Environmental Research 197 (2021) 111149

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Semi-outdoor filterless air purifier for smog and microbial protection with water purifier system

Arnon Jumlongkul, LL.B., LL.M., M.D., Dip.

School of Medicine, Mae Fah Luang University, Chiang Rai, 57100, Thailand

ARTICLE INFO

Keywords:
COVID-19
Filterless air purifier
Particulate matter
Smog

ABSTRACT

Purpose: Air pollution and COVID-19 problems are being increasingly scrutinized. This article discusses the optimum design of an indoor and semi-outdoor air purifier, using a water-based filtration system.

Methods: An air purifier was fabricated, then comparison of purifying efficacy of the system between untreated air and using an air pump was done. Incense smoke was generated within a room for 10 seconds. The number of particle sizes of PM0.3, PM0.5, PM1.0, PM3.0, PM5.0, and PM10 μm (particle/ m3) as well as the detection of mass concentration of PM1.0, PM2.5, PM5.0, and PM10 (mg/m3) at 0 and 5 min were recorded. Each experiment was repeated 10 times.

Results: Particles in untreated air, except PM10, showed the maximum increase rate of the number of particle sizes greater than the air pump experiment. The highest differentiation between two methods was that PM1.0 and PM0.5 of untreated air increased to 113.647 and 61.539 % whereas the air pump method showed 4.720 and 2.533 %, respectively. The PM mass concentration of untreated air increased from 50.217 to 51.167 % while the increased rate of PM using an air pump was 2.784 to 2.902 %.

Conclusion: This study proposed a water-based air filtration technique, which can reduce the level of particulate matter, and also is a low-cost prototype. For the next experiment, the study should extend test length, clarify an optimum ratio of disinfectant technologies, connect with the internet of things, compare the efficiency with a HEPA filter air purifier, and then also measure some particles which are smaller than 0.2 μm.

1. Introduction

As a result of the global pandemic of coronavirus disease-2019 (COVID-19 or SARS-CoV-2) situation, scientists around the world are discovering ways to control infectious spreading. Many policies have been proposed by each country to protect us from this virus. COVID-19 mainly spreads in 2 ways. Firstly, from person-to-person, especially in close contact, measured as being within about 6 feet, and also respiratory droplets via coughing or sneezing. These viruses will enter the recipient's lung via the patient's mouth or nose. Secondly, the virus may spread from surfaces or objects exposed to COVID-19. Later, when uninfected people touch an infected material and then bring their hand to their mouth, nose, or maybe their eyes, viral transmission may occur (Centers for Disease Contr, 2019).

Some reports have revealed that the appearance of this viral particle is a round or oval shape, measuring 60–100 nm in diameter. SARS-CoV-2 was more stable on plastic and stainless steel than on copper and cardboard whereas viable virus could be detected up to 72 h after application to these surfaces. The longest viability of SARS-CoV and SARS-CoV-2 was on stainless steel and plastic (Jin et al., 2020; van Doremalen et al., 2020). Even though we know the main infectious routes of COVID-19, the specific transmission of aerosol sizes, measuring 0.1–10 μm in diameter, has remained unclear (Konda et al., 2020).

Like the SARS-CoV-2, air pollution is one of the world's largest environmental health hazards, which correlates closely with dust exposure and respiratory as well as cardiovascular diseases, and has been related to acute psychological and neurological morbidity. One of the main components of air pollution is particulate matter (PM), which includes various types of tiny particles, for example, organic carbon, elemental carbon, sulfate, nitrate, iron, nickel, vanadium, etc. These are derived from many sources, such as soil and road dust, fuel combustion, biomass, and forest fires (Yang et al., 2018). In recent years, air pollution in the Asia-Pacific Region has shown the highest PM2.5 concentrations level in the world. The impact of this situation has resulted in an elevation of mortality rates, adult lung health (e.g. asthma, COPD, lower respiratory tract infections), and children's lung health (e.g. low birth

---

Thai Board of Forensic Medicine, Arnon Jumlongkul created this article solely.

