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Laboratory evaluation of a prototype portable gas chromatograph (GC) with a flame ionization detector (FID) for toluene, ethylbenzene, and xylenes (TEX) analysis

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Abstract

The standard method to evaluate human exposure to volatile organic compounds (VOCs) is in general performed by sampling the air on sorbents followed by liquid extraction and detection using laboratory gas chromatograph (GC). The conventional method is time and labor intensive and employs a toxic solvent which adds a risk factor as well as waste. Hence, there have been increasing demands for portable GC instruments which allow near real-time, in-situ analysis. In this study, the potential use of a prototype, dual column portable GC (protoGC) with flame ionization detector (FID) was examined by comparing its performance with a conventional GC laboratory method. Four target concentration levels (1x, 2x, 4x, and 8x; x = 1.12 ± 0.01 ppm) of toluene, ethylbenzene, and o-, m-, and p-xylene were generated in an exposure chamber (24 ± 1 °C and 50 ± 5% RH). The challenge atmosphere was directly sampled and analyzed with protoGC while for the conventional method it was sampled on a sorbent tube and analyzed with a laboratory GC/FID. The results of protoGC correlated well with the conventional method (r = 0.991–0.999), indicating that protoGC has comparable performance with the conventional method within the test conditions. Although two-way ANOVA showed significant differences in mean concentrations between the methods, the differences were small. protoGC would be useful to monitor VOCs in air with high temporal resolution or to quickly determine the safety of the environment of interest due to the substantial time savings in sampling and analysis. Further examinations at various environmental conditions and other analytes will be necessary to thoroughly evaluate its performance.

Keywords Volatile organic compounds (VOCs), Portable gas chromatograph (GC), Daul flame ionization detector (FID), VOC analysis, Micro GC, Ttoluene, ethylbenzene, and xylenes (TEX)

Introduction

Volatile organic compounds (VOCs) are organic chemical compounds that readily evaporate under normal indoor atmospheric conditions of temperature and pressure (EPA 2022). Workers or consumers are exposed to VOCs through a wide range of industrial processes and commercial products. Excessive, acute exposure to VOCs can cause eye, nose and throat irritation, nausea, and dizziness and chronic exposure to high concentration can cause liver/kidney disease, central nervous system (CNS)

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damage, and cancer (Minnesota Department of Health 2022). Toluene, ethylbenzene, and xylene (TEX) isomers are important environmental/occupational VOCs found in many products and emitted in numerous industrial processes. Elevated concentrations of TEX were reported in newly constructed and renovated homes as well as industrial settings (Li et al. 2021). Ethylbenzene is a possible carcinogen classified as Group 2B by the International Agency for Research on Cancer (IARC) (International Agency for Research on Cancer 2022). Toluene and xylenes are classified as Group 3 (i.e., inadequate evidence of carcinogenicity in humans).

The US Environmental Protection Agency (EPA) and National Institute for Occupational Safety and Health (NIOSH) developed sampling methodologies for VOCs using sorbents tubes to capture VOCs followed by a thermal desorption or chemical desorption and gas chromatography (GC) analysis (Wang & Austin 2006). For example, the NIOSH Manual of Analytical Methods (NMAM) 1501 for aromatic hydrocarbons (NIOSH 2003) collects the compounds on a charcoal sorbent tube by pulling the contaminated air using a sampling pump. The adsorbed compounds on the sorbent are chemically desorbed for at least 30 min with 1 ml of carbon disulfide (CS_2) and for subsequent analysis, a 1 µl-aliquot is injected into a GC coupled with a flame ionization detector (FID). The conventional sampling and analytical methods are well established but they have some disadvantages: use of a toxic solvent for which health effects on cardiovascular system and CNS are known (Gelbke et al. 2009) and which also adds waste; long turn-around time for analytical results which delays communication of risk data (Soo et al. 2018); costs for lab supplies and technicians; reduced sample mass (i.e., amount injected) due to the high dilution factor (1:1000) (Floyd et al. 2022); and use of a benchtop GC which limits portability for onsite analysis.

