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Microbiology Laboratories

IAQ Radio Episode 690

Connie Araps, PhD
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Advances in Reactive Indoor Air Cleaning Technologies

Good Day and welcome to IAQ Radio+ episode 690. This week we welcomed Dr. Connie Araps, PhD and Dr. Kishor Khankari, PhD to discuss their recent presentation at the ASHRAE Winter Conference called Advances in Reactive Air Cleaning Technologies. LEARN MORE on IAQ Radio+.

Dr. Connie Araps has an extensive background in chemistry, semiconductor technology and advanced engineering for manufacturing. She has a B.S.in chemistry from Rutgers University and a Ph.D. in organic chemistry from Princeton University. Dr. Araps is currently the president of Prometheus Strategies, which provides chemistry consulting services to companies in the field of advanced air and surface cleaning technologies. She is also a consultant to The Pyure Company and the Chair of Pyure's Scientific Advisory Board.

Dr. Kishor Khankari is the president and founder of AnSight LLC. He is a specialist in Computational Fluid Dynamics (CFD). A noted expert in his field, he has a Ph.D. in CFD from the University of Minnesota and has regularly published in several technical journals. Dr. Khankari is an ASHRAE Fellow and Distinguished Lecturer. He is also currently serving on the ASHRAE Board of Directors.

Nuggets mined from today's episode:

What is Photohydrolytic Hydroxyl Oxidation (PHO) and how does it work? Connie Araps

- PHO uses ultraviolet energy to cleave water vapor to generate hydroxyl radicals HO. Hydroxyls are powerful natural oxidants formed by the action of the sun that sanitize air and surfaces by decomposing VOC and killing microorganisms.

a. Hydroxyl devices sustain this dynamic indoors. They abstract Hydrogen atoms from ambient VOC to form organic peroxy radicals ROO, powerful oxidants which are stable enough to circulate throughout the treatment space via a series of chain reactions with successive VOC. Typical ROO radical chain "lifetimes" are 12 minutes.

- *How would you describe PHO to a child?* Connie Araps
  PHO machines use special lightbulbs to make chemicals to clean and purify indoor air in the same way that the sun cleans and purifies outdoor air.

- *How PHO is different than other reactive air cleaning technologies?* Connie Araps
  a. PHO devices are designed to generate a single, natural oxidizing agent: the hydroxyl radical. They are designed to maintain the same concentrations of hydroxyls and organic peroxy radicals found outdoors: 1-3 million OH/cm3. Each OH generates one organic peroxy radical (ROO).
     i. Because OH and ROO have such high oxidation potentials and fast reaction rates, they rapidly decompose VOCs and kill microorganisms by radical chain reactions.
     ii. The oxidation by-products they generate are also rapidly decomposed and do not accumulate. This is the same process that is going on outdoors.
  b. Other reactive air cleaners generate sanitizing agents differently.
     i. PCO devices coat surfaces with catalysts like TiO2 which adsorb contaminants and decompose them by activating the catalyst with UV energy to generate oxidants.
     ii. Ionizing devices use electrical energy to generate positive and negative ions, which serve two functions
        1. They ionize particulates causing them to aggregate making it easier to filter.
        2. The ions also decompose VOC and microorganisms by ionic chemical reactions.
        3. Are very effective improving filtration of even 2.5 u size particles because ionized particles aggregate and the larger the aggregate the easier it is to filter. Ions can decompose VOC and kill microorganisms but the efficacy declines as a

function of distance from the source. Published values for ion lifetimes are 1-2 minutes.

iii.

