data

MDPI

Data Descriptor

Influence of Temperature Variability on the Efficacy of Negative Ions in Removing Particulate Matter and Pollutants: An Experimental Database

Paola M. Ortiz-Grisales [1,*,†], Leidy Gutiérrez-León [1,†] and Carlos D. Zuluaga-Ríos [2,†]

1 Department of Electrical Engineering, Engineering Faculty, Institución Universitaria Pascual Bravo, Medellín 050036, Colombia; leidy.gutierrez@pascualbravo.edu.co
2 Institute for Research in Technology, Universidad Pontificia Comillas, 28015 Madrid, Spain; czuluaga@comillas.edu
* Correspondence: paola.ortiz@pascualbravo.edu.co
† These authors contributed equally to this work.

Abstract: Cities globally must make urgent decisions to ensure a sustainable future as rising pollution, particularly PM2.5, poses severe health risks like respiratory and heart diseases. PM2.5's harmful composition also impacts vegetation and the environment. Immediate government intervention is necessary to mitigate these effects. This study tackles the urgent problem of reducing PM2.5 levels in Medellín's urban and indoor environments, where pollution presents serious health risks. To explore effective solutions, this research provides new data on the interaction between particulate matter from various pollutants and negative ions under different temperature conditions, offering valuable insights into air quality improvement strategies. Using a high-voltage system, ions bind to pollutants, accelerating their removal. Experiments measured temperature, humidity, formaldehyde, volatile organic compounds, negative ions, and PM2.5 in a 40 cm^3 chamber across various conditions. Pollutants tested included cigarette smoke, incense, charcoal, and gasoline at two voltage levels and three temperature ranges. The data, available in CSV format, were based on 36,000 samples and repeated tests for reliability. This resource is designed to support studies investigating particulate matter control in urban and indoor environments, as well as to improve our understanding of negative ion-based air purification processes. The data are publicly available and structured in formats compatible with leading data analysis platforms.

Keywords: air quality; particulate matter; ionization technology; electrostatic recombination; ion–particle interaction database

check for updates

Citation: Ortiz-Grisales, P.M.; Gutiérrez-León, L.; Zuluaga-Ríos, C.D. Influence of Temperature Variability on the Efficacy of Negative Ions in Removing Particulate Matter and Pollutants: An Experimental Database. *Data* **2024**, *9*, 131. https://doi.org/10.3390/data9110131

Academic Editor: Juan-Carlos Jiménez-Muñoz

Received: 28 September 2024
Revised: 23 October 2024
Accepted: 27 October 2024
Published: 8 November 2024

1. Summary

The rising levels of particulate matter with a diameter of 2.5 µm (PM2.5) in urban environments pose significant health risks, contributing to respiratory and cardiovascular diseases [1]. This issue is particularly pressing in Medellín, Colombia, where air pollution, compounded by the city's unique geography, creates a persistent environmental challenge. Medellín's location in a valley, coupled with tropical mountainous weather, results in the accumulation of pollutants, exacerbating the health impacts of airborne particles [2]. The need for efficient, cost-effective air purification solutions is urgent, and the exploration of novel technologies such as negative ion generation could offer a viable alternative to traditional methods. This paper presents new data on the interaction between negative ions and PM2.5 in controlled environments to reduce airborne PM2.5 concentrations through electrostatic recombination. Negative ions, generated via a high-voltage system, bind to pollutants, increasing particle mass and accelerating their removal from the air. The experiments were conducted between March and August 2024 in a 40 cm^3 test chamber designed to simulate urban conditions, and included a range of common urban pollutants such as cigarette smoke, incense, charcoal, and gasoline [3]. The experiments measured variables such as temperature, humidity, formaldehyde (HCHO), total volatile organic compounds (TVOC), negative air ions (NAIs), and PM2.5 concentrations. Medellín's outdoor temperature ranges were mimicked in the chamber, covering low- (14–17 °C), medium- (23–27 °C), and high-temperature (39–51 °C) scenarios. Pollutants used included cigarette smoke, incense, charcoal, and gasoline [1], tested across two voltage levels (7500 V and 30,000 V). A total of 24 unique conditions were examined, resulting in 36,000 samples. The experimental setup involved two key devices: the KT-401 aerosol ion tester (for NAI measurements) and the DM306 portable air quality monitor (for PM2.5 and other parameters). The data, stored in CSV format, followed international standards and are available for further analysis. Each test was repeated five times for reliability, ensuring comprehensive coverage of the effect of negative ions on a reduction in PM2.5 under various conditions.

