Application Note AT-101

Ozone Monitoring and Control For Air Treatment Systems

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Introduction

While ozone has been used for about a century to treat water, only in the last decade or so, however, has ozone been applied on a large scale to heating, ventilating, and air conditioning (HVAC) systems. Major reasons for this surge of interest in ozone treatment of indoor air include:

- Heightened public awareness that something can be done about indoor air quality (IAQ).
- Increased IAQ problems due to sealed buildings and less makeup (outside) air metered into HVAC systems.
- Increased public intolerance for smoking and the realization that many common chemicals contribute to poor IAQ.
- New ozone generator and ozone monitor designs that make system control a reality.
- Attractive payback economics due to savings in energy and other factors.

The large majority of projects so far are for gaming facilities (casinos, bingo halls, card rooms) and larger hospitality businesses including restaurants, showrooms, and bowling centers. These users have found that there is a high return on investment in systems which create and maintain high air quality. Many projects, often much smaller in scale, have been completed for cocktail lounges, taverns, airport smoking areas, and even for advanced technology facilities for animal raising on a large commercial scale.

The major objection to ozone is safety. Its concentration in public areas must be kept below harmful levels. This is accomplished by new technology ozone generation and monitoring equipment combined as a self-controlling system. There is disagreement among cognizant agencies about what are safe levels and suitable guidelines for ozone concentrations. Safe concentrations generally are listed over the range 0.05-0.10 ppm. Most ozonated HVAC systems with automatic controls are programmed not to exceed concentrations ranging from 0.03 to 0.05 ppm. These concentrations are below naturally occurring outdoor levels in many regions, but are just high enough to reduce VOCs significantly. Furthermore, the ozone concentrations are much higher in the supply ducts, where the ozone generators feed in (typically 0.3-0.5 ppm). Bacteria, mold, mildew, and VOCs are greatly reduced in those ducts, and thus eventually in the entire HVAC system (Ozone drops in concentration by a factor of 10 or so due to these reactions as well as due to normal "half life" reversion back to oxygen).

Early Efforts and the Evolution of Systems Concepts

The mid-1990's saw a lot of efforts in ozone for air treatment. Among the businesses that got into ozonated air applications early were the traditional suppliers of industrial air filtration equipment and supplies. Two of the US pioneers who survive today in large scale ozonated HVAC systems are Airtronics Environmental (Hazel Crest, IL, USA) and Clean Air Systems (Bellevue, WA, USA). For them, using ozone sensors/controllers to control ozone generators in HVAC systems was a natural extension of the thermostat concept.

Early ozone generators for commercial scale HVAC applications were made by Tri Med (now part of Engineered Air, Desoto, KS, USA), and the Sonozaire Division of Howe-Baker Engineers, Inc.(Tyler, TX, USA). A pioneer systems integrator was and still is Ruks Engineering, Ltd. (Brampton, Ontario, Canada) who has specialized in large Mideast turnkey projects.

Much of the early efforts emphasized control of ozone generators by two monitor/controllers: one for VOCs such as cigarette smoke gasses to be removed from the air, and one for the ozone to do the removing. This approach has strong theoretical appeal, but as a practical matter its application must be done carefully. Most VOC sensors have at least some sensitivity to ozone (reduces their reading), and virtually all ozone sensors are fairly sensitive to VOCs (reduces their reading).

Therefore, many systems designers decided to use only one kind of sensor - usually ozone sensors - to control the system. The logic is: whatever the VOC level, keep the ozone on unless it exceeds a safety concentration limit. If such a measurable concentration of ozone exists, the excess ozone has been consumed by VOCs which are no longer there.

In 2001 Eco Sensors, Inc. (Santa Fe, NM, USA) worked with Howe-Baker to provide sensor/controller boards as component subsystems to incorporate into their HVAC and other air treatment ozone generators. The equipment has worked well in applications such as casino air quality control so it seems likely that this approach will be widely adopted.

Another approach is represented by highly engineered systems which have been proposed for destruction of the pathogens that cause contagious diseases. These might be termed "closed" ozone sterilizing systems. Very high concentration ozone would be provided only to a sterilizing section of the HVAC duct. Further downstream would be an ozone destruct section such as a catalytic pack. Since all unused ozone is destroyed, there is no need for ozone controllers for the generator. However, a leak in the catalytic pack could be catastrophic, so an ozone leak sensor connected to the generator would be very important. I am unaware of any major ozone HVAC system using this approach, but I speculate that due to the almost unlimited concentration of ozone possible in the treatment section of the HVAC duct, this approach will look increasingly attractive for assured destruction of rogue pathogens such as SARS. Researchers at Penn State tested this kind of system for *Escherichia Coli* and report kill rates in excess of 99.99% for ozone concentrations of 4-20 ppm (1).

