

Emission and exposure to SARS-CoV-2 and filtration options

Institute of Environmental Assessment and Water Research (IDAEA), CSIC

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This report is a translation of the Spanish report “Emisión y exposición a SARS-CoV-2 y opciones de filtración” in its version v2 from 11 April 2020. Translation carried out by IDAEA-CSIC.

What's new in the version v2 of the report compared to version v1:

- *filtration efficiency comparison for various particle sizes: 300 nm, 3 μm (1 μm - 4 μm), and respirable fraction (0 μm - 4 μm)*

The present report aims to compile the available scientific information on the SARS-CoV-2 emission, potential air transmission and filtration options. Thus, it aims to present a summary of the relevant information in the current situation, it is not intended at all to be an exhaustive compilation of all existing standards and sources.

SARS-CoV-2 in aerosols and droplets

The transmission of SARS-CoV-2 through aerosols takes place in particles of **nanometers to micrometers in size**, given that the virus (of about 100 nm in size) does not travel alone, but it travels being part of particles of different sizes (which also contain salts and proteins present in the mucosa of respiratory system). These particles behave as any other suspended particle.

In medical studies, traditionally, there is a distinction between “**droplets**” (>5 μm) and “**aerosols**” o “**micro-droplets**” (<5 μm), **although the reality is that the size distribution generated when breathing, coughing or sneezing is a continuous size range**. Figure 1 shows the particle size distribution generated by a human being while speaking. The original study shows similar distributions while breathing, speaking with sustained vocalization and coughing (Johnson et al., 2011). The particles and droplets, once emitted, vary their size getting smaller due to water evaporation.

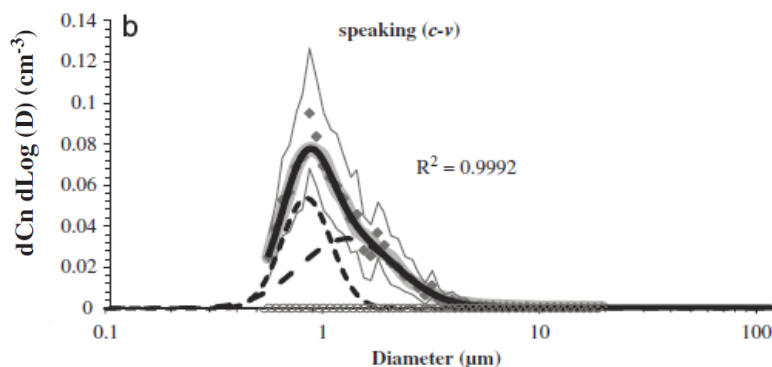


Figure 1. Particle size distribution generated by a human being while speaking (Johnson et al., 2011).

Several studies have determined the concentration of virus in droplets and aerosols generated by infected individuals. **The virus is present in all particle sizes, coarse ($>5\ \mu\text{m}$) and fine ($<5\ \mu\text{m}$).** See Figure 2 (Yan et al., 2018).

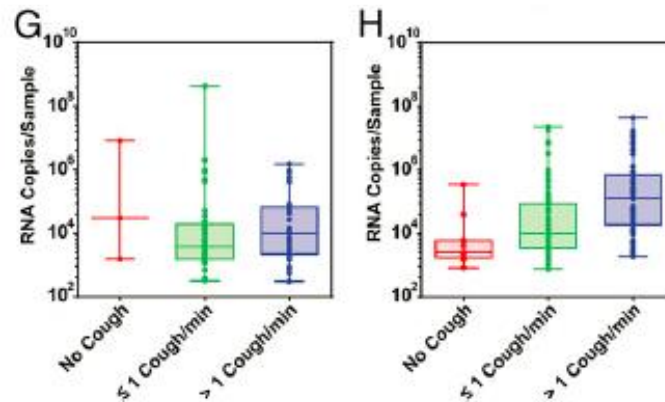


Figure 2. Virus copies in exhaled air while talking by patients infected with influenza virus, in the coarse fraction ($>5\ \mu\text{m}$) (G) and in the fine fraction ($<5\ \mu\text{m}$) (H) (Yan et al., 2018).