E-mail addresses: arnon.jum@mfu.ac.th, arnonjumlongkul@gmail.com.

https://doi.org/10.1016/j.envres.2021.111149
Received 4 January 2021; Received in revised form 15 March 2021; Accepted 6 April 2021

weight, chronic respiratory symptoms, asthma, lower respiratory tract infections) (North et al., 2019). In Southeast Asia, people have been suffering from the incidence of seasonal vegetative fires, also called "slash-and-burn" farming methods, which entails burning trees and plants on the farms because these are the traditional low-cost procedures to create nutrient ash and eradicate weeds (Cheong et al., 2019). Over the past decade Thailand, especially Chiang Mai, the second largest province of Thailand, has faced this haze problem, particularly in the summer season from February to May (Pardthaisong et al., 2018).

Most developed countries have focused on how to improve indoor air quality by the use of high level air filtration technologies, for example, electrostatic capture mechanisms, a combination of static charge and air filtration materials, and also the development of air filtration materials (e.g. glass fiber, High-efficiency Particulate Air (HEPA) filters, activated carbon fiber (ACF), Ultra Low Penetration Air (ULPA) filter, nano-titanium dioxide) (Liu et al., 2017). To reduce the risk of COVID-19 aerosol spreading, the efficiencies of HEPA filter are more effective than 95% for aerosols, measuring 0.25–1.0 μm in diameter, and almost 100% for those larger than 2.5 μm whereas the peak concentration of COVID-19 aerosols appears in 2 ranges, firstly, 0.25–1.0 μm, and then larger than 2.5 μm, respectively (Zhao et al., 2020). However, the huge demand for HEPA filters during a pandemic situation, as well as an ongoing air pollution disaster, has resulted in high-priced filters. Low and middle-income countries have some limitations according to budgetary resources, technology levels and also time limits. To build the infrastructure to fabricate HEPA filters within a short period of time or import recent technology is difficult and shipping from the manufacturing countries, over large distances is a major problem. According to cost-effectiveness analysis, HEPA filters are not suitable for semi-outdoor environments. A recent hybrid material, namely "SUStaiNable materials Synthesized from by-Products and Alginates for Clean air and better Environment" (SUNSPACE), has been suggested for PM entrapment. SUNSPACE is realized by using by-products (such as silica fume), low-cost materials (such as sodium bicarbonate) and low temperature thermal process. The capability of SUNSPACE was that it could collect ultrafine PM until to about 0.04 mm in depth from the sample space of the images of the Transmission electron microscope (TEM) as well as Scanning electron microscope (SEM) (Zanoletti et al., 2018). Just like the HEPA filter technique, it seems to be far away from local technology among developing countries.

Nowadays, almost all air purifiers have been used for an indoor, but also the air purifier, which is created for semi-outdoor, for example, the acute respiratory infection (ARI) clinic, airport terminals, railway station, or even the large closed room, has not been identified as the best prototype against COVID-19 and also haze pollution. As mentioned above, the objective of this article was to focus on an optimum design of an indoor and semi-outdoor air purifier for smog and microbial protection, using an easy water filtration technique, which could provide a cost-effective and low-cost fabrication solution without investment in a higher technology level.

2. Methods

The implementation of this study was divided into 2 sections. Firstly, the design and fabrication of this invention. Secondly, the comparison of purifying efficacy between untreated environmental condition and this air purification design.

