Ozone generation by 222nm (KrCl) lamps

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1. Introduction

With the increasing application of UVC lamps for air and surface disinfection questions about Ozone generation and related concerns are raised. This paper will give some background about ozone generation by lamps and the related risks and solutions.

2. Ozone, limits and calculations

Ozone is an inorganic molecule consisting of 3 oxygen atoms (whereas normal oxygen consists of 2 atoms). Ozone is generated by very short wavelength UV radiation, or in electric discharges (containing oxygen). Ozone can also be generated by a combination of certain "ozone precursors" (e.g. methane and products from fuel combustion) and radiation by relatively long wavelength UV (290-400nm?).

Ozone is an unstable gas (so it cannot be stored). During the decay of ozone to oxygen, free oxygen atoms create activated OH radicals which create very strong oxidizing effects (bleaching) and antimicrobial effects. This property is widely used in water treatment, various anti-microbial applications (FDA approved for food treatment) and odor reduction.

The amount of ozone is usually measured in parts per million (ppm), in some applications in gram per m^3 or µmol/mol.

Ozone has been shown to affect the respiratory, cardiovascular and central nervous system. It is highly regulated (e.g. EPA, FDA, ACGIH, NIOSH) and exposure limits have been established. There are various standards (e.g. UL867) and guidelines for ozone, especially for air cleaners.

The general limit for 8 hour exposure to ozone is a maximum concentration of 0.1ppm (OSHA (1)). The FDA sets the limit for extended exposure at 0.05ppm (=50 ppb).

Ozone can be smelled by most people at about 0.01-0.04ppm. However, that sense disappears very rapidly within a minute or so. So, when entering a room one can usually smell 0.1ppm, but after a short time one cannot smell it anymore (even much higher concentrations).

a. Ozone calculations

To calculate ozone concentrations in a room a few numbers are needed.

1 gram ozone/m^3 = 467ppm (1ppm= 0.00214gr/m^3)

The generation of ozone by an ozone generator (or ozone generating lamp) is measured in gram/hour

To calculate the expected ozone concentration in a room:

Ozone concentration (gram/m^3) = time (hours) ozone generation (gram/hour) / room volume (m^3)*

For example, assuming a lamp generates 1mg/hour and a room size of 20x15x10ft=85m^3

We can calculate the concentration in the room after one hour:

Concentration=1 hour x 0.001gram/hour/85m³=1.17E-5gram/m³ = 0.005ppm= 5ppb

Which is 1/10 of the FDA limits.

b. Ozone decay

In addition one has to consider the reduction of ozone in a room.

The natural decay time ("half life") for ozone in air seems to vary in the literature between 1 day (2) and 3 days (3). More important is the air exchange/ air refreshment in the room, and in addition the reaction of the ozone with odors and surfaces. All these factors are almost impossible to calculate or predict. So, a safe approach is to calculate the maximum concentration, knowing there is a safety margin in the real world.

It must also be considered that the lamp may only be turned on for short times during the day and the total amount of ozone at the end of the day will be less than the sum of single ozone generation during the short on time.

c. Ozone reduction

There are various methods of reducing the ozone amount emitted into a room.

Obviously, having an air outlet that exhausts to the outside is one method. This method is advised if high airflows around the lamp are required, since below mentioned ozone filters usually drastically reduce air flow.

If possible, tightly enclosing the ozone generating lamp into an envelope will very substantially reduce the emitted ozone. It must be considered that the envelope must be transmissive to the important wavelength of the lamps, and that the sealing material is ozone resistant (e.g. rubber will usually not withstand ozone (4))

Other methods are using specialized filters, like activated carbon filters which have been reported to reduce ozone by about 60-70% (5).

