Targeted Bipolar Pulsed Ionization: Using Electrical Charge to Target Airborne Contaminants

Abstract

Targeted Bipolar Pulsed Ionization, or TBPI™, is based on a simple but powerful physical principle: charged particles and surfaces interact through electrostatic forces. Opposite charges attract, like charges repel, and neutral particles can still be influenced by electric fields through induced polarization. These principles are already used in electrostatic precipitators, electret filters, powder handling, static-control systems, pharmaceutical aerosol delivery, and bioaerosol sampling. Peer-reviewed research shows that airborne particles, including biological particles, can carry measurable electrical charge and that electrostatic forces can significantly affect aerosol transport, deposition, filtration, and collection [1], [2], [3], [4]. TBPI applies this same electrostatic logic in a tunable way by controlling the polarity and timing of ion output. Rather than treating all contaminants with simultaneous positive and negative ion generation, TBPI can bias ion output toward the charge characteristics of the target contaminant class. This paper explains the scientific basis for charge-targeted contaminant control and how TBPI can use controlled polarity, pulsed operation, and electrostatic attraction to improve contaminant interaction while avoiding the aggressive chemical pathways associated with hard ionization, ultraviolet light or plasma oxidation.

---

1. Introduction

Most airborne contaminants are not simply passive particles floating through the air. Aerosols, dust, droplets, bacteria, fungal spores, smoke particles, and many virus-containing respiratory particles can carry electrical charge. Even particles that begin as neutral can become charged through contact, friction, ion attachment, triboelectric charging, diffusion charging, field charging, or interaction with charged surfaces [1], [2], [5].

Electrostatic forces are widely used to control particles. Electrostatic precipitators charge particles and drive them toward collection surfaces. Electret filters use persistent electric fields to improve capture of particles that would otherwise be difficult to remove mechanically. Static-control systems use ionizers to neutralize unwanted surface charge. Bioaerosol samplers use electrostatic forces to collect airborne microorganisms with lower pressure drop and gentler collection than some mechanical methods [3], [4], [6].

TBPI builds on these established principles. The core idea is that different contaminant classes behave differently in the presence of positive and negative ions. By controlling polarity and pulsing ion output, TBPI can be used to bias the electrical environment toward the target contaminant instead of producing simultaneous positive and negative ions that partially neutralize each other before they do useful work.

---

2. The Basic Physics: Opposites Attract

Electrostatic control begins with Coulomb's law. A charged particle experiences force in an electric field, and two charged bodies exert attractive or repulsive forces depending on the sign of their charge. Opposite charges attract. Like charges repel. Neutral particles can also be affected because electric fields can induce dipoles or attract polarizable particles.

For airborne contaminants, this means several interaction pathways are possible:

1. A positively charged ion can be attracted to a negatively charged contaminant.
2. A negatively charged ion can be attracted to a positively charged contaminant.
3. A neutral particle can become charged by ion attachment.
4. A charged particle can migrate toward an oppositely charged surface.
5. A charged particle can be more easily captured by an electret filter or grounded surface.
6. A charged particle can agglomerate with other particles through charge-mediated interactions.

This is not theoretical speculation. Electrostatic precipitators and electret filters are mature examples of using electrical charge to improve particle capture. Particle charging is described as an essential process in electrostatic precipitator performance, and research shows that particle charge can vary with particle properties, humidity, temperature, ion density, and electrode design [2].

TBPI uses this same principle, but instead of simply charging particles one way or producing both polarities simultaneously, it can tune and pulse polarity to influence specific contaminant classes.

---

3. Airborne Particles Carry Electrical Charge

A key scientific point supporting TBPI is that airborne particles can carry electrical charge. Mainelis and colleagues studied electrical charges on airborne microorganisms and found that biological particles in the airborne state can carry significant electric charge. The amount and polarity of charge depended on how the microorganisms were aerosolized, and some airborne microorganisms carried more than 10,000 elementary charges [1]. The authors also noted that electric charge can influence particle deposition, filtration, lung deposition, and electrostatic bioaerosol collection [1].

