Entegris

# Airborne Molecular Contamination (AMC) Solutions for the Microelectronics Industry

Microelectronics fabrication plants (fabs) are complex structures that require sophisticated air circulation and control. For management and energy savings, most of the conditioned air inside a fab is recirculated and may carry increasing amounts of contaminants that are produced internally, from humans, materials, chemicals, and equipment. About 5–20% of fresh air is provided from outside the fab, which may carry other potential contaminants. Small particles have been a well-controlled concern for decades, but modern microelectronics technology also requires a tight control of gas-phase, airborne molecular contamination (AMC) as it affects product, processes, and equipment. It is no longer possible to manufacture advanced semiconductors without AMC protection.

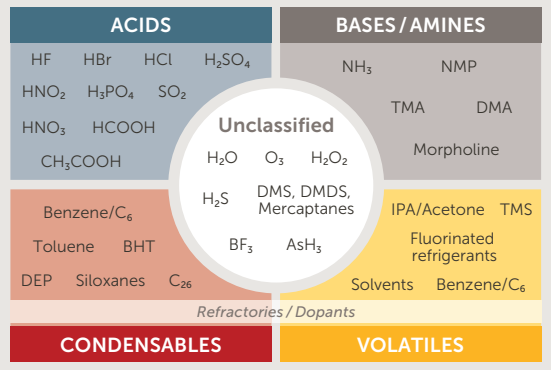
*See it. Control it.*

*Entegris is the leader in airborne molecular contamination control for the microelectronics industry.*

*The combination of competent AMC measurement and advanced materials provides a unique understanding of AMC filtration solutions that are widely adopted with confidence.*

## Airborne Molecular Contamination

AMC is usually classified based on SEMI standard F021-00-1016, which distinguishes acids, bases, condensable organics (those organic compounds that can condense on surfaces), metals, and dopants (chemicals that modify the electrical properties of semiconductive materials). Over time, volatile organic and refractory compounds (those that might change the refractive index of optics) became concerns and, more recently, also include many chemicals that have not been classified, but are known to cause process degradation. Some important unclassified compounds are reduced sulfur molecules and ozone, but can also include chemicals commonly found in ambient air.



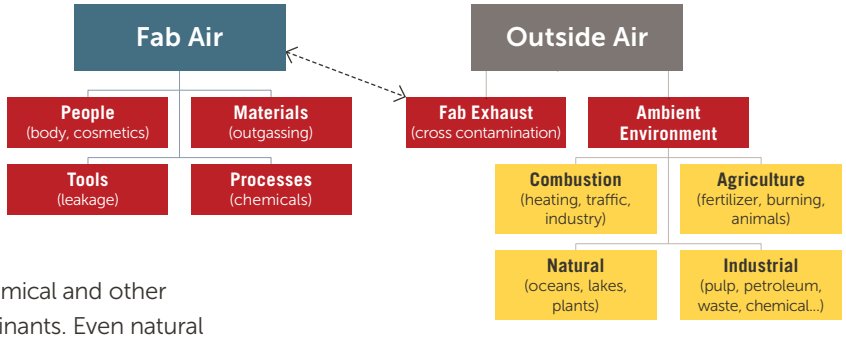

The SEMI standard describes AMC only qualitatively, but concentration levels for the industry are suggested by the ITRS and IRDS roadmaps. However, no industry-wide standard or regulatory entity exists to control AMC. The most stringent requirements come from scanner tool OEMs but IDMs and foundries amend these with their own requirements that depend on process nodes and their unique needs, AMC sources, and fab designs.

## AMC Sources

AMC comes from a variety of sources, both internal and external to the plant. Internal sources are people (e.g., ammonia, organic acids), materials (outgassing of mostly organic species) such as walls, furniture, clothing, and wafer tools and their processes, many of which require chemicals for the treatment of wafers. If these tools leak, they create AMC sources for the cleanrooms. Even without leakage, though, contamination can be transported via wafer to other processes and locations.

Even when properly exhausted, in cases of inadequate ventilation designs or unfavorable wind direction and local air flows around the fab, AMC can be drawn back into the fab.

