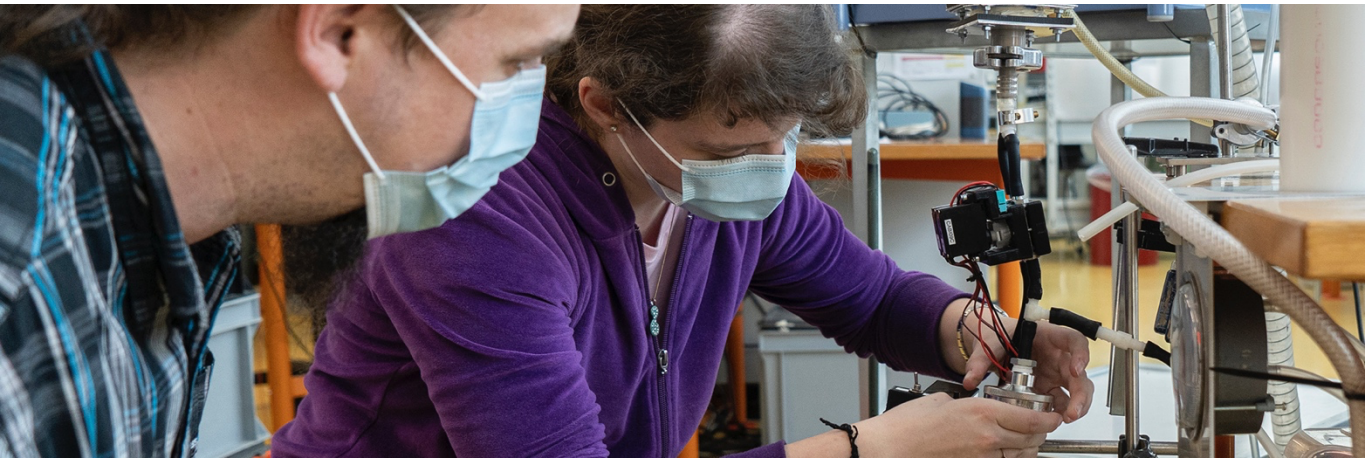
University of Applied Sciences and Arts Northwestern Switzerland
School of Engineering

Masks on the experimental test rig

How well do they protect against fine aerosol particles?



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1 Initial situation

Which masks protect effectively against viruses? This question has been on the agenda since the outbreak of the corona virus SARS-CoV-2 at the beginning of 2020. The demand for disposable and reusable protective masks has increased enormously worldwide - and could not be covered by the existing supply. The limited production capacities of existing manufacturers have resulted in textile companies, importers and distributors adding protective masks to their product range. But what properties must the filter materials have in order to provide the most effective protection against viruses or fine aerosols with a diameter of less than a thousandth of a millimeter?

1.1 Big differences: viruses in cough droplets or as fine particles in the air we breathe

If a person wearing a mask directly coughs or sneezes on you, even simple fabric masks can catch a large proportion of the droplets that are emitted, which are usually up to one millimeter in size. This means that the wearer of the mask protects fellow human beings from infection.

However, during normal breathing - and especially when speaking and singing - fine droplets and aerosols are also released with every breath. These are so small (< 5 microns) that they can float in the air for hours and can only be filtered by efficient masks. Since these sub-micrometer sized aerosol particles can also contain corona viruses, the transmission path through them is becoming increasingly important. This is especially the case because we often spend time in insufficiently ventilated indoor spaces and are therefore exposed to longer standing air with possibly increased concentrations of virus-carrying aerosols. We found that simple fabric masks usually offer neither the wearer nor the people around them protection against these ultrafine particles.

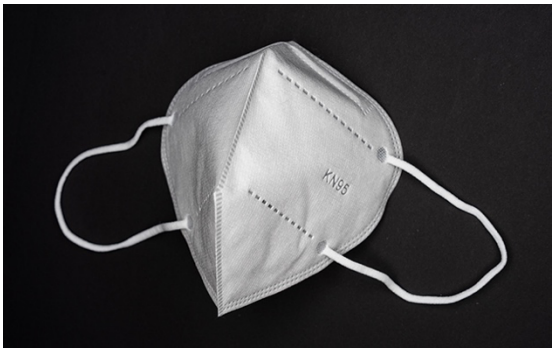
1.2 What are the material characteristics of a good mask?

For an effective filtering effect of the mask, the fiber material must have the correct pore size and pore length. This is the only way to ensure that on the one hand small aerosols are deposited by diffusion on the filter fibers, while on the other hand larger aerosols impact on them due to their inertia. These two processes depend, among other things, on the speed at which the person breathes through the mask.

