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ARTICLE
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A Low-Cost Open-Source Air Sampler for the Sorbent Tube Sampling for TD-GC/MS Analysis

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Abstract : In this study, we provide full descriptions of how to make a low-cost and completely open-source laboratory-made air sampler that will be used for sample adsorption for thermal desorption-gas chromatography mass spectrometry (TD-GC/MS) analysis. It is well known that harmful gases cause bad effects on human bodies, so it is necessary to identify the types and amounts of gases in industrial sites. One of the most commonly used methods for gas sampling is to utilize a sorbent tube using an air sampler. Commercially available air samplers are expensive, typically priced between $1,000 and $2,000, and their design often cannot be modified to fit the experiment. To address these shortcomings, we have developed a do-it-yourself (DIY) air sampler that is not only cheap enough, but also completely open-source. Furthermore, the performance of the fabricated air sampler was validated in conjunction with TD-GC/MS for the analysis of volatile compounds.

Keywords : air sampler, do-it-yourself (DIY), open-source, CNC machining, TD-GC/MS

Introduction

In workplace sites, hazardous chemicals can exist in the form of gas.[1-3] It is a well-known fact that when these substances enter the human body through the respiratory tract, they can cause adverse health problems such as respiratory diseases, irritation of mucous membranes, asthma, paralysis, or even cancer.[4,5] Because industrial workers are often exposed to these environments for an extended period of their time, it is neccassary to monitor their exposure to hazardous chemicals due to health and safety concerns.

One of the most commonly used methods for monitoring of gases or volatile compounds is to collect the gas using a sorbent tube and analyze it using a thermal desorption-gas chromatography mass spectrometry (TD-GC/MS).[6-9] The sorbent tube is a sampling tool filled with packing materials such as silica, charcoal, or microporous polymer (*i.e.* Tenax[TM] series), and can adsorb various chemicals that exist in the gaseous state. The adsorption capacity is often determined by the choice of packing material for the specific gaseous compounds of interest. In TD-GC/MS analysis, chemicals adsorbed within the adsorption tube are thermally desorbed in a form of gas and then gases are separated by gas chromatography. Finally, separated gases are detected using electron-impact ionization mass spectrometry.[10] Using the TD-GC/MS analysis method, it is possible to qualitatively and quantitatively analyze gases.

In order to sample air with a sorbent tube, a device called an air sampler is required. The air sampler houses an air pump to which a sorbent tube is connected. The air pump then draws the air in at a flow rate of 100 mL to 200 mL per min. While air is flowing through the sorbent tube, chemical substances present in the air are adsorbed onto the sorbent packing material.

There are a large number of commercially available air samplers, but come at a high price, *i.e.,* in the range of $1,000 to $2,000. Furthermore, there are often cases where the design or dimension of the commercial air sampler is not appropriate for the designed experiments. There are often situations, in which you can achieve better efficiency by slightly modifying the function of the air sampler depending on the nature of the experiment, but such modifications are hard to make because they are sold as finished products without their design files.

To overcome these issues, we have developed a laboratory-made do-it-yourself (DIY) air sampler. This sampler consists of a diaphragm pump, a battery, and electrical circuits for flow rate control. By adopting the DIY method, every part of the hardware, except for the

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Table 1. Materials and costs.

