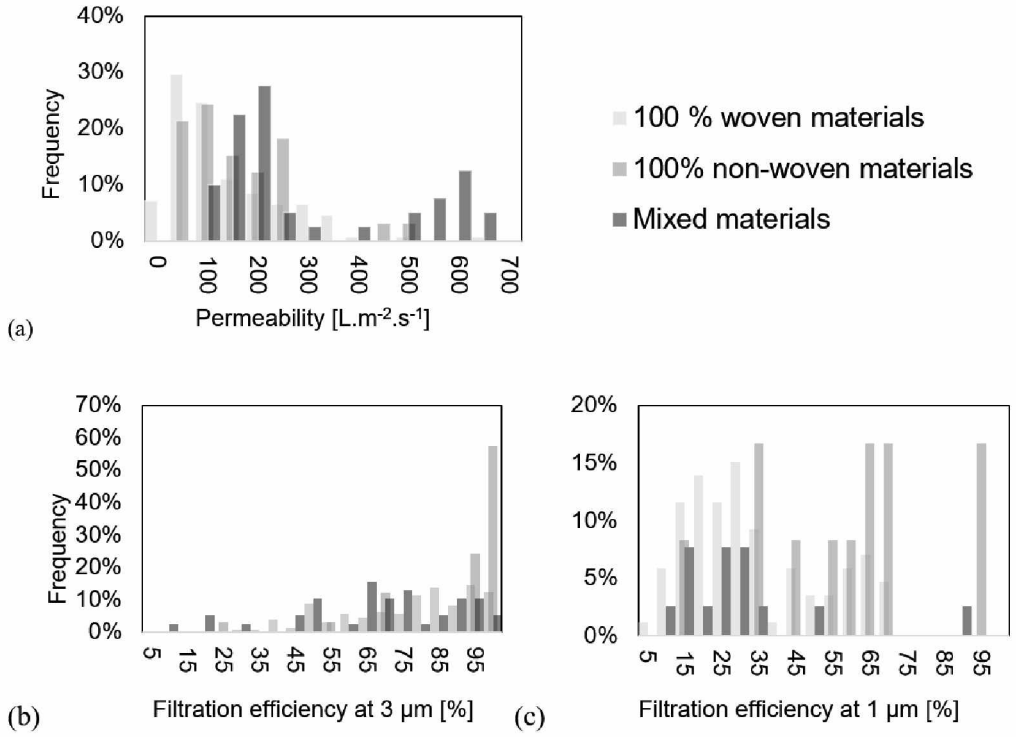


Fig. 4. Performances distribution of tested CoFC media.

woven, non-woven and mixed materials are presented in Table 2. Over the tested materials, only 70% present an air permeability higher than the requested value of 96 L m^{-2} s^{-1} for a pressure drop of 100 Pa (Fig. 4(a)). Within these samples, only 53% present a filtration efficiency higher than 70%, representing 35% of the entire set of tested media. This restricted number of materials fulfilling the CoFC technical requirements confirms the need for more precise and experimentally supported technical criterion.

More accurately, one can notice that the performances of filter media are correlated to their nature. Indeed, the woven media are globally less permeable than non-woven ones (Fig. 4(a)), while mixed ones are characterized by two extreme trends (nearly 200 and 600 L m^{-2} s^{-1}). In terms of filtration efficiency for both 3 and 1 µm (Figs. 4(b) and 4(c)), the non-woven media are characterized by a higher performance than the other materials.

This clear trend must be balanced by the fact that when only limit values of permeability and efficiency are considered (especially the values required by the CWA 17553:2020 specifications), the acceptance rate for each kind of media is equivalent (respectively 34, 30 and 38% for woven, non-woven and mixed media). Based on these acceptation rates, the threshold effect is in this case obvious and does not invite manufacturers to optimize the filtration efficiency without affecting the permeability of the employed materials.

Table 2. Statistical resume of performances for CoFC tested media according to the CWA 17553:2020 specifications (CEN, 2020).

