Tech note PVPS - F0001: – Filter selection and Design Author: Bob Senzig : Sept 17 2020

Pandemic Virus Protection Systems

Filter Background

An N95 disposable mask is considered an adequate protection for many healthcare workers. An N95 mask blocks 95% of incoming particles if properly fitted. This effectiveness is lesser for particles which are smaller than 0.3 microns. This may not be adequate for prolonged exposure or for use in areas where the viral load is high. Our goal is to create a device that offer more complete protection for those situations. Human breathing has a tidal volume of 0.5 liters 10-20 times a minute. This means that the human lungs are essentially a 0.35CFM pump. A N95 Filter is around 45 IN**2. This yields an air speed of around 0.2 inches/sec. A cough or sneeze is much higher speed but we will focus on steady state breathing. We will try to show that the powered PAPR design can provide much more protection than the N95 for the wearer. A powered PAPR is not a good choice in an environment where the virus load is low because there is not filtration of the exit air. Later in the technote you will be able to see why the N95 mask material cannot be used as is in a powered unit where the airflow is increased.

HEPA filters are rated to remove 99.97% of particles greater than 0.3 micron. HEPA filter are available in many configuration Vacuum Cleaner, Air Freshener, Auto cabin and commercial PAPR filters. Our focus was to find a practical and economical solution that would me our performance goals.

Filter Selection

Filter selection is key to effective protection. There are two main candidates for the PVP-P device filter:

1. Miller PAPR HE particle filter designed for use in a Miller T94-R™ Miller welding system (part number 235673). It is a HEPA rated filter and is designated as NIOSH purple (High Efficiency (HE) Filter, P100 Filters).
2. Freudenberg unreleased proto PAPR filter. This a filter designed by Freudenberg Filtration Technologies a leader in automotive, industrial and environmental filters for use in a PAPR. We were able to obtain prototype units for evaluation. We deprioritized this filter due to availability beyond the evaluation units.
3. Holmes air freshener filter provide a similar size but larger True HEPA filter that can be adapted to this use. We have deprioritized this filter due to the larger size and weight concerns.

Filter evaluation criteria were simple, a size and weight compatible with our head top PVP-P and backpack style PVP-D concepts, a back pressure compatible with the blower choice, excellent filtration capability, easily handles and replaced.

1. Filtration must provide adequate filtration at the max flow rate the PAPR is capable of
2. Size: must be less than ??? x?? x ??? and less than ??? grams to be considered
3. Back pressure must provide low resistance so that lightweight blowers can deliver the required minimum 6CFM and a higher flow rate of at least 9CFM

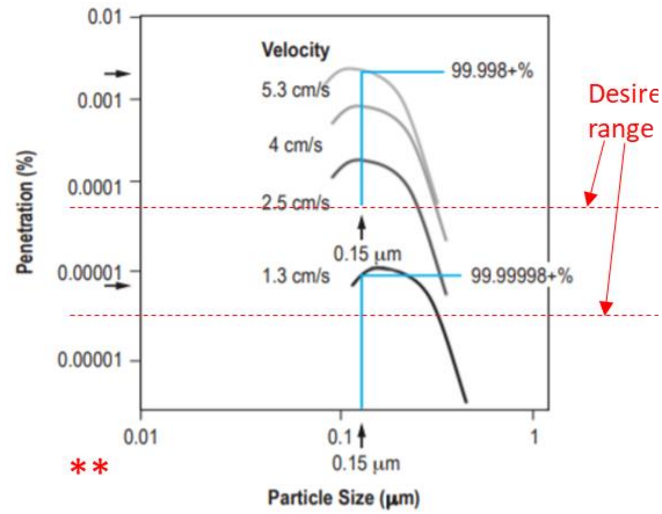
4. Easy to handle we felt that filters with a plastic carrier were easier to install and remove than the automotive style cartridge felt filters

1) Filter Design

Not being an expert in filter design we did some searching and found some useful information

a. Impact of air speed on filter efficiency

The NASA paper [Submicron and Nanoparticulate Matter Removal by HEPA-Rated Media Filters and Packed Beds of Granular Materials]- Perry et al shows the relationship of air speed and filtration in Figure 4. I added the red color annotation to show the range we want to operate in for the best filtration performance.