2.1. Mechanical design and disinfection technique

The idea of this machine was generated from the use of waterpipe tobacco smoking, also called the "water filtration technique". Waterpipe smokers have believed that waterpipes contained lower toxin levels than cigarettes. However, a study revealed the waterpipe method produced more smoke and CO than cigarette smoking (Eissenberg and Shihadeh, 2009). Moreover, according to indoor experiments, waterpipe tobacco can increase the concentrations of indoor air PM1.0, PM2.5, PM10, and nicotine (Naddafi et al., 2019; Feliu et al., 2020). Nevertheless, the water filtration stage successfully decreased exposure to heavy metals to around 3% of the total metal. Therefore, the traditional water bubbling stage has functioned incompletely (Al-Kazwini et al., 2015). From the author's observation, one technique, which could increase the efficacy of the waterpipe system, is to promote the solubility of liquid and gas using a physical technique. During a water-based air filtration, any bubbles must enter the water, then, travel to the surface of the water. In this process, if the bubbles are too large, they can transport toxic gases back into the environment. To prevent this phenomenon, this machine was designed to push polluted air through a high-pressure electric turbo air blower 240 V 50 Hz 120 W 6 kPa, which releases air at an output of 190 L/min. After that, to increase the opportunity of mixing of the water-air mixture, as well as diminish the varying sizes of the air bubbles, the end of the air pipe was amalgamated with an aquarium bubble diffuser. A chemical PE tank, storing up to 50 L, was chosen as a water supply. Any particulate matter and microorganisms will float to the surface of the water, then be collected in a 0.5-mm capturing polyurethane sponge (L × W × H = 0.5 m × 0.5 m × 0.02 m = 0.005 m^3), density 12±2 kg/m^3, elongation ≥ 60%, tensile strength ≥ 0.4 kg/cm^2, so that only fresh air will return to the environment. The final water product will be treated by a 0.5-μm capturing ceramic water filter, which used for a pipe measuring 0.635 cm in diameter, before return to the water resource. After saturation with PM, the sponge can be regenerated by rinsing water with household cleaners whereas the disposing of water filter, after it shows the drop of water pressure, should be recommended. The working method of a novel air purifier is shown in Fig. 1 and the machinery prototype, measuring 84 cm in width, 55 cm in length, and 67 cm in height, is shown in Fig. 2.

2.2. Data collection and analysis

Ten incense sticks, measuring approximately 2.5 mm in diameter, were selected to generate smoke within a closed laboratory room, measuring 126.36 m^3, for 10 s. This was set as the control experiment, then, the amount of air pollution at 0 and 5 min was recorded. This room, which is larger than an ordinary living room, was included in this study for creating the semi-outdoor mimic condition. The average percentage differences were calculated 10 times and recorded for each experiment. Before starting the next experiment, fresh air was ventilated into the testing room for 1 min. The results were then recorded using the air pump. A 30 L water within a 50 L tank was used for each experimental set. After that, the same experiments were done as the previous experiments, but the air purifier had been operated during each test. This was set as the treatment group.

As part of measuring tools, any haze was detected using two instruments. According to the size of viruses, the researcher should ideally use any instruments that can identify particles, which are smaller than 0.1 μm. However, our laboratories have lacked high-precision devices and also we cannot provide those machines from another academic institute due to the COVID-19 situation being. Therefore, the TSI AeroTrak® Portable Particle Counter Model 9310, flow rate 1.0 CFM (28.3 LPM), ±5% accuracy, for cleanroom certification, was used for calculating the number of particle sizes of 0.3, 0.5, 1.0, 3.0, 5.0, and 10 μm (particle/m^3), respectively. Another device, the DustTrak® DRX – Model 8533 Aerosol Monitor, was used for mass concentration detection of PM1.0, PM2.5, PM5.0, and PM10 (mg/m^3). The air purifier located at the center of the room. Both the particle counter and aerosol monitor were placed on the same table which was 0.8 m high, at a distance of 2.0 m away from the outlet of the air purifier. Incense smoke was generated at a distance of 5.0 and 7.0 m away from the air purifier and those two particle counters, respectively. Then the differences in 5 and 0 min of each parameter of the number of particle sizes as well as the number of mass concentration were analyzed. The results were interpreted in mean ± SD.

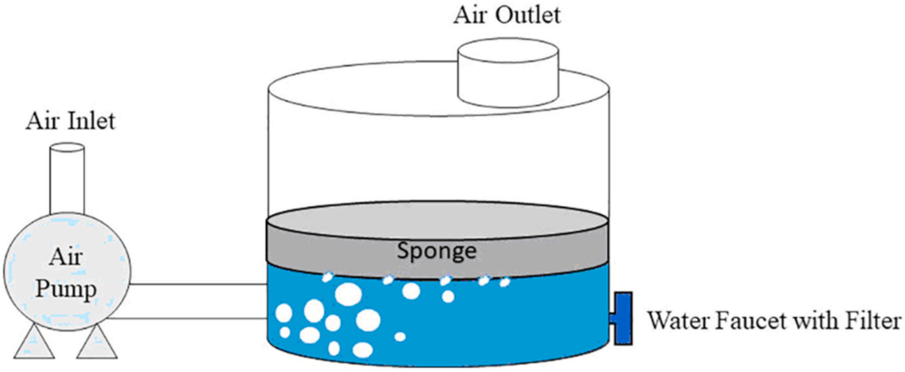

Fig. 1. Working method of semi-outdoor filterless air purifier.