	Woven		Non-woven		Mixed		total	
	N	%	N	%	N	%	N	%
Air permeability at 100 Pa								
> 96 L m^{-2} s^{-1}	106	**68%**	18	**55%**	36	**90%**	160	**70%**
< 96 L m^{-2} s^{-1}	49	**32%**	15	**45%**	4	**10%**	68	**30%**
3 µm filtration efficiency								
>70%	105	**66%**	27	**82%**	18	**46%**	150	**65%**
< 70%	55	**34%**	6	**18%**	21	**54%**	82	**35%**
> 70% filtration efficiency at 3 µm	53	**34%**	12	**30%**	15	**38%**	80	**35%**
> 96 L m^{-2} s^{-1} permeability at 100 Pa								

3.3 Experimental Results Analysis and CoFC Criteria Proposal

3.3.1 Air permeability versus filtration efficiency

Fig. 5 presents the correlation of 3 μm (aerodynamic equivalent diameter) filtration efficiency as a function of air permeability. This approach is convenient for identifying the most relevant media. For this purpose, horizontal and vertical grey areas are reported in Fig. 5 and correspond to poor performances in terms of filtration efficiency and air permeability (criteria of 70% at 3 μm and 96 L m^{-2} s^{-1} respectively in agreement with CWA 17553:2020 specifications (CEN, 2020)). Considering the woven materials, Fig. 5 demonstrates that 3 μm filtration efficiency is strongly linked to air permeability, with filtration efficiency decreasing with increasing permeability. It was not possible to identify a relevant woven material presenting both a filtration efficiency higher than 70% at 3 μm (aerodynamic equivalent diameter) and a permeability higher than 300 L m^{-2} s^{-1}. On the opposite site, the woven materials characterized by filtration efficiencies higher than 80% are generally characterized by air permeabilities lower than 96 L m^{-2} s^{-1}. For this class of materials, a new range of air permeability, ranging from 96 L m^{-2} s^{-1} to nearly 300 L m^{-2} s^{-1} could then be proposed to identify media with a filtration efficiency of at least 70%. The search for a breathable and very high filtration efficiency (larger than 90%) woven material is also difficult and needs additional treatment or a mixing with non-woven materials. For the mixed materials (woven and non-woven), in agreement with the woven ones, a similar behaviour is reported and the filtration efficiency decreases with increasing air permeability. In this case, only two mixed materials reach a filtration efficiency of at least 70% for permeability larger than 200 L m^{-2} s^{-1} (Corresponding to a comfortable device according to the comfort class of the NF; https://certification.afnor.org/securite/nf-masques-barrieres). The close agreement with performances measured for woven materials confirms that the behaviour of such mixed materials is still ruled by the structure of the woven media. These conclusions are also supported by several authors (Konda *et al.*, 2020; Zhao *et al.*, 2020) who tested common materials (silk, cotton, flannel, chiffon, nylon, paper) and concluded that fabrics with tight weaves and low porosity, in particular cotton woven/knit at a high density, present the best filtration efficiency. Non-woven materials are generally characterized by very high filtration efficiency and limited air permeability. In most cases, such materials are made of several layers of polypropylene fibres with diameter ranging from 1 to 10 μm. Their composition and the presence of an electret layer (an electrically loaded filter media (Łowkis and Motyl, 2001)), similar to surgical masks, justify a filtration efficiency generally larger than 95% at 3 μm.