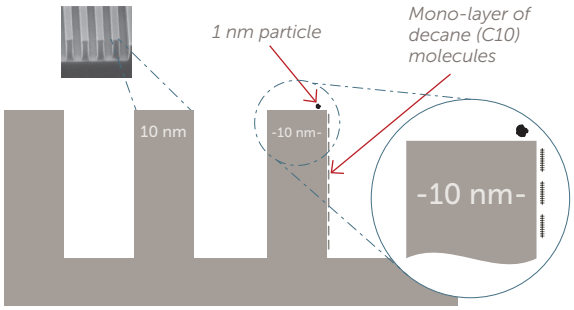
External AMC sources include the ambient atmosphere in general, with many gases reacting to break down or build up photo-chemically, as well as point sources around the fabs. Roads, parking lots, and employee traffic, nearby industrial power, pulp & paper, chemical and other plants all emit a variety of contaminants. Even natural objects such as lakes, swamps, forests, and agricultural fields may contribute substantial amounts of AMC.



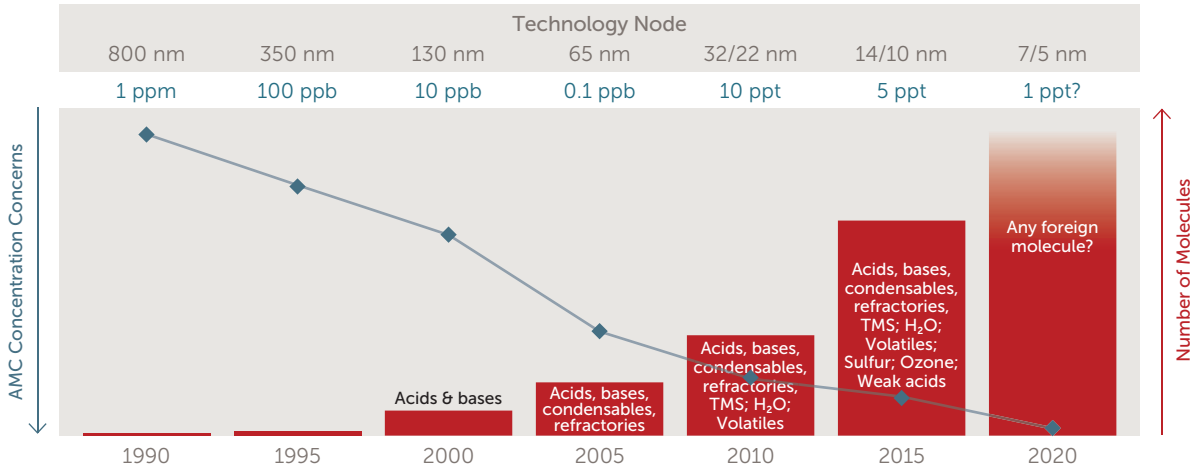

# AMC Trends

Today's fabs are manufacturing in cleaner environments as advanced processes are more AMC sensitive and there is a greater awareness of AMC impact. Early AMC concerns focused on a few molecules only, at the ppm level. Over time, and particularly with 193 nm technology, more and more chemicals cause concerns, and with the advent of 14 to 7 nm critical dimensions, most gas-phase compounds can be a concern in certain process steps.

At the same time, the AMC concentrations causing concern or affecting processes diminished. Most modern fabs operate at AMC concentrations of less than 10 ppb, with many areas in the 1–2 ppb range or less, and more frequent concerns about low parts per trillion (ppt, $10^{-12}$) concentrations. Measurement and control of AMC now requires advanced analytical capabilities and extremely clean materials for filtration solutions.

