From Moisture Transport to Mold Control:

Evaluating SCHN 135 Hydrophobic Coatings on HVAC Filters

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Abstract

Moisture retained within heating, ventilation, and air conditioning (HVAC) filtration media can create conditions favorable to fungal colonization and growth, making control of liquid transport an important factor for indoor environmental management. This study evaluates whether SCHN 135 (Integricote™), a hydrophobic organosilane sol-gel coating, reduces the passage of water-based aerosol particles across HVAC filters. Untreated and treated 1-inch Minimum Efficiency Reporting Value (MERV) 8, 5-inch MERV 8, and 5-inch MERV 13 filters were challenged with red dye particles using a K12 Nanofogger under controlled conditions. A downstream collector filter captured particles passing through the test filters, which were subsequently evaluated. Relative to untreated samples, SCHN 135 coating reduced downstream microscopic deposition by 77.1% for 1-inch MERV 8, 63.2% for 5-inch MERV 8, and 55.0% for 5-inch MERV 13 filters. These findings indicate that SCHN 135 treatment can reduce aqueous aerosol transport. Since this study evaluated liquid deposition rather than

standardized filtration efficiency or fungal growth, the results do not demonstrate enhanced MERV performance or antifungal activity. Instead, they support a potential mechanism to control moisture that may indirectly reduce conditions favorable to fungal growth, warranting further microbiological testing.

Introduction

Heating, ventilation, and air-conditioning (HVAC) systems are fundamental to the regulation of indoor environmental conditions, providing thermal control while continuously circulating and filtering large volumes of air through occupied spaces. Fibrous HVAC filters remove suspended particulate matter, biological aerosols, dust, pollen, and other contaminants; however, prolonged operation can also transform the filter itself into a site of secondary contamination. As a filter accumulates dust, organic material, microorganisms, and other deposited matter, prolonged exposure to elevated relative humidity, condensation, or liquid water can transform the filtration medium itself into an environment favorable to microbial persistence and growth. Fungal taxa have been identified within air conditioner filters, and filter materials that retain moisture containing accumulated organic matter can provide suitable substrates for colonization [1]. Controlled investigations have similarly demonstrated substantial microbial growth following nutrient loading and wetting, including within downstream portions of HVAC filter media [2]. Under sufficiently moist conditions, an HVAC filter should not be considered exclusively as a passive barrier; it may also become a reservoir where biological material is retained, exposed to moisture, and potentially reintroduced into the airflow.

The consequences of fungal contamination associated with moisture extend beyond filter performance. Epidemiological evidence consistently associates indoor dampness and mold with respiratory and allergic outcomes, including asthma exacerbation, wheeze, cough,

bronchitis, respiratory infections, and allergic rhinitis [3]. Studies of dampness and mold in schools have been linked with increased respiratory symptoms, microbial contamination, and elevated moisture levels [4], [5]. These findings show how inadequate moisture control is not simply a building maintenance problem; it can become an indoor environmental health problem.

In healthcare environments, the consequences may be particularly significant because immunocompromised patients are susceptible to opportunistic fungal infections. Hospitals have patients who may have consequences far worse than those experienced by healthy occupants in other buildings. In a multicenter examination of HVAC filters collected from seven different hospitals in the eastern United States, fungal colonization was identified in filters from five facilities, including *Aspergillus, Cladosporium, Penicillium,* and other genera [6]. The U.S. Centers for Disease Control and Prevention (CDC), therefore, emphasizes the significance of proper installation and maintenance of HVAC filters, elimination of excess moisture, and the use of high-efficiency particulate air (HEPA) filters in appropriate healthcare environments [7]. Reviews of nosocomial aspergillosis and investigations of hospital filtration systems further demonstrate the importance of controlling airborne fungal exposure in high-risk environments [8], [9]. These observations do not establish HVAC filters as the cause of hospital fungal infections; rather, they show how critically airborne fungal control can matter when susceptible patients are present.

Experimental and field investigations provide further evidence that the behavior of microorganisms on HVAC filters is strongly influenced by environmental moisture. Möritz et al. (2001) found that HVAC filters effectively reduced airborne microbial concentrations under comparatively dry conditions, whereas prolonged relative humidity above 80% was associated with microbial proliferation and subsequent release into filtered air [10]. Forthomme et al.

(2014) similarly demonstrated rapid proliferation of *Penicillium oxalicum* under highly humid conditions, including fungal development within downstream regions of fibrous filters [11]. Morisseau et al. (2017) subsequently showed that the water-retention characteristics of loaded filters influenced fungal growth and that fungal-associated particles could be released during simulated ventilation restart [12]. These studies support a mechanistic relationship in which accumulated biological material encounters sufficient water availability to permit fungal proliferation, after which fungal-associated material may potentially re-enter the airstream. Consequently, controlling water interaction at the filtration medium itself represents a logical target for intervention.

