# Detergent Aerosol and Electric Field Assisted Low Cost Emission Purifier for Automobiles

Nadeesha M. Gunawardana
*Faculty of Science*
*University of Peradeniya*
Peradeniya, Sri Lanka
n2m3g4@gmail.com

D.N.P. Ruwan jayakantha
*Faculty of Science*
*University of Peradeniya*
Peradeniya, Sri Lanka
r.jayakantha@gmail.com

Migara Karunarathne
*Department of Electrical Engineering*
*Sri Lanka Technology Campus*
Padukka, Sri Lanka
migarak@sltc.ac.lk

K. Rochana
*Department of Electrical Engineering*
*Sri Lanka Technology Campus*
Padukka, Sri Lanka
rochanad@sltc.ac.lk

Nanda Gunawardhana
*Faculty of Science*
*University of Peradeniya*
Peradeniya, Sri Lanka
kgngu@yahoo.com

***Abstract*—The increasing levels of air pollution have raised significant concerns about public health and environmental sustainability. On a global scale, air pollution is attributed to approximately 7 million premature deaths annually, 70% of those deaths occur in Asia-Pacific region. Air pollution poses a significant challenge in South Asian countries. WHO database states two major groups of air pollutants particulate matter (PM) and nitrogen oxides (NOx), the main source of them primarily arises from vehicular emissions. Sri Lanka is categorized as a country with a moderate level of air cleanliness with a US Air Quality Index (AQI) of 78. The average annual concentration of the pollutant $PM_{2.5}$ is at 25 μg/m$^3$[1-3]. Among the pollutants emitted by automobiles, microscopic particulate matter (PM) has been identified as a major contributor to respiratory disease and climate changes. This study presents a novel device designed to effectively trap and filter particles emitted from vehicle exhaust. The device incorporates a combination of three main components: cyclone filter, electrostatic barrier and unique purification method using aerosol cleaners. The cyclone filter removes the heavier particles, while aerosols interact with most of the fine PM. Additionally, an electrostatic barrier blocks the bypassing of the remaining contaminated aerosols. The objective of this study was to evaluate the device's performance in terms of pollute particle removal ability with distinct way and hence improve air quality. By focusing on removing PM from vehicle emissions, this approach contributes to the promotion of cleaner and greener transport technologies.**

***Keywords—Particulate matter (PM), detergent aerosol, vehicular emission***

## I. Introduction

Clean air is indispensable to mankind's wellbeing as well as the planet's sustainability for future generations. The breathable atmosphere has a principal bearing on our respiratory system wellness and our general quality of life. Unfortunately, air contamination has become a worldwide predicament, placing numerous hazards on human health and the environment. The exhausts spewed from cars are accounted to be a major factor amongst many others. The burning of fossil fuels in internal combustion motors generates harmful toxins, such as carbon monoxide, nitrogen oxides, particulate matter, and volatile organic compounds, causing serious adverse health effects and environmental deterioration. With the ever-growing number of vehicles on the roads, the need to devise impactful solutions to reduce car emissions has never been greater.

One of the most concerning pollutants in the atmosphere is particulate matter (PM). Particulate matter refers to tiny solid or liquid particles suspended in the air, varying in size, composition, and origin. It can be generated through natural processes such as dust storms and volcanic eruptions, as well as human activities including industrial processes, combustion of fossil fuels, and transportation.

PM pollution has obtained considerable attention due to its harmful effects on human health. These microscopic particles can enter the respiratory system and penetrate deep into the lungs, causing respiratory and cardiovascular problems. Fine particles, known as $PM_{2.5}$, are of particular concern as they are small enough to reach the lungs and enter the bloodstream directly, potentially leading to systemic health issues. Daily exposure to PM has been linked to increased rates of respiratory diseases, lung cancer, and even premature death. The impact of particulate matter extends beyond human health, affecting the environment as well. Fine particles can contribute to reduced visibility and haze formation and decreasing air quality. Additionally, certain components of particulate matter, such as black carbon, can absorb sunlight and contribute to global warming, influencing climate patterns [7-10].

Smoke purifiers, also known as automotive air purifiers or vehicle emission control systems, are designed to remove pollutants from the exhaust gases emitted by vehicles. These devices utilize various mechanisms to trap and neutralize harmful pollutants, thereby reducing their impact on human health and the environment. Commercially available emission control systems are incorporated with various technologies such as high efficiency particulate air (HEPA) filters, activated carbon filters, and UV-C sterilization to effectively trap and neutralize airborne particles and pollutants. These systems include components like catalytic converters and exhaust gas recirculation (EGR) systems. They work by converting or reducing harmful emissions, such as nitrogen oxides, carbon monoxide (CO), and hydrocarbons (HC), into less harmful substances. By evaluating the current state of smoke purifier technology, we aim to identify the potential challenges and opportunities for their widespread adoption in the automotive industry [11-15].