Fig. 2. Machinery prototype of semi-outdoor filterless air purifier.

3. Results

After 20 experiments, including 10 experiments for the control test as well as 10 experiments for the treatment group, in which each test was recorded at 0 and 5 min, the experimental results of particulate size concentration without air treatment and air pump treatment are shown in Table 1. After 5 min, all experiments showed an increase in the average percentage difference of the number of PM. The control experiment, except for PM10, showed an increased rate of air pollution greater than the air pump experiment. After 5 min PM1.0 and PM0.5 increased greatly to 113.647 and 61.539 %, respectively.

As part of the PM mass calculation in Table 2, air pollution from the untreated air method had strikingly increased to between 50.217 and 51.167 % for all parameters while the increased rate of PM using an air pump was only 2.784–2.902 %, respectively. Just like the number of particle sizes, after 5 min no trial revealed the decrease in the average percentage difference of PM mass concentration.

4. Discussion

According to the overall laboratory results, the air pump technique showed higher efficacy in reducing any sizes of particulate matter within 5 min than the control experiment. However, some details may influence the experiments should be considered. The study of air-purifying efficacy over a longer period, such as 30 min or more should be done. Some limitations of this research also included, firstly, the lack of a measuring tool that can detect air particles, which are smaller than 0.1 μm. Then the author cannot declare that this machine can trap SARS-CoV-2 absolutely. Secondly, nowadays scientists around the world have tried to identify the COVID-19 virus in the air, but also there is no appropriate technique which is capable of detecting this virus directly. Fortunately, some reports have revealed that not all droplets carry viruses but the

Table 1

The average results of percentage difference of the number of PM concentration (particle/m^3) among untreated air (control) and air treatment using an air pump when compared between 0 and 5 min.

Air pollutant diameter (μm)	Percentage difference of the number of PM (particle/m^3)							
	Control				Air pump			
	Mean	Min	Max	SD	Mean	Min	Max	SD
0.3	+12.623	−4.503	+31.546	±12.226	+0.458	−2.842	+7.686	±3.230
0.5	+61.539	−29.006	+192.471	±68.201	+2.533	−12.322	+38.964	±14.780
1.0	+113.647	−50.142	+421.682	±133.858	+4.720	−21.637	+56.200	±22.163
3.0	+19.151	−21.860	+88.520	±35.764	+9.246	−47.363	+205.550	±70.238
5.0	+25.847	−38.579	+210.769	±74.474	+19.449	−59.964	+348.333	±116.653
10	+9.444	−41.935	+90.000	±43.976	+28.564	−62.500	+287.273	±99.019

Table 2
The average results of percentage difference of PM mass concentration (mg/m^3) among untreated air (control) and air treatment using an air pump when compared between 0 and 5 min.

Air pollutant diameter	Percentage difference of PM mass concentration (mg/m^3)							
	Control				Air pump			
	Mean	Min	Max	SD	Mean	Min	Max	SD
PM1.0	+51.098	−16.589	+261.006	±82.140	+2.784	−12.209	+37.500	±13.196
PM2.5	+51.167	−16.589	+261.006	±82.105	+2.860	−12.186	+37.500	±13.177
PM5.0	+51.049	−16.355	+258.750	±81.533	+2.902	−11.992	+37.391	±13.097
PM10	+50.217	−14.685	+258.385	±81.269	+2.877	−11.753	+37.249	±13.035

