THE USE OF GASEOUS OZONE IN THE CATERING BUSINESS: A RESEARCH BY INOX BIM

Sanitization through gaseous ozone in the catering equipment business, as well as sanitization through ozonating cabinets of kitchen utensils, cutlery and other objects in contact with food (but also aprons, tea towels and so on), is proven to be a trending practice that soon (we are confident and we hope so) will get the attention of institutions, restaurateurs and customers aiming at greater hygienic standards.

What is ozone? How is its use regulated? What are the pros and cons?

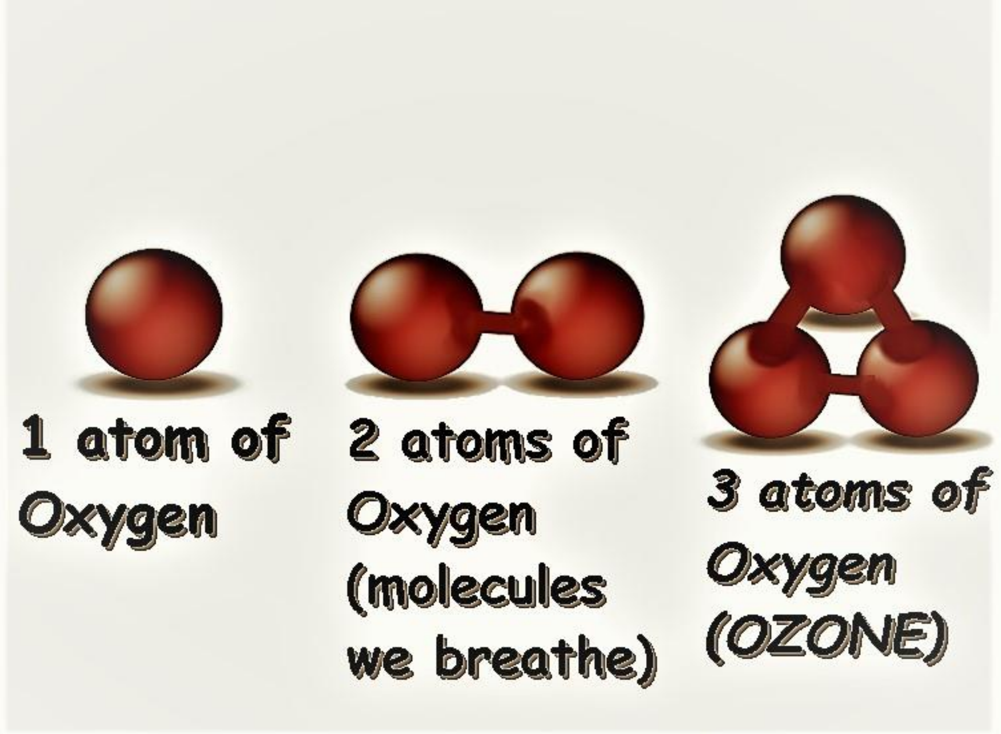
These are some of the (many) questions we are asked daily. We thought of putting everything on words then: here is a research, articulated as a F.A.Q. section, entirely dedicated to ozone!

At the end of the document, you can also consult the technical data sheets of the various products mentioned in the document itself: the ozone generator (IGO), the ozone refrigerated cabinets (IGF), the combined hot / cold ozone cabinets (IGFC), the environment ozone cabinets (IGA), the ozonating dressing cabinets (ASMO/ASPO)

INDEX

What exactly is the Ozone?

The ozone molecule is simply an oxygen molecule (O_2) enriched with an additional oxygen atom (which makes it an **O_3**).



Ozone is an unstable gas (reactive with other agents, therefore it dissolves in the air fairly quickly). It cannot be stored, and must be produced at the time of use. It is colourless, and has a fairly pungent odour[1], which you may have perhaps smell after a thunderstorm (the electric discharge of lightning, in fact, can generate ozone).

On a natural level, it is located 20km above our heads, in the stratosphere, and plays an essential role in protecting us from UV ultraviolet rays.

Here within our reach, however, it can be produced by *electric discharges*.

[1] Someone may reckon its smell as "metallic". See: https://molekule.science/what-does-ozone-smell-like/

How do we generate ozone?

The ozone is generated by *corona effect*. Let's have a look at it quickly:

several electrodes, powered by high voltage, are placed on a plate made of insulating material (in our case quartz, but beware that the cheaper models do not use this type of material). Through a process, called *photoelectric*, many small discharges are created.

These, in extreme synthesis, will break the bond between the two atoms of a normal oxygen molecule in the air (O2, composed of two oxygen atoms). The two atoms, now two *free oxygen radicals*, will attach individually to two other oxygen molecules present in the air, forming two triatomic oxygen molecules, i.e. **O_3**, or *ozone*.

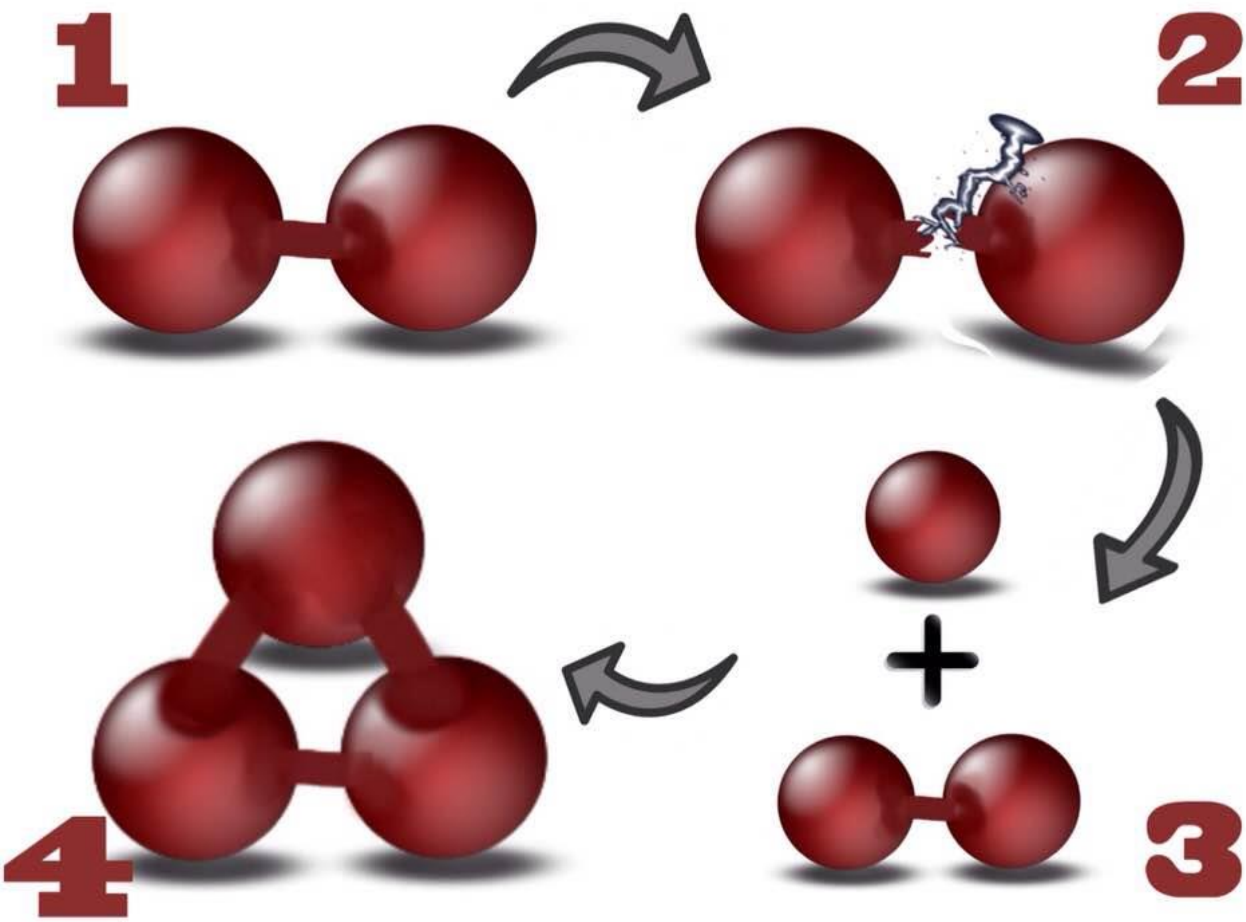


Image 1: a common oxygen molecule in the air, composed of two oxygen atoms

Image 2: the oxygen molecule is split into two free radicals through the corona effect

Image 3: the free radical join an oxygen molecule in the air

Image 4: here it is a new molecule of ozone, composed by three atoms of oxygen

<u>How is the ozone regulated around the world?</u>

The Regulation EC 852/2004 on the hygiene of foodstuffs, the main point of reference as it comes to HACCP rules in the European Union, states: "*As far as possible, food business operators are to ensure that primary products are protected against contamination, having regard to any processing that primary products will subsequently undergo*"[2]: all this will be way more easily reachable through the use of ozone.