In any environment with infected individuals by SARS-CoV-2, those individuals will emit droplets and aerosols containing virus when talking, coughing, sneezing or simply breathing. **The coarser particles ($>5\ \mu\text{m}$) tend to settle quicker. The finer particles remain suspended in the air for hours or days.** The SARS-CoV-2 may remain active while being part of suspended particles in the air for more than three hours (van Doremalen et al., 2020). The virus concentration in ambient air depends on the location. In open environments no studies have been found specifically for SARS-CoV-2. In indoor environments with high density of infected individuals, the virus ambient concentration may be high. A study carried out in Japan, based on transmission tracking, concluded that contagion from an infected person is 19 times more likely indoors than outdoors (Nishiura et al., 2020). In several hospitals in Wuhan, **SARS-CoV-2 was detected in ambient aerosols in different size ranges during the COVID-19 outbreak** in December 2019 (Liu et al., 2020) (Figure 3).

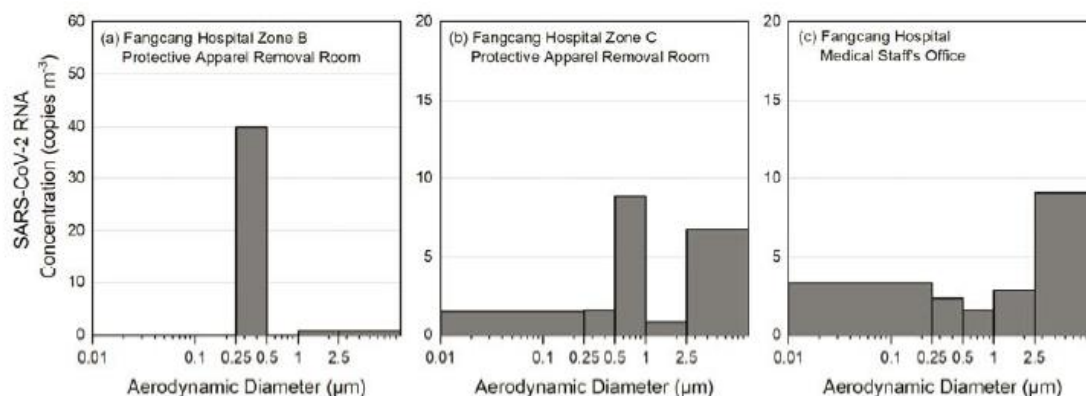


Figure 3. Concentration of airborne SARS-CoV-2 RNA in different aerosol size bins in different places in a hospital in Wuhan during COVID-19 outbreak (Liu et al., 2020).

Aerosols characteristics and filtration behaviour

The filtering capacity of any material depends on the particle size to be filtered. The filtration mechanism is different for small particles, which are filtered by diffusion (due to Brownian motion), and for coarse particles, which are filtered by impaction. The more difficult particle size to filter is around 300 nm. Therefore, the filtering capacity of a material determined at this particle size assures that any other particle size is filtered with a higher efficiency. That is the reason why filter regulations usually specify the filtering efficiency at 300 nm. Figure 4 shows this concept (NIOSH, 2003).

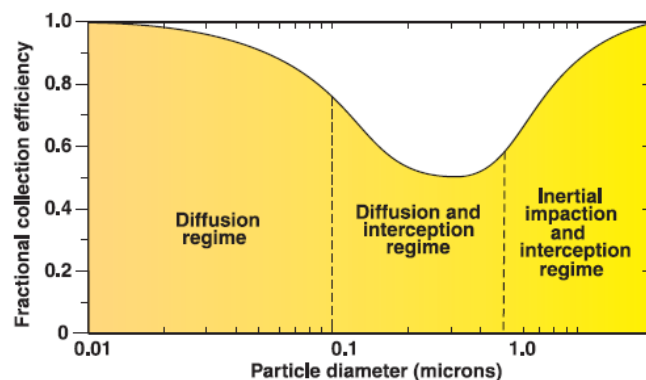


Figure 4. Fractional collection efficiency versus particle diameter for a mechanical filter. The minimum filter efficiency will shift based upon the type of filter and flow velocity (NIOSH, 2003).

Masks and respirators regulated in Europe

In the European regulation, there are specific Standards for medical face masks and respiratory protective devices, the latter also being called half masks or respirators.