1. There are no device standards for ion concentrations. Natural levels range from 200-500 ion/cm3.

- *What are the pros and cons of various reactive air cleaning technologies?* Connie Araps

Hydroxyl generators

- Pros
    a. Generate the same oxidants and in the same concentrations as found in nature, where they are the primary environmental sanitizing agents.
    b. Because they have the highest oxidation potential of any chemical other than elemental fluorine, and exceedingly high reactions rates they decompose by-products quickly so they do not accumulate.
    c. Toxicology studies conducted according to FDA guidelines (GLP 21 CFR Part 58) have shown that animals exposed to 2-3 times higher concentrations than normal over the requisite 13 weeks showed no negative effects either at the gross or cellular level.
- Cons
    a. Generate oxidized VOC – alcohols, aldehydes, ketones, acids
    b. Generate low ppb levels of ozone: published formation rate was 0.041 g/hr.
    c. Device filters remove larger particles, but not small particulates.

PCO Devices

Pros

- Use a range of UV energy to activate the catalyst that generates no ozone.
- Most oxidants consumed by reactions with adsorbed contaminants

Cons

- Low MW VOC and oxidation by-products do not bind well to the catalyst and accumulate.
- The catalyst is deactivated by adsorbed water and the accumulation of carbonized VOC.

- Scalability is limited by the catalyst surface area.
- Catalyst degrades producing fine particles of catalyst and carbonized VOC

Ionizers

Pros

- The main advantage is that they cause particles to aggregate, improving filtration, especially for very small particulates.
- They also decompose VOCs and kill microorganisms by ionic chemical reactions.
- Agglomerate particles and improve performance of filters.

d. Disadvantage
    i. Ion concentration and efficacy decreases as a function of time and distance from the source.
    ii. Ion lifetimes are short: 1-2 minutes, so high concentrations of ions in the range of 20-40 K/cm are required to treat large spaces. While, natural ion levels are ~200-1500
    iii. Most test data is done at lower ion concentrations of 2500-5000 ion/cm3.
    iv. Use of electrical energy generates ozone, minimized by methods such as needle point ionization and non-thermal plasma generation
    v. Generate VOC oxidation by-products can accumulate

- *Where PHO has been deployed and what is the outcome?* Connie Araps

Many vertical markets

a. Fire/Flood restoration: mold, odor (Service Master, Servpro, Aramsco, etc.)
b. Industrial plants, water treatment: VOC and odor mitigation (Toyota, Cargil)
c. Hospitals, ambulances – Surgery, procedure rooms (Steris, Mastel Surgical)
d. Elder Care (Cambridge House)
e. Schools: NJ school systems
f. Food, meat and beverage processing - Indian

g. Office space, data centers, commercial spaces to minimize the spread of infection and eliminate odor
h. Casinos – odor and smoke mitigation (Carnival, Churchill Downs)
i. Hospitality – Lowes, choice….etc.)
j. Military – Camp Lejeune

- I have used Odorox machines in fire restoration and after running a machine in a residential setting I noticed the air in the room became cloudy. I was told this cloudiness is related to ultra fine particles that either were produced by the hydroxyl machine or something in the room reacted in a negative way with the hydroxyls. Can you comment on that? Connie Araps
    a. Pyure's has been selling devices for the restoration industry for 15 years. It is rare to see the generation of a "haze" and it has happened when the site had been using a various chemical cleaners with phosphates and other additives. The haze dissipates with continued treatment and proper ventilation.

- I can sometimes detect low levels of ozone when running my Hydroxyl generator, is ozone produced by the UV lights that produce the hydroxyl radicals? Connie Araps
    a. Pyure devices generate very low levels of ozone as a by-product of hydroxyl generation. The formation rate of ozone was measured in a study done at the Lovelace Respiratory Research Institute and reported in a peer reviewed publication published on the Pyure web site, pyure.com. The formation rate for a two optic Boss™ device was 0.041g/hour.