Portable direct reading instruments (DRIs) which allow rapid, on-site analysis have been widely used for monitoring VOCs. The most common DRIs for workplace VOC monitoring include photoionization detectors (PIDs), infrared (IR) spectrometers, and flame ionization detectors (FIDs): all are fast in response time and easy to use but they cannot specify individual VOCs (Duarte et al. 2014). On the other hand, portable GCs coupled with a FID, PID, or mass spectrometry (MS) provide selectivity, sensitivity, and near real-time response. Several models are currently on the market, including Defiant Technologies Frog 4000 GC/PID, INFICON HAPSITE ER GC/MS, and PerkinElmer Torion T-9 Portable GC/MS. FIDs and PIDs are non-selective detectors which respond to all detectable compounds whereas detectors like mass spectrometers provide selectivity as to analyte types but they are more complex and expensive. Portable GC/MS can identify chemical compounds in the ppm-ppt range; however, it requires trained operators as well as high equipment cost. Portable GCs coupled with a PID can detect VOCs at sub ppb levels but humidity reduces PID lamp response (Frausto-Vicencio et al. 2021; Soo et al. 2018). Portable GCs with FID detectors can also provide ppb level detection while the hydrogen–oxygen flame requires independent hydrogen and air supplies. Recently, a prototype GC with dual FID was developed by CMS Field Products with the promising features of high sensitivity and fast response. Dual columns, with different characteristics when dedicated to the same atmospheric analysis, enables a GC analyzer to provide very high sensitivity with selectivity for compounds that co-elute. If unknown compounds are present, retention indices of the unknowns can be obtained, which can be used to estimate certain physical properties of the unknown compounds such as boiling point or vapor pressure. The purpose of the present study was to evaluate the performance of the prototype GC/dual FID (protoGC hereafter) by comparing its performance with the conventional GC analytical method (i.e., solvent sampling followed by a laboratory GC analysis) for potential applications in human exposure assessment.

Experimental

Chemicals

In this study, TEX was selected due to their universal presence and all were purchased from Fisher Scientific (Waltham, MA): toluene (≥ 99.5%), ethylbenzene (99.8%), o-xylene (99%), m-xylene (≥ 99%), and p-xylene (99%). For calibration solutions and chemical desorption, carbon disulfide (≥ 99%) was purchased from the same manufacturer as above. All were used without further purification.

Instrumentations and GC calibrations

The protoGC had default dual columns each connected to its individual FID for which the dynamic range was 5,000 and limit of detection for BTEX was 1 ppb in air: column 1 was 4 m of J&W DB-Wax GC column (Agilent, Santa Clare, CA), 0.10 mm ID, and 0.20 µm film thickness; column 2 was 4 m of J&W DB-1701 GC column (Agilent, Santa Clare, CA), 0.10 mm ID, and 0.40 µm film thickness. Hydrogen (Ultra High Purity Grade, Airgas, Radnor, PA) was the carrier gas regulated at a constant flow of 1.5 ml/min. The temperature of the inlet gas sample port was set at 70 °C and the dual FIDs at 200 °C. The internal sampling/desorption trap contained 6.2 mg of Tenax TA 60/80, set at 40 °C for sampling. Three calibration standards of 2.5, 10, and 25 µg/ml were prepared for calibration according to the manufacturer's instructions.

A stock solution for each analyte was prepared by spiking a known amount of each analyte into a known amount of CS_2 and a serial dilution was performed. 1 µl of each calibration standard solution was manually injected into the protoGC inlet using a 5 µl syringe (Microliter Syringe 95 N, Hamilton Company, Reno, NV) and the analysis of each analyte was in triplicate at each concentration level. R^2 obtained were 0.9948, 0.9993, 0.9958, 0.9990, and 0.9992 for toluene, ethylbenzene, o-xylene, m-xylene, and p-xylene, respectively.

For comparison with the traditional method, a laboratory GC/FID (6850, Agilent technologies, Santa Clara, CA) was used. The GC was equipped with a nonpolar standard polysiloxane capillary column 30 m in length, 0.25 µm film thickness, and 0.32 mm ID (J&W HP-1, Agilent technologies, Santa Clara, CA). Helium was the carrier gas. A stock solution of each analyte was prepared for serial dilution to produce a six-point calibration curve (0.5, 1, 2, 4, 8, and 20 µg/ml). An autosampler was used to inject 1 µl of each standard solution and the injection at each level of each analyte was in triplicate. R^2 was 0.9986, 0.9998, 0.9991, 0.9980, and 0.9995 for toluene, ethylbenzene, o-xylene, m-xylene, and p-xylene, respectively.

