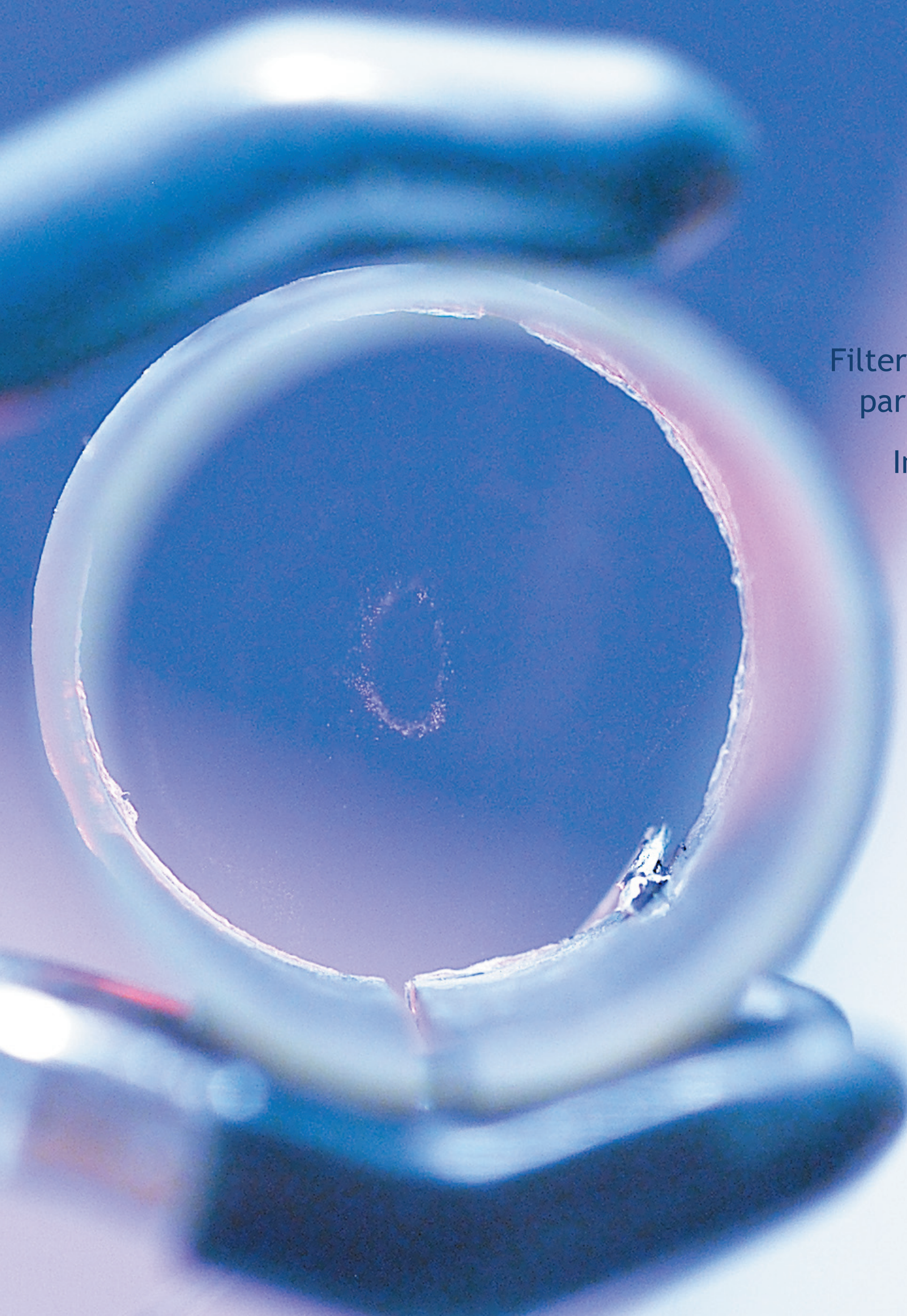
Available for License

Aerosonic

Acoustic Concentrator of Aerosol Contaminants



Filterless filter for many particulate air pollutants

Inexpensively concentrates aerosol contaminants using sound

Compact, low-power compatibility with hand-held detectors

Low-maintenance, durable, self-tuning solid-state design

Los Alamos
NATIONAL LABORATORY

LAUR-05-7788

Aerosonic

Technology Transfer Contacts
Technology Transfer Contacts:
Eric Canuteson
Charlie Gibson
Laura Barber
email: tmt-2@lanl.gov

Technical Contact
Greg Kaduchak

ABOUT THE COVER

Suspended against the force of gravity by sound pressure, a ring of aerosol droplets hovers within the cavity of Aerosonic's piezoelectric cylinder.