2. Data Description

The objective of this study is to analyze the interaction between negative ions and particulate matter in a controlled environment. This process is designed to reduce the concentration of PM2.5 in the air. This reduction occurs through an electrostatic recombination mechanism, in which negative ions, which possess a negative electrical charge, are attracted to particulate matter that often contains positive charges or is devoid of charge, making them electrostatically susceptible [4].

Negative ions are produced by a high-voltage electronic circuit (see Figure 1) that elevates the voltage to levels of 7500 V or 30,000 V. This increase in voltage generates an electrical discharge that ionizes the surrounding air molecules. These voltage levels enable adjustments in experimental conditions and ensure the efficient generation of negative ions, which are crucial for the ionization process and their interaction with PM2.5 particles in the controlled environment. In this process, negative ions bind to PM2.5 particles, increasing their mass and significantly reducing their ability to stay airborne. This electrostatic recombination leads to the formation of larger particle aggregates, which settle more rapidly under the influence of gravity. By this mechanism, the interaction between negative ions and particulate matter effectively accelerates the removal of pollutants from the air, contributing to a more efficient reduction in air pollution.

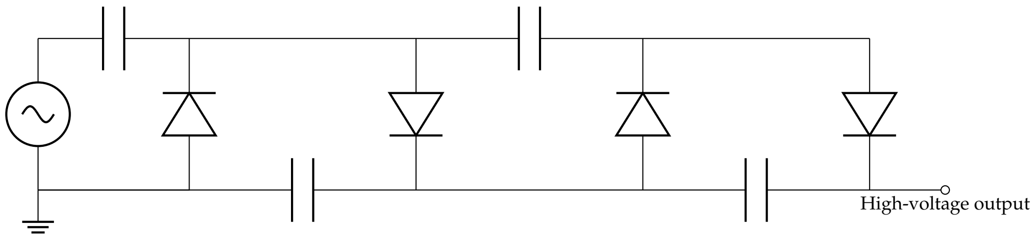

Figure 1. High-voltage electronic circuit that elevates the voltage to levels of 7500 V or 30,000 V.

Traditional methods of particulate removal in industrial settings often involve the use of dust collectors and electrostatic precipitators (ESPs). ESPs are particularly effective in capturing fine particles, such as PM, by inducing an electrostatic charge on the particles, which causes them to adhere to collection plates. While these systems are efficient in large-scale industrial applications, they require substantial infrastructure and energy consumption [5,6]. In contrast, the use of negative ions for air purification offers a more energy-efficient solution, especially for urban and indoor environments. Negative ion generators apply low energy primarily to the particulate matter, making them a promising technology for environments where air quality is critical, such as homes, offices, and smaller industrial settings. This approach provides an efficient method for air quality control [7,8]. Additionally, it offers a foundation for future research on the use of negative ions in the mitigation of PM2.5 [9]. The data were collected in a 40 cm^3 test chamber. The measurements include temperature, relative humidity (RH), formaldehyde (HCHO), total volatile organic compounds (TVOC), negative air ions (NAIs), and PM2.5 concentration.

2.1. Experimental Conditions

Experiments were conducted by adjusting three critical variables: the type of pollutant, the voltage applied for negative ion generation, and the ambient temperature. Four pollutants were selected as representative of urban and domestic environments: cigarette smoke, incense, charcoal, and gasoline [3]. These selections reflect common sources of air contamination, making this study highly relevant to real-world air quality challenges [10,11].

The experiments were conducted across three temperature ranges common to urban environments: 14–17 °C (low range), 23–27 °C (medium range), and 39–51 °C (high range). This combination of factors led to a total of 24 distinct experiments, resulting from the interaction of four different pollutants, two voltage levels, and three temperature ranges. Continuous measurements were recorded for each experiment over a duration of 300 s, with a sampling frequency of one measurement per second. This methodology enables the analysis of the temporal dynamics of the decontamination process in response to the varying experimental conditions. To ensure the validity and reproducibility of the results, each experimental combination was conducted five times, resulting in a total of 36,000 samples. This total is derived from 24 experiments, with each yielding 300 samples across five repetitions. Such extensive data collection enables robust statistical analysis and establishes a comprehensive database for evaluating the impact of negative ions on the reduction of particulate matter in the air.