## II. Methodology

Experimental setup (Figure 01) was composed with a cyclone filter, an electrostatic barrier, aerosol generators and a liquid filter. Cyclone filter was built with galvanized iron (GI) sheet to prevent corrosion. Inlet of the cyclone filter was connected PVC pipe and it was attached to a flexible GI hose. The flexible hose can directly be connected to the tail pipe of the vehicle. Here PVC pipe is acted as high voltage insulator in between the vehicle and purifying unit. The cyclone filter, positioned at the inlet of the device, this initial filtration step aids in reducing the load of coarse particulates entering the subsequent stages of the device.

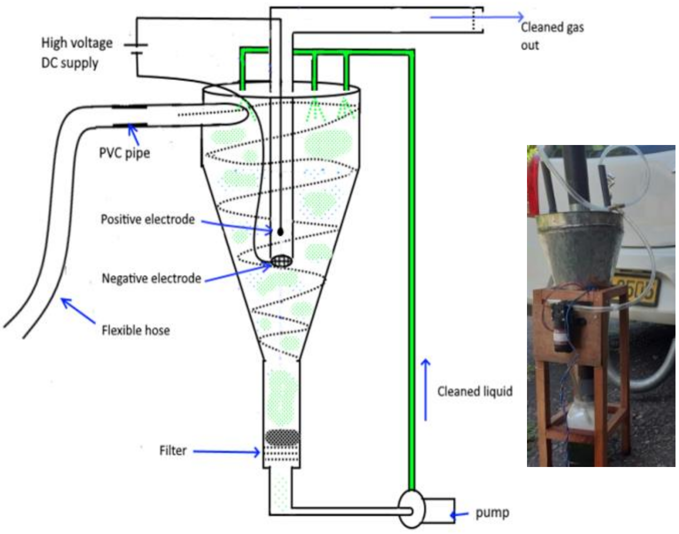


Fig. 1. Experimental setup and a photograph of the emission purifier

### A. Aerosol Generator

Detergent aerosol generators were built with commercially available low pressure atomizing nozzle and they were fixed inside the cyclone filter and also a cellulose filter was placed at the bottom of the cyclone filter. It was utilized to separate PM from detergent liquid and hence filtrate can be recycled and then it was circulated through the system with aid of mini water pump (12 V 2 A, 3.5 L/min). The flow rate of the cleaned liquid was controlled with motor speed controller (PWM 1803BK Mini DC Motor Speed Regulator 30 W) and therefore the atomization rate of liquid could also be varied. Commercially available dishwasher liquid was diluted with water to get different concentrations of detergent liquid for the experiment.

### B. Electrostatic Barrier

The Electrostatic barrier was made with two electrodes, negative electrode was iron mesh and an aluminum blind rivet was used as positive point electrode (Figure 02 (b), (c)). The electric field in this configuration exhibits radial symmetry, meaning it extends outwards in a symmetrical pattern from the point electrode towards the negative electrode (Fig. 2). Commercially available high voltage generator module (Fig. 3) was used as high voltage dc source.

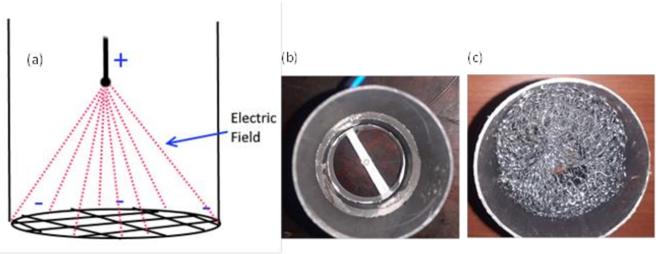


Fig. 2.(a) Electric field, (b) positive electrode and (c) negative electrode of electrostatic barrier

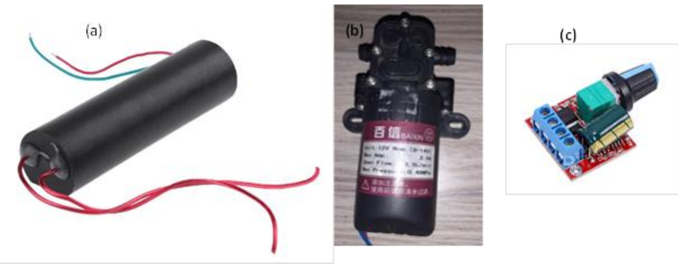


Fig. 3. (a) High voltage module, (b) mini water pump and (C) motor speed controller