To ensure that the mask can be worn over a longer period of time, it must also be designed in such a way that the breathing resistance does not exceed a defined, maximum limit value. The breathing resistance is proportional to the pressure drop caused by the filter. In addition to these material science requirements, other factors such as a "good and tight fit" of the mask to the face are crucial for good protection.

2 The three mask types

2.1 Filtering facepiece respirators which meet a test standard



These include FFP1, FFP2, FFP3 (Europe), KN95 (China) and N95 (USA). FFP stands for "Filtering Face Piece". FFP1 means that the mask must have a minimum filtering effect of 80 percent for particles larger than 600 nm. For FFP2 this is 94 percent, for KN95 and N95 95 percent and for FFP3 99 percent.

2.2 Hygiene masks (disposable masks)

Hygiene masks of "Type II" or "Type IIR" must achieve a minimum bacterial filter effect of 98 percent, while one of "Type I" must achieve 95 percent. Since bacteria are comparatively large (several micrometers), the filter performance for fine aerosols is weaker in hygiene masks than in respiratory masks.

2.3 Fabric masks (community masks)

Fabric masks (community masks) consist of several layers of fleece, cotton or microfibers. The masks can be used several times and are partly washable. However, their protective effect against fine aerosols is in most cases rather low.

3 Mask tests

3.1 Test setup

In our aerosol laboratory we offer the testing of materials for disposable and reusable masks as a service. The aim of our tests is to determine how efficiently the mask material filters the "large" coughing and sneezing droplets loaded with viruses on the one hand and the "small" aerosols from the air we breathe on the other. This assessment of the achieved filter efficiency provides valuable information on which parameter optimizations will have a positive effect on filtration efficiency if the filter materials are improved in the future. In addition, the measurement results enable customers to quickly and easily compare different filter materials with reference materials such as certified hygiene masks.

Picture 1: Cutting a sample from the material to be tested

Various particle types and test methods are available for the tests in our laboratory. For the characterization of the filtration capacity of aerosols with diameters in the range of $0.02 < D < 0.8$ µm synthetically generated salt or soot particles are used, which are electrically neutral. The size classification is carried out by means of electrostatic methods (mobility analysis) and condensation core counters. To evaluate the filtration efficiency of larger particles ($0.2 < D < 5$ µm) we use spherical droplets of an oil-like, non-volatile substance called DEHS (di-ethyl-hexyl sebacate). Here the size classification is done optically by single particle light scattering.

In accordance with the European Standard EN 14683, which defines requirements and test procedures for medical face masks, the separation efficiency of the filter materials is determined on a circular cutting of the respective filter material at an air flow velocity of 0.26 m/s. At the same time, the pressure drop across the filter caused by the air flow is measured, which plays a central role in the assessment of breathing resistance. In all our measurements we take measures to avoid electrostatic artifacts which could lead to incorrect measurements or misinterpretation of the results.

Our measuring equipment is not a test device according to EN 14683 and therefore does not replace a certification or proof of clinical protective masks. We also do not perform measurements with corona viruses but use test aerosols as a proxy for them. Furthermore, we do not currently carry out any measurements while wearing the mask - in our test we assume that the mask fits closely to the face everywhere and that all breathing air is filtered through the mask. Depending on the mask, this is a highly idealized picture, but it allows a fair comparison of the

filter materials themselves. How well the mask seals against the face depends, among other things, on breathing resistance, but also on the positioning of the mask by the wearer on the face and is not taken into account in our test.

3.2 Our test criteria in detail

- According to the Swiss National COVID-19 Science Task Force (NCS-TF), the filtration efficiency at 1 µm aerosol size must be at least 70% to meet the recommended specifications for community masks.

- There are no standard specifications for the deposition efficiency at 300 nm yet. The smaller the filter efficiency at this size, the better fine aerosols with viruses can pass through the mask and thus increase the probability of an infection of the mask wearer.

- The NCS-TF and the EN 14683 standard specify that the air permeability must not exceed a maximum value of 60 Pa/cm2 for a filter area of 4.9 cm2. This results in a maximum pressure drop of 294 Pa. If the pressure drop is higher, the mask has too low air permeability. This means that it is difficult to breathe through the mask and that more outside air is inhaled if the mask does not fit snugly against the wearer's face.

- Masks that have a valve make it easier for the wearer to exhale when the mask has low air permeability. Although the wearer is protected against viruses, the air he breathes out exits the mask unfiltered through the valve and thus does not reduce the risk of infection for others.