virus-laden droplets, measuring 20 μm (equivalent to ~10 μm desiccated residue diameter) or less from infected persons can transmit to other persons by airborne route in the restricted environment. Virusol formation and consequent infection transfer from droplet sizes above 2 μm were important for obviously severe cases. The particle sizes of infectious aerosols which have been defined as pathogens are commonly found in small-particle aerosols, measuring lesser than 5 μm, which are airborne and breathable. Then it may be unnecessary to concern about ultrafine particle filtration (Anand and Mayya, 2020; The Lancet Respiratory Medicine, 2020). Therefore, the measuring techniques in this article were used to assume that almost airborne pathogens could be efficiently removed from the air. In the future, if researchers can develop a high-performance viral detector from the air, then that method should be applied. To promote low-cost disinfection, chlorine was chosen for this purpose. The most common use of chlorine disinfectant is hypochlorite, which usually includes calcium hypochlorite in solid form and sodium hypochlorite in liquid form, respectively. The concentration of household bleach in aqueous solutions is 5.25–6.15% (or 52,500–61, 500 ppm) sodium hypochlorite. Several studies showed a 1:10–1:100 dilution of 5.25%–6.15% sodium hypochlorite has a tuberculocidal property and chlorine concentration only 200 ppm in 10 min can inactivate 25 distinct viruses (Centers for Disease Contr, 2008). To prevent mucosal irritation, some disinfectants should be added to water tanks after air-purifying processes. Further study should pay attention to an optimized water-chlorine ratio that can be used as an inexpensive disinfectant technology.

To analyze cost-effectiveness, if the initial cost (e.g. air blower, air purifier frame, and any equipment supports), as well as the electricity charge, were set identically, then the difference between an air purifier using HEPA filter and this air-purifying technique was only the type of filter elements. In Thailand, during the COVID-19 pandemic, the cheapest cost of HEPA filter for making DIY (do it yourself) air purifier was approximate 500 Thai Baht (THB), which was designed for a small living room. However, for a semi-outdoor air cleaner, maintenance expenses per month might be higher than 5,000 THB whereas the expenses for this filterless air purifier, which consisted of water 30 THB (10 THB/m^3, 3 m^3/month), polyurethane sponge 20 THB, and water filter 150 THB, also needed 200 THB totally. Therefore, this low-cost machine can be considered replacing the HEPA filter method and may be an alternative optimal way for creating an air purifier among developing countries.

Even though the water filtration technique is not a novel machine but the technique being applied here also presented how to improve the capacity of bubble dissolution using local technology, including a polyurethane sponge as well as a ceramic water filter. Therefore, the optimization of the semi-outdoor air-purifying technique for developing countries is to replace the HEPA filter with a water filtration system amalgamated with a sponge as well as a water filter. According to the emergency situation being, the author also made this low-cost machine rapidly. Another issue that should be of concern if we have enough time, is the endurance of electric devices. Being the main component of the air-purifying system, to prevent air pump damage, it should not run continuously. The internet of things (IoT) can include temperature and humidity sensors, air quality sensors, microcontrollers, Wi-Fi modules, LCD monitors, and software architecture that can be implemented with an air purifier (Shaikh, 2019). The smart filterless air purifier using an automatic control system, being remotely controlled by a smartphone, as well as comparing its efficiency with the HEPA filter technique will possibly be the next experiment.

5. Conclusions

This study showed how to design and develop an indoor and semi-outdoor air purifier using a water-based air filtration technique. The results showed an air purifier using an air pump can reduce the amount of particulate matter within 5 min. To promote the role of disinfection, chlorination should be applied to the water tank. Anybody who has interest in these methods can create their machines by following this study. For the next experiment, the study should extend test length, clarify an optimum ratio of disinfectant technologies, connect some monitoring instruments with the internet of things system, compare the efficiency with a HEPA filter air purifier, and should be done with a particle counter that can identify tiny particles which are smaller than 0.2 μm. Finally, I hope this idea may help us to overcome the environmental crisis as well as the global COVID-19 pandemic together.

Author contributions

Arnon Jumlongkul: Conceptualization, Methodology, Data curation, Writing – original draft, Writing- Reviewing and Editing.

Funding

The funding support was provided by the Princess Srinagarindra's Centenary Celebrations Foundation, Mae Fah Luang University, Thailand, fiscal year 2020, Memorandum No. 28/2563.

Declaration of competing interest

The author has no conflict of interest to declare.

Acknowledgements

Special thanks to Watchara Jamnuch, an electrical engineer, for technical ideation, Sitang Kongkratoke, a lecturer at School of Health Science, for technical support, Dr. Roger Timothy Callaghan, a lecturer and family physician at School of Medicine, for grammatical support, and also Mrs. Pitchayapa Jumlongkul, a pharmacist and my beloved wife, for statistical consultation.

