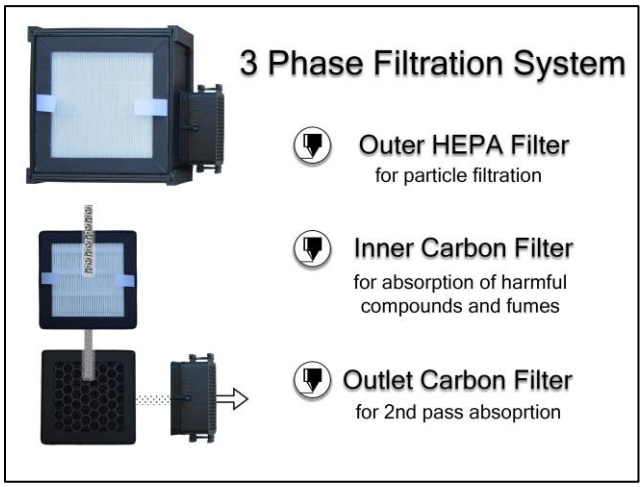
Assessment of Makergadgets' Adelina 3D Printer Enclosure and 3 Phase Air Purification System in Mitigating High Contamination Fumes and Particles Emitted During 3D Printing

BACKGROUND

ABS, Nylon and other Fused Deposition Modeling (FDM) materials used in 3D Printing are known for emanating high total volatile organic compounds (TVOCs), formaldehyde, styrene and particulate concentration levels. With the growth in popularity of desktop 3D printers across hobbyist, small business (known informally as print shop) and other user communities, the potential exposure of these toxic materials are increasing. To mitigate exposure, **Makergadgets** developed a closed-loop enclosure and 3 Phase Air Purification system, named the ***Adelina***. The 3 Phase Air purification system uses a combined HEPA/Activated Carbon Filter and an outlet Activated Carbon filter for filtration (depicted in Figure 1). The objective of this study is to measure the air cleansing performance of **Makergadgets** 3 Phase Air Purification system within the ***Adelina*** enclosure.

Figure 1. Makergadets 3 Phase Air Purification/Filtration System



METHODS

Performance testing was broken up into 4 main categories and compared to recommendations by ACGIH, NIOSH, EPA, DFG, and WHO maximum exposure limits per category. Some air quality institutions only have recommendations for some of the concentrations so only those values are compared. Where different institutions have different exposure limits, the testing group shows the efficiency against all limits.

The tests incorporated measuring the various contaminants during and after 3D Print jobs within the Adelina enclosure. Each test had a control labeled **Active Filtration OFF**: Adelina enclosure with an active 3D Printer ***without*** the 3 Phase Air Purification System turn on; and an observation run labeled **Active Filtration ON**: Adelina enclosure with an active 3D Printer ***with*** the 3 Phase Air Purification System turn on.

