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Headspace Determination of Acetone and Aromatic Hydrocarbons in Soil Using a Homebuilt, Inexpensive Gas Chromatograph with Photoionization Detection

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Abstract: We have designed, built, and characterized an inexpensive gas chromatograph with photoionization detection using readily commercially available components. These include a home carbonation CO_2 cylinder for the carrier gas, headspace sampling using a low pressure six port valve, a standard 30 m wide-bore capillary column, a consumer convection oven including added insulation with a thermocouple, and a photoionization sensor enclosed in a flow cell. The chromatography retention time reproducibility is good due to temperature control within 0.5 °C. The headspace linearity response using a 0.5 mL injection of benzene was from 10 to 250 ppm, with the limit of detection estimated at 4 ppm. The application of this instrument to the headspace monitoring of four soil samples spiked with a commercial adhesive cleaner containing acetone, ethyl benzene, and xylenes was possible. The interaction of acetone with the two different potting soil samples, likely due to their high organic content, was persistent for at least 30 min, even above an ambient temperature (60 °C). A comparison of linear plots of the signal versus volatilization time over the first 20 min showed substantially larger slopes for the two yard soil samples, indicating the rapid volatilization of acetone from these lower organic content soils, as compared to the two potting soil samples. This GC-PID instrument can be considered portable because it can be easily taken apart, transported, and reassembled. One viable option for the extension of the applications of this instrument is to provide hands-on teaching of GC.

Keywords: homebuilt portable gas chromatograph; photoionization detection; volatile organic compounds in soil

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1. Introduction

The determination of volatile organic compounds (VOCs) in environmental samples is important to follow the possibility of gasoline tank leaks and the improper disposal of hydrocarbon stripping or cleaning fluids, as well as the monitoring of industrial locations, such as refineries [1]. Sampling and analytical methods for such aromatic hydrocarbons in the air [2] and soil [3] have been reviewed. Although solid-phase extraction methods have been developed as a primary sample pretreatment method, recently solvent-free methods promoting "green" chemistry have been advocated. These can involve headspace sampling under temperature control at atmospheric pressure using a gas-tight syringe, either unpacked or packed with an adsorbent. Field testing of soil samples can be accomplished using a portable photoionization (PID) instrument. Because of the low ionization

potential of aromatic hydrocarbons in the 8–9 eV range, benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds can be easily detected. However, this approach will not permit the identification of specific BTEX compounds but only the total aromatic hydrocarbon concentration. Determination of aromatic hydrocarbons by gas chromatography (GC) with either flame ionization detection (FID), PID, or mass spectrometry (MS) are the most common analytical methods. However, GC-FID or GC-MS instruments are more commonly used in laboratory-based testing than in field testing. Portable GC-PID instruments have been developed for field testing. A comparison of three different GC instruments for the determination of BTEX in air has been made [4]. A portable GC with PID that is commercially available from Ametek Mocon was compared against laboratory-based GC-FID and GC-MS instruments. The GC-PID used 300 microliter headspace (HS) sampling, which differed from the cold trap sampling methods used by the other two instruments. The direct HS sampling approach did give competitive sensitivity and detection limits for BTEX compounds with similar chromatography analysis times. The commercially available Frog 4000 VOC analyzer is a hand-held micro GC-PID that was utilized for the identification and quantification of acetone, ethylbenzene, methyl isobutyl ketone, toluene, and xylenes trapped from the air in solid sorbent tubes [5]. Another commercial GC-PID has been miniaturized and adapted for real-time air sampling [6]. A commercial portable GC has been used for BTEX field analysis of soils [7]. However, these commercial instruments are very expensive. A micro GC with PID has been constructed using a sampling valve, an in-house designed resistively heated temperature control module, and the Ametek Mocon PID and was characterized for the determination of BTEX compounds [8]. A micro GC with a 6 m column could separate 10 compounds in about 2 min [9]. However, some of these homemade portable GC-PID instruments would be difficult to replicate [10].

We have designed, built, and characterized an inexpensive GC-PID instrument that can be easily replicated. The instrument has been assembled largely from readily available commercial components, such as a SodaStream CO_2 cylinder to provide the carrier gas, a moderate pressure six port sampling valve, a standard 30 m wide-bore capillary column, a consumer convection oven with a thermocouple, and a photoionization sensor enclosed in a flow cell. The signal output as function of time can be recorded by a teaching multichemical analysis (MCA) interface or an Arduino microcontroller interface, to be saved as a computer data file for later analysis. The sensitivity of the response was determined with BTEX compounds. The instrument was tested for the separation of alkanes before applying it to the detection of a commercial adhesive cleaning solvent (acetone, ethylbenzene, and xylenes) spiked in two different types of soil (two potting and two yard). Mixtures of acetone and aromatic hydrocarbons are typical solvents that are found in paint manufacturing industries [5]. Studies on the interactions of acetone, as well as aromatic hydrocarbons, with soil are not common [11]. Methanol, having a low response to PID and low GC retention, was found to be an effective extraction solvent that has apparently not been previously applied to soil studies using GC-PID. Weaker volatilization of acetone was noted for the higher organic content potting soils. A teaching application is also proposed.

2. Materials and Methods

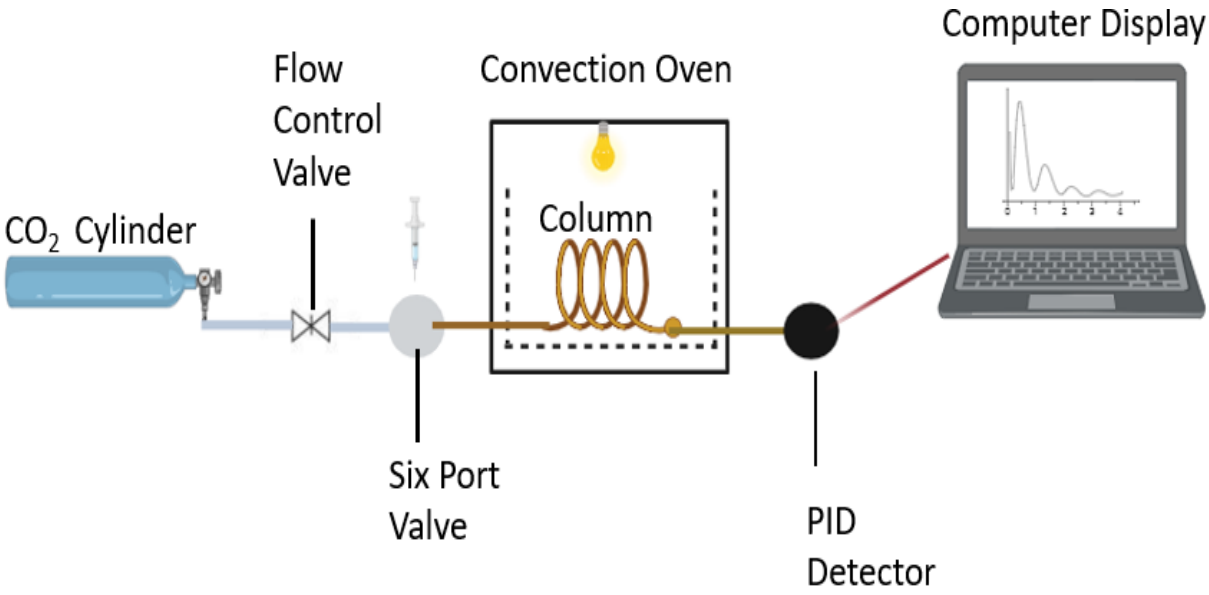
The GC-PID instrument (overall block diagram and photo shown in Figure 1) was constructed from readily available commercial components. The carrier gas is generated from a Soda Stream (Kfar, Saba, Israel) CO_2 tank connected to a standard inert gas pressure regulator (Fisher Scientific, Waltham, MA, USA) using a high pressure stainless steel ball valve with two high pressure ¼" NPT connectors (McMaster-Carr, Elmhurst, IL, USA) (Figure S1A). The six port Cheminert injection valve with either a 20 microliter or a 500 microliter stainless steel loop is a Model 14N-0273L from VICI, Houston, TX, USA

