Research Article

Water-based air purifier with ventilation fan system: a novel approach for cleaning indoor/outdoor transitional air during the pandemic

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Abstract
This article presents the design and fabrication of an air purifier that uses a water-based technique to clean indoor/outdoor transitional air to provide a low-tech air purifier against the annual smog crisis and the ongoing COVID-19 pandemic. The air purifier was designed and built. All tests were conducted in a closed room as well as a semi-outdoor area. Particle sizes of PM0.3, 0.5, 1.0, 3.0, 5.0, and 10 µm (particle/m³) were measured at an air inlet, air outlet, 2 m from an air inlet, and 4 m from an air outlet after 0, 5, 10, 15, and 20 min of air treatment, respectively, as well as CO₂ levels and relative humidity (RH). The average airflow rate was also measured. When compare to 0 min, all parameters, except semi-outdoor PM0.3 and CO₂ levels, tend to decrease in both indoor and semi-outdoor conditions. When measure by total airflow specification of a dual ventilation fan, the average airflow rate at an air outlet is reduced by 20 times.

Article Highlights

• Design and fabrication of a water-based air purifier.
• A low-tech air purifier helping to protect against the annual smog crisis and the ongoing COVID-19 pandemic.
• The novel water-based air purifier effectively traps air particles ranging in size from 0.5 to 10 µm.

Keywords COVID-19 · Haze · Particulate matter · Transition air · Water-based air purifier

1 Introduction

Particulate matter (PM) is a mixture of solid and liquid particles suspended in air. Its size, chemical, physical, and biological properties change depending on where it is and when it is measured. PM can have an immediate and long-term impact on health problems [1]. Acute PM2.5 exposure can trigger an inflammatory response, oxidative stress, and apoptosis in lung tissue [2]. Long-term exposure to PM2.5 may increase the incidence of cardiovascular diseases, renal disease, type 2 diabetes mellitus, and chronic obstructive pulmonary disease (COPD) [3]. PM also increases the risk of myocardial infarction, stroke, cardiac failure, coronary heart disease, pneumonia, acute respiratory distress syndrome, renal failure, hepatic injury, cerebrovascular diseases, gastrointestinal disorders, and inflammation in humans [4]. Air pollution can harm the nervous system by increasing oxidative stress, activating microglia cells, and causing brain damage [5]. Increased PM10 and PM2.5 levels in children have been linked to an increased risk of outpatient department (OPD) visit for respiratory illnesses [6]. There was a link between PM2.5 exposure and depression, anxiety, and suicide as part of the mental health effects [7]. Furthermore, exposure to PM...
is associated with an increase in hospital admissions for mental disorders as well as the economic burden of hospitalization for mental disorders [8].

According to [9], the minimum size of a COVID-19 containing respiratory particle is about 4.7 µm, while SARS-CoV-2 genes can be found in aerosols at 0.25–0.5 µm. Despite the fact that Coronavirus particles are quite small, measuring 65–125 nm in diameter [10]. SARS-CoV-2 aerosol particles, which are typically less than 10 µm in size, can remain suspended in air for hours and can be transported up to several meters from the source, a particular issue in asymptomatic people [11]. As part of saliva droplets, a study model revealed that the initial size of droplet vectors, measuring 20–50 µm, resulted in 4.7–12 µm solid residues within a few seconds [12]. Furthermore, scientists discovered some links between the SARS-CoV-2 virus and PM. For indoor conditions, ventilation systems are the primary means of controlling virus spread, whereas outdoor risk sources, such as aerosolized particles from wastewater treatment and PM, can become virus carriers [13]. In terms of biology, SARS-CoV-2 has been shown to have a high affinity for the angiotensin-converting enzyme 2 (ACE2) receptor, whereas PM exposure increases ACE2 expression in the lungs. As a result, in heavily polluted areas, PM may facilitate pulmonary SARS-CoV-2 viral adhesion [14]. Therefore, air cleaning processes can limit the spread of the COVID-19 virus as well as PM.

