MYCELX
TECHNOLOGIES CORPORATION

THE NATURE AND MECHANISMS OF AIR POLLUTION

Published in Environmental Protection

March, 2003

Author: Hal Alper

THE NATURE AND MECHANISMS OF AIR POLLUTION DEVELOPMENTS IN AIR FILTRATION

Hal Alper, President, MYCELX Technologies Corporation, Gainesville, GA.

When one studies the arc in the development of technology it is hard not to notice the similarities to evolutionary development. Although the perception of evolution is one of steady sequential adaptation, the truth of the matter in most cases is that species remain fairly constant for long periods of time until the advent of a major significant event such as an asteroid. In this contingency major changes and adaptations occur quickly resulting in a new steady state, which remains fairly constant for a long period of time. Air filtration technology is currently undergoing a similar revolutionary period. Some of the contributing factors for this state of flux are:

- Our increased understanding of the nature of air pollution and its impact on air quality due to advances in analytical techniques and detection methods.
- Increased understanding of the impact of air quality to the incidence of almost all types of maladies due to stress on the immune system
- More stringent performance requirements of air filters in order to address the types of contingencies presented in the advent of post September 11th events.

Until recently the evaluation of the performance of air filters, for the most part has been somewhat one-dimensional. Indoor air filters are generally evaluated based on ability to remove particulate matter from the air stream. Typically, this is done in the 1-10 microns range utilizing a standard particulate such as Arizona Road Dust and or Molocco Black and No.7 Cotton linters (4mm mesh screen). The efficiency of the filter in removing the range of particle sizes is measured versus the pressure drop across the filters. For the majority of commercially available air filters this is the extent of qualitative quantification. In some cases filters with impregnated adsorbent are also utilized in and evaluated for removal of VOC's and other gaseous phase compounds (for purposes of this article we will not be considering gaseous phase inorganic compounds such as hydrogen sulfide. Inorganic gaseous phase compounds are generally neutralized utilizing Acid-Base or Redox reactions with media impregnated into the filter matrix).

Generally carbon impregnated filters are used for VOC removal and the filters are typically challenged with one of the BTEX (Benzene, Toluene, Ethylbenzene, Xylene) as the test VOC (Volatile Organic Compounds). Often this data is used as a measure of effectiveness of the filter in removing airborne organic compounds. This is probably not an accurate picture. It is very unlikely that generated VOC's remain gaseous for very long. It has been shown that VOC's under ambient conditions will quickly adsorb on to airborne particulate matter and or will form liquid aerosol droplets with microparticulate nucleation sites usually as a result of condensation processes.

The simple model implied by the above tests belies the true complexity of indoor air pollution and mechanisms, which occur on the filter surface. Air pollution exists in many more forms in addition to particulate matter and gaseous phase compounds and each of these forms have different surface properties and bulk characteristics. A somewhat more complete picture of the nature and mechanisms of formation of the components of indoor air pollution is as follows:

1. 1.a. Primary mechanisms of air pollution formation

1. Formation of volatile organic compounds through evaporation and incomplete combustion.
2. Biological generation of volatile organic compounds.
3. Formation of liquid aerosol droplets through shear and turbulence related processes, from cooking and household solvent-based cleaners.
4. Anthropogenic generation of particulate aerosol.
5. Biological formation of particulate aerosols through decomposition and spore formation.
6. Particulate aerosol formation from geological and weather based phenomena.

1.b. Secondary mechanisms of air pollution formation

1. **CONDENSATION** - Liquid aerosol droplet formation due to condensation of gaseous phase components.
2. **ADSORPTION** - Adsorption of gaseous phase and liquid aerosol components onto particulate surfaces resulting in particulate aerosols with modified surfaces from adsorption of organic compounds and hydrous inorganic phases.

3. **NUCLEATION** - Liquid aerosol formation through precipitation onto micro particulate nucleation sites.

2. Forms of airborne pollution

The above processes will result in the following types of airborne species.

- Dry and hydrous carbonaceous material resulting from anthropomorphic and natural processes.
- Inorganic micro particulates such as aluminum oxide, silicates and other compounds resulted from geological processes.
- Spores, pollen seeds of biological origin.
- Endotoxins and other detritus resulting from biological decomposition processes.
- Liquid non-polar aerosols (all liquid).
- Liquid polar hydrous aerosols (all liquid).
- Liquid aerosol with particulate nucleation sites.
- Particulate aerosol with adsorbed non-polar liquid organic constituents on surface.
- Particulate aerosol with adsorbed hydrous liquids (polar).
- Particulate aerosol with mixed emulsion of hydrous and non-polar constituents.