2.2. Recorded Variables

The variables measured in each experiment are outlined in Table 1. These include elapsed time, PM2.5 concentration, formaldehyde levels, temperature, relative humidity, volatile organic compounds, and negative ion concentration. Additionally, the type of pollutant used and the voltage applied during the recombination process were recorded.

Table 1. Description of the columns in the database.

Variable	Description	Unit of Measurement
Time	The elapsed time since the start of the experiment.	Seconds
PM2.5	Concentration of particulate matter with a diameter of 2.5 microns	μg/m³
HCHO	Formaldehyde concentration	mg/m³
Temperature	Temperature	°C
RH	Relative humidity	%
TVOC	Concentration of volatile organic compounds	mg/m³
Ions	Concentration of NAIs	ions/cm³
Pollutant	Type of pollutant in the environment	Text
IonGenerationVolt	Voltage emitted by the negative ion generator	Volts

3. Materials and Methods

This section outlines the experimental setup and the experimental design used to develop a comprehensive database analyzing the interaction between negative ions and PM2.5 particles in a controlled environment.

3.1. Equipment and Techniques

The data for this study were obtained using two measurement devices—the KT-401 aerosol ion tester and the portable air quality monitor DM306 (see Figure 2)—along with a negative ion generation system utilizing voltage multiplication.

Figure 2. DM306 Portable monitor.

The KT-401 is a specialized instrument designed to measure the concentration of negative air ions (NAIs). Utilizing advanced electrode-based technology, it delivers precise readings of ionization in terms of ions per cubic centimeter (ions/cm^3). In contrast, the portable monitor DM306 was employed to evaluate a range of air quality parameters. This device measures the PM2.5 concentration, providing data on the micrograms of particulate matter present in the air per cubic meter. Additionally, it records ambient temperature in degrees Celsius (°C) and relative humidity as a percentage of water vapor content in the air. The monitor also quantifies the concentration of formaldehyde (HCHO), a highly volatile and flammable compound, expressed in milligrams per cubic meter (mg/m^3). Lastly, it assesses the total volatile organic compounds (TVOC) in the air, indicating the overall level of these compounds present. Both devices, along with the ion generation system, were housed in a controlled test cabinet (see Figure 3) constructed from transparent acrylic, with a volume of 40 cm^3. This setup facilitated direct observation of the measurement processes while effectively minimizing external interference during the experiments.

Figure 3. Controlled test cabinet.

3.2. Experimental Design

The experiment followed a factorial design with three primary factors: temperature, negative ion generation voltage, and pollutant type (independent variables). Three temperature ranges (low, medium, and high) and two voltage levels (7500 V and 30,000 V) were chosen. The concentrations of PM2.5 and negative ions in the air (dependent variables) were measured across four different pollutants [3], resulting in 24 distinct experimental combinations. For each combination, the pollutant was introduced into a controlled test cabinet, and the appropriate voltage was applied to generate negative ions. Throughout the experiment, key variables, as outlined in Table 1, were continuously monitored. Each test was repeated five times to ensure the consistency and reliability of the findings. To provide a clearer understanding of the behavior discussed earlier, Figure 4 presents two experimental realizations of the interaction between particulate material and negative ions within the test cabinet. The figure highlights three distinct temperature ranges and two voltage levels, while the quantity of negative ions was adjusted to observe how these factors influence the sedimentation of particulate matter, with cigarette smoke used as the pollutant.