Experimental setup

Figure 1 shows a diagram of the experimental setup of this study. An 8.5-L aluminum chamber was built for this experiment and a stainless mesh was placed into the inlet side of the chamber for better mixing. On the top of the chamber, there were three chamber monitoring ports (27 mm each in diameter) to allow a hand-held PID analyzer access, and four sampling inlets (6 mm each in diameter) for sorbent tubes sampling as well as the Teflon tubing for protoGC sampling. An air flow of 38.0 L/min generated from an air compressor (SF 2 FF, Atlas Copco, Sweden) was sent to the chamber inlet using a mass flow controller (SmartTrack 100, Sierra, Monterey, CA). Two syringe pumps were connected to the upstream of the chamber inlet: one (55-2222 Harvard Apparatus, Holliston, MA) for water injection to keep a constant humidity level and the other (Fusion 200, Chemyx Inc., Stafford, TX) for solvent injection to generate the target concentrations. The streamline temperature and humidity were maintained at a room temperature (24 ± 1 °C) and humidity (50 ± 5% RH) and monitored throughout the experiments. Four theoretical concentrations of 1.12, 2.24, 4.49, and 8.97 ppm (1x, 2x, 4x, and 8x; x = 1.12 ppm) were selected as target concentrations. A PID analyzer (Baseline VOC-TRAQ II, AMETEK Inc., Berwyn, PA) was used to monitor the concentrations of the challenge atmosphere of the chamber.

Sampling and analytical methods

Each analyte was used as individual challenge and the challenge atmosphere was directly connected to the protoGC sampling port with Teflon tubing connected to the chamber sampling inlet. The protoGC sampling rate was 23 ml/min and analytical parameters were as follows: sampling the for 30 s; solvent purge of sampling trap for 5 s; trap equilibrium for 15 s; trap heating from 40 to 240 °C at 25 °C/s ramping followed by 2.0 s hold; injection from trap onto dual columns for 1.8 s; column

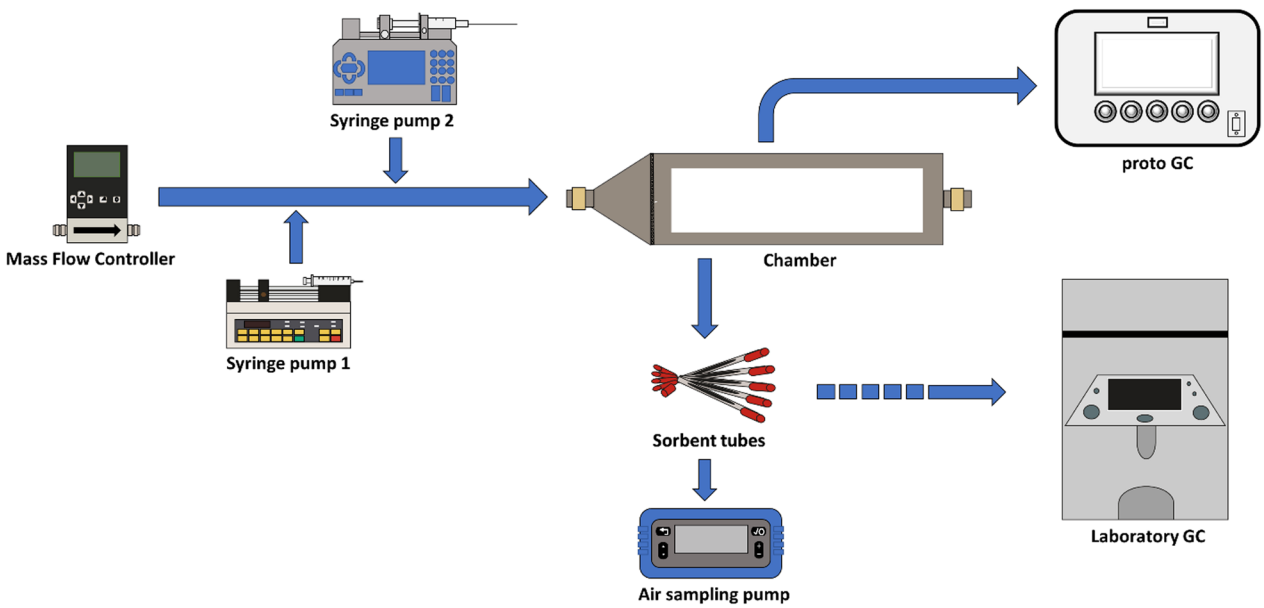

Fig. 1 Diagram of sampling and analysis via protoGC and conventional method

temperature ramping from 30 to 200 °C at 6 °C/s. Three replicate tests were performed at each target concentration, and for each replicate five consecutive measurements were made.