3. The above sources and processes will result minimally in the following general categories of airborne pollutants based on surface characteristics and affinities. This is important because the components of the filtration device must have complementary affinities.

- Particulate aerosol (charged or polar surface)
- Particulate aerosol (neutral or conductive surface)
- Liquid aerosol (organic)
- Liquid aerosol (hydrous)
- Liquid aerosol (mixed) – shown in Fig 1

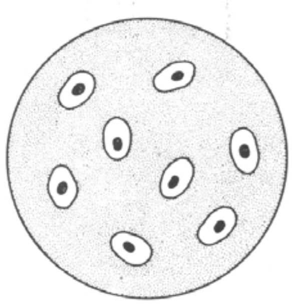


Fig 1: Representation of an electron micrograph of smog aerosol particles collected by a jet inertial impacter, showing electron-opaque nuclei in the centers of the impacted droplets

Note: WORD ABOUT AEROSOLS

Aerosols are formed spontaneously under ambient conditions in multiple ways. Particulate matter provides nucleation centers around which liquids and organic compounds self-assemble. Human activities like talking, breathing, sneezing create liquid aerosols. This is the vector for transmission for all cases of tuberculosis. Movement provides particulate nucleation centers and household systems, which move air creates oily aerosol droplets. Other pollutants spontaneously coalesce and adhere to these initial aerosol droplets.

Aerosols are defined as any liquid or solid less than 100 microns. In a typical distribution, at least 40% of the particles are less than 0.2 micron. At this size assuming low surface charge which inclusion of organic and ionic compounds will promote, these droplets will stay buoyant in air indefinitely. The strength of the surface tension is more than 100,000 times the mass of the droplet. Unless the droplet is opened, the pollutants will remain inaccessible. It is been shown that when liquid aerosols are recirculated through a filter the droplet size distribution becomes much narrower and tends towards the smaller micron ranges. In other words if a liquid aerosol is not adsorbed on to a filter surface smaller more robust droplets are formed with much higher surface tension to mass ratios.

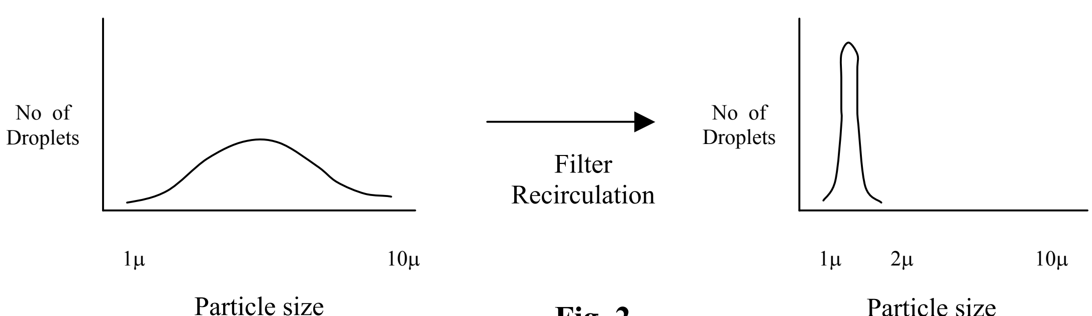


Fig. 2

Fig. 2 illustrates narrowing of particle size distribution and reduction in average particle size resulting from recirculation without adhesion through the filter. Decrease in particle size results in more robust droplets, which remain buoyant in air longer. Membrane of smaller diameter droplets is most easily opened by reduction in surface tension through physiochemical interactions such as in lung tissue and mucous membranes.

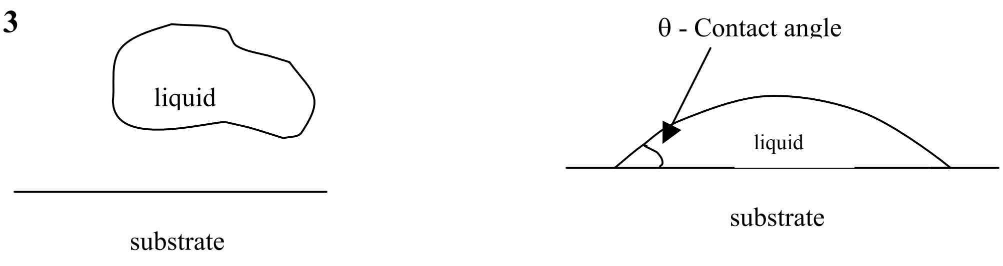
It is much harder to remove pollutants, which are entrapped in aerosol droplets than it is to remove single source free flowing compounds. The filter material must have complementary affinity for the surface of the suspended aerosol in order to entrap particulate aerosol material and in the case of liquid aerosols in order to reduce the surface energy at the interfacial membrane in order to expose the pollutants entrapped within the droplets. Picture # illustrates this. Note accumulation of micro fine dust particles on surface modified filters which have affinity for and or able to reduce surface tension of oily droplets. The particles entrapped in the oily droplets can be seen accumulated on the surface modified filters. By contrast standard air filter has no accumulation of micro fine particles demonstrating that the particles are protected from occlusion on to the filter due to being entrapped within the oily droplet.

