International Journal of Internet, Broadcasting and Communication Vol.15 No.3 239-245 (2023)
http://dx.doi.org/10.7236/IJIBC.2023.15.3.251

IJIBC 23-3-29

A study on Removal Method of Humidifier Particles Using Electrostatic Precipitation Technology

Inpyo Cha, Taekeon Jung, Hyunjun Yun, Chuljun Choi*

Researcher, Korea Electronics Technology Institute, Korea
chainpyo, taekeon, hjyun, cjchoi@keti.re.kr

Abstract

In this research, our objective was to investigate the efficacy of electrostatic precipitation in capturing mist particles. We assumed that it could be helpful in multi-functional facilities and similar environments where both humidification and dehumidification are required. We derived the air density of the humidified air based on its properties using Dalton's law. The analysis was performed to evaluate the collection efficiency of capturing mist aerosols of various sizes. As a result, we revealed that under the conditions of a dry-bulb temperature of 26.0°C and relative humidity of 8%, the system achieved a collection efficiency of 99.999% or more for aerosols larger than 2.5μm. These results indicate that electrostatic precipitation technology shows great promise as an effective method for capturing mist particles.

Keywords: *Mist Particles, Electric Precipitation, Multi-Use Facility, Dehumidification, Multi-Physics Analysis*

1. Introduction

Multi-functional facilities, including libraries, auditoriums, subway stations, and bus terminals, serve as enclosed spaces accommodating large gatherings of people, often suffering from inadequate ventilation. To establish a comfortable indoor environment, air purification systems are implemented, particularly in facility clusters surpassing indoor air pollution level standards. This research endeavors to investigate the practical application of electrostatic precipitation technology for indoor air quality management.

The employed electrostatic precipitation technology, utilizing carbon brushes, harnesses electrostatic forces through corona discharge to charge particles such as dust and mist. These charged particles are then directed toward collection electrodes for efficient capture. The process encompasses corona discharge formation, particulate matter charging, charged particle movement, and their subsequent collection on the electrodes. This mechanism exhibits superior efficacy in removing smaller particles compared to conventional mechanical filtration methods, owing to the electrostatic attraction, allowing for sustained efficiency and versatile applications across various domains, such as organic matter recovery, product quality enhancement, and air purification[1].

This study aims to explore the effectiveness of electrostatic precipitation technology in the removal of mist

Manuscript Received: July. 27, 2023 / Revised: August. 2, 2023 / Accepted: August. 4, 2023
Corresponding Author: cjchoi@keti.re.kr
Tel: +82-62-975-7015, Fax: +82-62-975-7019
Researcher, Korea Electronics Technology Institute, Korea

particles of diverse sizes. Through this investigation, we seek to discern the technology's efficiency concerning different particle sizes, thereby providing valuable insights into the realm of indoor air quality management.

2. Method

The electrostatic precipitation analysis was carried out utilizing the COMSOL Multiphysics software, renowned for its capabilities in multi-physics simulations, encompassing electric field particle flow (Corona and Laminar flow) and particle tracing analysis. Figure 1 visually depicts the modeling of the electrostatic precipitation system, along with the delineation of boundary conditions governing fluid flow[2].

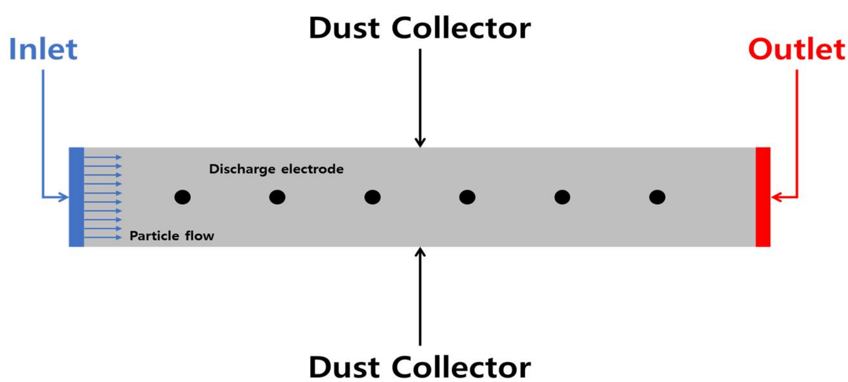

Figure 1. Electrostatic precipitate modeling

The setup boundary conditions for humidifier particles and fluid flow are as follows:

Average flow velocity = 1 m/s

Discharge voltage = 20 kV

Inlet particle count = 1,000,000 particles

Pressure = 1.0 atm

Particle density = 1.18 kg/m^3

The electrostatic precipitation analysis was performed based on the principles of particle charging and particle behavior according to the inference principle[3].

$$E = -\nabla v \tag{1}$$

$$J_C = \sigma E \tag{2}$$

$$\rho(t) = \rho_0 e^{-t/\tau} \tag{3}$$

$$\mathrm{n} = d_p \frac{kT}{2e^2}[1 + \pi d_p C_i e^2 N_i \frac{t}{2kT}] \tag{4}$$

E = Electric field

J_c = Current density

$\rho(t)$ = Spatial charge density

n = Number of charged particles

3. Derivation of Material Properties

To ascertain the properties of humidifier air in multi-functional facilities, we aim to calculate its estimated parameters. Among these parameters, air density is a crucial state variable influenced by dry-bulb temperature, relative humidity, and atmospheric pressure. The determination of air density necessitates the use of at least two parameters from the psychrometric chart. In our approach, we calculate air density by first deriving the dry air density and absolute humidity through Dalton's law of partial pressures, followed by the determination of the humidifier air density.

Dalton's law of partial pressures states that the pressure of humidifier air is the sum of the partial pressures exerted by its constituents, namely, dry air and water vapor. Each component exerts a specific pressure in relation to its volume in the gas mixture. The psychrometric chart typically represents air properties at standard atmospheric pressure, wherein the forces of dry air and water vapor are defined relative to this standard pressure. By incorporating Dalton's law of partial pressures and applying the gas state equation for humidifier air, we formulate the following expression[4-5].

$$P_{da} \cdot V = 1 \cdot R_{da} \left(29.27 \frac{kgm}{kg°K}\right) \cdot T \tag{1}$$

$$P_{wv} \cdot V = X \cdot R_{wv} \left(47.06 \frac{kgm}{kg°K}\right) \cdot T \tag{2}$$

$$P_{da} = \frac{(P_b - P_{wv})}{R_{da} \cdot T_n} \tag{3}$$

$$P_{wv} = \rho_{da} \cdot X \tag{4}$$

$$P_{ma} = \rho_{da} + \rho_{wv} \tag{5}$$

P_{da} = Dry air pressure
P_{wv} = Water vapor partial pressure
V = Volume
X = Absolute humidity
T_n = Absolute temperature
P_b = Atmospheric pressure
R_{da} = Dry air gas constant
ρ_{wv} = Water vapor density (kg/m^3)
ρ_{da} = Dry air density (kg/m^3)
ρ_{ma} = Humidifier air density (kg/m^3)

Table 1. Air quality calculation

Division	State value	Unit
Dry bulb temperature	26.0	℃
Wet bulb temperature	10.6	℃
Absolute humidity	0.0017	kg/kgDA
Relative humidity	8.0	%
Enthalpy	30351	J/kg
Dew point temperature	*-9.6*	℃
Water vapor partial pressure	*269.05*	pa
Discomfort index	*66.9*	Geniality
Specific volume	*0.85*	m^3/kg
Dry air density	*1.18*	kg/m^3
Wet air density	*1.18*	kg/m^3

In this study was derived with assumed environmental conditions of 26.0°C for the dry-bulb temperature and 8.0% for the relative humidity. The density of the humidifier air is calculated to be 1.18 kg/m³. The results of the air properties are as shown in Table 1.