Los Alamos
NATIONAL LABORATORY
Los Alamos NM 87545

Executive Summary

Aerosonic: Acoustic Concentrator of Aerosol Contaminants

Features

An inexpensive, low-maintenance, piezoelectric device, Aerosonic generates focused, resonance-based sound pressure to concentrate aerosols. The concentrated aerosols can then be directly isolated for analysis. Alternatively, when added as a front-end concentrator to existing low-sensitivity, hand-held detectors, Aerosonic increases detector sensitivity. Its light weight and low power consumption make it an ideal add-on. Functioning independently as a "filterless" filter, Aerosonic can—by removing the concentrated material—eliminate such air pollutants as diesel-engine combustion particulates, toxic byproducts from restaurant-kitchen exhaust, and airborne bacteria in hospitals.

Applications

- Facility Safety: Front-end sensitivity enhancer for hand-held detectors such as optical classifiers and particle sizers
- Air-Pollution Control: "Filterless" filter for diesel-exhaust particulates, combustion exhaust from restaurant kitchens, and airborne bacteria in hospitals
- Homeland Security: Concentrator for aerosol chemotoxins and biotoxins to facilitate their analysis

Benefits

- Extremely low-power operation and absence of moving parts minimize maintenance costs.
- Compact and lightweight—ideal for use with hand-held detectors.
- Simplicity of operation allows varied applications.
- Concentrates a wide variety of aerosol contaminants for analysis.
- Can function as a filter as well as a concentrator.

Overview

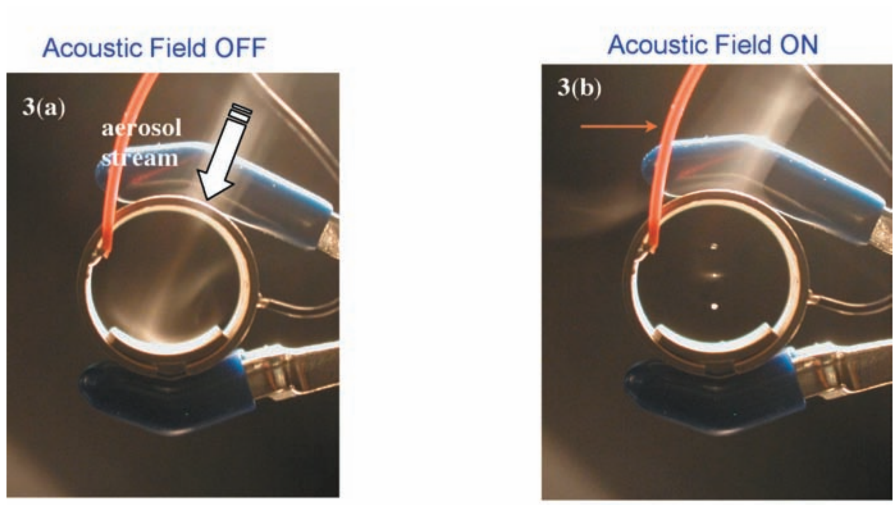
Employing a small, thin, piezoelectric cylinder to generate standing sound waves, Aerosonic uses sound pressure to locally concentrate many types of aerosols, ranging from smog particulates to suspended microorganisms. This capability also allows it to function as a “filterless” filter. Because of its small size, light weight, and efficient use of power, it is likewise ideally suited as an add-on to hand-held detectors.

Piezoelectric materials are capable of changing shape to produce a force when a voltage is applied. In Aerosonic, a hollow cylinder (or tube) of such material is stimulated with an alternating voltage, causing the material to rapidly change shape and vibrate. At a specific vibration frequency—governed by the frequency of the alternating voltage—the shape changes are radially uniform, and it appears as if the tube is “breathing” (Click on Button 1 of the accompanying DVD to view an animation). This “breathing mode” can be a very energy-efficient way to drive large-amplitude vibrations, known as “resonance.”