TEST 1: TVOC CONCENTRATIONS

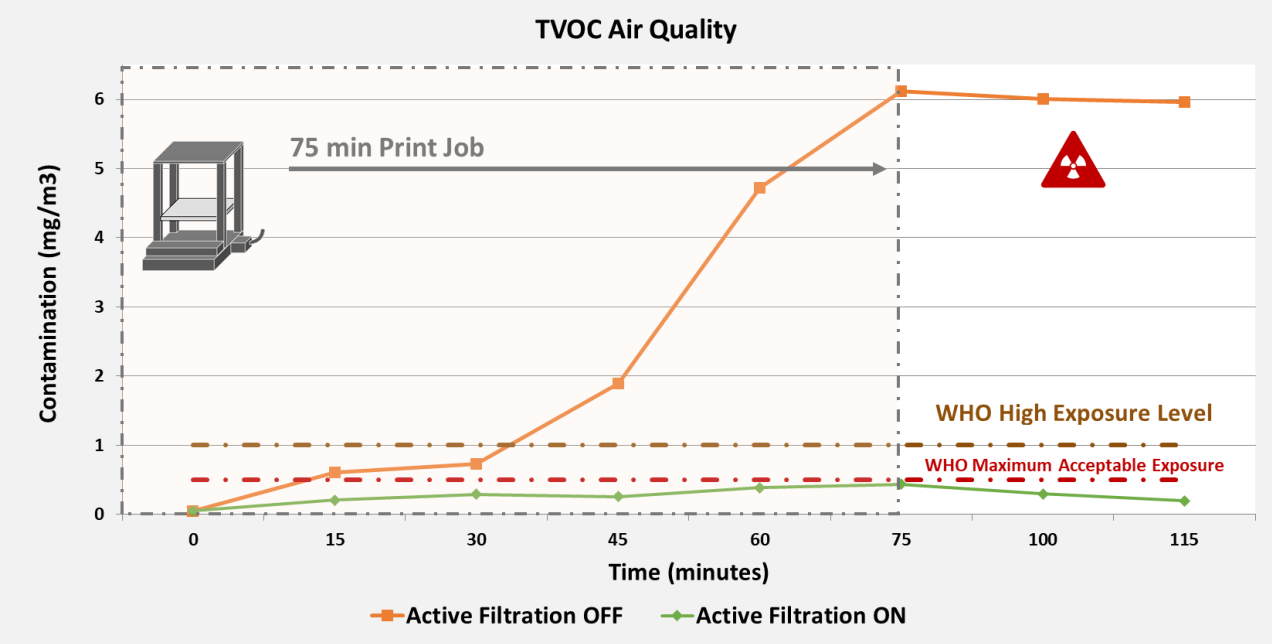
Volatile organic compounds are organic chemicals that become a gas at room temperature and are the main origin of air pollution at ground level. Total Volatile Organic Compounds (TVOCs) are a measure of the total concentration of multiple VOCs present simultaneously which gives an aggregate view into contamination of air. According to the WHO TVOC contamination levels for breathing should be classified as follows:

TVOC Level mg/m3	Level of Concern
Less than 0.3 mg/m3	Low
0.3 to 0.5 mg/m3	Acceptable
0.5 to 1 mg/m3	Marginal
1 to 3 mg/m3	High

High levels of TVOC contamination are known to cause throat irritation, nose irritation, respiratory infections, allergic reactions and headaches. It may also exacerbate existing issues with respiration and lung cancer.

In this test we ran an FDM type 3D printer for a 75-minute print job twice: once with the active filtration on and once *without* the active filtration on. We sampled TVOC measurements at 15 minute intervals. Results are charted below along with WHO exposure limit recommendations.

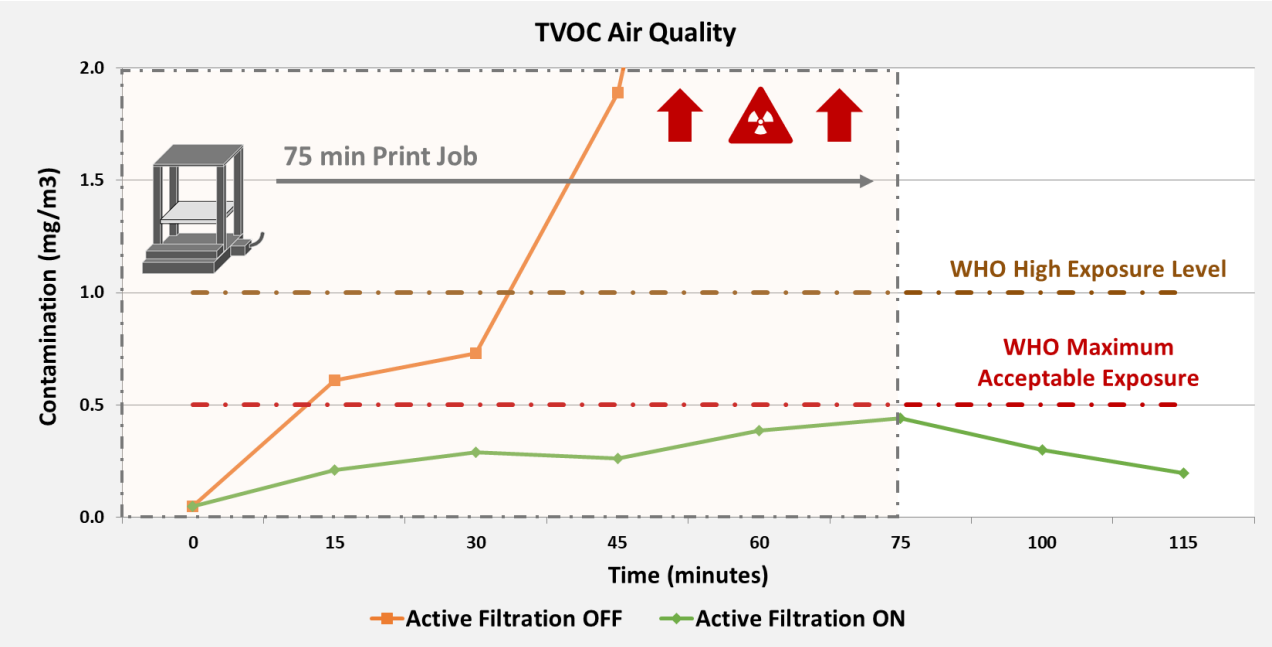
Figure 2. TVOC Cleansing Performance Test