(Figure S1B). The loop was wrapped with ½" × 24" silicone heat tape (BriskHeat, Columbus, OH, USA) and controlled at a temperature of 80 °C using a 3 amp Variac (Chennai, India) variable transformer.. Sample injection was done with a 1 mL Hamilton (Reno, NV, USA) gas-tight syringe. The GC capillary column ((Restek (Bellefonte, PA, USA) RTX-5, 5% phenyl: 95% methyl-silicone, 30 m × 0.5 mm ID, 0.5 micron film thickness)) was enclosed in a Model # 8217SIM Sharper Image (Novi, MI, USA) Super Wave infrared convection oven that was insulated with 1 inch thick ceramic fiber insulation (Baclaugh Co.) around the sides and bottom, with a small towel was placed over the column (Figure S1C). The column temperature was measured with Model 6802II digital thermometer with thermocouple (Gain Express, Hong Kong, China). The piD-TECH PID sensor (10.6 EV) was fitted with a piD-POD flow cell, both purchased from Ametek Mocon (Brooklyn Park, MN, USA) (Figure S1D). Chromatograms were generally collected on the MeasureNet MCA system (Cincinnati, OH, USA) with V3.1.2.23 software for peak height measurement. BTEX chromatograms were compared using the Arduino (Monza, IT, USA) microcontroller interface plus computer. Cost of the instrument is based primarily on the injector, GC capillary column, and the PID, each estimated to be about USD 600, for a total of about USD 2000, including the other parts.

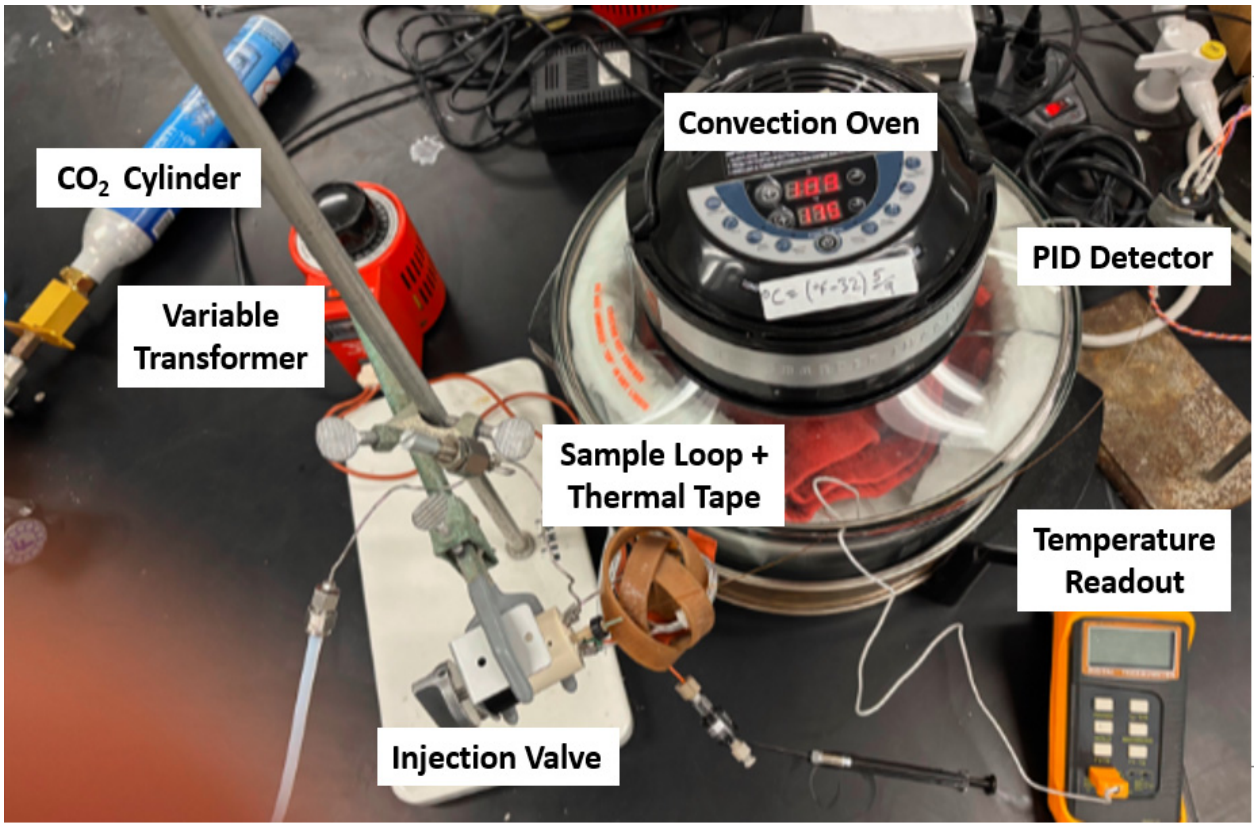
A 1 mL 2000 ppm BTEX standard was obtained from Sigma-Aldrich (St. Louis, MO, USA). The alkanes (C5, C6, and C8) and methanol were all reagent grade and were obtained from a variety of sources. The C7 heptane sample was technical grade. BTEX linearity was performed by taking headspace samples from 10, 50, 100, 250, 400, and 500 ppm solutions in methanol, all in 10 mL volumetric flasks.

The interaction of acetone plus aromatic hydrocarbons ethylbenzene and xylenes with four different soils as a function of time was tested using the commercial adhesive cleaning solution called Goof Off. Based on a 2024 material safety data sheet, Goof Off was determined to have acetone as the principle component (60–80%), ethylbenzene (1–5%), and xylenes (7–13%). Methanol (1–5%) and Stoddard solvent (alkanes, 5–10%) are also present but are not easily detected by PID. A GC-MS study confirmed this composition of solvents in Goof Off. Four soil samples (two potting and two yard varieties) were spiked with Goof Off and solvent outgassing was measured as a function of time. The potting soil samples were Miracle Grow Organic Choice Moisture Control Potting Mix (total % N 0.18) and Miracle Grow Cactus, Palm, and Citrus Succulent Potting Mix (total % N 0.06). Two yard soil samples from Oxford, OH, USA were also obtained. All soil samples were dried at 70 °C for about 20 h and then sieved through a 1 mm hole screen. Soils were chosen to have a wide difference in organic matter as determined by pyrolysis for 20 min at 1000 °C for triplicate samples. The Organic Choice potting soil had an organic content of 90.9% ± 1.5 and that for the Succulent potting soil was 59.7% ± 0.43. Yard soil A had a much lower organic matter content of 23.3% ± 0.3, as expected by the visible presence of clay, and that for yard soil B was 27.0 ± 0.64. Two approaches to follow the interactions of the organic compounds with soil were tested. For method 1, a soil amount of 3.5 g was added to a 20 mL glass vial and then spiked with 100 microliters of Goof Off. The vial was vortexed for 30 s to promote distribution of the VOCs throughout the soil. Vials of different 3.5 g soil samples, each spiked at 100 microliters, were left on the hot plate for various times. Then, the vial was removed, 6 mL of methanol was added, and this slurry was vortexed. The soil was allowed to settle out for 30 s before 1 mL HS sampling was done. For method 2, soil samples were spiked with 100 microliters of Goof Off, vortexed dry in the vial without the addition of methanol, and then spread out on a Petri dish warmed at a constant temperature of 60 °C before analysis by headspace every 10 min. For method 3, a soil amount of 3.0 g was added to a 20 mL glass vial and then spiked with 100 microliters of Goof Off. A 4 mL volume of methanol was added and the vial was vortexed for 30 s to