The vibration of the tube’s interior wall during the breathing mode excites the air molecules contained within the tube’s cavity, setting them into motion and thus generating sound waves (which are pressure waves created by the motion of air molecules). Amplification of the pressure waves inside the cavity results from wave interference and resonance. At certain well-defined excitation frequencies that depend on the physical properties of the air molecules in the tube, the pressure vibrations within the tube produce standing waves, waves produced whenever two waves of identical frequency interfere with each other while traveling in opposite directions. Standing-wave patterns are characterized by fixed locations along the wave-conducting medium—called nodes—which undergo no displacement of the medium’s molecules (in this instance, air molecules within the tube’s interior). Similarly, there are certain fixed points along the medium that undergo a maximal displacement. These points of maximal displacement are called antinodes.

At a frequency that produces standing waves, the nodes (and antinodes) are always located at the same places in the medium, giving the entire pattern of air-molecule displacement an appearance of standing still—thus the name “standing waves.” (This phenomenon cannot be seen by the naked eye but can be visualized by other methods.) A resonance is defined as a standing wave in which many waves interact simultaneously to amplify the maximum amplitude of the pressure field. Hence, based on this principle, by choosing the appropriate excitation voltage and frequency and controlling the tube's size and other properties, we can generate high-intensity pressure fields inside the piezoelectric tube at specific locations. (For a more in-depth treatment of the topics of resonance and standing waves, see the appendix document, "An Acoustics Primer: Standing Waves and Resonance.")

Upon entering the piezoelectric tube's air-filled cavity, where high-intensity acoustic standing waves have been generated, aerosol particles experience a force that transports them to the vicinity of either a pressure node or an antinode, thus suspending them in a localized fashion (Figure and cover). This effect has been known by physicists since Kundts observed it in organ pipes in 1874.



(a) Aerosonic's piezoelectric cylinder (white arrow) showing an aerosol stream passing through the interior acoustic cavity. The power—and therefore the acoustic field—is off. (b) Same situation after activation of power to the cylinder. The aerosol particles are concentrated at the three nodal positions shown. The orange arrow indicates electrical input to the cylinder wall.

Because of engineering challenges associated with power requirements and stability, acoustic-concentration devices that use resonant sound-pressure fields have, to this point, remained specialized research tools. Acoustic levitators, for example, are based on parallel-plate transducer assemblies and not only consume significant power but also require regular re-alignment. The uniqueness of Aerosonic stems from the fact that it uses the resonance amplification of the piezoelectric tube's breathing mode to drive a resonant sound-pressure field within its cylindrical cavity. The coupling of the two resonance phenomena—the breathing mode of the tube itself and the resonance of the air column inside the tube—results in a highly efficient production of sound within the device.

Such locally amplified sound pressure can be used to suspend concentrated aerosols, a form of acoustic levitation, so that small samples can be isolated—without a containment vessel—for a variety of analyses. For example, aerosol particles can be steered to precise locations within a flowing air stream (to within a few hundred microns) to detectors that require precise positioning of microorganisms or aerosolized toxic chemicals for rapid identification and characterization. (Click on Button 2 of the accompanying DVD to view the real-time "levitation/positioning" segment.) Alternatively, the concentrated aerosols can be directed to a particle sizer or optical classifier, with preconcentration of the aerosol serving to increase the efficacy of the instrument, functionally enhancing its sensitivity. Historically, the efficiency of such instruments has been limited by their low sensitivity (i.e., they respond to only relatively high aerosol concentrations).

Since Aerosonic is constructed from a commercially available piezoelectric tube and requires only low power, it is quite inexpensive to construct and operate. For example, only 0.1 watt of power is required to levitate a 1-millimeter droplet of water. This simplicity, together with its small size, makes Aerosonic ideal as a "front end" concentrator for hand-held, battery-powered detectors of aerosol and particulate toxins. Such low power consumption is accompanied by negligible "wear-and-tear" effects such as excessive heating of components.

Given its ability to concentrate particulates, Aerosonic can also function as a "filterless filter," by purging pollutants from high-particulate (e.g., diesel) automotive exhaust. The high-intensity sonic pressure field creates energetic collisions between small particles, inducing particle agglomeration—growing large particles from small particles. Aerosonic's incorporation into exhaust systems would significantly reduce emission of such particulates, especially critical in high-density commercial-traffic areas such as Southern California. Similarly, Aerosonic can filter small particulate pollutants from burning fats and other chemicals commonly found in restaurant exhaust, as well as bacteria and viruses, known to be ubiquitous in hospital environments. Endorsement letters for Aerosonic's varied applications are provided in the appendix. Publications elaborating Aerosonic's features and applications are also provided.