The print without active filtration on for a 75-minute job reached above 6 mg/m^3 which is 2 times the "High" limit and 12 times the "Acceptable" exposure limit provided by the WHO. Using active filtration in the enclosure, the contamination was maintained below 0.45 mg/m^3

throughout the print and dropped to 0.197 mg/m^3 30 minutes after the print was completed. A closer analysis focuses on active filtration contamination is shown below.

Figure 3. TVOC Cleansing Performance Test – Active Filtration ON Performance Focus



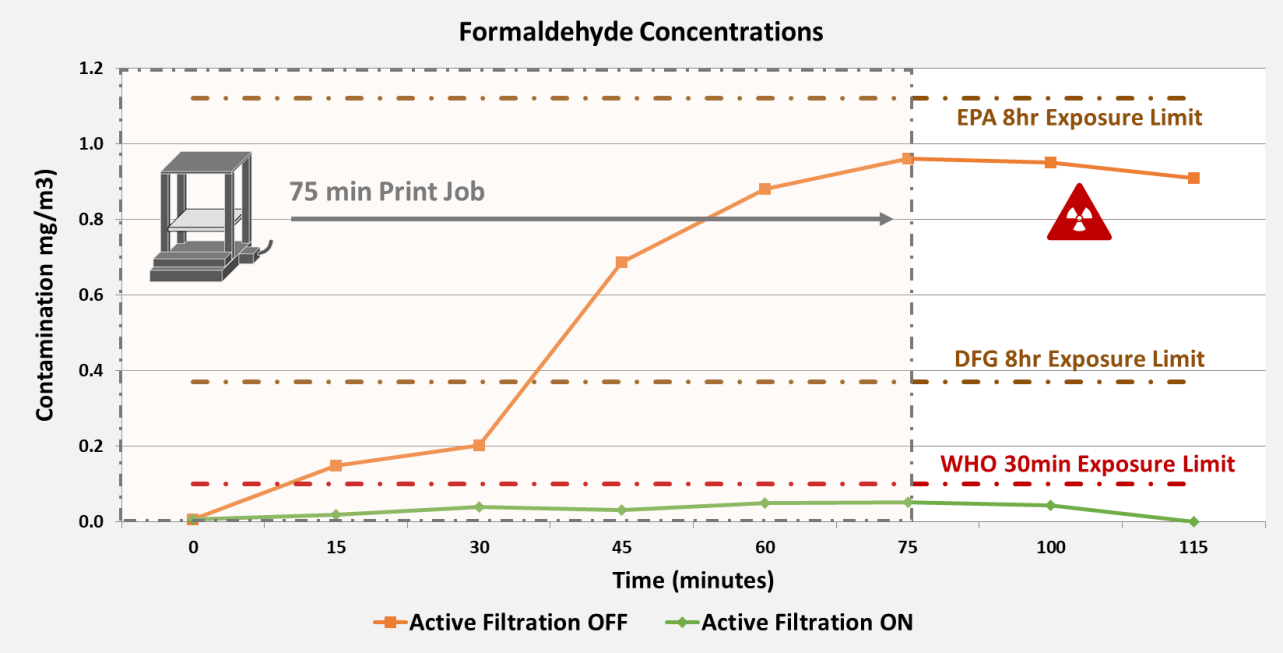
TEST 2: FORMALDEHYDE CONCENTRATIONS

A VOC present in FDM based 3D printing is formaldehyde. Much literature has been written about the adverse health effects of formaldehyde since it is ubiquitous in our indoor and outdoor environment. Many institutions have stated recommendations for exposure limits regarding this VOC. Some of the recommendations are listed below:

Organization	**Maximum Exposure limit (mg/m^3)**	
EPA	1.12	(8 hrs daily)
DFG	0.37	(8 hrs daily)
WHO	0.1	(30 minute exposure)

In this test we ran an FDM type 3D printer for a 75-minute print job twice: once with the active filtration on and once *without* the active filtration on. We sampled formaldehyde concentrations at 15 minute intervals. Results are charted below along with WHO, DFG, and EPA exposure limit recommendations.

Figure 4. Formaldehyde Concentration Cleansing Performance Test



The print without active filtration on for a 75-minute job reached almost 1 mg/m^3 which is more than twice the exposure recommendation by the DFG, almost 10 times that of the WHO and just below the maximum limit set by the EPA. When Active filtration is turned on, the same print stays well below the conservative limitation set by the WHO and goes to nearly ambient formaldehyde concentrations 30 minutes after completion.