References

Al-Kazwini, A.T., Said, A.J., Sdepanian, S., 2015 Dec. Compartmental analysis of metals in waterpipe smoking technique. BMC Publ. Health 15 (153), 1–7. http://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-015-1373-6.

Anand, S., Mayya, Y.S., 2020 Dec. Size distribution of virus laden droplets from expiratory ejecta of infected subjects. Sci. Rep. 10 (1), 21174.

Centers for Disease Control and Prevention, 2008. Chemical Disinfectants Guideline for Disinfection and Sterilization in Healthcare Facilities. https://www.cdc.gov/infectioncontrol/guidelines/disinfection/disinfection-methods/chemical.html.

Centers for Disease Control and Prevention. Coronavirus disease 2019 (COVID-19) [internet]. [cited 2020 mar 2]. Available from. https://www.cdc.gov/coronavirus/2019-ncov/index.html.

Cheong, Ngiam, Morgan, Pek, Tan, Lai, et al., 2019 Sep 6. Acute health impacts of the southeast asian transboundary haze problem—a review. Int. J. Environ. Res. Publ. Health 16 (18), 3286.

Eissenberg, T., Shihadeh, A., 2009 Dec. Waterpipe tobacco and cigarette smoking. Am. J. Prev. Med. 37 (6), 518–523.

Feliu, A., Fu, M., Russo, M., Martinez, C., Sureda, X., López, M.J., et al., 2020 May. Exposure to second-hand tobacco smoke in waterpipe cafés in Barcelona, Spain: an assessment of airborne nicotine and PM2.5. Environ. Res. 184, 109347.

Jin, Y., Yang, H., Ji, W., Wu, W., Chen, S., Zhang, W., et al., 2020 Mar 27. Virology, epidemiology, pathogenesis, and control of COVID-19. Viruses 12 (4), 372.

Konda, A., Prakash, A., Moss, G.A., Schmoldt, M., Grant, G.D., Guha, S., 2020 May 26. Aerosol filtration efficiency of common fabrics used in respiratory cloth masks. ACS Nano 14 (5), 6339–6347.

Liu, G., Xiao, M., Zhang, X., Gal, C., Chen, X., Liu, L., et al., 2017 Jul. A review of air filtration technologies for sustainable and healthy building ventilation. Sustain Cities Soc 32, 375–396.

Naddafi, K., Nabizadeh, R., Rostamy, R., Ebrahimi Kalan, M., Hassanvand, M.S., Fazlzadeh, M., 2019 Sep. Indoor air quality in waterpipe cafés: exposure level to particulate matter. Environ. Sci. Pollut. Res. 26 (26), 26605–26616.

North, C.M., Rice, M.B., Ferkol, T., Gozal, D., Hui, C., Jung, S., et al., 2019 May. Air pollution in the asia-pacific region: a joint asian pacific society of respirology/American thoracic society perspective (republication). Respirology 24 (5), 484–491.

Pardthaisong, L., Sin-ampol, P., Suwanprasit, C., Charoenpanyanet, A., 2018. Haze pollution in Chiang Mai, Thailand: a road to resilience. Procedia Eng 212, 85–92.

Shaikh, T., 2019 May 31. Iot based smart air purifier. Int. J. Res. Appl. Sci. Eng. Technol. 7 (5), 1896–1901.

The Lancet Respiratory Medicine, 2020 Dec. COVID-19 transmission—up in the air. Lancet Respir Med 8 (12), 1159.

van Doremalen, N., Bushmaker, T., Morris, D.H., Holbrook, M.G., Gamble, A., Williamson, B.N., et al., 2020 Apr 16. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. N. Engl. J. Med. 382 (16), 1564–1567.

Yang, Y., Pun, V.C., Sun, S., Lin, H., Mason, T.G., Qiu, H., 2018 Mar. Particulate matter components and health: a literature review on exposure assessment. J Public Health Emerg 2.

Zanoletti, A., Bilo, F., Borgese, L., Depero, L.E., Fahimi, A., Ponti, J., et al., 2018. SUNSPACE, A porous material to reduce air particulate matter (PM). Front Chem 6, 534.

Zhao, B., Liu, Y., Chen, C., 2020 Jun. Air purifiers: a supplementary measure to remove airborne SARS-CoV-2. Build. Environ. 177, 106918.