Since droplets emitted during human respiratory activities could present diameter smaller than 3 μm and that SARS-CoV-2 coronavirus diameter has been reported within 60–140 nm by several authors (Kim *et al.*, 2020; Park *et al.*, 2020; Ren *et al.*, 2020), additional care has been considered on the filtration efficiency for two additional particle diameters (0.2 μm of electrical mobility equivalent diameter measured with an SMPS and 1 μm of aerodynamic equivalent

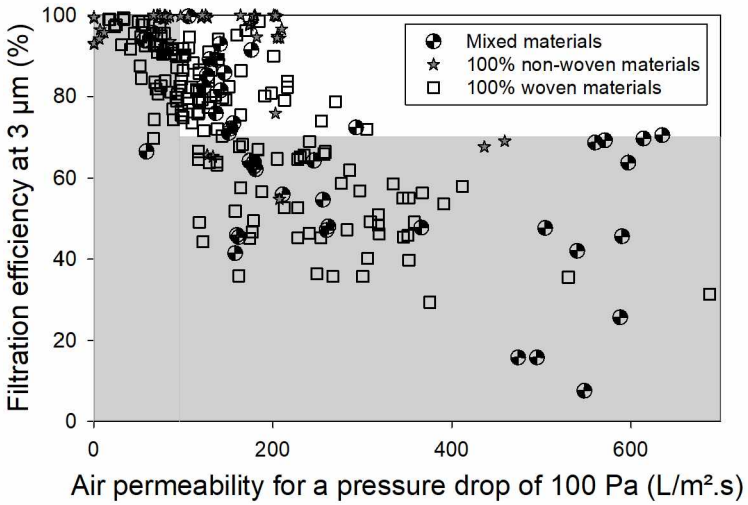


Fig. 5. Evolution of 3 μm filtration efficiency as a function of air permeability.

diameter measured with an APS). Nevertheless, one must also notice that such viruses are emitted in a droplet and are generally transported at the surface of a dry particles. Furthermore, 1 μm dried particles have been also recently demonstrated to have a relatively low probability (0.01%) to contain a virion (Eiche and Kuster, 2020; Stadnytskyi *et al.*, 2020), the size range 60–140 nm could then be assumed as a hypothetic lower size limit. Figs. 6(a) and 6(b) present the evolution of associated filtration efficiencies as a function of air permeability. Vertical grey area is still fixed at 96 L m^{-2} s^{-1} while the horizontal one (associated to filtration efficiency) is fixed at 30% which is a reasonable value for the considered materials. For 1 μm of aerodynamic equivalent diameter (Fig. 6(b)), a limited number of woven/mixed materials (17% of the woven and 17% of the mixed ones) and twice more of non-woven materials (49%) reach these requirements. For a diameter close to the size of coronavirus (0.2 μm of electrical mobility equivalent diameter, Fig. 6(a)), none of the woven and 18% of the mixed materials are able to reach the performance criteria whereas these criteria are reached by 44% of the non-woven ones. One must notice that all materials reaching a filtration efficiency of 30% for 1 μm and 0.2 μm also reach the limit value of 70% for 3 μm particles.

3.3.2 Prediction of 0.2 and 1 μm filtration efficiency from 3 μm filtration efficiency

Fig. 7 proposes to investigate a potential correlation between the filtration efficiencies measured at 1 μm (aerodynamic equivalent diameter measured by Labs 1 and 2) and 0.2 μm (electrical