3.3 Test results

Thanks to our aerosol expertise, we have been able to contribute to the further development of filter materials in recent months with measurement tests of mask filter materials for the Federal Department of Defence, Civil Protection and Sport (DDPS) and various Swiss textile companies, among others. For the Swiss consumer magazine "Beobachter", we carried out random tests on the aerosol filtration capacity of various fabric masks, hygiene masks and respiratory masks available on the market in July 2020. We found that commercially available masks filter fine aerosols with varying degrees of effectiveness. The assessment was carried out in accordance with the specifications of the Swiss National COVID-19 Science Task Force (NCS-TF) and the European standard EN 14683, using the above-mentioned DEHS as test aerosol for aerosol sizes of 300 nm and 1 µm.

There is a great need in the general population for more clarity about which mask type provides good protection against the virus. Therefore, typical deposition efficiency curves, which we measured in our test facility for various masks available in Switzerland, are listed below.

In the following graphs the filtration efficiency of the masks (vertical axis, in percent) is shown for a wide range of particle sizes (horizontal axis). The individual tested masks are marked with anonymized abbreviations. The measurement results are divided into the three main mask types mentioned above.

Filtering facepiece respirators

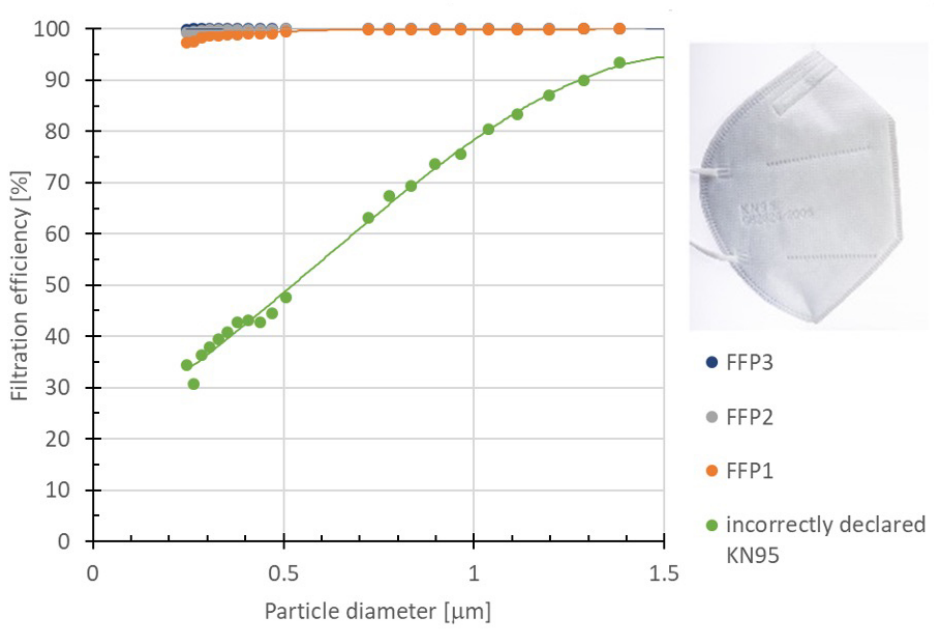


Figure 1: Filtration efficiency (%) of filtering facepiece respirators by particle diameter (nm).

As expected, (with the exception of an incorrectly declared "KN-95" mask, which has meanwhile been withdrawn from the market), the respirators show an excellent filtration efficiency and thus an effective filtering effect of fine, possibly virus-transferring aerosols.

