Solar Powered Outdoor Air Purifier with Air Quality Monitoring

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Abstract

This paper has documented the detailed design, fabrication and test of a solar powered air purifier prototypee with a High Efficiency Particulate Air Filter (HEPA) and Carbon Filters which can achieve air purification with self-sustainable ability. Besides. Several tests have been conducted to assess the performance of the proposed solar operated air purifier. In the first test, a 67.37% efficiency is achieved for the solar panel. Second test of air purifier test has shown the efficiency of cleaning ammonia pollutant in the air as 43.55% for burning cigarettes and 35.33% for floor detergent using the equipped two MQ135 sensors. The findings are showing that the floor detergent might have higher rate of diffusion than ammonia molecule found in cigarette smoke.

Keywords: Solar Power, Air purifier, HEPA, Air Quality

1. Introduction

Air pollution has plagued the world with millions of diseases and deaths to humanity. The effects of air pollution are of more influence at urbanized areas compared to rural areas. As technology advances, richer countries use active technology and efficient designs to improve their air quality over time. In contrast, lower income and developing countries have none or little emphasis in constructing strict guidelines and regulations. Progress of improving air quality is often downplayed and ignored as the economic growth of these countries is far more important than the environment [1].

All countries have their own standards of measuring air quality. Since this design project is based in Malaysia, the project is designed according to the Malaysian Standards. According to Malaysia ambient air quality standards, it incorporates six air pollutants criterion, including particulate matter with a size less than PM 10. SO2, CO, NO2, and O3 ground level ozone, as well as another extra parameter, particulate matter with a size less than PM 2.5 micron [2]. Fine particulate matters are contaminants found in the air that have been linked to both acute and chronic health problems. Even though most particulate matter research is focused on outdoor exposures, most of the individuals are spending most of their time indoors, where particulate matter from outdoors can penetrate to indoor with ease. Particulate matter is proven to affect respiratory, cardiovascular, and nervous systems, and linked to higher mortality risk [3]. For example, respiratory diseases like COVID-19 in recent years, the virus SARS-CoV-2 is largely spread via droplets and particulate matter in the air, thus transmitting it into the human respiratory system. It also prolongs the recovery phase from the disease's symptoms [4].

An air purifier with HEPA Filter is being used widely to prevent harmful substances like particulate matter and chemical from entering a space in exchange of clean air. HEPA stands for high efficiency particulate air filter. It is a type of mechanical filter. Substances in the air like dust, pollen, mound, germs, and other airborne particles larger than 0.3 μ m can potentially be removed by a HEPA filter. The 0.3 μ m diameter standard expresses the worst-case situation, the particle size with the highest penetration. Larger or smaller particles are captured with considerably greater efficiency with a HEPA filter. There are tons of different air purifiers available in the market with HEPA filters. To differentiate the performance of different air purifiers, the Minimum Efficiency Reporting Value (MERV) was introduced by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for the rating of filter efficiency. For air purifier with filter that can filter out dust and particulate matter need at least MERV rating 13 [5].

2. Methodology and Experimental Setup

2.1 The prototype design details

The conceptual design was carried out using the SOLIDWORKS programme for planning, visual concept generation, modelling, feasibility evaluation, prototyping, and project management. The system under consideration is having an air purifier unit and the solar unit for the solar power supply. The air purifier unit consists of the core components which are the *HEPA* filter, *DC* fan, and car battery. While the solar unit having fold-able and flexible solar panel, solar charge controller and car battery. The working principle is based on the solar unit to be placed at an outdoor location during sunshine hours of the day. The car battery will be charged by the connection to the solar panel via charge controller. After full charging, the charged car battery will get disconnected from the solar unit and to be transferred to the air purifier unit and connected to the *DC* fan. The running *DC* fan will blow the air to the *HEPA* filter where it can filter up the air. The separation of solar charging and air filtration units has been decided to give better mobility and flexibility in using the system. With the portability of fold-able and flexible solar panel, it can be placed at locations of less shading and more solar radiation.

The final design has been modified by adding MQ-135 Sensor and Arduino Uno for testing the air quality of the solar powered air purifier. The MQ-135 Sensor could show reading of air quality while connected to the Arduino Uno board. It can send the data back to the computer to show the performance of the air purifier unit. Two MQ-135 sensors are placed in front of the air duct outlet and back of the air duct inlet to ensure the sensor could detect accurate data. Figure 1 showing the fabricated testing Solar-Air Filter Purifier

Fig. 1 Final prototype testing equipment

3. Result and Discussion

To achieve all the objectives of the project, the following two different experiments have been conducted.

