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

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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/m^3) as well as the detection of mass concentration of PM1.0, PM2.5, PM5.0, and PM10 (mg/m^3) 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
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 vegetarian 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 “SustaNable 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) (Zanotti 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 (Eisenberg 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 poly-urethane sponge (L × W × H = 0.5 m × 0.5 m × 0.02 m = 0.005 m³), density 12±2 kg/m³, elongation ≥ 60%, tensile strength ≥ 0.4 kg/cm², 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 m³, 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 AerO-Trak® 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/m³), 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/m³). 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.
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

| Air pollutant diameter (μm) | Percentage difference of the number of PM (particle/m³) | Air pump |
|-----------------------------|--------------------------------------------------------|----------|
|                             | Control (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 | +4.729 -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 |
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$^3$) | Air pump |
|------------------------|----------------------------------------------------------|----------|
|                        | Control Mean | Min | Max | SD | Mean | Min | Max | SD |
| PM0.3                  | +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 |

**Table 2**

**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.

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**Declaration of competing interest**

The author has no conflict of interest to declare.

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