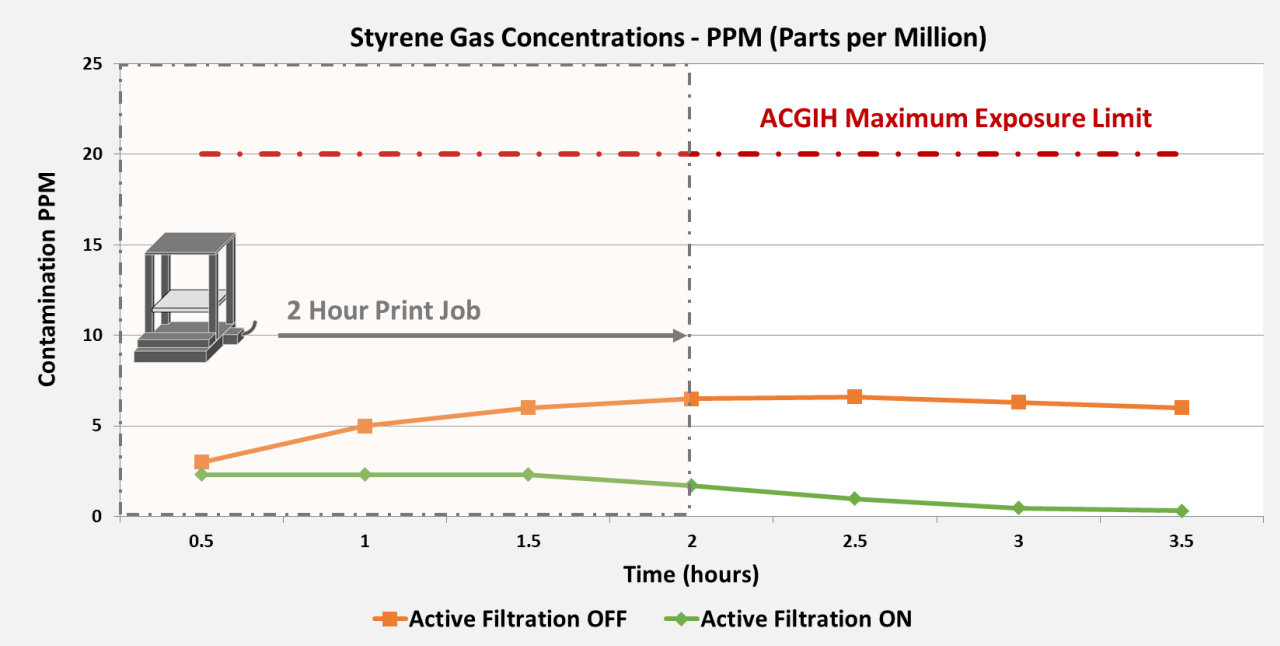
TEST 3: STYRENE CONCENTRATIONS

Our final test focused specifically on a chemical related to ABS printing. Styrene is a common industrial chemical that has shown adverse effects on humans when exposed above air quality standards. Since ABS is one of the most durable and commonly used FDM materials, we focused on understanding the effects of mitigation toxins let off during printing. Many organizations provide exposure limit recommendations but we chose to use 2 of them specifically since they were the "most aggressive" or conservative values. If the enclosure would pass these more aggressive recommendations then the rest would follow.

Organization	**Maximum Exposure limit (ppm)**	
ACGIH	20	(10 hrs daily)
NIOSH	50	(10 hrs daily)

In this test we ran an FDM type 3D printer for a 2 hour print job twice: once with the active filtration on and once *without* the active filtration on. We sampled styrene concentrations at 30 minute intervals. Results are charted below along with WHO, DFG, and EPA exposure limit recommendations.

Figure 5. Styrene Gas Concentration Cleansing Performance Test



The print without active filtration reached a high of 6.5 ppm which was already below the most conservative of recommendations. Using the active filtration, these numbers were maintained at approximately 2 ppm a 70% reduction and after 1 hour of job completion 0.5 ppm; nearly completely cleaned.