Each one of the earlier mentioned general categories will have somewhat different surface characteristics and affinities in addition to size ranges to well below 0.1 micron. Processes such as aerosol formation due to condensation from vapor phase are capable of generating particle sizes much smaller than have been addressed to date. Such small entities are probably removed from the air stream much more effectively through affinity interactions, as conventional filtration techniques would yield untenable differential pressures. The above types of pollutants can probably be reduced to 3 or 4 general categories based on affinity. Any air purification device must be able to address all of these categories in order to be generally effective.

The concentration distribution of the proportion of each type of constituent of air pollution must be determined under ambient conditions in a statistically rigorous fashion in order to gauge the physical effectiveness of air filtration devices and to subsequently design the optimal configuration based on complementarily to ambient distribution.

In order to design the optimal air filter or air filtration device it is necessary to ascertain the concentration distributions of the components of the various categories of airborne contaminants. In this way the device or filter can be designed to have complementary capacity. There are potentially hundreds of chemical compounds and other materials present in air pollution. It is quite unlikely that these compounds remain in gaseous state for very long. Typically a gaseous phase molecule will encounter thousands of collisions per second. Due to weak molecular interactions (van der Waal's forces, pi-pi interactions and others) most natural systems will tend toward organizational self-assembly. Although it is facile to consider filter affinity for each pollutant individually it is very unlikely that the filter is exposed a procession of individual compounds and materials. In reality in most cases under ambient conditions what the filter is exposed to are liquid/solid conglomerate aerosols into which many of the pollutants are incorporated. Therefore the problem reduces to the chemical affinity of the filter media and its ability to overcome the surface tension of the interfacial membrane within the droplet. Once the droplet membrane is cleaved all the pollutants trapped within are able to be adsorbed. This is not as simple as it sounds because when droplet sizes become smaller than 100 microns the membrane strength due to surface tension is many orders of magnitude greater than the mass of the droplet. Molecular affinity is required to reduce the surface tension and therefore increase the contact angle so as to burst the bubble. Fig. 3 illustrates that before adhesion the contact angle is effectively nonexistent and therefore the substrate does not have access to the pollutants. When the surface has affinity to the membrane a low contact angle is achieved and the filter material is able to adsorb and absorb the entrapped pollutants.

Fig. 3



Before adhesion After adhesion

In the case of the particulate aerosols the most difficult to remove tend to be less than 3 microns in size and to have a neutral or insulating surface. In this case filtration efficiency can be increased by modifying the filter substrate surface to have affinity for the non polar particle surface. Without filter affinity if one relies wholly on physical filtration mechanisms untenable differential pressures quickly develop across the system.

Part 2 of this article will address kinetics and dynamics at the filter interface and the interfacial affinities that are requisite in addressing the categories of airborne pollution. The author will discuss a novel chemical surface modification, which exhibits affinity for particulate and liquid aerosols without any increase in differential pressure across the filter eliminating the problems associated with corona charged filters.

References

Samet, J. M.; Dominici, F.; Curriero, F. C.; Coursac, I.; Zeger, S. L. , "Fine particulate pollution and mortality in 20 U.S. cities, 1987-1994", N Engl J Med.,vol. 343, pp 1742-9, 2000 Dec 14

Highsmith, V. R.; Hardy, R. J.; Costa, D. L.; Germani, M. S., " Physical and chemical characterization of indoor aerosols resulting from the use of tap water in portable home humidifiers" , Environmental Science & Technology, 1992 vol.26, pp.673-680

Jakobi, G., (Muenchen Univ., Freising (Germany). Lehrstuhl fuer Bioklimatologie und Immissionsforschung), "Requirements on air pollution measurements for studies in environmental medicine, meeting of BIOMET of 'Fachausschuss BIOMET of DMG' jointly with the 'Gesellschaft zur Foerderung Medizin-Meteorologischer Forschung e.V", 19-20 Apr 1999

