The Synergistic Improvement of Indoor Air HEPA-Filtration using Concurrent Dehumidification

Introduction

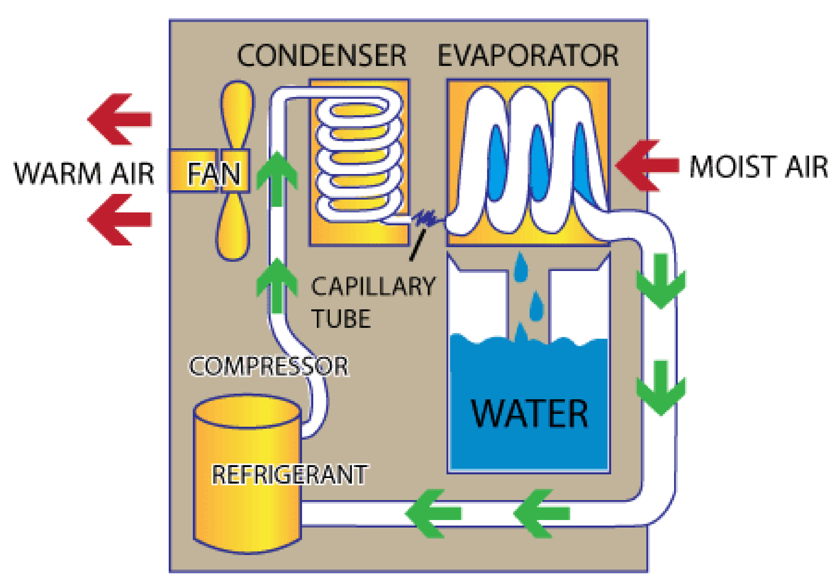
Indoor air quality is a pressing issue in our society and has risen to a major health concern globally. 1 in 4 people that reside in the US, for example, live in a household with polluted indoor air. Low air quality originates from fireplaces, cooking appliances, household cleaning products, paints, insecticides, insulation, and second-hand tobacco (or marijuana) smoke. All of these products release hazardous chemicals that lead to around 3.2 million deaths per year, including over 237,000 deaths of children under the age of 5. Even worse, on average about 90% of Americans' time is spent indoors - where pollution tends to be 2 to 5 times higher than outdoor concentrations. This poses an even larger threat and higher chance of serious illness. There are many ways to get rid of these indoor pollutants ranging from using mechanical air filters (such as particulate air HEPA filters and sorbent absorbers), to electronic air cleaners (electrostatic precipitators and UV-lamp cleaners of biological contaminants). These products are somewhat successful at removing particles, as well as biological and chemical pollutants, however their filtering efficiencies may be markedly enhanced when combined with dehumidification.

Engineering Goal

This research will demonstrate the increased removal efficiency of gaseous indoor airborne contaminants in a simple, inexpensive, and easy to use dual-component filtration system, with both HEPA filtration and concurrent dehumidification of the polluted air. Filtration of indoor air pollutant tobacco second-hand smoke will be examined with simple HEPA filtration, as well as combined HEPA-filtration and concurrent air dehumidification, in this experiment to highlight increased filtration efficiency of the newly-combined method.

Dehumidification Process

Figure 1. In the dehumidification process, Warm, moist air is drawn into the dehumidifier by a fan at the rear of the unit. As the air crosses the cooled "evaporator" coils, moisture in the air condenses on the coils, and is collected in a bucket at the bottom of the unit. The now dried air that passes through to the condenser is reheated by heat that is generated by the air-cooling process, and is released at the rear of the dehumidifier. (image courtesy of achooallergy.com)



Charcoal Filtration with a $1 Filter

- To measure whether the addition of an inexpensive charcoal filter would aide in the dehumidification filtration of cigarette second hand smoke, simple, $1 filters that are intended to absorb contaminants within a household compost bin, were purchased from Amazon.
- These filters are easily cut, and can be taped to the back of the small, portable $20 dehumidifier, at the air-inlet panel.

Figure 2 . A $1 Compost Bin Charcoal Filter was used to supplement Dehumidification Filtration of SHS. (image courtesy of Amazon.com)

The Experimental Design

- To evaluate the removal of secondhand smoke air pollutants, a 21-L airtight glovebox side-chamber was used (Fig. 3a), at a Relative Humidity of 45%. For each experiment, the chamber was first purged with nitrogen. Then, two cigarettes were lit (Fig. 3b), and permitted to burn to completion in a ceramic dish, within the chamber.
- At hourly intervals, 500µl of the time-point headspace gas was analyzed via Gas Chromatography (GC).
- Figure 3a. highlights the condition of the gastight chamber after the two cigarettes were completely burned, at time zero of the experiment.