	Designator	Component	Number	Cost per unit KRW*	Total cost KRW*	Source of materials	Material type
	A1, A3, A6, A7, A8, A9, A10, A12, A13, A14, A15, A17, A18	Acrylic Plate (12 T)	0.3	19,670 (300 mm x 400 mm)	5,901	http://auction.kr/iBKeNQq	Acryl
	A2, A4, A5, A11, A16, A19, A20, A21, A22, A23, A24	Acrylic Plate (3 T)	1.2	4,700 (300 mm x 400 mm)	5,640	http://gmkt.kr/gpdtFT	Acryl
	S1, S2, S3, S4	Silicone Sheet (1 T)	0.08 (60 mm x 60 mm x 2)	1,700 (300 mm x 300 mm)	136	https://www.e-silicone.com	Silicone
	S5	Silicone Sheet (2 T)	0.04 (60 mm x 60 mm x 1)	3,500 (300 mm x 300 mm)	140	https://www.e-silicone.com	Silicone
	SUS Tubing	SUS Tubing (1/4" O.D.)	0.027 (40 mm x 2)	11,920 (3 m)	322	http://gmkt.kr/gBVcotY	SUS
	PTFE Tubing	PTFE Tubing (6 mm I.D. x 8 mm O.D.)	0.008 (40 mm x 2)	29,990 (10 m)	240	https://www.navimro.com/g/194592	PTFE
	Bearing	Bearing (625, 16 mm O.D.)	2	820	820	https://smartstore.naver.com/bearingstore	-
	Rubber Leg Tip	Rubber Leg Tip (M4)	4	1200 (2 ea)	2,400	http://auction.kr/iBO3IB3	Rubber
[Materials] Hardware	-	Wrench Bolt (M3*12 mm)	4	40	160	https://smartstore.naver.com/goodnightmall	SUS
	-	Wrench Bolt (M3*20 mm)	6	50	300	https://smartstore.naver.com/goodnightmall	SUS
	-	Wrench Bolt (M3*25 mm)	2	50	100	https://smartstore.naver.com/goodnightmall	SUS
	-	Wrench Bolt (M3*30 mm)	2	60	120	https://smartstore.naver.com/goodnightmall	SUS
	-	Wrench Bolt (M3*35 mm)	4	60	240	https://smartstore.naver.com/goodnightmall	SUS
	-	Wrench Bolt (M3*50 mm)	2	90	180	https://smartstore.naver.com/goodnightmall	SUS
	-	Wrench Bolt (M5*25 mm)	1	80	80	https://smartstore.naver.com/goodnightmall	SUS
	-	Hex Socket Button Head Cap Screw (M3*15 mm)	5	40	200	https://smartstore.naver.com/goodnightmall	SUS
	-	Hex Socket Button Head Cap Screw (M4*10 mm)	2	40	80	https://smartstore.naver.com/goodnightmall	SUS
	-	Socket Set Screw (M3*5 mm)	1	30	30	https://smartstore.naver.com/goodnightmall	SUS

Table 1. Continued.

	Designator	Component	Number	Cost per unit KRW*	Total cost KRW*	Source of materials	Material type
[Materials] Electrical Wiring	Motor	Motor (MB4266-2451)	1	22,000	22,000	https://www.motorbank.kr	-
	-	Motor Driver (DMC-22)	1	9,900	9,900	https://www.motorbank.kr	-
	-	12 V Battery Pack (DMBP-LF128-4S1P-B8)	1	36,000	36,000	http://devicemall.co.kr	LiFePO4
	-	Power Adapter (DC 12 V, 2 A)	1	4,500	4,500	http://auction.kr/iBmnAPc	-
	-	Fast Recovery Diode (FR307)	1	900	900	https://www.mcuboard.com (P.N. 3021)	-
	-	Toggle Switch	1	600	600	https://www.mcuboard.com(P.N. 30735)	-
	-	DC Jack Plug (2.1 mm I.D. x 5.5 mm O.D.)	1	430	430	https://www.mcuboard.com (P.N. 4581)	-
	-	DC Jack Cable (2.1 mm I.D. x 5.5 mm O.D.)	1	1,200	1,200	https://www.mcuboard.com (P.N. 1078078)	-
	-	Female Crimp Terminal	2	100	200	http://samdimall.com	-
	-	Wire (18 AWG, Red)	0.025 (50 cm)	9,900 (20 m)	248	https://www.mcuboard.com (P.N. 1378219)	-
	-	Wire (18 AWG, Black)	0.025 (50 cm)	9,900 (20 m)	248	https://www.mcuboard.com(P.N. 1378218)	-
	-	Shrink Tube (8 mm I.D.)	0.1 (10 cm)	370 (1 m)	37	https://smartstore.naver.com/artbeads	-
	-	Shrink Tube (10 mm I.D.)	0.1 (10 cm)	520 (1 m)	52	https://smartstore.naver.com/artbeads	-
[Tools]	-	Drill Bit (2.6 mm)	1	3,900 (10 ea)	390	Official domestic sales department (YG-1, Korea)	HSS
	-	Drill Bit (3.3 mm)	1	5,300(10 ea)	391	Official domestic sales department (YG-1, Korea)	HSS
	-	Tapping Bit (M3)	1	2,500	2,500	Official domestic sales department (YG-1, Korea)	HSS
	-	Tapping Bit (M4)	1	3,200	3,200	Official domestic sales department (YG-1, Korea)	HSS
	-	Tapping Bit (M5)	1	3,300	3,300	Official domestic sales department (YG-1, Korea)	HSS
	-	Electrical Drill (GSB 18-2-LI, BOSCH, Germany)	1	161,500	161,500	http://www.compuzone.co.kr (P.N. 688062)	-
	-	End Mill (2 mm, E5E8802012)	1	15,000	15,000	Official domestic sales department (YG-1, Korea)	-

