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Research Article

The Optimization of Electrostatic Air Filter Layers for Small Dust Particles Reduced

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Abstract:
Air pollution, stemming from natural and industrial sources, necessitates effective air purification methods. Electrostatic air filters offer an eco-friendly alternative to high-efficiency particulate air (HEPA) filters, characterized by low pressure drop, minimal noise, cost-efficiency, and reusability. This study investigates the enhancement of electrostatic air filter performance by increasing layer count. Experimental tests in a 1×1×1 m^3 chamber, using small dust particles (1 µm, 2.5 µm, and 10 µm), reveal that adding layers significantly improves filtration efficiency. Optimal layer counts of 5, 5, and 4 for respective particle sizes maintain compliance with ASHRAE 52.2 MERV Rating 14 standards. According to ISO16890 standards, these filters require maintenance or replacement after 72 cycles when efficiency falls below 60%. This research promotes wider adoption of electrostatic filters for health benefits and energy conservation.

Keywords: *Electrostatic air filters, Small dust particles, Layer of filter*

1. Introduction

Air pollution continues a significant cause on human health worldwide. The World Health Organization (WHO) reports that in 2016 around 3.2 million people died as a result of household smoke and 4.2 million ambient air pollution. In 2022 almost the entire global population (99%) breathes air that exceeds WHO air quality limits, and threatens their health [1, 2].

To reduce the number of tiny dust particles in the air. Install a high efficiency particulate air (HEPA) filter with a filtration efficiency of up to 99.97% for small particles with a diameter of more than 0.3 µm in home air purifier [3]. Despite the excellent air filtration efficiency of the HEPA filter. However, it comes at a high cost in terms of airflow resistance. As a result of the dense weave of the fibers, the exhaust fan requires more energy [4]. To cut down on using energy, an air filter with lower airflow resistance is necessary, known as Electrostatic air filter. Particles are trapped in filters due to electrostatic charge phenomenon [5]. They are also less expensive than HEPA filters, although their dust-filtering effectiveness is still inferior to that HEPA filters.

This research study to improve the dust filtration efficiency of electrostatic air filters. Small dust particles of three sizes, 1, 2.5, and 10 µm, will be evaluated in a closed chamber measuring 1x1x1 m^3 with the method of increasing the number of layers of the filter. To corroborate the optimal number of layers in electrostatic filter will improve dust filtration efficiency, when compared to the HEPA filters. The results of this study can be utilized to inform future research on air pollution or transmission of airborne viruses.

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2. Theory

2.1 Electrostatic Air Filter

The electrostatic air filter made of polypropylene fibre [6] that has been charged with both positive and negative charges since its manufacture. Polypropylene fibre be woven into an air filter with a dense network of channels or holes through which air can pass. It's rough, which allows air to readily travel through the air filter. The tiniest particles that pass through the electrostatic air filter are both positively and negatively charged. The Negative Ionizer is a device that converts negative ions into positive ions. When these airborne particles pass through the air filter, the positively charged particles are drawn to the negatively charged fibre area using the airborne negative ionizer technique. The negatively charged particles are drawn to the positively charged fibres' area.

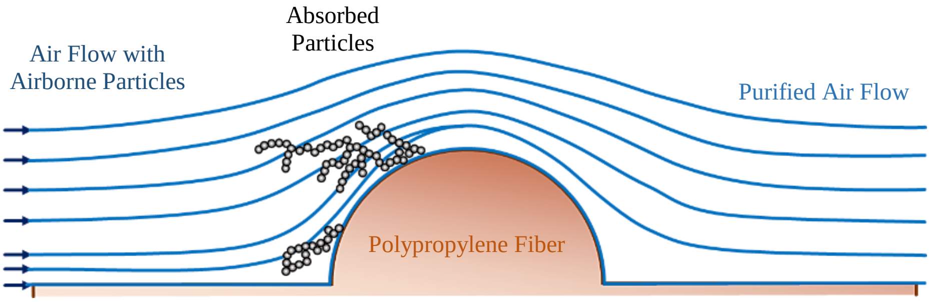

Fig. 1. Electrostatic air filter mechanism.

