ISBN 978-974-625-956-9
RMUTR & RICE International Conference 2022, pp. 49-58,
22-24 June 2022

doi: 10.14457/RMUTR.res.2022.6
Received 09.05.22/ Revised 15.06.22/ Accepted 15.06.22

Investigation of Main Experimental Factors to Small Electrostatic Precipitator Prototype for PM 2.5 Elimination

Rungrote Sumarat[1,*]

Parnuwat Usapein[1]

[1]Rattanakosin College for Sustainable Energy and Environment,
Rajamangala University of Technology Rattanakosin
*E-mail address: rungrote.sum@rmutr.ac.th
Corresponding author

Abstract

Electrostatic precipitator (ESP) is well known for dust removal with high efficiency; however, it still needs to be developed to reduce the amount of PM2.5 in a specific area due to the complexity of the PM2.5 emissions sources. In this research, the new ESP prototype was developed to investigate the factors affecting the efficiency of an electrostatic precipitator for PM2.5 removal in Thailand.

In this work, the prototype of ESP was constructed with a range of DC voltages from 0-30 kV. Pulse width modulation (PWM) was used to adjust the voltage for supplying a high direct voltage to the model. Electrode plates are made of stainless steel with the dimension of 0.8 mm thickness, 410 mm wide, and 400 mm high. Three key parameters (e.g., voltages (0-30 kVDC), air velocity (0.2-1.6 m/s), and time of the experiment (0-120 mins) were investigated to find the suitable condition for capturing PM2.5.

The results found that the highest efficiency of PM2.5 removal was 95% at 48 minutes of time experiment, the air velocity of 0.2 m/sec, and the voltages of 24 kVDC. When relative humidity and air velocity increase, the efficiency of PM2.5 removal tends to decrease. In addition, the too low distance between electrostatic wire and electrode plate can occur corona discharge breakdown voltage.

Keywords: *Electrostatic Precipitator, Particulate Matter, Experimental Factors,*

1. Introduction

The current urban dust situation continues to create a health risk for people, which needs to be addressed early. At present, there is cooperation from many parties on methods for eliminating and reducing the number of particulate matter smaller than 2.5 microns (PM2.5), 5 microns (PM5), and 10 microns (PM10), but there are still PM2.5 particles that exceed the standard in many areas around the world. PM2.5 in an urban area can be generated from different sources, for example, the emissions of toxic smoke, diesel combustion, construction, roadside, and restaurants. In the case of industrial areas, PM2.5 can be generated from factories, for instance, cement plants, metal casting factories, and power plants (ARB, 2022). In addition, it can be emitted from forest burning or burning in agricultural areas. PM2.5 is also related to transboundary smog from neighboring countries in different seasons depending on wind direction. PM2.5 can enter the body and accumulates in the lung membranes, causing the lungs to deteriorate and the human respiratory system becoming less efficient, causing pneumonia and people can suffer from asthma (Xing et al., 2016).

Standard values of PM2.5 dust in Thailand according to the Notification of the National Environment Board No.36, B.E. 2553 (2010) have set the average amount of particulate matter in the atmosphere (PCD, 2010). For ambient air standard, PM2.5 must not more than 50 micrograms per cubic meter ($\mu g/m^3$), as 24-hours average value. The average concentration in 1 year is not more than 25 $\mu g/m^3$. Information from the Bangkok Air Quality and Noise Management Division website on April 10, 2022. There is a list of particulate matter that exceeds the 24-hour average standard in the Bangkok area in 68 areas beginning to affect people's health, which can be measured in the range of 58-99 $\mu g/m^3$.

According to guidelines for reducing the amount of small dust from the government sector (PCD, 2019), there are three measures for driving the national agenda, which are:

(1) Increasing the efficiency of spatial management. Focus on the management/control of pollution from sources in the area by defining guidelines for solving problems during crises, including taking urgent action on solving air pollution problems to cope with the situation in crisis problem areas and dust-prone areas, optimizing spatial management

(2) Prevention and reduction of pollution at the source. Focuses on the control and reduction of air pollution emissions from sources. including reducing the number of pollution sources

(3) Increase the efficiency of pollution management by developing systems, tools, and management mechanisms. Develop knowledge in various fields as information for decision making and setting guidelines for preventive measures and solving problems in the future. It consists of short-term and long-term measures.