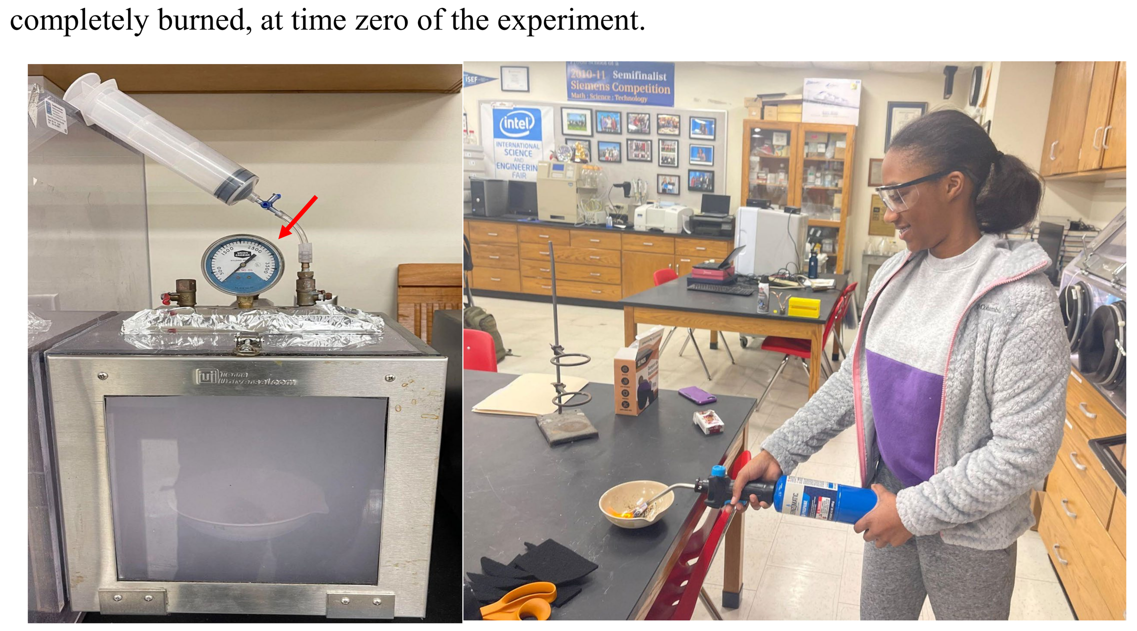


Figure 3A (right): Use of a glovebox side-chamber for measure of filtration of SHS; *Figure 3B (left): Two cigarettes were pre-lit, and allowed to burn to completion, for each experiment.*

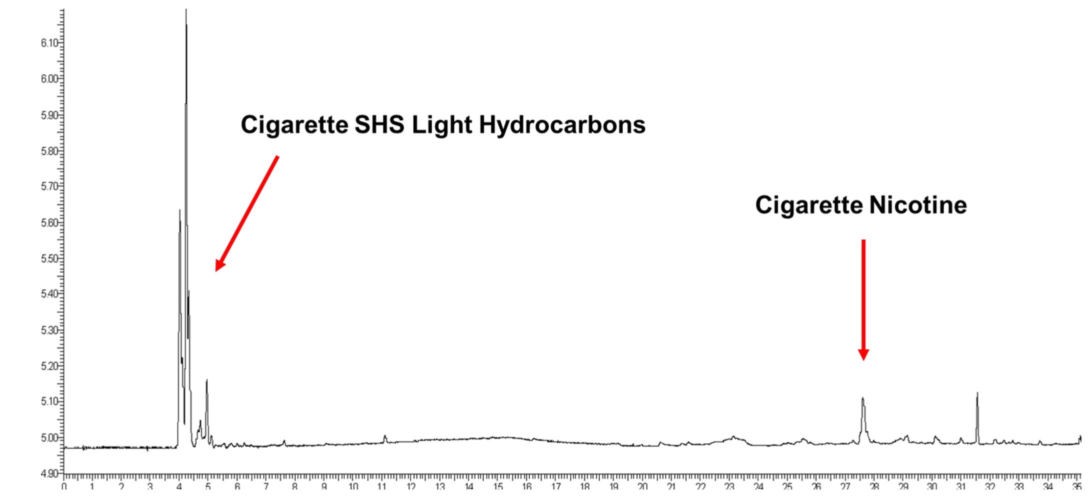
Unless otherwise noted, all images and graphs were taken or created by the student researcher.