From 1 September 2013, coming into force the *Biocidal Products Regulations (EU) 528/2012 (BPR)* came into force, Ozone is regulated as an "active substance" under the BPR. Its use as "biocide substance" is mentioned by the ECHA, European Chemicals Agency[3].

In the USA, the Food and Drug Administration (FDA) on June 2001 stated "*the ozone may be safely used in the treatment, storage, and processing of foods*"[4], declaring officially the ozone as *GRAS* (Generally Recognized As Safe).

After years of experiments, ozone has been approved for use as a food additive by the Japanese Ministry of Health and Welfare in 1996[5].

Ozone is approved for use in Australia and New Zealand under food Standards (FSANZ), as a processing aid and an ingredient. It is also permitted as a bleaching agent and as a washing and peeling agent used in food manufacturing.

In India, the Food Safety Standard Authority (FSSAI) includes the Ozone in several practices, like removal of residual of pesticide, or sanitizing water and foodstuff.

The World Health Organization (WHO) has declared ozone as the most effective agent for drinking water sanitation[6].

The Global Harmonization Initiative (GHI) an international non-profit network of individual scientists and scientific organizations aiming at the harmonization of global food safety

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[2] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02004R0852-20090420&from=BG
[3] https://echa.europa.eu/substance-information/-/substanceinfo/100.030.051
[4] https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=173.368
[5] *Ozone contibution in food industry in Japan*. Naito and Takahara. (2006)
[6] https://www.who.int/water_sanitation_health/dwq/S04.pdf

regulations, has been working since 2004 for the adoption of ozone as safe and environmentally friendly technique for the food processing industries[7].

Is ozone harmful to humans?

Ozone can be harmful to humans if inhaled in large quantities or for an extended period of time, *which in any case are far greater than what can happen even if not perfectly performing what is recommended*. It goes without saying that our advice is to carry out the operations according to the manual, in order to eliminate any risk, even if minimal.

Guidelines have been proclaimed, commonly accepted in Europe, by the American agency *OSHA* (for worker safety) and by the *FDA* (Food and Drug Administration).

* 0,06 ppm for 8 hours per day, 5 days per week (ppm = Parts Per Million)

* 0,30 ppm for no longer than 15 minutes

These limits are the maximum acceptable concentration. It should be added that these concentrations are much higher than the odour threshold at which ozone can be smelled (0.008-0.02 ppm).

Another American agency, *ACGIH*, the American Conference of Governmental Industrial Hygienists, has set a maximum limit of 0.20 ppm, for a time that does not exceed two hours.

A study published by the National Research Council (US) Committee on Toxicology states*: "Healthy men have been exposed deliberately to ozone at up to 0.75 ppm for 2 h. Light exercise was also taken at this concentration. A reduction in ventilatory capacity (25% reduction in forced expiratory volume) was reported. Chamber exposures have since shown that a critical ozone concentration for a ventilatory response is probably around 0.3-0.5 ppm* (…)*. Most studies have failed to show any effect at 0.25 ppm"*[8]*.*

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[7] *Health and Safety Aspects of Ozone Processing*, in Ozone in Food Processing. Rice (2012)

[8] *Emergency and Continuous Exposure Limits for Selected Airborne Contaminants: Volume 1, Ozone*. National Research Council (US) Committee on Toxicology (1984)

The absorption of the substance through the skin (in the absence of deep wounds) is negligible. To what is known so far, ozone does not cause damage to the gastro-intestinal tract [9]

In substance, ozone can be disturbing to the respiratory tract, or cause irritation to the eyes and throat, but if inhaled in quantities. *And in any case this does not happen if all the safety measures are respected* which basically, consist in not staying in the environment while disinfection takes place, waiting an hour after the treatment is finished, and finally ventilating the room for about ten minutes more.

Any disturbance related to the presence of ozone generally end if the affected people stay in healthy and ventilated environments[10]. However, if you don't feel well after an ozone treatment, we recommend contacting your doctor even if there are no symptoms.

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[9] Research conducted by IFA, Institute for Occupational Safety and Health of the German Social Accident Insurance: http://gestis-en.itrust.de/nxt/gateway.dll/gestis_en/000000.xml?f=templates$fn=default.htm$vid=gestiseng:sdbeng$3.0

[10] In Italian: https://www.emergency-live.com/it/wiki/intossificazione-da-ozono

Is the Ozone Generator suitable for the Catering Business?

Absolutely so! Thanks to its non-toxic nature, ozone can be used for the sanitation of surfaces used for contact with food.

The oxidizing action of ozone makes it the most effective bactericidal, fungicidal, and inactivating agent for viruses; this oxidizing action (higher than that of chlorine and hydrogen peroxide) sanitizes air and indoor environments.

It eliminates and destroys 99% of the bacteria including the most "popular" ones in professional kitchens such as *Escherichia coli*, *Salmonella enterica*, *Listeria* and *staphylococcus aureus*, in addition to many others that we do not mention for reasons of space! A concentration in between 0,25 and 0,30 ppm can kill up to 99% of the airborne bacteria[11].

Viruses (including SARS-CoV-1, close relative of the virus responsible for the Covid-19 pandemic[12]) are sensitive to the sanitizing action of ozone, but are more difficult to inactivate, however, not beyond the capacity of the generator. A good number of viruses (Norovirus, Rotavirus, Vesicular Stomatitis Virus, Influenza A Virus and others) are inactivated with concentrations up to 5ppm for one hour[13]: the *Norovirus*, common in fresh produce as the lattuce, it's inactivated with concentrations of 6.25ppm, with a generation of around 10 minutes[14].

Aspergillus types of mold[15] as well as the ones belonging to the family of *Cladosporium* and *Stachybotrys*[16], fungi as such as *Candida*[17] are very sensitive to ozone, even though, to be sure that a large majority of these are eliminated, a working period of around 3 hours is needed.

And finally, insects such as common dust mites, as well as *Tyrophagus putrescientiae*, responsible for various allergies and skin reactions.

So far, we talked about the use of the ozone generator in the kitchen. But what about the lounge?

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[11] *Effect of Ozone on Airborne Microorganisms*. Heindel, Streib, Botzenhart (1993)
[12] http://www.triroc.com/sunnen/topics/sars.html
[13] *A new ozone-based method for virus inactivation: Preliminary study*. Sattar (1997)
[14] *Ozone Inactivation of Norovirus Surrogates on Fresh Produce*, Hirneisen, Markland, Kniel (2011)
[15] *Inactivation of Aspergillus spp by Ozone Treatment*, Zotti, Vizzini, Porro, Mariotti (2008)
[16] *The Effect of Ozone on Common Environmental Fungi*, Korzun, Hall, Sauer (2008)
[17] *Inactivation of Aspergillus spp by Ozone Treatment*, Zotti, Vizzini, Porro, Mariotti (2008)

Yes! Ozone is also suitable for the lounge!

