Development of a novel sanitization method for aircraft lavatory

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Abstract— *Evaluating the efficacy of aqueous ozone as a disinfectant in the field of aviation and its potential to replace traditional chemical disinfectants is a major task. Aqueous ozone is a sustainable and environmentally friendly disinfection solution that rapidly inactivates a wide range of microorganisms, including bacteria, viruses, fungi, and protozoa. Through a comparative analysis, the research found that aqueous ozone offers several benefits over conventional chemical disinfectants in terms of broad-spectrum antimicrobial activity, extended disinfection capabilities, and eco-friendliness. The study proposes the development of a compact, portable aqueous ozone generator specifically designed for use within aircraft lavatories, which serve as environments with an intensified presence of pathogens, necessitating effective disinfection measures. The research concludes that aqueous ozone is a promising disinfectant for aircraft lavatories, providing an efficient and sustainable solution for maintaining high levels of hygiene and minimizing the risk of microbial transmission and a portable aqueous ozone generator will be a better system to apply. However, practical considerations such as equipment requirements, operational protocols, and regulatory compliance need to be addressed for successful implementation. Overall, this research highlights the potential of aqueous ozone as a replacement for chemical disinfectants in aircraft lavatories, suggesting its adoption can lead to improved hygiene standards and enhanced passenger health-related safety.*

*Keywords***—** *Aqueous ozone, Aircraft lavatory*.

I. INTRODUCTION

The aviation industry faces several challenges in the means of passenger safety within the calibre of the international level. A survey conducted by the IATA in 2020 April establishes that 45% of respondents willingly postpone their travel by air since the covid outbreak, and their willingness to travel by air significantly decreased (IATA, 2020). After facing the deadly coronavirus outbreak, the aviation industry is fully concerned about hygienic attributes with new disinfection regulations, and many airlines have put increased sanitizing precautions into operation and redesigned their standard disinfecting procedures, especially concentrating on key touchpoints such as lavatories, so they can get passengers fly again in a healthy manner.

Aircraft lavatories are compact, yet functional spaces designed to meet the hygiene and comfort needs of passengers during air travel. Despite their limited dimensions, lavatories are thoughtfully designed to optimize space utilization, accessibility, and safety. They incorporate essential amenities and features that promote hygiene, waste management, and passenger convenience. Aircraft lavatories will likely incorporate even more innovative features as aviation technology advances. Models and configurations of aircraft can affect the dimensions of the lavatory.

A lavatory's capacity will be limited to less than 2 cubic meters. The standard dimensions of an aircraft lavatory restrict

a. Width = 0.9 meters
b. Depth = 1.2 meters
c. Height = 1.8 meters

These dimensions are optimized to accommodate passenger comfort while ensuring efficient use of space within the aircraft cabin (Airbus, 2021).

II. LITERATURE REVIEW

Alcohol, the most used disinfection in aviation works by acting directly on S-H functional groups to break cellular membranes, and solubilize lipids, and denaturant proteins. For their biocidal effect, ethyl and isopropyl alcohols are the most often utilized alcohols. These alcohols are efficient against lipid-containing viruses and a wide range of bacteria, but not against spore-forming bacteria.

Table 1: The summary of previous research related to the topic.

Research	***Areas***	***Findings***
Alcohol disinfection in aviation (Curran, 2019)	*Ethyl and isopropyl alcohols are effective against viruses and bacteria, but not spore-forming bacteria.*	*Limited effectiveness against spore-forming bacteria.*
Health risks of chemical disinfectants (Makatimed, 2020)	*Improper use of chemical disinfectants can cause health hazards, including skin/eye irritation, respiratory conditions, light-headedness, and asthma.*	*Risks of disinfectant materials such as alcohols in specific environments like aircraft lavatories.*
Efficacy of ozone disinfection (Makatimed, 2020; Martinelli, 2017)	*Ozone is highly efficient against bacteria, fungi, and viruses on surfaces and in the air. Ozone acts through oxidation, effectively killing microorganisms.*	*Exploration of ozone as a safe disinfectant for practical implementations.*

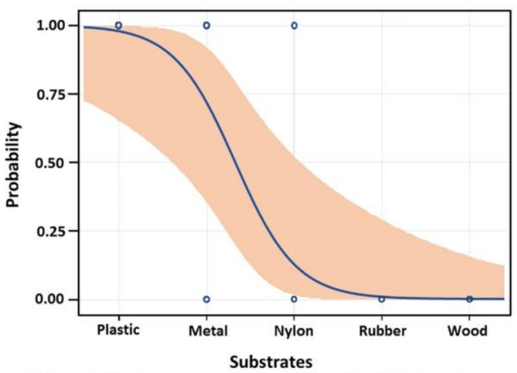

Figure 1: Probability plot for the ability of aqueous O3 of 4 ppm for 4 minutes exposure to decrease bacteria load with 5-log$_{10}$ on different materials. The curve shows the probability of 5-log $_{10}$ bacteria reduction for each material with a 95% confidence interval for the probability (Ameer Megahed, 2018).