I. Measure of Cigarette Second Hand Smoke (SHS) via GC-FID

To first characterize the detection of cigarette second hand smoke, 2 cigarettes were burned within the gastight side-chamber, and 500µl of box headspace was withdrawn, and analyzed via GC-FID, with the parameters shown to the right.

- Column Type: Supelco Equity-1 30mm x 0.25mm, 0.25um film
- Injection Volume: 500µl
- Injector Temperature: 200°C
- FID Detector Temperature: 230°C
- Oven temperature: 40°C initial, hold for 6 minutes, ramp by 6°C/min to 180°C, and hold for 10 minutes
- Split Ratio: 19:1, 20ml/min split flow
- He Carrier Flow: 1ml/min

Figs. 4a-b: (a, above): The GC-FID analytical parameters used to analyze Cigarette SHS; (b, right): The resulting gas chromatogram highlights the presence of light hydrocarbons from 3-9 minutes, with additional peaks at 29 and 31.5 minutes.



II. Verifying the Air-Tightness of the Glovebox Side-Chamber

To evaluate the "air-tightness" of the glovebox side-chamber, 2 lit cigarettes were placed inside of the previously nitrogen-purged chamber and 500µl of the gas within was extracted and measured, each hour for a total of 7 hours. Results from Table 1., Figure 5, and Figure 6 highlight only 0.59% loss of SHS contaminants over the 7 hour time period. Thus, this experiment acts as a control for future SHS filtration experiments, as any reduction in SHS beyond 0.6% would be attributed to dehumidification and/or charcoal filtration.

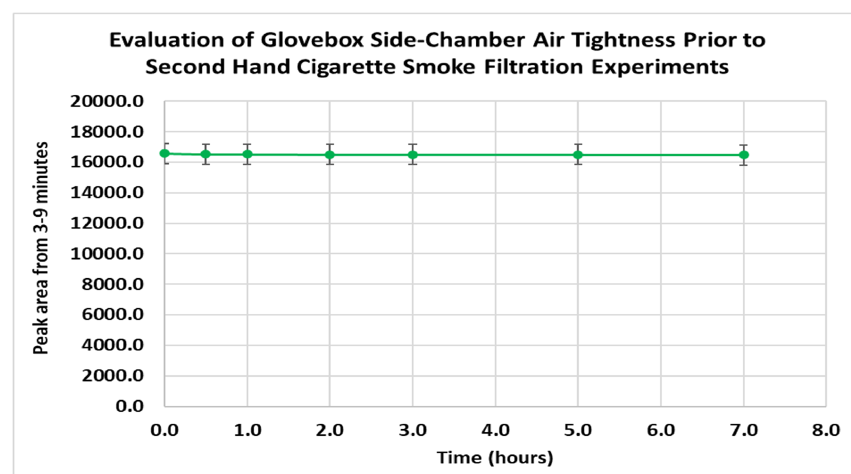


Figure 5. A plot of 3-9 minute average peak area versus time highlights the Air-Tight nature of the glovebox side-chamber, so that it is ideal for future SHS filtration experiments.