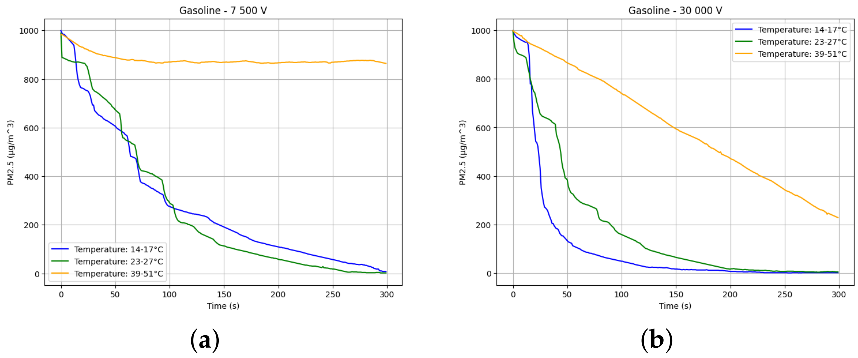

Figure 4. Effect of negative ions on particulate matter sedimentation across three temperature ranges. (**a**) Ion generation at 30 kV with gasoline as the pollutant. (**b**) Ion generation at 7.5 kV with gasoline as the pollutant.

As observed in Figure 4, expanding the temperature intervals could reveal even more significant results. For example, at lower temperatures (e.g., 12–17 °C), we hypothesize that particles possess less kinetic energy, which would reduce recombination between the particulate matter and ions. However, since air is more viscous at lower temperatures, particle movement slows down, promoting sedimentation and adhesion to surfaces. Conversely, at higher temperatures (e.g., 37–51 °C), the increased kinetic energy of particles leads to more collisions and greater ion–particle recombination. Yet, the lower air viscosity at elevated temperatures results in faster particle movement, making it harder for particles to adhere to surfaces. Therefore, we propose that optimal decontamination through electrostatic precipitation occurs when there is a balance between air viscosity and particle kinetics.

3.3. Formatting and Storage of Data

The generated database contains structured information in CSV format and was stored following the international data interoperability standards to ensure accessibility and reusability. Key parameters such as PM size and concentration, amount of negative ions, and changes properties over time as a function of temperature were recorded. Each row represents a sample, and each column corresponds to a variable. Data preprocessing was conducted to remove outliers. The measurements were performed under controlled environmental conditions, within the operational limits of measurement equipment.

4. User Notes

The database from this study holds significant potential for a range of applications. It provides a valuable resource for advancing air quality research by offering detailed insights into the interaction between negative ions and PM2.5 particles under varying environmental conditions. Researchers can leverage these data to investigate how factors such as temperature and relative humidity impact ionization efficiency [12]. For instance, higher humidity levels may diminish the recombination ability between ions and PM2.5 particles [13]. Moreover, the database enables an exploration of how different contaminants influence reductions in particle levels via electrostatic recombination [14]. Beyond research, the data can be instrumental for urban planners and environmental scientists in designing more effective air purification systems, particularly for cities battling severe pollution. They also serve as a valuable foundation for developing indoor air purification technologies tailored to environments like homes or workplaces where common pollutants such as smoke and gasoline are prevalent. Additionally, the data offer insights for optimizing industrial pollution control strategies by fine-tuning ionization systems to address specific pollutants and environmental conditions, such as varying temperature ranges.

Author Contributions: Conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, visualization, and final version of the manuscript, P.M.O.-G., L.G.-L. and C.D.Z.-R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Institución Universitaria Pascual Bravo and was derived from the research project titled "Modeling the air purification system using negative ions with a structure for capturing particulate matter employing computational intelligence methods", with grant number PCT00004.

Institutional Review Board Statement: Not applicable for studies not involving humans or animals.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets analyzed during the current study are publicly available. The data are available in the general repository, "Open Science Framework" at https://osf.io/r6h38/?view_only=11511e12d8304cc79ccc1960710ea50d. Accessed on 27 September 2024.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of this study; in the collection, analyses, or interpretation of data; in the writing of this manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

PM2.5	Particulate matter with a diameter less than 2.5 µm
HCHO	Formaldehyde
TVOC	Total volatile organic compounds
RH	Relative humidity
°C	Celsius (temperature)
V	Voltage
NAIs	Negative air ions
CSVs	Comma-separated values

