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Understanding Ozone:

Emissions and Remediation in the Ventiva ICE9™ Thermal Management Systems

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1. Overview

As the Ventiva® ICE9™ thermal management systems gain broad consumer adoption, questions have arisen regarding ozone emissions from products using the company's patented Ionic Cooling Engine (ICE®) technology. Emissions from ICE9 solutions are well below the limits established by regulatory agencies and standard-setting organizations. This document provides an overview of ozone, its effects, methods of measurement, and how Ventiva addresses and mitigates ozone emissions.

2. Sources of Ozone

Ozone (O_3) is a molecule composed of three oxygen atoms, distinct from the more common diatomic oxygen (O_2) found in the atmosphere. While ozone exists naturally in the air, the highest concentrations are found in the earth's upper atmosphere, where it plays a critical role in shielding the planet from harmful ultraviolet (UV) radiation.

At ground level, ozone forms naturally through photochemical reactions involving sunlight and oxygen-containing molecules. UV radiation from the sun splits oxygen molecules (O_2) into individual oxygen atoms (O), which then combine with other O_2 molecules to form ozone. Additional ozone is produced as a byproduct of chemical reactions involving volatile organic compounds (VOCs) and nitrogen oxides (NOx_xx), emitted from both natural sources (plants, soil, and wildfires) and human activities (pollution). Appendix A provides charts illustrating naturally occurring ozone levels in various urban and rural areas worldwide.

Ozone can also form through electrical discharges, often identified by its distinct smell, which people describe as "the smell of electricity." This odor is commonly detected near electric motors, high-voltage lines, or after lightning storms. Many commercial products, such as vacuum cleaners, laser printers, and copiers, generate small amounts of ozone, a practice in use for over a century.

In ICE technology-enabled products, ozone is generated as a byproduct of the cooling process when the corona-generating electrode is energized. This occurs only while the coronas are active and not when the ICE9 device is off. Ozone is an unstable gas that reverts to oxygen, leaving no residual byproducts.

3. Effects of Ozone and Regulations around it

The ability to detect ozone varies significantly among individuals, as does their sensitivity to its effects. In general, the longer the exposure duration, the lower the permissible exposure level. Appendix B details the relationship between ozone concentration and duration of exposure in humans.

In high concentrations, ozone can cause irritation to the eyes, nose, throat, and lungs. Symptoms may include headaches, dryness, and discomfort. At low concentrations, ozone has a sweet smell, but at higher concentrations, it becomes pungent.

Ozone produced by ICE9 solutions has a short lifespan, decomposing into oxygen rapidly. In typical office or home environments, ozone concentrations dissipate within minutes after the ICE9 device is turned off. The devices are specifically engineered to maintain ozone levels well below thresholds set by global regulatory authorities. The table below summarizes these limits:

Ozone Level Targets and Recommendations (in ppm)

OSHA	NIOSH	FDA	EPA	CARB	ECMA
0.100	0.100	0.050	0.080	0.070	0.100

4. Spatial Distribution of Ozone around ICE9

ICE technology propels ionized air in a controlled, nominally straight line from the collector side of the air mover. As the air exiting the ICE9 device diffuses, ozone concentration decreases rapidly with distance from the device. Additionally, as ozone is unstable, it naturally reverts to oxygen over distance.

For example, concentrations decrease by a factor of four within 400 mm from the device. Ionization levels are highest near the center of the air mover and diminish at wider angles and farther distances. Figure 1 below illustrates the dramatic reduction in ozone concentration as a function of distance and angle relative to the ICE9 device. This is the unmitigated level of ozone from the ICE9 device.