According to the measures from the government, there are both short-term and long-term measures. The installation of dust concentration monitoring equipment and the installation of additional dust treatment and filtering equipment is one of these measures. Therefore, this research has foreseen the need to have a device to collect PM2.5 particles that can be produced by ourselves in Thailand. Previous research both abroad and domestic found that the generation of negative charge from free ion dissociation in the atmosphere with high direct current voltage to generate high strength of electric field can be used to capture PM2.5 particles. This technique can provide the efficiency of dust capture as high as 99.9% with low energy consumption. Electrostatic precipitator (ESP) are widely used in various industrial applications such as applications to capture dust particulate from fuel combustion in power plants in metallurgy plants (Parker, 2003), and oil vapor from machinery (Zhang et al., 2022b), and etc.

Previous research has been conducted on the application of the ESP to a variety of situations. (Lusiandri et al., 2019) studied the application of the ESP to reduce pollutant from the result burning in the ship main engine. They found that the level of nitrogen oxide (NO_x) was dropped to 50%, and the sulfur dioxide was dropped to 45.2%, when ESP was operated. To increase the efficiency of ESP, the model of ESP was developed by optimizing the corona wire arrangement (Wang et al., 2021). When adjusting different wire-plate and wire-wire distances from 300 mm to 100 mm, the efficiency was decreased to 58.1%, 45.2%, and 37.4%, respectively. (Zhang et al., 2022a) designed a numerical computational method to study the effect of ionic wind and applied magnetic field under the capability of the ESP and wire-plate. They found that when the air velocity increased, the dust collection efficiency tends to decline non-linearly. The efficiency of collecting small dust particles was lower than that of larger ones. The collaboration of the ionic wind and applied magnetic field can be more efficient than the applied electric field alone. In summary, there are much research on ESP in various application, but the investigation on the main experimental factors (such as: voltage, air velocity, and time duration) is limited, especially the condition of ambient air in Thailand. In view of this, the objective of this study was to investigate the influence of voltage, air velocity, and time duration on the efficiency of capturing PM2.5 by ESP. The new ESP prototype was built in lab-scale, and the main factors affecting trapping performance were analyzed.

2. Methodology

In this research, a prototype was created to trap PM2.5 particles with electrostatic charges. Three variables namely, voltage level, air velocity, and time duration, were tested. The electrode plate and wire were made of stainless steel to prevent corrosion from rust. The barbed wire is chosen because it has a better distribution property of the electric field around the barbs than the smooth wire (Gao et al., 2020). The configuration of the ESP prototype was designed based on the Deutsch-Anderson equations, which was modified by (Matts & Öhnfeldt, 1963) as shown in equation (1) to (3):

$$\eta(\%) = \left[1 - \exp(-\left(N_{De,1}\right)^{k})\right] \times 100\% \quad (1)$$

where $N_{De,1}$ is the original Deutsch number, it can be defined as:

$$N_{De,1} = \omega_k \frac{A_c}{Q} \quad (2)$$

where ω_k is the effective migration velocity of particles, k is a constant ranging from 0.4 to 0.6, A_c is the area of the collecting plates (m), and Q is the air flow rate (m^3/s).

$$\omega = \frac{\rho \varepsilon_0 E_c \, E_\rho \, D_\rho}{3 \, \mu_g} \quad (3)$$

Where ω is migration velocity(cm/s), ρ is penetration (fraction), ε_0 is free space permittivity (F/m), E_c is electric strength of charge field (v/m), E_ρ is electric strength of collecting field(v/m), D_ρ is diameter of particle(m) and μ_g is air viscosity (kg/m-s)

2.1 ESP prototype design

2.1.1 Voltage power supplies

High voltage DC power supplies are created from the flyback converter adjustable; the voltage was adjusted by pulse width modulation (PWM) control. The input voltage can be accepted as alternative voltage 220-240VAC and then supplies voltage to the stepdown transformer; after that, converts it into a direct current of magnitude +12 volts. Then, the voltage was added to the input voltage (primary) for the flyback transformer, as shown in Figure 1.