There are also more specialized ozone catalyst filters which are able to reduce ozone by much higher degrees (up to 99%?). (6)

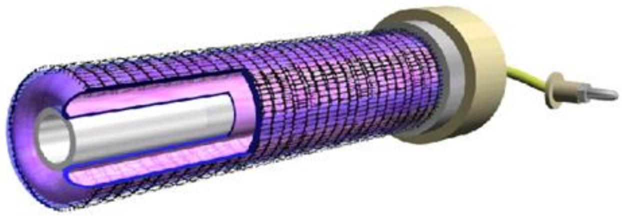
Again, ozone filters will drastically reduce airflow around the lamp and need to be carefully evaluated if active lamp cooling is required. The maintenance and life time of these filter should also be considered.

3. Ozone generation by KrCl (222nm) lamps

As mentioned above there are 2 main ozone generation mechanisms: optical short wave radiation and electrical discharge in air

a. Electrical discharge as ozone generator in KrCl lamps

Looking at a typical design of an excimer lamp there are 2 electrodes – the inner electrode (typically a "solid" piece of metal tube) and an outer metal mesh electrode.



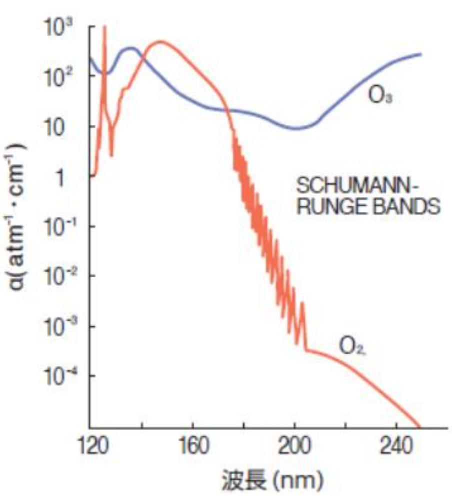
The basic principle of an excimer lamp is that a discharge within the (KrCl) gas, within the glass enclosed gap of the lamp, will take place, creating the typical excimer radiation (in this case the typical 222nm spectrum). However, when we look at the microscopic details of this design, one quickly realized that neither electrode will attach flat to the glass over the entire area. There are little gaps of 100um or more between the metal and the glass surface. Since the operating voltage of these lamps is usually in the 8-10kV range, a very small discharge can and will form over these gaps, on the outside, in air, which will create ozone. The amount of ozone generated will depend on the gaps, the applied voltage and the power of the lamp.

Ushio has overcome most of this problem in new lamp designs where the electrodes are printed directly on the glass and therefor reducing the ozone production by a large degree.

It should also be mentioned that using lower wattage lamps, which also require less operating voltage will drastically reduce the amount of generated ozone.

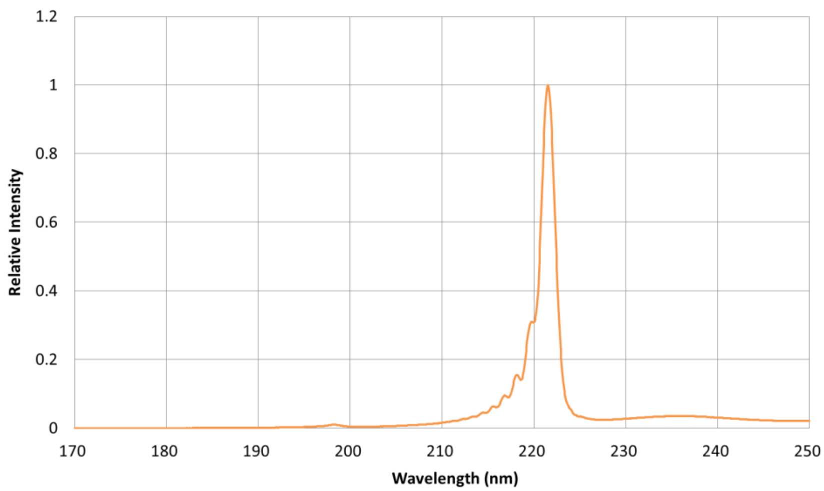
b. Ozone generation by radiation

The efficiency of ozone generation depending on wavelength is shown in below graph, correlating with the O2 absorption.