Table 1. Continued.

	Designator	Component	Number	Cost per unit KRW*	Total cost KRW*	Source of materials	Material type
[Tools]	-	Hollow Punch (3 mm)	1	990	990	https://smartstore.naver.com/sanupmall	Iron
	-	Hammer	1	3,310	3,310	https://www.navimro.com/g/53104	Iron
	-	Multi Driver Set	1	2,950	2,950	http://gmkt.kr/gBslcBY	-
	-	Table Bice	1	3,900	3,900	http://www.imarket.co.kr (P.N. 1039001773)	-
	-	Cutter Knife	1	800	800	Office supply store (Offline)	-
	-	Ruler (15 cm)	1	500	500	Office supply store (Offline)	-
	-	Tube Cutter (For SUS 1/4" Tubing)	1	4,710	4,710	http://gmkt.kr/gBtw2wg	-
	-	Wire Stripper	1	1,950	1,950	http://www.11st.co.kr/products/2116991354	-
	-	Instant Glue	1	800	800	Office supply store (Offline)	-
	-	Soldering Iron	1	4,570	4,570	http://www.11st.co.kr (P.N. 1939615601)	-
	-	Tweezers	1	1,570	1,570	http://www.ysmall.kr (P.N. 8808482911218)	-
	-	Hand Press for Terminal	1	18,000	18,000	https://smartstore.naver.com/danja	-

* KRW (WON) is official currency of South Korea.

** The exchange rate between the KRW and the USD is 1 USD = 1,092 KRW at December 16th 2020.

*** Items that are sold in bulk but only need one or a few are marked with decimal quantities.

motor and the battery, are fabricated in the laboratory, which can reduce the cost of an air sampler to 93,400 KRW (about $86).[12] In the following, all the information regarding materials, costs, design files, and instructions necessary to build an air sampler in one's own laboratory will be provided, particularly in the Supplementary Materials section.

Experimental

Materials and costs

All the materials and costs used to make an air sampler are summarized in Table 1.