Hygiene masks

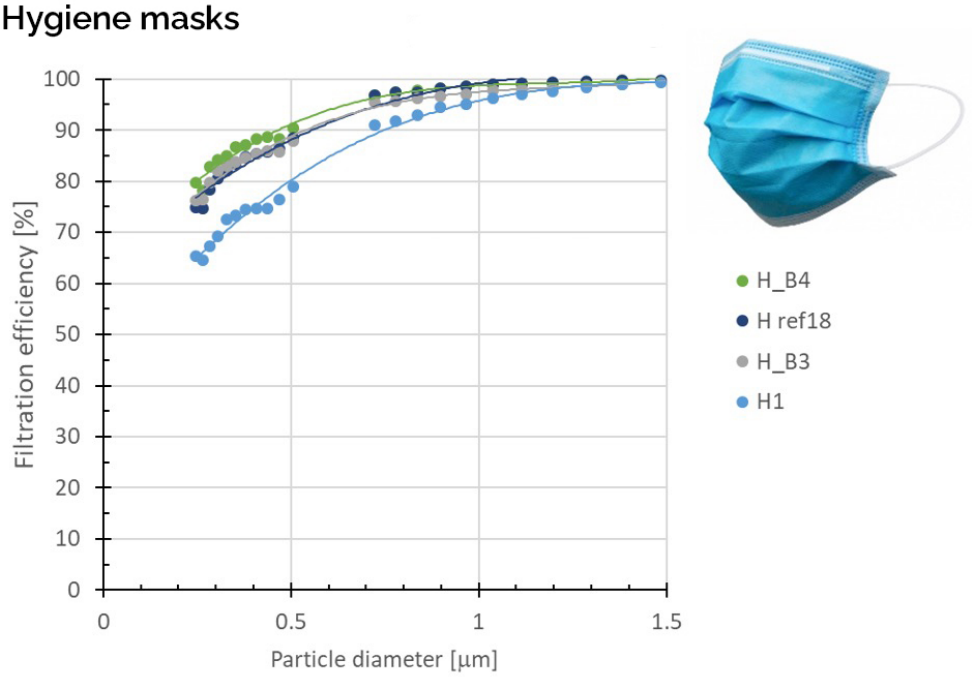


Figure 2: Filtration efficiency (%) of hygiene masks by particle diameter (nm).

The examined hygiene masks also show a good (greater than 65%) filtration efficiency of fine aerosols. An indication of "good quality" of the hygiene masks is the marking of the packaging unit with a four-digit CE number (e.g. CE 0121) and a note of the standard EN 14683, type IIR.

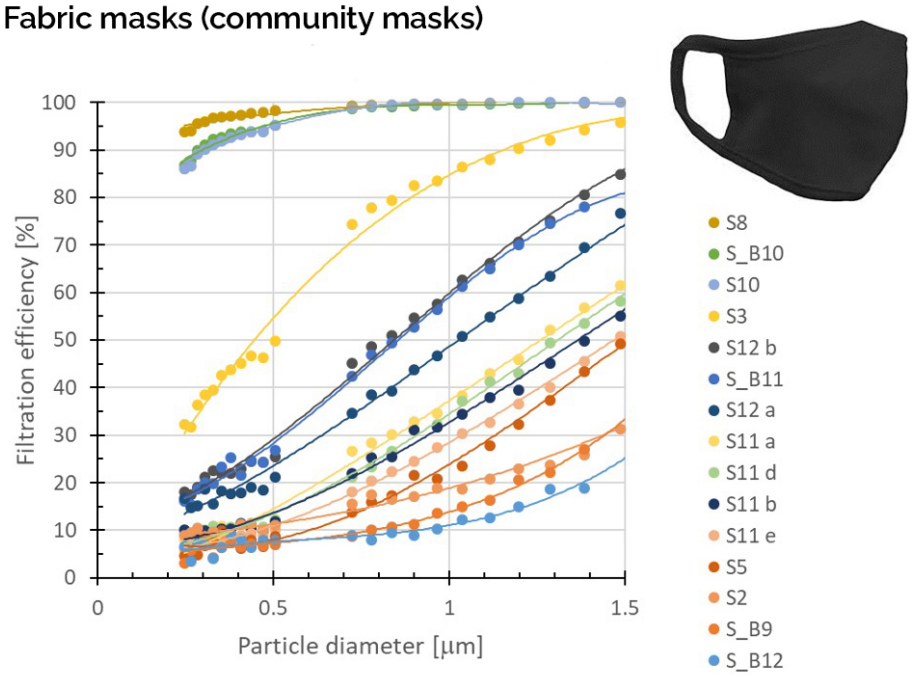


Figure 3: Filtration efficiency (%) of fabric masks by particle diameter (nm).

Fabric masks and community masks showed a mixed picture: certain products even proved to be better than hygiene masks in the test, while other fabric masks let the fine aerosol particles pass through practically unfiltered.

Our recommendation to the consumers who want to get a good fabric mask: Obtain information from the seller / importer of the masks. Does he know the filtration performance of his product and can he show test reports or labels from trustworthy institutes? Here too, quality has its price.

In general, every mask is better than no mask at all, especially with regard to the protection of fellow human beings. In order to effectively protect oneself from aerosols, however, the mask must filter fine particles well. And regardless of the type of mask, make sure that it fits well on the face and seals tightly when worn. Even the best filter material is useless if the air you breathe passes the mask unfiltered.

4 Further information

4.1 The mask test in the media (in German)

- Beobachter 16/2020: Welche Masken halten, was sie versprechen?
- Beobachter 17/2020: Wirrwarr um Masken-Zertifikate

4.2 Project information

- Client: Federal Departement of Defence, Civil Protection an Sport and other companies
- Execution: FHNW Institute for Sensors and Electronics
- Project Team: Nadine Karlen, Tobias Rüggeberg, Prof. Dr. Ernest Weingartner