This is important because biological particles are not always electrically neutral. Bacteria, spores, and biological fragments may enter an airstream with charge already present. Respiratory droplets and droplet nuclei can also acquire charge during generation, evaporation, transport, and interaction with surfaces. Non-biological particles such as dust, smoke, fibers, and polymer particles can also become charged through triboelectric processes.

From a TBPI perspective, this means airborne contaminants can be influenced by charge-based targeting. If a contaminant is already charged, the system can bias ion polarity to encourage attraction, neutralization, deposition, or capture. If the contaminant is weakly charged or neutral, ions can attach to the contaminant and alter its electrical behavior.

---

4. Electrostatic Precipitation as Proof of Principle

Electrostatic precipitation is one of the clearest demonstrations that charged particles can be controlled in moving air. In an electrostatic precipitator, particles are charged and then exposed to an electric field that drives them toward a collection surface. This basic method has been used for decades in industrial air pollution control and has also been adapted for fine particle and bioaerosol collection.

Research on particle charging in electrostatic precipitators shows that particle charge is not random or irrelevant. Zheng and colleagues found that particle charging can be influenced by temperature, humidity, particle dielectric properties, electrode geometry, and current density. Their study reported that higher relative humidity significantly accelerated particle charging, with average charge on particles greater than 0.1 microns increasing by more than 50% when relative humidity increased from 30% to 80% under the tested conditions [2].

That finding matters for indoor air because many indoor contaminants exist in the same general size range where electrostatic forces can be meaningful. Fine particles, droplet nuclei, smoke, and many bioaerosols are small enough that even modest charge can affect transport, deposition, filtration, and agglomeration.

TBPI does not need to function as a traditional high-voltage electrostatic precipitator to use the same physics. It only needs to place controlled ions into the airstream so contaminants can acquire or interact with charge. Once a contaminant has charge, it can be influenced by nearby surfaces, filters, electric fields, other particles, or oppositely charged ions.

---

5. Bioaerosol Collection and Electrostatic Forces

Bioaerosol research strongly supports the importance of electrostatic interactions. Bioaerosol samplers increasingly use electrostatic collection because it can capture airborne biological particles with relatively low pressure drop and reduced mechanical stress compared with some impaction methods [3], [4].

A 2024 study introduced an electrostatic bioaerosol sampler for rapid bioaerosol collection, reflecting continued interest in electrostatic methods for collecting airborne biological particles [3]. Hong and colleagues also noted that electrostatic samplers have been increasingly studied for viral and bacterial aerosols and are useful where concentrated collection and viability preservation are important [4].

Viral bioaerosol research also supports the concept. Preston and colleagues demonstrated that electrostatic precipitation could efficiently capture and inactivate aerosolized enveloped and non-enveloped viral particles in a closed-system model. Capture and inactivation improved with higher voltage and with two discharge electrodes [6]. This does not mean TBPI operates the same way as that device, but it does show the broader point: viral particles in aerosols can be influenced and collected by electrostatic methods.

This is the technical foundation for targeted ionization. If electrostatic collection can capture biological aerosols, then controlled ion polarity can reasonably be used as part of a strategy to influence the behavior of biological contaminants in air. In addition to the targeting and charging of biological aerosols, it is well understood that bipolar ionization can inactivate SARS-CoV-2, as well as other virus, bacteria and mold. There are two methods of biological control with TBPI. First, TBPI targets the contaminants via electrostatic attraction, and oppositely charged particles agglomerate and form larger particles. The larger particles are more easily influenced by the HVAC system airflow allowing the particles to return to the system filter for capture. Second, the ions have the ability to inactivate or kill contaminants in the duct or occupied space when the ions contact those biological contaminants, even without agglomeration.

---

6. Electret Filtration and Charge-Based Capture

Electret filters are another important proof of principle. Unlike a purely mechanical filter, an electret filter contains persistent electric charge or polarization that improves particle capture. This is why many high-performance respirators and HVAC filters can capture particles more effectively than mechanical interception alone would predict. Please note, electret filters may lose their charge over time and the MERV rating will drop from what may be published for that filter.