3.1 Solar Panel Efficiency Test

The major measurement of this test was to measure the operating current from the solar panel which is a photovoltaic current. The test required the solar panel, solar charge controller, car battery, 100W yellow light source and a multi-meter.

This test is to measure the current output from the solar panel. A multimeter has been choosen. The measured readings are recorded in two decimal points for ease of comparison and calculations when compared to solar panel's performance under lab test conditions.

3.2 Air Purifier Test

The air purifier test is conducted to test the ammonia level of the inlet and outlet of the air purifier unit and assess the filtration efficiency. The test has been conducted by using 2 MQ135 Sensors placed at the inlet and outlet of the air purifier. The ammonia content readings would be compared between outlet and inlet to show the differences.

The tests conducted have followed Chen et al. experimental procedure [6]. The room should be clear from any object like furniture and to be clean and left untouched for 24 hours before initiating the filtration test.

The room chosen for the test is having 33.5 m^3 of volume. with trapezium shape. The air purifier is placed at the middle of the room and a tray is placed 60 cm away from the inlet of the air purifier. The test is run with sealed room to ensured there's no external particle movement from outside of the room.

The following detailed procedure has been followed to run the air purifier test.

1. Set testing tray 60cm away from the inlet of the air purifier unit.
2. Set up Arduino Uno by connecting to the laptop.
3. Ensure connection between battery and PWM motor controller.
4. Set up burning cigarette on testing tray for 10 minutes of injection period.
5. Remove test subject and wait for 10 minutes of static period.
6. Wait for 6 hours for dynamic period.
7. Set 100 percent power on PWM motor controller and activate Air purifier unit.
8. Start collect data to the laptop.
9. Wait for 6 hours for Data collection period.
10. Stop collect data to the laptop.
11. Repeat Steps 4 to 10 using multipurpose floor cleaner.

3.3 Battery Discharging Test

The battery discharging test is used to test the car battery depth of discharge and fan running time under fully charged car battery. The test results were used to compare with theoretical results and design results relate to fan running time and car battery charge level. The control variable has been set for fan running with 36W and 12V connected to a fully charged 45 AH car battery for 6 hours. The test has run simultaneously with air purifier test. The voltage of the car battery is measured with multi-meter before connected to the fan. After 6 hours, the car battery charge is measured again using the multi-meter. The following detailed procedure has been followed to run the battery discharging test.

1. Measure and record car battery voltage using multi-meter.
2. Connect the car battery to the fan using clamp terminals.
3. Start the on/off button on PWM fan controller.
4. Wait for 6 hours.
5. Measure and record car battery voltage using multi-meter.

3.4 Solar panel efficiency test result.

Results of the solar panel verification test are compared with the provided manual solar panel specifications under lab test conditions. The comparison results of the measured and lab test solar panel current is found to be 77.7%, Voltage at 86.77%, and wattage at 67.37%. The efficiency of the solar panel can be calculated by using the following equation (1).

$$n = \frac{Power\ out\ of\ solar\ cell\ (watt)}{Solar\ Power\ incident\ on\ solar\ cell\ (watt)} \tag{1}$$

The power output of the solar cell is measured at 53.90w while the solar power incident on solar cell was 80w as the solar panel have received more than maximum of 100w yellow light. The calculation of the efficiency was 0.6737 which was 67.37 percent. Therefore, the solar panel could only produce 53.90 watt under 100w yellow light. Following equation (2) and (3) are percentage error equations to calculate the percentage error between theoretical and experimental wattage from solar panel.

$$Percentage\ error = \frac{theoretical - experimental}{theoretical} \times 100\% \quad (2)$$

$$= \frac{80-67.37}{80} \times 100\% = 15.79\% \quad (3)$$

3.5 Air purifier test results.

Figure 2 shows the test results for the air purifier performance when the cigarette is used to cause the air pollution.