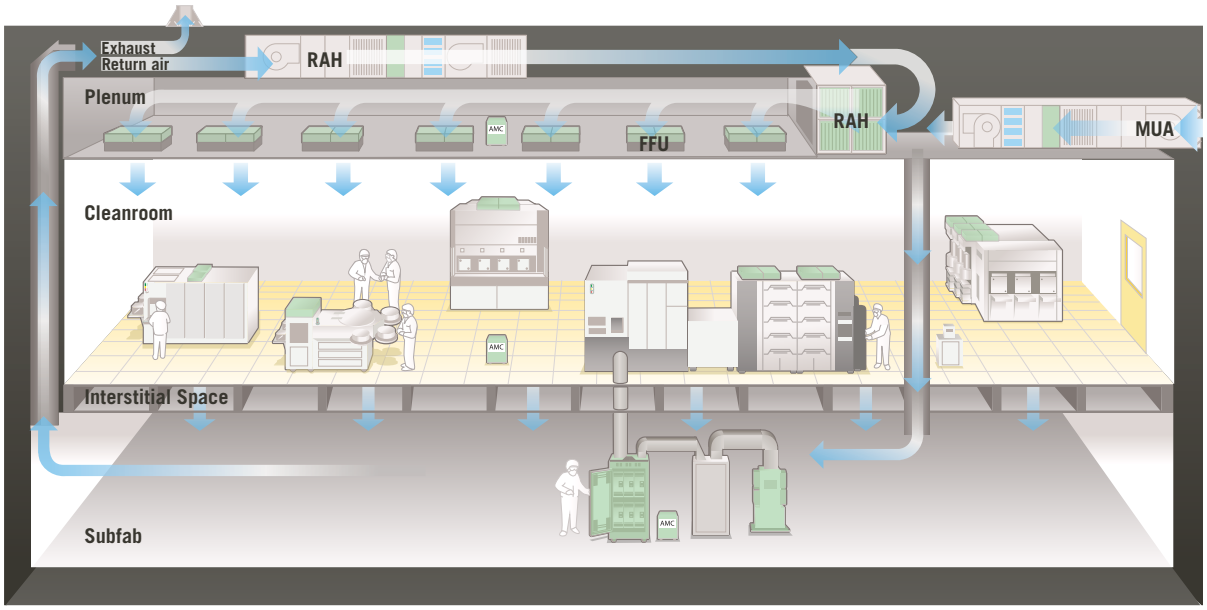



As critical dimensions shrink, smaller and more volatile molecules are becoming a concern. With molecular sizes now approaching "visibility" in comparison to the feature, many concerns revolve around adsorption of AMC on surfaces, even if just temporary, because they might interfere with coating and deposition steps and cause delamination. And, of course, with the introduction of EUV technology, any foreign molecule can cause mirror degradation and any organic molecule will burn into the metal as a carbon residue, regardless of boiling point or molecular weight.



# AMC Applications

Given the number of internal and external AMC sources, semiconductor processing now requires a multilayer approach to contamination control. A typical fab employs AMC filters at the ambient air inlet (make-up air handler, MAH), often in the recirculation or return air handlers (RAH) and on top of cleanroom ceiling fan filter units (FFU). Lithography tools have used AMC filters since the introduction of DUV technology 25 years ago. For advanced processes below 28 nm, however, there are increasing requirements for non-lithography tool protection. Sub-fab and plenum spaces below and above cleanrooms are not yet filtered in most fabs, but may be AMC controlled in the future. The Entegris line of VaporSorb™ AMC filters is tailored to address these multi-level contamination control needs.




# The VaporSorb Advantage

Entegris Vaporsorb AMC filters are designed from the ground up for gas-phase contamination removal and low outgassing. High quality materials with low or no AMC outgassing provide chemically clean filter solutions. The pleated design assures low pressure drop and optimized cost of ownership.

All filter products are backed by advanced analytical measurements, both for material validation and product performance verification. The capability to measure AMC at the low- and sub-ppt level and test filters at low parts per billion (ppb, $10^{-9}$) levels enables Entegris to understand how AMC filters behave in real world situations, a goal that cannot be achieved when testing filters at parts per million (ppm, $10^{-6}$) levels or even higher concentrations, as most other filter suppliers do.

AMC applications can be categorized into two main flow regimes, low and high flow installations. Air handlers usually require high flows with a 2–3 m/s linear air velocity across the filter. FFU and tool filters typically supply air at a lower flow with linear velocity at about 0.5–0.7 m/s, with some installations at 1.0 m/s. The flow regime has a direct impact on filter design, where pressure drop becomes a main concern. That, in turn, dictates how much adsorbent can be accommodated in the filters, having an impact on capacity and filter lifetime.

Entegris controls the supply chain and manufactures its own filters. This enables freedom to change designs as needed and to provide custom solutions when standardized categories no longer suffice. Some

environments have an unusual mix of AMC classes and one portion of the filter may be used up faster than others, much like older style three-color inkjet cartridges. Entegris can adjust adsorbent mixes such that all adsorbents last about the same amount of time, based on measurements of AMC in that environment.

In either case, a good understanding of the environment AMC concentrations is essential to select an optimized filter solution. In combination with three decades of relationships with OEMs, IDMs and foundries, and the understanding of all applications and environments, Entegris provides the best AMC filtration solutions in the industry. All manufacturing operations are accredited for the ISO 9001-2015 standard.

## AMC Filter Products

The AMC trends we observe in the industry are reflected in the needs of AMC filter solutions. Common AMC requirements and standard Entegris filtration solutions, are tabulated below.