The sampling and analytical conditions for the traditional method were followed according to the NIOSH NMAM 1501 with minor modifications. The challenge atmosphere was sampled with sorbent tubes (Anasorb CSC 226-01, SKC Inc., Eighty Four, PA) at the chamber sampling inlets using a sampling pump (GilAir Plus, Sensidyne, LP, St. Petersburg, FL) at 200 ml/min for 30 min. The pump was calibrated against a primary flow meter (DryCal DC-Lite, Bios International Corporation, New Jersey) before and after each experiment. Three replicate tests were performed at each target concentration, and for each replicate three sorbent tubes (two samples plus one blank sample) were used. For sample preparation, the front and back sections of the charcoal sorbents were placed in separate vials and desorbed with 1 ml of CS_2 for 30 min with occasional agitation. Approximately 1 ml of the sample aliquot was transferred to GC vials and a 1 µl-sample aliquot was injected into GC-FID with an autosampler. The injection port was heated to 250 °C, the column temperature was set at 190 °C isothermal, and the detector at 250 °C.

Data analysis

Pearson correlation coefficients (r) were calculated to examine how well the mean concentrations obtained from protoGC and traditional method were correlated to each other. A two-way ANOVA was performed at each target concentration to examine the effect of method (i.e., protoGC and conventional) and analyte (i.e., toluene, ethylbenzene, and o-, m-, and p-xylene) on mean concentrations to mainly determine whether the mean concentrations were statistically different between methods as well as analytes. SPSS Statistics version 29 (IBM Corp., Armonk, NY) was used, and $p < 0.05$ was considered statistically significant.

Results and discussion

Mean concentrations by method

Table 1 shows the mean concentrations of the five individual analytes including toluene, ethylbenzene, o-xylene, m-xylene, and p-xylene at four theoretical target concentrations (1x, 2x, 4x, and 8x; x = 1.12 ± 0.01 ppm) obtained from protoGC (column 1 and column 2) and conventional method. The relationship between the mean concentrations of the two methods is shown in Fig. 2. Correlation coefficients (r) of protoGC- column 1 and conventional method were 0.999, 0.998, 0.999, 0.996, and

Table 1 Mean concentrations of toluene, ethylbenzene, o-xylene, m-xylene, and p-xylene at theoretical target concentrations of 1x, 2x, 4x, and 8x (x = 1.12 ± 0.01 ppm) by sampling/analytical method