The systems discussed above are summarized in Table I.

Table I. Sensor/control concepts for ozone generators

Generator/monitor/con-troller system		Application	Generator
1	Generator only in small room.	Simple, low cost, but keep generator away from infants and other susceptibles.	< .1 g/h
2	Monitor/controller at end of long cable.	Locating monitor/controller will always entail difficult trade-offs.	< .5 g/h
3	Ozone and VOC Monitors/controllers.	Good for selected areas with easily destroyed VOCs.	> 1 g/h
4	Large generator in HVAC air handler. Sensor/controller at the entrance to the return duct.	Typical approach for very large public areas such as casino gaming room.	> 5g/h
5	Sensor/controller in the generator.	Easy installation but more difficult to monitor and adjust ppm distribution.	> .1 g/h
6	Closed system in the HVAC duct (complete ozone destruction).	Experimental. Probably most cost-effect for pathogen (microbes) rather than VOC destruction.	> 1 g/h

Large HVAC Systems

Large HVAC systems usually deal to a large degree with cigarette smoke (2). Filtration will remove particulates and the small percentage of the gas-phase pollutants that have adsorbed to the surface of the dust. But particulate filters don't remove the majority of gas phase pollutants, and the high-efficiency filters required for tobacco smoke particulate have a very considerable impact on airflow.

High ventilation-rate systems, including even 100% make-up air systems with no re-circulation, will reduce particulates through dilution, but are only nominally effective at reducing VOCs. High ventilation-rate systems also waste tremendous amounts of energy, even when energy recovery ventilators are implemented.

Carbon is effective at removing the VOCs from the air that flows through the carbon, but with a huge replenishment expense in heavy smoking environments. Ozone reduces VOCs more effectively than carbon, has no replenishment expense, oxidizes residual VOCs from finish surfaces, reduces demand for outside air, and through the "stat" effect, eliminates the growth of microbial matter inside the condensate drip pans, coils and heat exchangers, and ductwork.

The conditioned air residence time in occupied areas is typically about 15 minutes, or about the half-life of ozone in such environments. Because the ozone concentration typically drops about 90% from supply ducts to return ducts instead of about a 50% drop predicted by half-life, we see that much of the ozone has reacted with VOCs.

Sometimes reducing the VOCs by ozone eliminates the need to increase the makeup air when the area population increases. This in turn eliminates the additional energy otherwise required to heat or cool the additional make-up air.

The ozone monitors/controllers to shut off the ozone generators are usually located at the entrance to the return air duct (see system 4 above). This usually represents the most representative point to sample the air being breathed by the room occupants.

When implemented correctly, ozone offers superior performance to any other method currently in use for gas, odor, and VOC control; has benefits which none of the other strategies offers; and results in lower ownership costs due to lack of replenishment expense and decreased make-up air heating and cooling requirements.

Case Study: Dubai International Airport

The Dubai International Airport may be the largest ozonated HVAC system in the world with air treatment in all buildings. There are over 300 ozone sensor/controllers and many

VOC sensor/controllers as well. (See system 3 above). There are many small ozone generators spread along the HVAC ductwork along with the ozone and VOC sensors. Virtually all interior spaces are treated including the freight terminal.

Eco Sensors was selected as the ozone sensor/controller for the Dubai International Airport in the late 1990's. As we have not been there since then, and we are not a prime contractor, we are not familiar with recent operations or developments.

The Dubai International Airport was the sixth fastest growing airport in the world processed 10 million passengers in 1998. The growth rate of passenger throughput exceeds 10% annually and is due to Dubai’s ranking as a leading leisure and business destination. Dubai is one of the Arab Emirates at the Eastern end of the Persian Gulf.

Early in the airport’s growth, the airport’s manager, the Department of Civil Aviation, felt that superior air treatment was required to give a clean, fresh air to which major international travelers are accustomed. It was decided to try the novel approach of ozonation of the air inside all buildings in preference over the traditional approach of carbon filtering. Preliminary results in terms of passenger satisfaction and operating economics have exceeded expectations. The airport was recently voted a World's Favorite Airport by readers of Conde Nast Traveler magazine.