To address these trends, Entegris VaporSorb products employ a variety of adsorbents that have specific functionality. Activated carbon adsorbents for organic AMC removal are optimized for high capacity at short contact time. To remove other types of AMC, adsorbents may be coated with chemicals to invoke a reaction on contact. For the removal of ammonia and other bases, Entegris has patented solutions using ion exchange media with strongly acidic character.

| Process | Cleanroom/ Air Handler | Track | Scanner | CMP | Wet Etch & Clean | Dry Etch | Metrology | Deposition | Electro-chemical Deposition |
|---|---|---|---|---|---|---|---|---|---|
| 45 nm | B | B | A, B, O | | | | | | |
| 32 nm | B | B | A, B, O | | | | O | | |
| 28 nm | A, B | A, B | A, B, O | A | A | A | A, B, O | O | |
| 22 nm | A, B, O | A, B | A, B, O | A, S | A, B | A, B, O | A, B, O | O | A, O |
| 14 nm | A, B, O, wA, vO, S, $O_3$ | A, B, O, wA, $O_3$ | A, B, O | A, S | A, B, O, wA, S | A, B, O | A, B, O | O | A, O, vO |
| 10 nm | A, B, O, wA, vO, S, $O_3$ | A, B, O, wA, $O_3$ | A, B, O, wA, vO | A, B, O, wA, S | A, B, O, wA, S | A, B, O | A, B, O | A, B, O | A, O, vO |
| 7 nm | A, B, O, wA, vO, S, $O_3$ | A, B, O, wA, $O_3$ | A, B, O, wA, vO | A, B, O, wA, S | A, B, O, wA, S | A, B, O | A, B, O | A, B, O | A, O, vO |
| Impact: | General process and tool impact | Satellite defects, salts, T-topping, adhesion | Optics haze, T-topping, corrosion | Corrosion | Corrosion, salt formation, wafer defects | Etch rate uniformity, corrosion, salts, wafer defects | Salt formation, wafer defects, optics haze | Film de-gradation, adhesion problems | Corrosion, bath chemistry, film de-gradation |
| Filter: | VaporSorb CLN | VaporSorb TRK | VaporSorb SCN | VaporSorb CMP | VaporSorb WEC | VaporSorb ETC | VaporSorb MET | VaporSorb PVD, CVD | VaporSorb ECD |

*A: acids, B: bases, O: condensable organics, vO: volatile organics, wA: weak acids, S: sulfur, $O_3$: ozone*

## SCANNER CHEMICAL FILTRATION SYSTEM

Entegris VaporSorb SCN scanner filters are the preferred solution in the industry. The advanced, asymmetric design of the SilverSet™ filter ensures that chemical reactions are minimized and formation of problematic compounds like TMS and acetic acid are suppressed[1]. Filter capacities and lifetimes usually exceed industry requirements by up to 2x in modern, low-AMC environments.

## PRE-FILTER SYSTEM

For additional scanner protection, a prefilter system can be deployed. Both filter cabinets are designed to minimize footprint and to match existing air conditioning and sub-fab designs, as well as enable AMC measurement with multiple sampling port options. The prefilter cabinet can also be used to clean and circulate the air of smaller spaces or enclosed rooms.

## PROCESS TOOL CHEMICAL FILTRATION

Entegris VaporSorb TRK clean track filters fit the latest tool designs and replace OEM filters or provide additional AMC removal that is not provided by OEM filters.

Process tool specific filters are offered in a variety of form factors to match tool OEM requirements. A VaporSorb filter solution is available for any non-lithography process.

## FACILITIES CHEMICAL FILTRATION

VaporSorb CLN cleanroom filters for make-up or return air handlers are available in standard or custom dimensions. Media are optimized for individual ambient air challenges, targeting AMC classes that vary by fab location. Fabs in urban and industrial spaces tend to have higher amounts of chemicals, but fabs in more rural areas can be impacted by oceans, lakes, agricultural fields, and forests. High flow applications are served with single layer pleated filters removing the most common AMC classes to levels that can be further reduced inside the fab.

Recirculation or return air handler filters usually have different challenges than those feeding ambient air, due to internal chemical emissions.

In many fabs, cleanrooms have their own protective layer by adding AMC filters on top of the HEPA particle filters. Entegris can match the FFU design and provide long-lasting filter solutions.

Entegris AMC filters can be provided in a wide variety of form factors, materials, and media configurations with handles, gaskets, and screens to match installation guidelines.