The electrostatic air filter may absorb particles that pass through the air purifying sheet and collect or trap them all over the surface. As shown in Fig. 1, this air purifier's life is extended by moisture resistance is good because the air filter is constructed of moisture-resistant polypropylene fibers, there will be no germs on it.

2.2 Light Scattering Dust Meter

Light scattering principle shown in Fig. 2, was used to determine the quantity and size of particles. When a particle passes through a laser beam from a light source, it is measured of traveling through space. Depending on the size of the particles that the laser beam strikes, light diffraction occurs at different angles. The particle size is inversely proportional to the angle of diffraction. This is the light's intensity the probe of the particle size meter is used to measure laser diffraction at various angles and can be expressed as the average particle size and is calculated as a percentage and the value of that particle size [7].

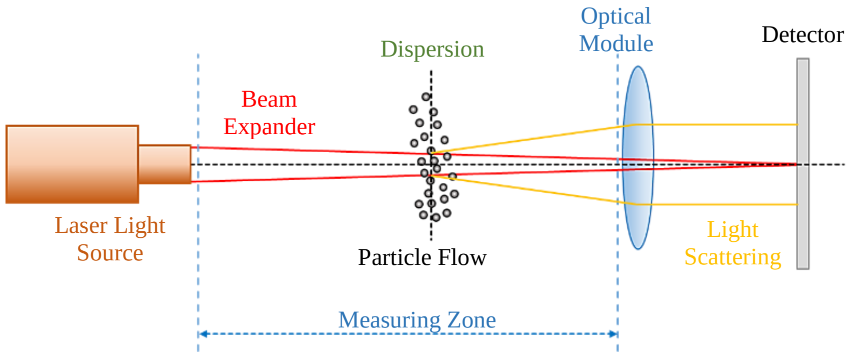

Fig. 2. The principle of light scattering.

2.3 Filtration Efficiency

The filtration efficiency is a variable that indicates how much dust or pollution the filter has filtered out. To determine the filtration efficiency in a closed chamber, dust concentrations of 1, 2.5, and 10 µm were measured. The air purifier should be turned on by turning the fan on with the highest setting measure the original dust concentration, then wait 15 minutes before measuring it again. The filtration efficiency [8] can be calculated as shown in Eqs. (1).

$$\eta = \left(1 - (c_i/c_0)\right) \times 100 \tag{1}$$

where c_0 is the dust concentration when the air purifier is at 0 min. c_i is the dust concentration when the air purifier is at i min. η is the filtration efficiency that combines natural dust precipitation.

3. Methodology

3.1 Air Purifier Design

The design of the air purifier to be used in the experiment is 12 cm wide, 12 cm long, and 25 cm tall as shown in Fig. 3. The air purifier housing is made of transparency acrylic plate. Setting an exhaust fan wind speed average: 2.32 m/s 12V power supply on top. The filter is an electrostatic air filter with dimensions of 10 x 10 cm^2 and a clean air delivery rate (CADR) of 12 m^3/hr in middle.

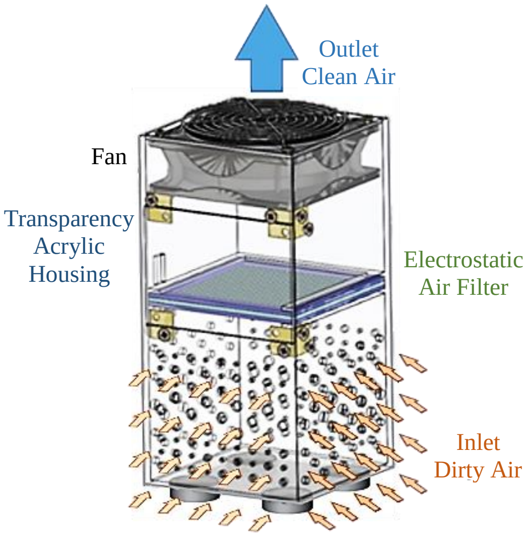

Fig. 3. Air purifier design.