promote distribution of the VOCs throughout the soil. The soil slurry was then distributed evenly on a 10 cm diameter weighing dish and allowed to equilibrate on a hotplate set at 60 °C. One mL head space samples were taken from a different quadrant of the surface of the soil area every 10 min for analysis and injected into the injector sample loop. All four soil samples were tested. The GC temperature for the analysis of the soil samples was about 71 °C.



(**A**)



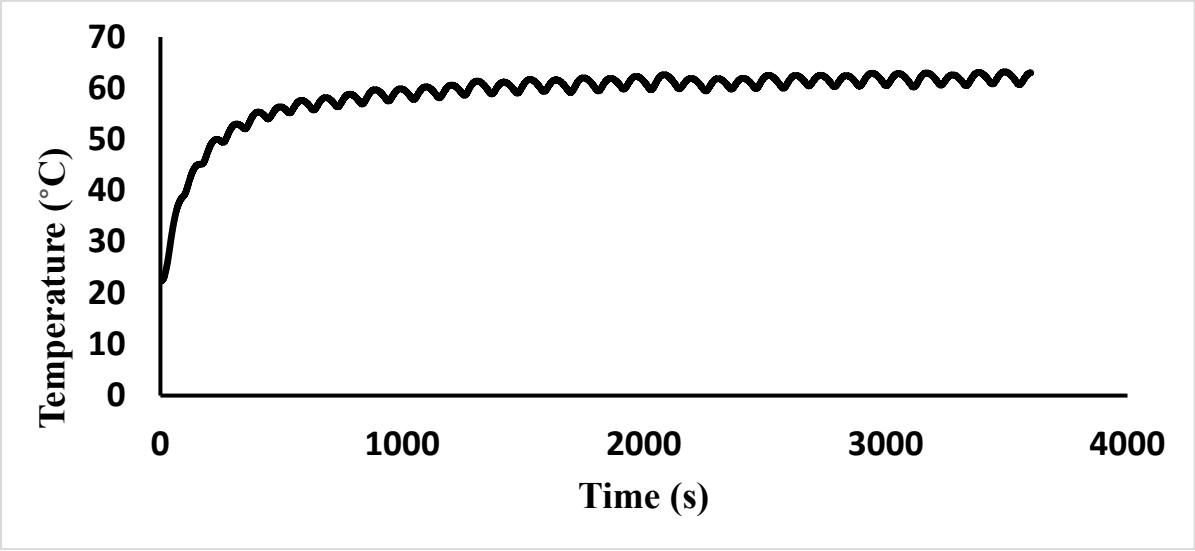
(**B**)

Figure 1. (**A**) Block diagram of the GC-PID. (**B**) Overview of homebuilt GC-PID. See Figure S1 for close-up identity of components.

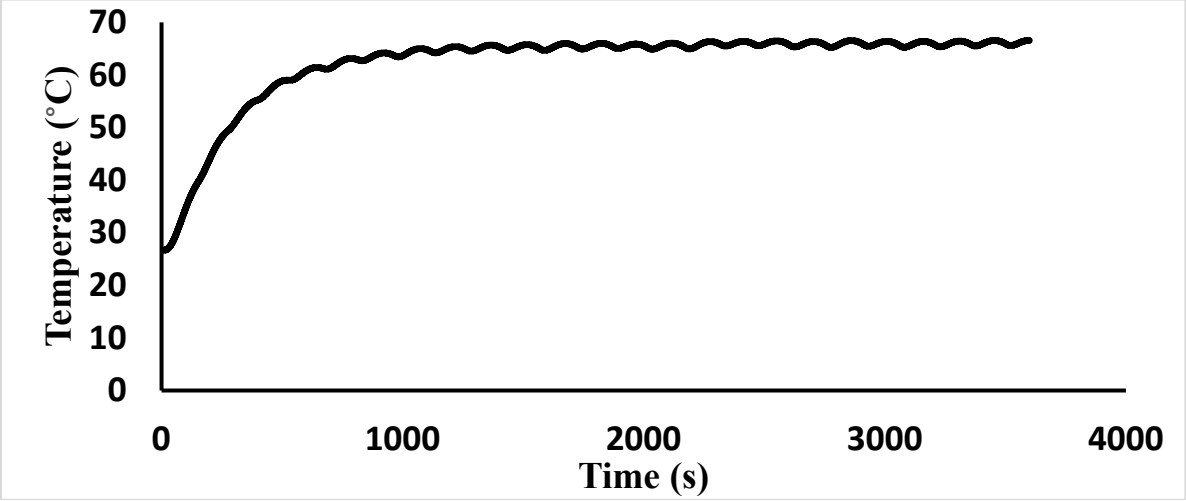
3. Results and Discussion

3.1. Characterization of Instrument

Initially, the temperature stability of the GC oven was tested without and with insulation (Figure 2). The rise time for the oven to achieve about 60 °C from room temperature is about 1500 s or 25 min. The temperature stability of the insulated oven, measured as a baseline standard deviation of 0.135, was about 10 times better than that for the uninsulated oven. The fluctuation of the column temperature was about 0.5 °C.



