

# PECO Technology Review

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## *Abstract:*

*Molekule is commercializing a scalable, patented photo-electrochemical air disinfection technology that completely destroys pollutants in air. Molekule uses PECO (photo electrochemical oxidation) technology for air purification. PECO works when light shines on a specially designed nanoparticle coated filter. This action of light on the surface of the filter creates a reaction that is able to completely oxidize pollutants in the air. Through third party independent testing and through Molekule's own internal tests, the technology has shown great efficacy in the destruction of airborne bacteria, viruses, mold, and VOCs. These test results show complete destruction of pollutants and no remaining residue on the PECO filter surface.*

## **I. Introduction**

Molekule has invented an innovative new air purification technology known as photo-electrochemical oxidation (PECO). Unlike conventional filter technologies which merely trap some subset of pollutants, Molekule's technology is able to destroy the full spectrum of indoor air pollution including airborne bacteria, viruses, mold, allergens, and volatile organic compounds (VOCs).

The process of PECO works as light excites a nanoparticle coated filter, creating a chemical reaction on the surface of the filter that results in the creation of hydroxyl free radicals. These same radicals are used to kill cancer cells in radiation therapy. The free radicals oxidize pollutants at the surface of the filter and convert them into harmless elements like trace amounts of water and carbon dioxide.

By innovative manipulation of the electron flow, this new photoelectrochemical oxidation (PECO) technology works orders of magnitude faster than conventional photocatalytic processes. The resulting high quantum efficiency produces a dramatic increase in hydroxyl radical production on the surface the filter, greatly surpassing the limitations of traditional photocatalytic oxidation technologies (PCO).

The immediate and high concentration of hydroxyl radicals

oxidizes bacteria, viruses, mold, allergens and VOCs up to fifteen to one hundred times faster than competing PCO devices. Conventional technologies, such as HEPA, carbon and electrostatic filters do not destroy these contaminants at all.

## **II. Testing Summary**

A series of laboratory tests have been conducted, both independently and internally, on PECO technology prototypes. A variety of bioaerosols and VOCs were tested in a number of configurations including testing single pass, as well as recirculating duct configurations. A number of comparison tests were performed following the same procedures for HEPA as well as carbon filters. The experiments and sampling techniques followed standard laboratory procedures. The experiments whose results are reported herein were performed by the University of South Florida Center for Biological Defense and the Clean Energy Research Center, University of Florida Disinfection and Sterilization Laboratory, University of Minnesota Particle Calibration Laboratory, and Aerosol Research and Engineering Laboratories (ARE Labs).

### III. Results

Results indicate the efficacy of Molekule's PECO technology on a broad range of indoor air pollutants, including VOCs, viruses, bacteria, and mold.

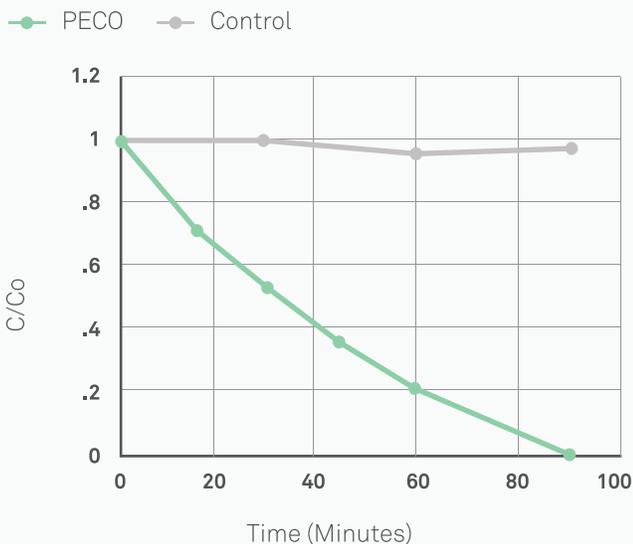
#### A. Performance on Volatile Organic Compounds

Molekule's PECO technology was tested for performance in destruction of a range of Volatile Organic Compounds including Toluene and Acetone. Measurements were made via chromatography using both flame ionization (FID) and photo ionization (PID) detectors.

Toluene destruction was measured in a 600L steel chamber, from which samples were taken and measured using an FID gas chromatograph calibrated to standard concentration of Toluene. Sufficient toluene was injected to reach a concentration of 1 ppm, the chamber was allowed to equilibrate and then the PECO device was activated. Subsequent concentrations were measured relative to the control, the chamber without the PECO device. Complete destruction of the toluene was achieved over the course of 90 minutes.