Ozone, in the quantities released by the Sanitizing Cabinet, do not fade away fabrics[18], does not felt wool[19] does not spoil silk[20], nor other fabrics usually used for the restaurants' refurbishment. Its use brings a great advantage on saving water and other types of detergents (which does not replace, but implements and reduces the necessary quantities), in addition to having excellent deodorization power[21]. Carpets, pillowcases, sofa covers, chair covers, duvets and much more, can be easily ozonated.

The same applies to any steel cutlery, glasses and glass bottles, food packaging plastic. These materials, as can be seen in the table attached at the end of this paper, do not fear any type of corrosion.

It is important to specify that ozone does not replace "ordinary" cleaning, but it is rather a complement of this. The presence of residues of substances (both organic and inorganic) in fact influence the stability of the ozone itself, substantially reducing its effectiveness[22].

The ozone generated can reach difficult, if not impossible, places to be reached with the traditional "elbow grease". The result is a saving in terms of time spent by the operators, in addition to a markedly better sanitation in terms of quality.

[18] As mentioned above, ozone can be used as a bleaching agent, but at much higher concentrations

[19] Rather the opposite, Ozone enhance wool'shydrophily properties: *Use of Ozone in the Textile Industry*. Körlü (2018)

[20] *Ozone-Gas Treatment of Wool and Silk Fabrics*. Wakida, Lee, Jeon, Tokuyama (2004)

[21] *Use of Ozone in the Textile Industry*. Körlü (2018)

[22] *Ozone as disinfectant in the food industry*. Dobeic. (2017)

Why using ozone for sanitizing environments dedicated to catering or foodservice activities?

- *Because it operates in hardly accessible places:* being heavier than air, this creeps into those cracks and slots that are difficult to reach during ordinary cleaning operations. Where air enters, in a nutshell, ozone can too.

- *Because it's clean*: ozone, at the concentration used in cleaning operations, leaves no residues nor toxic by-products; it doesn't stain nor fade fabrics [23].

- *Because it deodorises:* in extreme synthesis, in oxidation a molecule of ozone quickly binds to each component with which it comes into contact; among these, even those so-called *odorigenous particles*, those that the human sense of smell perceives. By breaking these down into elementary particles, the odours disappear or diminish considerably. Do you ever leave a jacket on the terrace, which maybe smells like smoke or fried food, to make it get some fresh air? What happens is that the odorigenous particles are oxidized by the oxygen present in the air. Ozone, having one more molecule, does the job much faster! The ozone is very effective especially on those chemical compounds responsible for bad odors in kitchens or in food processing plants, such as aldehydes, ketones, acids, ammonia, alcohol, sulphites, thiols, hydrogen sulphites[24].

- *Because it's economic*: ozone is generated through electrical discharge: it doesn't need any tank or any refill whatsoever. The only cost coming from its use, which is by the way ridiculous, it's the electricity power.

[23] Ozone is used industrially to bleach fabrics, but at much more massive doses than those that serve purposes in catering and foodservice in this paper described

[24] *Ozone for Food Waste and Odour Treatment, in Ozone in Food Processing*. Arvanitoyannis (2012)

How does the ozone generator work?

The ozone generator is quite user-friendly.

The air is introduced into the generator through a particulate filter first, and then a compressor. Compression dries the air, and therefore the relative humidity of this will be lower (this is good, as humidity is a vehicle of bacteria). In addition, nitrogen and humidity, combined with ozone, can generate nitric acid, which can corrode the generator[25] (and, way worse, be harmful to the workers). Same thing applied to the nitrogen dioxyde, a substance classified as "carcinogen" by the World Health Organization.

The ozone is then generated on quartz plate: this, unlike the electric tracks mounted on the cheaper models, does not deteriorate easily and has a way longer span-life.

We recommend that you place the ozone generator in the centre of the room, perhaps in an elevated position, as ozone is heavier than air.

We recommend removing or covering all materials that can be spoiled by ozone with acrylic or Teflon sheets (see table).

During the treatment, an audible / visual alarm warns the operators outside the room of the work in progress (neither people nor animals can remain inside the treated environment). Once the treatment is finished, it is highly recommended to wait another 30-60 minutes (unless the catalyst is connected), after which you can re-enter the environment by making it air further for a few minutes. This will accelerate the dissolving of ozone.

Ozone does not have an instantaneous effect. It must be left working for a period that varies according to the type of target (bactericidal, virucidal, fungicidal), and concentration. The higher the concentration, the faster the "collision" operation between the ozone molecules and the particles that you aim to oxidize[26].

In the case the catalyst is connected through the cable (which works also as electrical charge), the waiting period will be considerably shorter.

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[25] *Ozone*. Horváth, Bilitzky, Hüttner (1985)
[26] *Microbial decontamination of food using ozone*. Chawla, Kasler, Sastry and Yousef. (2012)

How long shall one make the ozone generator work?

So, let's do a few calculations to see roughly what the need for ozone can be in order to sanitize.

Take for example a restaurant lounge that can contains 50 people. That is to say 80m², approximately 240m³.

If we assume 60m³ are occupied by furniture, or internal walls, we'll have 180m³.

For 180m³, we think that, using IGO Ozone Generator with an ozone production of 10grs/h, 10 minutes will suffice. At the end of the hour, there will be approximately 9 ppm of ozone. However high the concentration may seem, referring to what has been said before, it is still non-toxic [27] and in any case, one does not get in touch for an extended period; and more, this will already be reduced after the 60 minutes in which ozone is left to work in its action (we calculate a 50% reduction in time, 30 minutes then, if the catalyst is in use). At the end of the aforementioned time and of the following phase, that is to say the ventilation of the room for about ten minutes, the concentration will drop, probably even below the odour threshold (0.02 ppm).

What we just did is basically an approximate calculation, in which we assume there's a mild temperature around 20-25˚, and a not too high relative humidity.

A study has even demonstrated that there are faster ozone decay times in the presence of wallpapers, plywood, carpeting and plaster [28].

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[27] L'ozono generato, con un alto livello di purezza (con bassa percentuale di decontaminazione di altri gas) non è tossico sotto i 20 ppm*: An investigation of the merits of ozone as an aerial disinfectant*. Eflord, Van Den Ende (1941)

[28] *Concentrations and Decay Rates of Ozone in Indoor Air in Dependence on Building and Surface Materials*. Moriske, Ebert, Konieczny, Menk, Schöndube (1998)

The use of gaseous ozone in presence of surfaces that come into contact with foodstuff

Gaseous ozone, considering its advantages listed above (it leaves no by-products, deodorises, etc.) is highly recommended in professional kitchens and food processing plants.

Ozone has a higher microbicidal charge than chlorine-based detergents[29]; said microbicidal charge is active already at relatively low gas-concentrations[30].

Furthermore, it is more effective than hydrogen peroxide (H_2O_2) on the most common bacteria in kitchen environments, such as *E-Coli* or *Bacillus Subtilis*[31].

In seafood processing plants, airborne microorganisms are significantly reduced by ozone, even at low concentrations, for a prolonged period [32].

The ozone is used as successfully for reducing the bacterial airborne charge in cured meat processing plants [33].

Very important in the disinfection and sanitization of silos or other tools dedicated to the storage of cereals, since ozone is an enemy of moulds belonging to the *Aspergillus*, *Penicillium* and *Fusarium* genera, it is capable of killing the vast majority of the infesting fungi warehouses subjected to these types of conservation[34].

A study conducted by the Italian Ministry of Health has confirmed the extraordinary value of ozone in the dairy industry: the use of gaseous ozone in the cheese maturing chambers in fact favours the elimination of moulds present in the maturing environment, and not those already present in the cheese, thus not altering the normal fermentation and maturing processes[35].