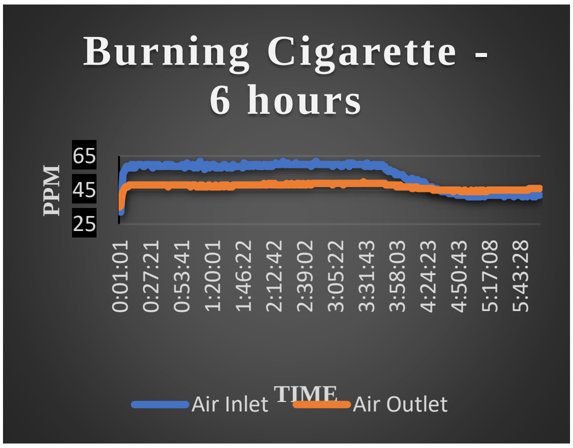

Fig. 2 PPM vs times of 6 hours burning cigarettes.

Figure 3 is showing the test results for the air purifier performance when the floor detergent is used to cause the air pollution.

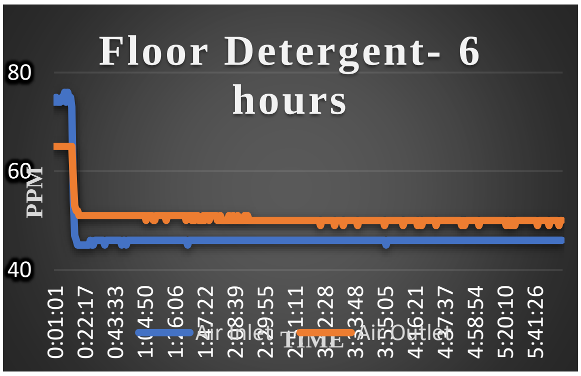

Fig. 3 PPM vs times of 6 hours floor detergent.

Control set of the air purifier test was recorded without any ammonia test subject has shown constant of 0 to 1 ppm fluctuation with majority of 0 ppm from air outlet and inlet sensor during the 6 hours testing. According to Li et al. [7] study found that typical indoor air ammonia content range around 10 to 70 ppb, which is 0.01 ppm to 0.07 ppm. The data has proven the accuracy of the sensor and let the user calibrate the sensor according to the data received. In this case, the MQ135 sensor detected majority of 0 ppm in both inlet and outlet which show little or close to none of ammonia content in the room air.

The floor detergent used in the test contains quaternary ammonium with 11.5 % (W/V). The test sample taken from the floor detergent is 100ml which contains 11.5ml of quaternary ammonium salt. The 11.5 % are converted to 115000ppm of quaternary ammonium salt in 100ml. The ammonium chloride in the quaternary ammoniums salts would travel at the rate of 0.228 ± 0.012 $cm^2 \cdot s^{-1}$ at 1 atm and 25 ℃. No dependence on relative humidity was observed over the range 10–92% [8].

As for cigarette, Cigarette ammonia content is varying from brands to brands. According to a study from Inaba et al. [9], the ammonia in cigarette is 870 ± 400 ppm per stick with 0.071 ± 0.006 $cm^2 \cdot s^{-1}$ diffusion rate [10].

The results are measured with Air inlet and Air Outlet of the air purifier. Both of the test pollutants chosen are containing significant amounts of ammonia. The test results have shown that the floor detergent has diffused more in the room as the highest detected amount of ammonia is 76 ppm at air inlet while burning cigarette recorded highest amount of ammonia is 60 ppm. It can be concluded that the floor detergent is having higher content amounts of ammonia than the cigarettes. The cigarette graph has shown that air inlet ammonia ppm was relatively high when compared to the air outlet ppm at the first 3 hours and 45 minutes of the test. The cigarettes smoke inside the room has been diffused into mid-air. The hot smoke released by the burning cigarettes get cooled down rapidly during the static period and dynamic period of the test. The cooled down smoke was descended to lower part of the room as smoke is heavier than the air. Both air inlet and air outlet ppm has started declined at 3 hours and 45 minutes. The decline of both air inlet and air outlet ppm meets a crossing point of 45 ppm at 4 hour and 30 minutes marked at the graph. The air outlet has remained constant of 45 ppm while air inlet has declined to 41 ppm at 5 hours mark. The cigarette smoke at lower level of the room has been cleared out while at the upper level of the room remains some residue of smoke. The in-balance of the smoke ppm in the room might been caused by minimal circulation of air in room.