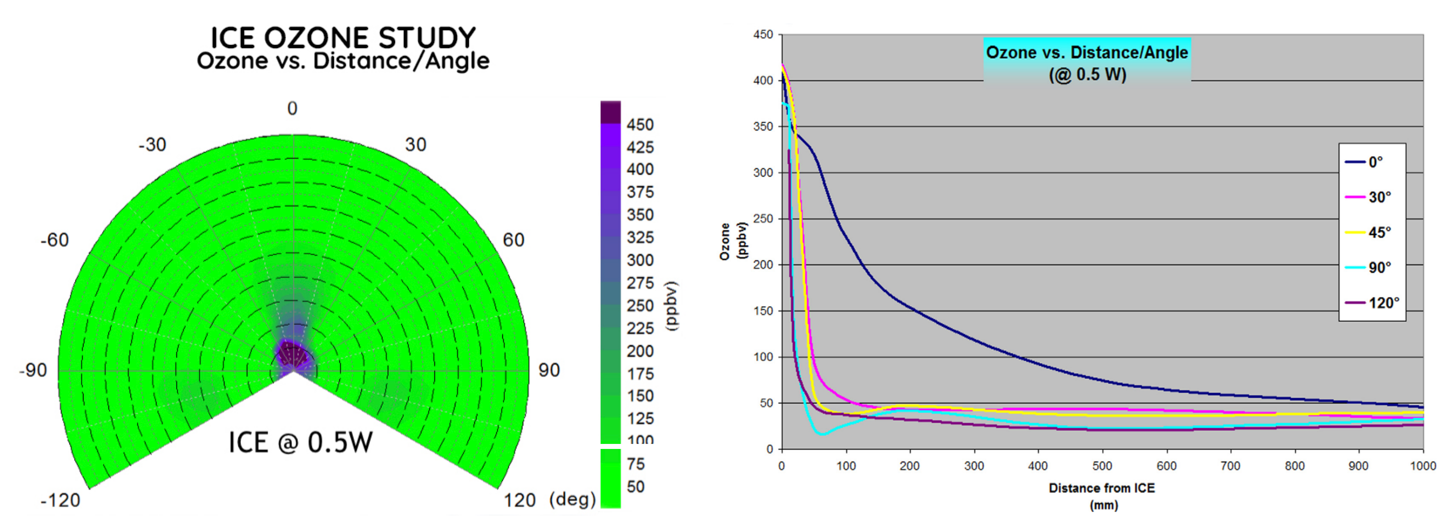

Figure 1: Ozone concentration at the exit of the ICE device measured as a function of distance and angle shown in two different ways.

5. Ozone Removal Techniques

Ozone is a highly unstable gas that naturally decomposes over time. However, in specific situations, it may be desirable to accelerate its removal. To address this, Ventiva has developed efficient catalytic decomposition techniques for converting ozone gas back to oxygen gas under ambient conditions.

Ventiva uses **manganese dioxide (MnO_2)** as a catalyst to expedite ozone decomposition. A catalyst increases the rate of a chemical reaction without being consumed in the process. MnO_2 is a well-known, cost-effective, and robust material for ozone removal. It can be applied in various forms directly to surfaces in contact with ionized air.

5.1 MnO_2 Application in Ventiva-Based Systems

Ventiva incorporates MnO_2 by coating honeycomb structures or heat sinks positioned at the outlets of ICE9 devices. These structures vary in porosity to optimize performance for ozone removal. In the case of laptop application, Ventiva has developed a technology to utilize the thermal module fins to act as both heat removal and ozone removal surface. The catalyst can also be applied to other surfaces, such as the outlets grills or surfaces. These design decisions are left to the discretion of the OEM.

Figure 2 shows a thermal module with its fins coated with the MnO_2 catalyst.

Figure 2: Thermal module with the fins stack coated with MnO_2 (Shown in black).

The efficiency of ozone destruction is influenced primarily by the airflow rate from ICE9 devices. At lower flow rates, the “dwell time” of ionized air on the catalyst increases, enhancing conversion rates. This is particularly useful for systems where the catalyst is positioned at a distance from the ICE9 device. Furthermore, multiple catalyst-coated surfaces can be employed in a single system to achieve higher levels of ozone destruction as required.

6. Ventiva's Ozone Emission Testing and Analysis

Ventiva rigorously characterizes the ozone emissions of all ICE9 devices. These devices are tested in controlled environmental chambers, where ozone emission rates are directly measured. The results are used to calculate the expected ozone concentration in an ambient environment with low air ventilation but high device usage. These concentrations are then compared to global occupational exposure limits and stricter indoor air quality guidelines, such as the U.S. OSHA Permissible Exposure Limit of 0.1 parts per million (ppm) as shown in **figure 3**.

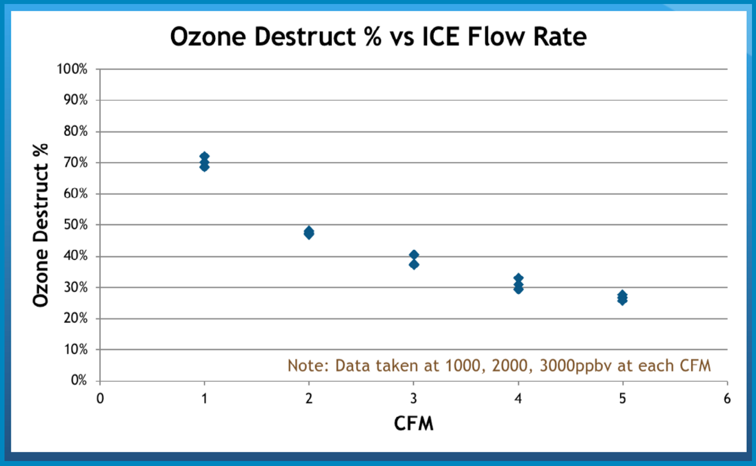

Figure 3: Ozone destruct rates from a typical "heat sink" in a laptop. The expected flow rate during operation is about 1 CFM, with about 70% efficacy in ozone removal.