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[29] *Ozone as an alternative disinfectant*. Wysok, Uradziński, Gomółka-Pawlicka (2006)
[30] This is especially true (but not exclusively) with regard to gram-negative bacteria: *Ozone and its current and future application in the food industry*. Kim, Yousef, Khadre. (2003)
[31] *Use of ozone in the food industry*. Guzel-Seydim, Greene, Seydim. (2003)
[32] An experiment conducted in a frozen fish processing plant revealed as sufficient a concentration of 0.18ppm for 6 h, 5 times a week: *Ozone contibution in food industry in Japan*. Naito and Takahara. (2006)
[33] A research shows an effective debacterization, in Italian cured "speck" production plants, that took place at concentrations of 0.4 ppm for several hours, already effective after two weeks from the start: *Application of ozone in food industries.* Pirani (2010)
[34] *Advances in postharvest storage and handling of barley: methods to prevent or reduce mycotoxin contamination*. Jin, Schwarz (2020)
[35] *Ozone*. Horvath, Bilitzky, Hüttner (1985)

Ozone is also reliable for eradicating the most common insects in food storage places, such as beetles, ants or cockroaches; however, for this task, they are needed quite high levels of concentrations, and a period of few days of supply[36].

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[36] *The use of ozone gas for the control of insects and micro-organisms in stored products*. Isikber, Athanassiou (2014)

Which ones are the Ozone Sanitizing Cabinets from Inox Bim?

There are different types of INOX BIM ozone sanitizing cabinets: different types of work (cold or combined), dimensions, and divided into standard or professional versions.

- *Cold sanitizing cabinets*: ideal for sanitizing with ozone and storing food, just like a refrigerator of the other types in the INOX BIM list. Available with one door (in version with nominal capacity of 700 and 900 litres) and two doors (version with nominal capacity of 1400 litres).

- *Combined sanitizing cabinets*: this line combines the characteristics of the refrigerated cabinet with the possibility of heating: in practice it can go from 0˚ to 69˚C. Useful for regenerating food, for heating dishes, tools, cutlery and any object that is considered to be thoroughly cleaned, such as wipes and towels, reusable shopping bags, recycling bins, jackets and duvets, and much more Available with one door (in version with nominal capacity of 700 and 900 litres) and two doors (in version with nominal capacity of 1400 litres).

- *Neutral sanitizing cabinet*: there are two versions of this range: S (standard) and P (professional). These do not control temperature, but simply sanitize through ozone discharges. The S version is equipped with an ozone generator. The P version, in addition to this, is equipped with a forced ventilation system (which helps to uniform the flow of ozone in the cell) and a digital system which, as we will see, allows different functions such as temperature control, ozonation, the event log, the ability to monitor or change settings, even remotely.

- *Ozonized locker room cabinets*: ozonating neutral cabinets, particularly suitable for work clothes, overalls, cushions, curtains or other equipment.




How does the ozone generator work in Sanitizing Cabinets by INOX BIM?

Introductions of ozone, controlled through an analog or digital timer, are performed inside the cell, which is hermetically sealed and does not allow any gas to escape outside.

In addition, for greater safety protection, the intake fan is equipped with an FP-1 filter, i.e. filtering at least 80% of the particles of size 0.6 μm (micrometres) present in the air.

At the end of the cleaning operations, it is recommended to leave the ozone for a period of time between 30 and 60 minutes.

If connected, the catalyst will then eventually operate. It is extremely important that the air is cleaned before ozonation, as it is the microparticles present in the air that decrease the effectiveness of the catalyst[37].

In the versions where ventilation control is provided, this can be used about ten minutes before opening the cabinet, to boost the decay of the ozone still in the air.

The safety device does not allow any ozone emission with the door open, both in the S (standard) and in the P (professional) models.

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[37] *Ozone-removal efficiencies of activated carbon filters after more than three years of continuous service.* Weschler, Shlelds, Naik (1994)

How can be the Neutal Ozone Sanitizing Cabinet (IGA) be used in Catering or Foodservice?

The IGA cabinet can be used to sanitize films and other materials used for food packaging[38] (especially in the foodservice business), or containers of advanced ingredients that can no longer be stored in their original packaging, or left-overs from the kitchen.

The materials most often used for the packaging of fresh food, such as Teflon, PVC, CPVC, polyethylene and other polymers, are compatible with ozone and are not damaged by this, at least not by the concentrations generated by the cabinet (see table).

The ozonating cabinet can be used to sanitize work clothing, or pillowcases and cushions for room furnishings, as well as tablecloths, napkins and more: as specified before, ozone, in the quantities released by the sanitizing cabinet, does not spoil fabrics and, by oxidizing the particles responsible for the smell, it does make them “more fresh”.

How can be Combined Ozone Sanitizing Cabinet (IGFC) be used in Catering or Foodservice?

The combined sanitizing cabinet is equipped with both a refrigeration unit and a heating system, that can bring the temperature of the inner chamber up to approximately 69˚. This equipment, basically, can sanitize and then heat, or vice versa!

Kitchen tools can be easily sanitized, with excellent results even from low concentrations[39].

Making a list of objects that can be sanitized would take a ton of ink! We just give you some ideas:

- feeding bottles, stuffed animals and toys for children

- bunks for pets and “sand for cat” containers;

- stainless steel drawers;

- sink drains;

- air conditioner filters;

[38] *Health and Safety Aspects of Ozone Processing,* in Ozone in Food Processing. Rice (2012)
[39] *Application of ozone in food industries.* Pirani (2010)

- reusable grocery shopping bags;

- recycling bins.

- safety footwear[40].

Are Ozonization operations with Climatic Cabinet risky?

No, it does not pose any danger, because the chamber is hermetically closed, and it is not possible for ozone to get out of there (remember: ozone can only pass where air passes), and also because the quantities harmful to the worker are much bigger than what is needed for the sanitization purposes for which the Cabinet is used (see chapter "Is ozone harmful to humans?").

In the USA, the Food and Drug Administration (FDA) has officially declared the ozone as GRAS (Generally Recognized as Safe).

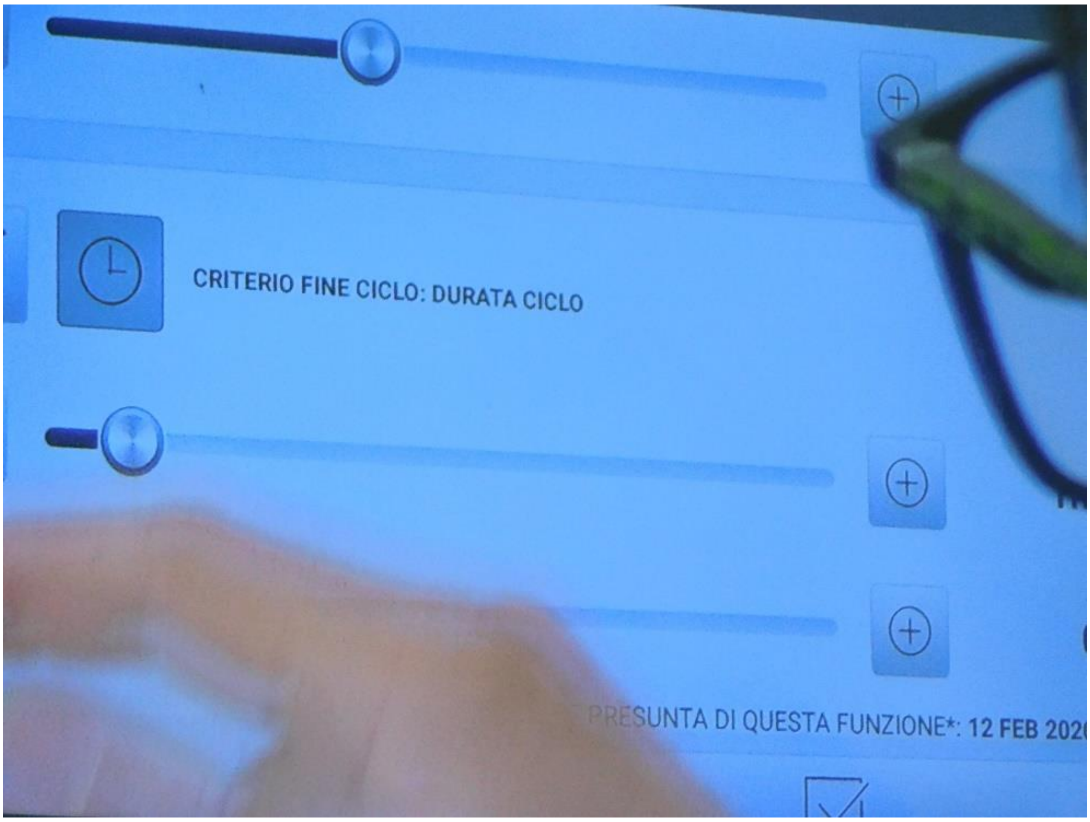
[40] Even in small quantities, ozone gas is effective in drastically reducing the pathogens of nail mycosis (onychomycosis): *Sanitization of Contaminated Footwear from Onychomycosis Patients Using Ozone Gas: A Novel Adjunct Therapy for Treating Onychomycosis and Tinea Pedis?* Gupta, Brintnell. (2012)

Why the digital control?

