# Comprehensive Characterization of Protective Face Coverings Made from Household Fabrics

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## Abstract

**Background:** By serving as source control, face coverings constitute an important strategy for containing pandemics, such as COVID-19. Infection from airborne respiratory viruses including Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) can occur through at least three modes: aerosols (typically < 1.0 µm) generated through multiple mechanisms including talking, breathing, singing; large droplets (> 0.5 µm) generated during coughing and sneezing, and macro drops (> 5000 µm) transmitted via contact. While there is a growing number of studies looking at the performance of household materials against some of these situations, to date, there has not been any systematic characterization of household materials against all three transmission modes.

**Methods:** A three-step methodology was developed and used to characterize the performance of 21 different household materials with various compositions (e.g., cotton, polyester, polypropylene, cellulose and blends), using sub-micron sodium chloride aerosols, water droplets, and mucous-mimicking macro droplets over an aerosol-droplet size range of ~ 20 nm to 0.6 cm.

**Results:** Except for one-thousand-thread-count cotton, most single-layered materials had filtration efficiencies < 10% for sub-micron solid aerosols. However, several of these materials stopped > 80% of larger droplets, even at sneeze-velocities of up to 1700 cm/s. Three or four layers of the same material, or combination fabrics, would be required to stop macro droplets from permeating out or into the face covering. The pressure drop across such combination fabrics can be high compared to N95 respirators, making them harder to breathe through. Still, the combination mask would be below the NIOSH recommended limit of 35 $mmH_2O$ (343 Pa). Such materials can also be boiled for reuse.

**Conclusion:** Four layers of loosely knit or woven fabrics, independent of the composition (e.g., cotton, polyester, nylon or blends), are likely to be effective source controls. One layer of tightly woven fabric combined with multiple layers of loosely knit or woven fabric, in addition to being source controls, can have sub-micron filtration efficiencies > 40% and may offer some protection to the wearer. However, the pressure drop across such fabrics can be high (> 100 Pa).

## Introduction

FDA regulated respirators, such as surgical or non-surgical NIOSH-approved N95s help prevent healthcare personnel exposure to contagious airborne pathogens such as SARS-CoV-2, which is the virus responsible for the COVID-19 pandemic. At the same time, the CDC has recommended that face masks be worn by adults and children two years and older as source control to help stop the spread of COVID-19. As a result, many are wearing do-it-yourself (DIY) face masks for source control. As source control, face masks are intended to protect others from the respiratory secretions of the wearer. However, there have been questions as to whether face masks also offer any respiratory protection to the wearer. This has led to a surge in the research of different materials for DIY facemasks. SARS-CoV-2 can be transmitted in three different modes: aerosols (typically < 1.0 µm) generated through multiple mechanisms including talking, breathing, singing; large droplets (> 0.5 µm) generated during coughing and sneezing; and macro drops (> 5000 µm) transmitted via contact. Much of the research on the effectiveness of different materials for DIY facemasks has been focused on one specific method of transmission. There has not been any systematic characterization of materials for DIY facemasks. Our research aims to bridge that gap and characterize the protection from all three modes of transmission offered by materials used in DIY facemasks and identify household materials that can be used to fabricate breathable cloth coverings with decent filtration efficiency (FE).

## Materials and Methods

**Materials:** 21 different materials present in existing literature were chosen. These materials are a variety of different compositions such as cottons, polyesters, polypropylene, and cellulose based materials. Several properties of these materials were measured such as pressure drop, areal density, followed by our three-method characterization testing (Figure 1).

**Method 1 - Aerosols:** This setup was based on 42 CFR 81 regulation that is used by NIOSH to approve N95s. It utilized a nebulizer with a solution of Sodium Chloride (NaCl) at a concentration of 0.o25% or 1%. This creates particles around 80-90 nm in diameter. The aerosolized NaCl was then pumped to a dryer and a charge reducer before reaching the test chamber. The concentration was dependent on if the material would get saturated NaCl before the test chamber would reach steady state. A vacuum sucked the aerosols into the sample material at a constant velocity of 9 cm/s. Sample probes upstream and downstream allowed us to measure the concentration and particle distribution on both sides of the material with a Scanning Mobility Particle Sizer (SMPS, TSI Inc.) and allows us to calculate an FE for the material under test.

