Collection Performance of the NuWave OxyPure Challenged with Porcine Respiratory Coronavirus Aerosol

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Executive Summary

This report summarizes the methods and results utilized in University of Minnesota testing of NuWave's OxyPure Air purifier unit in terms of its removal efficiency of porcine respiratory coronavirus (PRCV) aerosol. PRCV was nebulized from a suspension with a virus titer of 3.16 x 10^6 $TCID_{50}$ mL^{-1} using a custom made and characterized wind tunnel to a mean diameter of 2 μm by volume. Virus laden aerosol was collected upstream and downstream of the OxyPure unit operated at a volumetric flow rate of 70 cubic feet per minute CFM (fan speed level 1). Collection of the virus aerosol using Andersen impactors sampling at 90 L min^{-1} for 30 minutes, yielded a virus titer of 4803 ± 1420 $TCID_{50}$ mL^{-1} upstream of the OxyPure air purifier, and 84.41 ± 25.27 $TCID_{50}$ mL^{-1} downstream, with the measurement uncertainty determined by the standard deviation resulting from triplicate measurements. Comparison correlation tests in the absence of the OxyPure air purifier yielded an upstream concentration of 31,622 $TCID_{50}$ mL^{-1} and a downstream concentration of 18,343 $TCID_{50}$ mL^{-1}. Using the virus titer results directly from the upstream and downstream measurements with the OxyPure air purifier in place yields a removal efficiency of 98.24% ± 0.55% (with the uncertainty based upon the root-sum-square method of uncertainty propagation). Under the assumption that this collection efficiency is weakly dependent on flow rate, the clean air delivery rate (CADR) of the unit will be 0.9822 x operating flow rate. Using the upper flow rate of 350 CFM, yielding a sealed CADR of 343.8 CFM, a 1200 square foot room with a height of 8 ft for a room volume of 9600 cubic feet would see a 4 log reduction (99.99% removal) in virus concentration over a period of 257 minutes (4.28 hrs) assuming proper mixing within the room.

Swab samples were taken from the HEPA filter and ESP walls within the OxyPure unit following testing. Swab samples collected from the HEPA filter yielded a virus concentration of 562 $TCID_{50}$ mL^{-1} while on the walls of the electrostatic precipitator the viable virus titer was 10,000 $TCID_{50}$ mL^{-1} immediately following the completion of tests. While this result is strongly influenced by the extraction efficiency of the wipe test, it suggests that 95% of the collected viral particles, for the aerosol tested, is collected on the ESP walls. Swab samples collected an hour after the completion of tests, where the OxyPure unit remain in operation, yielded no change in the virus titer on the filter but a reduction in ESP concentration to 3162 $TCID_{50}$ mL^{-1}, which is a 70% reduction in titer after 1 hour. However, further testing would be needed to refine this number or to extrapolate it to longer times.

Background

Recirculating air purification units offer a means to effectively increase ventilation rates in any indoor space if they can efficiently remove air pollutants, including viruses. However, to determine if an air purifier removes viruses requires direct testing with the virus in question or a suitable surrogate virus. Because of high levels of structural similarity, the viability of different coronavirus variants in aerosols is similar, hence tests on one coronavirus should serve as a reasonable proxy for the behavior of other coronaviruses (including SARS-CoV-2). To test the efficacy of the NuWave OxyPure air purifier in removing coronaviruses from aerosols, the University of Minnesota was tasked with the aerosolization of porcine respiratory coronavirus (a surrogate for SARS-CoV-2) using an atomizer, with air samples collected upstream and downstream of the OxyPure air purifier in a sealed flow through manner. Evaluation of percent inactivation of viable viruses by the device using virus culture methods was performed and total RNA copies using qRT-PCR serves as control for aerosol generation. Tests were performed in triplicate at a flow rate specified by NuWave. After a discussion with NuWave personnel, this flow rate was determined to be 70 cubic feet per minute (70 CFM). The deliverable is this test report detailing the test methods graphically, the OxyPure air purifier single pass removal efficiency for the removal of coronavirus and clean air delivery rate (CADR). Using the CADR, the log reduction in a 1200 ft^2 and 9600 ft^3 room (dimensions of 40 ft x 30 ft x 8 ft for example) is estimated.

Results

Table 1 provides a summary of all virus titer measurements made throughout experiments. In the absence of the OxyPure unit, tests yielded a mean upstream concentration of 31,622 $TCID_{50}$ mL^{-1} and a mean downstream concentration of 18,343 $TCID_{50}$ mL^{-1}. Conversely, with the OxyPure unit, measurements yielded a virus titer of 4803 ± 1420 $TCID_{50}$ mL^{-1} upstream of OxyPure air purifier, and 84.41 ± 25.27 $TCID_{50}$ mL^{-1} downstream. Correspondingly, we estimated the coronavirus removal efficiency to be 98.24% ± 0.55%. Swab samples collected from the HEPA filter yielded a virus concentration of 562 $TCID_{50}$ mL^{-1} while on the walls of the electrostatic precipitator the viable virus titer was 10,000 $TCID_{50}$ mL^{-1} immediately following the completion of tests. While this result is strongly influenced by the extraction efficiency of the wipe test, it suggests that 95% of the collected viral particles, for the aerosol tested, is collected on the ESP walls. Swab samples collected an hour after the completion of tests, but with the OxyPure unit remaining in operation, yielded no change in the virus titer on the filter but a reduction in ESP concentration to 3162 $TCID_{50}$ mL^{-1}. However, this change is not sufficient to conclude that the viruses collected by the ESP are inactivated after deposition, as changes in titer by an order of magnitude over an hour on a surface are commonplace. Overall, we find that most of the virus is collected by the ESP, although we do not recommend removal of the HEPA filter.