3.2 Calibration

It is important to calibrate the dust measuring device with known value because this research creating a dust measuring instrument based on the laser scattering sensor with Arduino Leonardo. As a result, a 4-digit digital scale was calibrated to show that the creating instrument is accurate and useable.

The unfiltered filter is first weighed on a 4-digit digital scale, the findings are recorded, and the filter is then fitted in an air purifier that will filter the air in a closed control volume chamber. Small dust particles are introduced into chamber, which has an air purifier in the form of incense burning. Then determine the amount of microscopic dust particles (sizes of 1, 2.5 and 10 µm) present to a concentration of 800-900 µg/m^3 (An inconsistency must be defined as a scope). Make sure there isn't any little dust leaking. The air inside the chamber was then stirred with a fan, allowing the microscopic dust particles to disperse equally across the chamber. Turn on the air purifier with a built-in air filter. Filter the air until the fine particulate matter concentration in the chamber is measured at 0 µg/m^3 by the concentration sensor. Calculate the difference in fine dust particle concentrations reported by the sensor. The results were calculated by converting the concentration of particulate matter at the start point minus the concentration of particulate matter at the end point (0 µg/m^3) to weight. Remove the air filter that has been filtered. Calculate the difference between the weight of the air filter after the filter and the weight of the air filter before the filter using a digital scale with 4-digit digital scale. The weight difference between the sensor measurements should be compared. Repeat the calibration 10 times with a 4-digit digital scale and construct a bar chart comparison between sensor measurements with a 4-digit digital scale.

3.3 Small Particulate Natural Reduction Experiment

This experiment was designed to investigate the behavior of the reduction of small dust particles in a closed chamber measuring 1x1x1 m^3 as shown in Fig. 4 without using an air purifier to investigate the behavior of the reduction of small dust particles in the chamber that there is a reduction of small dust until the concentration of small dust reaches a certain level. The results of this experiment will be used as a baseline against which the filtration of a chamber air purifier will be compared.

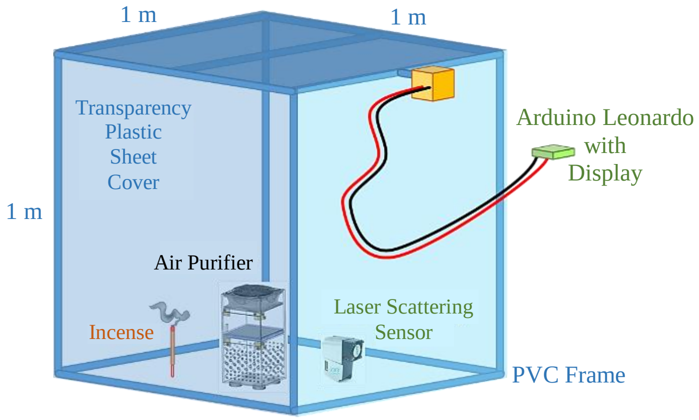

Fig. 4. Air purifier design.

It begins with a little amount of dust being inserted into a sealed chamber through the use of incense. Then, at a concentration of 350 µg/m^3, measure the concentration of small dust to a dust concentration of 1, 2.5 and 10 µm. The air inside the chamber is then stirred by a fan, allowing the microscopic dust particles to disperse equally across the chamber. Within 60 min, the dust content in the confined chamber was measured every 1 min. The experiment was carried out three times.

3.4 Electrostatic air filter small dust filtration experiment

This experiment is a consider of ability to reduce the concentration of fine dust particles of electrostatic air filters by adding a layer of the number of filters, tested in a closed chamber with a size of 1x1x1 m^3. The experiment is divided into 3 sizes of dust: 1, 2.5 and 10 µm, respectively. It begins with a little amount of dust being inserted into a sealed chamber, through the use of incense. Then determine the amount of small dust particles present 350 µg/m^3 is the maximum concentration. The air inside the test chamber is then circulated by a fan, allowing the small dust particles to spread uniformly across the chamber. Turn on the air purifier with a built-in air filter. (Begin with a single layer of filter) Filtration of the air for 60 min, with results recorded every minute.