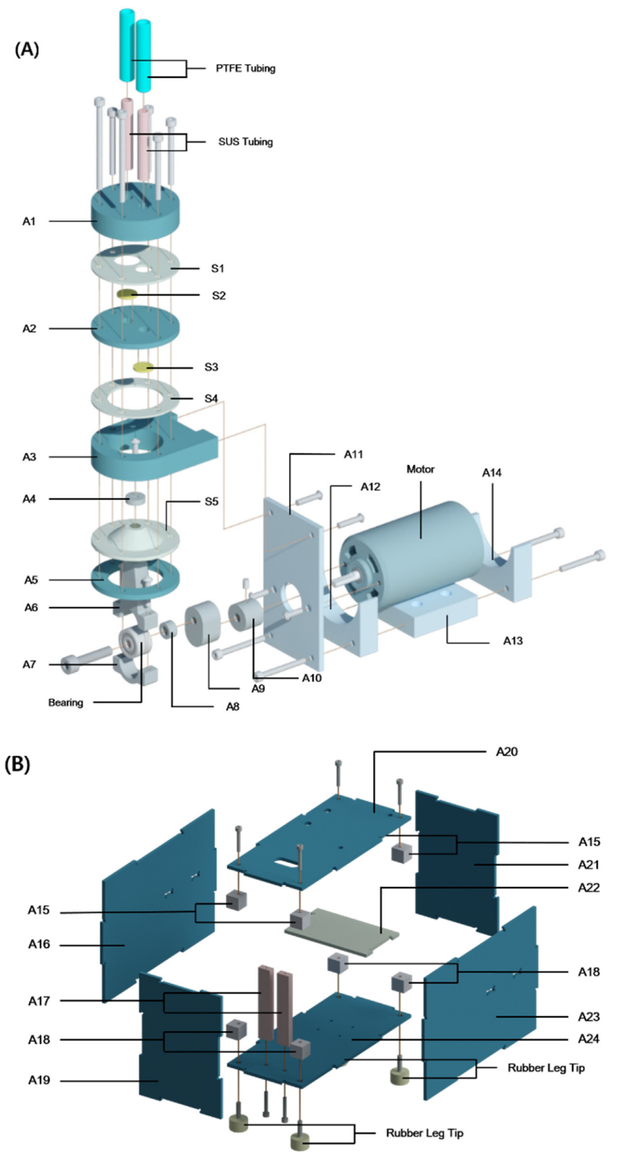

Figure 1. Designs of the air sampler composed of (A) a diaphragm pump and (B) a hardware case.

Hardware design

Computer modeling software AutoCAD 2016 (Autodesk, USA) was used to design an air sampler. The design blueprint was saved in the DXF file format for the subsequent CNC machining. The DXF file for the diaphragm pump and the hardware case can be accessed in Files S1 and S2 in Supplemenatry Materials.

CNC machining and post-processing

For the fabrication of hardware parts, an entry-level computer numerical control (CNC) machine was used. In particular, the parts marked with alphabet A in Figures 1A and 1B were fabricated using a CNC machine (MR-C3040, MR. Machine, Korea). For CNC machining, a TXT file containing coordinates and machining parameters is required, so the DXF drawing file was converted to TXT file using software Aspire 3.0 (Vectric, UK). CNC machining was done using software Mach 3 (Artsoft, USA). A 2 mm end mill (E5E8802012, YG-1, Korea) was used with a spindle speed of 30,000 rpm at a feed rate of 200 mm/min, and several acrylic plates with a thickness of 3 T or 12 T was processed.

Following the completion of CNC machining, post-processing was carried out using an electrical drill (GSB 18-2-LI, BOSCH, Germany), which involved drilling a hole where it is difficult to process with a CNC machine or tapping. All the 2.6 mm/3.3 mm diameter drill bits and M3/M4/M5 tapping bits were purchased from YG-1 (Korea). To make this easier, several acrylic guide tools have been fabricated using the remaining pieces. The design file of the guide tools are accessible in File S3 (Supplementary Materials), and the instruction for the CNC machining, and the post-processing are accessible in File S4 (Supplementary Materials).

Hardware assembly and electrcial wriring

After the parts were manufactured, they were assembled to make the finished hardware. A DC motor (MB4266-2451, Motor Bank, Korea) was used to make a diaphragm pump. Electrical wiring was made as shown in Figure 2, which includes the connections to the power-supply, on-off control, and the flow rate control of the diaphragm pump. A 12 V DC battery pack (DMBP-LF128-4S1P-B8, Powercraft, Korea) was used for power-supply, and a motor driver (DMC-22, Motor Bank, Korea) was used to control the pump speed. The instructions for the hardware assembly and wiring are also available in File S5 (Supplementary Materials).