III. METHODOLOGY

Ozone, tri-atomic oxygen has proven to be the most efficient against bacteria, fungi, and disarming viruses both on the surfaces and in the air (Oriana Motta, 2021) Ozone (O3) is a highly reactive gas that can be used for disinfection and sterilization. The mechanism by which ozone kills microorganisms is through oxidation, meaning that ozone chemically reacts with the cell membrane, nucleic acids, and other cellular components of microorganisms. Ozone will be an effective alternative for virucidal purposes, as it can infiltrate into the entire room spaces and even it can disinfect the surrounding air since it has a powerful oxidant. (Martinelli, 2017).

Table 2: Comparison of ozone and other chemicals

Disinfectant	***Inactivation (mg. min/L)***		
	1-log	***2-log***	***3-log***
Chlorine[1]	*35*	*69*	*104*
Chloramine[2]	*615*	*1230*	*1850*
Chlorine Dioxide[3]	*7.7*	*15*	*23*
Ozone[3]	*0.48*	*0.95*	*1.43*
Values were obtained from AWWA 1991.			
[1] Values are based on free clorine residual ≤ 0.4 mg/L, tempreature of 10 C and pH 7. [2] Values are based on free chlorine residual ≤ 0.4 mg/L, temperature of 10 C and pH 6-9. [3] Values are based on free chlorine residual ≤ 0.4 mg/L, temperature of 10 C and pH 6-9.			

Table 2 elaborates on the inactivation of various other disinfectants with the help of ozone. Ozone is an unstable gas at room temperature, it has a half-life of 40 min at 20 °C and of about 140 min at 0 °C (Jani, 2012) It has a longer half-life in a gaseous state than in an aqueous solution thus it is relatively stable in air but unstable in water and decomposes in a very short time. Nikola Tesla patented the first ozone generator in the United States of America (Edwards, 2013), and this accelerated the usage of ozone in several sectors mainly for medical usage.

Aqueous ozone has been widely studied and demonstrated to be highly effective in killing various types of microorganisms, including bacteria, viruses, and fungi. Its strong disinfection capabilities are attributed to its oxidative properties. When aqueous ozone comes into contact with microorganisms, it reacts with their cell membranes and other cellular components, leading to the destruction of the microorganisms. (Norasak Kalchayanand, 2019).

Aqueous ozone shows strong antibacterial activity within a short contact time. It has been reported that the survival rate of microorganisms is reduced from 5% to 0.001% within 15 s of exposure to a low concentration of aqueous ozone in vitro (Farooq. S, 1983). The half-life of Aqueous ozone is estimated to be 2 to 20 min in aqueous solution (Wickramanayake, 1984; Tomiyasu et al., 1985). Moreover, the half-life of Aqueous ozone becomes shorter in the presence of contaminants including organic matter, because the contaminants consume ozone. Therefore, the effective time of Aqueous ozone exposure is recognized to be approximately 1 min.

Designing a portable disinfection system for the aircraft lavatory presents several challenges at this stage of research. While the concept of portable disinfection systems holds promise for improving cleanliness and reducing the spread of pathogens in aircraft lavatories, there are significant hurdles to overcome before implementing such a system. One of the primary difficulties lies in the complexity of the aircraft's lavatory environment.

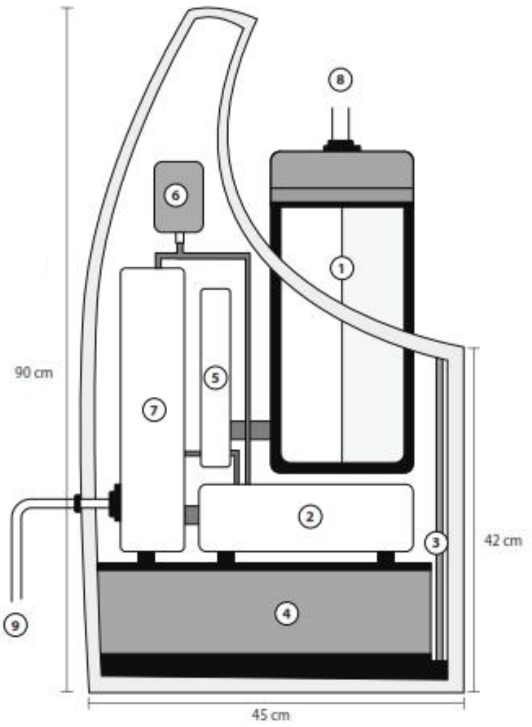

Figure 3: Proposed portable aqueous ozone generator

1- Water stabilizer – It filters the cold-water stream provided through the inlet and pumps the treated water to the water dispenser.