4. Result

Following the completion of the spatial domain analysis, a multi-physics examination was undertaken by introducing water vapor particles into the domain for the purpose of conducting electrostatic precipitation analysis. The results of this comprehensive analysis for the 1st spatial domain are depicted in Figures 2 to 5. Figure 2 represents the velocity field analysis results, showing a maximum velocity of 1.6 m/s. Figure 3 illustrates the pressure distribution analysis results, demonstrating that the pressure field is appropriately formed around the discharge electrode region in accordance with the flow dynamics. Figure 4 displays the potential analysis results, indicating the formation of potential differences between points within a uniform electric field. Figure 5 shows the results of electric field formation analysis, confirming the proper establishment of electric fields at each point. The analysis of the primary spatial domains proceeded smoothly without any issues, confirming successful progress in each case.

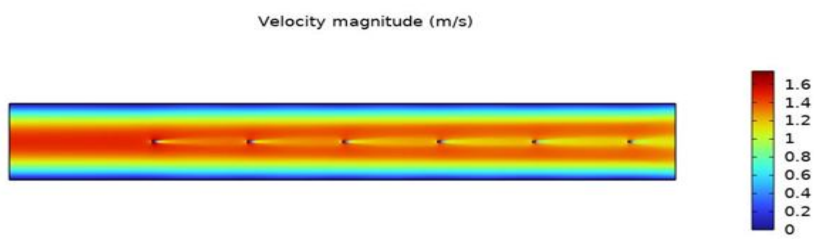

Figure 2. Velocity field analysis

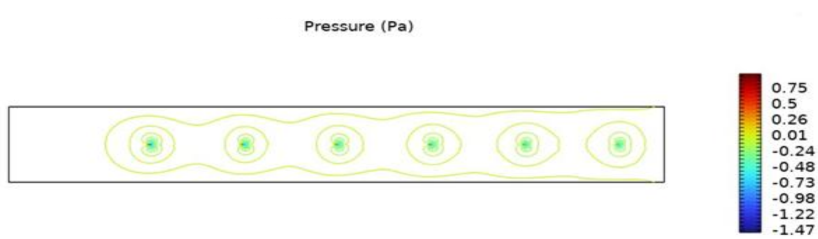

Figure 3. Pressure distribution analysis

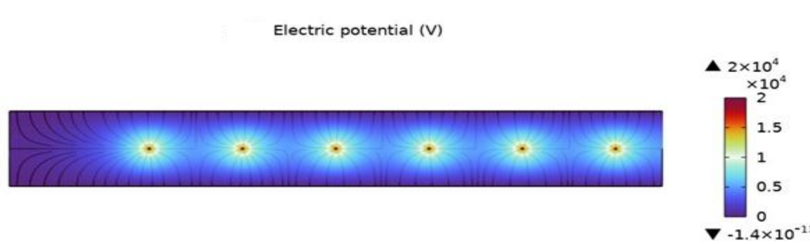

Figure 4. Electric potential analysis

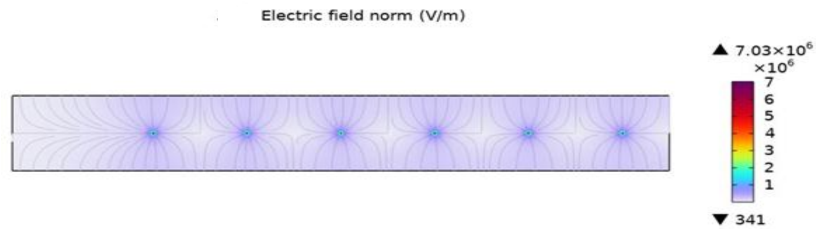

Figure 5. Electric field formation analysis

During the second phase of the analysis, electrostatic precipitation analysis was carried out to examine the behavior of humidifier particles with varying sizes. The considered particle sizes included 0.01 µm, 0.1 µm, 0.3 µm, 2.5 µm, 5 µm, and 10 µm, resulting in six distinct types of water vapor particles subject to the collection analysis. The outcomes of this comprehensive electrostatic precipitation analysis for each of the aforementioned mist particle sizes are presented in Figures 6 to 11.