Flow rate calibration

The calibration for the flow rate of the air sampler was made using a DIY bubble flow meter consisting of a 50 mL mass cylinder as shown in Figure 3. The connection between the sorbent tube and the stainless steel (SUS) tubing of the air sampler was made using a PTFE tubing with 6 mm I.D. The sorbent tube was positioned so that the outside air could pass through the inner packing materials and into the inlet port located on the right side of the air sampler. The design of the acrylic parts of the bubble flow meter and instructions for the fabrication of the DIY bubble flow meter are also available in Files S6, and S7 (Supplementary Materials), respectively, and the flow rate calibration and the operating guides of the air sampler are available in File S8 (Supplementary Materials).

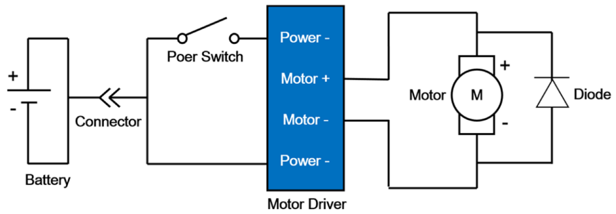

Figure 2. Wiring diagram of circuits.

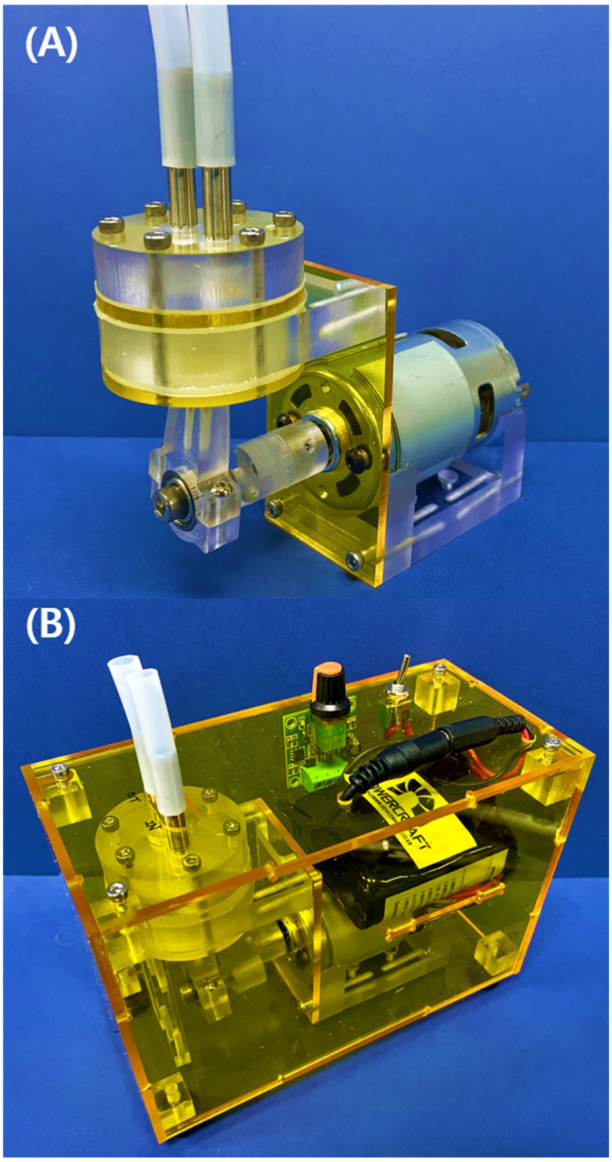

Figure 3. Experiment setup diagrams for flow rate calibration.