The ozone is injected into the central air conditioning system. The ozone generators are controlled by sensors activated by excessive VOC concentrations and turned off by excess ozone concentration sensors. Carbon dioxide sensors call for makeup air if the carbon dioxide concentration exceeds a standard set-point. The air conditioning system is large and energy-consuming because outdoor temperatures routinely exceed 40 deg C in the warmer months. All systems and components are controlled by a computerized building control system (BCS). The ozone monitors are the Eco Sensors model C-30Z (the design has been revised and is now sold as the C-30ZX) which keep the ozone concentrations in the occupied areas to less than .05 ppm.

The VOCs to be minimized by the ozone treatment include cigarette smoke, jet fuel and exhaust fumes in the makeup air, and building chemical fumes such as from paint, carpets, and cleaning chemicals.

The conditioned air residence time in the passenger areas is about 15 minutes or about the half-life of the ozone in such environments. Because the ozone concentration drops about 90% from supply ducts to return ducts instead of about a 50% drop predicted by half-life, we can see that much of the ozone has reacted with VOCs.

An unexpected finding was that the makeup air could be cut by 50% without compromising the carbon dioxide concentration criterion. The ozone is destroying the VOCs sufficiently to significantly reduce the makeup air without reducing the building's air perceived quality. This translates to great energy savings because cooling the very hot makeup air requires large amounts of energy. The indicated energy saving should recover the cost of the ozone equipment in about one year.

After operation of the system for about one year, the preliminary findings were:

- Passengers and employees note a pleasing air quality without the distinct smells that are often found in busy airports.
- The savings of ozone replacing carbon filters are very large. Carbon filters have high replenishment costs and occupy a lot of valuable space.
    - The energy savings in reducing the makeup air requirement are significant.

Other HVAC system maintenance costs are reduced such as less cleaning of the ducts, due to virtually no mold and mildew accumulation

Scaling Up for High Concentration Applications

Extensions of the application of ozone systems for air treatment have gone in two directions: fumigation of unoccupied living spaces (3) and food storage. Fumigation usually involves temporary placement of one or more large (> 4 g/h) ozone generators in the area to be treated. Operators working inside the area while the ozone is on wear protective clothing and ozone blocking respirators. The ozone concentration is brought up to several ppm (5 ppm is a typical target) for a length of time depending on the odor and other contaminants to be destroyed. Simple but strong household odors may call for only 4-6 hours of treatment; smoke and mildew odors after a fire may require 48 hours. Ozone instruments are used to monitor the concentration while fumigating, and to indicate when it is safe (< .1 ppm) for unprotected personnel to enter the treated area.

Food treatment and storage in agricultural warehouses often requires similar concentrations of ozone (4). The maximum is often determined by the concentration that causes unsightly oxidation of the fruit or other food. Several ppm of ozone is commonly used. Ozone monitor/controllers are required to keep the ozone concentration at desired levels.

The complication with this application is that the temperature (T) and relative humidity (RH) are at extreme ends of the operating range for many sensors and instruments. A T of 3-5 degrees C and a RH of 95% are typical. Smart probes under development have a microprocessors integrated with ozone, T and RH sensors so that an accurate corrected reading can be transmitted by a digital local area network (LAN) to the programmable logic controller (PLC). These advanced multisensor digital probe technologies will doubtless find their way back to the more traditional HVAC applications.

I will now try to summarize the trends and new developments that have ben discussed in this paper. These are:

- Precalibrated disposable sensor modules
- Decentralized and modular sensor systems
- Digital output to LANs, wireless systems and mesh networks
- High intensity treatment within "closed" ducts such as for SARS eradication
- Extensions of technology and designs developed for ozonated food storage

In what exact forms these will emerge is in the minds and hands of you the systems designers. Good luck!

Conclusions

Ozone monitoring and control for air treatment systems has come a long way in the last decade. Scaling has been successfully carried out going from table top generators for living rooms with no sensors and controls to extremely complex multimillion dollar systems integrated into the HVAC systems of most major casinos. Sensor technology is progressing to tiny multisensing devices with digital transmission to remote control computers.

Extensions of this technology have found their way into fumigation, and food treatment and storage. Recent experiments indicate that systems can be developed to destroys pathogens that cause contagious diseases as they pass through the HVAC ducts.

Acknowledgement

This paper draws heavily upon a paper I presented at the 2003 World Ozone Congress in Las Vegas sponsored by the International Ozone Association. It is entitled A Review of Ozone Monitoring and Control for Air Treatment Systems. I wish to thank my colleagues there for all their comments.

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