

AEIRO RESEARCH & TECHNOLOGY

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

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Abstract

Targeted Bipolar Pulsed Ionization (TBPI) applies established electrostatic principles to controlled ion polarity and timing. Charged particles and surfaces interact through electric forces, and neutral particles may acquire charge or respond to electric fields. Electrostatic precipitators, electret filters and bioaerosol samplers demonstrate the relevance of charge to collection and transport [1, 2, 3, 4]. TBPI is designed to use controlled ion output to influence contaminant interactions in an airstream. These general principles support investigating the approach, but do not establish AEIRO-specific particle reduction, biological inactivation, VOC/odor removal or emissions performance. This paper separates the physical basis, proposed control strategies and evidence needed to evaluate a specific product and application.

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 electrostatic principles by allowing ion polarity and pulse timing to be controlled. Different aerosols can have different charge distributions, and ions of opposite polarity can recombine. The design aims to influence the electrical environment around a target; the benefit relative to simultaneous output requires a controlled comparison.

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 acquire charge through ion attachment.
4. A charged particle can migrate toward an oppositely charged surface.
5. Particle charge can influence capture by an electret filter or another collection surface.
6. Charge-mediated interactions can influence particle agglomeration.

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 controllable polarity and pulsed output to investigate these interactions. Selecting a contaminant category is a control input; it does not by itself establish removal efficiency for that category.

3. Airborne Particles Carry Electrical Charge

Mainelis and colleagues found that airborne microorganisms can carry measurable charge, with magnitude and polarity depending on organism and aerosolization conditions [1]. That research supports considering charge in aerosol transport and collection; it does not prescribe a universal polarity for every biological contaminant.

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.

Zheng and colleagues investigated how humidity, particle properties, electrode configuration and current density affect charging in an electrostatic precipitator [2]. Their results show why environmental and device conditions matter. They should not be transferred directly into a TBPI performance estimate.

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 operate as the collection system described in every cited electrostatic-precipitation study. Introducing ions into an airstream can influence charge, but removal also depends on transport, collection surfaces, filters and the

actual installation. These differences need to be accounted for when evaluating the design.

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. Electrostatic collection research shows that biological aerosols can be influenced and collected using electrostatic methods. That broader proof-of-principle supports evaluating controlled ion polarity as part of an airborne-contaminant strategy. It does not, by itself, establish AEIRO TBPI-specific biological reduction, kill, or inactivation performance. Any such AEIRO product claim should be tied to an applicable product-specific test report, organism, test method, operating condition, and measured outcome. The cited electrostatic-precipitation research [6] used a different collection system and should not be treated as direct evidence of TBPI biological inactivation.

6. Electret Filtration and Charge-Based Capture

Electret filters contain persistent charge or polarization that contributes to particle capture. Their performance depends on media design, particle characteristics, loading and exposure conditions. Any statement about loss of charge or a change in a filter rating should use the applicable filter manufacturer's data and test method rather than assuming the same change for every electret 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].

These studies show that charge can matter for filtration. They provide a reason to evaluate whether upstream ion control improves capture in a particular HVAC arrangement. They do not establish a TBPI-specific increase in filtration efficiency.

The proposed HVAC strategy is to evaluate whether controlled ion delivery can:

- change the charge distribution of airborne particles;
- influence interactions with charged or grounded collection surfaces;
- improve capture in a specified downstream filter;
- promote particle agglomeration under the relevant conditions;
- reduce the concentration of suspended particles;
- support a polarity strategy suited to a measured contaminant condition.

Each proposed benefit requires its own measured outcome. Biological reduction or inactivation is a separate endpoint and requires applicable product-specific testing.

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 controls polarity and timing so the two polarities can be separated in time. The intended benefit is lower immediate recombination and useful downstream ion availability. That benefit should be quantified under the airflow, humidity, geometry and output settings relevant to the installation.

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 may acquire charge through several mechanisms. Electrostatic-precipitator research demonstrates that charge influences removal in the tested collection systems [2]. For TBPI, particle reduction, deposition, agglomeration or capture should be measured for the specified model, filter and installation.

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, controlled ion polarity may influence their behavior in air and their interaction with filters, surfaces, or other charged particles. These electrostatic observations are proof-of-principle; they do not establish that AEIRO TBPI kills or inactivates bacteria or fungal spores without applicable AEIRO product-specific biological testing.