The refrigerated, the combined cabinets, and neutral cabinets P range (professional) are equipped with a digital control tab: this allows you to monitor the operation of the machines you own, or you are servicing. Making story short: remote control.

Basically any modification to the software, as well as the modification of parameters and programs, can be carried out remotely, whether from the reseller's warehouses, from the offices of the parent company or from the technician's smart-phone….

To do this, of course, it is necessary that the machine is connected to the internet (via Wi-fi or 3G / 4G), and that the subscription (basic or advanced) is active. No special apps are needed, nor are programs. Simply access the control screen through a common browser.



Refrigerated cabinets and ozone in food storage

There is a vast scientific literature showing that ozone does not deteriorate, nor does affect the organoleptic properties of food[41] (at least, not with the quantities needed for sanitization purposes). This even if the food is stored a short distance, up to 2 cm, from the dispenser[42].

Furthermore, it hasn't yet been found a food that is altered by a concentration lower than 1 ppm[43].

Numerous researches have highlighted the positive aspects of ozone in the conservation of fruit, vegetables, meat, fish, and dried fruit. On the following pages, you will find a table with concentrations and results for different types of products.

Ozone is, first and foremost, the ideal for removing pesticides in fresh food, at least certainly the most superficial ones[44]. The shelf-life of the foodstuff is, in many cases, augmented by the ozone[45], and most of the time this is due to the ethylene oxidization[46].

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[41] *Ozone Technology in Food Processing: A Review*. Prabha, Barma, Singh, Madan (2015)
[42] *Evaluation of ozone emissions and exposures from consumer products and home appliances*. Zhang, Jenkins (2016)
[43] *Ozone in the Food Industry: Principles of Ozone Treatment, Mechanism of Action, and Applications. An Overview*. Brodowska, Nowak, Smigielski (2017)
[44] The nature of Food Surface affects the incidence of Gaseous Ozone: *Ozone and its current and future application in the food industry*. Kim, Yousef, Khadre (2003)
[45] *Ozone in the Food Industry: Principles of Ozone Treatment, Mechanism of Action, and Applications. An Overview*. Brodowska, Nowak, Smigielski (2017)
[46] This is true especially, but not solely, for the Citrus Fruits. *Effect of ozone on qualities of fruits and vegetables in cold storage*. Skog, Chu (2001)

Gaseous ozone and fruit storage

Ozonation during fruit storage brings numerous advantages, both in terms of sanitizing the food, and extending the shelf life, compared to very few, and in any case potential, disadvantages. By sanitization we mean debacterization, as well as the elimination of pesticide residues used during cultivation.

Apples

- In an experiment on *Empire* and *Delicious* apples, the oxidation of ethylene outside the fruit significantly increased the shelf-life, leaving the ethylene content intact inside, and therefore not affecting colour, consistency, flavour and nutritional properties, over a period of 107 days, in which the fruit was stored at 1˚ C with a concentration of about 0.66 ppm[47].

- In another experiment, types of "*Royal Gala*", "*Golden Delicious*" and "*Fuji*" were stored at around 1.5° C, in a chamber ozonised at 0.82 ppm for 2 months. Ozone treatment has reduced mushroom populations and *patulin* production, making it clear, according to the researchers themselves, that ozone could be used to increase the shelf life of these varieties, keeping intact the food's quality[48].

Apricots

- A private experiment carried out at Inox Bim has shown a slowdown in the ripening of apricots with an ozone concentration of 1 ppm[49]. Shelf-life was extended to 10 days, doubling the period commonly indicated as usual[50].

[47] *Effect of ozone on qualities of fruits and vegetables in cold storage*. Skog and Chu (2001)
[48] *Ozone for post-harvest treatment of apple fruits*. Yaseen, Ricelli, Albanese, Turan (2015)
[49] Apricots were harvested, and then split in two groups: a group stored in a fridge without ozone, and another group in a fridge with an ozone concentration of 1 ppm. Temperature and humidity conditions were for both groups +4˚ C, 85% (±10%) RH.
[50] *Food Storage Guidelines for Consumers.* Boyer, McKinney (2018)

Bananas

- Enhancement of nutritional properties by 20- and 10-minutes supplies through an ozone generator with a production capacity of 8mL/s [51].

- A private experiment carried out at Inox Bim has shown that a concentration of 1ppm increases the shelf-life of bananas by at least 3 days[52].

[51] *Ozone-induced changes of antioxidant capacity of fresh-cut tropical fruits*. Alothman, Kaur, Fazilah, Bhat, Karim (2010)

[52] The bananas were purchased when already at a medium state of maturation, and then a group stored in a fridge without ozone, and another group in a fridge with an ozone concentration of 1 ppm. Temperature and humidity conditions were for both groups +4˚ C, 85% (±10%) RH.

Blackberries

- Inhibition of gray molds growth with low concentrations (up to 0.3 ppm) for 12 days in a refrigerated environment at 2 ° C, with no loss of quality [53].

Cantaloupe

- Exposure to ozone at concentrations of 4.3 ppm for 5 minutes, followed by storage for 24 hours at room temperature, led to a drastic reduction of *Salmonella Poona*[54].

Citrus fruits

- Debacterization on "Valencia" oranges and "Eureka" lemons with concentrations up to 0.3 ppm. Ozone has not reduced molds, but has delayed the occurrence of those by about a week[55].

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[53] *Ozone storage effects on anthocyanin content and fungal growth in blackberries*. Barth, Zhou, Mercier, Payne (1995)
[54] *A comparative study on the effectiveness of chlorine dioxide gas, ozone gas and e-beam irradiation treatments for inactivation of pathogens inoculated onto tomato, cantaloupe and lettuce seeds*. Trinetta, Vaidya, Linton, Morgan (2011)
[55] *Effect of Gaseous Ozone Exposure on the Development of Green and Blue Molds on Cold Stored Citrus Fruit* . Palou, Smilanick, Crisosto, Mansour (2007)

- An ozone concentration from 0.6 up to 2 ppm acts preventively on the formation of mould, drastically reducing the sporulation of *Penicillium digitatum* and *Penicillum italicum*[56].

- Experiment on lemons, exposed to 10-hour ozonation cycles at 0.3 ppm at 4.5° C for 9 weeks, followed by continuous exposure at 1 ppm at 10° C for 2 weeks. Sporulation of blue mold was reduced by the first cycle. The presence of green molds was substantially reduced by the second cycle[57].

Clementines

- Containment of grey mould growth on the product stored at 13° C with an ozone concentration of 0.16 ppm[58].

Dates

- A 60-minute treatment at 5 ppm reduces the number of *Staphylococcus aureus* and other coliform bacteria without affecting the quality of the fruit. [59].

Grapes

- Inhibition of grey mould growth (*Botrytis cinerea)* in the seedless quality *"Thompson"* thanks to a continuous ozone exposure at 0.3 ppm and storage for 7 weeks at 5˚ C and 90% RH[60].