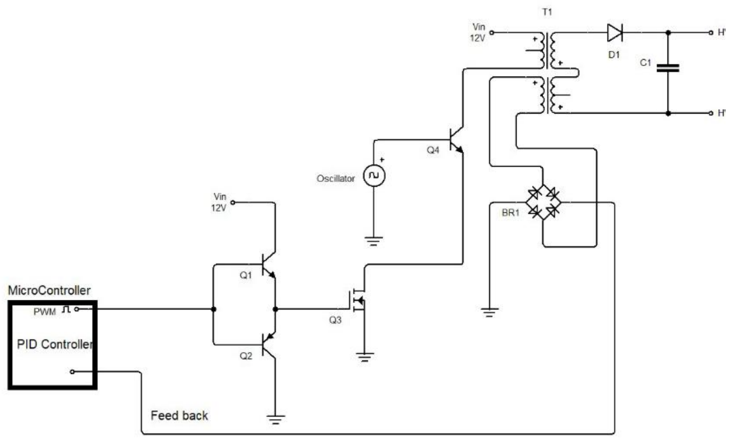

Figure 1 Electrical diagram of ESP prototype in this study

2.1.2 Structure of ESP prototype

The main component of ESP had consisted of two main parts: (1) the discharge part which was a wire electrode and (2) the collecting part that was electrode plate. Electrode wires were made of stainless steel for the advantage of corrosion resistance. Its dimension was of length 336 mm, and diameter 0.8 mm. It was a needle wire on both sides of the axial wire, the length of the barbed on each side was 9.5 mm. A wire electrode had consisted of seven rows. The distance between the electrode wire rows was 57 mm.

Another part is the collecting sheet plate. It is made of 8 stainless steel plates, 0.8 mm thick, 410 mm wide, 400 mm height, for allowing dust particles to adhere after being charged negatively. The distance between the pads was 57 mm. The distance between the pads and the electrode wire was 28.5 mm. The structure of ESP prototype is shown in Figure 2.

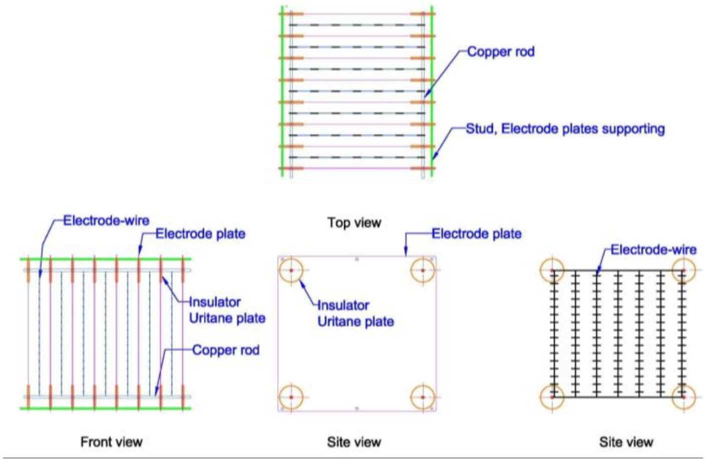

Figure 2 The structure of ESP prototype in this study

2.2 Influence of voltage on ESP efficiency

To study the effect of voltage on ESP efficiency, the speed of air inlet was controlled constant at 1.0 m/s. DC-Voltage was varied from 2 kVDC – 30 kVDC. At the inlet air, PM2.5 was generated from diesel

lamps. Then, air dust was passing through ESP by blower fan. The concentration of PM2.5 at inlet air and outlet air of ESP were measured by Lighthouse Handheld 3016-IAQ (HH3016-IAQ). The dust collection efficiency is calculated by the equation 4.

$$\eta = \frac{C_i - C_o}{C_i} * 100 \qquad (4)$$

2.3 Influence of air velocity on ESP efficiency

In this experiment, the speed of inlet air was adjusted to compare with the PM2.5 particle trapping efficiency. The air velocity can be adjusted by adjusting the damper mounted on the outlet side of the model between the model and the blower. Different air velocities were adjusted at 0.2, 0.4, 0.6, 1.0, 1.2, 1.4, and 1.6 m/s, respectively.