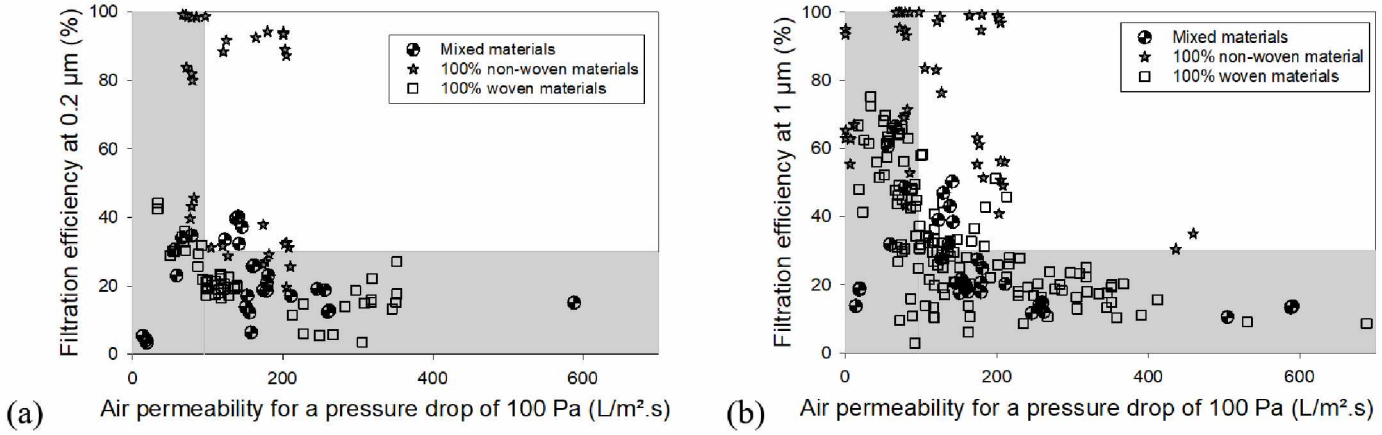


Fig. 6. Correlations of 0.2 μm (electrical mobility equivalent diameter) and 1 μm (aerodynamic equivalent diameter) filtration efficiencies as a function of air permeability.

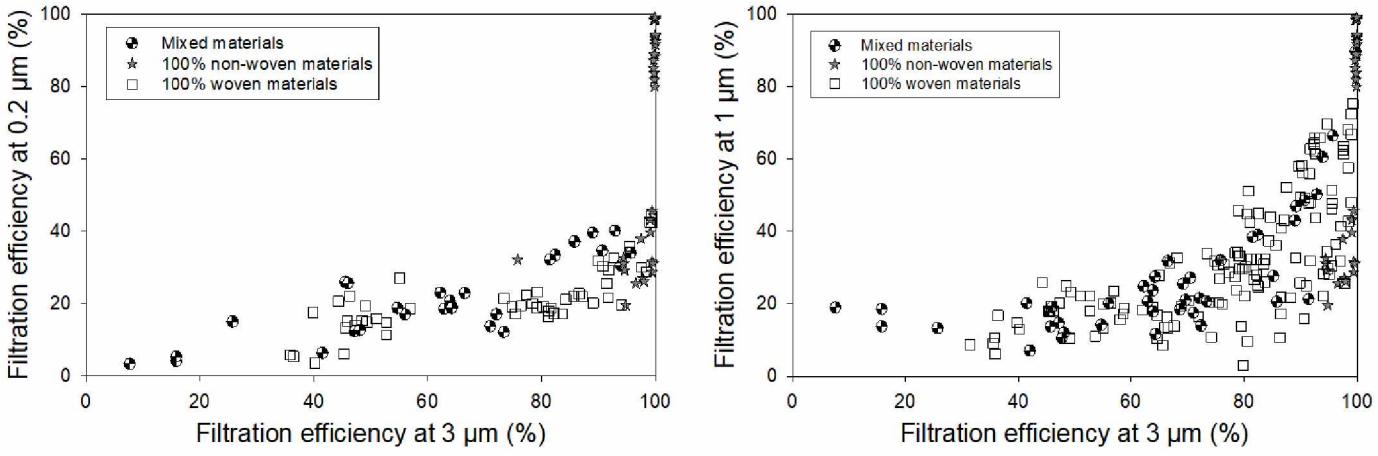


Fig. 7. (a) and (b) presents the relation between the filtration efficiency for respectively 0.2 and 1 μm as a function of the filtration efficiency for 3 μm as required for the AFNOR and CEN specifications (AFNOR, 2020; CEN, 2020).

mobility equivalent diameter measured by Lab 2) with the 3 μm (aerodynamic equivalent diameter) filtration efficiency required by the CWA 17553:2020 (CEN, 2020) specifications independently to their ability to fulfil these specifications. As expected, a trend can be identified for all kinds of media. However, one must notice that for most of the non-woven materials, the filtration efficiency for 0.2 μm and 1 μm particles remains high. This leads to a better protection for the whole potential droplet size distribution as it has been described in the literature on the topic. This trend and the relation between the efficiency at various particle diameters is a consequence of the fibrous structure. This can be easily viewed on the whole spectral efficiencies (see next section).