**Figure 1**

Destruction of Toluene by PECO relative to control.

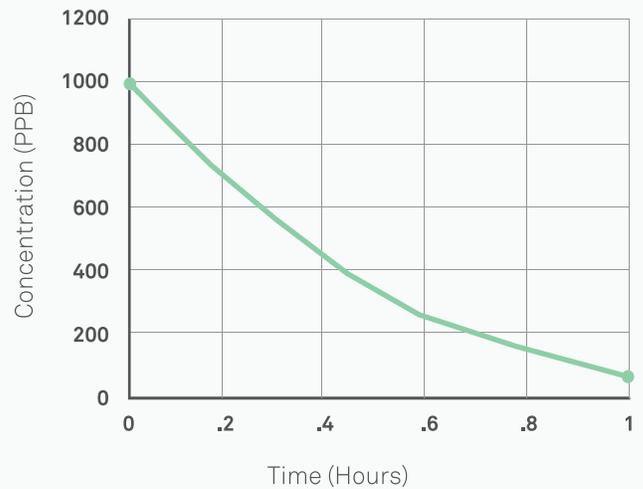


University of Minnesota Particle Calibration Laboratory

Similar testing was performed with acetone. Acetone was injected in the 600L steel chamber to achieve a concentration of 1 ppm at complete equilibrium. Total volatile organic compound (TVOC) concentration was measured by a realtime PID probe and the PECO process was initiated. Here the TVOC concentration was reduced to background levels in one hour.

**Figure 2**

Destruction of Acetone by PECO.



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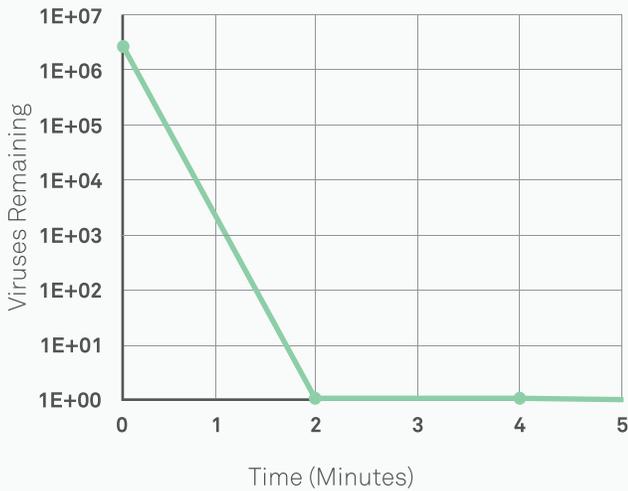
#### B. Performance on Airborne Viruses

Molekule's PECO technology was tested for performance in destruction of airborne viruses. Bacteriophage MS2 was used as the challenge pollutant. Testing was conducted both in recirculating and single pass configurations.

In the recirculating configuration, the viruses, total of 20 ml of an initial concentration of 1013cfu/ml, were aerosolized from solution upstream of the device, and measurements were taken on the filter surface at set intervals of operation time. Complete destruction was achieved prior to the first sampling at two minutes.

**Figure 3**

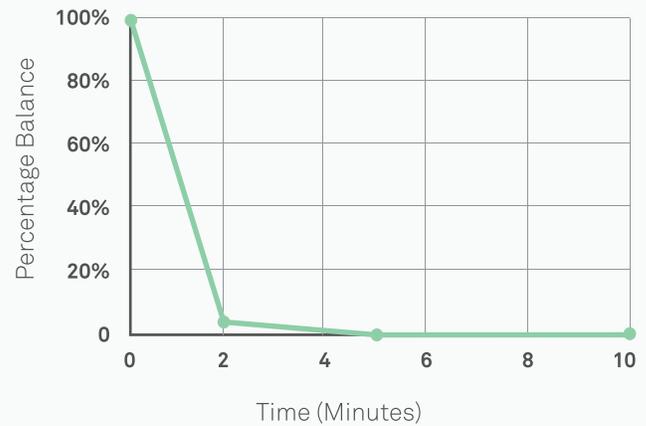
Destruction of Bacteriophage MS2 by PECO.



*University of Florida Disinfection and Sterilization Laboratory.*

**Figure 4**

Destruction of E. coli by PECO.