(**A**)

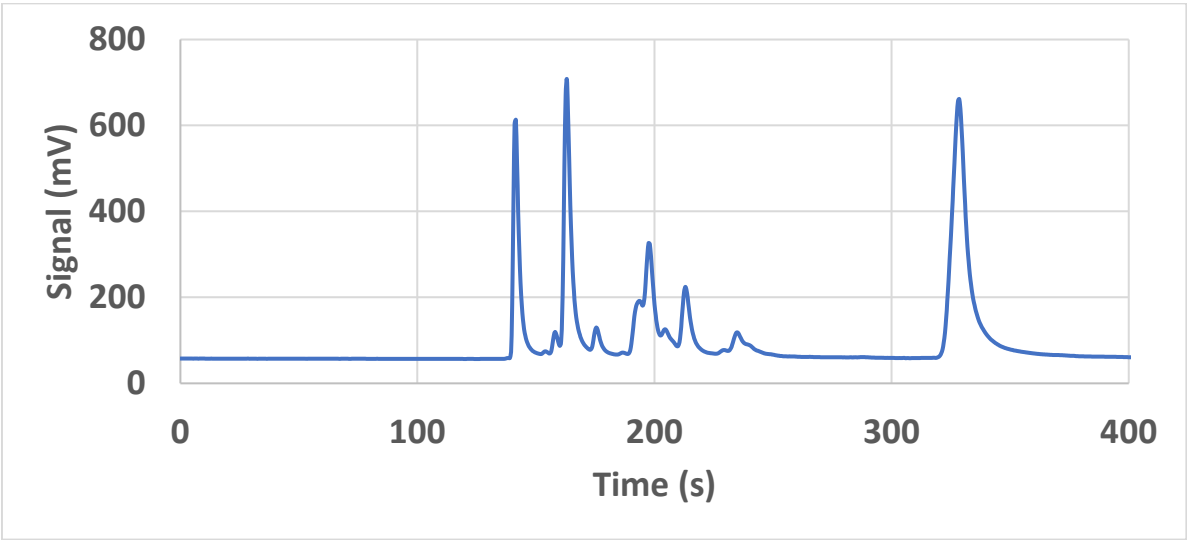


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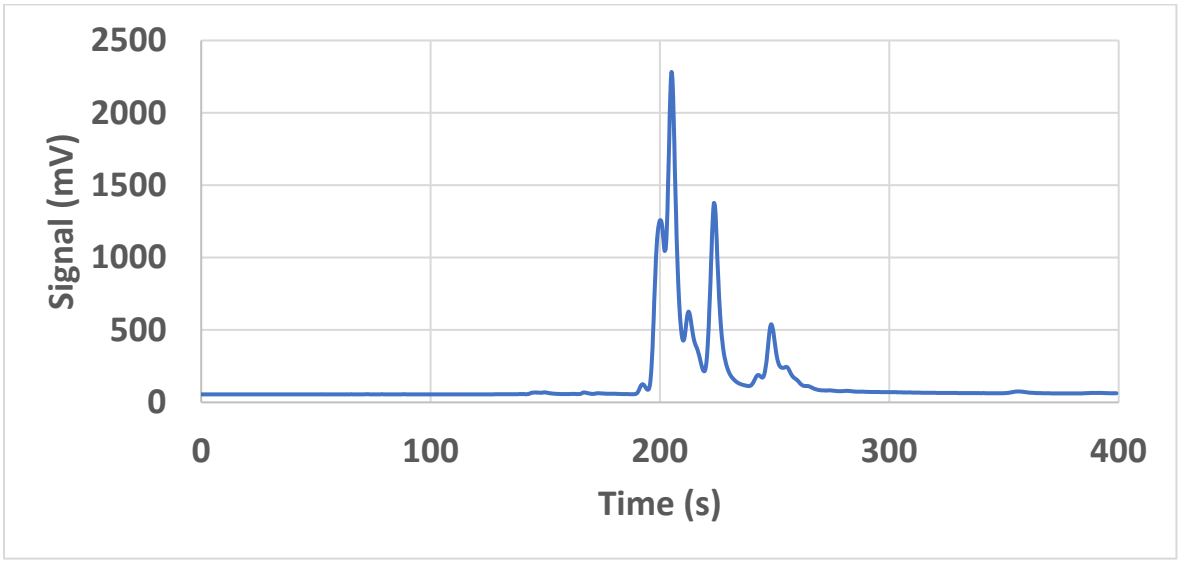
Figure 2. (**A**) Temperature (T)–time plot for uninsulated GC oven. Average T = 62.55; Std. Dev. 1.21; RSD 1.94. (**B**) Temperature–time plot for insulated GC oven. Average T = 66.18; Std. Dev. 0.136; RSD 0.206.

The qualitative capability of this GC using a 20 microliter loop was tested using an alkane test mixture with the MeasureNet interface. The n-pentane, hexanes, heptanes, and n-octane mixture was separated in about 6 min with good resolution (Figure 3A), indicating the presence of C7 isomers (Figure 3B). The use of CO_2 as a carrier gas for GC is very unusual [12], but the loss of column efficiency due to mass transfer in the mobile phase is not a significant problem, especially for the separation of straightforward samples. The flow rate of about 22 cm/s was comparable to the 20 cm/s flow rate that is recommended

for a wide-bore GC column [13]. The plate count, using the peak width at half height equation, was calculated to be between 15,000–20,000 plates for the various peaks.



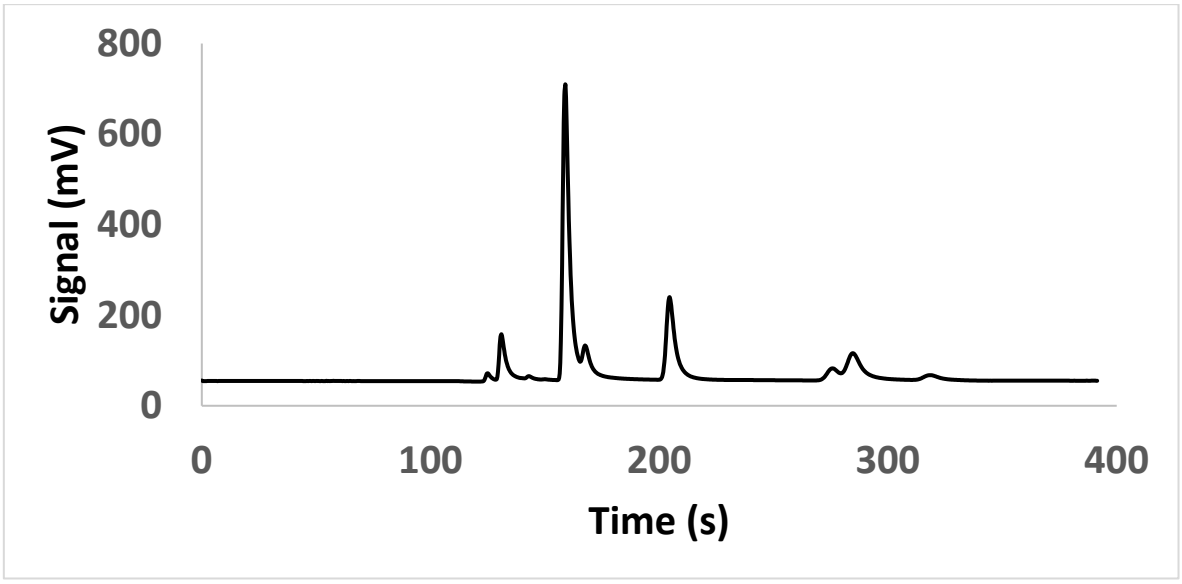
(**A**)