3.3.3 Spectral filtration efficiency

To enhance the clearness of the results, only the filter media showing a permeability over 96 L m^{-2} s^{-1} have been considered. One of the involved laboratories (Lab 2) performed the filtration efficiencies for particle sizes from 0.025 μm (electrical mobility equivalent diameter) to 3 μm (aerodynamic equivalent diameter) by combining measurements performed by a SMPS (X-ray neutralizer 3088, classifier 3082 with long DMA column 3081 and particle counter CPC 3775 from TSI) for the submicron particles size range and an APS (model 3321 from TSI) for the micron particles size range.

As a reminder, the U-shape of the spectral efficiency is induced by the well-known interaction of 3 main filtration mechanisms (diffusion, interception and impaction (Yeh and Liu, 1974)). The width of the most penetrating particle size (MPPS) is a direct consequence of the fibrous structure in terms of fiber size distribution and packing density. The width of this interval has a direct impact on the ability of the respiratory protective devices to protect the environment and the user. Indeed, as noticed in the review of Gralton *et al.* (2011), the aerosols emitted during respiratory activities are highly polydispersed in diameter due to complex emission phenomena but also due to the fact that their diameter might change during their ageing in ambient air. Figs. 8(a) and 8(b) show the results obtained for non-woven and woven/mixed filter media. While the non-woven materials present a sharper minimum of efficiency (Fig. 8(a)), the woven and mixed materials (Fig. 8(b)) are characterized by wider minimum of efficiency ranging from 0.2 to 1 μm. For the non-woven media (Fig. 8(a)), the filtration efficiencies continuously increase from 0.3 μm to 2 μm. Some of the tested samples even show the kind of behavior that can be measured on FFPx or N95 masks (around 90–100% efficiency), denoting a minimum efficiency for particles lower than 0.2 μm (Konda *et al.*, 2020; Drewnick *et al.*, 2021) induced by electrostatic effects. In the one hand, this strongly overcomes, for submicronic particles, the minimal performances required for this kind of CoFC, but in the other hand, this performance could decrease significantly when the CoFC has been cleaned or even wear for a long time (as it has been demonstrated for FFPx and N95 masks (Mahdavi *et al.*, 2015; Steinberg *et al.*, 2020)).

4 CONCLUSIONS

The first part of the present work aimed to compare and validate different test protocols (according to the the CWA 17553:2020 ((CEN, 2020), Annex D) requirements) associated to several test benches proposed by three laboratories involved in the French aerosol community. All the results for the CoFC tested media show discrepancies less than 27% with a 95% confidence interval between the filtration efficiency measured at 3 μm reported by Lab 1 and 2 versus the reference Lab 3. In the second part, the results reported for a large amount of tested materials show, as it might be intuitively stated, there is a global trend linking the filtration efficiency to the air permeability. Nevertheless, no deterministic correlation can be proposed between both parameters. The results show beyond any doubt the best performances of non-woven media for the use as CoFC as they present a higher permeability and filtration efficiency than woven media. Moreover, the filtration efficiency measured for 1 μm and 0.2 μm particle size show that a very few of the woven media can reach satisfying performances. Indeed, the performances for lower particle size is an important indicator for the protection ability of these masks since droplet could eventually evaporate after emission. The shape of the spectral efficiency curve has also been tested for some of CoFC media in agreement with CWA 17553:2020 requirements (CEN, 2020).