# AMC Services

The Entegris AMC business unit operates 3,000 square feet of laboratories exclusively for the development and support of AMC filters. The facility houses both R&D and Analytical Services labs. R&D develops and tests the original adsorbents, media, and prototype filters. Analytical Services supports quality, manufacturing, and customer installations. The co-location of labs, engineering, quality control, and manufacturing ensures that Entegris AMC filters and all materials are validated by our analytical experts at every step from conception to deployment and beyond.

Most of the analytical filter test methods are accredited for ISO 17025, a competence standard for test laboratories that goes much beyond the ISO 9001 standard. Traceability of measurement standards,

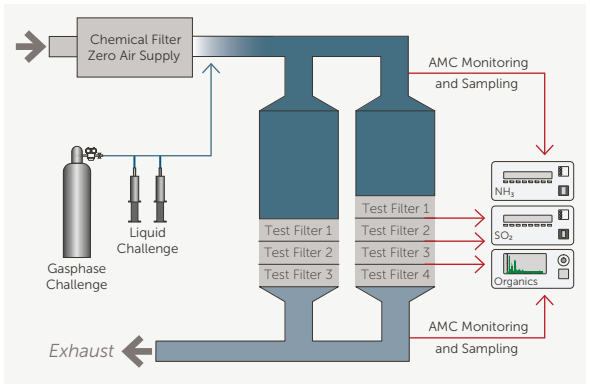
proficiency test comparisons to other industry labs, and rigorous quality control are all requirements for this standard.

ACCREDITED
Certificate # 2578.01

## RESEARCH & DEVELOPMENT

R&D filter development is done in three stages. The first step involves testing raw adsorbent materials to gauge relative performance against one another. The second step tests small scale patches of media, as used for AMC filters. The final step uses actual filters to characterize performance. In addition, R&D develops and tailors adsorbents to address AMC removal needs and carries out advanced numerical modeling to better understand AMC removal on filters, optimize filter designs, and predict filter performance.

For filter testing, Entegris operates five small scale and seven full size wind tunnels that allow testing of individual filters or stacks of multiple filters, and to measure the concentrations upstream (challenge), between multiple filters (interstack) and downstream (exhaust). All wind tunnels are operated under real-world conditions (flow, temperature, humidity). Challenge concentration is the only increased parameter to speed up testing, but Entegris is the only AMC filter supplier to specify filter lifetime based on tests with no more than 1,000 ppb and often as low as 30 ppb. The lower the test concentration, the more realistic the capacity/lifetime estimate becomes. High concentration (ppm) testing artificially inflates capacity estimates for physical adsorbents, such as activated carbons. This is a principle known as adsorption isotherm.




Understanding the chemistry around AMC filters is increasingly important. Some chemicals react on AMC media to form other, often undesired, contaminants that may escape the filter and enter the microelectronics environment. Some chemical reactions reverse at high concentration and it is important to select the right, lower concentrated test parameters[1]. Entegris publishes such findings and analytical methods in technical journals.

## ANALYTICAL SERVICES

To support AMC filter customers, Entegris Analytical Services provides a worldwide commercial service with trained sampling operators to measure most AMC classes in the industry's shortest sampling time (4-6 hours), providing ppt-level results for fab environments and filter installations. Clean handling and correct placement of sample probes upstream and downstream of filters are essential for accurate filter performance measurements.

Entegris Analytical Services is one of very few commercial laboratory services specializing in semiconductor environments. Analytical Services is approved for ASML™ and Nikon™ scanner OEM validation and has worked with OEMs to define AMC guidelines and measurement practices.

The following services are provided:

### Onsite AMC measurements

- Ambient cleanroom, sub-fab, plenum, air handler, fab environments and surrounding
- Filter performance (FFU, air handlers, tools): upstream and downstream
- Scanner filter cabinets (e.g., Entegris E2600) using dedicated AMC sampling ports
- Inert supply gases (XCDA®, CDA, OFA, $N_2$, $O_2$, $CO_2$, Ar, He...)

### Laboratory based services

- Post-mortem AMC filter testing
  - Physical tests (pressure drop, outgassing, particle shedding)
  - Current removal efficiency
  - Remaining lifetime/capacity
  - Captured content on the adsorbent
- Material and gas testing
  - Material outgassing
  - Particle shedding
  - Gas purity

Analytical Services is one of about 30 Entegris global laboratories. That combined analytical expertise is shared and can be provided to our customers for services not outlined here.

Entegris provides annual measurement programs for scanner operation compliance as well as on-request sampling support for troubleshooting, environment characterization, and filter performance evaluation.