**Method 2 - Droplets:** This setup utilized a Heart Continuous Nebulizer and compressed air to aerosolize water to create water droplets. These water droplets were around >0.5 to 10 µm in diameter. An Aerodynamic Particle Sizer (APS, TSI Inc.) sucked in these droplets thru an orifice to create a velocity of 485 cm/s and 1700 cm/s across the material under test, depending on the orifice used. The velocities chosen were in between the range of a normal sneeze which is between 150 and 2800 cm/s. The APS can measure the concentration and particle distribution. An FE can be calculated by doing the test with and without the material under test in front of the orifice. Materials that were tested were the best and worst materials from the Aerosols method.

**Method 3 - Macro Droplets:** This was a custom test that utilized a syringe to dispense 0.1 mL drops of a sputum mimicking fluid (Biotene, GSK Inc.) on a material under test. Materials chosen for this test were multilayered coupons chosen based on the results from the previous test methods. One hour after application, the material was evaluated for failures. Failures were defined as complete fluid penetration. The pressure drop of these materials were then measured.

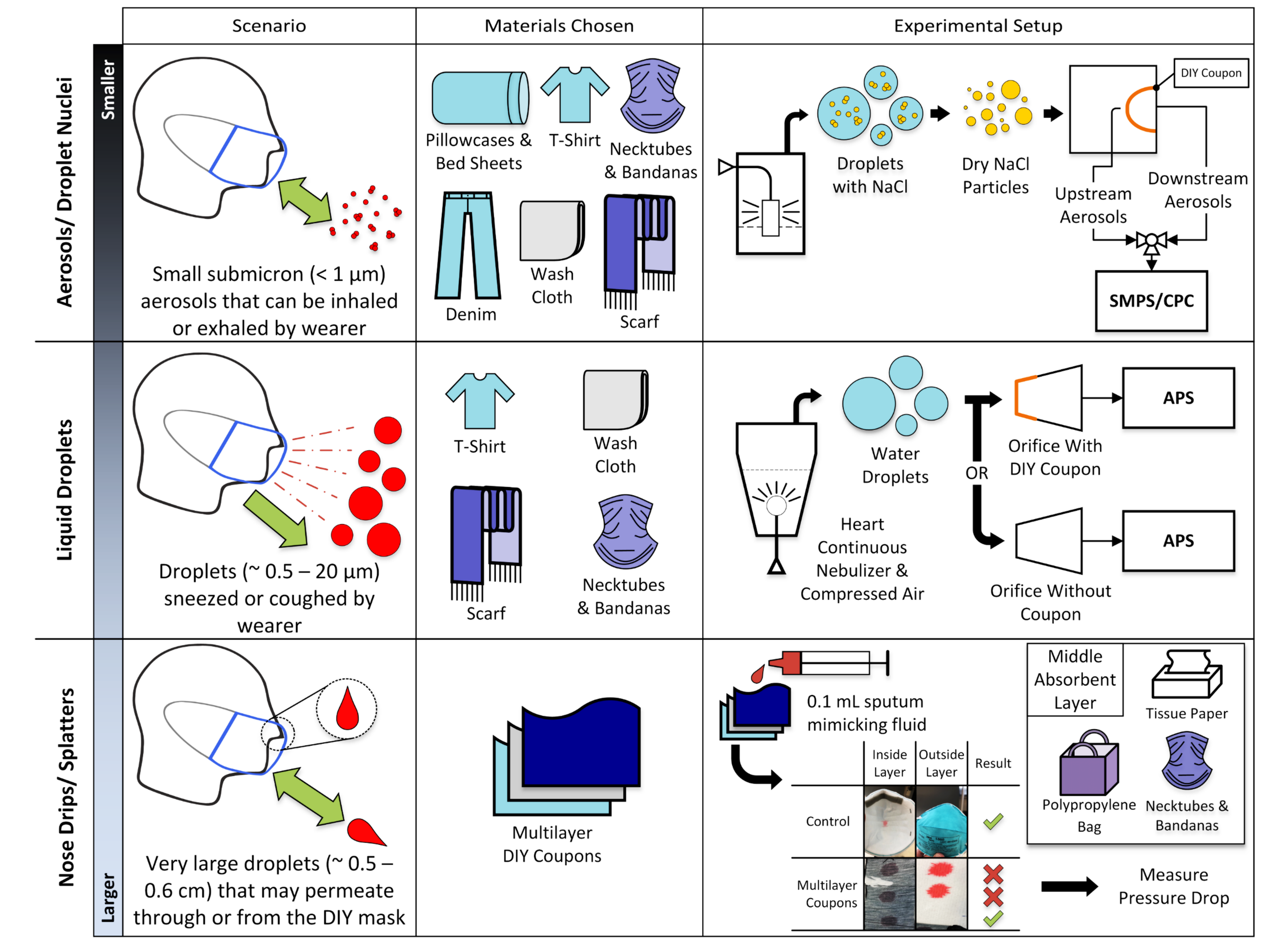


**Figure 1.** Overview of our methodology for characterizing the performance of DIY facemask materials for all three different modes of transmission

## Results and Discussion

**Method 1 - Aerosols:** Most of the materials tested for Aerosol effectiveness had an FE below 10% (Figure 2). A few materials that had above average FE were high thread count cotton bedsheets (1000 TCBS) and pillowcases (1000 TCPC), Microfiber pillowcase (Microfiber PC1), polypropylene based and Silk pillowcase (Silk PC). After measuring the pressure drop of the materials with higher-than-average FEs, there was an increasing trend with pressure drop along with increasing FE (Table 1). The CDC sets an inhalation resistance of 35 $mmH_2O$. Based on the results, masks made from multiple layers of high filtration household fabrics can reduce the breathability of a face covering.

