Odor Remediation of Environnemental Tobacco Smoke

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ABSTRACT

Environmental Tobacco Smoke or ETS is a technical term which describes the contaminants released into the air when tobacco products burn or when smokers exhale. Due to their aerosol nature, the smoke particles are sticky and will inevitably clog the surface of any types of air filters, making them quickly wasted and thus ruling out the solution of simple filtration. Their stickiness makes them cling to walls, carpets, fabrics, and clothing, thus impregnating the environment with long lasting nasty smells. This short white paper describes those challenges and explores from a fundamental point of view the shortcomings of common classical remediation methods such as filtration, electrostatic filters and air ionizers. Finally, the paper explains how the proper use of ultraviolet photo-oxidation process can provide an effective solution to eliminate the odors caused by environmental tobacco smoke.

INTRODUCTION

Environmental Tobacco Smoke or ETS is a technical term which describes the contaminants released into the air when tobacco products burn or when smokers exhale. At room temperature, many of these compounds are gaseous but most are solid ash particulate and liquid droplets called aerosol.

Particles in tobacco smoke are especially problematic to remove not because of their small size (0.1 to 1 micron), but because they are coated with tar, nicotine, phenols, and many other pungent odorous compounds. They can remain airborne for hours after smoking stops.

Due to their aerosol coating, tobacco smoke particles are not dry but rather sticky and will inevitably clog the surface of any types of air filters, making them quickly wasted and thus ruling out the solution of simple filtration. Their stickiness makes them cling to walls, carpets, fabrics, and clothing, thus impregnating the environment with a lasting nasty smell.

This white paper describes those technical challenges and explores from a fundamental point of view the proper use of ultraviolet photo-oxidation process as a solution to remediate the odors caused by environmental tobacco smoke.

COMPOSITION OF CIGARETTE SMOKE

Studies have shown that cigarette smoke contains over 3800 chemical compounds. Some of these compounds are shown in Table 1 below. Cigarette smoke aerosols are essentially condensable gases resulting from incomplete combustion. Combustion being an oxidation process, those aerosols can be rendered less sticky and turned into dry ash by completing their oxidation. Their odors would even disappear if they could be fully oxidized down to water vapor and carbon dioxide, which are odorless compounds. If one could draw the smoke cloud directly into the combustion chamber of an industrial fume incinerator at 850 ^{o}C for two seconds, the odorous molecules cocktail listed in Table 1 would be completely oxidized and consequently odorless. Although it would work perfectly, this solution is obviously not economically sound.

Source:Introduction to indoor air quality: a reference manual, EPA/40013-91/003		
Duration of smoke production (sec)	20 sec	550 sec
Characteristics or compound	**Mainstream Smoke**	**Sidestream smoke**
Particles (Number per cigarette)	1.05E+12	3.50E+12
a) Solid particles and aerosols	**(mg/cigarette)**	**(mg/cigarette)**
Tar	20.80	44.10
Nicotine	0.92	1.69
Benzo (a) pyrene	3.50E-05	1.35E-04
Pyrene	2.70E-04	1.01E-03
Fluoranthene	2.72E-04	1.26E-03
Benzo (a)fluorene	1.84E-04	7.51E-04
Benzo(b/c)fluorene	6.90E-05	2.51E-04
Chrysene, benz(a)anthracene	1.91E-04	1.22E-03
Benzo (b,k,j) fluorenthrene	4.90E-05	2.60E-04
Benzo (e) pyrene	2.50E-05	1.35E-04
Perylene	9.00E-06	3.90E-05
Dibenz (a,j) anthracene	1.10E-05	4.10E-05
Dibenz (a,h) anthracene, ideno-(2,3) pyrene	3.10E-05	1.04E-04
Benzo (g,h,i) perylene	3.90E-05	9.80E-05
Anthanthrene	2.20E-05	3.90E-05
Phenols (total)	2.28E-01	6.03E-01
Cadmium	1.25E-04	4.50E-04
Polonium 210, pCi	7.00E-02	1.30E-01
b) Gases and vapors		
Water	7.50	298.00
Carbon monoxide	18.30	86.30
Ammonia	0.16	7.40
Carbon dioxide	63.50	79.50
NOx	0.014	0.051
Hydrogen Cyanide	0.240	0.160
Acrolein	0.084	0.000
Formaldehyde	0.000	1.440
Toluene	0.108	0.600
Acetone	0.578	1.450

Table 1. Chemical composition of cigarette smoke

AIR FILTRATION AND IONIZATION LIMITATIONS AGAINST TOBACCO SMOKE

Inspection of Table 1 shows that filtration alone could not handle cigarette smoke aerosols. Past experience has shown that the very small sub-micron size of the particles requires expensive HEPA filters that become tar coated and consequently clogged very quickly.

Besides classic filtration, there is another well-known way to remove sub-micron particulates from the air. Electrostatic air filters also called air ionizers have this capability. Instead of capturing particles mechanically like classic filters, the idea behind electrostatic or electronic filtration is to electrically charge the particles so that they will migrate due to electrical forces toward nearby surfaces. The same effect is obtained by rubbing a balloon on one's hair and then sticking it to a wall. Eventually, the balloon loses its charge and falls back to the floor.