Analyte	Target Concentration		ProtoGC—Column 1		ProtoGC—Column 2		Conventional method	
	Ratio (x)	ppm	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI
Toluene	1	1.12	1.05 ± 0.03	1.03–1.07	1.05 ± 0.03	1.03–1.07	1.05 ± 0.02	1.03–1.07
	2	2.24	2.19 ± 0.04	2.17–2.21	2.20 ± 0.04	2.17–2.22	2.06 ± 0.04	2.02–2.10
	4	4.49	4.57 ± 0.14	4.49–4.65	4.62 ± 0.14	4.54–4.69	4.20 ± 0.17	4.02–4.38
	8	8.97	8.79 ± 0.16	8.70–8.88	8.55 ± 0.13	8.47–8.62	8.84 ± 0.51	8.30–9.38
Ethylbenzene	1	1.12	0.99 ± 0.04	0.97–1.01	0.99 ± 0.04	0.97–1.01	1.06 ± 0.03	1.04–1.09
	2	2.24	2.05 ± 0.08	2.00–2.09	2.05 ± 0.08	2.00–2.09	2.16 ± 0.04	2.11–2.20
	4	4.49	4.24 ± 0.20	4.13–4.35	4.27 ± 0.20	4.16–4.38	4.45 ± 0.10	4.35–4.55
	8	8.97	7.85 ± 0.12	7.79–7.92	7.34 ± 0.12	7.27–7.40	9.21 ± 0.11	9.09–9.32
o-xylene	1	1.12	1.00 ± 0.03	0.99–1.02	0.97 ± 0.06	0.94–1.00	1.05 ± 0.02	1.03–1.07
	2	2.25	2.15 ± 0.09	2.10–2.20	2.04 ± 0.08	1.99–2.09	2.15 ± 0.06	2.08–2.21
	4	4.50	4.13 ± 0.14	4.05–4.21	3.93 ± 0.14	3.85–4.01	4.15 ± 0.09	4.06–4.24
	8	8.98	7.96 ± 0.18	7.86–8.06	7.32 ± 0.15	7.24–7.40	8.57 ± 0.14	8.43–8.72
m-xylene	1	1.12	1.00 ± 0.02	0.98–1.01	1.01 ± 0.02	0.99–1.02	1.21 ± 0.02	1.19–1.23
	2	2.23	2.10 ± 0.16	2.01–2.19	2.19 ± 0.12	2.12–2.25	2.55 ± 0.10	2.45–2.65
	4	4.49	4.39 ± 0.16	4.31–4.48	4.43 ± 0.12	4.36–4.50	5.10 ± 0.04	5.06–5.14
	8	8.97	7.37 ± 0.10	7.32–7.42	6.95 ± 0.08	6.91–6.99	9.89 ± 0.14	9.74–10.04
p-xylene	1	1.12	0.93 ± 0.02	0.92–0.94	0.95 ± 0.02	0.94–0.96	1.13 ± 0.01	1.12–1.15
	2	2.24	1.9 ± 0.03	1.90–1.93	1.96 ± 0.04	1.94–1.98	2.21 ± 0.06	2.14–2.28
	4	4.49	3.95 ± 0.07	3.91–3.99	4.07 ± 0.06	4.04–4.11	4.53 ± 0.08	4.44–4.61
	8	8.97	7.21 ± 0.15	7.12–7.29	6.82 ± 0.15	6.74–6.91	9.43 ± 0.30	9.11–9.75

SD standard deviation, *CI* confidence interval

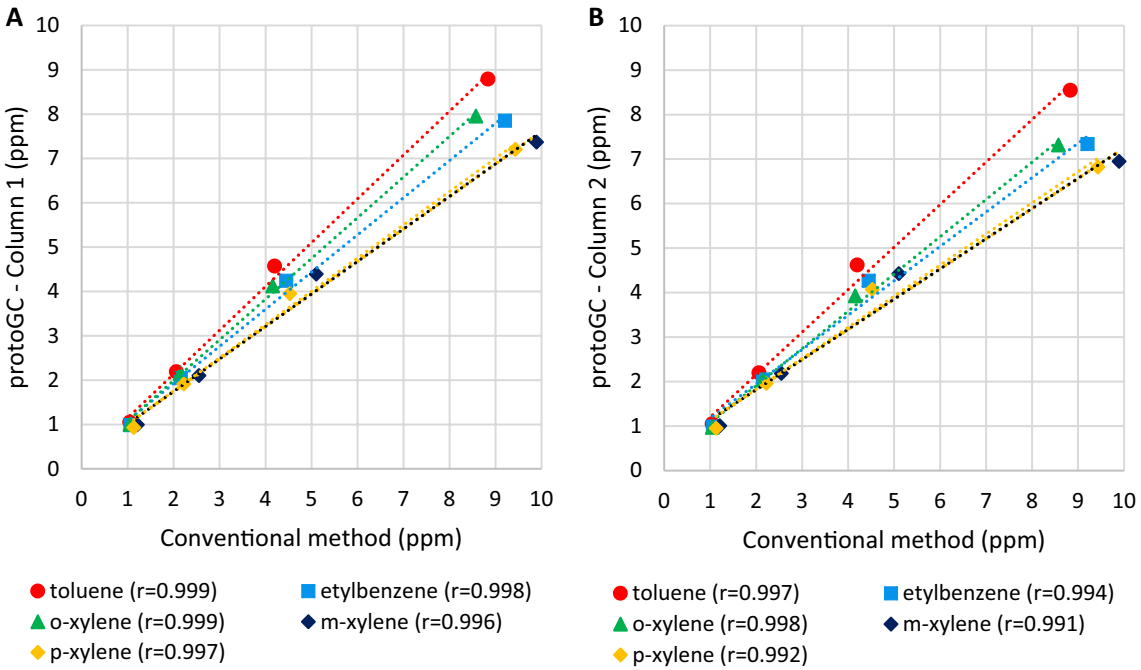

Fig. 2 Correlation of mean concentrations between (**A**) protoGC- Column 1 and conventional GC and (**B**) protoGC- Column 2 and conventional GC by analyte