The efficiency of these devices depends on three factors:

- The filtering efficiency of the material with which the device is made.
- The fit of the device to human face, i.e., the absence of leaks.
- Whether the objective is to filter the particle emission from an infected individual, or to filter particles in ambient air breathed by a healthy individual.

The tests to determine each of the factors are clearly different.

A summary of the medical face masks and respiratory protective devices more relevant in the current situation is shown below.

Medical face masks

They are regulated by EN 14683:2019 Standard.

They are designed to avoid the emission of pathogens by the individual wearing it.

The EN 14683 Standard describes, among others, the bacterial filtration efficiency test, which determines the filtering capacity of the material with which the mask is made. It uses particles with bacteria in a **mean size of $3 \pm 0.3 \mu\text{m}$** and the collected material is left for some hours for subsequent colony counting.

The EN 14683 Standard states specifically in its Annex A that if the objective is to protect the individual wearing the mask, the regulation on personal protective equipment must be followed and it makes reference to the EN 149 Standard. It emphasizes therefore that these masks are not meant to protect the individual wearing it.

Personal protective equipment: half masks FFP2, FFP3.

They are regulated by the EN 149:2001 Standard, which makes reference to the EN 13274-7:2019 Standard to determine the filtering capacity of the material with which they are made.

They can be called **respiratory protective devices, respirators or filtering half masks**. They consist of high-filtration half masks (FFP2, FFP3 in Europe; approximately equivalent to N95, N99 in USA, respectively). **They are designed to protect the individual who wears it from the particles present in ambient air, independently of the particle nature or size.** These half masks may or may not have an exhalation valve. If they do not have an exhalation valve, the half mask protects both the individual wearing it and vice versa (the rest of the persons are protected from the individual wearing it). If they have an exhalation valve, they only protect the individual wearing it, but it does not prevent this individual to emit pathogens in case of illness.

The EN 13274-7:2019 Standard describes the filtration test using particles in the range 60-100 nm if sodium chloride is used or in the range 395-450 nm if paraffin oil is used. This test determines the filtering efficiency of the material with which the half mask is made. The filtering efficiency has to be higher than 94% and 99% for FFP2 and FFP3, respectively.

Moreover, given that the efficiency of the final device depends on the absence of leaks between the half mask and the face (which is notoriously difficult), the EN 149:2001 Standard describes the fit test to the human face and the leak test through the exhalation valve (if any) and it uses a particle size range of 20-2000 nm. With this test the efficiency of the final product is assessed. Results are given as leaks towards the inner part and they should not be higher than 8% and 2% for FFP2 and FFP3, respectively.

Feasible alternatives in an emergency situation

Given the inability to manufacture enough regulated protective material, and in the absence of the ability to carry out all standardized tests on alternative material, **a system has been designed at IDAEA-CSIC to determine the filtering capacity of materials that can be used in the current emergency situation. It is not intended to be an alternative to certification protocols or a replica of standardized systems**, but has been designed based on scientific and technical knowledge on particulate filtration and SARS-CoV-2 and considering feasibility with the available means.

The system consists of the determination of the filtering capacity of materials and fabrics, candidates for use in the manufacture of masks and respiratory protection devices for use in the emergency situation by COVID-19. **The system is based on the generation of aerosols, selection of the 300 nm particles, and determination of the concentration of particles generated before and after passing through the material to be tested** (Figure 5). For materials with high performance at 300 nm, one test can be done at 100 nm and another at 500 nm or 2000 nm to ensure their high performance across the size range.

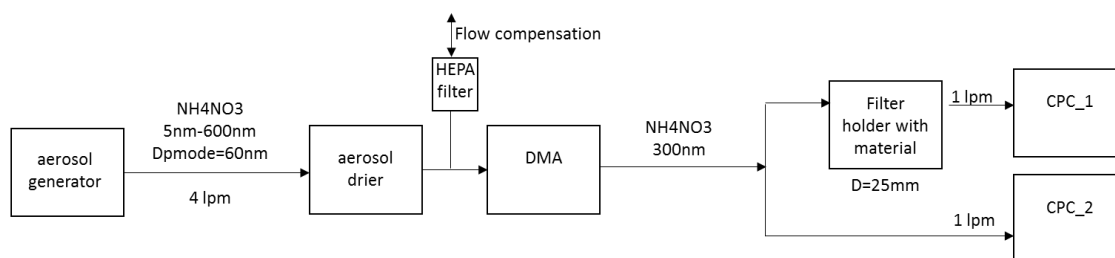


Figure 5. Experimental setting for the determination of filtering efficiency.