Since we know this virus may spread through the air, scientists have attempted to develop multiple technologies to protect humans from it. Numerous techniques have been used to improve indoor air quality (IAQ), such as an indoor plantation to promote a green environment, purified air circulation, maintaining social distance, wearing face masks, portable air purifiers with filters (e.g. activated carbon, HEPA filters, ionization, photo-catalytic oxidation (PCO), germicidal UV radiation), humidification, adequate ventilation, and lockdown policies [15]. Because of inefficient conventional air filters, Heating, Ventilation, and Air–conditioning (HVAC) systems, which are installed as part of air conditioners, may aid in the spread of infectious indoor air. An innovative air circulation concept should combine HEPA or ULPA filters, the use of Ultraviolet Germicidal Irradiation (UVGI) and/or ionization in the airstream, and a moisture control system (relative humidity (RH) in the 40–60% range is recommended) [16]. A systematic review found that the risk of outdoor SARS-CoV-2 transmission was low (< 10%), and the probability of indoor transmission was very high when compared to outdoor transmission [17]. As a result, air purifiers for open spaces may be ineffective. However, transitional areas between indoor and outdoor air, also known as “semi-outdoor” as well as large-open places that are always crowded with people (e.g. platforms, front doors of large buildings, halls, large canteens), have been highlighted. In this area, critical information about the effectiveness of air treatment has been scarcely available. High-performance filtration technologies may be inappropriate under these conditions.

As stated previously, the goal of this article is to focus on the design and fabrication of an air purifier, using a water-based technique for cleaning indoor/outdoor transitional air, as well as to test its efficiency, in order to provide a low-tech water-based air purifier, both against the smog crisis and the COVID-19 pandemic. The following section of the article discusses how to build the water-based air purifier as well as testing methods. Section 3 presents the results of laboratory tests, while Sects. 4 and 5 introduce the discussion and conclusion sections, respectively.

## 2 Methods

The water-based air purifier is the second version of the semi-outdoor filterless air purifier, which uses a high-pressure 120 W air blower which produces 11.4 m³/h of air output [18]. The basic concept of both the old and new machines is the same, except that the air blower has been replaced by a dual duct ventilation fan 50 Hz 220 V 130 W, capable of releasing air at 900 m³/h and with a static pressure of 380 Pa, for a total of 1800 m³/h. Smart functions such as air quality, temperature, humidity, and an LCD monitor have been added to this water-based air purifier.

### 2.1 Machine design

Figure 1 depicts the outer dimensions of the water-based air purifier, which was primarily made of aluminum composite. As a result, it is light in weight and easy to transport. The structural components of the machine’s air purifying system is mainly made of 304 stainless steel sheets, with a thickness of 1.2 mm. After entering the gap between a water tray and a cap, dirty air is passed through a 0.5-mm capturing polyurethane sponge measuring 2.54 cm in thickness that is soaked with 5 Litres of water. The air flow is then directed to the inner side of the stainless cap, the dual ventilation fan, and finally back out into the surrounding environment. The prototype of the novel water-based air purifier is shown in Fig. 2. Figure 3 depicts how the water-based air purifying system works. Figures 4 and 5 illustrate the stainless cap and water tray drawings, respectively.

### 2.2 Data collection and analysis

All tests were carried out at two locations: the first, a closed laboratory room measuring 11.7 × 16.2 × 3 (W × L × H) m³, and the second, a semi-outdoor space...
within a building, measuring $9 \times 12 \times 3$ (W $\times$ L $\times$ H) m$^3$. The Portable Particle Counter Model 9310 TSI AeroTrak®, which can calculate particle sizes of PM0.3, 0.5, 1.0, 3.0, 5.0, and 10 μm, was used to measure the amount of air pollution at 0, 5, 10, 15, and 20 min at the same locations, including the air inlet, air outlet, 2 m, and 4 m distance from one of the air inlets. Throughout the test, the water-based air cleaner was running continuously. Meanwhile, the Q-Trak Indoor Air Quality Monitor 7575 was used to measure CO$_2$ (PPM) and relative humidity (RH). The results were expressed as a percentage difference in PM concentration versus haze particles at 0 min, when pollution was declared to be 100%. The average air speed was measured at four different locations in the vicinity of an air outlet using the Q-Trak Monitor, and the data was then averaged along with CO$_2$ and RH. After 3 h of continuous machine work, the volume of water within the stainless tray was measured again.

### 3 Results

In Table 1, as part of the PM mass concentration at 568.62 m$^3$-indoor condition, PM from all distant locations, except PM0.3 at 4 m away from an air inlet, decreased after 20 min when compared to 0 min. PM ranging from 0.5 to 5 μm maximum decreased at 15 min, at the air inlet, which also remained 13.669 to 67.904%, while PM0.3 (91.839%) and PM10 (0%) levels were lowest at 10 min and 20 min at the air outlet, respectively. Large particles were cleaned better by the water-based air purifier than small particles. Overall, the best performance of the water-based air purifier was demonstrated at the 15-min air inlet measurement. The CO$_2$ level was also at its lowest (92.789%) at this condition. The relative humidity ranged from 90.827 to 100.276% when compared to 0 min.