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[56] *Ozone gas penetration and control of the sporulation of Penicillium digitatum and Penicillium italicum within commercial packages of oranges during cold storage*. Palou, Smilanick, Crisosto, Mansour, Plaza (2003).
[57] *Effect of Gaseous Ozone Exposure on the Development of Green and Blue Molds on Cold Stored Citrus Fruit* . Palou, Smilanick, Crisosto, Mansour (2007)
[58] *Deployment of low-level ozone-enrichment for the preservation of chilled fresh produce*. Tzortzakis, Singleton, Barnes (2007).
[59] *Efficacy of ozone to reduce microbial populations in date fruits*. Najafi, Khodaparast (2009)
[60] *Effects of continuous 0.3 ppm ozone exposure on decay development and physiological responses of peaches and table grapes in cold storage*. Palou, Crisosto, Smilanick Adaskaveg, Zoffoli (2002)

Kiwis

- A private experiment carried out at Inox Bim has shown a slowdown in the ripening of kiwis with an ozone concentration of 1 ppm. Shelf-life was extended to 6 weeks, one week longer than the *"control group"*[61].

Peaches

- Continuous ozone exposure at 0.3 ppm inhibited bacterial proliferation and sporulation on "*Elegant Lady*" type peaches during a 4-week storage period at 5 ° C and 90% relative humidity[62].

- A private experiment carried out at Inox Bim has shown a slowdown in the ripening of peaches with an ozone concentration of 1 ppm, +4˚, 85% (±10%) HR, compared to a control group of the same batch, stored under the same conditions but without ozone. The peaches stored in the ozone refrigerated cabinet had a shelf-life of 12 days, therefore significantly longer than the 5 days indicated as standard[63].

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[61] Kiwis were bought, and then split in two groups: a group stored in a fridge without ozone, and another group in a fridge with an ozone concentration of 1 ppm. Temperature and humidity conditions were for both groups +4˚ C, 85% (±10%) RH.

[62] Bacterial proliferation and sporulation are resumed when the product is put back into the environment: *Effects of continuous 0.3 ppm ozone exposure on decaydevelopment and physiological responses of peaches andtable grapes in cold storage*. Palou, Crisosto, Smilanick, Adaskaveg, Zoffoli (2001)

[63] *Food Storage Guidelines for Consumers.* Boyer, McKinney (2018)

Pears

- Shelf-life extension of *Anjou* and *Bosc* quality pears, up to 107 days; they were maintained at 0˚C with a RH around 95%, and ozone concentrations between 0.08 and 0.66 ppm[64].

Plums

- Containment of gray molds growth on the product stored at 13° C with an ozone concentration of 0.16 ppm [65].

Pineapple

- Enhancement of nutritional properties by 20-minutes supplies through an ozone generator with a production capacity of 8mL/s [66].

Strawberries

- Reduction of the proliferation of gray molds (Botrytis cinerea), on strawberries stored for 3 days at 2 ° C, with 2.5 ppm of ozone, and then transferred to room temperature. Reduction of weight loss and a general increase in shelf life have been noted[67].

- Effective bacterial reduction with maintenance of the nutritional properties and appearance of the fruit with an exposure of 30 minutes at 40 ppm[68].

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[64] *Effect of ozone on qualities of fruits and vegetables in cold storage*. Skog and Chu (2001)

[65] *Deployment of low-level ozone-enrichment for the preservation of chilled fresh produce*. Tzortzakis, Singleton, Barnes (2007).

[66] *Ozone-induced changes of antioxidant capacity of fresh-cut tropical fruits*. Alothman, Kaur, Fazilah, Bhat, Karim (2010)

[67] *Growth of Botrytis cinerea and Strawberry Quality in Ozone-enriched Atmospheres*. Nadas, Olmo, Garcia (2006)

[68] *Impact of food disinfection on beneficial biothiol contents in strawberry*. Demirkol, Cagri-Mehmetoglu, Qiang, Ercal, Adams (2008)

Gaseous ozone and vegetable and mushroom storage

There are several vegetables for which the effectiveness of ozone has been proven for both tasks: sterilization and shelf-life extension. Much depends on the surface of the vegetable to be ozonated, as mentioned in the previous paragraphs. instance, lettuce can have different results depending on how it is shredded[69].

Broccoli

- Extension of the shelf-life without altering the qualities, despite a browning of some parts (easily removable by the way), with a conservation of 21 days at 3˚C, about 95% RH, and an ozone concentration of 0.066 ppm[70].

Carrots

- Long product storage (6 months) at 0.5° C, and RH around 95%, with ozone concentration of 0.08 ppm, caused a slight browning of the product surface, without however having any impact on the organoleptic properties, nor on quality[71].

- Ozonation through concentrations up to 11 ppm on carrots stored at 18˚C and 80% RH has led to a reduction in pesticides still present on the surface and a consequent increase in the shelf-life of the product[72].

Cucumbers

- Shelf-life extension by reducing the bacterial load, with a 17-day storage at 3˚C, about 95% RH, and an ozone concentration of 0.066 ppm. No quality alterations, despite the treated product had a slightly dehydrated appearance[73].

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[69] *Ozone and its current and future application in the food industry*. Kim, Yousef, Khadre. (2003)
[70] *Effect of ozone on qualities of fruits and vegetables in cold storage*. Skog and Chu (2001)
[71] *Effect of a continuous low ozone exposure (50 nL L−1) on decay and quality of stored carrots*. Hildebrand, Forney, Song, Fan, McRae (2008).
[72] *Effects of ozone treatment on postharvest carrot quality*. Souza, Faroni, D'Antonino, Fernandes, Cecon, Gonçalves, Carvalho, Prates, Figuereido. (2018)
[73] *Effect of ozone on qualities of fruits and vegetables in cold storage*. Skog and Chu (2001)

Lettuce

- Exposure of the lettuce to a concentration of about 2.5 ppm ozone for 5 minutes has led to a substantial reduction in mesophilic and psychotropic bacteria, without affecting the appearance or nutritional properties[74].

- An experiment conducted on "*iceberg*" type lettuce, stored at 4˚ C with an ozone concentration of 0.2 ppm, showed that, after 7 days, the product had no colour change, unlike a sample of the same batch kept stored without ozone. Bacterial load has also been effectively reduced thanks to ozone storage[75].

- An ozonation at 4.3 ppm for 5 minutes, followed by a rest period at room temperature for 24 hours, led to an over 99.9% reduction of the *E-Coli*[76].

Mushrooms

- Shelf-life extension obtained storing the product for 14 days at 4˚C, 95% RH approximately, and an ozone concentration of 0,066 ppm. No alterations in quality or coulour were detected[77].

Onions

- The alternating ozonation between 0.05PPM during the day and 0.25PPM at night of a cold room containing onions, at a temperature of 0˚ C and a RH of around 70%, has led to a decrease in colour loss, a reduction in bacterial load, without however affecting the organoleptic properties[78].

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[74] *Use of ozone to inactivate microorganisms on lettuce*. Kim, Yousef, Chim (1999)
[75] *Application of ozone in fresh-cut iceberg lettuce refrigeration*. Galgano, Condelli, Caruso, Stassano, Favati. (2015)
[76] *A comparative study on the effectiveness of chlorine dioxide gas, ozone gas and e-beam irradiation treatments for inactivation of pathogens inoculated onto tomato, cantaloupe and lettuce seeds*. Trinetta, Vaidya, Linton, Morgan (2011)
[77] *Effect of ozone on qualities of fruits and vegetables in cold storage*. Skog and Chu (2001)
[78] *Biological Effects of Corona Discharge on Onions in a Commercial Storage Facility*. Song, Fan, Hildebrand, Forney (2000)

Spinach

- Slight reduction in bacterial load with exposure to 40 ppm for one hour [79].

Tomatoes

- Extension of shelf-life, and quality improvement proven by a "blind test", on tomatoes stored at 13 ° C and 95% RH, with ozone concentrations from 0.005 to 1 ppm[80].

- An ozone treatment on "*cherry*" type tomatoes, at high concentration (45 ppm) for 15 minutes, completely inactivated the *Salmonella bacterium*, without affecting the properties of the product[81].