Performance validation

The performance of the fabricated air sampler was validated in conjuction with TD-GC/MS for the analysis of the BTEX (benzene, toluene, ethylbenzene, and o-xylene) sample. Experimental setup, parameters for analysis, and results are accessible in File S9 (Supplementary Materials).

Rseults and Discussion

Hardware design

The air sampler consists of a diaphragm pump, battery, and an electric controlling circuit. The pictures of the diaphragm pump and the hardware case are shown in Figures 4A and 4B, respectively.

Figure 5 shows the configuration of silicone membrane valves that act as check valves for the air-flow control in the diaphragm pump. Only the sides of thin silicone membranes S2 and S3 close to the central part of A2 are attached to A2 and thus cannot move. On the other hand, the far sides of the membranes were designed to freely move up and down in response to the air flow (see Figure 5A). As pictorially described in Figure 5B, when the air flows from the top to the bottom, the air flow presses down the membrane and the movable part goes down. Thus, S2 membrane sticks to the flat floor of A2 and blocks the hole, while S3 goes down to open the hole. Conversely, when air flows from the bottom to the top, the membrane experiences the pressure from the bottom to the top. Thus, the left hole becomes open and the right hole becomes closed. Through this mechanism, A2 and thin silicone membranes act as check valves.

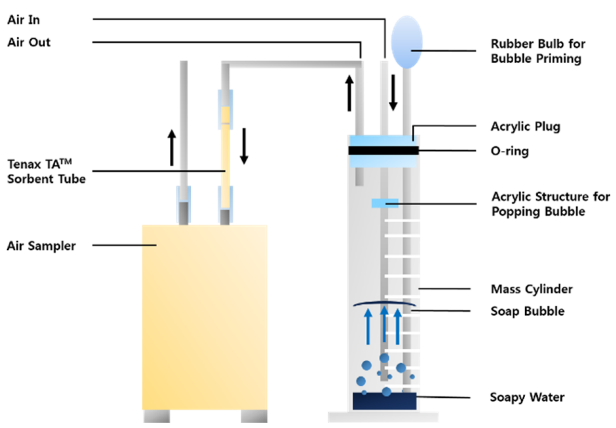

Figure 4. The pictures of the assembled (A) diaphragm pump and (B) the air sampler.

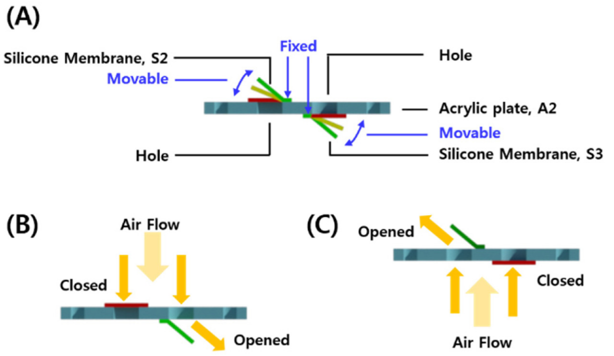

Figure 5. The configuration of the silicone membrane valves. (A) Cross-sectional view of the membrane valves consisting of A2, S2, and S3; (B) valve position when air flows from the top to the bottom and (C) from the bottom to the top.