With each filter experiment, the test was repeated 3 times. The results were averaged. Filter layers were added one at a time, and the experiment was repeated. Until it was discovered that adding a filter did not significantly improve air filtration capacity. The filtration efficiency was calculated using the results of each addition experiment. The effect of adding a filter layer on the filter efficiency values is compared by calculating with Eqs. (1).

In addition, the project creator will compute the electrostatic air filter's economic efficiency. Based on a percentage per baht to determine the number of filter layers that will provide the best economic value.

3.5 The Cycles Use of an Electrostatic Air Filter Experiment

Experiment to find out how many cycles the electrostatic air filter must have. In the chamber, an air purifier with an electrostatic filter was installed. Then 2.5 μm dust was added at a concentration of 350 μg/m^3. Activate the air purifier and monitor the dust reduction every 1 min for the next 60 min.

When completed, calculate the filtration efficiency of dust reduction using the results obtained, and keep track of the performance metrics dust with a 350 μg/m^3 concentration. Repeat for 100 cycles, concluding that the filter should be replaced when the dust reduction efficiency is less than 60%, as defined by ISO16890.

4. Results and Discussion

The difference in pre-filter weight between a 4-digit digital scale and the laser scattering sensor measuring revealed an average error of 7.22 %. Which can be displayed as a graph in Fig. 5.

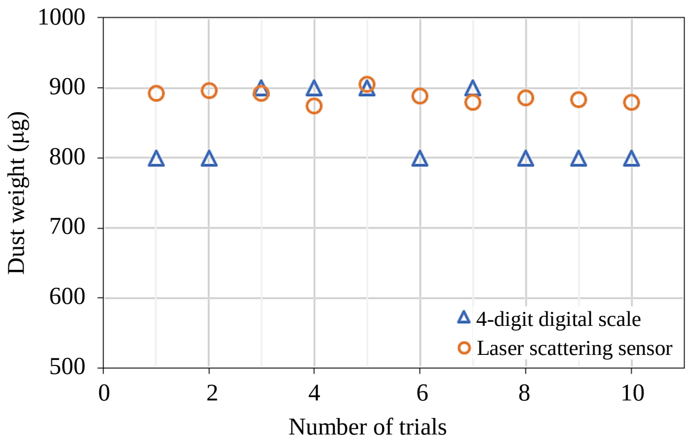

Fig. 5. Comparison of dust weight between 4-digit digital scale and Laser scattering sensor.

The natural reduction of small dust particles in a closed chamber 1x1x1 m^3 without placing an air purifier inside within 60 min was calculated from Eqs. (1) found that 1, 2.5 and 10 μm of dust have a filter efficiency of 11.20%, 23.02% and 23.34%, respectively.

Small dust reduction experiment using an electrostatic air filter. Filter out the dust in the enclosed space. Then, until the 7th layer, increase the number of layers of the filter. The results of the 1, 2.5 and 10 μm dust filtration experiment are shown in Fig. 6.

Fig. 6 shows that reductions in dust concentrations of 1, 2.5 and 10 μm respectively, resulted in a very small reduction in dust concentration with 0 filter layers, but there was a greater reduction in dust concentration when the number of filter layers was increased. The more layers there are, the better the dust concentration can be reduced. Table 1 shows the average efficiency in the dust reduction of the three dust sizes in each layer.

According to the hypothesis testing using P-value, the filtration efficiency of 1, 2.5 and 10 μm in the number of electrostatic air filter layers 5 and above showed no difference in filtration efficiency. The three dust sizes were the same at the significance level of 0.01. As a result, the best number of layers of dust reduction electrostatic air filter of 1, 2.5 and 10 μm dust was 5 layers, with filtration efficiency of 94.28 %, 98.34 %, and 98.38 %, respectively.