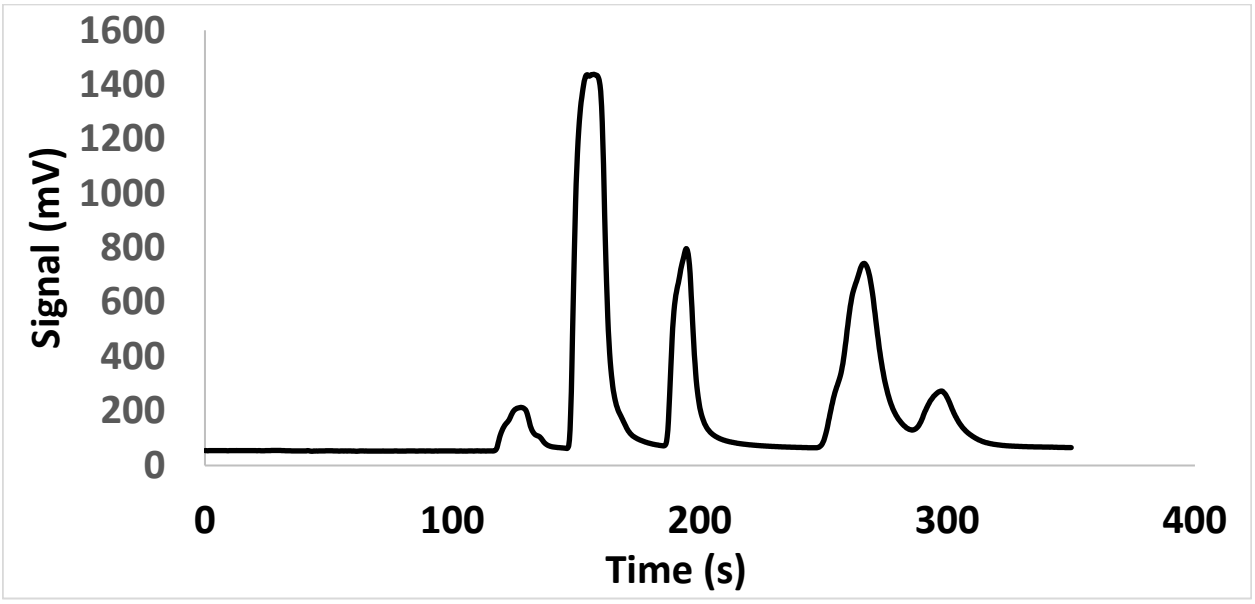
(**B**)

Figure 3. (**A**) Separation of n-alkanes (C5, C6, C7, and C8 major peaks) at 65 °C. (**B**) Separation of technical grade heptanes showing isomers.

Initially, quantitative headspace sampling using toluene was tested with the MeasureNet and linearity was shown from 10 to 500 ppm (Figure S2). The reproducibility of the triplicate injections for each point is shown by the error bars. Therefore, HS sampling of spiked soil samples was deemed possible. Because of the interest in the detection of BTEX using GC-PID, linearity and detection limit studies were conducted for this sample. Chromatograms for the HS sampling of 2000 ppm of BTEX, comparing the 20 microliter and 500 microliter loops, are shown in Figures 4A and 4B, respectively. As expected, peak resolution for ethylbenzene and the xylene isomers is diminished using the larger loop size. Although resolution of the major BTEX components is still evident, the plate count for benzene using the 500 microliter loop is markedly reduced as compared to that (22,400) for the 20 microliter loop.



(**A**)



(**B**)

Figure 4. (**A**) Chromatogram of BTEX using a 20 microliter loop. Major peaks are benzene-160 s, toluene-205 s, ethylbenzene-277 s, xylenes-287 s, and o-xylene-320 s. (**B**) Chromatogram of BTEX using a 500 microliter loop. Major peaks after the methanol solvent peak are benzene, toluene, ethylbenzene, and xylenes.

Linearity and sensitivity were determined using the 2000 ppm of BTEX standard diluted down to 10 ppm for benzene and 75 ppm for the other VOCs using the 500 microliter loop injection (Figure S3). We have shown that linearity of toluene and ethylbenzene is possible down to 10 ppm. The HS limit of detection (LOD) for benzene, based on three times the baseline noise/slope, was estimated to be 4 ppm for the 500 microliter loop. Because of the variability of HS sampling conditions, this detection limit is difficult to compare to previous related papers, many of which were pre-concentrating large-volume air samples on adsorption cartridges. Because of the toxicity of benzene, extended studies of BTEX in soil samples were not considered and the presence of Goof Off in the soil was investigated. Previous work considering the interactions of ketones in soil is not common. Using the larger loop, the peak resolution of the major components of Goof Off (acetone,

ethylbenzene, and xylenes) should be fine and these analytical figures of merit should be adequate for detection of residual organic solvents in soil.

3.2. Goof Off-Spiked Soil Studies

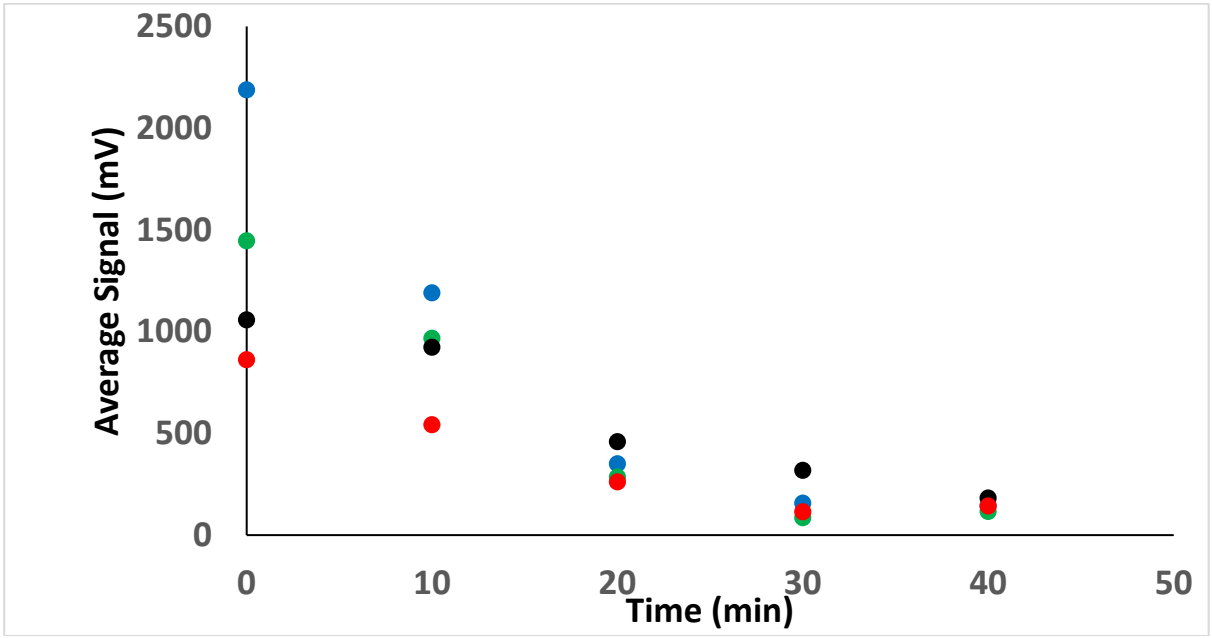
Method 1 for the analysis of spiked soil incorporated a methanol extraction step to ensure sampling of the soil would be complete. The complete miscibility of Goof Off, ethylbenzene, and xylenes, each at a weight ratio of at least a 1:1 in methanol, was noted. The headspace sampling of a 6 mL sample of methanol in a vial showed a weak response, about 140 mV, as was expected due to its high ionization potential of 10.8 eV. The trials in triplicate on conducted on different days showed a relative standard deviation (RSD) of about 15%. With the soil kept in the vial and using this extraction method, the acetone peak tends to be off-scale at shorter times (Figure S4A). However, the ethylbenzene and xylenes peaks are still measurable (Figure S4B). The small peak at 560 s is likely o-xylene.