*University of Florida Disinfection and Sterilization Laboratory*

In single pass testing of the device the viruses were aerosolized upstream of the device via a nebulizer, and measured at the inlet and outlet of the device via impingers. An average of 3.4 million pfus were injected, with an average of 32 pfus found downstream of the device for a 5 log reduction in viable concentration of airborne viruses.

### C. Performance on Airborne Bacteria

Molekule's PECO technology was tested for performance in destruction of a variety of airborne bacteria in both recirculating and single pass conditions.

Testing was performed on both gram negative and gram positive bacteria. Escherichia coli was used as the gram negative bacteria challenge pollutant.

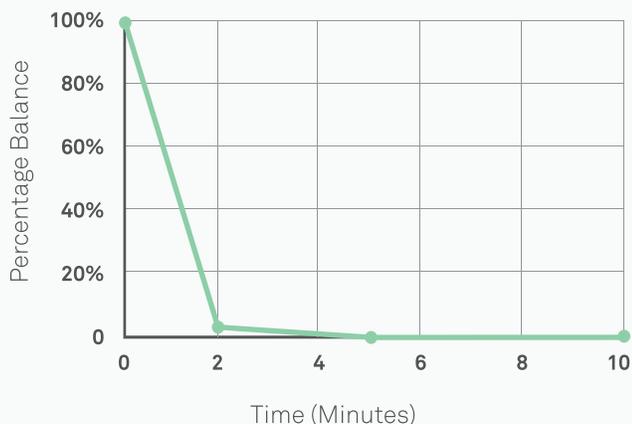
In the recirculating configuration, the bacteria was aerosolized upstream of the device via a nebulizer. 20 ml of an initial concentration of 109cfu/ml was injected. The surface of the filter was swabbed for measurement. Complete destruction of airborne e. coli was achieved prior to the second sampling at five minutes.

In the single pass configuration, the bacteria were aerosolized upstream of the device via a nebulizer, and measured both upstream and downstream of the device via impingers. An average of 9.7 million cfus were injected, with an average of 130 cfus found downstream of the device for a 4.9 log reduction in viable concentration of airborne bacteria. This testing was completed by ARE labs.

Staphylococcus aureus was used as the gram positive bacteria challenge pollutant in the recirculating configuration. Test protocol remained the same. Complete destruction was observed prior to the second sampling at five minutes.

**Figure 5**

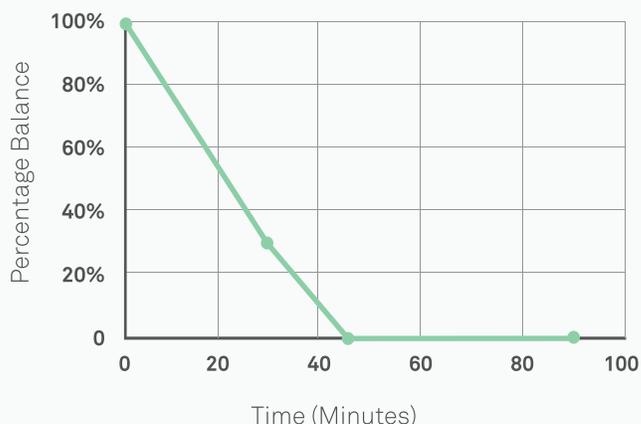
Destruction of *S. aureus* by PECO.



*University of Florida Disinfection and Sterilization Laboratory*

**Figure 6**

Destruction of *A. niger* by PECO.



*University of Florida Disinfection and Sterilization Laboratory.*

In the single pass configuration, tested at ARE labs, the related gram positive bacteria, *Staphylococcus epidermis*, was used. An average of 3 million cfus were injected, with an average of 140 cfus found downstream of the device for a 4.4 log reduction in viable concentration of airborne bacteria.

#### **D. Performance on Airborne Mold**

Molekule's PECO technology was tested for performance in destruction of airborne mold in a recirculating environment. The mold spores were aerosolized and destruction was measured at the filter surface. *Aspergillus niger*, commonly known as black mold, was used as the challenge pollutant. The experimentation involved injecting 20 ml of pure fungal spore suspension, initial concentration of 105cfu/ml, inside the recirculating environment. Complete destruction was observed in less than 45 minutes.

In single pass testing conducted by ARE labs, an average of 3.4 million cfus of *A. niger* were injected, while an average of 34 cfus were measured downstream for a 5 log reduction in viable mold spores.