Carrying out the test at 300 nm ensures that the filtration is being tested in the worst case scenario (i.e., when the filtration capacity is minimal), thus ensuring that the filtration capacity of the material is not overestimated. If a material has a filtration efficiency of 95% at 300 nm, its filtration efficiency for 1 μm particles or for 100 nm particles will be equal or greater. However, if a filtration efficiency of 95% at 1 μm is determined, it cannot be ensured that the filtration efficiency for smaller or larger particles is the same. Since SARS-CoV-2 is present in the size range from hundreds of nanometers to hundreds of micrometers, it is extremely important that the filtration capacity is determined in the full size range or, failing that, in the worst case scenario, which is the 300 nm proposed here.

In this system, the filtration efficiency at a certain size is measured by measuring the number of particles. If polydispersed aerosols with a wide range of sizes are used, for example 0.02 μm to 2 μm , it is important to make the determination of filtration efficiency for different size ranges. If it is done for the polydispersed aerosol as a whole, it is not advisable to use the particle mass as a parameter, since the resulting efficiency would not be valid, as it will be determined by the coarse fraction, given that a single particle of 2 μm can weigh as much as a million particles of 0.02 μm .

See the section included in this version v2 at the end of the report for comparing filtration efficiency at different particle sizes, such as 3 μm (1 μm - 4 μm) and 0.3 μm .

Limitations:

1. The speed of air passage through the material (known as "face velocity") must be as similar as possible to that expected in a working half mask. Resting human respiration has an average flow rate of 5 liters per minute. It can be assumed that inspiration occurs during a third of the time (the other two thirds being of rest and exhalation), and therefore the flow rate during inspiration will be 15 liters per minute. Assuming an area of 25 cm^2 for a half mask, the speed of passage is 10 cm/s . If the test is carried out at a very different speed, **the filtering capacity of the tested materials could be overestimated.** However, one study determined little or no difference in filtration capacity at speeds of 5.5 cm/s and 16.5 cm/s (Rengasamy et al., 2010).
2. The filtration efficiency corresponds to the material itself. The efficiency of a half mask made with the material will also be determined by the fit of this half mask to human face. Therefore, **it is necessary to check the fit factor to the half masks once they are made**, either following the UNE 149 Standard, or by any other system designed in the present emergency situation.

Evidence of the efficiency in the use of masks by infected individuals to reduce pathogen emissions

There are several studies evaluating the effectiveness of the use of surgical masks in terms of reducing the emission of pathogens by the person wearing it. As an example, results are shown in Figure 6 (Milton et al., 2013) and Figure 7 (Leung et al., 2020).

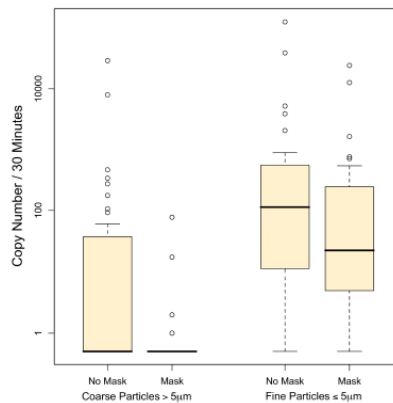


Figure 6. Influenza virus copy number in aerosol particles exhaled by patients with and without wearing of an ear-loop surgical mask, in the coarse fraction ($>5 \mu\text{m}$) and the fine fraction ($<5 \mu\text{m}$) (Milton et al., 2013).

