Design and Development of an Ozone-Based Food Processing System

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Fish is one of the highly perishable food products. Hence it has to properly cleaned and washed and kept under refrigerated storage for immediate consumption. In the same way frozen seafoods are also required to be processed immediately after harvest. Traditionally the seafood industries use chemical sanitizers, including quaternary ammonium, iodine, and chlorine, chlorine dioxides, organic acids, peracetic acids and hydrogen peroxides as sanitizing agent at the food-processing surfaces, but they are not approved for direct application to seafood products. Seafood processing industries uses huge quantity of chemicals for cleaning and sanitation of the processing or handling equipments/surfaces. The use of such chemicals which involves excess use of water and wastewater discharge rates leaving chemical residues. While chlorine has been widely used as the sanitizer of choice for seafood industries, there is a rising concern of adverse environmental effects with the widespread use of chlorine. Due to the environmental and health risks posed by the use of conventional chemical disinfectants, their use in the food product is prohibited (Gee, 2016).

The use of clean and green technology must be adopted and widely used in the recent future. Ozone is an emerging alternative to chemical disinfectant and approved by Food and Drug Administration as generally recognized as safe (GRAS) to use in foods (Ölmez and Kretzschmar, 2009). The ozone is being the powerful oxidizing agent can act as the sanitizer/disinfectant on the food contact surfaces and on the food itself without leaving any harmful residues. The ozone dissolved in water or in aqueous form can be used for this purpose. Ozonated water generator can thus bring out transition in seafood processing industries. Hence steps are taken in priority to gradually phase out the use of chlorine from food-processing plants. Ozone has the power to oxidize and deactivate a large number of micro-organisms, including bacteria, fungi, yeast, parasites and viruses and can also oxidize natural organic compounds as well as synthetic substances such as detergents, herbicides and composite pesticides. The use of ozone in gaseous and aqueous forms as an antimicrobial agent on food, including seafood is generally considered as safe by FDA. Hence, ozonated water can be used in a range of food processing facilities as a surface cleaner/sanitizer/disinfectant. Ozonated water treatment has also proved to extend the shelf life of seafoods to some extent and can be thus used as a pre-processing technology in seafoods.

The food processing industry is currently facing challenges in delivering safe, healthy, and high-quality food. Advanced technologies promoting the concept of clean and green label food have been widely accepted. Ozonation is one such advanced technology that assists in maintaining food product quality and safety (Dubey *et al*., 2022). Ozone was used to disinfect water for drinking purposes from many years. The other commercial applications were disinfection of bottled water, swimming pools and wastewater treatment *etc*. (Gonçalves, 2009). Ozone is one the most powerful oxidizing agent (second to fluorine) in water disinfection in the world destroying up to 99.9% of pesticides and microorganisms commonly found on food. Zero residue production make it a promising food disinfectant technique. Ozone being disinfectant can be widely used in washing, sanitizing, disinfecting equipment or surfaces, odour removal, water treatment and in fruits, vegetable, meat and seafood processing. Ozonation in foods is also found not to alter its nutritional, sensory and physicochemical characteristics. The key objective is to reduce the bacteriological index that occur during storage systems of foods (in refrigeration, freezing or fresh storage).

Ozone is widely used in fruits and vegetables processing for cleaning and disinfection. The respiration rate of fruits and vegetables can be inhibited by ozone treatment (Zhang *et al*., 2005; Palou *et al*., 2002). Ripening of fruits also delayed by ozone treatment. Enzymatic browning in vegetables also controlled using ozonated water treatment (Nie *et al*., 2020; Zhang *et al*., 2005).

An ozonation treatment system was designed and developed to minimally process onions. Box-Behnken design and Response Surface Methodology was used to optimize the sanitization procedure for cut onion slices in order to investigate the effects of ozone concentrations between 1-5 ppm, exposure times between 3-8 min, and aqueous pH between 3-5 on microbial log reductions, pyruvate content, colour change, and overall acceptability. It was found that the splashing method produced the highest microbial log reductions (5.04) of the several ozone administration techniques tested at 5 ppm ozone concentration, followed by the dipping (4.5) and spraying (4.22) methods. Aqueous ozone at a concentration of 5 ppm splashed on the surfaces for 8 minutes at an aqueous pH of 3.01 produced optimal sanitization for the sanitization of cut onion slices; microbial log reductions, pyruvate content, and overall acceptability were recorded as 5.6 log reductions, 0.127 µM/mL, and 8.2, respectively (Aslam *et al*., 2022).

Ozone treatment has been widely used in meat and poultry products for killing the pathogenic and spoilage micro-organisms. The bacterial load can have 1-3 log reduction by the ozone treatment prior to fresh, refrigerated and frozen storage (Ayranci *et al*., 2020; Megahed *et al*., 2020; Chawla *et al*., 2007; Hassenberg *et al*., 2007; Castillo *et al*., 2003; Novak and Yuan, 2004).