2.4 Influence of time duration on ESP efficiency

The air velocity was adjusted to 0.2 and 1.6 m/s, which was the air volume through the test model was 115.2 m^3/hr and 921.6 m^3/hr respectively. The relative humidity and temperature of the air flow through the model were recorded as reference data. The relative humidity was measured as 63 percent, while the airflow temperature through the model was 32.5 degrees Celsius. the DC voltage was adjusted from 0 to 30 kVDC. Voltage increased up to 30 kVDC by using 60 minutes; after that, the performance and current measurements were performed every 5 minutes until 120 minutes.

3. Results

In this study, main experimental factors were considered to identify the suitable condition of capturing PM2.5 with ESP prototype. The detail result in each factor can be shown as follows.

3.1 Effect of voltage

As shown in Figure 3, when the voltage was increased, the current was also increased. Corona discharge starts to occur when the voltage reaches 2 kVDC. It gave a maximum current of 800 microamps(μA) at a voltage of 26-30 kVDC.

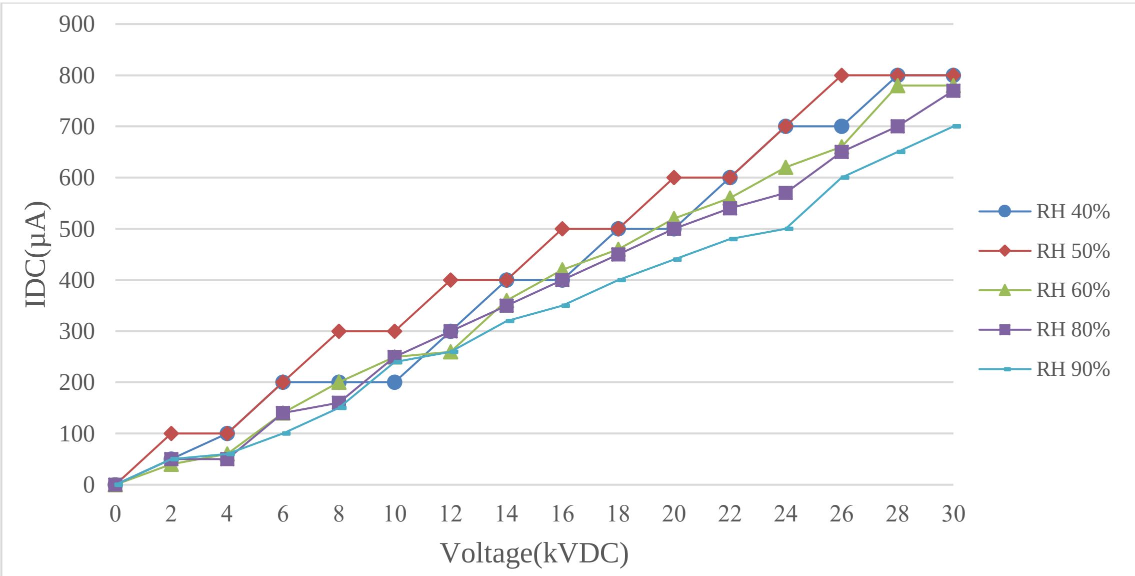

Figure 3 Effect of voltage adjustment on electric current

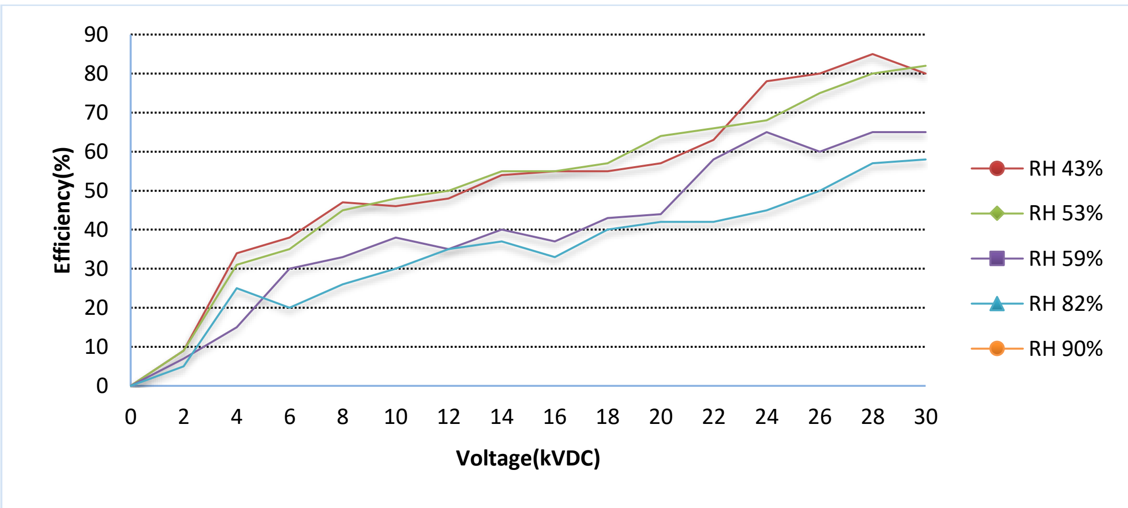

Figure 4 Effect of voltage adjustment on collection efficiency

Increased voltage and current results in corona power generation being increased as well. The corona power has a direct effect on dust collection according to the relation of equation 3 and equation 5. When the voltage increases, the effect of the corona power intensity increases. Therefore, as shown in Figure 4, the corona power affects the capture efficiency, which is consistent to equation 7.