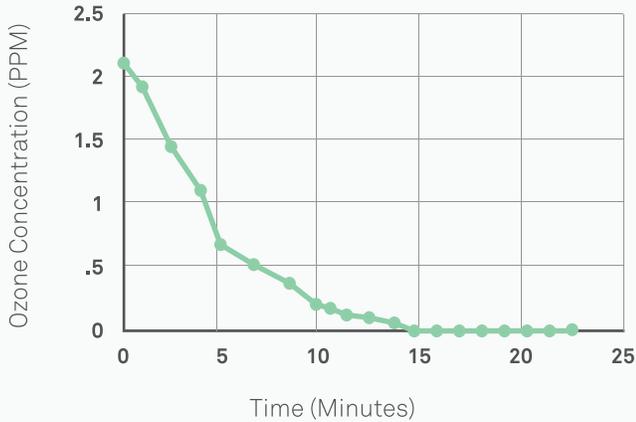
#### **E. Performance on Ozone**

While ozone has in the past been used for air purification, it is now recognized as an air pollutant itself that has adverse health consequences. Molekule's PECO technology does not produce ozone, and in fact actively reduces ozone concentration in the air through its chemical reaction process.

To test ozone destruction, an ozone generator was placed in a 600L steel chamber along with the Molekule device. Ozone concentration was allowed to rise to 2ppm before the PECO process was initiated. Ozone concentration was measured realtime over the course of the experiment.

**Figure 7**

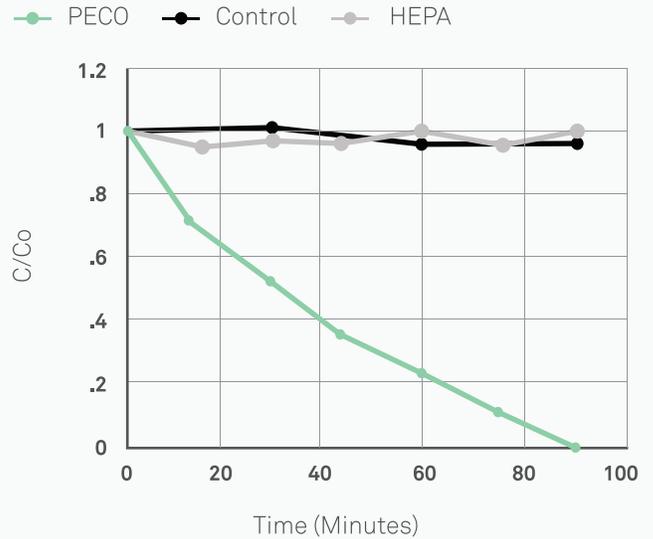
Destruction of Ozone by PECO.



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**Figure 8**

Comparison of PECO vs HEPA filter on VOC destruction.



*University of Minnesota Particle Calibration Laboratory.*

#### IV . Comparisons with Existing Technologies

Molekule's PECO technology was also tested in comparison with a number of existing technologies, namely HEPA filters and Carbon Filters as well as existing PCO technology on a range of challenge pollutants.

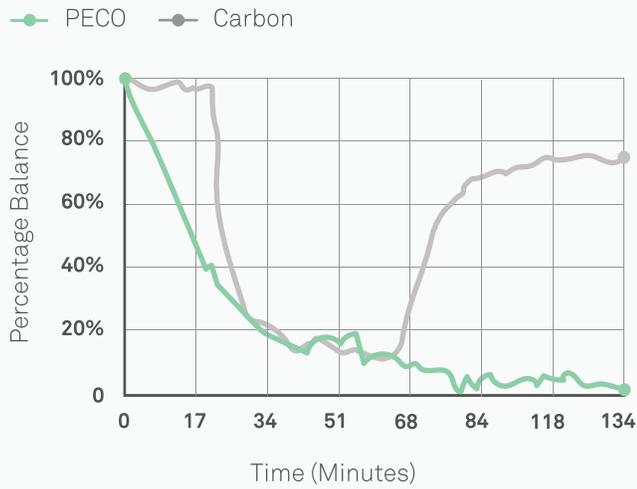
##### A. Comparison on VOCs

Volatile organic compounds are among the most difficult pollutants to remove from air. At sizes ranging from 2 to 20 Å (10-10 m) these are approximately 1000 times smaller than particles filtered by a HEPA filter. In a comparison test using toluene as the challenge pollutant, the HEPA filter did not deviate significantly from the control, while PECO achieved complete destruction.