Together, these findings suggest that reducing the interaction between liquid water and the filter medium itself may provide an additional line of defense. Unlike an impermeable barrier, which would interfere with the porous structure required for airflow, hydrophobic surface modification can reduce affinity for liquid water while preserving interconnected air pathways. Liu et al. (2021) produced silanized cellulose-nanofiber filters with a water contact angle of approximately 152° and improved resistance to high humidity and condensed droplets, while preserving the filtration performance [13]. Kim et al. (2023) similarly developed hydrophobic nanofibrous filtration media that resisted wetting and promoted droplet removal from the surface [14]. Sol-gel surface modification has produced comparable behavior. Dong et al. (2021) prepared sol-gel-modified polyethylene terephthalate filtration media with water contact angles exceeding 160° while retaining the underlying porous microstructure, whereas Li et al. (2023) produced TiO_2-SiO_2@PDMS-modified filter media with a water contact angle of approximately 158° [15,16]. These studies demonstrate that filter wettability can be substantially modified while maintaining the porous architecture required for air filtration. Direct testing of SCHN 135 on fibrous textile substrates similarly demonstrated repellency of

aqueous liquids, with contact angles above 90°, providing evidence that SCHN 135 can modify interactions between liquids and fibers [17].

Previous work with the Self-Cleaning Hydrophobic Nanocoating (SCHN) platform provides additional rationale for extending this approach to HVAC filtration media. The organosilane-based SCHN system is designed to form a three-dimensional, nano- to micro structured hydrophobic network within porous substrates rather than functioning solely as a continuous external film [18].

This characteristic is relevant to filtration applications because excessive film formation could obstruct pores and negatively affect airflow. Related SCHN formulations have also demonstrated substantial reductions in water transport through porous materials. Kabani et al. (2026) compared SCHN 158-treated and untreated masonry using absorptivity measurements and reported approximately 84% lower initial water sorption in SCHN-treated specimens relative to untreated controls [19]. Previous work with Sol-158-3 also provides preliminary evidence that the physical properties of the coating may influence microbial establishment. In masonry exposed to sulfate-reducing bacteria, the pure Sol-158-3 treatment exhibited markedly less observable bacterial growth and reduced polysaccharide-associated signatures interpreted as evidence of reduced biofilm formation [20].

Although masonry differs fundamentally from fibrous HVAC media in material composition, pore architecture, and fluid-transport mechanisms, these findings establish that the coating chemistry can substantially modify aqueous penetration in a porous material and therefore provide a direct materials-based rationale for evaluating its performance on HVAC filters.

Additional work on porous wood substrates provides complementary evidence that SCHN treatment can reduce water uptake [21], while related poly(organosiloxane) sol-gel

coating reduced overall aqueous leachate from creosote-treated wood by 66% after 3 hours [22]. SCHN 146-based formulations have been investigated as water repellent protective systems for wood, which are moisture sensitive [23].

Wang *et al.* evaluated a sol-gel-derived hydrophobic coating, Capture Coating™, on MERV-rated filters using thermally inactivated SARS-CoV-2 as an aqueous biological challenge and reported substantially lower downstream viral detection when filters were hydrophobically treated [24]. Although Capture Coating™ and SCHN 135 are different formulations, the findings provide prior HVAC-specific evidence that hydrophobic modification of filter fibers can reduce the transport of aqueous material.

Despite evidence linking moisture to fungal proliferation and evidence that hydrophobic treatments can alter aqueous transport, the effect of SCHN 135 on liquid penetration through conventional HVAC filters has not been established. The present study therefore targets moisture transport rather than direct antifungal activity. The proposed mechanism is that hydrophobic modification of the fibers of the filter reduces wetting and liquid migration, potentially creating conditions less favorable for subsequent fungal colonization.

To evaluate this question, the present study employs an upstream test filter followed by a downstream collector filter, enabling material that penetrates the test medium to be detected separately from liquid retained upstream. The present experiment is not an ASHRAE 52.2 or ISO 16890 certification procedure because it evaluates comparative liquid breakthrough rather than standardized particulate-removal efficiency; nevertheless, its upstream challenge and downstream collection architecture follow the same fundamental experimental principle [25], [26]. A water-based red dye aerosol was used as a visible tracer, and was not intended to represent mold, biological contamination, or fungal spores, and is not

a biological surrogate. Controlling airflow, humidity, and pressure is necessary to ensure that differences between coated and uncoated filters are associated primarily with the surface treatment rather than uncontrolled aerodynamic variation, since liquid-aerosol behavior in fibrous filters is influenced by airflow and moisture [27], [28].

The present experimental study compares untreated and SCHN 135 (Integricote™) treated filtration materials across multiple geometries and performance classes. In addition to conventional 1-inch MERV 8 filters, 5-inch MERV 8 and 5-inch MERV 13 media are evaluated. The objective of this study is therefore to determine whether hydrophobic sol-gel treatment reduces water-based aerosol penetration and downstream deposition through HVAC filtration media when compared with untreated materials under the same, controlled conditions. It is hypothesized that filtration media treated with sol-gel will demonstrate lower downstream deposition because the altered surface chemistry reduces wetting and liquid migration through the fibrous structure. A positive result alone would not demonstrate the prevention of mold growth; however, it would establish a physical moisture-control mechanism that may subsequently be investigated microbiologically. The broader significance of this study is its potential application to environments in which filtration reliability and moisture control are particularly consequential. Including hospitals, hotels, schools, commercial buildings, and other highly occupied spaces.

Physics of Aerosol Transport and Surface Wettability

The physical basis of the experiment can be separated into three successive processes: transport of droplets toward the filter, interaction of droplets with the fibrous medium, and movement of liquid after contact with the fibers. Airflow determines the first process, particle size and inertia influence the second, and surface wettability influences the third.

Airflow and Fan Performance

The volumetric flow rate through a cross-sectional area is described by conservation of volumetric airflow,

$$Q = AU \tag{1}$$

(Q) is the volumetric airflow rate in m^3, (A) is the cross-sectional area in m^2, and (U) is the mean face velocity in m/s.