Maroni, M, "Health Effects of Indoor Air Pollutants and their Mitigation and Control", Radiation Protection Dosimetry, vol. 78 PP. 27-32, 1998

Fine, Philip M.; Cass, Glen R.; Simoneit, Bernd R.T., "Characterization of fine particle emissions from burning church candles", Environmental Science and Technology, v 33, pp 2352-2362, 1999

Kim, Yoon Shin; Lee, Hak Sung, "Characterization of indoor and outdoor PMSUB2SUB.SUB5 in selected Korean homes", Proceedings of the Air & Waste Management Association's Annual Meeting & Exhibition 1998, Air & Waste Management Assoc, Pittsburgh, PA, USA. 8pp 98-MA9A.04.

Leovic, Kelly W.; Mason, Mark A.; Sparks, Leslie E. EPA's R&D program for indoor air source characterization and pollution prevention control Proceedings of the Air & Waste Management Association's Annual Meeting & Exhibition 1996. Air & Waste Management Assoc, Pittsburgh, PA, USA. 13pp 96-WA61.01

Johnston, Pauline K.; Cinalli, Christina A.; Girman, John R.; Kennedy, Patrick W. Priority ranking and characterization of indoor air sources ASTM Special Technical Publication n 1287 May 1996. p 392-400 1996

Mason, Mark A.; Roache, Nancy F.; Guo, Zhishi; Costa, Daniel Design and characterization of a small chamber for chemical and biological evaluation of sources of indoor air contamination ASTM Special Technical Publication n 1287 May 1996. p 112-120 1996

Chaffin, C.T.; Marshall, T.L.; Jaakkola, P.T.; Kauppinen, J.K.; Fateley, William Assessment of indoor air quality using extractive Fourier (FTIR) Measurements Proceedings of SPIE - The International Society for Optical Engineering v 2365 1995. Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, USA. p 140-150 1995

Batterman, Stuart A.; Burge, Harriet HVAC systems as emission sources affecting indoor air quality: a critical review HVAC&R Research v 1 n 1 Jan 1995. p 61-80 1995.

Daisey, J.M.; Hodgson, A.T.; Fisk, W.J.; Mendell, M.J.; Brinke, J. Ten Volatile organic compounds in twelve California office buildings: classes, concentrations and sources Atmospheric Environment v 28 n 22 Dec 1994. p 3557-3562 1994

Stanetzek, Ines; Giese, Ulrich; Schuster, Robert H; Wunsch, Gerold Chromatographic characterization of adsorbents for selective sampling of organic air pollutants American Industrial Hygiene Association Journal v57n2

Howard, E. M.; Mason, M. A.Large Indoor Air Test Chamber Characterization Engineering Solutions to Indoor Air Quality Problems

Mason, M. A.; Howard, E. M.; Guo, Z.; Bero, M. Characterizing Sink Effects in Large Environmental Chambers Acurex Environmental Corp., Research Triangle Park, NC United States 1997-01-01

Heitbrink, W. A.; Spencer, A. B.; Deye, G. J. In-Depth Survey Report: Characterization of Metalworking Mists during the Evaluation of a Commercial Air Cleaner at Sauer Sundstrand, Ames, Iowa, Report Engineering Control Technology Branch, Division of Physical Sciences and Engineering, NIOSH, Cincinnati, Ohio, 1996-04-25

Stanevich, R. S.; Hern, S. C.; Stetzenbach, L. D. Characterization of Airborne Microorganisms: Two Indoor Case Studies Indoor Air '90, The 5th International Conference on Indoor Air Quality and Climate, Toronto, July 29 - August 3, 1990, Volume 4, pages 677-682

Cole, E. C. Aerosol Characterization Proceedings of the Workshop on Engineering Controls for Preventing Airborne Infections in Workers in Health Care and Related Facilities, July 14-16, 1993,

Yang, C. S.; Zampiello, F. A.; Dougherty, F. J.; Lewis, F. A.; Mangiaracina, L. Microscopic Characterization of Settled Dusts Collected in Office Buildings in the Mid-Atlantic Region Environments for People, IAQ 92, October 19-21, 1992, San Francisco, California, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia, pages 191-196

Li, C-S.; Jenq, F-T.; Lin, W-H. Field Characterization of Submicron Aerosols from Indoor Combustion Sources Journal of Aerosol Science, Vol. 23, Supplement 1, pages S547-S550

Knoppel, H. Sampling and Analytical Issues Pertaining to the Characterization of Indoor Source Emissions Annals of the New York Academy of Sciences, Vol. 641, pages 112-124