Due to the presence of positive and negative electrodes, an electric field is established in the vicinity of the system. When an aerosol droplet passes by the negatively charged electrode (mesh), the electric field induces ionization in the surrounding air molecules and polarizes the aerosol. This ionization process involves the removal of electrons from the air molecules, leading to the creation of positive ions and free electrons. The negatively charged electrode exerts an attractive force on the positive ions within its proximity. Consequently, these positive ions are drawn towards the electrode due to coulombic attraction. Positive ions can either reach the negative electrode or come into contact with the polarized aerosol. If a polarized aerosol encounters a positive ion or a free electron, the aerosol droplet acquires a net negative or positive charge, respectively. As a result, it can adhere to the electrode. This process can be regarded as a trapping mechanism for capturing contaminated aerosols (Fig. 4) [18-20].

The electric field near the positive point electrode is highly concentrated and intense. As a result of this strong electric field positively charged aerosol droplets are not allow to pass the positive electrode. This arrangement of electric field acts as a barrier for charged aerosol droplets.

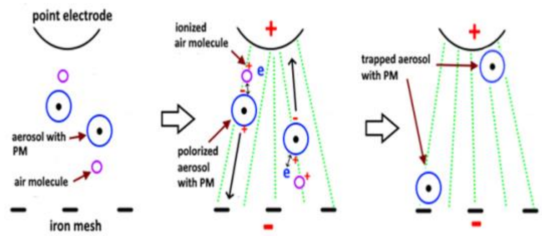


Fig. 4. Charging and trapping mechanism of aerosols with electric field

### C. Mechanism of Purification

First, exhausted gas from vehicle is entered to the cyclone filter so gas is in swirling motion toward the bottom of the cyclone filter while making contact with detergent aerosol which is coming from aerosol generators. Larger and heavier particles in gas are migrated towards the walls of the cyclone filter because of the centrifugal force and they are washed down with detergent subsequently. Detergent aerosol acts as a surfactant, enhancing the interaction between the aerosol and the particles, facilitating their dissolution and subsequent capture by filtrations. This innovative approach aims to improve the overall particulate matter removal efficiency, especially for hydrophobic and stubborn particles that may be resistant to conventional filtration methods.

The remaining aerosol mixture, consisting of PM particles with detergent aerosol droplets, is directed into the electrostatic barrier. Here, these particles have two possible outcomes: they can either adhere to the electrodes or be pushed back towards the cyclone filter. This behavior is a result of the electric field's influence, as previously discussed. The primary purpose of this stage is to ensure that aerosol droplets do not escape from the purifier.

### D. Detection of PM

Monitoring and detecting PM concentrations in the exhausted gas is crucial. The PM monitoring unit (Figure 05) was made with the SDS011 sensor and few other electronic components (arduno-nano, oled display, etc.). It can be used for measuring PM levels in real-time. The SDS011 sensor is an optical air quality sensor specifically designed to measure $PM_{2.5}$ and $PM_{10}$ concentrations. It utilizes a laser-based scattering principle to detect and quantify the concentration of particles suspended in the air. The sensor consists of a laser diode that emits light and a photo-detector measures the scattered light intensity. By analyzing the amount of scattered light, the sensor can estimate the concentration of $PM_{2.5}$ and $PM_{10}$ particles in the surrounding environment [21, 22].