Entegris Analytical Services develops its own analytical methods. In 2009, the only commercially available method for measurement of volatile silicon compounds (TMS, HMDSO, $D_3$) was published, because standard trap technologies do not capture these compounds or do not release them for thermal desorption analysis[2].

The laboratory also developed the TruTOC® method for the combined sampling and analysis of volatile and condensable organic AMC in one step[3], as well as a dry trap method for sampling acids and bases that does not require water-filled impingers or bubblers[4]. Impingers produce many artifacts and are difficult to handle and easy to contaminate.

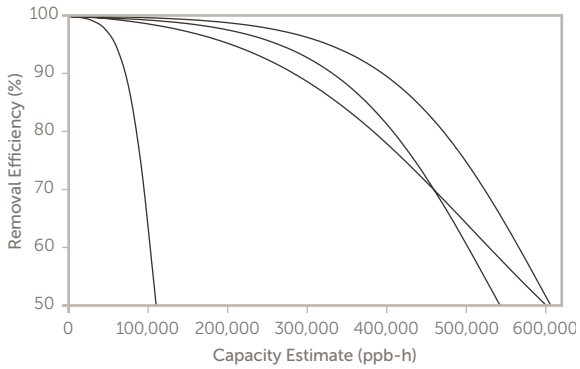
# The Entegris Advantage

Protecting semiconductor environments and processes from AMC has become an essential part of enabling the latest technology nodes. AMC filtration requires expertise, chemically clean materials, and analytical support from conception to in-field support. By providing all of these, Entegris is a trusted supplier and has received many customer quality and supplier awards.

AMC control requires a comprehensive approach and multilayer protection. Entegris optimizes AMC filter lifetimes and validates their performance in the laboratory and in customer installations. Entegris interprets the data and puts them into applications context to avoid measurement artifacts and out of context data conclusions.

# Best AMC Practices

Entegris AMC filter capacity/lifetime enables the user to estimate in-field lifetime for the targeted application. Capacity is a product of challenge concentration and test time; the unit is parts per billion – hours (ppb-h). Performance curves show the removal efficiency of the filter for a particular AMC as a function of capacity, which gradually exhausts. This allows the use of on-site measured AMC concentration (in ppb) to calculate filter lifetime (in h).




To ensure optimized protection from AMC for any high technology process, a multilayer approach should be adopted, which includes air filtration at the make-up air handler, recirculation air handlers, ceiling fan filter units, tool tops, and scanner supply air. Each can be single or dual layer implementations at different air flows.

AMC challenges should be characterized for each environment. Gas-phase contamination does not necessarily follow laminar down-flow streams, but rather diffuses laterally and is heavily influenced by local sources. A cleanroom typically exhibits widely varying concentrations of the same contaminants across and in different tool vicinities.

AMC measurements should always be interpreted as a trend, decisions for AMC filters or process protection should not be based on a single data point. AMC measurements are involved and capture only a point in time, but environment challenges change over time, sometimes rapidly. A short excursion that triggers process alarms may well come back to normal when a second sample is taken.

Once the local flow regime and challenge is known, AMC filter performance should be validated using a competent, accredited, and OEM-approved laboratory. AMC sampling inlet and outlet locations need to be very close to the actual filter installation. For the above-mentioned reasons, cleanroom locations cannot be used to gauge the performance of filters installed several meters/tens of feet away. Air swirls and lateral diffusion need to be considered.

Continued environment monitoring is important to avoid AMC filters from prematurely exhausting, or from exchanging filters before their end of life is reached. Through monitoring, changing AMC challenges and new molecules that may cause known process issues can be identified.

Analytical results should be interpreted carefully and can be discussed with the Entegris laboratory to avoid the conclusion that perceived threats require costly filter solutions. Many compounds may have acidic or basic character or contain atoms that are known to cause issues but may not actually impact the process due to their volatility or chemical inertness. A good example is $HNO_2$, which is nominally an acid, but so unstable that it is formed and destroyed on all surfaces, effectively not causing corrosion or impacting process[5]. Entegris' laboratories can assist with chemical evaluations and AMC data interpretation.

# References

All publications can be downloaded from Entegris' website, *www.entegris.com*.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[5] Jürgen M Lobert, Reena Srivastava, and Frank Belanger, *"Airborne molecular contamination: formation, impact, measurement and removal of nitrous acid ($HNO_2$)"*, ASMC Proceedings, ISBN 978-1-5386-3748-7, 180-185, 2018.





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