The AC Infinity CLOUDLINE T10 used in this study has a manufacturer-rated airflow of 1201 $ft^3/\,min$ (CFM) and a maximum static pressure of 1059 Pa [29]. The maximum rated airflow is approximately 0.567 $m^3/\,s$. Using the 10-in. (0.254-m) circular duct area of approximately 0.0507 m^2, the maximum idealized mean duct velocity is approximately 11.2 m/s. The affinity laws indicate that airflow increases in proportion to fan speed, while pressure increases approximately with the square of fan speed [30].

If controller speed levels 5 and 7 were treated as 50 and 70% of maximum rotational speed, their velocity values are approximately 5.6 and 7.8 m/s, respectively.

Pressure and Suction

The airflow produces a pressure difference across the filtration system. The dynamic pressure associated with an air velocity (U) can be represented by

$$q = \frac{1}{2}\rho U^2 \tag{2}$$

ρ is air density. Using $\rho \approx 1.20\ kg/m^3$, the nominal velocities of 5.6 and 7.8 m/s

correspond to dynamic pressures of around 18.8 and 36.5 Pa, respectively. These values provide an order of magnitude description of the airflow energy available to transport aerosol toward the filter but are not measurements of the differential pressure across the filter.

Droplet Size, Inertia, and Interaction with Filter Fibers

Aerosol interaction with individual fibers depends strongly on particle inertia. The tendency of a particle to follow the airflow around individual filter fibers can be represented by the Stokes number [31]:

$$Stk = \frac{\tau_p U}{L_c} \tag{3}$$

τ_p is the particle retention time, and L_c is a characteristic dimension of the filter structure. Small particles with low Stk tend to follow airflow streamlines, whereas increasing particle size or air velocity increases inertial effects and the likelihood of interaction between particles and the filter. This relationship is particularly relevant to the nominal 20-50 μm droplets generated during the present experiments.

Droplet Coagulation and Coalescence

Aerosol particles may also change size through collisions. For liquid droplets, collisions followed by coalescence are the relevant analogue of aerosol coagulation. A simplified Smoluchowski representation expresses the decrease in number concentration (N) as

$$\frac{dN}{dt} = -KN^2 \tag{4}$$

Where (K) is an effective coagulation coefficient [27]. The relationship emphasizes that the extent of coagulation depends strongly on aerosol number concentration and collision dynamics.

The effect of coalescence on droplet size can be illustrated by conservation of liquid volume. If (n) identical spherical droplets of initial diameter (d_i), their equivalent diameter is

$$d_e = n^{\frac{1}{3}} d_i \quad (5)$$

Thus, eight 5 μm droplets would make a 10 μm droplet, and 64.5 μm droplets would make a 20 μm droplet. This provides a physical model for understanding how initially fine aqueous aerosol may evolve toward larger droplets, although coagulation measurements were outside the scope of the present experiment.

Surface Wettability and Capillary Transport

After a liquid droplet contacts the filtration media, its movement through the filter depends partly on how easily water spreads across and enters the fiber surfaces. On a wettable surface, water tends to spread and move into the small spaces between fibers. This process, called wicking, can carry liquid deeper into the filter. On a hydrophobic surface, water does not spread easily. Instead, droplets tend to remain more localized and may resist entering the small pores between fibers. As the surface becomes more hydrophobic, the tendency of water to move through the filter decreases. SCHN 135 is therefore expected to reduce liquid transport by changing the interaction between water and the filter fibers after the droplets contact the filter. The coating is not intended to form an impermeable barrier or a complete block of airflow.

Materials and Methods

This experiment aims to determine the effectiveness of SCHN 135 in preventing the passage of moisture through various types of MERV-graded filters. SCHN 135 was obtained from Integricote Inc., Houston, TX, and served as the treatment for all trials. A K12 Nanofogger, an aerosol spray bottle, was used to generate aerosol droplets ranging from 20 to 50 μm. In order to visualize these particles, a water-based red food dye was utilized and diluted with water to ensure an appropriate concentration and visualization when conducting trials. An AC Infinity CLOUDLINE T10 fan was utilized in a built-in HVAC system, shown in figure 1, to simulate air speed conditions in average households and buildings. With this system, both temperature and

humidity were recorded and controlled to prevent unrealistic conditions from interfering with data collection.