$$P_C = \frac{1}{2}(V_P + V_m)I_C \quad (5)$$

P_C is corona field power(watts) V_P is peak voltage(volts), V_m is minimum voltage(volts). I_C is average corona current (Ampere). The current changes with the change in voltage when the resistivity of the gas flowing through the tester is constant.

$$ŋ = 1 - e^{-\omega(A/Q)} \quad (6)$$

where ŋ is the capture efficiency(percent), e is the natural base logarithm, 2.718, ω is the migration velocity(cm/s), A is the collection area (m^2), Q is the air volume (m^3/s)

$$ŋ = 1 - e^{-K*Pc/Q} \quad (7)$$

where, ŋ is the capture efficiency, e is the natural base logarithm, 2.718, k is the constant between 0.5-0.7, P_C/Q is the corona power intensity. Units are watts per cubic meter per hour (watt/m^3/hr).

3.2 Effect of air velocity

The effect of air velocity on ESP efficiency is shown in Figure 5. The result found that the highest efficiency of ESP was 95 percent when the air velocity was 0.2 m/s. The ESP efficiency was high when air velocity was low. The low air velocity through the model resulted in higher PM2.5 particles capturing efficiency than the high air velocity. At the highest air velocity of 1.6 m/sec, the ESP collection efficiency was dropped to 65 percent. High air velocity resulted in large air volumes, which affected the ESP collection efficiency, as shown in Equation 6.