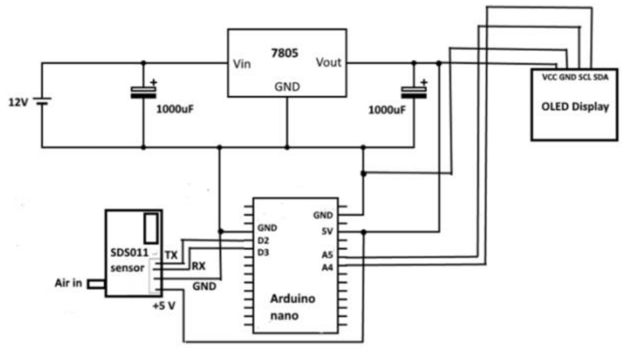


Fig. 5. Circuit diagram of PM monitoring unit

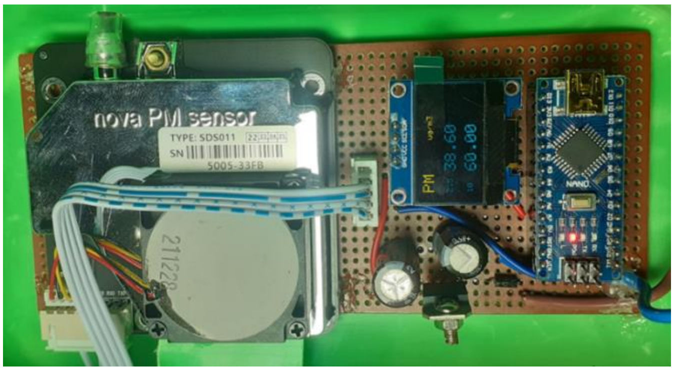


Fig. 6. PM monitoring unit with SDS011 sensor, OLED display with arduino nano

## III. Experimented Results

### 1. Testing Purifier Unit with Diesel Vehicle

The experiment involved the use of a Nissan Vanette diesel van as test vehicle. Initially, the concentration of particulate matter (PM) in the exhausted gas was recorded with PM detector without attaching an emission purifier unit. Throughout the experiment, the van was maintained in neutral mode without acceleration. Subsequently, the emission purifier unit was affixed to the van's tailpipe. To identify the dispersion of PM in detergent liquid, the cellulose filter was temporarily removed, and detergent liquid was collected in a transparent container for duration of 10 minutes. The transformation of the detergent liquid from green to black with time was observed through visual inspections (Figure 06).

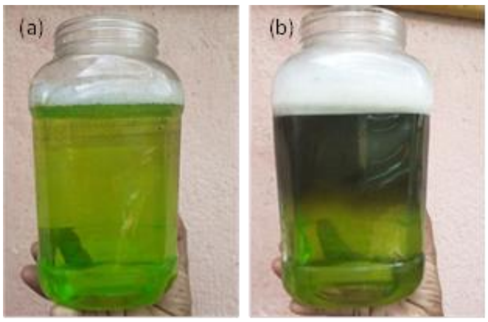


Fig. 7. Detergent liquid (a) initial and (b) after circulation through the system for 10 min

Then the collected samples of detergent liquid were characterized with UV visible spectroscopy

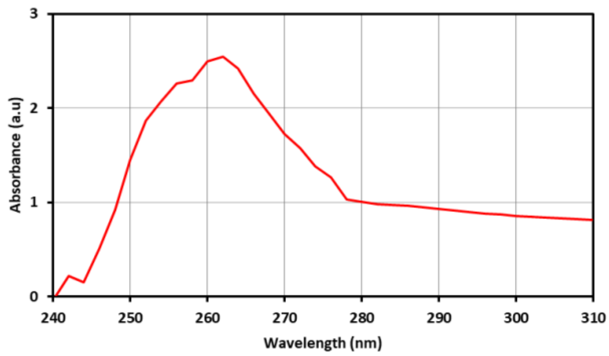


Fig. 8. UV-visible spectrum of detergent liquid with PM

The emergence of a peak within the UV-visible spectrum serves as a confirming indicator of the presence of a extrinsic substance which was coming from exhausted gas of vehicle compared to the pure detergent liquid. To further validate PM dispersion in detergent, three liquid samples were collected at varying circulation times. As the circulation time increased, it was evident that PM dispersion in the liquid had indeed grown, as confirmed by the heightened peak observed in the UV-visible spectrum (Fig. 8).

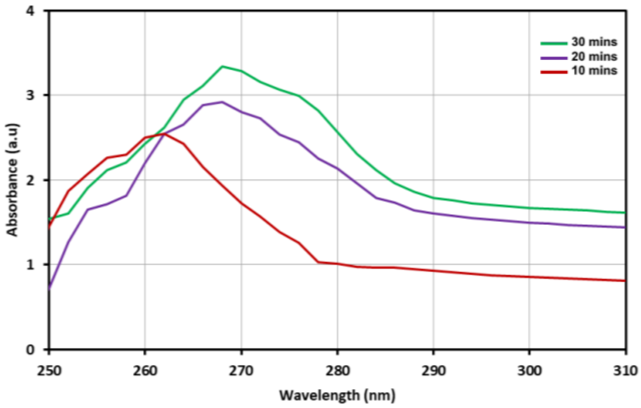


Fig. 9. UV-visible spectrum of collected detergent liquid after different circulation time of liquid

Prior to assessing the device's effectiveness, cellulose filter was installed back into the system. The exhaust gas from the vehicle was then directed into a purifier maintaining a constant flow rate during this process. As the gas exited the purifier, it was recorded the PM concentration along with the corresponding detergent concentrations. Subsequently, the PM reduction percentages and detergent percentages were calculated based on this data. Finally, it was graphically represented for analysis. This process allowed us to evaluate the performance of the device and its efficiency in reducing particulate matter emissions from the vehicle.