Competition

There are no commercial products that concentrate aerosol particles acoustically. The only sound-based technologies in use—parallel-plate transducers—are limited to research laboratory settings. However, there are many nonacoustic technologies available for aerosol concentration.

The following two products exemplify the nonacoustic concentrators available.

HEPA Filter: A HEPA (high-efficiency particulate air) filter is placed in an aerosol flow stream to trap larger particles. A large pressure drop is typically required across the filter for efficient operation, and the filter must be changed periodically to prevent it from clogging. For applications in which the collected aerosols are to be sampled, real-time analysis is not possible. The exemplary technology compared in the matrix, is the **Air System International HV-108SP.**

Virtual Impactor: A virtual impactor operates by accelerating an air stream of particles through a nozzle. While traveling through the nozzle, the major portion of the flow is diverted from the side of the nozzle's channel (the impaction junction). Larger particles are unable to follow the flow because of their inertia and continue in the forward direction. Virtual impactors require a large pressure drop across the impaction junction. Once past the junction, the particles are still homogeneously distributed across the air stream. The exemplary technology compared in the matrix, is the **MSP Bioconcentrator Model 4220.**

Comparison matrix

Parameters	Aerosonic	MSP Bioconcentrator Model 4220	Air System International HV-108SP (HEPA Filter)	Comments
Power Consumption/ Efficiency	0.1 to several watts; negligible pressure drop across device	150 watts	1020 watts	Tuning a resonance frequency of Aerosonic's hollow vibrating piezoelectric cylinder to that of the resonance frequency of the column of air in the cylinder's interior lowers the power required to achieve sufficient sound pressure for agglomerating and concentrating aerosols. The negligible pressure drop across our device saves an appreciable amount of energy that would otherwise be required for a vacuum pump to draw the air flow through the cylinder's interior. Instead, a simple battery-operated cooling fan suffices to generate this flow. By contrast, in HEPA filters, a vacuum pump must compensate for a large pressure drop across the filter.
Precisely Positions Particles in a Flow Stream?	Positions particles within a several-hundred-micrometer region in a flow stream	No	No	The nodal makeup of Aerosonic's acoustic field precisely "positions" particles by forcing them to highly localized regions of the flow stream. This is the only instrument that can precisely position aerosol particles in a flow stream, a highly desirable property for any detector that uses a laser as a scanning probe. (See question 10C for more detail. For details on the physics underlying this precise positioning, see question 9 and the appendix document, "An Acoustics Primer: Standing Waves and Resonance.")
Size/Portability	1–30 cu in./ 1 lb	2170 cu in./ 33 lb	6160 cu in./ 30 lb	Small, lightweight, and inconspicuous, Aerosonic can be used in a wide variety of applications.
Maintenance	Low	High	High	Aerosonic's patented design is constructed from a piezoelectric tube—it contains no moving parts. Its vibrational motion with applied alternating voltage is miniscule. Its large-opening cross section eliminates clogging; there are no small apertures that can clog with particulates. The MSP Bioconcentrator's nozzle openings can clog with aerosol build up. HEPA filters must be periodically changed.
Versatility	Multiuse	Only concentrates aerosols	Only collects aerosols on filter media for later analysis	Aerosonic has multiple uses. As a front end to existing detectors, it can concentrate aerosols or steer them to exact locations to increase particle throughput and detector sensitivity. As a back end to industrial processes, Aerosonic can be used as a filterless filter to isolate harmful particulates for collection or to agglomerate small aerosol particles for removal from exhaust streams. Both HEPA filters and the MSP Bioconcentrator are single-application devices.
Cost	$200	$30,000	$895., plus filter-replacement charges and man hours to maintain a filter-replacement schedule	Aerosonic's low cost makes it an attractive investment for laboratories and businesses seeking a cost-efficient solution to their aerosol-analysis or filtration needs.