gure 4. Filter efficiency dependence on velocity; lower velocity increases efficiency. (© R. Vijayakumar. *Used with permission.*)

b. HEPA filter efficiency for COVID-19 sized particles

[Filtration of airborne microorganisms: Modeling and prediction – 1999 Kowalski et al] provides info on HEPA filter performance with different size particles. Here the size of the COVID particle is added for clarity. So even though the rating for a HEPA filter is a 0.3microns it does very well on COVID-19 sized particles. In Figure 9 from that publication shows the performance with Coronavirus size particles

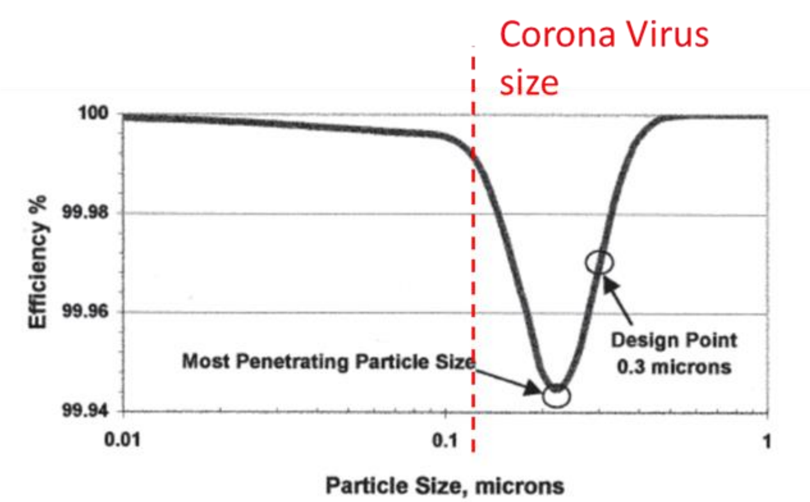
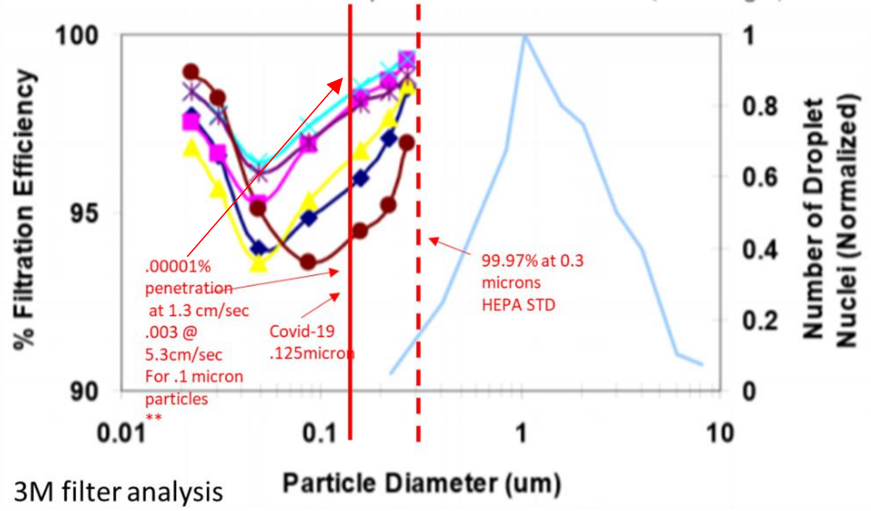


Figure 2 *Typical performance of a HEPA 99.9% filter.*

Figure 1.* Averaged Filtration Efficiency for Six N95 Respirators* (on the left), and Size Distribution of Droplet Nuclei from a Sneeze (on the right).



This figure from a 3M analysis of how N95 masks performs against a water droplet (cough) and Covid-19 sized particles shows that even having an airspeed higher than 5.3 cm/sec the HEPA filter yields superior performancehttps://fastlifehacks.com/n95-vs-ffp/