In Table 2, the air cleaning efficiency appeared to be lower in a semi-outdoor environment measuring 324 m$^3$ than in an indoor condition. Only the 20 min measurement at the air outlet showed a reduction to 80 percent of PM10.
when compared to the 100 percent control. PM from 1 to 5 µm maximum decreased at 10 min of 4 m distance from an air inlet, which also remained 57.209 to 88.525%, while PM0.3 (96.206%) and PM0.5 (92.045%) levels were lowest at 5 min of air inlet. At 20 min, CO₂ levels were minimally elevated for all conditions (101.191 to 107.207%), whereas RH levels were slightly decreased (91.089 to 95.658%).

The average airflow rate as part of an air cleaning volume was 0.0247 m³/s, which can treat an air volume of 88.92 m³/h. This volume was 20 times less than the total airflow specification of a dual ventilation fan (1800 m³/h). The volume of water within the stainless tray decreased from 5 to 4.5 L after 3 h of continuous machine work. As a result, the water evaporation rate of this air purifier in an indoor environment was approximately 0.167 L/h (17.3 to 22.9 °C, 70.1 to 82.2%RH).

4 Discussion

According to the findings of this study, the use of the water-based air purifier in an indoor environment showed a significant difference when compared to a semi-outdoor environment. In an indoor environment, the target area of an air treatment system should be near both the air entry point as well as the air outflow point. This air purifier is suitable for gradual PM reduction, ranging from 0.5 to 10 µm, most effective after 15 min of machine operation. Therefore, it is appropriate for preventing dust as well as COVID-19 airborne particles in large spaces. Even though PM0.3 was not significantly reduced and SARS-CoV-2 genes were found in aerosols at 0.25–0.5 µm, data from an introduction section claims that the water-based air purifier can trap COVID-19 at respiratory particle levels measuring 4.7 µm. The water-based air purifier can emit humidity, which has no effect on the overall RH within a 568.62 m³ closed room or a 324 m³ semi-outdoor condition, and it also has a minor effect on CO₂ levels. Despite the fact that the author only filled water to the upper surface of the polyurethane sponge, measuring 2.54 cm in thickness, the airflow rate dropped to 1/20 of the maximum efficiency of the air purifying system. As a result, for
the next experiment, water-resistant pressure should be calculated. Natural air is one of the most important factors influencing the airflow rate in a semi-outdoor environment, where the site is approximately half that of an indoor testing condition. The use of this air purifier is then available for areas at least 4 m away from the air cleaning site. Uncontrolled variables, such as wind speed, the amount of space that the air occupies, and air pressure,
Table 1: The percentage differences in PM concentration, CO₂, and relative humidity of indoor air when compared to 0 min

| Location       | Time (min) | PM mass concentration (%) | CO₂ (%) | RH (%) |
|----------------|------------|---------------------------|---------|--------|
|                |            | PM0.3 PM0.5 PM1 PM3 PM5 PM10 |         |        |
| Air inlet      | 0          | 100 100 100 100 100 100 100 |        | 100 100 |
|                | 5          | 98.558 82.164 62.665 41.068 57.554 240 | 97.154 | 93.540 |
|                | 10         | 97.222 71.250 44.546 31.553 46.763 60 | 96.774 | 90.827 |
|                | 15         | 97.079 67.904 39.099 13.856 13.669 40 | 92.789 | 91.990 |
|                | 20         | 99.456 70.863 39.680 13.856 15.108 40 | 95.066 | 91.860 |
| Air outlet     | 0          | 100 100 100 100 100 100 100 |        | 100 100 |
|                | 5          | 95.548 79.236 65.819 52.155 64.706 200 | 97.697 | 93.309 |
|                | 10         | 91.839 69.903 56.209 39.224 46.763 60 | 97.697 | 94.282 |
|                | 15         | 93.503 69.678 51.401 20.490 45.494 60 | 95.010 | 93.309 |
|                | 20         | 95.436 68.856 47.171 34.914 29.412 60 | 92.789 | 92.944 |
| 2 m from air inlet | 0         | 100 100 100 100 100 100 100 |        | 100 100 |
|                | 5          | 97.410 83.678 66.245 46.993 60 | 87.5 | 98.656 |
|                | 10         | 93.705 72.464 50.410 20.490 20 | 87.5 | 97.268 |
|                | 15         | 98.471 75.690 47.211 20.490 20 | 94.434 | 98.634 |
|                | 20         | 98.342 74.728 43.995 23.831 23.831 | 93.282 | 96.585 |
| 4 m from air inlet | 0         | 100 100 100 100 100 100 100 |        | 100 100 |
|                | 5          | 101.233 89.071 72.380 109.385 103.571 366.667 | 96.518 | 98.204 |
|                | 10         | 95.563 78.218 54.870 37.540 40 | 95.358 | 100.276 |
|                | 15         | 98.457 79.607 50.970 44.660 40 | 98.066 | 99.033 |
|                | 20         | 103.372 82.953 51.790 44.984 50 | 93.617 | 98.619 |