0.997 for toluene, ethylbenzene, o-xylene, m-xylene, and p-xylene, respectively. r between protoGC- column 2 and conventional method was 0.997, 0.994, 0.998, 0.991, and 0.992 for toluene, ethylbenzene, o-xylene, m-xylene, and p-xylene, respectively. The correlation analysis showed a strong positive association between the two methods for all analytes. Soo et al. examined the performance of a portable GC/PID using seven VOCs under various environmental conditions (25°–35° and 25–75% RH) (Soo et al. 2018). Correlation coefficients between the portable GC/PIDs and traditional sorbent-based method were 0.733, 0.818, 0.994, and 0.851 for toluene, ethylbenzene, o-xylene, and m, p-xylene, respectively, at 0.125 to 10 ppm. All of those analytes showed a correlation coefficient lower than our results, and especially toluene concentrations collected by the portable GC/PIDs became substantially lower as the theoretical target concentration level increased. The sorbent of the portable GC preconcentrator used in the Soo et al.'s study was reported to be a silica gel aerogel and it is known that polar compounds are preferentially adsorbed onto silica gel which may have affected the adsorption of the non-polar toluene compound.

Among the five analytes examined, toluene showed the smallest difference in mean concentrations between protoGC (both columns) and traditional method. In general, mean concentrations of protoGC from both columns were lower than the results from traditional method and the difference was the largest at the highest challenge concentration (i.e., 8x) except for toluene: protoGC- column 1 minus traditional method was − 0.05, − 1.35, − 0.62, − 2.52, and − 2.23 ppm and protoGC- column 2 minus traditional method was − 0.29, − 1.87, − 1.25, − 2.94, and − 2.61 for toluene, ethylbenzene, o-xylene, m-xylene, and p-xylene, respectively. The protoGC is intended to be used for environmental applications where contaminants' concentrations are generally much lower than in occupational settings. The narrow peaks of the protoGC columns (see Additional file 1: Fig. S1) produces high efficiency separations but the narrow GC peaks along with shorter column length lowers overall peak areas, thus reducing sampling capacity. For the applications of the protoGC in occupational exposure assessment, it is desirable to either sample smaller volumes of air before introducing to the inlet of protoGC or use shorted GC injection times. The majority of standard deviations (SDs) were below 0.1 ppm for both methods while the range of the conventional method was larger than protoGC (0.02–0.20 ppm for both columns of protoGC vs. 0.01–0.51 ppm for conventional method). The conventional method involves multiple steps of sampling and analytical process which are prone to random errors as well as systemic errors (Plog 2012). For BTEX, the sampling time of the protoGC which depends on the breakthrough volume of analytes is 5–120 s and the injection time which depends on the capability to trap

analytes on the column head is 0.2–2.5 s. The sampling times as well as injection times are easily adjustable when sampling fairly high ppm levels using the protoGC. Therefore, the protoGC can be used at both ppm and ppb level sensitivity without any instrument modifications by merely changing the sampling and injection times of the instrument.

A two-way ANOVA showed that method and analyte had a statistically significant effect on mean concentrations at all four theoretical target concentration levels regardless of protoGC column type as shown in Table 2. Traditional method had higher mean concentrations than protoGC- columns 1 at all challenge concentration levels: $F(1,95) = 369.27$, $p < 0.001$ at 1x; $F(1,95) = 58.44$, $p < 0.001$ at 2x; $F(1,95) = 59.65$, $p < 0.001$ at 4x; and $F(1,95) = 1095.93$, $p < 0.001$ at 8x. Likewise, traditional method had higher mean concentrations than protoGC- columns 2 at all challenge concentration levels: $F(1,95) = 235.53$, $p < 0.001$ at 1x; $F(1,95) = 72.01$, $p < 0.001$ at 2x; $F(1,95) = 63.23$, $p < 0.001$ at 4x; and $F(1,95) = 2061.78$, $p < 0.001$ at 8x. m-xylene concentration was the highest among the five analytes at 1x, 2x, and 4x while toluene concentration was the highest at 8x for both protoGC columns. There was a significant interaction between method and analyte at all theoretical target concentration levels regardless of column types. At 1x and 8x levels, when challenged with toluene, no significant difference was detected between protoGC- column 1 and traditional method ($p = 0.979$ at 1x and $p = 0.616$ at 8x) while comparison between methods was significantly different for all the other analytes. At 2x and 4x concentration levels, o-xylene was the only analyte which showed no significant difference between protoGC- column 1 and conventional method ($p = 0.897$ at 2x and $p = 0.664$ at 4x). Similarly, no significant difference was found at all target concentration levels except toluene at 1x between protoGC-column 2 and conventional method ($p = 0.959$). Overall, the differences in mean concentrations between methods were small especially at the lower challenge concentrations: 0–0.21 ppm at 1x, 0–0.45 ppm at 2x, 0.02–0.71 ppm at 4x, and 0.05–2.94 ppm at 8x. The statistical analysis using a two-way ANOVA had limitations. There were several outliers which were not excluded in the analysis since they were believed to be true values. Equality of variance assumption did not meet except for 1x level for the protoGC- column 1 and traditional GC test, which may have increased a type I error rate.