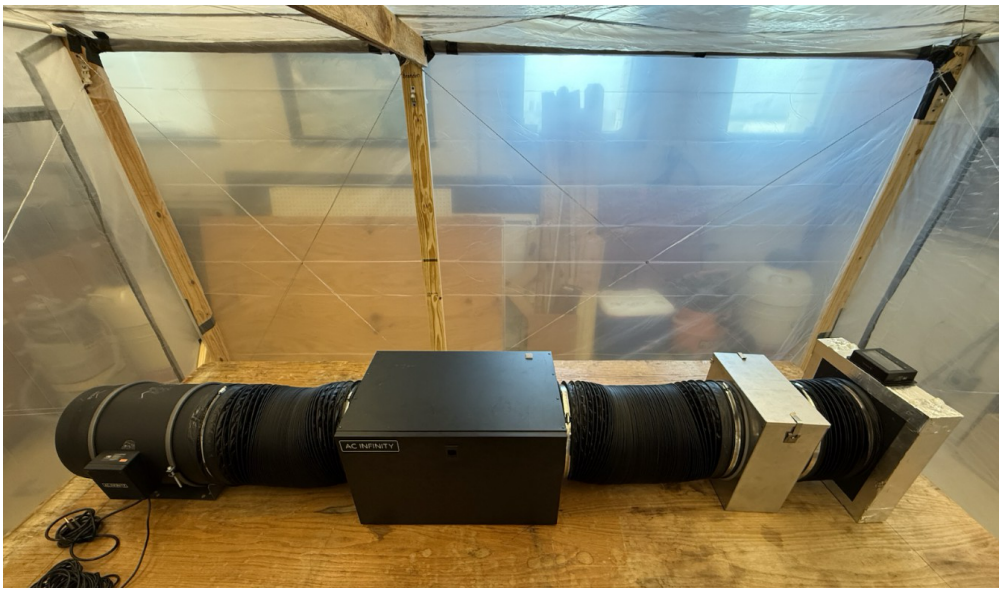


Figure 1. *Experimental HVAC apparatus used for the study setup in a clean room. Airflow proceeded from right to left through the experimental filter (treated or untreated), followed by the downstream collector filter used for deposition analysis, a secondary cleanup filter for residual material capture, and the inline fan.*

Three HVAC filter groups were evaluated: 12 x 12 x 1 inch MERV 8 filters, 20 x 20 x 5 inch MERV 8 filters, and 20 x 20 x 5-inch MERV 13 filters. Both visual and measured comparisons were made between treated and untreated filters within each group under the same conditions. MERV 8 filters from Filterbuy were utilized as a control group, while MERV 8 filters from Trueblue were utilized as a treatment group. The 5-inch MERV 8 and MERV 13 filters were obtained from Filterbuy and Glasfloss, respectively.

Preparation of Filters

Each treated filter was coated with SCHN 135 and left to dry for 24 hours before trials were run. A second coating was applied and left to dry once more to ensure full coverage across the entire filter. Once filters were dry and the coating was evenly distributed, 15 x 15 cm sections were cut out to fit within the frame designed in the HVAC system. Separate, untreated MERV 8 filters were also cut out into sections to serve as a collector that was used to determine the

number of particles that penetrated a coated filter. These collector filters were also utilized with untreated MERV 8 and 13 filters to set a standard of how many particles penetrated the filter. For the 20 x 20 x 5-inch pleated filters, a chamber was designed to hold the entire filter without tampering with the filter. This was done differently due to the frame not being designed to accommodate 5-inch pleated filters, as shown in figure 2.



Figure 2. *The modified HVAC system for the 5-inch filters used in the study.*

HVAC Airflow and Aerosol Transport

Airflow through the experimental system was generated using an AC Infinity AI-CLT10, a 10-inch inline duct fan. According to the manufacturer, the fan has a maximum airflow capacity of 1201 ft^3/min (CFM), 10 controller settings, and a maximum static pressure of 1059 Pa [24]. The fan provided the pressure difference required to transport aerosol droplets from the upstream Nanofogger toward and through the test filtration media. During the experiment, fan settings were held constant across testing groups.

Table 1. *Experimental conditions*

Filter Type	**Air Speed***	**Spray Duration**	**Nanofogger Distance**
MERV 8 (12 x 12 x 1 in.)	Speed 5 (~5.6 m/s)	Two 30 s applications separated by 10 s	30 cm.
MERV 8 (20 x 20 x 5 in.)	Speed 7 (~7.8 m/s)	Two 60 s applications separated by 60 s	30 cm.
MERV 13 (20 x 20 x 5 in.)	Speed 7 (~7.8 m/s)	Two 60 s applications separated by 60 s	30 cm.

**: Air speed was estimated from calculations using maximum airflow from the manufacturer [29] using idealized fan-affinity scaling [30]; velocities were not directly measured at the filter face.*

Conditions for the trials were determined based on the amount of visual deposition on collector filters utilizing untreated filters. Conditions that resulted in no visual deposition were not utilized in the experiment in order to standardize a quantitative analysis of particle penetration.

Different conditions were utilized for the 20 x 20 x 5 inch filters due to the increased thickness of the filters, requiring a higher air speed to result in visual deposition on the collector filter.

Assessment of Downstream Deposition

Following each trial, the downstream collector filter was removed and examined for deposited red tracer. Macroscopic examination was performed to identify visible droplets, localized deposits, and larger regions of accumulation. The collector media was then examined under a microscope to identify smaller depositions that were not visible to the naked eye. Microscopic particles were defined as distinguishable, circular red deposits that were separate from those that made up visible droplets. Fibers that appeared stained, or different colored deposits, were not included in the particle count. A 2 by 2 cm sampling frame was used to define microscopic counting regions. For the 1-inch MERV 8 filters, representative regions from the upper, middle,

and lower portions were collected to be examined. Counts obtained from these regions were scaled according to the collector area to generate a total microscopic downstream deposition count. For the 5-inch filters, the collector area was around 36 of the 2 by 2 cm regions. Particles within a 2 by 2 cm region were multiplied by 36 to obtain an estimate of the whole collector.

Results

Table 2. *Amount of particle penetration in MERV 8 (12 x 12 x 1 in.) filters.*

	Untreated	**Treated**	**Reduction**
Visible Particles	429	NQ*	—
Microscopic Particles	852	195	77.1%

**NQ, not quantifiable. Particles were indistinguishable, but a noticeable red hue was present on the filter.*

In Table 2, visible and microscopic particles were determined on treated and untreated 1 in. MERV 8 filters. The untreated filter, upon initial view, demonstrated individual particles that were distinguishable from one another. However, the treated filter showed a red hue that spread across the top of the filter, which made the visual particles indistinguishable. These constraints prevented numerical representation of these particles and can strictly be analyzed through visual observation alone.