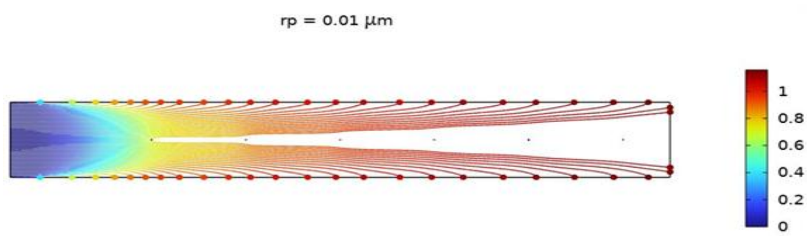

Figure 6. 0.01 ㎛ particle

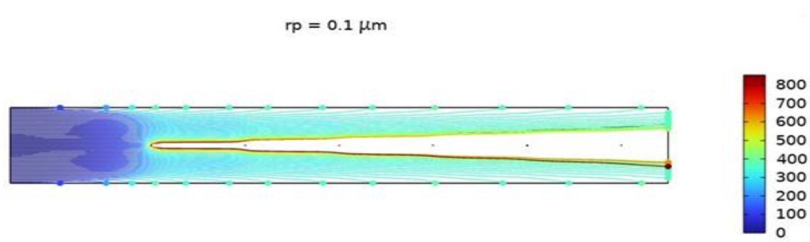

Figure 7. 0.1 ㎛ particle

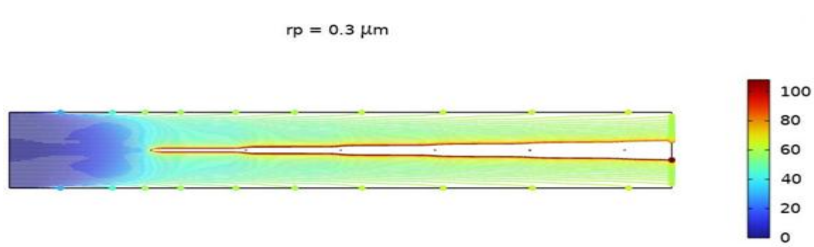

Figure 8. 0.3 ㎛ particle

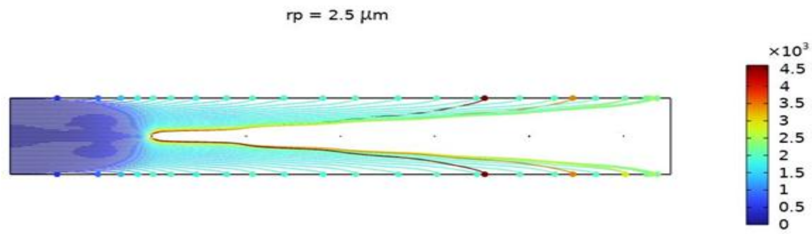

Figure 9. 2.5 ㎛ particle

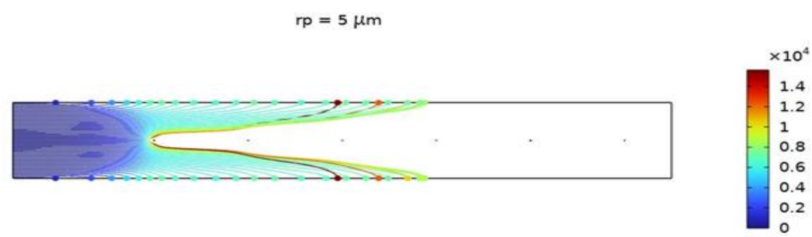

Figure 10. 5 ㎛ particle

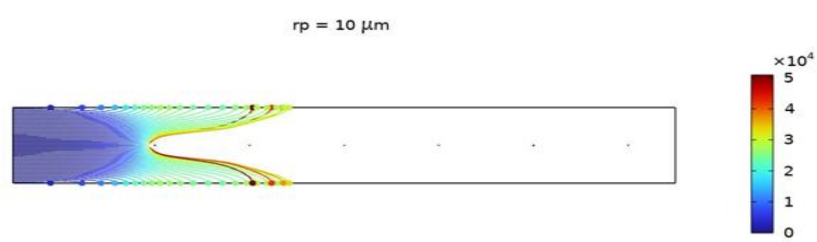

Figure 11. 10 ㎛ particle

The analysis of collection efficiency based on particle size is presented in Figure 12.