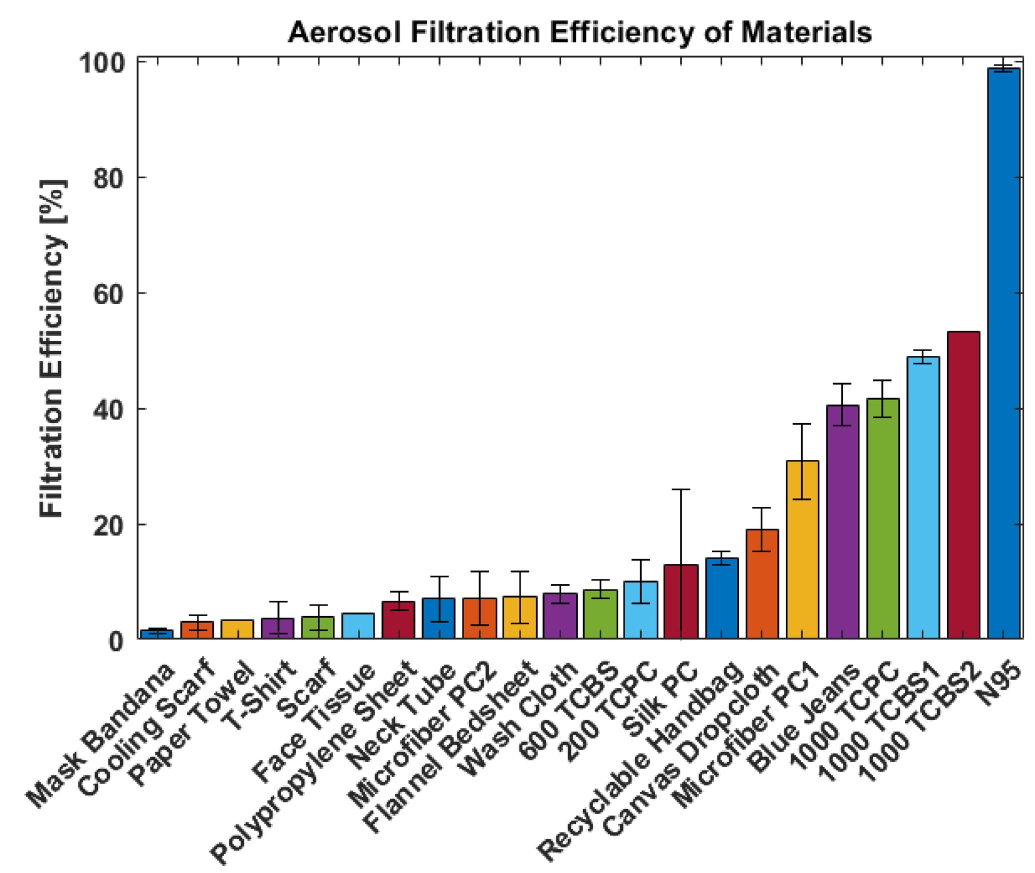


**Figure 2.** Bar Plot of the Aerosol Filtration Efficiency (FE) of the materials tested.

**Table 1.** Table of Several Tested Materials with their Aerosol (Dry) FE and Pressure Drop Measurement.

| Material | Composition | Dry Filtration Efficiency (%) | Pressure Drop ($mmH_2O$) |
|---|---|---|---|
| N95 | - - - | 98.84 ± 0.49 | 5.8 ± 0.8 |
| 1000 TC Bedsheet 1 | 100% Cotton | 48.95 ± 1.16 | 27.7 ± 3.2 |
| 1000 TC Pillowcase | 100% Cotton | 41.62 ± 3.2 | 23.6 ± 1.5 |
| Microfiber Pillowcase | 100% Polyester | 30.82 ± 6.58 | 20 ± 1.5 |
| Recyclable Handbag | 100% Polypropylene | 14.08 ± 1.14 | 0.9 ± 0.0 |
| Silk Pillowcase | 100% Mulberry Silk | 12.90 ± 12.99 | 1.1 ± 0.1 |
| Flannel Bedsheet | 100% Cotton | 7.32 ± 4.56 | 1.1 ± 0.0 |
| T-Shirt | 100% Cotton | 3.68 ± 2.79 | 0.6 ± 0.2 |
| Cooling Scarf | 100% Polyester | 2.94 ± 1.28 | 0.2 ± 0.0 |
| Hydrophobic Mask Bandana | 100% Polyester | 1.52 ± 0.44 | 0.2 ± 0.1 |

**Method 2 - Droplets:** Out of the best and worst non cellulose materials that were tested for droplet testing at 475 cm/s, most of the materials performed well with most tested materials stopping >75% of droplets (Droplet FE) (Figure 3). Dry materials and wet materials (Samples analyzed for FE later in the test) performed equally well in terms of droplet FE. This indicates that Droplet FE is independent of Aerosol FE. We tested two materials at 1700 cm/s and between the slow or fast velocities, the droplet FE, did not significantly change between the two.