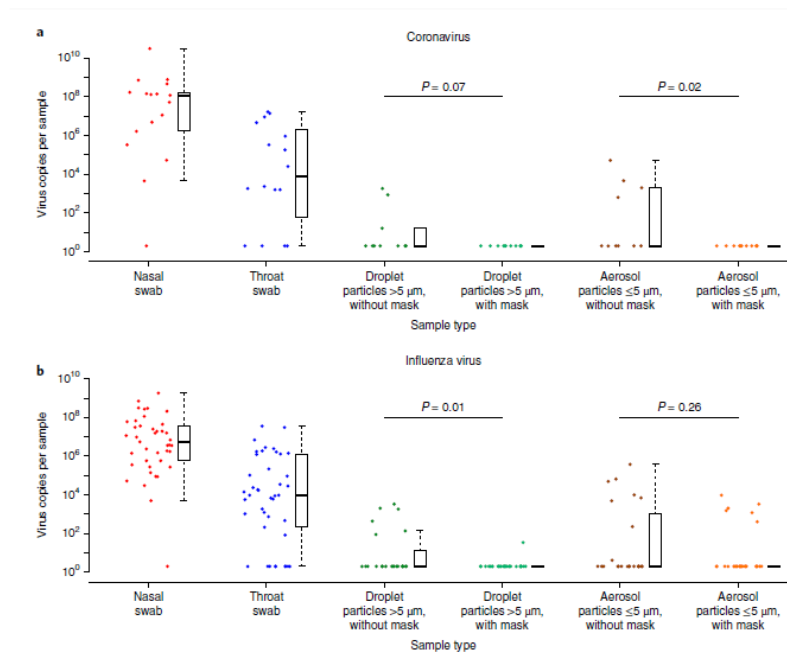


Figure 7. Efficacy of surgical face masks in reducing respiratory virus shedding in respiratory droplets and aerosols of symptomatic individuals with coronavirus and influenza virus. Virus copies per sample collected in nasal swab, throat swab, and respiratory droplets ($>5 \mu\text{m}$) and aerosols ($\leq 5 \mu\text{m}$) collected for 30min while not wearing or wearing a surgical face mask (Leung et al., 2020).

Comments on the French protocol from 29th March 2020

The French protocol of March 29th, 2020 on masks for non-sanitary use (https://www.entreprises.gouv.fr/files/files/home/Masques_reservees_a_des_usages_non_sa

nitaires.pdf) proposes a filtration control of materials for particles of 3 μm . This particle size is more similar to the test for surgical masks, and therefore would be adequate to prevent the person who wears it from emitting pathogens if infected. These masks could be used by the general population to reduce potential contagion. However, these masks are recommended in the protocol for gendarmes and personnel exposed in public places, theoretically for their own protection. The proposed test does not guarantee the protection of the person wearing the mask, especially in closed spaces where poor ventilation can result in a concentration of viruses in ambient air. It is necessary to perform an assay at various particle sizes or, failing that, at 300 nm, to ensure that the filtration is adequate and can protect the person wearing it.

Comparison of filtration capacity at various particle sizes

Tests have been performed to quantitatively compare the filtration efficiency at different particle sizes:

- 300 nm: the system described here has been used for 300 nm. The determination is equivalent in mass and number as it is a monodisperse aerosol of known and constant composition.
- 3 μm : a system has been designed to determine the filtration efficiency for particles between 1 and 4 μm in size, using the fraction between 1 μm and 4 μm of a polydispersed aerosol. The determination has been made in mass concentrations.
- 0 μm - 4 μm , called PM4 or respirable fraction. It is the fraction that is used in health impact studies as a breathable fraction and corresponds to the fraction that we breathe and can reach the alveoli. A system has been designed to determine the filtration efficiency for particles of size between 0 and 4 μm , using a polydispersed aerosol. The determination has been made in mass concentrations.

Figure 8 shows the comparison of the filtration efficiency at different particle sizes. The results correspond to more than twenty materials tested.

A filtration efficiency of 70% at 3 μm corresponds to:

- 10% filtration of the 300 nm particles.
- 20% filtration of the particles of the respirable fraction (0 to 4 μm).

Filtration efficiency of 90% at 3 μm corresponds to:

- 40% filtration of 300nm particles
- 18-55% filtration of the particles of the respirable fraction (0 to 4 μm).

The range of efficiencies obtained for the respirable fraction for materials having a filtration efficiency of 90% at 3 μm is due to the variety of materials and different material characteristics. Determining only the filtration efficiency at 3 μm , the efficiency at other sizes cannot be known. For the tested materials, this was always less than 55% and higher than 18%.