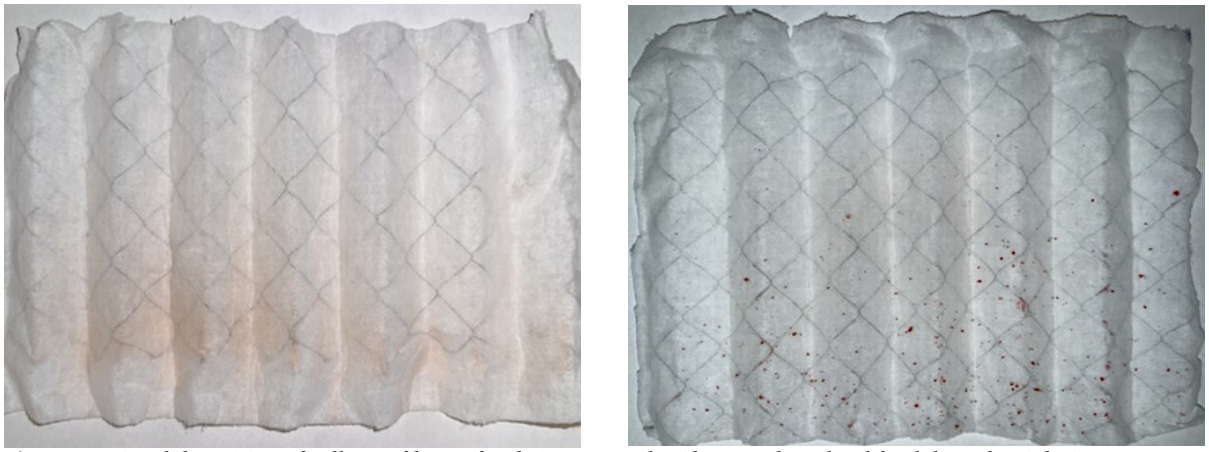


Figure 3. *Visual deposition of collector filters after being sprayed with water-based red food dye. The right is an untreated MERV 8 filter, and the left is a treated MERV 8 filter.*

Based on Figure 3, the untreated filter demonstrated more abundant, individual particles compared to the treated filter. These particles are much deeper in color than the treated filter, determining that more particles penetrated the untreated filter.

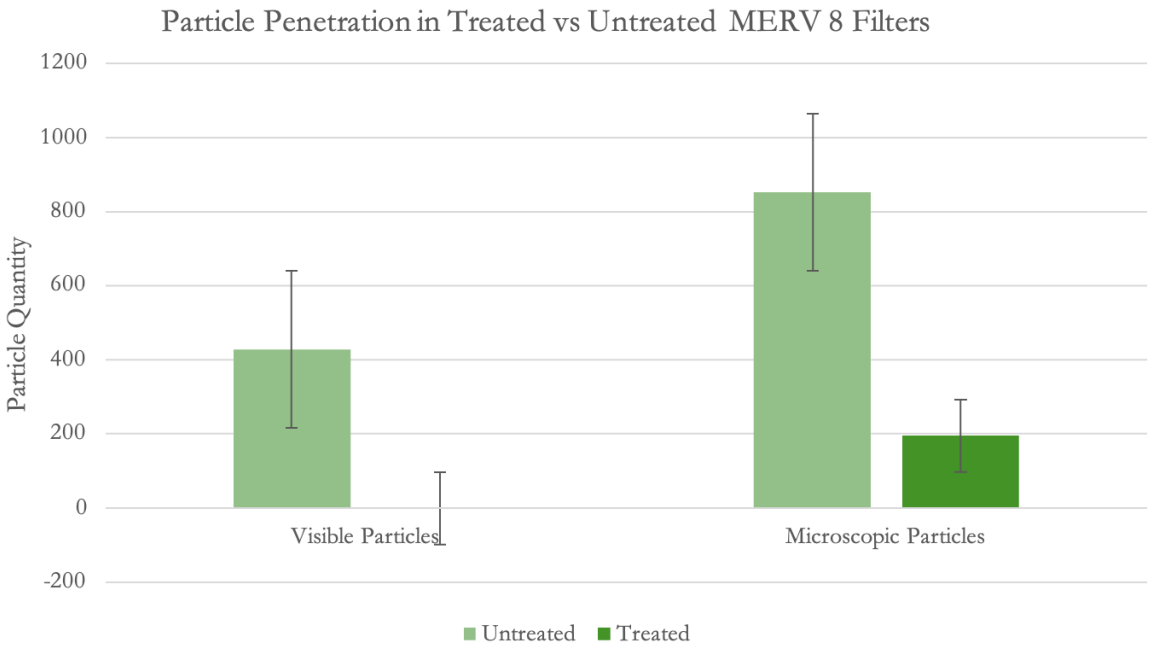


Figure 4. *Particle penetration in treated vs. untreated MERV 8 filters.*

In Figure 4, both visible and microscopic particle penetration were compared with one another based on treatment. Microscopic downstream deposition was estimated using the defined 2 x 2 cm sampling procedure described in Materials and Methods. Counts obtained within the sampling regions were scaled according to the collector area to obtain descriptive whole-collector estimates. Because deposition was spatially nonuniform and the entire collector was not counted, these values should be interpreted as estimated deposition rather than exact counts. For the 1-inch MERV 8 filters, estimated microscopic deposition decreased from 852 particles to 195 in the untreated, corresponding to a 77.1% reduction.