Advantages

To concentrate aerosols, Aerosonic uses less than one-tenth the power (0.1–1 watt compared with >10 watts) by comparison with typical virtual impactors or HEPA filters. Such low power consumption is important when it is used in conjunction with detectors that are either placed in remote areas or are hand held and run on only batteries. As an added benefit for detectors that run autonomously for long periods of time, Aerosonic requires virtually no maintenance since it contains no moving parts.

Aerosonic's minimal size, weight, and power consumption provide the versatility needed to serve as a front-end concentrator to effectively increase the sensitivity of inline biological and chemical detectors in the biomedical, industrial, environmental, and homeland security applications (see the letter in the appendix from Interferometrics Co.). The fact that there is virtually no pressure drop across the tube means that the airflow through Aerosonic can be generated with a simple battery-operated cooling fan such as those used on integrated circuit assemblies. Thus, weighing much less than a pound, Aerosonic is the only device that can be outfitted to work in hand-held instruments.

Additionally, Aerosonic can be used to steer and position particles in the air-flow stream—an extremely valuable feature that no other aerosol concentrator can accomplish. Many detectors use lasers as the detection probe, and during that detection process, they require a large amount of optical energy to fluoresce or detect scattering from small (one micrometer or smaller) aerosol particles. For this reason, optical engineers are trying to focus laser beams to a diameter of less than 300 micrometers to increase their optical power. Precise particle positioning is required for these high-sensitivity laser-based detectors. Aerosonic is capable of positioning particles in a flow stream within this 300-micrometer window.

One of the most attractive features of Aerosonic is its simplicity. Its patented design matches two acoustic resonances, and it is constructed from a single piezoelectric tube. The electronics package to drive the concentrator is very simple and inexpensive. The cost to manufacture a single concentrator is less than $100.

The technology's uniqueness is to some extent illustrated by a letter in the appendix from the McGraw-Hill Company—an invitation to submit an article to the *2005 Yearbook of Science and Technology*.

Principal applications

Aerosonic's ability to concentrate chemotoxins and biotoxins for analysis gives it obvious applications in the homeland security area. Additional applications are concentration and detection of biotoxin and chemotoxin aerosols for industrial and commercial applications. For example, in industries using beryllium in manufacturing (jewelry, sports equipment, dental apparatus, and others), Aerosonic's ability to concentrate aerosols can facilitate detection of the presence of low levels of this toxic metal in work environments. Likewise, in hospitals, environmental bacteria and viruses that account for a large number of hospital-acquired infections can be more readily detected and quantified.

Other applications

As a filterless filter for diesel-exhaust particulates and restaurant-kitchen toxics, Aerosonic can serve as a back-end purifier, by removing these human-health and environment-damaging substances from the exhaust stream. Particle fractionation is another potential application for Aerosonic. By appropriately adjusting the concentrator's parameters, it is possible to select a certain particle size for concentration, while allowing particles of other sizes to pass through without being concentrated.

Summary

Based on principles of resonant sound reinforcement and made with commercially available piezoelectric material similar to that used in certain microphones or loudspeakers, Aerosonic is capable of concentrating or filtering airborne contaminants and pollutants. By creating sound pressure inside a small hollow tube of piezoelectric material, Aerosonic will isolate or filter particulate (e.g., smog), chemotoxin (e.g., chemical weapons), and biotoxin (e.g., viral or bacterial) contaminants. Commercial filtering applications include such toxins as particulates in diesel-engine exhaust and in exhaust from restaurant kitchens.

Additionally, the ability of Aerosonic to concentrate aerosols effectively enhances the sensitivity of existing detectors. Because of its small size and its low electrical-power requirements, Aerosonic is particularly well suited as a front-end add-on to battery-powered, hand-held instruments. In this context, it can serve as the enabling technology for several types of bio-detectors used in homeland security and environmental surveillance initiatives, as well as in screening for toxic byproducts in research laboratory and industrial settings. It also has applications in health care, namely as a concentrator of bacteria- and virus-containing aerosols that account for a large number of hospital-acquired infections, which average about 2,000,000 annually, with nearly 90,000 annual fatalities (Centers for Disease and Prevention Control statistics).

By comparison with existing products, Aerosonic is virtually maintenance free. Completely solid state with no moving parts, it consumes far less electrical power than any comparable technology, and is autotuned: it has no parallel acoustic elements that must be aligned.

Aerosonic is a simple sound-based concentrator that is well suited to a variety of concentration, detection, and filtering uses.