Figure S5 shows similar peak profiles for the Organic Choice potting soil and yard soil A samples as a function of time. This is likely due to the soil compacted in the vial, limiting volatilization for both samples. The replicates of peak height for ethyl benzene in the headspace samples taken from the potting soil 20 min vial were 109 and 106 and those for the xylenes were 16 and 15. Because the soil is present in an enclosed vial and there is a methanol extraction step, the reproducibility of method 1 is considered good. Considering Goof Off was spiked at 100 μL in 3.5 g of soil and has a density similar to acetone (0.784 g/mL), ethylbenzene at 10% represents a concentration of about 2 μg of this solvent component per kg of soil. With a signal at 0 min of about 200 units, ethylbenzene levels below 1 μg/kg of soil should be detectable. This is very comparable to the linear range starting at 1 μg/kg of soil cited in a similar HS soil sampling paper [7].

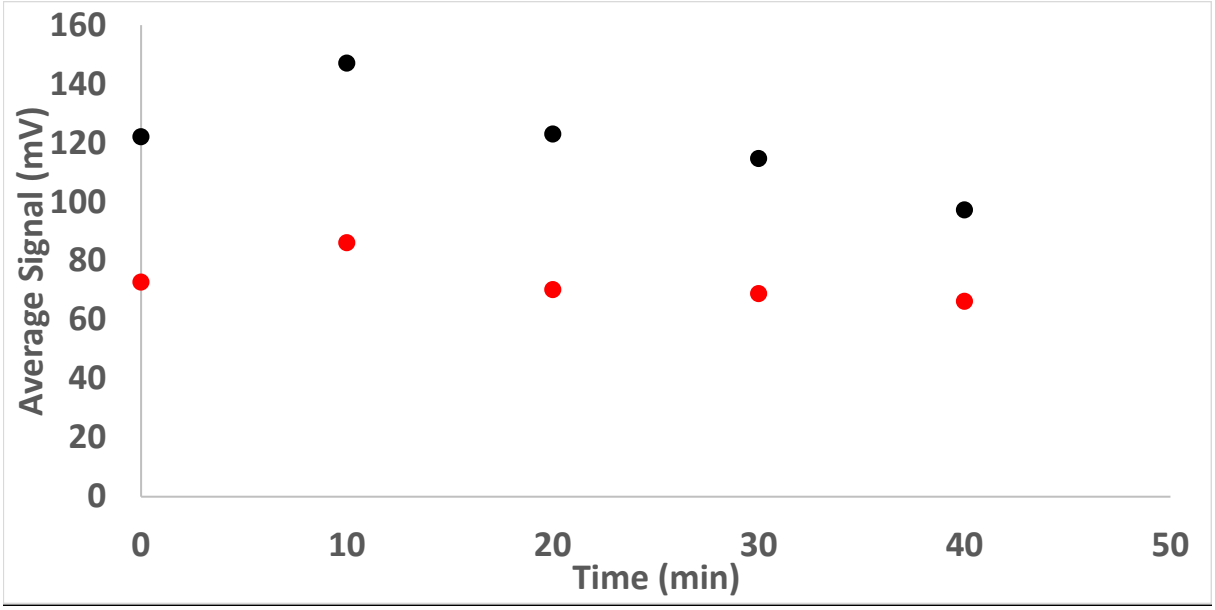
To be more representative of testing soil samples in the field, method 2, with dry soil spiked with Goof Off and spread out on a warmed Petri dish for subsequent analysis by headspace, was carried out. Figure S6 shows a chromatogram of a Goof Off-spiked Organic Choice potting soil sample warmed for 60 min. The isothermal separation of ethylbenzene and xylenes is known to be challenging. Significant peaks for all the organic solvents are apparent, even for acetone and the less volatile aromatic hydrocarbons. A comparison of the signal profiles for acetone, ethylbenzene, and xylenes as a function of time is shown in Figure S7. The decrease in signal is more linear for the aromatic hydrocarbons. Apparently, the high organic content in the Organic Choice potting soil (90.9%) provides a strong affinity for carbonyl compounds. A comparison of Goof Off affinity for the yard soil A sample was also made (Figure S7). At 10 min, the peak signal is only one fourth of that of the potting soil for both acetone and ethylbenzene. At 30 and 60 min, the peak signals for all organic solvents are low, around 10 for the carbonyl compounds and 1–3 for the aromatic hydrocarbons. Volatilization does appear to be greater for the yard soil than the potting soil, consistent with the trends in Figure S5. The much lower affinity of the yard soil A sample may be due to its low organic content (23.3%) with a significant amount of visible clay content. Although the overall trends in Figure S7 are clear and similar to what has been reported previously for BTEX compounds [14], the reproducibility of this sampling approach at the soil surface and the possibility of incomplete coating of the soil by the spiked sample are concerns.

Method 3, which ensured even methanol distribution of the VOCs in the soil samples before air exposure, was applied to both the potting soil samples and the yard soil A and B samples. An example chromatogram is shown in Figure S8 and the signal trends for acetone, ethylbenzene, and xylenes with air exposure times are shown for all four sample in Figure S9. The acetone trends for the two potting soil and two yard soil samples are compared in Figure 5A,B, which also shows the volatility (loss of ethylbenzene and xylenes)

with time for the Organic Choice potting soil. Some affinity of acetone is likely due to the high organic content in the soil and a more stable interaction with ethylbenzene and xylenes, as profiled before in Figures S5 and S7.



(**A**)



(**B**)

Figure 5. (**A**) Signal trends as a function of time for acetone in decreasing order at time 0 for Yard A soil (blue points), Yard B soil (green points), Organic Choice (black points), and Succulent (red points). (**B**) Signal trends as a function of time for ethylbenzene (black) and xylene (red) in the Organic Choice potting soil.

Figure 6 shows the linear plots of the volatility of acetone away from each of the soil samples over the first 20 min of sampling time. The slope values for the yard A and yard B samples are −92 and −58, respectively. However, the slopes for the potting soil samples are significantly lower, both at −30. The significantly higher % of organic matter in the potting soils as compared to the two yard soil samples is likely causing a slower release of acetone. Visually, yard soil A has more clay and a lower organic content as compared to yard sample

B, which could partially explain this difference in slopes. This is also consistent with the trends found previously for yard soil A using methods 1 and 2. The triplicate runs of these method 3 sampling trends showed the average RSD for the points to be about 25%, with a range generally from 10 to 40%. These quite large RSD values for the field sampling of air exposed soil on a dish in the laboratory are not really unexpected. However, this affinity of acetone with higher organic content potting soil samples as compared to yard soil samples appears to be a valid conclusion.