The protoGC showed similar results in mean concentrations between column 1 and column 2 at lower atmospheric challenge concentrations for all analytes while the difference was apparent at the highest challenge concentration: column 2 consistently showed lower concentrations than column 1 at 8x. The range of mean concentration difference was from 0.24 to 0.64 ppm for all analytes at 8x, with o-xylene being the largest in difference. The column 1 was the DB-Wax column with a polyethylene glycol (PEG) stationary phase which has high polarity, making it suitable for analyzing polar compounds with similar boiling points (Shende et al. 2003). On the other hand, the column 2 (DB-1701) was a low/mid polarity column with a (14% cyanopropyl-phenyl)-methylpolysiloxane phase, which would be more appropriate for the nonpolar analytes examined in this study. However, as both columns were close to reaching the capacity limit, it is difficult to explain the small but consistent difference at that high concentration.

Table 2 Two-way ANOVA results

Target concentration	Method				Analyte				Method*Analyte			
	SS	*F*	*df*	*p*	*SS*	*F*	*df*	*p*	*SS*	*F*	*df*	*p*
ProtoGC—column 1 and conventional GC												
1x	0.25	369.27	1	< 0.001	0.07	27.15	4	< 0.001	0.16	58.65	4	< 0.001
2x	0.44	58.44	1	< 0.001	0.71	23.52	4	< 0.001	0.91	29.94	4	< 0.001
4x	1.13	59.65	1	< 0.001	3.67	48.43	4	< 0.001	3.21	42.36	4	< 0.001
8x	39.21	1095.93	1	< 0.001	3.49	23.57	4	< 0.001	18.77	126.87	4	< 0.001
ProtoGC—column 2 and conventional GC												
1x	0.25	235.53	1	< 0.001	0.10	23.41	4	< 0.001	0.12	28.77	4	< 0.001
2x	0.41	72.01	1	< 0.001	0.99	43.32	4	< 0.001	0.59	26.00	4	< 0.001
4x	1.06	63.23	1	< 0.001	4.63	68.79	4	< 0.001	2.88	42.75	4	< 0.001
8x	68.86	2061.78	1	< 0.001	5.52	41.35	4	< 0.001	19.46	145.64	4	< 0.001