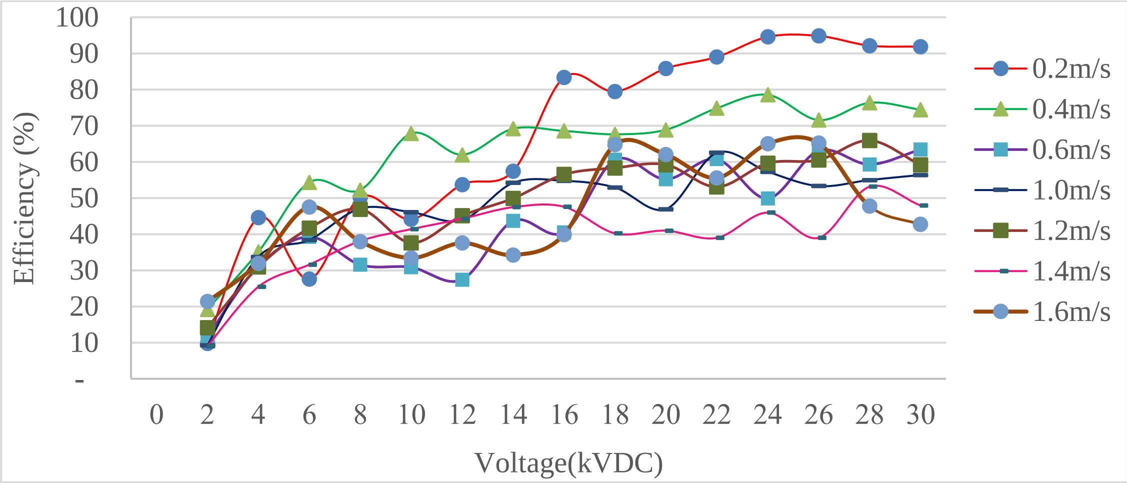

Figure 5 Effect of air velocity on ESP efficiency

3.3 Effect of time duration

At time duration between 0-60 minutes, the trend of current was increased. After 60 minutes, the current tended to decrease, as shown in Figure 6. When tested, the voltage was adjusted up to 24 kVDC to achieve the highest capture efficiency. ESP prototypes take 48 minutes to increase voltage from 0-24 kV. When the voltage was adjusted to over 24 kV, the measured current was

still higher from 480 to 650 µA; however, the ESP efficiency began to decline after 60 minutes of testing. From the time experiment at 60 – 120 minutes, ESP electric current has dropped from 650µA to 480 µA.

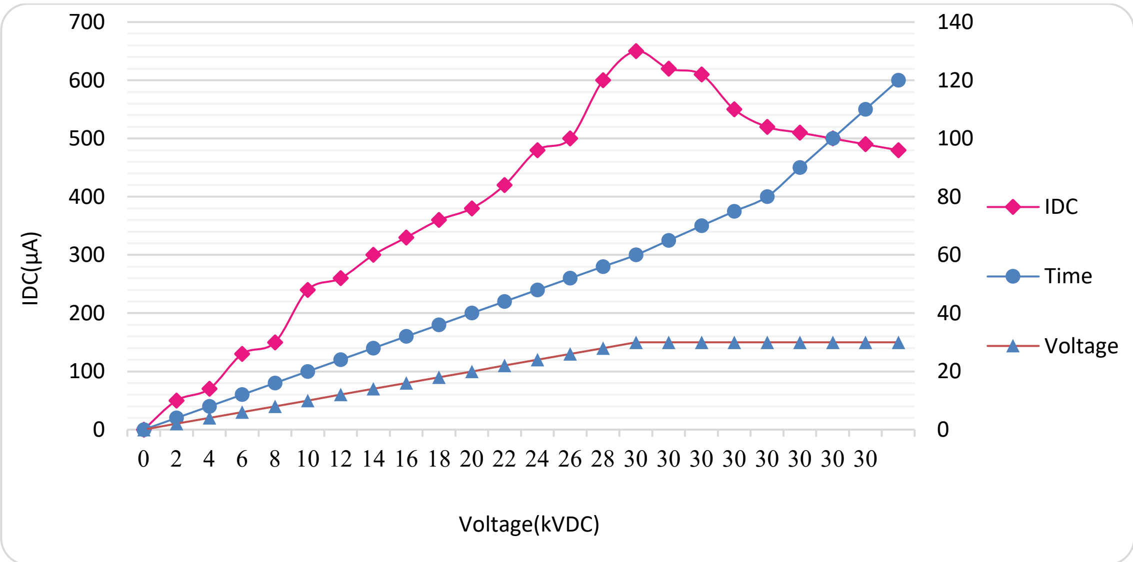

Figure 6 Effect of time duration on electric current

4. Conclusion

From testing the ESP prototype for PM2.5 particles trapping in this study, it was revealed that the influence on the collection efficiency of the ESP was based on three parameters: voltage, air velocity, and time. The highest efficiency of the ESP is 95%, when air velocity is 0.2 m/s. It can be summarized that the suitable conditions to operate the ESP prototype are the voltage of 24 kV, air velocity of 0.2 m/s, and time experiment of 60 minutes. The total duration of the experiment was for 120 minutes, where after 60 minutes the electric current decreased and the dust collection efficiency decreased also. This is because when the experiment is carried out, some of the dusts were settled on the plate. In this condition the current is harder to pass through, resulting in lower values of the measured current and lower the collection efficiency of the ESP. However, this ESP prototype shows higher efficiency in eliminating PM2.5 compared to other research works (Asanavijit et al., 2019; Ruttanachot et al., 2011).