TEST 4: FINE PARTICLE CONCENTRATIONS

Figure 6. 10 micron Particle Cleansing Performance Test

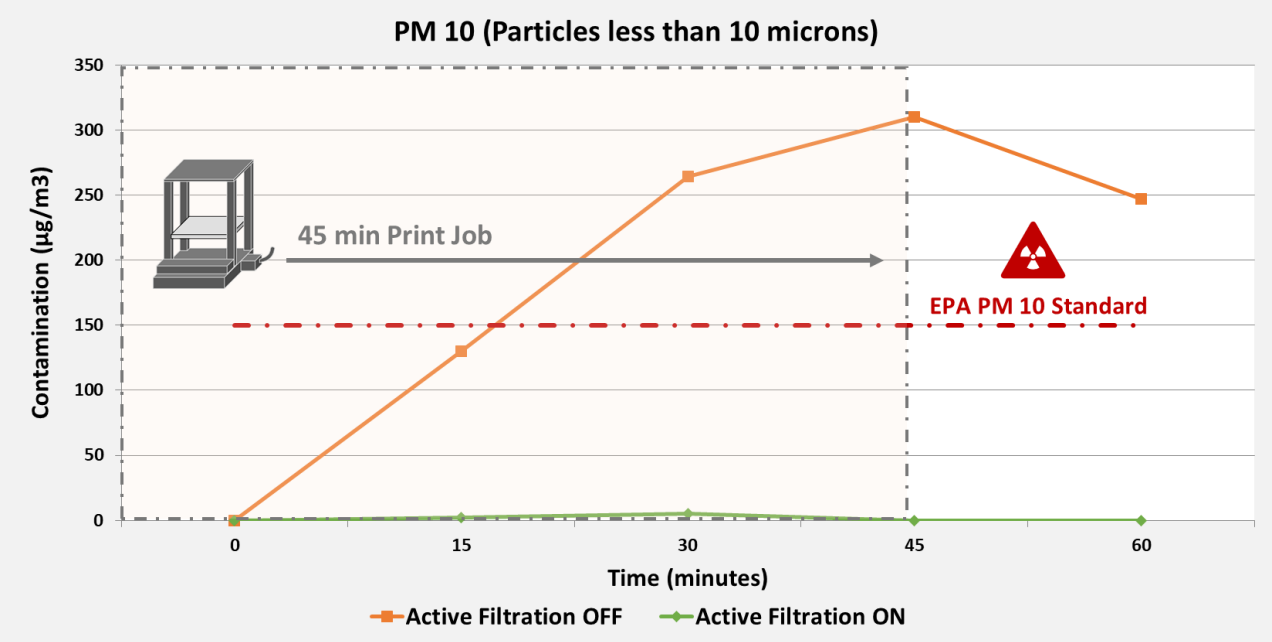