Table 3. *Amount of microscopic particle penetration in MERV 8 and 13 (20 x 20 x 5 in.) filters.*

	Untreated MERV 8	**Treated MERV 8**	**Untreated MERV 13**	**Treated MERV 13**
Total Squares	36	36	36	36
Total Concentrated Squares	5	3	5	3
Particle Count (One Square)	38	14	20	9
Total Particle Count	1,368	504	720	324
Relative reduction with treatment	—	63.2%	—	55.0%
Total Concentrated Particle Count	190	42	100	27
Relative reduction in concentrated area	—	77.9%	—	73.0%

In Table 3, both MERV 8 and 13 filters were treated with SCHN 135 and compared to those without coatings. While visible deposition on the collector filter was noticeable, individual particles were unable to be distinguished, so particles were strictly quantified utilizing a microscope. For MERV 8 filters, the untreated collector contained 38 particles within a microscopic sampling region, an estimate of 1,368 particles across the whole filter. The SCHN 135 treated MERV 8 filters had 14 particles, corresponding to 504 total particles. Therefore, the treatment produced an estimated reduction of 63.2%. When looking at the concentrated region, the reduction was around 77.9%. A similar trend was seen with the MERV 13 filters, with a 55% reduction in whole-collector deposition and a 73% reduction within the concentrated area. Across both MERV 8 and 13 5-inch filters, the SCHN 135 treatment led to a lower estimated downstream deposition.

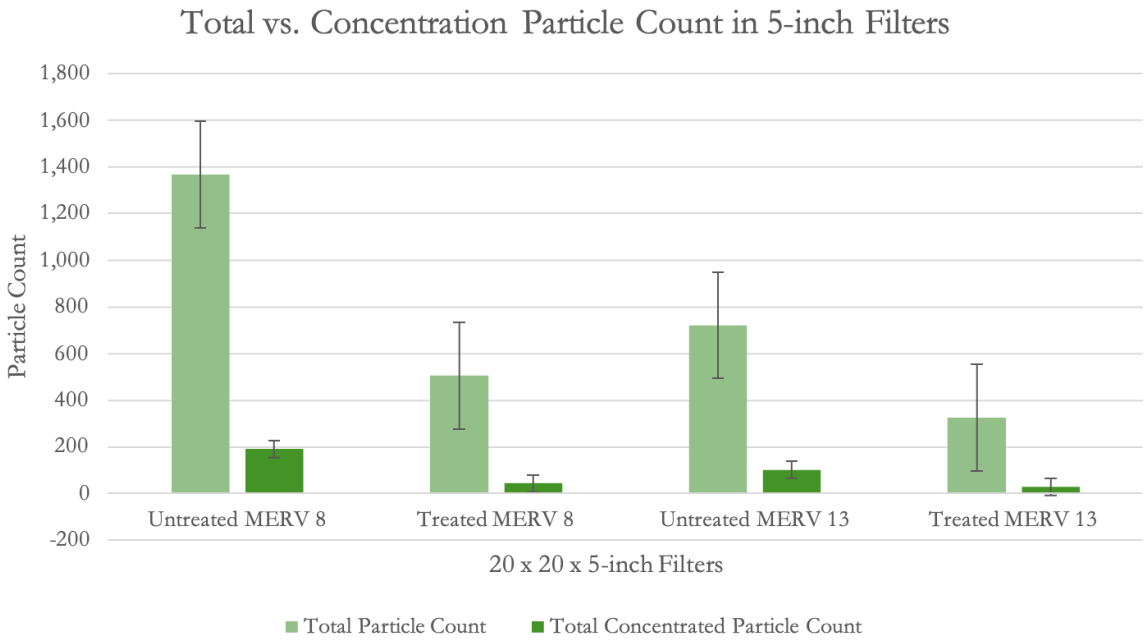


Figure 5. *Total and concentrated microscopic particle penetration across different 20 x 20 x 5 in. filters.*

Assuming an equal distribution of filters across the entire filter, the treated filters proved to have significantly less penetration compared to the untreated filters. However, there was no equal distribution across the filters, and rather a concentrated region where penetration was located. To accommodate the uneven distribution of particles penetrated, the 2 x 2 cm frame was also utilized to determine an approximate size of the concentrated region. This allowed for more specific estimations of how many particles were located within the concentrated region. Including this parameter, there was still a significant decrease in particle penetration with the treated filters compared to the untreated filters.