For the future development, there are some suggestions that should be considered: (1) as the gas passing through the prototype may not be distributed evenly over the entire cross-sectional area, in the next design of the diffuser, Computer software (Computational Fluid Dynamics: CFD) to simulates the flow of uniform air distribution over the entire cross-sectional area should be performed; and (2) a half-bridge rectifier circuit was used in this study; however, it is recommended to use a full bridge rectifier to achieve more smooth DC voltage waveform.

5. Acknowledgments

The authors would like to thank Rattanakosin College for Sustainable Energy and Environment, Rajamangala University of Technology Rattanakosin for their support of this research.

6. References

ARB. (2022). *Inhalable Particulate Matter and Health (PM2.5 and PM10)* California Air Resources Board Retrieved April 30 from https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health#:~:text=5%3F-,PM10%20and%20PM2.,a%20significant%20proportion%20of%20PM10.

Asanavijit, V., Panpang, T., & Intra, P. (2019). Design and Evaluation of a Multiple-tube Electrostatic Collector for Particulate Matter Removal from Tobacco Monopoly Exhaust. *Journal of Science & Technology MSU*, *37*(6), 789-803.

Gao, W., Wang, Y., Zhang, H., Guo, B., Zheng, C., Guo, J., Gao, X., & Yu, A. (2020). Numerical simulation of particle migration in electrostatic precipitator with different electrode configurations. *Powder Technology*, *361*, 238-247. https://doi.org/10.1016/j.powtec.2019.08.046

Lusiandri, A. Y., Kristiyono, A. E., & Waskito, K. L. (2019). The Application of Electrostatic Precipitator (ESP) as Pollutant Reduction in Ship. *Research, Society and Development*, *8*(12). https://doi.org/10.33448/rsd-v8i12.1650

Matts, S., & Öhnfeldt, P. (1963). Efficient gas cleaning with SF electrostatic precipitators. *Flakten Rev*, *6*, 93-110.

Parker, K. (2003). *Electrical operation of electrostatic precipitators*. IET.

PCD. (2010). *National Ambient Air Quality Standards (NAAQSs) in Thailand*. Bangkok Pollution Control Department Retrieved from http://infofile.pcd.go.th/air/cri170353_sec3.pdf

PCD. (2019). *Action Plan to drive the National Agenda to Solve the Problem of Dust Pollution* (978-616-316-535-0).

Ruttanachot, C., Tirawanichakul, Y., & Tekasakul, P. (2011). Application of Electrostatic Precipitator in Collection of Smoke Aerosol Particles from Wood Combustion. *Aerosol and Air Quality Research*, *11*(1), 90-98. https://doi.org/10.4209/aaqr.2010.08.0068

Wang, Y., Zhang, H., Gao, W., Shao, L., Wu, Z., Zhao, Z., Ge, C., Hu, D., Zheng, C., & Gao, X. (2021). Improving the removal of particles via electrostatic precipitator by optimizing the corona wire arrangement. *Powder Technology*, *388*, 201-211. https://doi.org/10.1016/j.powtec.2021.04.087

Xing, Y.-F., Xu, Y.-H., Shi, M.-H., & Lian, Y.-X. (2016). The impact of PM2.5 on the human respiratory system. *Journal of thoracic disease*, *8*(1), E69-E74. https://doi.org/10.3978/j.issn.2072-1439.2016.01.19

Zhang, J., Wang, J., Jiang, Z., & Xu, D. (2022a). Trapping PM2.5 particles from electrostatic precipitator equipped with magnetic field under different gas velocities. *Process Safety and Environmental Protection*, *158*, 115-122. https://doi.org/https://doi.org/10.1016/j.psep.2021.11.035

Zhang, J., Wang, J., Jiang, Z., & Xu, D. (2022b). Trapping PM2. 5 particles from electrostatic precipitator equipped with magnetic field under different gas velocities. *Process Safety and Environmental Protection*, *158*, 115-122.