Electrostatic capture is especially important for small particles, including particles in the most penetrating particle size range. Leung and colleagues studied electrostatically charged nanofiber filtration for airborne coronavirus-sized particles and described the value of charged filter media for improving capture efficiency [7]. Javidpour and colleagues modeled electrostatic interactions between SARS-CoV-2 and charged electret fibers, showing that virus-fiber electrostatic interactions depend on environmental conditions such as pH and salt concentration and on charge regulation of the viral spike proteins [8].

This is directly relevant to TBPI because it shows that charged biological particles and charged surfaces can interact in ways that matter for filtration and particle capture. TBPI can enhance this type of charge-based interaction by influencing the charge state of contaminants before they reach filters, surfaces, or collection regions.

In practical HVAC terms, TBPI supports contaminant control by:

- increasing the charge on airborne particles;
- improving particle interaction with charged or grounded surfaces;
- increasing filter capture probability;
- encouraging agglomeration of fine particles into larger particles;
- reducing the number of airborne particles that remain suspended;
- biasing ion polarity toward the electrical behavior of the target contaminant.
- inactivation or killing of contaminants when in contact with ions.

---

7. Why Tunable Polarity Matters

Traditional bipolar ionization systems often produce positive and negative ions at the same time. This can be useful in some applications, especially static neutralization, but it also creates a built-in inefficiency: positive and negative ions can recombine with each other before reaching the target contaminant.

TBPI improves on this by controlling polarity and timing. Instead of always generating both polarities simultaneously, TBPI can bias output toward positive or negative ions and can pulse the output with a delay between polarities. This allows more useful ions to survive long enough to interact with contaminants.

The targeting logic is straightforward:

- If a contaminant or surface tends to behave as positively charged, negative ion output can be emphasized.
- If a contaminant or surface tends to behave as negatively charged, positive ion output can be emphasized.
- If the goal is charge neutralization, polarity can be alternated.
- If the goal is agglomeration or enhanced filtration, ion output can be adjusted to increase useful particle charging before the contaminant reaches a filter or surface.

This is similar to static-control practice. Static-control ionizers are used because excess surface charge causes attraction, repulsion, dust deposition, handling problems, and electrostatic discharge risk. Ionization is used to bring charge into balance. TBPI extends that principle from simple neutralization toward contaminant-specific charge targeting.

---

8. Contaminant Classes and Charge-Based Targeting

TBPI can be described as a platform technology because different contaminant classes can be addressed by different ion strategies.

Particles and dust

Dust and fine particles commonly acquire charge through friction, contact, and movement through air or ducts. Once charged, these particles can be attracted to oppositely charged surfaces or influenced by electric fields. Electrostatic precipitator research shows that particle charging is central to removal performance [2]. TBPI can support particle control by increasing charge interactions and improving the probability that particles deposit, agglomerate, or are captured by filters.

Bacteria and fungal spores

Airborne microorganisms can carry measurable charge, and biological particles can differ from non-biological particles in their charge characteristics [1]. Because bacterial cells and spores can be electrostatically collected, TBPI can use ion polarity to influence their behavior in air. This may improve interaction with filters, surfaces, or other charged particles. While agglomeration is useful to help capture the contaminant, the ions are also capable of killing bacteria and fungal spores.

Viruses and virus-containing aerosols

Viruses usually travel indoors inside respiratory droplets or dried droplet nuclei rather than as isolated naked virions. These carrier particles can acquire charge. Electrostatic collection has been shown to capture viral particles from bioaerosols [6], and modeling work has shown that SARS-CoV-2 can interact electrostatically with charged electret fibers [8]. TBPI can target virus-containing aerosols by influencing the charge state of the carrier particles and improving their interaction with capture surfaces. Virus can be inactivated by continued impact with ions.

Mold and allergens

Mold spores, pollen fragments, and allergen-bearing particles are airborne biological particles that can be influenced by electrostatic effects. Their size and charge characteristics can make them candidates for enhanced deposition or filtration through charge-based treatment.

VOCs and odors

VOCs are more complicated. Many VOC molecules are neutral gases, and electrostatic attraction alone is not usually enough to remove them the way it can affect particles. TBPI is not a plasma oxidation technology like DBD, PCO or hard ionization.   For TBPI to reduce VOCs and odors, a system must have particles and a particle filter. The ions force interation of VOCs and odors with airborne particles causing the VOCs and odors to adsorb and absorb on to and into particles. As the particles are filtered from the air the with VOCs and odors attached, the VOCs and odors are reduced.