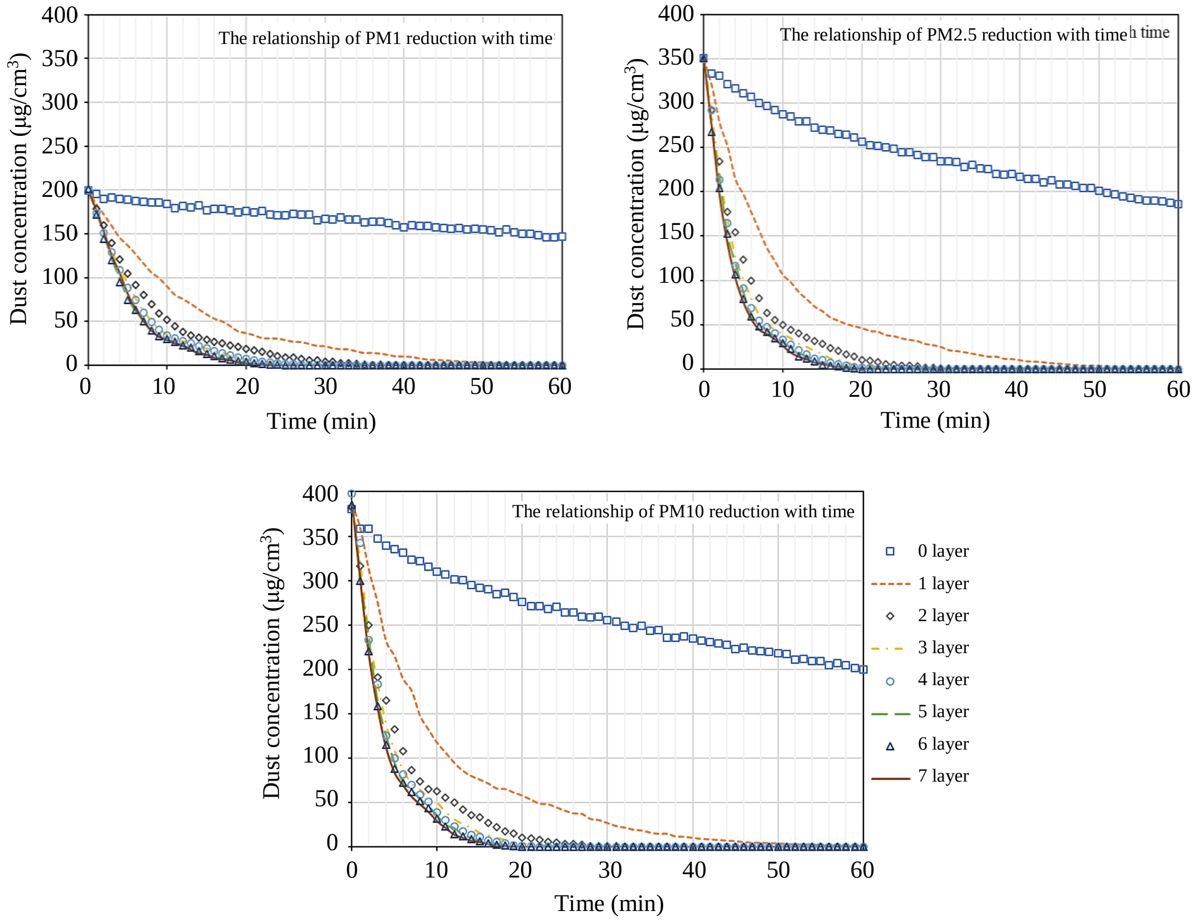

Fig. 6. The relationship of PM1 PM2.5 and PM10 reduction with time by adding a layer of filter.

Table 1: Average filtration efficiency by increasing the number of layers of the filter.

Number of layers	**Average filtration efficiency (%)**		
	1 μm	**2.5 μm**	**10 μm**
1	71.28	80.78	78.94
2	84.63	91.48	91.17
3	90.69	95.48	95.71
4	90.82	97.48	97.68
5	94.28	98.34	98.38
6	94.12	98.73	98.67
7	94.89	98.96	99.04

The pressure drop of an electrostatic air filter is directly proportional to the number of layers. And the pressure drop is inversely proportional to the size of the dust, with 1 μm dust having the highest pressure drop and 10 μm dust having the lowest pressure drop. The pressure drop across the filter is shown in Fig. 7 compared to the number of filter layers by filtering dust of 1, 2.5 and 10 μm, respectively.