2- Ozone activator - the corona discharge method involves passing a high-voltage electrical discharge through a gas, typically oxygen or ambient air, to generate ozone.

3- Circuit board- The circuit board regulates the power supply to the ozone generator, ensuring that the appropriate voltage and current levels are maintained. It helps prevent electrical fluctuations or overloading that could affect the performance or safety of the device. The circuit board processes the user input and translates it into appropriate commands for the ozone generator's operation.

4- High voltage battery unit - A high-voltage power supply is connected to the electrodes of the ozone activator. This power supply delivers a high-voltage electrical current to the electrodes, creating a strong electric field in the surrounding gas. The high-voltage battery unit is typically designed to provide sufficient power capacity for extended operation. It allows the portable ozone generator to run for a desired duration without the need for frequent recharging or replacement of batteries. The high-voltage battery unit is often rechargeable, allowing users to replenish the battery's energy when needed. This feature makes the ozone generator more cost-effective and environmentally friendly, as the batteries can be reused multiple times. In some cases, the battery unit may also be replaceable, providing the option to swap out depleted batteries with fully charged ones for continuous operation.

5- Water dispenser- The water dispenser provides a controlled environment for the introduction of ozone gas into water. It allows ozone to dissolve and become dispersed in the water, forming aqueous ozone. The design of the water dispenser ensures efficient contact between ozone and water, maximizing the dissolution process. The water dispenser incorporates mechanisms or features to promote thorough mixing and agitation of ozone and water. This helps to ensure the uniform distribution of ozone throughout the water, enhancing the efficiency and effectiveness of ozone dissolution. It may include elements such as nozzles, diffusers, or turbulence-inducing components to aid in the mixing process.

6- Flow control mechanism- The flow control mechanism ensures that the ozone gas is fully saturated before it is introduced into the water. By regulating the flow rate, it allows sufficient contact time between ozone and the activator material, maximizing the conversion of oxygen (O_2) to ozone (O_3). This helps to achieve a higher concentration of ozone in the gas stream. The flow control mechanism helps to improve the overall efficiency of the ozone generation process. It ensures that unsaturated ozone gas is not wasted or released into the environment prematurely.

7- Unsaturated ozone dispenser - The unsaturated ozone dispenser allows for controlled and regulated release of ozone gas into the target area. It ensures that the dispersion of ozone is gradual and controlled, preventing excessive concentrations that may be harmful to humans or sensitive materials. Ozone gas has a distinct odour that can be strong and unpleasant in high concentrations. The unsaturated ozone dispenser helps to control and minimize the odour by releasing ozone in controlled amounts. This allows for effective odour elimination without overwhelming the surrounding environment. Ozone gas is known for its powerful disinfectant and deodorizing properties. The unsaturated ozone dispenser is used in applications where air purification is desired, such as in commercial spaces, homes, or vehicles. It helps to neutralize odours, eliminate airborne bacteria and viruses, and reduce allergens and pollutants in the air. It serves the purpose of controlled and safe distribution of ozone gas for air purification, surface disinfection, and various environmental treatments.

8- Water Inlet- The water supply will be connected to this line.

9- Water Outlet- Ozonated water will be provided to the nanobubble through this line for better disinfection.

This engineering setup efficiently and safely produces aqueous ozone through a water treatment and ozone generation process. Water is filtered and treated at the water stabilizer before entering the system. Using the Corona discharge method, an ozone activator powered by high voltage current converts stored oxygen gas into ozone gas by breaking the oxygen bonds. Simultaneously, ozone gas is pumped into the dispenser tank alongside the water, creating pressure that ensures thorough mixing and the formation of aqueous ozone. The ozone-water mixture flows into the unsaturated ozone dispenser tank and is then directed to the ozone activator tank through a gas flow control valve to prevent gas leakage. Finally, the system produces aqueous ozone, which can be used for various engineering applications, while maintaining strict safety measures.