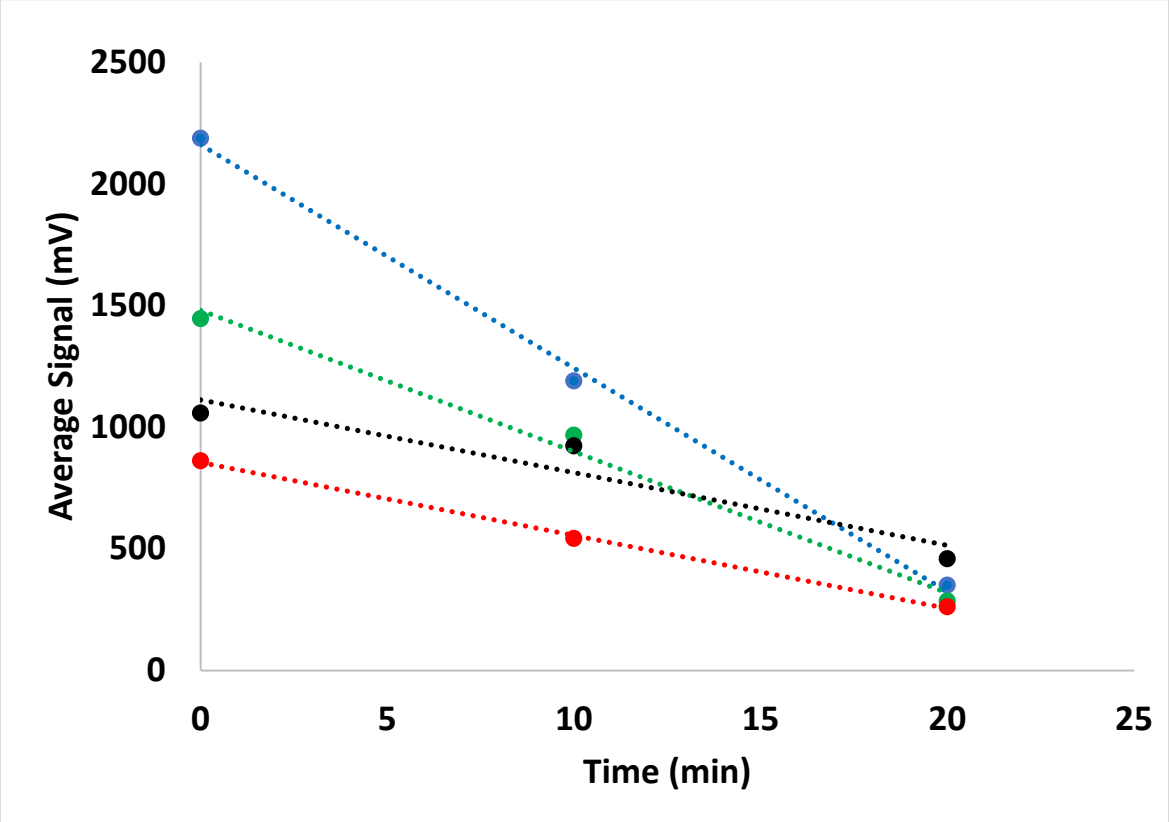
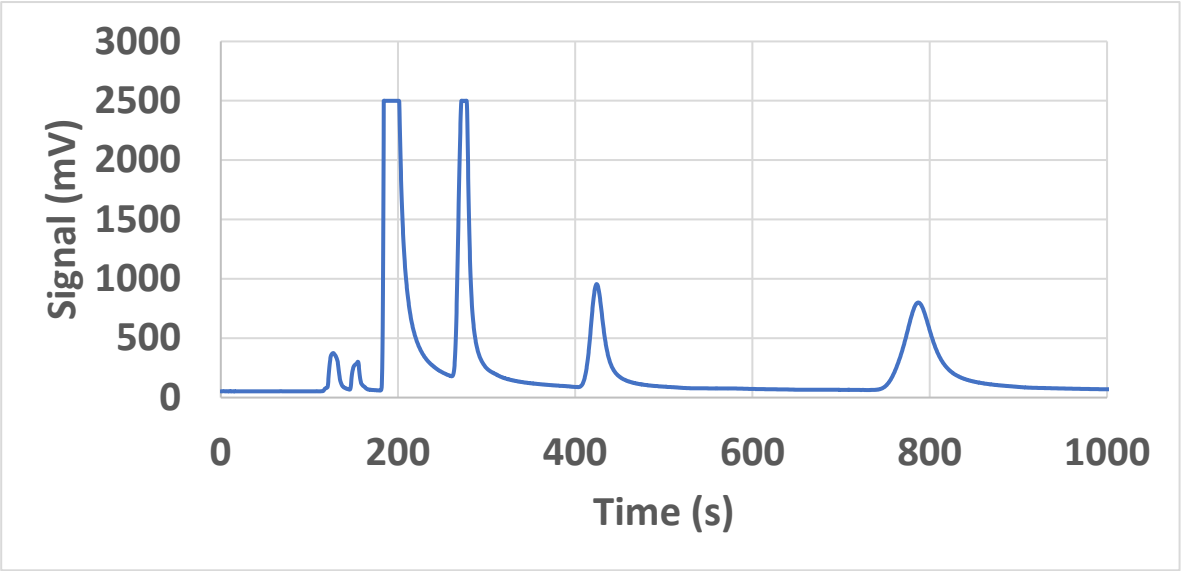


Figure 6. Linearity of acetone as a function of time in four soil samples. Yard A soil (blue points): $y = -91.869x + 2161.6$, $R^2 = 0.9976$. Yard B soil (green points): $y = -58.051x + 1480$, $R^2 = 0.9899$. Organic Choice (black points): $y = -29.922x + 1112.5$, $R^2 = 0.9081$. Succulent (red points): $y = -29.998x + 855.15$, $R^2 = 0.9986$.

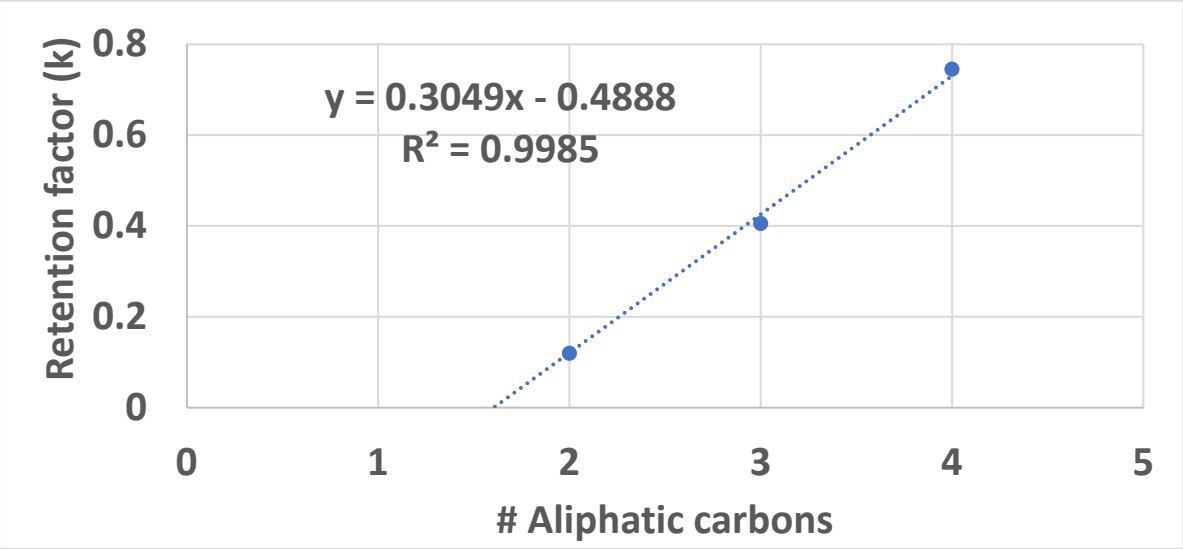
Our soil data trends are comparable to the previous literature. For dry soil, three main sites in soil for adsorption of VOCs are as follows: 1. mineral surfaces, 2. soil organic matter, and 3. soil mesopores [11]. Hydrocarbon retention is more effective in dry soil [15]. The volatilization of BTEX compounds from the soil at ambient conditions showed an upward trend before plateauing at about 4 h [16]. Less volatility of BTEX compounds as a function of increasing soil organic matter has been reported [17]. The trends towards a weaker recovery of BTEX compounds in higher organic content soil by extraction with an aqueous salt solution [10] are analogous to our trends comparing potting and yard soil. Comparison data for the interactions of carbonyl compounds with soil do not seem to be as readily available. A comparison of the adsorption of alkanes, aromatic hydrocarbons, and methyl ethyl ketone on sand, clay, and limestone showed that the highest adsorption occurred for methyl ethyl ketone, followed by the aromatics, and then the aliphatics [18]. The vapor uptake rate of acetone with peat was about six times greater than that for hexane, likely due to the decayed plant matter in peat, which contains polar functionalized humic acid [19].