Table 2: The percentage differences in PM concentration, CO₂, and relative humidity of semi-outdoor air when compared to 0 min

| Location       | Time (min) | PM mass concentration (%) | CO₂ (%) | RH (%) |
|----------------|------------|---------------------------|---------|--------|
|                |            | PM0.3 PM0.5 PM1 PM3 PM5 PM10 |         |        |
| Air inlet      | 0          | 100 100 100 100 100 100 100 |        |        |
|                | 5          | 96.206 92.045 92.070 66.071 91.346 125 | 103.820 | 95.332 |
|                | 10         | 101.955 100.650 104.618 94.841 117.308 175 | 105.393 | 93.918 |
|                | 15         | 99.417 92.248 92.712 74.802 113.462 325 | 102.023 | 89.816 |
|                | 20         | 98.951 93.948 95.280 68.452 84.615 150 | 104.045 | 91.089 |
| Air outlet     | 0          | 100 100 100 100 100 100 100 |        |        |
|                | 5          | 100.575 103.299 97.931 91.688 112.941 140 | 101.099 | 96.567 |
|                | 10         | 102.026 104.834 103.062 65.974 92.941 140 | 101.978 | 96.280 |
|                | 15         | 100.678 94.882 90.087 102.078 138.823 220 | 111.648 | 93.419 |
|                | 20         | 100.056 95.933 89.432 108.312 148.235 80 | 101.539 | 92.704 |
| 2 m from air inlet | 0         | 100 100 100 100 100 100 100 |        |        |
|                | 5          | 104.829 105.851 102.337 83.437 92.174 800 | 133.333 | 99.270 |
|                | 10         | 102.269 100.943 97.877 76.190 98.261 1200 | 109.910 | 98.248 |
|                | 15         | 102.072 97.587 95.192 75.569 79.130 300 | 104.955 | 96.058 |
|                | 20         | 101.855 98.974 97.337 114.700 156.521 1700 | 107.207 | 95.328 |
| 4 m from air inlet | 0         | 100 100 100 100 100 100 100 |        |        |
|                | 5          | 101.565 101.445 96.564 82.326 105.921 150 | 101.191 | 100.145 |
|                | 10         | 101.457 97.417 88.525 57.209 63.158 150 | 97.619 | 96.527 |
|                | 15         | 101.526 98.561 94.443 80.310 101.316 137.500 | 101.191 | 97.250 |
|                | 20         | 99.0163 96.167 92.491 73.333 93.421 137.500 | 101.191 | 95.658 |
were also involved during experiments as part of a semi-outdoor condition, and the results were not satisfactory. The fan size used in these experiments may not have been appropriate. The calculation between the specification of a ventilation fan and the available space should be mentioned in the next experiment.

The water-based air cleaner requires only a 260 W-dual ventilation fan and a time/day water observation as part of its low-tech and maintenance costs. Water measurement using a microcontroller and an ultrasonic sensor can be combined with the water-based air purifier to promote an automation system [19]. In comparison to the wet scrubber, the wet scrubber can remove any air pollutants using liquid droplets. As a result, this method necessitates the use of at least two mechanical systems to power the air purification process including, air blowers and sprayer systems [20]. Therefore, the air purifier employing the wet scrubber technique requires the use of more specialized technicians than the water-based air purifier. More research should be conducted to compare the effectiveness of those two methods in terms of cost effectiveness, air cleaning rate, and usability. Any limitations of this study also include, we do not have a dust particle counter that can measure at the level of COVID-19 diameters, so we cannot conclude that the air purifier has an effect on COVID-19 directly, and we do not know the viability of viruses after they sink into water. Accurate measuring instruments, as well as a viral viability test, should be recommended for future research.

5 Conclusions

In summary, the prototype’s design concept also includes ventilation fans, a stainless tray, a stainless cap, a polyurethane sponge, and water. The novel water-based air purifier effectively traps air particles ranging in size from PM0.5 to 10 µm. For the next experiment, researchers should compare the efficacy of the wet scrubber technique to that of the water-based methods in all aspects. Water level and rate of water evaporation should be calculated to maximize the efficiency of this air purifier prototype. Finally, the author hopes that this low-tech machine will help the world combat both the COVID-19 pandemic and the air pollution crisis.

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Author contributions A.J. designed, analyzed, and drafted the manuscript solely.

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Declarations

Conflict of interest The author has no conflict of interest to declare.

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