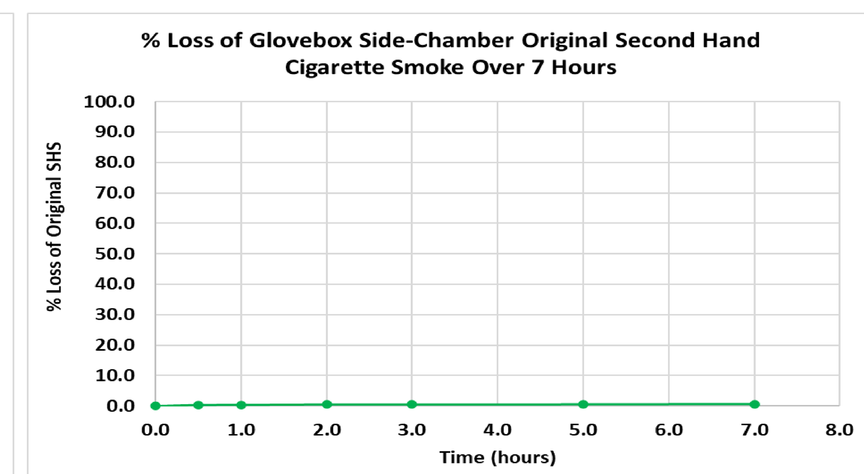


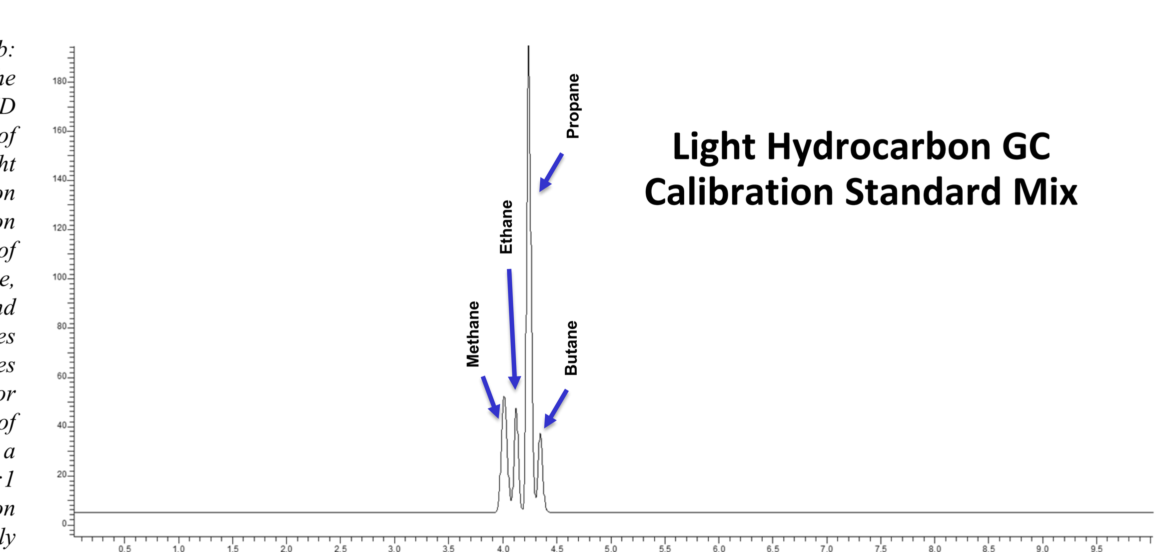
Figure 6. A plot of %Loss of SHS contaminants over 7 hours, indicates that only 0.59% of contaminants are lost. This highlights the Air-Tight nature of the glovebox side-chamber, so that it is ideal for future SHS filtration experiments.

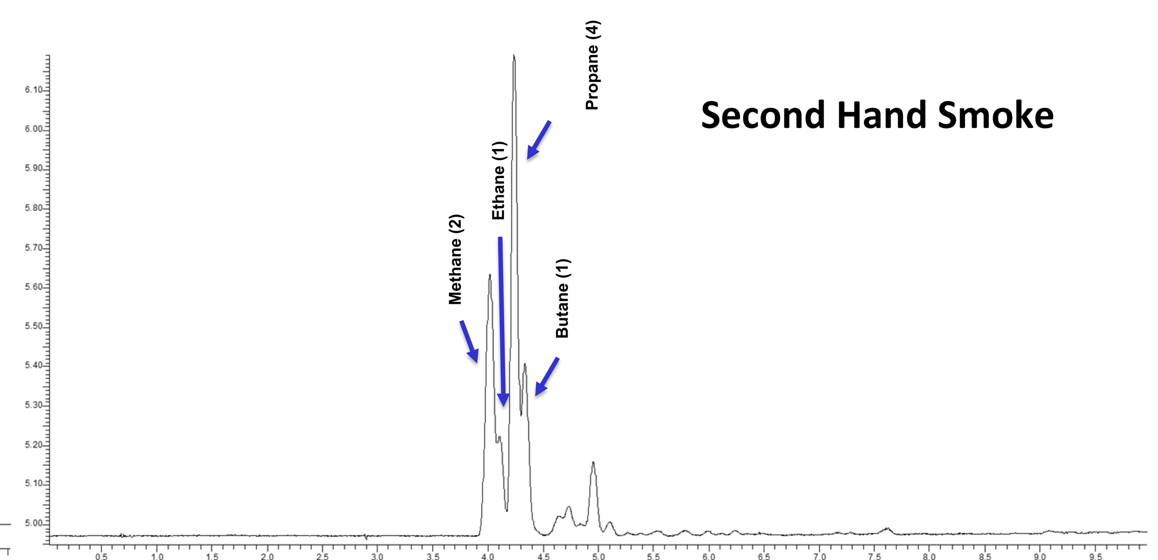
Time (hours)	Average No Treament Control Peak Area	% Loss of Original SHS
0.0	16580.0	0.00
0.5	16528.5	0.31
1.0	16518.9	0.37
2.0	16502.8	0.47
3.0	16500.4	0.48
5.0	16496.8	0.50
7.0	16481.6	0.59