- The manufacture states that it is perfectly safe to use in occupied areas. Is this true, using these large commercial hydroxyl generators in occupied areas is safe? Connie Araps
    a. Pyure technology is quantitative because the amount of OH.ROO formed is based on measurable and known parameters: the output of the optics – which is specified by the manufacturer , relative humidity and temperature. The target concentration of OH/ROO is 1-3 million molecules/cm3: the same as found outdoors. This ensures that levels

are both effective and safe. Natural levels of OH and its by-products do not pose a health risk.

b. This was verified in studies done at the Lovelace Respiratory Research Institute and published on the pyure.com web site.
c. Devices safely scale to larger spaces based on increasing the number and power of the optics.
d. Operational use guidelines were developed after extensive testing in various sized spaces to ensure that oxidant levels (ozone and ROO) remained below regulated levels (less than 50 ppb) as measured by ozone sensors.
e. Systems also include sensor driven interactive process controllers which send data from sensors throughout the treatment space wirelessly to modulate optic output in real time. Data is displayed on a dashboard and logged continuously for quality control.

- Is there any data that has established the PEL for hydroxyls? How is the output level of hydroxyls measured? And how is that level adjusted in these machines? Connie Araps
    a. Hydroxyls in natural concentrations are not toxic. Humans, plants and animals have evolved symbiotically with OH/ROO and are impervious to them.
    b. See above for how OH/ROO levels are adjusted for different sized spaces.

- How can a building manager compare different types of hydroxyl generators? Are some more efficient than others? What is a "normal use" condition for a test chamber? Connie Araps
    a. Manufacturers must measure the formation rate of OH and ozone in ultra clean rooms as was done by Pyure at the Lovelace Respiratory Research Institute published on the pyure.com web site. You cannot measure OH formation in a regular chemical laboratory: it reacts too quickly.
    b. Such chambers feature Teflon lined walls to minimize wall interactions in which is introduced a known amount of single VOC that does not react with ozone. Highly sensitive analytical devices like the GC-MS take air samples to measure the rate of oxidation of the VOC by OH: the only chemical interaction that can occur. Experiments are done at night to eliminate ambient photochemical reactions.

- Knowing that the species of chemicals generated by your device are highly reactive and after only testing your devices in test chambers, how can you be sure that your devices are safe for use in occupied environments containing unknown levels of background chemicals and fire related residues? Connie Araps
    a. Pyure devices are designed to generate natural levels of chemicals found outdoors, which do not pose a health risk.
    b. The safety of the by-products generated by the device was evaluated according to FDA guidelines by conducted toxicology GLP FDA studies which found no difference between treated and untreated animals after 24 hour exposure for 13 weeks.

Device Pricing? Connie Araps

- A base typical package can start anywhere from under $1000 to $3000 depending on space and requirements. Pricing is dependent upon the size, number of optics and other features like fan/blower and sensor driven interactive process controllers.

- *Where PHO cannot be applied?* Connie Araps
    a. Not applicable to high ppb concentrations of VOC
    b. Rapidly moving air streams in industrial plants, stacks

- *Separating Fact from Fiction* Kishor Khankari

  Consumers may choose from a variety of air cleaning technologies and devices. With all of the manufacturers claiming that their device is best; the need exists to bring engineers and chemists together to discuss air cleaning devices, create uniform testing methods and develop industry standards. Kishor chaired a panel of manufacturers at the ASHRAE winter conference. ASHRAE has formed a committee which will lead to the development of uniform test methods and industry standards.

- *What is the role of CFD?* Kishor Khankari

  PHO devices involve the generation of reactive chemicals that clean air and surfaces. PHO devices can supplement the dilution. PHO devices dilute and reduce target contaminate counts. The life of the agent is critical as the agent needs to get into the breathing zone of the occupants,

What is Computational Fluid Dynamics (CFD)?

Computational Fluid Dynamics (CFD) is a science that deals with the simulation and analysis of fluid flow, heat transfer, mass transfer, and other similar transport processes. CFD involves laws of Physics such as conservation of mass, momentum, and energy. CFD employs numerical methods to solve the underlying transport equations. It thus predicts temporal and spatial variations of governing entities such as velocity, pressure, temperature, chemical concentrations, etc. CFD simulations yield a wealth of information related to time-varying three-dimensional distributions of these entities that is difficult to obtain through prototyping or physical testing.