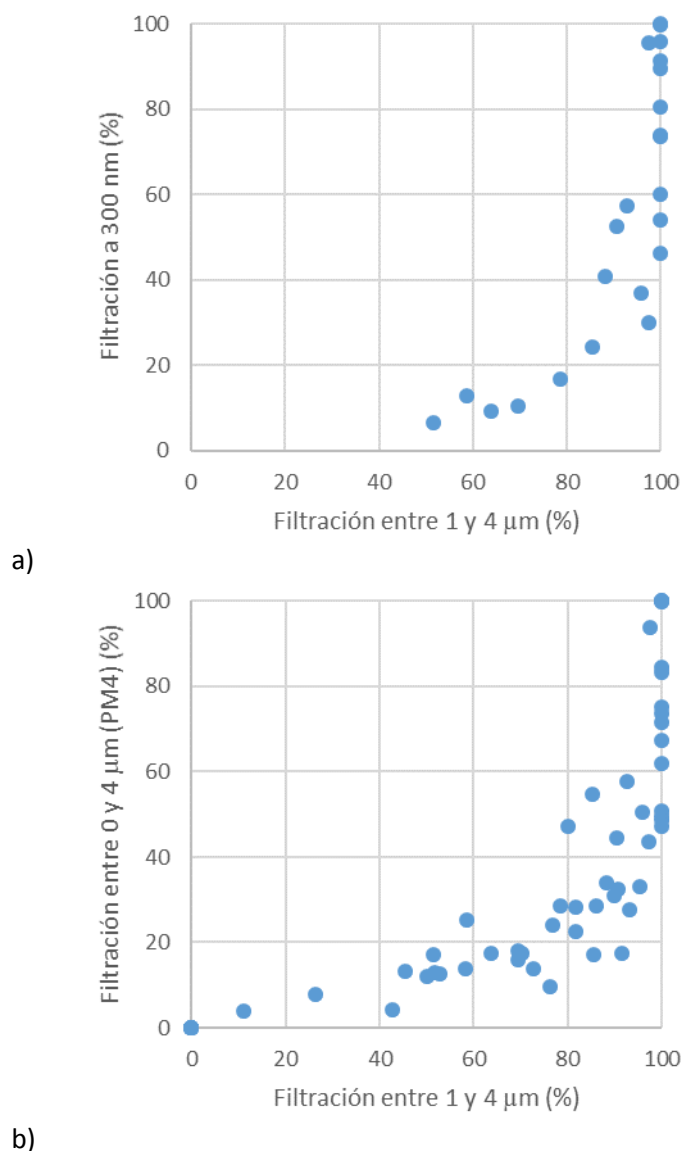


Figure 8. a) Filtration efficiency of various materials to 300 nm particles compared to 1-4 μm particles. b) Filtration efficiency of various materials to particles of 0-4 μm compared to particles of 1-4 μm . Tests carried out by IDAEA-CSIC.

Conclusions

1. There is viral load in all particle sizes, both droplets ($> 5 \mu\text{m}$) and aerosols ($< 5 \mu\text{m}$).
2. Fine particles ($< 5 \mu\text{m}$) can remain in the air for several hours.
3. The virus can remain active for more than three hours when it is in the air.
4. Protection systems:
 - a. Surgical masks (EN 14683: 2019 Standard): designed to prevent the individual wearing it from spreading or emitting pathogens. Its filtering capacity is tested for medium size particles of $3 \pm 0.3 \mu\text{m}$.
 - b. FFP2, FFP3 respirators or half masks (EN 149: 2001 and EN 13274-7: 2019 Standards): designed to protect the person wearing it from particles in the environment. These half masks are effective for coarse and fine particles. Its filtration capacity is tested for particles of size 60-450 nm.

5. In the framework of the emergency generated by COVID-19, a non-regulated system has been developed to determine the filtration capacity of materials that may be candidates for the manufacture of filtering masks or half masks. The system determines the filtering capacity at 300 nm. It allows for the option to test at different sizes like 100 nm and 500 nm.
6. The filtration efficiency depends on the particle size. An efficiency of 70% at 3 μm corresponds to 10% for 0.3 μm and 20% for the breathable aerosol (between 0 and 4 μm).

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