Efficiency to Clean Air Delivery Rate

The measurements performed here provide the single pass collection efficiency for a PRCV (porcine coronavirus) aerosol with a mean diameter near 2 micrometers. The single pass efficiency CE, can be used to determine the clean air delivery rate (CADR), via the equation:

$$CADR = CE \times Q \quad (3)$$

where Q is the volumetric flow rate. Subsequently, using a well-mixed room volume, the reduction in virus concentration in the air R, can be calculated via the equation:

$$R = exp\left(-\frac{CADR}{V}t\right) = exp\left(-\frac{Q}{V}CEt\right) \quad (4)$$

where V is the room volume. For a flow rate of 350 CFM, a room area of 1200 ft^2 and a room volume of 9600 ft^3, R= 10^{-1} yields t = 64.3 minutes, R= 10^{-2} yields t = 129 minutes, R= 10^{-3} yields t = 193 minutes, and R= 10^{-4} yields t = 257 minutes. For 70 CFM, we find R= 10^{-1} yields t = 322 minutes, R= 10^{-2} yields t = 643 minutes, R= 10^{-3} yields t = 965 minutes, and R= 10^{-4} yields t = 1286 minutes. Such calculations assume CE is limited by leaks and is not dependent on flow rate. The ratio $\frac{Q}{V}t$ is also the number of air changes, with $1 - R$ the multipass efficiency. For 350 CFM and R= 10^{-4}, $\frac{Q}{V}t = 9.4$, hence 9.4 passes are required to reach a 4-log reduction. Additional calculations are summarized in Table 2, showing the removal efficiency for the low and high (projected) settings and the number of air changes resulting for application in a 1200 ft^2 and 9600 ft^3 room.

Table 1. Summary of all virus titer measurements in all experiments.

		OxyPure ON			**OxyPure Uninstalled**		
Air sampler	**Location**	**Replicate 1 TCID50/ mL**	**Replicate 2 TCID50/ mL**	**Replicate 3 TCID50/ mL**	**Replicate 1 TCID50/ mL**	**Replicate 2 TCID50/ mL**	**Replicate 3 TCID50/ mL**
Initial Virus in Fluorescein	NA	3.16x10^6			1.78 x10^7		
Andersen Filter	Upstream	3.16 x10^1	3.16 x10^1	3.16 x10^1	3.16 x10^1	3.16 x10^1	3.16 x10^1
Andersen - Stages 0, 5, 6	Upstream	5.62 x10^3	5.62 x10^3	3.16 x10^3	3.16 x10^4	3.16 x10^4	3.16 x10^4
Andersen Filter	Downstream	3.16 x10^1	3.16 x10^1	3.16 x10^1	3.16 x10^1	3.16 x10^1	3.16 x10^1
Andersen - Stages 0, 5, 6	Downstream	1.00 x10^2	1.00 x10^2	5.62 x10^1	1.78 x10^4	3.16 x10^4	5.62 x10^3
NuWave HEPA filter wipe	NA	5.62 x10^2					
NuWave ESP filter wipe	NA	1.00 x10^4					
NuWave HEPA filter wipe - 1 hr	NA	5.62 x10^2					
NuWave ESP filter wipe - 1 hr	NA	3.16 x10^3					
Final Virus in Fluorescein	NA	3.16 x10^6			3.16 x10^7		

Table 2. Calculated removal efficiencies and number of air exchanges in a 1200 ft^2 and 8 ft ceiling height room (9600 ft^3), operating a sealed OxyPure Unit in the low setting (70 CFM) and high setting (350 CFM).

1200 Square Foot Room	Low Setting (70 CFM)	High Setting (350 CFM)*
1 Hour	34.930386%	88.334828%
2 Hours	57.659453%	98.639238%
4 Hours	82.072781%	99.981483%
6 Hours	92.409517%	99.999748%
8 Hours	96.786148%	99.999997%
Number of Air Changes	**Low Setting (70 CFM)**	**High Setting (350 CFM)***
1 Hour	0.44	2.19
2 Hours	0.88	4.38
4 Hours	1.75	8.75
6 Hours	2.63	13.1
8 Hours	3.50	17.5
*Assumes the collection efficiency is not flow rate dependent		

Conclusions

A high single pass efficiency of 98.24% for PRCV removal was obtained for the OxyPure unit. The unit performs very well and can be used even on its lowest setting to efficiently clean the air of a 1200 ft^2 room over time.