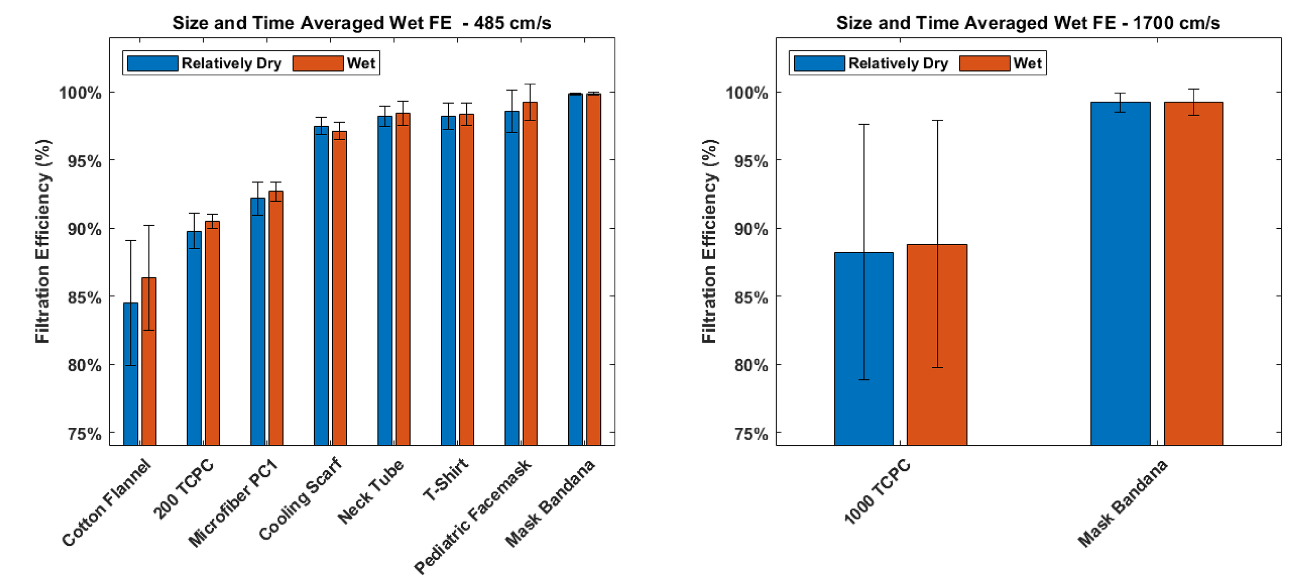


**Figure 3.** Bar Plot of the Droplet FE for the materials tested at 485 cm/s (Left) and 1700 cm/s (Right)

**Method 3 - Macro Droplets:** Out of several different combinations of multilayered materials chosen from the previous testing results (Table 2), we found that 3 to 4 layers of material would be needed to stop macro droplets from penetrating thru the facemask. We also found that materials with a middle absorbent layer of either cellulose based materials or polypropylene may be effective at stopping large splatters. The added pressure drop of having multiple tightly woven fabrics would make it difficult to breath. Instead, keeping one layer and replacing the other layers with more absorbent layers would provide sufficient protection against macro droplets. Additionally having 3 layers of hydrophobic household fabrics or 4 layers or loosely knit fabrics would provide similar protection.

**Table 2.** Table of Several Tested Layered Materials with their rate of passing the Permeability Test and Pressure Drop Measurements.

| Material Combination (Top -> Bottom) | Permeability Test (Pass/Overall) | Pressure Drop ($mmH_2O$) |
|---|---|---|
| 1000 TCPC (4 Layers) | 3/3 | > 50 (Clipped) |
| Polypropylene | 3/3 | 0.5 |
| T-Shirt – T-Shirt – T-Shirt | 3/3 | 1.8 ± 0.0 |
| Hydrophobic Mask Bandana (3 Layers) | 3/3 | 0.7 ± 0.1 |
| Cooling Scarf – Cooling Scarf – Cooling Scarf | 0/3 | 0.4 ± 0.0 |
| 1000 TCPC – Mask Bandana – Mask Bandana | 3/3 | 18.9 + 0.7 |
| 1000 TCPC – Tissue Paper – Mask Bandana | 3/3 | 19.2 ± 0.8 |
| 1000 TCPC – Polypropylene – Polypropylene | 3/3 | Not Measured |

## Conclusion

In addition to serving as source control to stop the spread to others, face coverings may also offer some protection to the wearer. At least two types of these face coverings can be made with household fabrics:

**Multiple Layers of Loosely Knit or Woven Household Fabrics**
Having multiple layers of loosely knit or woven fabrics can help with stopping droplets when the wearer sneezes or coughs and helps stop large splatters and are easy to breathe thru. But they do not offer protection against submicron aerosols.

**1 Layer 1000 TC Cotton w/ 2-3 Layers Hydrophobic Materials**
Having one layer of high thread count cotton with 2-3 layers of hydrophobic materials also offers protection against droplets when the wearer sneezes or coughs and helps stop large splatters. They are harder to breathe through compared to N95 respirators but *may* offer some respiratory protection against submicron aerosols (~40% FE).