Table 1 (left): The average "NO TREATMENT" Peak areas from 3-9 minutes, per hourly timepoint

III. Identification of Cigarette Second Hand Smoke Components

Figures 7a-b: Comparison of the GC-FID chromatogram of the light hydrocarbon calibration mixture of methane, ethane, propane, and butane identifies these same gases as the major components of cigarette SHS, in a 2:1:4:1 concentration ratio, respectively





The same GC-FID method was used to identify the light hydrocarbon components of cigarette second hand smoke. As in the previous experiment, 2 cigarettes were completely burned in the 21-L glovebox side-chamber, and 500µl of the chamber headspace was analyzed via GC-FID. The second hand smoke chromatograph was compared to similar analysis of methane, ethane, propane, and butane to identify these SHS components, which were present in relative and respective 2:1:4:1 concentration ratios. Each of these light hydrocarbons are flammable.

IV. Remediation of Cigarette SHS via Dehumidification & Charcoal Filtration

To measure filtration of cigarette SHS smoke by simple dehumidification, the air-tight side chamber was similarly pre-purged with nitrogen, followed by the complete burning of 2 cigarettes. For this set of experiments, a $20 (Amazon) Makayla Portable Dehumidifier (Fig. 8) was inserted into the chamber, so that it could filter the SHS via dehumidification only. Figure 9 highlights the consistent reduction in cigarette SHS contaminants over time. The chromatograms for 0, 1, 2, 3, and 4 hours are shown. The same set of experiments was then repeated using the same $20 portable dehumidifier, however this time, a $1 charcoal filter was attached to the rear, air-inlet, for possible, additional filtering performance.

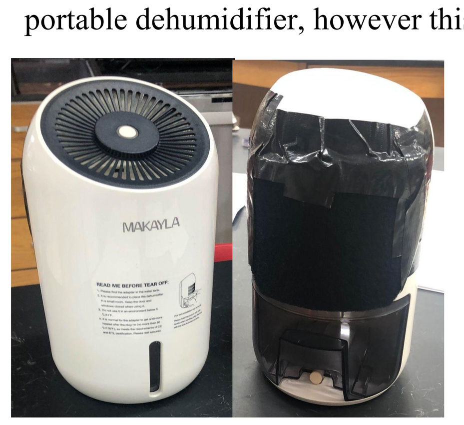


Figure 8a-b. Simple SHS Filtration was performed using a Makayla $20 portable dehumidifier (from Amazon), first on its on (left), and later with a $1 charcoal filter added (right).

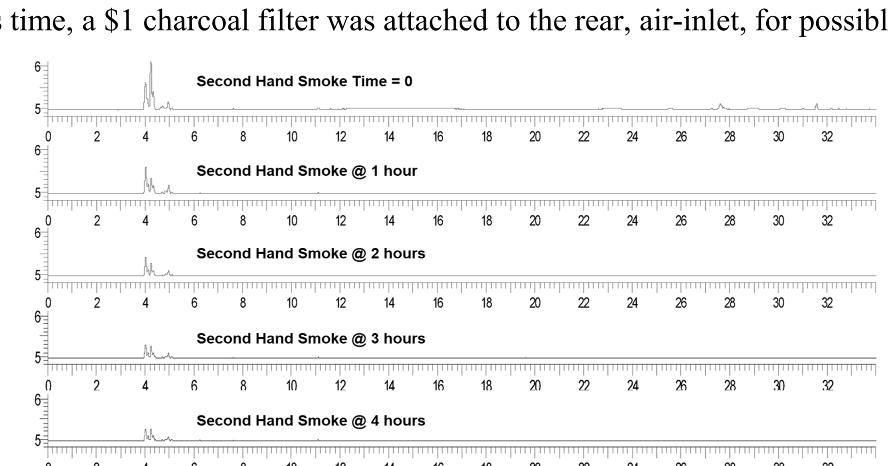
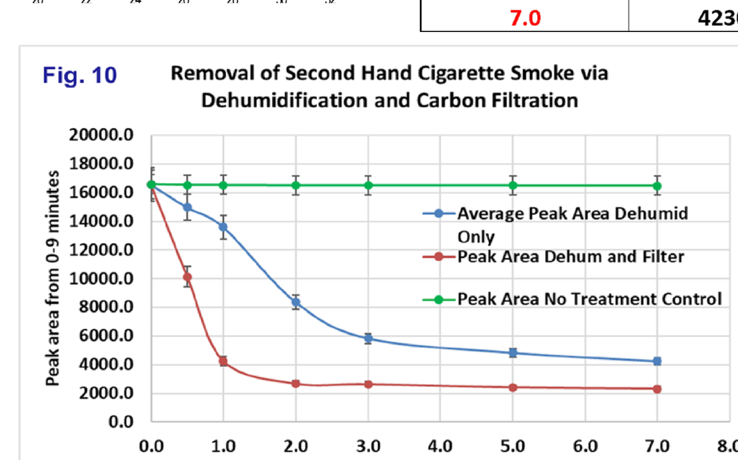