IV. DISCUSSION

To develop a portable aqueous ozone generator, numerous factors have been considered. The outer casing of the machine will be carefully designed to ensure durability, lightweight construction, and portability. High-grade plastic or aluminium can be chosen as suitable materials that provide both strength and weight reduction. The casing will enclose and protect the internal components of the machine while offering ease of handling and transportation. The ozone generation system is a crucial component responsible for converting oxygen (O2) from the surrounding air into ozone (O3). Various ozone generation technologies can be considered, such as corona discharge or UV irradiation. The system will need to be efficient, reliable, and capable of producing ozone at the desired concentration levels for effective disinfection. Here corona discharge method has been considered. Corona discharge is produced by applying a high voltage, high-frequency signal to an electrode separated from a grounded plane by an air gap and a buffer dielectric. Modern corona generators produce sinusoidal voltages up to 20 kV peaks, with a frequency in the range of 20 to 40 kHz. The voltage multiplication is achieved by an LC series resonant circuit. The resonant circuit is driven by a bridge-type voltage-source resonant inverter. (NándorBurány, 2008). The dispenser is equipped with a source of oxygen, typically ambient air, which is supplied through a replaceable filter cartridge. This ensures that the oxygen used for ozone generation is clean and free from impurities.

The corona discharge produces a localized region of intense electrical activity. Within this region, oxygen molecules (O_2) are subjected to high-energy electrons. As the high-energy electrons collide with the oxygen molecules, they transfer energy to the molecules, breaking the weak double bond that holds the oxygen atoms together. This results in the formation of individual oxygen atoms (O). The individual oxygen atoms (O) created by the electron impact then rapidly combine with nearby oxygen molecules (O_2) to form ozone (O_3). This process involves the recombination of oxygen atoms to create ozone molecules. Within the machine, a dedicated ozone mixing chamber will be designed. This chamber will facilitate the mixing of the ozone generated by the ozone generation system with the water from the water supply. The chamber's design should ensure thorough mixing to create a homogeneous and stable aqueous ozone solution.

The spray mechanism is responsible for dispersing the aqueous ozone solution in a fine mist to ensure effective coverage of all surfaces in the aircraft lavatory. The machine can feature multiple strategically positioned spray nozzles that can be adjusted to control the spray angle, pattern, and droplet size. The spray mechanism should be designed to provide uniform distribution of the solution for comprehensive disinfection. The machine will require a reliable power source to operate its internal components. The power source can be a rechargeable battery or an electrical connection.

1. Electrical Requirement: 230V, 50 or 60Hz, 1 phase 30A circuit.
2. Water Flow Range: 4 - GPM (15 LPM)
3. Water Pressure Range: 20-30 psi (1.4-2.1 bar)
4. Dimensions (HxWxD) – 90 x 40 x 45 (cm)
5. Weight - Dimensions of 90 x 40 x 45 cm might weigh anywhere between 10 to 30 kilograms. It's important to note that this estimate is based on common portable ozone generator models.

As Sri Lankan Airlines which is the prominent carrier in the country with a fleet of A320s, and A330s, we take a model area of the lavatory of an A320. As per previous studies, with a concentration of 5 ppm (or 5 mg/L) and a 1 cubic meter area to disinfect, it would require approximately 5 litres of aqueous ozone solution.

The approximate volume of the lavatory in an Airbus A320 is below 2 cubic meters. To disinfect this volume of the lavatory with a 5 ppm concentration of aqueous ozone, the total needed volume can be calculated by multiplying the volume (2 cubic meters) by the concentration (5 L). Since the system produces 15 L of aqueous ozone per minute, the required quantity of ozonated water to disinfect the lavatory can be produced within one minute.

V. CONCLUSION

The findings and discussions presented strongly support the notion that aqueous ozone offers significant advantages over IPA in terms of disinfection efficacy and environmental impact. Numerous studies have demonstrated the high effectiveness of aqueous ozone in killing a wide range of microorganisms, including bacteria, viruses, and fungi. Its oxidative properties and broad-spectrum disinfection capabilities make it a promising solution for ensuring thorough disinfection in aircraft lavatories. Compared to IPA, aqueous ozone offers several key benefits. Firstly, it has a faster disinfection rate, reducing the contact time required for effective sanitization. Secondly, aqueous ozone is a natural and environmentally friendly disinfectant, as it decomposes back into oxygen and water, leaving no harmful residues behind. This aligns with the increasing focus on sustainable and eco-friendly practices in the aviation industry. Moreover, the application of aqueous ozone with the aid of a portable aqueous ozone generator will provide consistent and efficient disinfection processes in aircraft lavatories. This eliminates the variability and potential human error associated with manual disinfection methods.

VI. FUTURE WORK

The implementation of aqueous ozone as the primary disinfectant offers technical benefits such as improved passenger safety, sustainability, and a cleaner travel environment. Future work should focus on the development of a portable automated ozonated water generation system for integration into aircraft lavatories. This system would reduce costs, logistical challenges, and environmental impact, solidifying aqueous ozone as a superior replacement for IPA in aircraft lavatory disinfection.

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