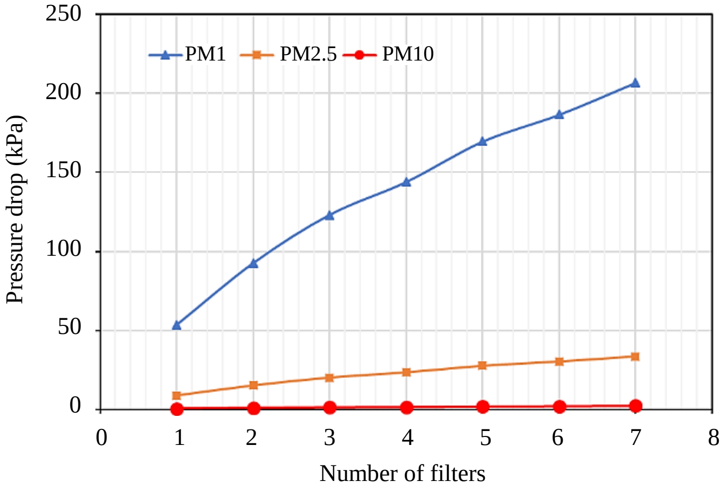

Fig. 7. The pressure drop across to the number of filter layers.

To determine the number of cycles, 2.5 µm of dust were filtered at a dust concentration of 350 µg/m^3. After 100 cycles of use, it was discovered that the filter should be replaced after the 72nd cycle of use. The filtration efficiency is 59.76 %, which is less than the ISO standard 16890 of 60 %. Fig. 8 shows the degradation of filtration efficiency as a function of the number of uses.

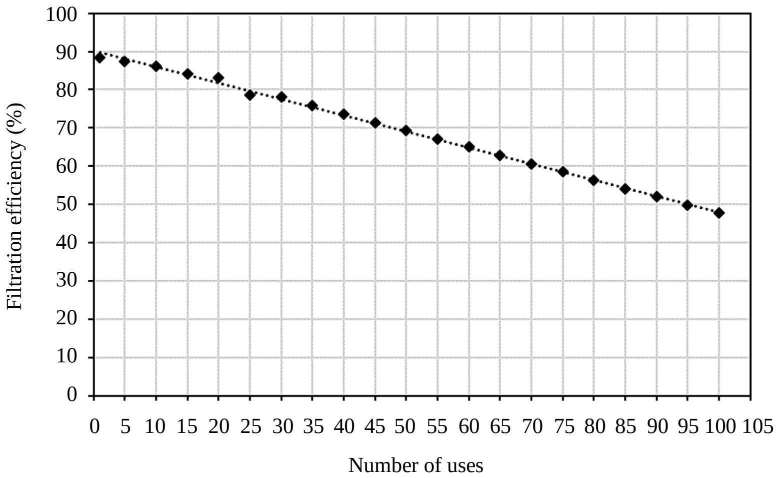

Fig. 8. Decreased efficiency of dust reduction per number of uses.

5. Conclusion

Based on research and experiments, the results were found to be satisfactory and to have achieved the intended purpose or scope. It was discovered that increasing the number of electrostatic air filter layers increased filtration efficiency. When the results were analyzed using the P hypothesis test, it was discovered that the number of filter layers providing the highest efficiency. There are 5 layers of filter for dust size of 1, 2.5 and 10 µm, filtration efficiency in a greater number of filter layers, which statistically makes no difference.

However, when the results were analyzed in terms of economic efficiency, it was discovered that the number of layers of filter 2 layer would be the most economically worthwhile and good quality enough by minimum efficiency reporting value (MERV) rating.

When compared to the pressure drop generated by the high efficiency filter (HEPA filter), the pressure drop of the electrostatic air filter was found to be highest at 1 µm, followed by 2.5 µm, and the lowest at 10 µm. It indicates that the addition of an electrostatic air filter provides filtration efficiency comparable to a HEPA filter while causing less pressure drop.

According to the ISO16890 standard, the number of cycles of use of the electrostatic air filter reported that the filter should be replaced when the filtration efficiency is below 60% at the 72nd cycle. Dust will be able to pass through the filter at 1 µm of dust can reach the deepest parts of the human lungs, resulting in health hazards.

Acknowledgments

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