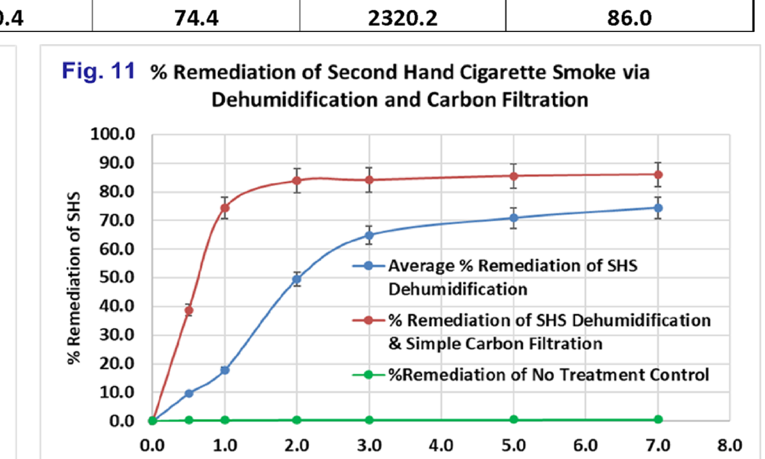
Figure 9 (above). The GC-FID Chromatograms for 0,1, 2, 3 and 4 hours of simple dehumidification (as examples) highlight the successful removal of cigarette SHS light hydrocarbon contaminants from the side-chamber headspace.

Table 2. displays the complete dataset for average dehumidification-only filtration, over 7 hours, as well as the average Dehumidification-Charcoal Filter filtration of SHS, over the same 7 hour time period. Simple dehumidification removed 74.4% in 7 hours, while the addition of the charcoal filter increased remediation efficiency to 86% over the same 7 hours.

Time (hours)	Average Peak Area Dehumid Only	Average % Remediation of SHS Dehumidification	Peak Area Dehum and Filter	% Remediation of SHS Dehumidification & Simple Carbon Filtration
0.0	16548.6	0.0	16548.6	0.0
0.5	14955.0	9.6	10133.0	38.8
1.0	13585.3	17.9	4249.0	74.3
2.0	8358.8	49.5	2675.0	83.8
3.0	5828.4	64.8	2636.0	84.1
5.0	4824.2	70.8	2414.0	85.4
7.0	4230.4	74.4	2320.2	86.0

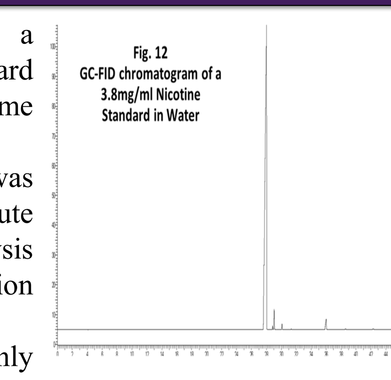
Figures 10 & 11 (right). For each filtration experiment, the peak area from 0-9 minutes from each time-point GC-FID chromatogram was plotted against time, and is shown in Figure 10., along with the control/airtight data. Using the peak area (16580) for time 0 as the 100% SHS, or fully contaminated side-chamber SHS content, the peak areas are converted to % Remediation, and once again plotted versus time in Figure 11. After 7 hours, dehumidification-only filtration of the SHS removed 74.4% of the contaminants, while for dehumidification and charcoal filtration, the % Remediation (at 7 hours) is increased to 86.0%. With correction for 0.6% loss for the control, which represents side-chamber leakage, the overall performance of dehumidification filtration was 73.8%, while dehumidification and charcoal filtration removed 85.4% Further, while dehumidification reached near-peak performance in 3 hours, filtration by the combined method reached near-peak filtration performance in only 2 hours.