In all configurations tested, after the catalytic intervention provided by the thermal module or other similar structures, Ventiva's ICE9 technology demonstrated ozone emissions significantly below all known targets and recommendations. The table below summarizes average ozone emission levels for different scenarios:

6.1 Average Ozone Emission Levels for ICE9 Devices

	Number of Devices with ICE™	Operating Hours	Exposure Hours	Room Volume m^3	Average Ozone ppm
Office	4	8	24	32	.008
Public place	12	8	24	185	.004
Bedroom	2	3	24	32	.002
Living Room	4	4	24	213	.001

Notes:

1. These results are based on the UL exposure model, a one-box model accounting for mechanical ventilation and variable usage patterns for different equipment types. Dilution into adjacent rooms and ozone decay due to reactivity are not included in this analysis.
2. Tests were conducted with ICE9 devices operating at 1 Watt.
3. Data and analysis were performed by Air Quality Sciences Inc., an ISO 17025-accredited indoor air quality company.

6.2 Detailed Testing for Laptops

Ventiva also performs detailed laptop-level ozone emission tests in compliance with the European Union's ECMA (ISO 16000-9) chamber standards. In one example, a laptop was equipped with three ICE9 devices operating to cool a 20 W TDP CPU based laptop utilizing the thermal module shown earlier. Testing was conducted in a closed room (12 ft x 12 ft x 9 ft) with a ventilation rate of 0.5–1.0 exchanges per hour, as specified by the ECMA standard. The room temperature was maintained at 73°F (23°C) with relative humidity of 47% RH.

The sampling inlet of the ozone monitor was positioned 16 inches above the table edge to simulate a person sitting and using the laptop. Eight hours average data was about 30 ppBv, well below the most stringent limit by any regulatory body. Detailed data is available upon request.

Figure 4: Test setup as per ISO 16000-9 test standard for a laptop. Tests performed at an accredited third party laboratory.

Conclusion

Ozone is naturally present in the air and is also produced by many types of products in common use: from laser printers to vacuum cleaners. Ozone quickly reverts to oxygen and leaves no residual element. Ventiva's ICE9 thermal management system produces some ozone when operating but has been designed and thoroughly tested to exceed the most rigorous standards for safe indoor ozone levels and air quality.

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Appendix A

Surface Ozone Concentration (PPBV) at Various Worldwide Locations

It is useful to compare typical “background” ozone levels against ozone producing devices. Data varies by location and ground level ozone is present in rural as well as urban areas, irrespective of the other air borne ground pollution. In many locations, pre-existing background ozone (i.e. ozone already present) may be substantially higher than any ozone produced by an operating ICE9 device.

Figure A.1 shows average rural measurements from various countries around the world. Since ozone level changes depending upon the season, in some months, the actual eight hour ozone levels are significantly higher than these numbers.[1]

Figure A.2 shows the ozone levels in Seoul, South Korea over the entire year. Many of the locations in the US have even worse levels of ozone. Please note that 1 ppm = 1000 ppbv, i.e. the outdoor ozone level is up to 0.07 ppm in April and May timeframe[2].

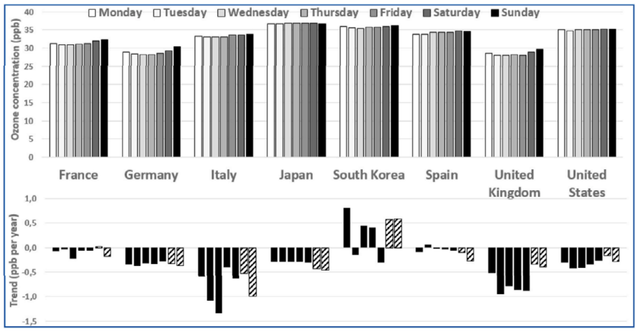

Fig. 1. Averaged daily ozone mean concentrations (ppb) and annual significant trends (ppb per year, at $p < 0.05$) calculated by joining daily data from rural monitoring stations over the time period 2005–2014. The striped histograms represent the trends during weekends (Saturday and Sunday). No rural station in Canada met the selection criteria at $p < 0.05$.

Figure A.1 Average daily ozone data from various locations around the world.