In order to capture these VOCs, typically an activated carbon filter is used. Such activated carbon filters chemically adsorb VOCs on their surface. However, this adsorption is an equilibrium process, and carbon filters can easily saturate and re-emit VOCs back into the indoor environment if conditions change. To simulate changing indoor conditions, the challenge concentration of VOCs was injected, and after the chamber equilibrated, the chamber was opened to inject fresh air. Molekule's device continued to destroy VOCs below the level observed as the background fresh air concentration. The carbon filter did the opposite, off gassing VOCs into the chamber until the total VOC concentration was 75% of the initial concentration before evacuation.

**Figure 9**

Comparison of PECO vs Carbon filter in changing environmental conditions.



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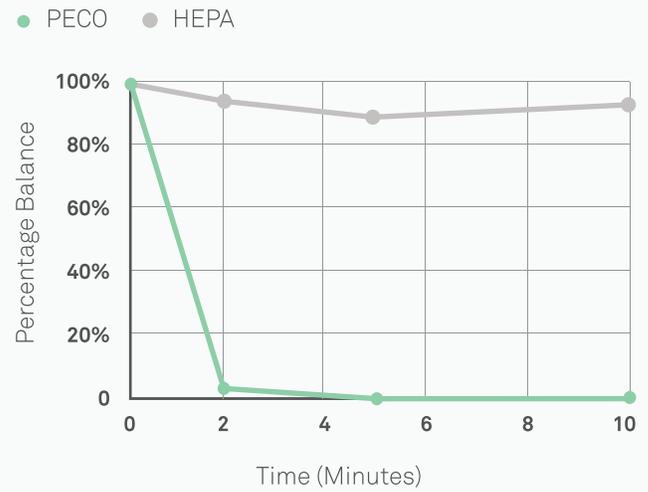
PECO was shown to effectively destroy VOCs which are too small for HEPA filters, and continue destruction as opposed to carbon filters which can become sources of pollution themselves.

### **B. Comparison on Bacteria and Mold**

While HEPA filters may capture bacteria and mold, these organisms can survive on the filter surface. In contrast, PECO technology completely breaks down these organisms. Filter surfaces were inoculated with bacteria (*E.coli*), and then swabbed to sample for surviving concentrations at set time intervals. While most of the bacteria continue to survive on the HEPA filter, the PECO process completely breaks them down in under five minutes. Bacteria may survive for up to 200 days on a HEPA filter, and even when they die may release endotoxins. By breaking down the bacteria and completely oxidizing the bacteria, PECO avoids this problem.

**Figure 10**

Comparison of PECO vs HEPA filter on VOC destruction.

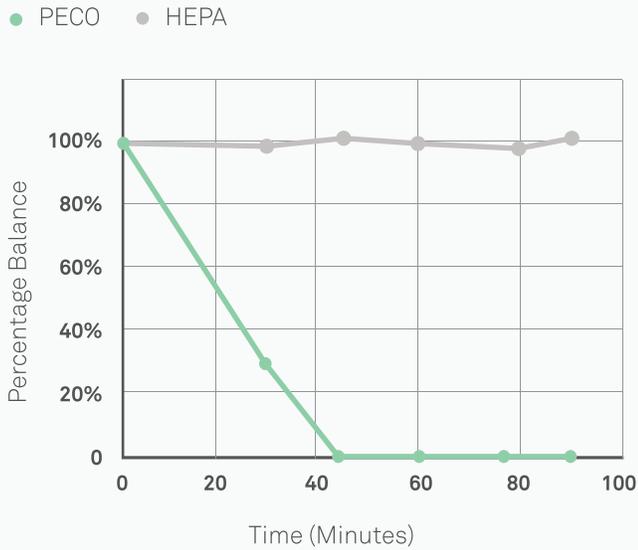


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A similar process of inoculation and sampling was conducted for mold. In the PECO process, there was no mold remaining after 45 minutes, while the mold continued to thrive on the surface of the HEPA filter. Mold can grow both on and through HEPA filters, eventually breaching the filter.

**Figure 11**

Surface Destruction of Mold PECO vs HEPA.



*University of Minnesota Particle Calibration Laboratory.*

## V. Conclusions

Through a variety of tests on challenge pollutants such as VOCs, viruses, bacteria, and mold, Molekule's PECO technology was shown to be an effective solution for destruction of the full spectrum of indoor air pollutants. Single pass testing verified downstream reduction of concentrations, and filter swab testing verified complete destruction and removal of the pollutants. Furthermore, PECO was shown to be a more effective solution as compared to HEPA or Carbon filters in the destruction of VOCs, as well as biological pollutants. Molekule's PECO technology represents an innovative leap forward in indoor air purification.