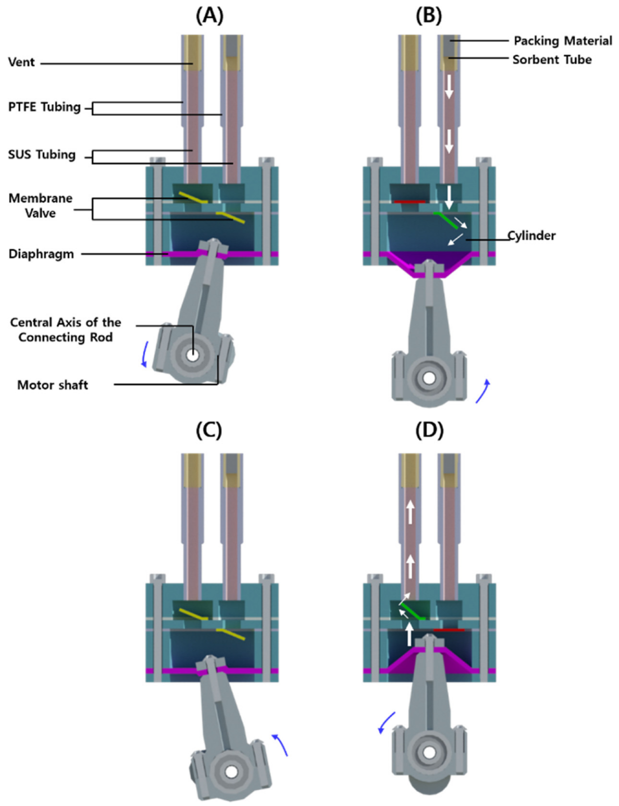

Figure 6. The cross-sectional view during the operation of the diaphragm pump. The pump moves continuously in the order of (A), (B), (C), and (D), repeatedly.

The principle of the diaphragm pump fabricated in this study is illustrated in Figure 6, which shows the cross-sectional views at the moments of its operations.[13-15] The central axis of the connecting rod fastened to the diaphragm forms an eccentric circle at a distance of 7.5 mm from the motor shaft. As sa result, when the motor rotates, the central axis of the connecting rod performs a vertical linear reciprocating motion up and down, and the diaphragm also moves up and down. Using a PTFE tubing, a sorbent tube is connected to the right SUS tubing and a vent line is connected to the left SUS tubing. As can be seen in Figures 6A and 6B, when the diaphragm moves down, the inner volume of the diaphragm pump increases with the concomitant drop of the inner pressure. The lowered pressure within the diaphragm pump draws the air in from the outside to the inside of the diaphragm pump. At this moment, the right membrane valve S3 becomes open, while the left memberane valve S2 remains closed. While the air is being drawn from the outside to the inside of the diaphragm pump, the air should pass through the sorbent tube in which sorbent materials are packed. During this process, chemicals in the air are adsorbed to the packing material of the sorbent tube. Conversely, when the diaphragm moves up (see Figures 6C and 6D), the left membrane valve S2 opens and the right membrane valve S3 becomes closed, allowing air within the diaphragm pump to discharge through the vent line. The pumping cycle repeats.

Hardware production

For the hardware production, 3 T and 12 T acrylic plates were processed with a CNC machine to produce the necessary parts. After the machining, we did some manual post-processing, because the CNC in our lab was not able to complete 3D machining and tapping like most entry-level CNCs. To make this easier, several acrylic guide tools were used for post-processing.

After all the processing, the hardware parts were assembled together. Since our equipment needs power-supply, we installed a battery in the hardware. Furthermore, several circuits were configured for the on-off control and the flow rate control of the pump. At this time, the pump speed was controlled through voltage control using a motor driver.

Flow rate calibration

To sample gas most effectively using a sorbent tube, the flow rate of the air through the tube should be adjusted between 100 mL to 200 mL per min. A back-pressure of about 1-3 bar is exerted due to the fine packing material within the sorbent tube. Since the flow rate changes sensitively in response to the exerted pressure, it is necessary to calibrate the flow rate when the the tube is packed with packing material. Figure 3 shows the whole set up for the control of the flow rate. The flow rate was measured using a DIY bubble flow meter consisting of a mass cylinder. First, 5 mL of soapy water was placed in the mass cylinder, and then the pump was turned on. Next, the rubber bulb was pressed to initially prime a bubble at the bottom of the tubing. When the air is drawn in by the air sampler, the air makes the soap bubble swell. By measuring the volume of the bubble while the air sampler is on, the flow rate can be determined. The air sampler was designed in a way that the voltage applied to the pump can adjust the speed of the motor speed, and thus the flow rate of the air sampler up to 200 mL per min.