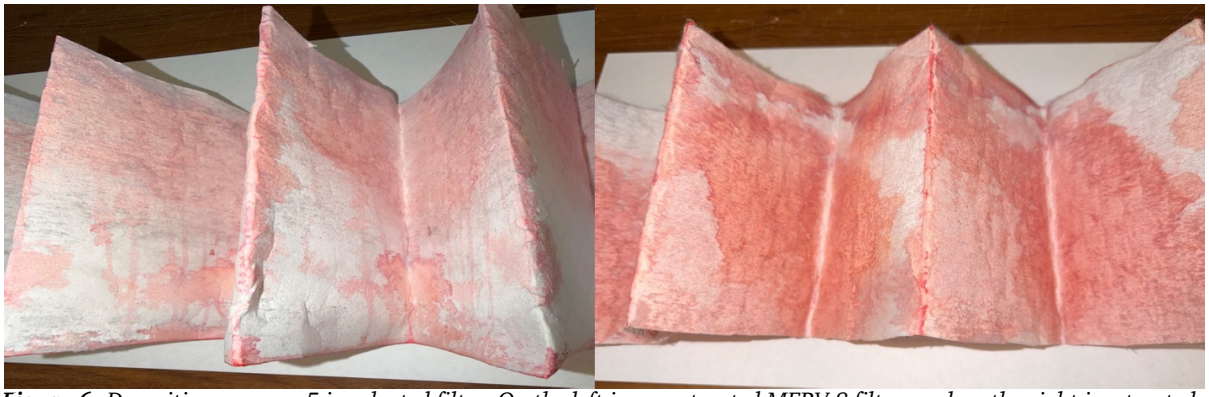


Figure 6. *Deposition across a 5 in. pleated filter. On the left is an untreated MERV 8 filter, and on the right is a treated MERV 8 filter.*

In Figure 6, particle deposition is observed throughout the 5 in. pleated filters. Sections of the experimental filter were cut out and extended to determine the distance the particles traveled throughout the filter. However, due to the gradient appearance of the filter, qualitative observations were utilized to analyze the results. The untreated filter shows a deep, red hue across the filter, nearly covering the entire 5 in. width. This coloration is significantly more concentrated, representing a greater increase in particle penetration. The treated filter is the opposite, showing a lighter coloration and less coverage across the 5 in. width.

Table 4. *Temperature and humidity of HVAC system for 12 x 12 x 1 in. and 20 x 20 x 5 in. filters, respectively.*

Filter Type	**Average Temperature**	**Maximum Temperature**	**Minimum Temperature**	**Average Humidity**	**Maximum Humidity**	**Minimum Humidity**
12 x 12 x 1 in. MERV 8	21.3°C	22.2°C	21.0°C	71.7%	76.0%	69.0%
20 x 20 x 5 in. MERV 8	**21.5°C**	**22.5°C**	**21.0°C**	**69.9%**	**74.0%**	**67.0%**

Filter Type	Average Temperature	Maximum Temperature	Minimum Temperature	Average Humidity	Maximum Humidity	Minimum Humidity
20 x 20 x 5 in. MERV 13	21.5℃	22.5℃	21.0℃	69.9%	74.0%	67.0%

In Table 4, the average temperature and humidity throughout the experiments remained consistent, with little variation across trials. This was done to prevent external environmental factors from interfering with data collection.

Discussion

Effect of SCHN 135 on Downstream Aerosol Deposition

The results of this study demonstrate that treatment of HVAC filtration with SCHN 135 reduced downstream deposition of a water-based aerosol tracer through each filter type evaluated. For the 12 x 12 x 1 in. MERV 8 filters treated with SCHN 135, there was an estimated 77.1% reduction in microscopic downstream deposition compared with the untreated filter. Estimated reductions of 63.2% and 55.0% were observed for the 20 x 20 x 5 in. MERV 8 and MERV 13 filters, respectively. These findings support the hypothesis that SCHN 135 treatment can reduce the transport of water-based aerosols through fibrous HVAC filtration media under the conditions evaluated.

Hydrophobicity and Mechanism of Reduced Liquid Transport

Transport of a liquid aerosol through fibrous filtration media involves both the initial interaction of airborne droplets with the filter fibers and the subsequent movement of liquid after deposition. The K12 Nanofogger used in the study generated water-based droplets approximately 20-50 μm in diameter. Airflow transported these droplets toward the filtration medium, where mechanisms including inertial impaction can promote contact with individual

fibers. Larger droplets possess greater inertia and maybe less able to follow airflow around fibers, increasing their probability of contact.

After deposition, surface wettability becomes increasingly important. On relatively wettable fibers, liquid can spread along the surface and migrate through interconnected regions of the filter by capillary action and wicking. Hydrophobic modification reduces the affinity of the surface for water and can therefore limit spreading and migration of deposited droplets through the fibrous structure. This provides a plausible mechanism for the lower downstream deposition observed in SCHN 135-treated filters without assuming that the coating forms an impermeable barrier or directly increasing the initial particle capture efficiency of the filter.

Although these materials differ from the commercial HVAC filters evaluated in the present study, the collective literature demonstrates the principle that surface interactions can be modified to produce favorable interactions between liquid and filters. The results in the present study further extend this concept to SCHN 135 treated MERV 8 and MERV 13 HVAC filters, where the lower downstream deposition of water-based aerosol particles was observed following the results of the treated filters.

Implications for Mold and Fungal Growth

Reduced liquid transport may be particularly important when considering the context of microbial threats contaminating HVAC filters. Moisture availability is an important factor in the microbial survival and proliferation on filter media. Möritz et al. reported that HVAC filters effectively reduced airborne microbial concentrations when under dry conditions, compared to when under prolonged humidity above 80% there was microbial proliferation and subsequent release into the filtered air [10]. Forthomme et al. similarly demonstrated a substantial proliferation of *Penicillium oxalicum* under high humid conditions, including fungal

development and accumulation within the filter material [11]. Morisseau et al. further demonstrated that water retention characteristics of materials influence fungal growth on loaded filters, and showed that fungal growth on filters could be released into the circulating air during simulated ventilation [12]. These studies establish an important relationship between the moisture conditions over filters and the fungal behavior within filters. Therefore, reducing the potential liquid penetration through HVAC filters may represent one approach towards decreasing this environmental condition and stopping the perpetuation of fungal development before it begins.