Static electricity

Static control is the most direct application of polarity management. If a space, surface, process, or material has excess positive or negative charge, TBPI can provide the opposite polarity or alternate polarity to reduce static imbalance. This follows the same principle used in industrial static-control ionization.

---

9. Targeting Is Not Magic: It Requires Matching Polarity, Contaminant, and Application

TBPI targets contaminants by controlling the electrical environment. The system uses known or measured contaminant behavior to select ion polarity, pulse timing, and output strategy. The user simply uses a smart phone app or desktop app to select the contaminant of concern and the system reconfigures to best target that contaminant.

The targeting concept depends on several variables:

- particle size;
- particle charge;
- particle dielectric properties;
- humidity;
- airflow velocity;
- ion concentration;
- ion lifetime;
- distance from ion source to target;
- filter or surface properties;
- whether the contaminant is a particle, droplet, bioaerosol, or gas-phase molecule.

This is consistent with aerosol science. Zheng and colleagues showed that particle charging depends on humidity, temperature, particle composition, electrode form, and current density [2]. Mainelis and colleagues showed that airborne microorganism charge depends on aerosolization method and biological particle condition [1]. Javidpour and colleagues showed that electrostatic virus-fiber interactions can depend on environmental factors such as pH and salt concentration [8].

TBPI can tune ion polarity and timing to improve charge-based interaction with selected contaminant classes.

---

10. Why TBPI Is Different from Conventional Bipolar Ionization

Conventional bipolar ionization typically generates positive and negative ions together. That can create useful air ions, but it also allows immediate recombination. When positive and negative ions are created at the same time and in the same region, some portion of the ion output is lost before it reaches contaminants. This is why some manufacturers suggest mounting the ion device such that air flows over both ion polarities simultaneously (in parallel) versus having the air cross one polarity and then the next (in series) directly cancelling out the ions in close proximity to the device.

TBPI is different in three ways:

First, TBPI is tunable.

The user can manually set the outputs or the control system can control the output in “auto” mode based on the contaminant selected. In auto mode, the ion output is biased toward the polarity most likely to interact with that target.

Second, TBPI is pulsed.

Positive and negative output can be separated in time, reducing immediate cancellation and allowing more useful ion delivery into the airstream and the occupied space.

Third, TBPI is target-oriented.

The purpose is not just to produce ions. The purpose is to produce the right polarity, at the right time, for the contaminant being addressed.

This gives TBPI a more sophisticated control logic than conventional simultaneous bipolar ionization.

---

11. Safety and Byproduct Considerations

TBPI is a soft ionization technology. Its purpose is to use electrical charge and ion-contaminant interactions, not to chemically oxidize air contaminants through high-energy plasma chemistry.

That distinction matters. Electrostatic targeting does not require fragmenting VOCs, photolyzing oxygen, or generating ozone. TBPI should therefore be considered separate from hard ionization, dielectric barrier discharge, corona-discharge VOC destruction, and UV-driven photochemistry.

TBPI is designed to control airborne contaminants through charge-based interactions rather than destructive oxidation chemistry. By tuning ion polarity and timing, TBPI can increase useful electrostatic interaction with target contaminant classes while avoiding the high-energy pathways associated with ozone formation and chemical byproducts.

---

12. Practical TBPI Control Strategy

A practical TBPI control strategy could be described as follows:

1. **Identify the target contaminant class.**
   Examples include particles, bacteria, virus-containing aerosols, mold spores, VOC-associated particles, odors, coil cleaning or static electricity.
2. **Select the polarity strategy.**
   If the target tends to carry or present a positive charge, bias negative ions. If the target tends to carry or present a negative charge, bias positive ions. If the goal is neutralization, alternate polarity.
3. **Pulse the output.**
   Use a programmed delay between positive and negative ion generation to reduce immediate recombination.
4. **Use the HVAC system as the delivery path.**
   Place the ion generator where ion delivery is optimized, such as near the fan inlet or supply airstream, depending on product design.
5. **Use downstream capture mechanisms.**
   Charged particles are more likely to agglomerate and interact with filters.
6. **Verify performance.**
   Measure particle reduction, VOC/odor reduction, biological reduction or ion output