Floor detergent graph is showing sudden drop from 73 ppm to 45 ppm at air inlet while 65 ppm to 51 ppm in 5 after 20 minutes of the test started. The ammonia molecule in floor detergent might have higher rate of diffusion than ammonia molecule found in cigarette smoke. Air inlet and air outlet of floor detergent test has shown constant 46 ppm and 50 ppm respectively for the rest of the test. The Figure 2 graph pattern is found similar to the pattern in Figure 3. The ammonia at lower level of the room has been cleared out while at the upper level of the room remains some of ammonia residue. The in-balance of the ammonia ppm in the room might been caused by minimal circulation of air in the room.

The following equation (4) can calculate the efficiency for both ammonia test with cigarette and floor detergent in 6 hours.

$$n = \frac{C_{Hin} - C_{Lout}}{C_{Hin}} \times 100\% \qquad (4)$$

Where C_{Hin} is highest ammonia ppm reading at the inlet of air purifier and C_{Lout} is lowest ammonia ppm reading at the outlet of air purifier. Table 1 is showing the efficiency of both ammonia test with cigarette and floor detergent in 6 hours.

Air purifier ammonia test	Efficiency (Percentage, %)
Burning Cigarette	43.55
Floor Detergent	35.53

Table 1 Efficiency of both ammonia test with cigarette and floor detergent in 6 hours.

The floor detergent might have a higher rate of diffusion than ammonia molecule found in cigarette smoke.

4. Conclusion

4.1 Conclusion

The solar powered air purifier has been designed, fabricated, and tested. It has been proven that the solar power could produce enough energy to run the low-cost air purifier that could be built by using locally available materials and resources.

The test results have shown 67.37% efficiency from solar panel in charging the used battery.

The MQ135 sensor used in air purifier test has shown the efficiency of cleaning ammonia pollutant in the air as 43.55% for burning cigarette and 35.33% for floor detergent.

It also found that floor detergent might have higher rate of diffusion than ammonia molecule found in cigarette smoke.

The proposed solar powered air purifier prototype is found useful and of low cost. It provides affordable and economical energy to power nearby applications for the developing country. Not only that, but the electricity power generation process does also not pollute the environment due to zero usage of fossil fuels and can be a good implementation of the sustainable development goals (SDG's).

Nomenclature

Symbol	Description	Dimension / Unit
PM 10	Particulate Matter 10 Micron	-
S02	Sulfur Dioxide	-
CO2	Carbon Monoxide	-
NO2	Nitrogen Dioxide	-
PM 10	Particulate Matter 2.5 Micron	-
HEPA	High Efficiency Particulate Air Filter	-
MERV	Minimum Efficiency Reporting Value	-
DC	Direct Current	
ppm	Parts Per Million	ppm
µ	Micro Meter	µm
IDE	Integrated Development Environment	-

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References

1. WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Executive summary. (2021). Geneva: World Health Organization. Licence: CC BY-NC-SA 3.0 IGO
2. Malaysia Ambient Air Quality Standard. (2021). Ministry of Environment And Water: Air Quality Standards.
3. Malaysia Ambient Air Quality Standard. (2021). Ministry of Environment And Water: Air Quality Standards.
4. Prinz, A. L., & Richter, D. J. (2022). Long-term exposure to fine particulate matter air pollution: An ecological study of its effect on COVID-19 cases and fatality in Germany. Environmental Research, 204, 111948.
5. ANSI/ASHRAE Standard 52.2-2017. (2017). ASHRAE
6. Chen, W., Zhang, J. S., & Zhang, Z. (2005). Performance of air cleaners for removing multiple volatile organic compounds in indoor air. ASHRAE transactions, 111(1), 1101-1114.
7. Li, M., Weschler, C., Bekö, G., Wargocki, P., Lucic, G., & Williams, J. (2020). Human Ammonia Emission Rates under Various Indoor Environmental Conditions. Environmental Science &Amp; Technology, 54(9), 5419-5428.
8. Spiller, L. (1989). Determination of Ammonia/Air Diffusion Coefficient Using Nafion Lined Tube. Analytical Letters, 22(11-12), 2561-2573.
9. Inaba, Y., Uchiyama, S., & Kunugita, N. (2018). Spectrophotometric determination of ammonia levels in tobacco fillers of and sidestream smoke from different cigarette brands in Japan. Environmental Health And Preventive Medicine, 23(1).
10. John, E., Coburn, S., Liu, C., McAughey, J., Mariner, D., & McAdam, K. et al. (2018). Effect of temperature and humidity on the gas–particle partitioning of nicotine in mainstream cigarette smoke: A diffusion denuder study. Journal Of Aerosol Science, 117, 100-117.

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