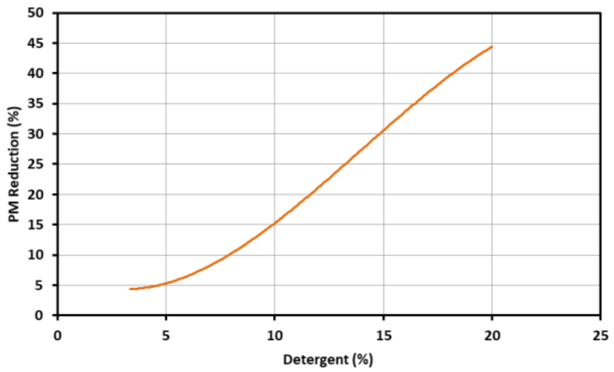


Fig. 10. The reduction percentage of PM with respect to the detergent liquid percentage

The graph indicates that as the detergent percentage increases, the reduction percentage of PM also rises. However, this increase in detergent content is accompanied by an elevation in liquid viscosity. Consequently, the escalating viscosity poses challenges to the filtration process of the contaminated liquid, primarily due to the thicker consistency of the liquid. In order to maintain continuous filtrations process, detergent percentage was kept at 20% and hence the maximum PM reduction percentage was 44% under the above conditions.

## IV. Conclusion

The removal of particulate matter (PM) from vehicle exhaust gases, particularly using the novel detergent aerosol method, was successfully demonstrated through this innovative approach. It was validated through visual inspection and further confirmed via UV-visible spectroscopy. In the entire purification process of this device, detergent aerosols serve as the primary cleaning agent, while the electrostatic barrier technique is employed as a secondary step to prevent the bypassing of any remaining aerosols. When examining the gas flow path of the purifier, it's important to note that there are no barriers, ensuring that there is no increase in engine pressure of the vehicle. This presents a significant advantage compared to commercial and industrial smoke purifiers. Being the initial prototype, this device is primarily befitted for diesel vehicles, especially those with substantial emissions like public buses. However, there is potential for further advancement to create a smaller, more compact device suitable for all types of automobiles. Automation can be incorporated to dynamically adjust aerosol generation speed in response to vehicle acceleration, achieved through enhancements in the filtration and detergent liquid recycling processes. Moreover, this study will provide valuable insights for automotive manufacturers and researchers, fostering informed decision-making in the pursuit of more environmentally friendly transportation system by bridging the gap between theory and practice, also this research aim to contribute to a cleaner and healthier environment for current and future generations.

## V. Acknowledgements

This work was supported by the RRSG project at SLTC. (Grant No: RRSG.22.0712.1)

## VI. References


[1] Air quality index (AQI) and PM2.5 air pollution in Sri Lanka (https://www.iqair.com/sri-lanka, accessed 09/2023)

[2] Rathnayake L.R.S.D, Sakura G.B, Weerasekara N.A, (2023). Review of Outdoor Air Pollution in Sri Lanka Compared to the South Asian Region. Nature Environment and Pollution Technology, Vol. 22, No. 2, 609-621. DOI : https://doi.org/10.46488/NEPT.2023.v22i02.006

[3] Air quality database: Update 2022 (WHO) (https://www.who.int/data/gho/data/themes/air-pollution/who-air-quality-database/2022, accessed 09/2023)

[4] Depcik, C., Langness, C., and Mattson, J., "Development of a Simplified Diesel Particulate Filter Model Intended for an Engine Control Unit," SAE Technical Paper 2014-01-1559, 2014, https://doi.org/10.4271/2014-01-1559.

[5] Miller B, (2015). Emissions Control Strategies for Power Plants, Coal Energy Systems, 2005, Pages 283-392. DOI: https://doi.org/10.1016/B978-012497451-7/50006-1.

[6] Daniel A. Vallero, (2019). Chapter 13 - Air pollution control technologies, Quantifying Pollutant Formation, Transport, Transformation, Fate and Risks, 2019, Pages 377-428. DOI : https://doi.org/10.1016/B978-0-12-814934-8.00013-2.