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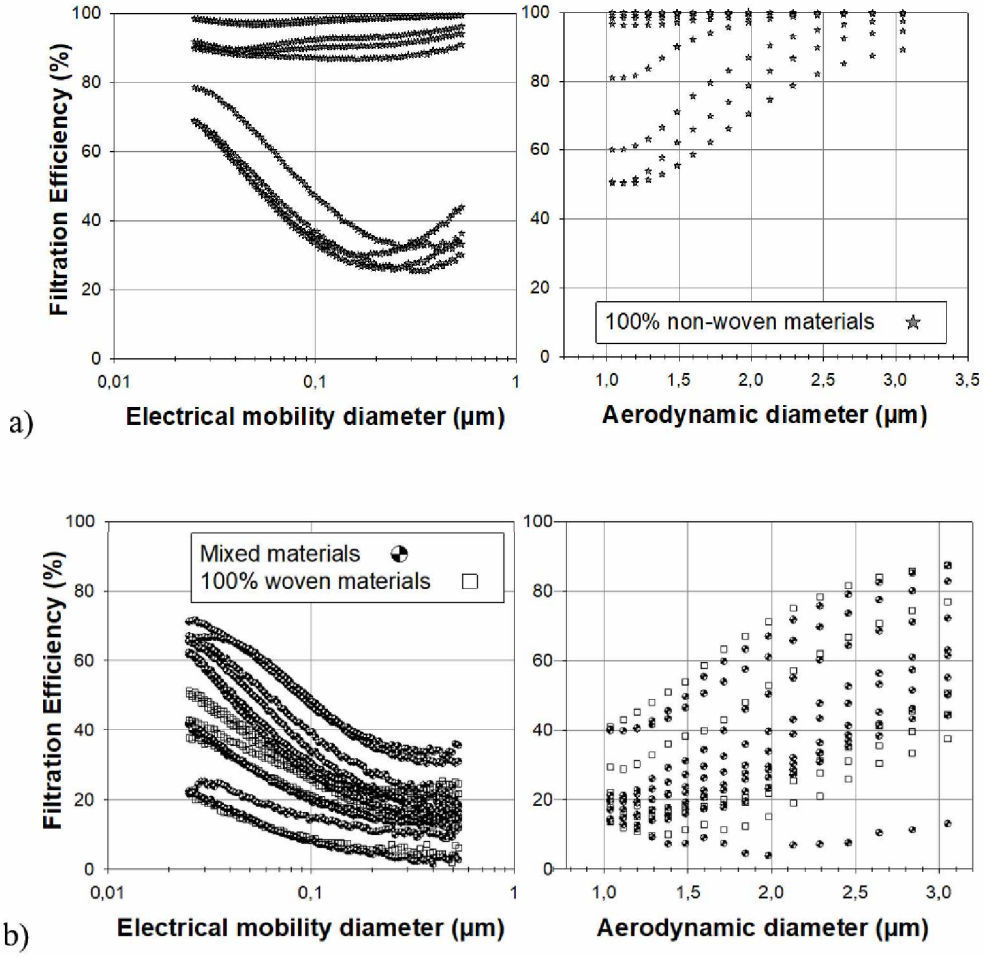


Fig. 8. Spectral filtration efficiency measured for (a) non-woven and (b) woven/mixed materials. Left part: SMPS measurements, right part: APS measurements.

This showed that the minimal efficiency ranges from 0.2 to 1 µm for woven media while this minimal is not as large for non-woven media.

Another point that needs to be pointed out is the performances of some woven materials, especially knitted ones, when expended. Indeed, in this article, the materials have been tested without tension. This point should also affect the filtration efficiency in a non-negligible manner.

In this work, the design of CoFC has not been tested. Indeed, the air flow passing through unavoidable leakages between the face of the user and the mask can strongly vary with the kind of design and the air permeability of the material used. A higher permeability of the material will lead to a higher part of the expired/inspired flow passing through the media, while a low permeability media will induce a higher part of the flow passing through the leaks and thereby not filtered. This point should be of interest for mask manufacturer and should incite them to choose preferentially materials with an optimal balance between filtration efficiency and permeability depending on the mask design (Chen and Willeke, 1992). In the present state of the art, CoFC are not considered as an individual protection device, therefore this discussion is not current. Nevertheless, this point should be discussed for further revision of CoFCs performance criteria.

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SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at https://doi.org/10.4209/aaqr.200615

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