References

1. Bedregal, P.; Ubillus, M.; Cáceres-Rivero, C.; Olivera, P.; Garay, R.; Rojas-Quincho, J.; Zafra, R.; Urdanivia, R. Determination of atmospheric aerosol components in an urban area to evaluate the air quality and identify the sources of contamination. *J. Radioanal. Nucl. Chem.* **2023**, *332*, 3507–3514. [CrossRef] [PubMed]
2. Muñoz Duque, L.A.; Estrada Acuña, R.A.; Munn, T.; Bañol Muñoz, L.C.; Johnson, S.; Gilbert, M.R.; Hayes-Conroy, A. What matters beyond particle matter?: Examining air pollution's synergistic effects on bodies and health through Bio3Science in Medellin. *Soc. Sci. Med.* **2024**, *361*, 117331. [CrossRef] [PubMed]

3. Zhang, L.; Ou, C.; Magana-Arachchi, D.; Vithanage, M.; Vanka, K.S.; Palanisami, T.; Masakorala, K.; Wijesekara, H.; Yan, Y.; Bolan, N.; et al. Indoor Particulate Matter in Urban Households: Sources, Pathways, Characteristics, Health Effects, and Exposure Mitigation. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11055. [CrossRef] [PubMed]
4. Lindgren, E.B.; Chan, H.K.; Stace, A.J.; Besley, E. Progress in the theory of electrostatic interactions between charged particles. *Phys. Chem. Chem. Phys.* **2016**, *18*, 5883–5895. [CrossRef] [PubMed]
5. Zhao, Z. Enhancing Dust Removal Efficiency in Electrostatic Precipitators with Homogeneous Flow. *Acad. J. Sci. Technol.* **2023**, *7*, 84–88. [CrossRef]
6. Chen, H.; Li, H.; Wang, S.; Han, Y.; Zhai, X.; Xiao, L. Synergistic Humidification and Chemical Agglomeration to Improve Capturing the Fine Particulate Matter by Electrostatic Precipitator. *Coatings* **2024**, *14*, 420. [CrossRef]
7. Wang, J.; Li, Z.; Liang, X.; Zhang, H.; Ou, Y. PM2. 5 Removal by Negative Ions and The Effects of Temperature Humidity and Negative-Ion Concentration. *Fresenius Environ. Bull.* **2021**, *30*, 5844–5854.
8. Ortiz-Grisales, P.; Patiño-Murillo, J.; Duque-Grisales, E. Comparative Study of Computational Models for Reducing Air Pollution through the Generation of Negative Ions. *Sustainability* **2021**, *13*, 7197. [CrossRef]
9. Xiao, S.; Wei, T.; Petersen, J.D.; Zhou, J.; Lu, X. Biological effects of negative air ions on human health and integrated multiomics to identify biomarkers: A literature review. *Environ. Sci. Pollut. Res.* **2023**, *30*, 69824–69836. [CrossRef] [PubMed]
10. Avila, B.S.; Mendoza, D.P.; Ramírez, A.; Peñuela, G.A. Occurrence and distribution of persistent organic pollutants (POPs) in the atmosphere of the Andean city of Medellin, Colombia. *Chemosphere* **2022**, *307*, 135648. [CrossRef] [PubMed]
11. Jorquera, H.; Montoya, L.D.; Rojas, N.Y. Urban Air Pollution. In *Urban Climates in Latin America*; Henríquez, C., Romero, H., Eds.; Springer International Publishing: Cham, Switzerland, 2019; pp. 137–165. [CrossRef]
12. Orejas, J.; Pfeuffer, K.P.; Ray, S.J.; Pisonero, J.; Sanz-Medel, A.; Hieftje, G.M. Effect of internal and external conditions on ionization processes in the FAPA ambient desorption/ionization source. *Anal. Bioanal. Chem.* **2014**, *406*, 7511–7521. [CrossRef] [PubMed]
13. An, Y.; Su, M.; Hu, Y.; Hu, S.; Huang, T.; He, B.; Yang, M.; Yin, K.; Lin, Y. The influence of humidity on electron transport parameters and insulation performance of air. *Front. Energy Res.* **2022**, *9*, 806595. [CrossRef]
14. Lima, F.d.A.; Medeiros, G.B.; Chagas, P.A.M.; Aguiar, M.L.; Guerra, V.G. Aerosol Nanoparticle Control by Electrostatic Precipitation and Filtration Processes—A Review. *Powders* **2023**, *2*, 259–298. [CrossRef]