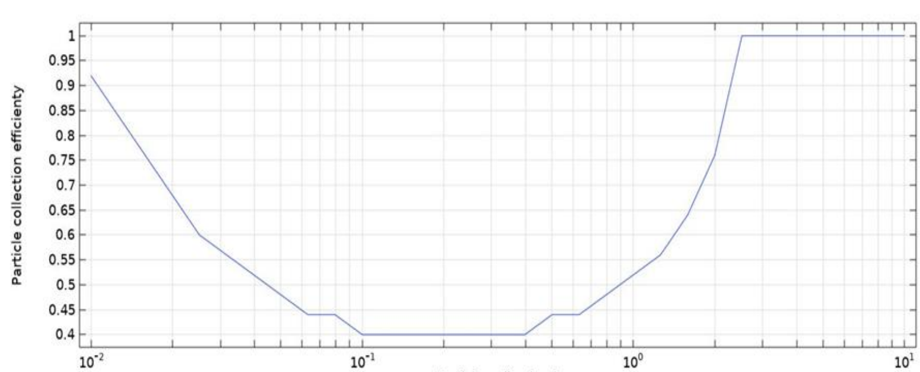

Figure 12. Collection efficiency by mist particle size

5. Conclusion

This paper delves into the calculation process of humidifier air density based on air properties and investigates the relationship between mist particle sizes and electrostatic precipitation efficiency. The accurate determination of air density necessitates considering factors such as temperature, relative humidity, and atmospheric pressure, which define the air's state. Despite being electrically neutral overall, mist aerosols possess local charges that make them amenable to collection through electrostatic precipitation technology. Our comprehensive analysis examined the collection efficiency of particulate matter, taking into account its size. We revealed that, under specific conditions with a dry-bulb temperature of 26.0°C and a relative humidity of 8%, mist aerosol larger than 2.5 μm exhibited an exceptional collection efficiency of upper 99.999% or more. We findings suggest that electrostatic precipitation technology holds significant promise as an effective method for purifying humidified and dehumidified aerosols, particularly in environments with specific requirements for humidification and dehumidification processes.

Acknowledgement

This work was supported by the Technology development Program(S3268336) funded by Ministry of SMEs and Startups(MSS, Korea)

References

[1] SPS-KACA 002-0132:2018 Indoor Air Cleaners.
DOI: http://www.kaca.or.kr
[2] C. S. Moon, “A Study on the characteristics of Corona Discharges According to the Geometry of Discharge Electrode,” KOSENV, pp. 27-29, 1996.
DOI: https://www.dbpia.co.kr/pdf/pdfView.do?nodeId=NODE06754201
[3] H. S. Lee, J. H. Kim, H. H. Kim, and Atsushi. O, 2008, “Development of Collection Efficiency in Electrostatic Precipitator Using Electrospray,” KOSAE, pp. 449-450, 2008.
DOI: https://www.dbpia.co.kr/pdf/pdfView.do?nodeId=NODE01078738
[4] J. W. Kim, “Moist Air Density Calculation for Air Condition,” Trans. Korean Soc. Mech. Eng, Vol. 2, No. 2, pp. 105-111, 2014.
DOI: https://www.dbpia.co.kr/pdf/pdfView.do?nodeId=NODE07252970
[5] ASHRAE STANDARD, 1987 With Minor Editorial Changes, ANSI/ASHRAE 41, 2-1987 (RA 92)