---

13. Conclusion

TBPI is built on a well-established physical principle: electrical charge affects how particles move, deposit, agglomerate, and interact with surfaces. Peer-reviewed research shows that airborne microorganisms can carry significant electrical charge, that electrostatic precipitators rely on particle charging for removal, that electrostatic methods can collect bacterial and viral bioaerosols, and that charged electret filters can enhance capture of difficult-to-remove particles [1], [2], [3], [4], [6], [7], [8].

The innovation in TBPI is controlled targeting. Instead of producing positive and negative ions simultaneously and allowing them to cancel, TBPI can bias polarity and pulse output based on the contaminant class. This allows TBPI to use charge-based attraction and interaction more efficiently.

TBPI is a targeted electrostatic contaminant-control technology. It does not need to chemically destroy contaminants through hard ionization, ozone, or UV photochemistry. Its advantage is that it uses soft ionization, polarity control, and electrostatic attraction to improve contaminant interaction while avoiding the byproduct risks associated with more aggressive air-treatment technologies.

References

[1] Mainelis, G., Willeke, K., Baron, P., Reponen, T., Grinshpun, S. A., Górny, R. L., and Trakumas, S. "Electrical Charges on Airborne Microorganisms." *Journal of Aerosol Science*, 2001. The study found that airborne microorganisms can carry measurable electrical charge, in some cases more than 10,000 elementary charges, and that charge affects deposition and collection behavior.

[2] Zheng, C., Duan, D., Chang, Q., Liu, S., Yang, Z., Liu, X., Weng, W., and Gao, X. "Experiments on Enhancing the Particle Charging Performance of an Electrostatic Precipitator." *Aerosol and Air Quality Research*, 2019. The study describes particle charging as essential to ESP removal and shows that humidity, dielectric properties, electrode design, and current density influence particle charge.

[3] Pang, Z., et al. "Development of a Novel Electrostatic-Based Bioaerosol Sampler." 2024. This study reflects continued development of electrostatic collection as a method for rapid bioaerosol collection.

[4] Hong, S., et al. "Physical Collection and Viability of Airborne Bacteria Using Electrostatic Sampling." 2021. The study notes that electrostatic samplers have increasingly been studied for viral and bacterial aerosols.

[5] Xi, J., et al. "Electrostatic Charge Effects on Pharmaceutical Aerosol Deposition." 2014. The paper reports that electrostatic charging occurs in many aerosol generation processes and can significantly influence particle deposition rates and patterns.

[6] Preston, H. E., et al. "Capture and Inactivation of Viral Particles from Bioaerosols by Electrostatic Precipitation." *iScience*, 2023. The study demonstrated efficient capture and inactivation of aerosolized enveloped and non-enveloped viral particles using electrostatic precipitation.

[7] Leung, W. W. F., et al. "Electrostatic Charged Nanofiber Filter for Filtering Airborne Novel Coronavirus." 2020. The study addresses charged nanofiber filtration for capture of airborne coronavirus-sized particles.

[8] Javidpour, L., Božič, A., Naji, A., and Podgornik, R. "Electrostatic Interactions between the SARS-CoV-2 Virus and Charged Electret Fibre." 2021. The study modeled electrostatic interactions between SARS-CoV-2 and charged electret fibers and showed that environmental conditions can affect the scale and sign of interaction.

[9] Byeon, J. H., et al. "Collection of Submicron Particles by an Electrostatic Precipitator." *Journal of Aerosol Science*, 2006. The study experimentally investigated collection of submicron aerosol particles using a two-stage electrostatic precipitation system.

[10] Lee, S. A., et al. "Assessment of Electrical Charge on Airborne Microorganisms by a New Bioaerosol Sampling Method." *Journal of Occupational and Environmental Hygiene*, 2004. The paper focused on electrical charge as an important parameter affecting collection of airborne microorganisms.