Figure 7. 2.5 micron Particle Cleansing Performance Test

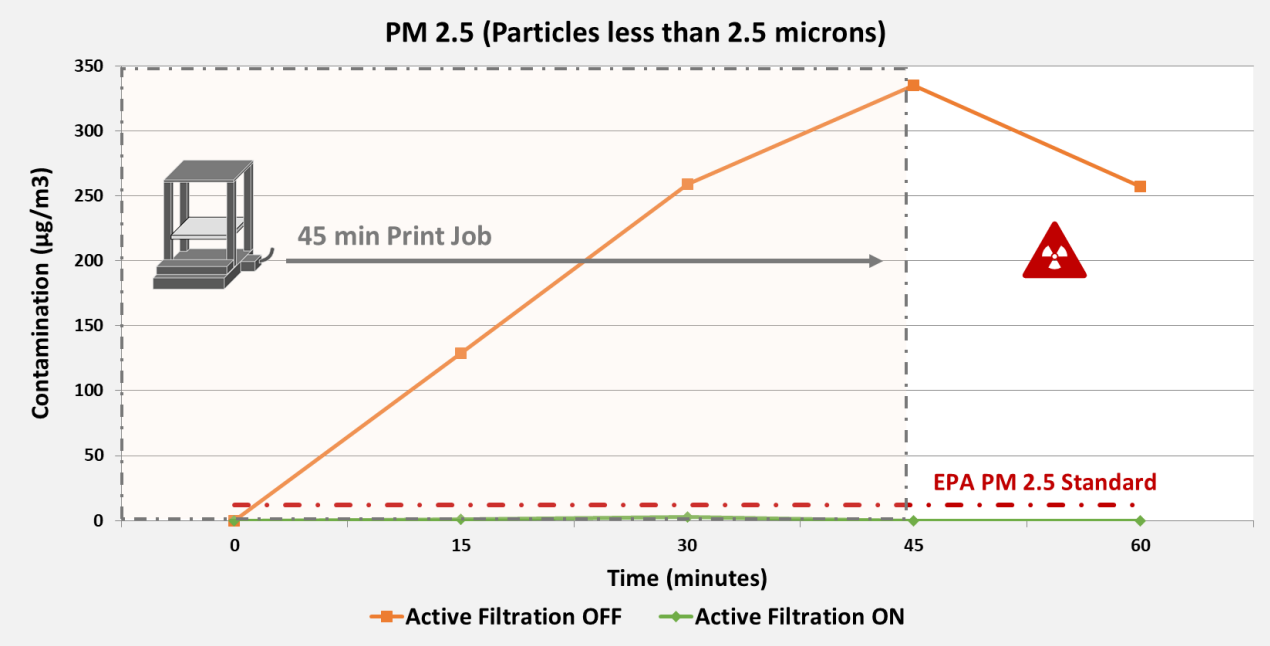
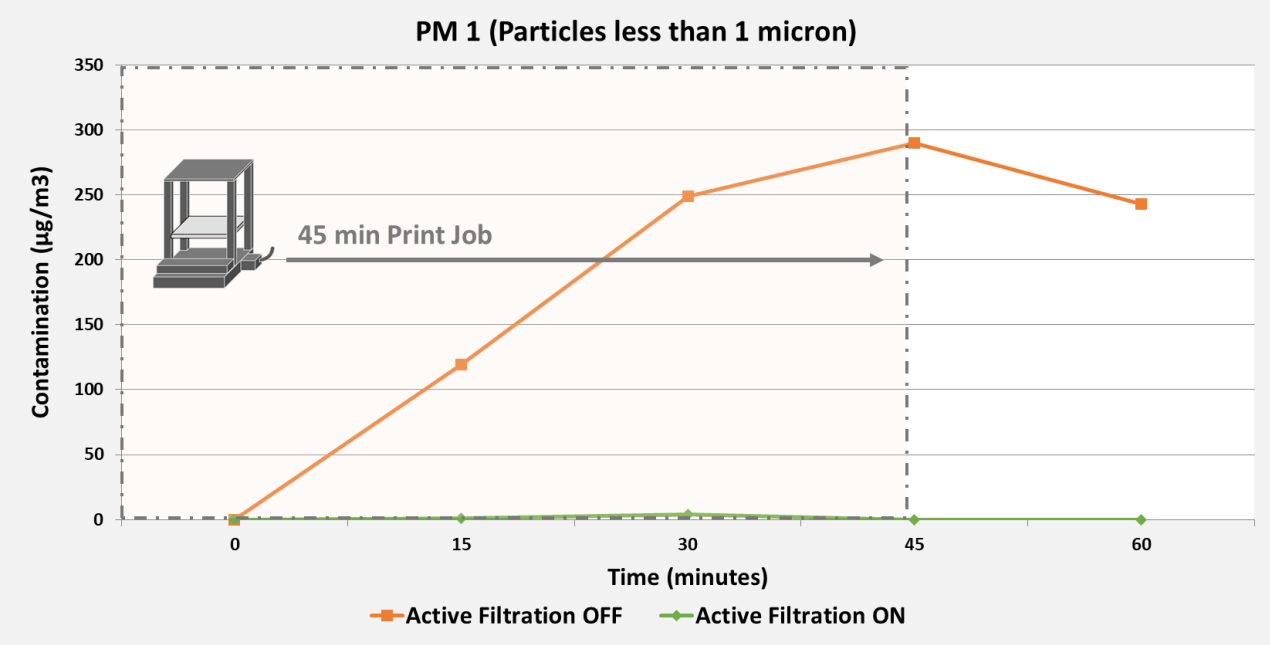