Currently there is no standard method for testing air cleaning devices. CFD can be used to model the way various air cleaning technologies work and the effect the technology has in the room in which it being applied.

Air is the carrier for airborne reactive agents. CFD can: demonstrate what is happening in occupant breathing zones, demonstrate how infection spreads indoors, determine probabilities of infection, demonstrate the effects of increasing or reducing fresh air dilution, etc.

- *What is the future of reactive air cleaning?* Connie and Kishor
    a. Reactive air cleaners address the growing concern about the risk of transmitting infections in occupied spaces because they are dynamic and interact with pathogens in real time in the breathing zone.
    b. Disease transmission significantly reduced indoors when integrating reactive air cleaners with HVAC compared to using ventilation alone

- *What testing standards are needed in this space?* Connie and Kishor
  Standards for testing to evaluate efficacy and safety
  Efficacy
    - Methods for quantitatively measuring reactive agent
        i. formation rates
        ii. lifetimes
        iii. kill rates of pathogens in air and surfaces
    b. Methods for measuring changes in VOC concentrations

c. Methods for microorganisms testing which specify
    i. Testing in licensed third-party labs
    ii. Using industry standard techniques, guidelines
    iii. Testing chamber size
    iv. Use of commercial devices sized for the test chamber operating at normal use conditions

Safety

- Standards for measuring steady state VOC concentrations
- FDA GLP Toxicology studies

Marketing & Advertising

- Uniform marketing terminology
- "The dose makes the poison" when is too much, too much?
    - What are the Permissible Exposure Limits.
        - OH – the only known standard is natural concentrations
        - BY-products – organic compounds
            - Can be measured using standard analytical methods for stable alcohols, aldehydes, ketones, and acids for example
            - Published safe levels available from MSDS sheets, EPA, FDA
- The question of EPA Standards for indoor air cleaners came up. The EPA has standards for air cleaners that remove particulates but does not have standards for those that remove VOC and kill microorganisms
    - *Excerpted from: EPA: Residential Air Cleaners*
    - With the exception of the DOD method in Military Standard 282 (see reference 1 below), used only to rate particle reduction by high efficiency filters, the federal government has not published any guidelines or standards for use in determining how well an air cleaner works in removing pollutants from indoor air. However, standards for rating particle removal by induct or portable air cleaners have been published by two private standard-setting trade associations (see reference 2 and 3 below). These estimate the efficiency or effectiveness of an air-cleaning device in removing particles from indoor air, and can be used for comparisons among different devices.

Standards for air cleaners now focus only on particle removal. No guidelines or standards are available for use in assessing the comparative ability of air cleaners

to remove gaseous pollutants or radon and its progeny, and research is currently inadequate to draw firm conclusions regarding the relative effectiveness of air-cleaning devices in removing such pollutants.

References:

1. U.S. DOD. 1956. MILSTD282. Military Standard. Filter units, protective clothing, gasmask components and related products: Performance test methods. Washington, DC: U.S. Department of Defense.
2. ASHRAE. 1976. ASHRAE standard 5276. Method of testing air-cleaning devices used in general ventilation for removing particulate matter. New York, NY: American Society of Heating, Refrigerating, and Air-conditioning Engineers Inc.
3. Association of Home Appliance Manufacturers. 1988. American national standard method for measuring performance of portable household electric cord-connected room air cleaners. ANSI/AHAM AC-1-1988. Chicago, IL: Association of Home Appliance Manufacturers.

Z-Man Signing Off

Trivia Question:

Name the holder of a patent for a device “to provide a simple, cheap, and effective apparatus for the production of ozone or such gases as are obtained by the action of high-tension electrical discharges?

Answer: Nikolai Tesla
Answered by: Don Weekes, Ottawa, Ontario Canada