3.3. Teaching Capabilities

We have used this homebuilt GC-PID extensively to teach GC to undergraduate chemistry or biochemistry majors. We plan to incorporate some of these soil studies into our analytical chemistry classes, similar to what has been reported previously [20]. A separation of toluene, ethylbenzene, propylbenzene, and butylbenzene is shown in Figure 7A. The plot of the log retention factor (k) versus aliphatic carbon number (Figure 7B) is linear, as expected from chromatography theory, indicating the free energy of partitioning is related to the log of the partition coefficient as measured by the retention factor [21]. The slope can be considered as a measure of the partitioning of the methylene (CH_2) group with the stationary phase and equals $-\Delta G/[2.303(RT)]$, where the gas constant R = 8.3145 J/[mole(K)] and T = column temperature °K.



(**A**)



(**B**)

Figure 7. (**A**) Chromatogram of major peaks for toluene, ethylbenzene, propylbenzene, and butylbenzene at 72 °C. (**B**) Log k versus number (#) of aliphatic carbons for toluene, ethylbenzene, propylbenzene, and butylbenzene. ΔG = −2014 J/mole.

Considering the slope of the data taken at 72 °C (345 °K) is 0.3049, a ΔG for the partitioning of the methylene (CH_2) group with the column stationary phase of −2014 J/mole

can be calculated. Similar log k versus number of aliphatic carbons plots based on chromatograms taken at two other temperatures are shown in Figure S10. An average ΔG value of −1994 ± 39 (n = 3) with an RSD of 2% is close to −2138 J/mole, as reported previously for alkane data (C8–C14) [21], and −2289 J/mole, as calculated for ΔG data for six n-alkanes (C4–C9) [22]. Variations in the ΔG values can be explained by the differences in the polarity of the GC stationary phase used. The qualitative identification of soils as unknowns spiked with different combinations of these aromatic hydrocarbons is also part of this experiment.

This instrument has proven to be very robust; it has been taken apart and transported to a high school for the detection of esters by their students. The instrument can be disconnected easily into the following four sections for transport. The four sections are as follows: 1. CO_2 tank, regulator, and variable valve, 2. Variac with heat tape, 3. column oven with a column and the injection valve inside, and 4. PID detector that all can be easily moved and the fittings reconnected. For the high school work, their Vernier (Beaverton, OR, USA) interface was used for the chromatography readout. The feasibility of using the Arduino interface for the chromatogram readout has been considered to minimize costs and permit complete portability. Chromatograms for 2000 ppm of BTEX using the same 50 and 2000 microliter loop sizes with the Arduino microcontroller interface readout are shown in Figure S11A,B. A comparable peak resolution is shown; though the baseline has more noise. However, the detection of contaminated soil at medium ppm levels using the 500 microliter loop should still be feasible.

4. Conclusions

We have designed, built, and characterized an inexpensive GC-PID instrument using readily available commercial components. These include a small CO_2 cylinder for the carrier gas, headspace sampling using a six port valve, a standard 30 m wide-bore capillary column, a consumer convection oven including added insulation with a thermocouple, and a photoionization sensor enclosed in a flow cell. Chromatography retention time reproducibility is good due to temperature control within 0.5 °C. Headspace linearity response using a 0.5 mL injection for toluene could be from 10–500 ppm and 10–250 ppm for benzene. Application of this instrument to headspace monitoring of soil samples spiked with a commercial adhesive remover containing acetone, ethyl benzene, and xylenes was possible, showing strong interactions between these VOCs and high organic content potting soil. This GC-PID instrument can be considered portable because it can be easily taken apart, transported, and reassembled. One viable option for the extension of the applications of this instrument is to provide hands-on teaching of GC, with all the parts clearly visible.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/separations12020046/s1, Figure S1: Identity of GC components; Figure S2: Linearity of toluene response by headspace sampling; Figure S3: Linearity of BTEX response using 500 microliter loop (A) benzene, (B) toluene, (C) ethylbenzene; Figure S4: (A) Chromatogram generated from method 1 sampling of meth-anol extract of a Goof Off spiked potting sample in a vial after 10 min at 60 °C. Major peak: 1: acetone. Smaller peaks: 2: ethylbenzene; 3-xylenes. (B) Expanded version of chromatogram in (A) showing ethylbenzene and xylenes peaks; Figure S5: Peak signals of Goof Off spiked potting soil samples using Method 1 of potting soil (orange top trace) and yard soil (blue bottom trace) at 10, 30, and 60 min. A-acetone; B-ethylbenzene; C-xylenes; Figure S6: Chromatogram generated from method 2 head space sampling of a Goof Off spiked potting sample exposed to the air on a petri dish for 60 min at 60 °C. Major peaks: 1: acetone; 2: ethylbenzene; 3-xylenes; Figure S7: (A) Peak signals using Method 2 of Goof Off spiked potting soil sample at 10, 30, and 60 min. Top-acetone; middle-ethylbenzene; bottom-xylenes. (B) Peak signals using Method 2 of Goof Off spiked yard soil sample at 10, 30, and 60 min. Top-acetone; middle-ethylbenzene; bottom-xylenes; Figure S8: Chroma-togram generated from method 3 head

space sampling of a yard soil sample exposed to the air on a weighing dish for 30 min at 60 °C. Major peaks: 1: acetone; 2: ethylbenzene; 3-xylenes; Figure S9: Peak signals using Method 3 for the four soil samples as a function of time; Top-acetone (black); middle-ethylbenzene (blue); bottom-xylenes (red). (A) Goof Off spiked Organic Choice potting soil sample; (B) Goof Off spiked Succulent potting soil sample; (C) Goof Off spiked yard soil A; (D) Goof Off spiked yard soil B; Figure S10: Log k versus # aliphatic carbons for toluene, ethylbenzene, propylbenzene, and butylbenzene. (A) T = 94 °C, $\Delta G = -1949$ J/mole. (B) T = 64 °C, $\Delta G = -2020$ J/mole; Figure S11: (A) Arduino chromatogram of 2000 ppm BTEX with the 20 microliter loop. (B) Arduino chromatogram of 2000 BTEX using the 500 microliter loop.

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