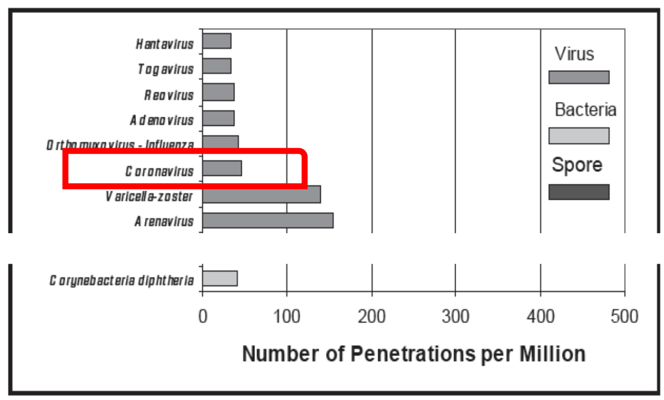
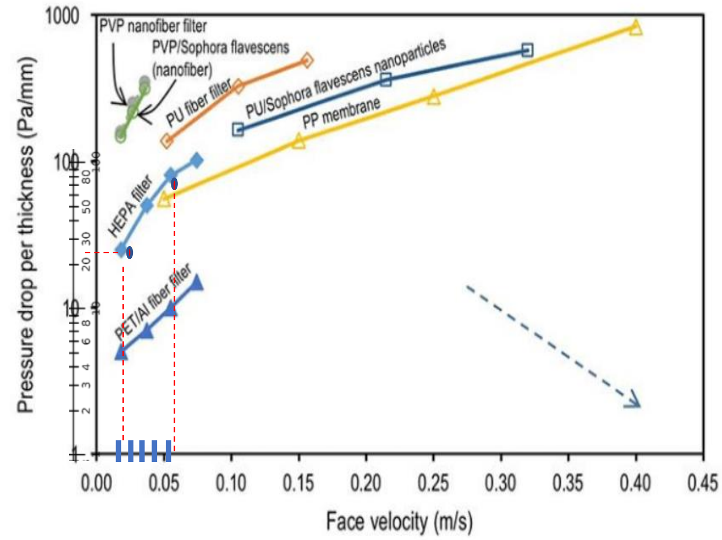


Figure 9 The most penetrating microorganisms: HEPA 99.9% filter, single pass.

In this figure the impact of speed on pressure drop is shown. To get a reasonable pressure drop so the blower does not have to work as hard a low air speed is desired. I added the scale to make interpretation easier. This is from [Recent advances in antimicrobial air filter – Komaladewi et al]



2) Filter Physical Size

The Face Shield/Hood structure in the PVP-P concept and the mini backpack desired in the PVP-D design limit the practical filter size to 5 x 10" inches. For PVP-P a smaller 7x4" is more desirable. Filter size to achieve the desired air speed you can calculate the needed filter square area from the CFM flow rate and the desired speed. It is not possible to meet the size constraints with a single layer filter. A pleated filer design is required. This equation was described in a design notes created by [Arron Sun on the OPEN PAPR Facebook site]. The following table shows 3 different available filters that we down selected and the anticipated filter performance,

Filter Efficiency

The pressure drop generated by the filter is dependent on the linear flow rate through the filter, thus the filter linear flow rate is inversely correlated with the total area of the filter. As most filters are pleated, this area is larger than the area of the individual filter.

$$A = w\sqrt{h^2 + (pd)^2}, f_l = f_v/A$$

- A = total filter media area
- w: width of filter package
- h: height of filter package
- d: depth of filter package
- p: the total number of heightwise pleats over the entire package
- f_l: linear flow for the filter media
- f_v: target volumetric flow

Filter	Height	Width	thickness	#Folds	Sq In filter area	Pressure drop @6CFM	Operating CFM	Air Speed in/sec	Penetration %
Freudenberg	6.3	4.8	.86	51	458	Med	6	.376	0.000006
Holmes	9.5	4.1	1.13	53	418	Low	6	.414	0.00001
Miller	6.5	3.75	.5	65	224	High	6	1.026	0.00016
N95	7	7	N/A	N/A	49	N/A	0.35	.201	5%

From this analysis, the packaging and the availability criteria, the Miller filter was chosen as the primary filter. We also considered that this particular filter would not be in high demand for healthcare use because of the weight and design of the commercial Miller welding PAPR, the unit is not practical in a healthcare environment. We thought that this would likely mean filters would stay readily available.

Revision History			
Revision	Date	Who	Description
0	9/22/2020	Bob Senzig	Creation

3) Ease of filter change/Packaging

This 3M publication presents performance of a N95 mask vs particle size. Technical Data Bulletin #174 Respiratory Protection for Airborne Exposures to Biohazards