- An ozonation at 4,3 ppm for 5 minutes, followed by a rest period at room temperature for 24 hours, led to an over 99.9% reduction of the *Salmonella Poona*[82].

- An ozonation carried out for 5, 10 and 20 minutes at 10 ppm, followed by a storage period at 20° C and 95% RH for a total of 9 days, led to a reduction in the weight loss of the fruit, keeping intact the consistency, with an unchanged quality and external appearance[83].

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[79] *Impact of food disinfection on beneficial biothiol contents in vegetables*. Qiang, Demirkol, Ercal, Adams (2005)
[80] *Impact of atmospheric ozone enrichment on quality-related attributes of tomato fruit*. Tzortzakis, Borland, Singleton, Barnes (2007).
[81] *Effect of controlled atmosphere storage, modified atmosphere packaging and gaseous ozone treatment on the survival of Salmonella Enteritidis on cherry tomatoes*. Das, Gurakan, Bayindirli. (2006)
[82] *A comparative study on the effectiveness of chlorine dioxide gas, ozone gas and e-beam irradiation treatments for inactivation of pathogens inoculated onto tomato, cantaloupe, and lettuce seeds.* Trinetta, Vaidya, Linton, Morgan (2011)
[83] *Effect of short-term ozone treatments on tomato (Solanum lycopersicum L.) fruit quality and cell wall degradation*. Rodoni, Casadei, Concellon, Alicia, Vicente (2010)

Gaseous ozone and dried food storage

Ozone is effective on debacterization of flours and spices, although at high concentrations, which are sometimes difficult to obtain through a cabinet not used for scientific studies[84].

Buckwheat (Flour)

- A treatment of 60 minutes at 10 ° C has shown a substantial reduction of *thermophilic* and *mesophilic* bacteria, as well as of some types of fungi, already at concentrations between 0.5 and 2 ppm. The bacterial load remains low even after the flour is packed in plastic bags used for commercial use[85].

Dried Figs

- A continuous ozonization of 1 ppm for 360 minutes is sufficient to drastically reduce the population of *Escherichia coli* and *Bacillus cereus* in dried figs. During the experiment, the product was placed in a chamber at 20° C, with a relative humidity of 70%. No significant changes were observed in the colour, pH, and moisture content of the dried figs after the ozonization treatments, nor significant changes in sweetness, rancidity, taste and appearance[86].

- An exposure of 7 minutes and 30 seconds at a concentration of 13.8 ppm is sufficient to eliminate completely *E-Coli*, and also to reduce *aflatoxin B1* and *coliform bacteria* by 48%[87].

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[84] Usually, said concentrations are over 40ppm: *Ozone and its current and future application in the food industry*. Kim, Yousef, Khadre. (2003)

[85] *Changes in Microflora of Ozone-treated Cereals, Grains, Peas, Beans and Spices during Storage*. Naito, Okada, Sakai (1988)

[86] *Application of Gaseous Ozone to Control Populations of Escherichia Coli, Bacillus Cereus and Bacillus Cereus Spores in Dried Figs*. Akbas, Ozdemir. (2008)

[87] *The influence of gaseous ozone and ozonated water on microbial flora and degradation of aflatoxin B(1) in dried figs*. Zorlugenc B, Zorlugenc FK, Oztekin, Evliya (2008)

Green pepper

- Experiment conducted on two groups of samples, ozonated with concentrations of 2 and 8 ppm, for 10 and 40 minutes, at a RH of 60 and 90%, in both cases with a temperature of 22˚C: the *E-coli* bacterium has been substantially inactivated[88].

Oregan

- Experiment with continuous ozone jets at concentrations of 6 and 11.3 ppm for 30, 60 and 120 minutes. A substantial reduction in *Salmonella* already at lower concentrations, without any change in the smell or taste of the product[89].

Rice

- An experiment has shown an effective reduction of *Bacillus Cereus* with an exposure to 0.4 ppm of ozone in an environment of 20˚ (± 3˚) with a relative humidity of 50%[90].

Sultana grapes

- Continuous exposure of sultanas to concentrations close to 28 ppm for 2 and 4 hours led to a good reduction in *type A Ochratoxin* (60.2% and 82.5% respectively) without any significant reduction in phenolic compounds or other nutrients[91].

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[88] *Response surface modelling for the inactivation of Escherichia coli O157: H7 on green peppers (Capsicum annuum) by ozone gas treatment*. Han, Floros, Linton, Nielsen, Nelson (2002)
[89] *Efficacy of gaseous ozone against Salmonella and microbial population on dried oregano*. Torlak, Sert, Ulca (2013).
[90] *Application of gaseous ozone to inactivate Bacillus Cereus in processed rice*. Karim Shah, Abdul Rahman, Ling Tau Chuan, Mat Hashim.
[91] *Use of gaseous ozone for reduction of ochratoxin A and fungal populations on sultanas*. Torlak (2018)

Gaseous ozone and meet and animal products storage

Ozone is mainly used in meat *dry-ageing*, a process in which ozone effectively controls the formation of mold and bacteria in the cold storage rooms; doing so, the humidity can be kept at a higher degree, reducing then both weight and aroma losses. What has to be avoided in the ozonation of meat (especially red meat) is that of excessive oxidation of lipids or fatty acids[92].

Duck

- An experiment has shown that an ozone injection of 15 minutes every two hours (4.9 ppm per injection), in a total of 4 days, has led to an extension of the shelf-life of the product through a sustained reduction of the bacterial load; however, it was a slight change in the color of the meat, due to the oxidation of the lipids[93].

Cheese

- A study demonstrates the inhibition of mold growth on *Cheddar* type of cheese at concentrations of 0.3 ppm, without these having had an influence on reducing its characteristic odour[94].

- A research has evaluated the possibility of holding the growth of the bacterium *Listeria monocytogenes* on *Ricotta Salata, Gorgonzola DOP* and *Taleggio DOP*. On these, an ozone treatment was carried out at 4 ppm for 8 minutes. On *Ricotta Salata*, the use of ozone has proved to be able to substantially reduce contamination even after 7 days of storage in refrigerated conditions. For *Taleggio* and *Gorgonzola*, the effectiveness of the treatment was satisfactory respectively at 6 and 3 days of seasoning, while in later times the effectiveness on the elimination of bacteria has decreased[95].

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[92] *Ozone in Meat Processing*, in Ozone in Food Processing. Pohlman (2012)
[93] *Effects of Gaseous Ozone Exposure on Bacterial Counts and Oxidative Properties in Chicken and Duck Breast Meat*. Muhlisin, Utama, Ho Lee, Choi, Ki Lee. (2016)
[94] *Ozone for controlling mold on Cheddar cheese*. Gibson, Elliot, Beckett (1960).
[95] *Impiego di ozono per il controllo di Listeria monocytogenes in diverse tipologie di formaggio*. Morandi, Brasca, Lodi, Battelli. (2009)

- The use of ozone in a *Parmigiano Reggiano* ripening chamber, at concentrations of 0.24ppm, has contributed to a reduction in bacteria on the surface of the edible product, as well as in the environment (more than 99.9%)[96].

Beef

- A treatment of the beef carcass at low concentration (0.03 ppm), in conditions of 1.6° C at 95% RH, has demonstrated the reduction of the bacterial load on the carcass, not affecting neither smell nor taste, although this increased the layer of "blackened" meat to be discarded[97].

Poultry

- The ozone treatment of smoked chicken in Japan for the preparation of chicken rolls, at concentrations between 0.3 and 0.8 ppm, led to excellent results in terms of bacterial reduction[98].

- Continuous treatment with gaseous ozone on poultry, for 13 days, at high concentration (40 mg/h) for 13 days, at a temperature of about 2° C and a relative humidity around 93%: ozone inhibited the growth of the superficial bacterial flora, *E-Coli* and *Salmonella* above all, without any negative effect on the sensorial quality of the product[99].