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]. These studies support the general relevance of electrostatic interactions to viral aerosols, but they do not establish AEIRO TBPI-specific viral reduction or inactivation. Any such claim requires applicable product-specific testing and a defined measured outcome.

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 and odors require more careful treatment than particles. Many VOC molecules are neutral gases, so electrostatic attraction alone should not be assumed to remove them in the same way that charge can influence particles. TBPI is described as a soft-ionization technology rather than a plasma-oxidation process. AEIRO has proposed that ions may influence interactions between VOCs/odors and airborne particles, with subsequent particle filtration contributing to removal. The supplied materials do not include an AEIRO-specific test that demonstrates this adsorption/absorption pathway or quantifies the resulting VOC/odor reduction. Accordingly, this should be treated as a proposed mechanism unless an applicable test report identifies the compound or odor, particle/filter conditions, method, operating conditions, and measured reduction.

Static control

Static control is a direct use of polarity management. An appropriate ion balance can be used to reduce excess surface charge. For a TBPI application, verify the required charge-decay time and ion balance at the target under the intended operating conditions.

9. Matching Polarity, Contaminant, and Application

The TBPI control concept uses a selected contaminant category to choose an ion polarity, pulse timing and output strategy. Available app modes and manual settings depend on the product and software version. The control rule and any claim of improved treatment should be documented and tested for the target application.

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].

Tunable polarity and timing provide adjustable control inputs. Their effect on a selected contaminant should be measured rather than assumed from the selected mode.

10. Why TBPI Is Different from Conventional Bipolar Ionization

Simultaneous positive and negative ion generation can allow recombination near the source or downstream. The extent depends on emitter geometry, airflow, humidity, ion concentration and residence time. Installation decisions should follow the applicable product instructions and measured performance rather than a generalized cancellation allowance.

TBPI is different in three ways:

First, TBPI is tunable.

Where supported by the product and software, a user can select a mode or adjust available output settings. The resulting polarity strategy is a programmed design choice, not an independent measurement of the target's charge or of treatment success.

Second, TBPI is pulsed.

Positive and negative output can be separated in time. This is intended to reduce immediate recombination; the effect on ion delivery and contaminant outcomes needs application-specific verification.

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 changes the available control strategy. Comparative treatment performance requires an appropriate test against a defined baseline.

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.

Electrostatic targeting and intentional gas-phase oxidation are different design approaches. However, a description of mechanism does not establish the absence of ozone or every possible byproduct. Model-specific emissions testing is needed for the stated endpoints.

Claims about biological inactivation, VOC/odor removal, particle reduction, byproduct formation or improved energy use should identify the tested product, settings, environment and outcome. General electrostatic literature provides context, not a substitute for those data.

12. Practical TBPI Control Strategy

A practical TBPI control strategy could be described as follows:

1. Identify the target and endpoint. Distinguish particle concentration, a specified biological outcome, a named VOC/odor, static charge or coil condition.
2. Select the control strategy. Document the proposed polarity and timing rule and the available product/software settings.
3. Set pulse timing. Record the positive and negative output periods, delay and other relevant settings for the comparison.
4. Apply the product instructions. Choose the approved mounting arrangement and document airflow, geometry and environmental conditions.
5. Specify collection and filtration. Describe filters or other removal mechanisms and measure their contribution where relevant.
6. Verify the outcome. Measure the target contaminant or charge-decay endpoint using an appropriate method. Ion-output measurements alone do not prove contaminant removal or biological inactivation.

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 TBPI design adds selectable polarity and pulse timing to ion delivery. Its practical value should be evaluated with a defined contaminant, installation, control setting and baseline rather than inferred from the presence of those controls.

The scientific literature establishes that charge can affect aerosol interactions and collection. Demonstrating that a particular AEIRO implementation improves a

treatment outcome or has a specified emissions profile requires applicable product testing. The proposed VOC/particle-filtration pathway remains a hypothesis unless demonstrated for the stated conditions.

References and source types

Research citations provide background for the stated mechanisms and tested systems. They do not automatically validate AEIRO product performance. Manufacturer literature, public guidance and internal references are labeled separately. Product claims require evidence for the relevant model, endpoint and operating conditions.

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