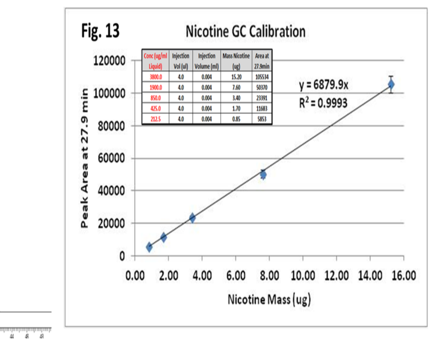


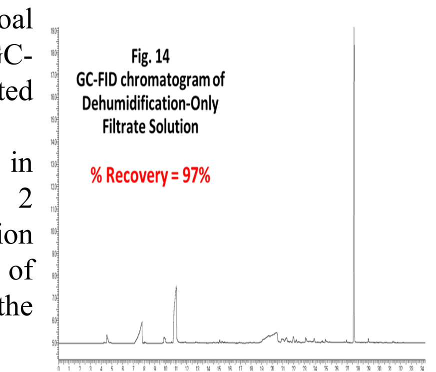


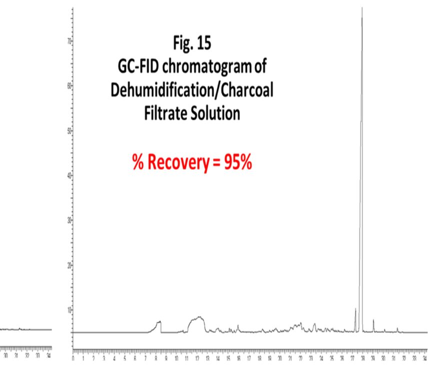
Detection of Nicotine in Dehumidification Filtrate

- GC-FID analysis of 2ul of a 3.8mg/ml nicotine in water standard highlights a nicotine retention time of 27.9 minutes *(Fig. 12)*.
- A nicotine calibration plot was constructed based on 27.9 minute peak areas from a GC-FID analysis of 0.2-3.8mg/ml nicotine calibration standards in water *(Fig. 13)*.
- The filtrates for the dehumid-only and combined dehumid-charcoal filtration were analyzed via GC-FID, and their peak areas converted to nicotine content *(Figs. 14-15)*.
- Correlating nicotine recovered in solution to original content in 2 cigarettes burned, each filtration methods recovered 95-97% of nicotine, removing it from the breathing air.