- The effects of treatment with gaseous ozone on bacterial proliferation and the shelf life of chilled boneless chicken breasts and the impact on quality from the point of view of color, odor and consistency were studied. Treatment at concentrations of 40, 60 and 70 ppm for 20 minutes effectively reduced the number of bacteria and mold, and prolonged the shelf life of the chicken breast for longer than 9 days, without negatively affecting colour, smell, and its structure[100].

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[96] *Use of ozone to control fungi in a cheese ripening room*. Pinto, Schmidt, Raimundo, Raihmer (2007).
[97] *Effects of Ozone on Beef Carcass Shrinkage, Muscle Quality and Bacterial Spoilage*. Greer, Jones (1989)
[98] *Ozone contibution in food industry in Japan*. Naito and Takahara. (2006)
[99] *Effect of ozone on bacterial flora in poultry during refrigerated storage*. Nieto, Jiménez-Colmenero, Pelaez (1984)
[100] *Effect of ozone on preservation of chilled chicken*. Hafez, El Dahshan, El Ghayaty (2013)

- An experiment has shown that a system of 15 minutes injections every two hours (4.9 ppm per injection), in a total of 4 days, has led to an extension of the shelf-life of the product by means of a sustained reduction of the bacterial load, and negligible lipid oxidation[101].

- A treatment with a concentration between 0.44 and 0.54 ppm, prior to storage in a refrigerated cabinet at 3˚ C, carried out on chicken thighs, marked an effective reduction in bacteria and an increase of at least two days of shelf-life[102].

Pork

- An experiment showed how, in the maturation of pork sausages of the "Milano" type (70% pork meat, 25% pork fat), in which *Penicillium italicum* was used as a starter, the ozonization of 8 hours a day at 0.5 ppm during the maturation period led to a drastic reduction of dark spots due to various moulds[103].

- The ozonization at 0.4 ppm during the night hours, carried out in different Speck ripening chambers for a two months period, showed a substantial reduction of *Tyrophagus putrescentiae* and *T. longior* mites, and the absence of traces of mould for at least one month after the end of the treatment[104].

Eggs

- The debacterization by ozone of egg shells (especially from *Salmonella*) without alteration of the properties of the product, has been demonstrated by many studies[105].

- An experiment shows how three different degrees of ozonation, at 2, 4 and 6 ppm, carried out for both 2 and 5 minutes, allowed a storage period of 6 weeks at room temperature around 24˚ C; the nutritional properties of the product have remained intact. Especially the concentration at 4 ppm, which has left no visible marks on the shell, unlike that at 6 ppm[106].

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[101] *Effects of Gaseous Ozone Exposure on Bacterial Counts and Oxidative Properties in Chicken and Duck Breast Meat*. Muhlisin, Utama, Ho Lee, Choi, Ki Lee. (2016)
[102] *Ozone and improvement of quality and shelf life of poultry products*. Jindal, Waldroup, Forsythe (1995)
[103] *Application of ozone in food industries.* Pirani (2010)
[104] *Application of ozone in food industries.* Pirani (2010)
[105] *Microbial decontamination of food using ozone*. Chawla, Kasler, Sastry and Yousef. (2012)
[106] *Ozone treatment of shell eggs to preserve functional quality and enhance shelf life during storage*. Yucer, Aday, Caner. (2015)

- A group of researchers stated it hasn't been proved yet that exposures at concentrations below 50ml / l (over 18000 ppm) can alter the nutrients of the yolk and egg white[107].

[107] *The effect of gaseous ozone treatment on egg components*. Fuhrmann, Rupp, Buchner, Braun (2009)

Gaseous ozone and seafood storage

Ozone is also successfully used in the conservation and drying process of fish. Unlike chlorine-based disinfectants, active only on some specific enzymes, ozone acts as a general oxidizing agent[108].

In general, storing seafood at a temperature between 1 and 3° C with humidity percentages around 90%, combined with ozone in a gaseous state in concentrations between 2.5 and 3 ppm, leads to an increase in the product shelf-life and a reduction in bacterial growth and bad smells[109].

Squid

- An experiment has demonstrated an effective reduction of bacteria and fungi (such as *micrococcus* and *candida*) on smoked squid, thanks to ozonization treatments up to 1 ppm[110].

Atlantic horse mackerel

- The treatment carried out on the common Atlantic Horse Mackerel (Trachurus trachurus) has demonstrated an effective reduction of bacteria on the surface, and a consequent increase in shelf-life[111].

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[108] *Ozone in the Food Industry: Principles of Ozone Treatment, Mechanism of Action, and Applications. An Overview*. Brodowska, Nowak, Smigielski (2017)
[109] *Ozone - an Emerging Technology for the Seafood Industry*. Gonçalves (2009).
[110] *Ozone treatment of broiling squid for storage*. Naito (1986)
[111] *Microbial decontamination of food using ozone*. Chawla, Kasler, Sastry and Yousef. (2012)

Ozone and Material Corrosion

INOX B.I.m. KITCHEN EQUIPMENT

MATERIAL COMPATIBILITY WITH GASEOUS OZONE

MATERIAL	EXCELLENT RESISTANCE (NO TRACE OF EVIDENT CORROSION EVEN OVER THE LONG PERIOD)	GOOD RESISTANCE (MINIMUM VISUAL EFFECTS OF DECOLORATION OR LIGHT CORROSION OVER THE LONG PERIOD)	MODERATE RESISTANCE (THE MATERIAL MAY BE AFFECTED BY CONTACT WITH OZONE IF SUBJECT TO DAILY OPERATIONS)	SCARCE RESISTANCE (CONTACT WITH OZONE IS NOT ADVISED)
ABS (Thermoplastic)		X		
Acrylic fiber		X		
Aluminium		X		
Brass		X		
Bronze		X		
Butyl rubber	X			
Carbon steel			X	
Cast iron			X	
Copper		X		
CPVC	X			
Crosslinked polyethylene (Pe-X)	X			
Elastomere Hytrel			X	
EPDM rubber		X		
Ethylene propylene rubber (EPM)	X			
Fluorosilicone	X			
Glass	X			
Gold	X			
Hastelloy	X			
High-density Polyethilen	X			
Hypalon rubber			X	
Inconel alloy	X			
Kalrez (often used for sealing)	X			
Low-density Polyethilene (LDPE)		X		
Natural rubber				X
Neoprene			X	

MATERIAL	**EXCELLENT RESISTANCE** (NO TRACE OF EVIDENT CORROSION EVEN OVER THE LONG PERIOD)	**GOOD RESISTANCE** (MINIMUM VISUAL EFFECTS OF DECOLORATION OR LIGHT CORROSION OVER THE LONG PERIOD)	**MODERATE RESISTANCE** (THE MATERIAL MAY BE AFFECTED BY CONTACT WITH OZONE IF SUBJECT TO DAILY OPERATIONS)	**SCARCE RESISTANCE** (CONTACT WITH OZONE IS NOT ADVISED)
Nitrile				**X**
Nylon				**X**
Ordinary steel				**X**
Polyacrylate		**X**		
Polyamide			**X**	
Polycarbonate	**X**			
Polychlorotrifluoroethylene (PTFCE)	**X**			
Polyether ether ketone PEEK	**X**			
Polyethilene		**X**		
Polypropylene			**X**	
Polysulfides		**X**		
Polyurethane	**X**			
PTFE (also known as: Teflon, Fluon, Algoflon, Hostaflon, Inoflon)	**X**			
PVC		**X**		
PVDF (also known as: Solef, Hylar, Kynar, Sygef)	**X**			
Santoprene	**X**			
Silicone	**X**			
Silver	**X**			
Stainless steel of austenitic type(eg: AISI 304 e 316)	**X**			
Stainless steel of non-austenitic type (es: AISI 430)		**X**		
Titanium	**X**			
Zinc				**X**

Source: Cole-Parmer, rivately held scientific and industrial instrument distributor based in USA; "Handbook of Corrosion Data", Bruce D. Craig, David S. Anderson, 1995

The above table is merely indicative. INOX BIM declines all liability.