Many of the popularly called "smoke eaters" use the electrostatic principle to collect smoke particles on metal plates. The effect of ionizers on the smoke particles in the air is the same except that they have no collecting plates and the charged particles end up sticking on the walls and surfaces of the room. It is worth noting that since the cigarette particles are sticky with tar, they will overtime coat all the room surfaces with pungent smelly yellow-brown tar extract.

Experiences with ionizers into small volumes like a hand jar is quite conclusive where the smoke particles of one cigarette can be easily dispersed toward to jar walls within 15 to 20 seconds. However when repeating the same experience in a larger volume like a 3m x 3m x 3m room, the time required to clear the air from the same amount of smoke goes up to several hours!

The explanation for this loss of effectiveness as the room size increases is rooted into basic fundamental physics of electrostatic forces: the Coulomb Law, which states that the electrical forces between charged particles decreases with the square of their distance. The Coulomb Law implies that when the distance is doubled, the electrical force is reduced by a factor of 4. When comparing the electrical forces in the small jar where the particles are within less than a few centimeters from one another and from a nearby wall with that of a room of a few meters wide, the electrostatic forces responsible for the dispersion of the smoke particles are down by the square of the ratio of 1 meter to 1 centimeter i.e. the square of 100 or 10,000 times less electrical force !

This fundamentally explains why experiment based on removing the same number of smoke particles in a normal size room takes several hours(10,000 + seconds) whereas the old sales-pitch demonstration videos performed in a hand size container takes seconds. Not only air ionization does not remove the odors due to the walls and surface tar coating effect, but their electrostatic actions are way too slow to have any significant cleaning effect except in a small jar. On top of their ineffectiveness, the fact that room surfaces will get gummy as they accumulate the electrically charged tar particles instead of using some internal cleanable capture plates like in all electrostatic smoke eater units, the air ionizers are in fact an ill-conceived version of an electrostatic smoke eater and an overall bad idea.

EFFECT OF ULTRAVIOLET LIGTH ON CIGARETTE SMOKE

When ultraviolet UV-C light photons hit a tar or nicotine molecule, they carry enough impact energy to break the interatomic chemical bonds and shatter the molecule into many smaller molecules. The energy of germicidal UV photons at 254 nm wavelength is 470 kJ/mole, an energy greater than the energy of all the chemical bonds listed in Table 2. By comparison, visible light with an average wavelength of 550 nm has photon energy of only 217 kJ/mol.

It is therefore quite clear that some bonds within tar, nicotine and phenols molecules in the smoke can be broken down by UV-C irradiation but not by visible light.

Chemical Bond	**Chemical Bond Average Energy (kJ/mol)**
C – C	347
C – H	413
C – N	305
C – O	358
C – S	259
N – H	391

Table 2. Chemical Bonds Strength [4]

Therefore, the chemical bonds between carbon atoms and hydrogen, nitrogen, oxygen and sulfur atoms will be broken down by UVC ultraviolet photons, resulting broken pieces of molecules. Following this process, the broken molecules can now be further oxidized to complete their combustion and reduce their odor potential.

This oxidation can be accomplished by using a higher energy ultraviolet of 185 nm wavelength called UVV, where the second V stands for Vacuum. UVV photon have an energy of 645 kJ/mole but can only propagate into a vacuum because the dioxygen molecule in the air absorbs it and as a result gets broken up into monoatomic oxygen. At normal atmospheric pressure, UVV photons are almost totally absorbed within less than 5 mm away from a standard low pressure mercury quartz lamp UVV source. These free oxygen atoms generated by the UVV light are then able to react and complete the oxidation of the broken-down tar, nicotine, and phenols molecules.

The end products of this photo-oxidation process are then dry non-sticky ashes particles that can now be captured by adequate standard filters. This way the odors are eliminated by the oxidation process and the dry resulting particles removed by filtration.

The proper sizing to avoid oversizing of photo-oxidation system is of utmost importance. Should there be nothing to react with, the UVV generated oxygen atoms O* will react with dioxygen molecules O_2 to produce ozone O_3, another undesirable compound. Ozone is a not a stable molecule and will decompose naturally into normal dioxygen at ambient room temperature within 20 to 30 minutes depending upon relative humidity. The OSHA limit for 8 hours exposure is 0.05 ppm of ozone. Because the generation rate and the rate of decomposition of ozone in the absence of any smoke or other volatile contaminants in a given room size at an ambient temperature and ventilation rate can all be adequately calculated, it is possible to size an ultraviolet photo-oxidation system that will never exceed the OSHA safety limit.

CONCLUSION

This paper has described in detail the nature and composition of cigarette smoke and the consequential inherent shortcomings of classical filtration and electrostatic filters or air ionizers. Many years of experimental evidences backed by calculations based on cigarette smoke chemical composition show that the odor of cigarette smoke cannot be removed without altering the structure of the molecules responsible for the odors which are essentially tar, nicotine, and phenols. Besides thermal incineration, ultraviolet photo-oxidation has proven to be the most effective way to accomplish this by degrading and oxidizing those molecules. Their oxidation render the smoke particles dry and non-sticky which make them acceptable candidates for standard filtration. Care must be taken to adequately engineer the ultraviolet photo-oxidation system with respect to the room size and ventilation rates to keep the potential residual ozone well within the OSHA limit when the treated room becomes free from tobacco smoke.

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