SS sum of squares, *F* test statistic, *df* degree of freedom

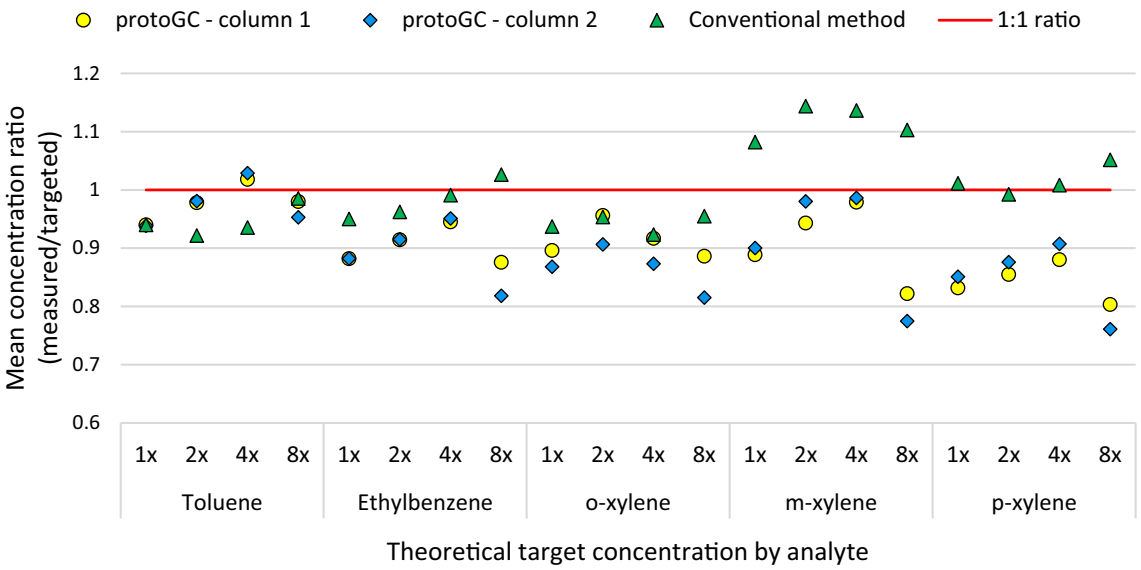

Fig. 3 Mean concentration ratios of measured concentration to target theoretical concentration

Comparison with target theoretical values

The mean concentration ratios of measured values from protoGC and traditional GC method to theoretical target values for each analyte are shown Fig. 3. The protoGC had the concentration ratios below 1 at all concentration levels for all analytes except one case (toluene at 4x) indicating that the protoGC tended to underestimate the challenge atmospheric concentrations. The underestimation was the largest at the highest theoretical target concentration for ethylbenzene, and o-, m-, p-xylene with p-xylene being largest underestimation for both columns, 0.80 for column 1 and 0.76 for column 2. Overloading of the protoGC columns was possibly the major reason for the underestimation at the highest theoretical target concentration. On the other hand, conventional method showed some ratios over 1. The overestimation of the challenge atmosphere was observed in m-xylene and p-xylene at all concentration levels except one case (p-xylene at 2x). Although the recovery rates of the sorbent tubes were not determined in this study, it is not uncommon to observe over 100% recovery rate for TEX (Hazrati et al. 2016; Neyshabur 2017). PID monitoring results verified the challenge atmospheric concentrations, but at the lowest concentration level (1x), the PID readings were deviated from the theoretical concentrations (27% lower on average). There were small variations in theoretical target concentrations generated between the five analytes as noted as 1x, 2x, 4x, and 8x; $x = 1.12 \pm 0.01$ ppm. However, the largest difference between analyte was 0.01 ppm which effect on the results would be negligible.

Conclusion

The prototype portable GC/FID (protoGC) examined in this study showed comparable performance with the conventional method within the experimental conditions, $r = 0.991–0.999$. protoGC, which is intended to be used for environmental applications, tended to underestimate ethylbenzene and xylenes at the highest challenge atmospheric concentration compared to the traditional method primarily due to the overloading of the columns, making it desirable to use shorter sampling volumes in highly concentrated environments. Using lower sampling times and shorter injection times are more appropriate for protoGC when sampling these high levels of VOCs. Although statistical analyses showed significant differences in mean concentrations between protoGC and conventional method, the differences were small especially at lower target concentrations. The shortened sampling/analysis time (i.e., > 5 min for protoGC vs. at least 30 min desorption alone for traditional method) will be the added benefit to protoGC in time critical applications to quickly determine the safety of the environment of interest. The portable GC/FID will need to be further examined at various environmental conditions of temperatures and relative humidities as well as with other compounds to thoroughly evaluate its performance.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40543-023-00404-2.

Additional file 1: **Figure S1**: Individual chromatograms obtained with the prototype GC/dual FID at 2x concentration for (A) toluene, (B) ethylbenzene, (C) o-xylene, (D) m-xylene, and (E) p-xylene and 5-repetition

chromatograms from DB-1701 column at 2x concentration for (F) toluene, (G) ethylbenzene, (H) o-xylene, (I) m-xylene, and (J) p-xylene

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Not applicable.

Author contributions
GK, EBO, JO, JW, and CTL contributed to Conceptualization and Methodology; SY and JO contributed to Investigation and Writing—Original draf; JO and GK contributed to Supervision; JO, GK, CTL, EBO, and JW contributed to Writing—Review & Editing.

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Availability of data and materials
The data that support the findings of this study are available on request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors have no competing interests to declare.

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