Please note that the y axis is in logarithmic scale. What this means is that there is a huge difference between ozone generation at wavelengths below 200nm and above.

Comparing this with a typical spectrum of an unfiltered KrCl lamp, one will find that there is an insignificant, but existing amount of radiation below 200nm.



It should be noted that this spectrum is inherent to all KrCl discharges, so it typically does not depend on manufacturer, lamp design or used technology.

However, Ushio has developed sophisticated filter technology to not only suppress radiation above 230nm (Care222) but also applies filter technology to reduce wavelengths below 200nm significantly and therefor reduce ozone production further.

It also must be noted that the total amount of ozone generation will depend on the total amount of optical radiation (Watts). Therefor a high power lamp (e.g. 300W) will proportionally create much more ozone that a 12W lamp. In addition, the actual run time of a lamp (typically within 8 hours) has to be considered.

c. Ushio lamp example calculations

i. Care222 B1 module

Ushio has measured the ozone generation of this 12W filtered 222nm module as 0.012mg/hr.

Taking a "standard room" size of 3x4x2.5meter=30m^3, it will take 267 hours to fill that room to 0.05ppm. Or, within 24hours (constantly running the lamp) one would fill the room to 0.0045ppm (4.5ppb). That amount would not be smelled and is well below any FDA limits!

This would be the maximum amount to be expected. In reality, the lamp will likely not run more than 1 hour per day (some time in occupied, some time in non occupied room). For a 1 hour run time the ozone concentration would be 0.2ppb. Obviously, if multiple B1 modules are installed in one room, these numbers will have to multiplied, and if the room size changes the concentration will be different.

Nonetheless, the above calculations show that under no circumstance an ozone level of 50ppb can be reached in any practical installation with B1 modules.

ii. 300W oval lamp

Ushio has measured the ozone generation of a 300W oval lamp to be 1.32mg/hr.

So, this is roughly 100 times more than a B1 module. As mentioned above, there are several reasons- total power, but also applied voltage and lamp construction add to the much higher ozone generation.

Using this lamp for 24 hours in a 30m³ room would lead to 0.5ppm ozone concentration, which would be very dangerous and must be prevented. Depending on the application, several of the above mentioned methods can be applied. For example, the same room would only get to 20ppb if the lamp runs only for 1 hour. Since this lamp requires active cooling and is usually used in a reflector housing with a filter glass, there is a possibility to implement an ozone filter and lower the ozone emission of the fixture. It should also be considered that the OSHA limit for 8 hour exposure is 0.1ppm. Although this should not be a level to be achieved, it could be taken into account for certain application environments.

What is important to note, is that the fixture should be evaluated for ozone, especially if the lamp is intended to run for long duration or in small rooms.

iii. Cylindrical 300W lamp

As of August 2020 Ushio does not have reliable ozone generation data for this lamp. At the moment it should be assumed to be at least 3 times higher than the above mentioned oval lamp. However, it should also be considered that this lamp is typically operated at substantial lower power than 300W which will lower the ozone generation.

It should be noted that essentially all high power competitor lamps have the same design like this cylindrical lamp and will have most likely similar or higher amounts of ozone generation.

For this kind of lamp, it is absolutely necessary to measure the ozone generation of the fixture since potentially dangerous levels can be achieved in a very short time frame.

4. Conclusions

Ozone concentration in rooms is an important design consideration when using 222nm lamps. Depending on design and power KrCl lamps can emit considerable amounts of ozone. This has to be taken into account and measured when designing fixtures with KrCl lamps.

The Ushio Care222 B1 module emits such minute amounts of ozone that legal limits are unlikely to be achieved or exceeded in any practical application. Especially in applications where the runtime of the module is limited due to TLV limits there should be no concern about ozone.

References

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