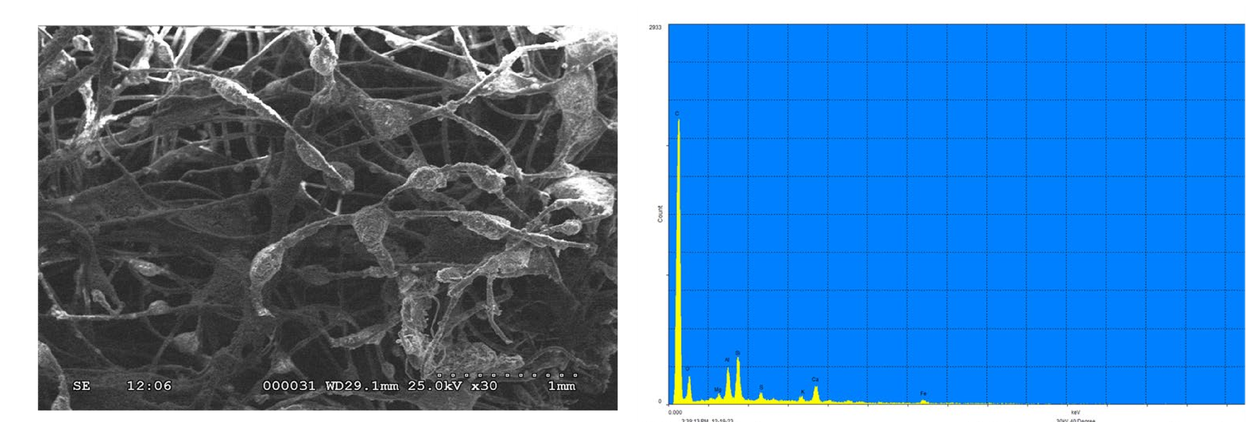




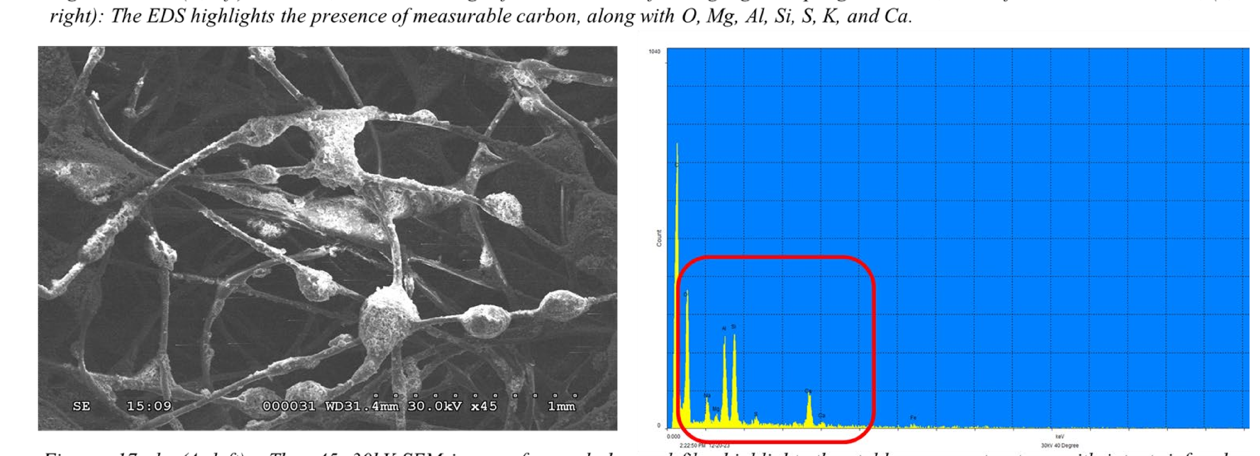


SEM and EDS Analyses of the Charcoal Filtrate

- The SEM image of Figure 16a highlights the sponge-like structure of the charcoal filter, with added activated-carbon infused within the material.
- The EDS of Fig. 16b highlights the presence of measurable carbon, along with O, Mg, Al, Si, S, K, and Ca.
- Conversely, similar analysis (Figures 17a-b) of the used charcoal filter highlights the stability of activated carbon in the sponge, however use has led to the absorption of increased oxygen, along with Mg, Al, Si, S, K, and Ca elements, from the absorption of SHS.
- Capture of these additional contaminant elements may suggest the presence of pesticide components that have made their way from treatment of the tobacco plant to the cigarette, and ultimately, into our breathing air.



Figures 16a-b: (A, left): The x30, 25kV SEM image of a new charcoal filer highlights a sponge structure, with infused activated carbon; (b, right): The EDS highlights the presence of measurable carbon, along with O, Mg, Al, Si, S, K, and Ca.



Figures 17a-b: (A, left): The x45, 30kV SEM image of a used charcoal filer highlights the stable sponge structure, with intact, infused activated carbon; (b, right): The EDS of the used filter highlights increased presence of oxygen, Mg, Al, Si, S, K, and Ca, along with constant carbon content.

Discussion/Conclusion

Over 6.7 million people die prematurely per year because of poor air quality. One leading cause of poor air quality is second hand smoke (SHS), brought about by cigarette smoking. Although this issue is often neglected, dehumidification and low-cost filtration that may offer an inexpensive and simple solution to remove SHS. This research will investigate the process of low-cost dehumidification, along with the simple addition of an equally-inexpensive charcoal filter, at effectively removing indoor air pollutants, using a SHS model contaminant. Initial gas chromatographic analysis of SHS identified the primary components as methane, ethane, propane, and butane. To measure removal of these contaminants from room air, 2 cigarettes were burned within a 21L gas-tight box at 45%-RH, and the resulting headspace filtered with simple dehumidification. Hourly GC-FID analysis of the headspace gases demonstrated that ~74% of SHS was removed in 7h., while addition of a charcoal filter increased SHS-contaminant removal to 85% in the same period. SEM and EDS analyses highlighted increased carbon and oxygen content on the used charcoal filter, providing evidence for its absorption of SHS. EDS analysis of the used charcoal filter also shows elevated Mg, Al, Si, S, K, and Ca elements, perhaps indicating the migration of tobacco pesticides into the cigarettes, and ultimately our breathing air. Finally, GC-FID analysis of each experiment's captured-water highlighted the presence of nicotine, where 97% was recaptured from burning cigarettes using dehumidification, while 95% was recaptured with the dehumidifier and filter. This suggests that nicotine removal was primarily via dehumidification. The combined results demonstrate compelling evidence that a $20 dehumidifier, combined with a $1 charcoal filter, can simply and efficiently remove indoor air pollutants, particularly SHS, which is a significant component.

Future Research

Future research would discover how significantly the Second Hand Smoke components were removed from the air. This includes discovering what would get rid of them even more effectively than we already have. Additionally, further research would include a deeper investigation into what other components were detected and how they impact our health. Also, further investigation is needed regarding possible pesticide migration in cigarette tobacco, and thus, second hand smoke.