Figure 8. 1 micron Particle Cleansing Performance Test



PM 2.5 and PM 10 have guidelines given by the EPA (12µg/m3, 150µg/m3). Fine particle concentrations reach exceptionally high in the experiments at 290, 345 and 320µg/m3 for PM1, PM2.5, PM10, respectively. When filtration is turned on, the closed loop system brings these numbers down by 99.9%, in other words all particles are removed from the air. By virtue of Fine Particles being removed, ultra-fine particles are also removed since the efficiency of HEPA against ultra-fine is higher than again fine particles. This counterintuitive concept is due to the "Brownian Motion" occurring with particles at the nanometer scale (UFPs).

RESULTS

The results for our four tests show a substantial improvement in air quality for FDM printing. Recommendations given by various global and state institutions have been met when enclosing FDM printers in the Makergadgets' **Adelina** enclosure. In short, TVOCs were maintained below the conservative acceptable limit set forth by the WHO of 0.5 mg/m^3, Formaldehyde concentrations were mitigated to a level well below conservative recommendations by the WHO of 0.1 mg/m^3 and finally styrene concentrations levels, although already below conservative exposure limits are reduced further by more than 90%. Fine and Ultra fine particles were completely removed from the air through HEPA technology.

SOURCES

New Jersey Department of Health, *Styrene Monomer Facts*, 2016
World Health Organization, *Indoor Air Quality: Organic Pollutants, EURO Reports and Studies 111*, 1989
Tecam Group, *What are acceptable VOC level in air,* 2019