Performance validation

To verify whether the air sampler can sample the gas well, a mixture of BTEX chemicals were sampled using a Tenax TA^{TM} sorbent tube. The fours chemicals were clearly separated and detected in the obtained GC-MS chromatogram; the chromatogram is available in File S9 (Supplementary Materials).

Conclusions

In this study, we have developed a low-cost DIY air sampler. Most of the parts were fabricated with inexpensive materials and can be manufactured readily using CNC machining. The operating performance of the manufactured air sampler was evaluated using TD-GC/MS analysis for a BTEX mixture, and it turned out to be successful. Moreover, all the information needed for the fabrication, including design files, are open to the public.

Acknowledgments

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Supplementary materials

All supporting information required for fabrication of the air sampler are available at https://drive.google.com/file/d/1IAVn7KIi3UnUiapaPOPU3TQQESiLqbaL/view?usp=sharing.

References

1. Duan, W.; Chen, G.; Ye, Q.; Chen, Q. *J. Hazard. Mater.* **2011**, 186, 1489, DOI: 10.1016/j.jhazmat.2010.12.029.
2. Santella, N.; Steinberg, L.J.; Sengul, H. *Risk Anal.* **2010**, 30, 635, 10.1111/j.1539-6924.2010.01390.x.
3. Jung, S.; Woo, J.; Kang, C. *Saf. Sci.* **2020,** 124, 104580, DOI: 10.1016/j.ssci.2019.104580.
4. Misra, V.; Pandey, S. D. *Environ. Int.* **2005**, 31, 417, 10.1016/j.envint.2004.08.005.
5. Wang, B.; Wu, C.; Reniers, G.; Huang, L.; Kang, L.; Zhang, L. *Sci. Total Environ.* **2018**, 643, 1, DOI: 10.1016/j.scitotenv.2018.06.174.
6. Woolfenden, E. *J. Air Waste Manag. Assoc.* **1997**, 47, 20, DOI: 10.1080/10473289.1997.10464411.
7. Kim, K. H.; Kim, Y. H.; Brown, R. J. C. *Anal. Bioanal. Chem.* **2013**, 405, 8397, DOI: 10.1007/s00216-013-7263-9.
8. Kim, K. H.; Lee, M. H.; Szulejko, J. E. *Anal. Chim. Acta.* **2014**, 835, 46, DOI: 10.1016/j.aca.2014.05.042.
9. Peng, C. Y.; Batterman, S. *J. Environ. Monit.* **2000**, 2, 313, DOI: 10.1039/B003385P.
10. Son, M.; Yang, J.; Cho, S.; Lee, J.; Oh, H. B. *Bull. Korean Chem. Soc*. **2018**, 39, 1368, DOI: 10.1002/bkcs.11607.
11. Cha, E.; Jeong, E. S.; Han, S. B.; Cha, S.; Son, J.; Kim, S.; Oh, H. B.; Lee, J. *Anal. Chem.* **2018**, 90, 4203, DOI: 10.1021/acs.analchem.8b00401.
12. Lee, J. U.; Oh, H. B. *Anal. Sci. Technol.* **2017**, 30, 167, DOI: 10.5806/AST.2017.30.4.167.
13. Cabuz, C.; Herb, W. R.; Cabuz, E. I.; Son, T. L. *IEEE International Conference on Micro Electro Mechanical Systems (MEMS)* **2001**, 519.
14. Wang, J.; Liu, Y.; Shen, Y.; Chen, S.; Yang, Z. *Micromachines* **2016**, 7, 219, DOI: 10.3390/mi7120219.
15. Yang, X.; Grosjean, C.; Tai, Y. C.; Ho, C. M. *Sens. Actuators A Phys*. **1998**, 64, 101, DOI: 10.1016/S0924-4247(97)01660-9.