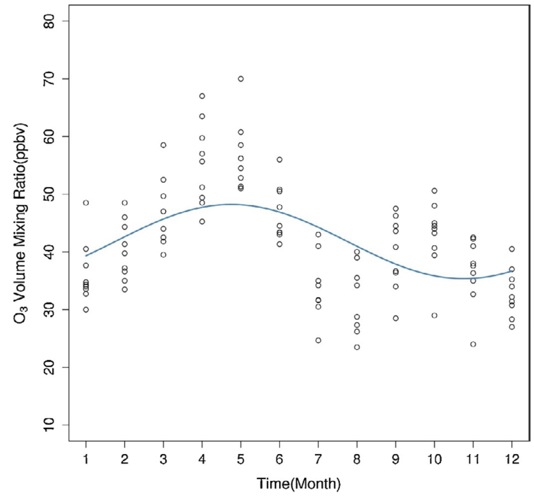

Figure A.2: Monthly averaged surface O_3 concentrations in the South Korea (circles) over 10 years. (2005–2014) and its fitted curve (line) to a sine function.

[1] Sicard P, Paoletti E, Agathokleous E, Araminienė V, Proietti C, Coulibaly F, De Marco A. Ozone weekend effect in cities: Deep insights for urban air pollution control. Environ Res. 2020 Dec;191:110193. Available for download here

[2] Hyun-Chae Jung, Byung-Kwon Moon, Jieun Wie. Seasonal changes in surface ozone over South Korea. Heliyon 4 (2018) e00515. doi: 10.1016/j.heliyon.2018. e00515)

Appendix B

Effect of Prolonged Exposure of Ozone to Humans

Prolonged exposure to ozone can have mild to moderate effects on human health, particularly on the respiratory system. Higher concentrations of ozone may cause temporary irritation in the eyes, nose, and throat, along with coughing or discomfort in the chest for some individuals, especially those with preexisting respiratory conditions such as asthma. Overall, maintaining ambient ozone levels within regulatory guidelines helps minimize these potential health impacts and supports general well-being. The chart below shows that the accepted exposure time is inversely proportional to exposure time. Ozone level generated by ICE9 is well within the lower bounds of the non-symptomatic region and should not be of any concern.

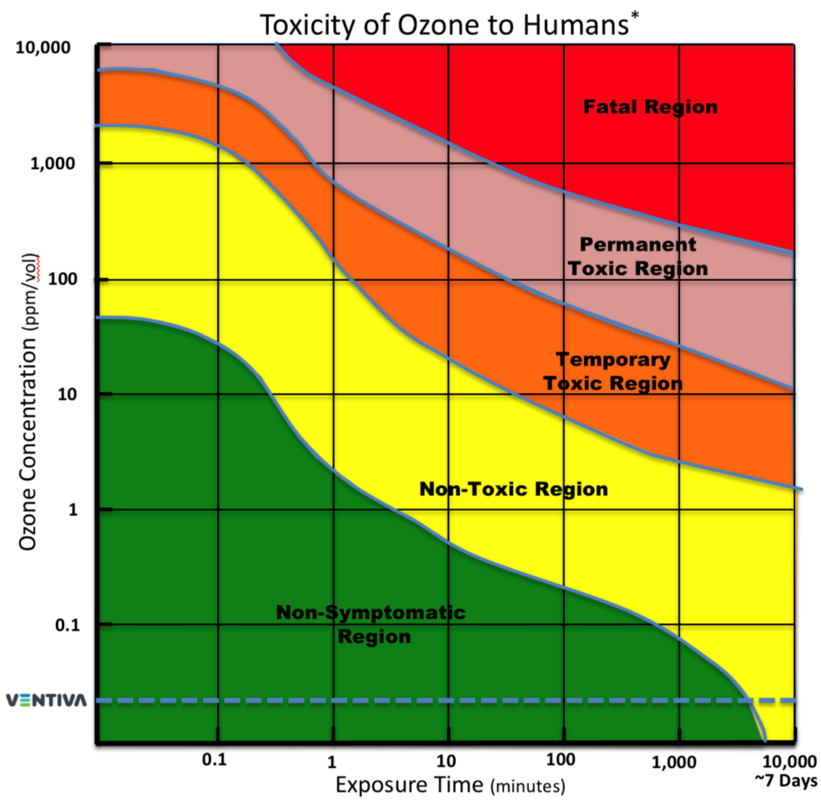

Figure B.1: Human tolerance chart for Ozone as proposed by Lagerwerff[3].

[3] LAGERWERFF JM. Prolonged ozone inhalation and its effects on visual parameters. Aerosp Med. 1963 Jun;34:479-86. PMID: 13928063.