[7] Hamanaka RB, Mutlu GM, (2018). Particulate Matter Air Pollution: Effects on the Cardiovascular System. Front Endocrinol (Lausanne). 2018 Nov 16;9:680. doi: 10.3389/fendo.2018.00680.

[8] Crinnion W. Particulate,(2017). Matter Is a Surprisingly Common Contributor to Disease. Integr Med (Encinitas). 2017 Aug;16(4):8-12. PMID: 30881250; PMCID: PMC6415634.

[9] Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E, (2020). Environmental and Health Impacts of Air Pollution: A

Review. Front Public Health. 2020 Feb 20;8:14. doi: 10.3389/fpubh.2020.00014. PMID: 32154200; PMCID: PMC7044178.

[10] Singh K and Tripathi D (2021) Particulate Matter and Human Health. Environmental Health. IntechOpen. DOI: 10.5772/intechopen.100550.

[11] Simpson B. H. (1971). Automotive Emissions Control. Journal of the Washington Academy of Sciences, 61(2), 128–137. http://www.jstor.org/stable/24535478

[12] Dong X, (2021). Design of a filtering car air purifier, IOP Conference Series: Earth and Environmental Science, Volume 632, DOI 10.1088/1755-1315/632/5/052095.

[13] Song X, Hao Y,(2021). Research on the Vehicle Emission Characteristics and Its Prevention and Control Strategy in the Central Plains Urban Agglomeration, China. Sustainability. 13(3):1119. https://doi.org/10.3390/su13031119

[14] Watson AY, Bates RR, Kennedy D, editors. Air Pollution, the Automobile, and Public Health. Washington (DC): National Academies Press (US); 1988. Automotive Emissions. Available from: https://www.ncbi.nlm.nih.gov/books/NBK218144/

[15] Mazza S, Aiello D, Macario A, De Luca P,(2020). Vehicular Emission: Estimate of Air Pollutants to Guide Local Political Choices. A Case Study. Environments. 2020; 7(5):37. https://doi.org/10.3390/environments7050037

[16] Peirce J.J, Weiner R.F, Vesilind P.A, (1998). Chapter 21 - Air Pollution Control, Pages 297-313. DOI : https://doi.org/10.1016/B978-0-7506-9899-3.X5000-7 .

[17] Pham T-D, Lee B-K, Lee C-H, et al. (2015) Emission Control Technology. Current Air Quality Issues. InTech. DOI: 10.5772/59722.

[18] Chester T. O'Konski and Henry C. Thacher Jr.(1953) The Distortion of Aerosol Droplets by an Electric Field. The Journal of Physical Chemistry 1953 57 (9), 955-958. DOI: 10.1021/j150510a024

[19] Dmitrii N. Gabyshev, Alexander A. Fedorets, Nurken E. Aktaev, Otto Klemm, Stepan N. Andreev,(2019). Acceleration of the condensational growth of water droplets in an external electric field, Journal of Aerosol Science, Volume 135, 2019, Pages 103-112, ISSN 0021-8502, https://doi.org/10.1016/j.jaerosci.2019.06.002.

[20] Jennings S.G,(1975). Electrical charging of water drops in polarizing electric fields, Journal of Electrostatics, Volume 1, Issue 1, 1975, Pages 15-25, ISSN 0304-3886, https://doi.org/10.1016/0304-3886(75)90004-2.

[21] Patwardhan I, Sara S, Chaudhari S, (2021). Comparative Evaluation of New Low-Cost Particulate Matter Sensors. 2021 8th International Conference on Future Internet of Things and Cloud (FiCloud), Rome, Italy, 2021, pp. 192-197, doi: 10.1109/FiCloud49777.2021.00035.

[22] Migos T, Christakis I, Moutzouris K, Stavrakas I, (2019). On the Evaluation of Low-Cost PM Sensors for Air Quality Estimation. 2019 8th International Conference on Modern Circuits and Systems Technologies (MOCAST), Thessaloniki, Greece, 2019, pp. 1-4, doi: 10.1109/MOCAST.2019.8742041.

[23] Nikam J, Chavan N, Patil A, Prof. Pisal N.S, Salunkhe R, (2022). Design and Development of Silent Air Purifier and Humidifier Using Water Filter, International Journal for Research in Applied Science & Engineering Technology, ISSN: 2321-9653; Volume 10 Issue VII July 2022, https://doi.org/10.22214/ijraset.2022.45508.