Supporting this moisture control concept on a different porous material, wood that was treated with SCHN showed reduced water uptake and inhibition of the growth of *Aureobasidium pullulans, Aspergillus niger, and Penicillium* under the conditions evaluated [21]. Although wood is not directly comparable to HVAC filters, these findings are consistent with the broader hypothesis that limiting moisture availability can reduce conditions favorable to fungal colonization.

The present results, however, do not demonstrate that SCHN 135-treated filters directly kill or inhibit fungi. There were no fungi, fungi spores, or biological organisms used in the current experiment. The red food dye only served as an adequate visible tracer for the representation of water-based aerosol transportation. Therefore, the relationship proposed between SCHN 135 and fungal contamination is indirect. If the hydrophobic treatment on filters reduces liquid penetration and migration through a filter, then it may produce conditions that are less favorable for fungal growth and survival. However, moisture is only one factor when considering other factors that contribute to fungal growth alongside temperature, filter capacity, fungal species, and other environmental conditions. Further studies with direct microbiological testing will be required to determine if the reduction of liquid transportation

translates to reduced fungal colonization and proliferation.

Potential Applications in HVAC Systems

Reducing liquid transport may have practical relevance in highly occupied environments, including healthcare facilities, schools, hotels, commercial buildings, and similar settings. This particularly consequential in healthcare environments, where susceptible patients can experience severe outcomes following exposure to opportunistic fungi and where HVAC moisture control is already an established component of environmental infection control [6], [7]. Hydrophobic modification of filtration media could potentially complement these existing strategies by reducing the interactions of the filters with liquid-based aerosols, enhancing the efficiency of the filters, and establishing infection control practices that stop the accumulation of potential fungi. Such practices would not replace where appropriate filter selection or HEPA filtration is established, rather this poses an alternative method to enhance the already existing filter media population.

Limitations and Future Work

Several limitations should be considered when interpreting the present findings. First, the water and red food dye tracer do not produce biological properties or behaviors of fungal spores or other biological aerosols. Therefore, this study evaluated liquid transportation as a representation of water-based aerosols rather than actual fungal filtration or growth. Second, microscopic downstream deposition was standardized and estimated using a 2 x 2 cm sampling frame across larger areas on the collectors. Because deposition was nonuniform, these values represent estimations rather than direct counts of the whole filter. However, an evaluation of concentrated deposition regions did produce the same overall trends of reduced downstream deposition following measurement of the treated filters. Additionally, different airflow and

aerosol challenges were required for the 1-inch and 5-inch filters due to their difference in configuration and structure to produce measurable and consistent data. Another limitation is the SCHN 135 coating used in the experiments being more than five years old at the time of testing. Prolonged storage may have resulted in chemical aging or degradation of the coating, potentially reducing its hydrophobic performance and allowing greater liquid transport than fresh material. The reductions observed in this study may not represent the maximum performance achievable with SCHN 135.

Most importantly, future studies should directly compare fungal colonization on treated and untreated filtration media under controlled temperature, humidity, and moisture conditions. Such experiments would determine whether the physical reduction in liquid transportation has a direct effect on producing measurable biological growth. Long-term aging and repeated wetting alongside drying studies could further determine if the SCHN 135-treated filters can remain stable under the same conditions of an HVAC system's filters. Together, these investigations would potentially determine whether SCHN 135 can provide durable moisture resistance while maintaining adequate filtration performance and whether a moisture-controlled mechanism could ultimately create an environment less favorable for fungal growth and development.

Conclusion

Summary of Findings

This study investigated the ability of SCHN 135 hydrophobic sol-gel treatment to reduce the penetration of water-based aerosols through HVAC filters. Across all filter configurations and types evaluated, SCHN 135-treated filters demonstrated consistently lower estimated downstream deposition compared to untreated filters. Microscopic deposition was reduced by approximately 77.1% in the 1-inch MERV 8 filters, while reductions of 63.2% and 55.0% were

observed for the 5-inch MERV 8 and MERV 13 filters. Analysis of the concentrated deposition regions showed similar reductions of 77.9% and 73.0% for the treated 5-inch MERV 8 and MERV 13 filters. Together, these findings support the hypothesis that hydrophobic enhancement with SCHN 135 can reduce water-based aerosol transport through HVAC filters and filter materials.

Significance and Future Direction

The significance of these results lies in the potential relationship between moisture control and biological microbial growth within HVAC filtration systems. Because moisture availability contributes to favorable conditions for fungal growth and proliferation on filters, reducing the amount of liquid penetration is considered a strategy for limiting such conditions. However, since the present study evaluated liquid transport rather than an evaluation of fungal growth, there is no direct antimicrobial or antifungal effect by SCHN 135. Instead, there findings establish a physical basis for investigating whether hydrophobic modification of HVAC filters can influence fungal growth when under reduced moisture conditions.

Future studies should directly test this relationship by comparing fungal colonization on SCHN 135 treated and untreated HVAC filters under controlled environmental conditions. Further evaluation will also be needed to ensure that air filtration performance of the filter isn't being compromised while still performing its reduced moisture capabilities. Establishing both biological efficacy and long-term engineering performance would ultimately determine whether SCHN 135 treatment can serve as a practical and complementary strategy for HVAC filtration systems.

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