Ozone technology also applied in seafood industries. Tilapias stored at 0°C after short time ozone pre-treatment prolonged their storage life by 12 days and improved their quality characteristics through one month's storage (Nash, 2002). The ozonized water for dipping and washing fish or fish fillets resulted in an effective reduction of microflora (Gelman *et al*., 2005). Significant reductions in plate counts when live catfish and fillets were washed in ozonated water (Kim *et al*., 2000). It is also claimed that ozonized water can be used as a powerful surface disinfectant at the fish handling surfaces (Tapp and Sopher, 2002). Ozonated water treatment found to improve the quality of shrimp by reducing spoilage bacteria during mechanical peeling. Soaking peeled shrimp meat in ozonated water was found to be more effective and did not increase lipid oxidation in the shrimp immediately after treatment (Chawla *et al*., 2007). The ozone technology fish storage system was developed for on-board fishing red tilapia was exposed to ozone concentrations from 0.5 ppm to 4.5 ppm which reduced the total bacterial count without affecting the organoleptic and TVBN of fish (Nur *et al*., 2014).

The quality and the safety are the highest priorities of the fish industries by the control of the deteriorative/pathogenic organisms such as *Listeria monocytogenes* and *Vibrio sp*. As FDA declared ozone as approved food additive and ozone has been verified to produce greater lethal effect to microorganisms when compared with chlorine or other chemical agents. The advances in the generation of ozone and technologies of the uses have continued making most reliable and economic process.

Ozone is being a potent sanitizer/disinfectant has promising applications in the modern seafood industry. It can be used as a safe and effective antimicrobial agent in many seafood-processing applications. Compared to chlorine which is widely used in the seafood industry and other chemical disinfectants, lower concentrations and shorter contact times are enough in reducing microbial counts. Ozone is also more effective than other disinfectants against resistant organisms such as parasites and viruses. Exposure to ozone during processing or storage extends the shelf life of seafoods while preserving their sensory attributes. Ozone does not produce significant toxic residues in the environment after treatment. Its stability and efficacy at chilling temperatures constitute attractive savings for the seafood industry (Global Aquaculture Advocate, 2004).

Ozone is an unstable gas at room temperature. Although ozone degrades quickly (Manley and Niegowski, 1967), its half-life in gaseous form is longer than that in aqueous form (Rice, 1986). The ozone 13 times more soluble as oxygen between 0 and 30°C, and it gets increasingly more soluble in lower temperature (Rice, 1986). The two methods which are used to produce ozone on a commercial scale are: passing an oxygen-containing gas through a high-energy electrical field or an ultraviolet (UV) radiation source known as the photochemical (UV) approach, and the corona discharge (CD), sometimes known as "plasma techniques.

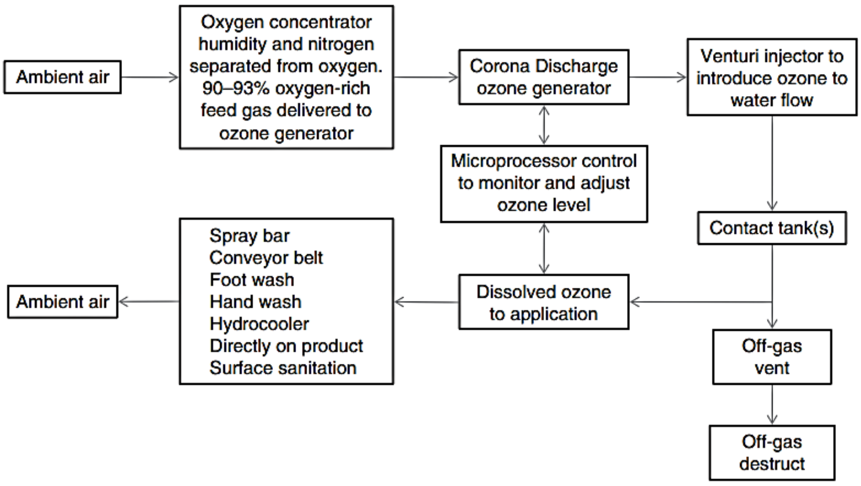

Fig. 1 Process of ozone generation

Table 1 Different technique for ozone generation

Parameter	UV radiation	CD
Maximum ozone production rate	1.94 g/kWh using 185 nm lamps Lower yields are obtained from 254 nm UV bulbs	>55 g/kWh from dry air
Concentration of ozone in output gas	1.8 g/m^3 ~0.14% by weight	12–60 g/m^3 0.1–4.8% by weight
Energy required to generate 1 kg of ozone	44 kWh	6–8 kWh
Need to dry feed gas	Desirable but not critical	Critical
Consistency of ozone production	Variable	Constant
Capital costs	Relatively low	Relatively high
Operating costs (electrical energy)	High	Low

The process of transferring ozone in large quantities into water for the purpose of purifying it or making ozone aqueous solutions for surface sanitation/disinfection is usually achieved through two independent techniques known as fine bubble diffusion and venturi injection. Both methods have an impact on ozone dissolution in water, depending on the specific use(s) in the food processing.

Ozone generator and a mixing chamber is required to generate ozonated water. The ozone is produced by applying a high electrical field in an ozonator. Whenever oxygen or dry air passes through this high electrical field, the oxygen molecules (O_2) breakdown into nascent oxygen molecules (O) and immediately becomes ozone (O_3) by colliding with other oxygen molecules (O_2). When this oxygen is mixed with water and used at the targeted surfaces it breaks down heavy chemicals, fertilizers, pesticides, biomaterials, bacteria, viruses *etc*., and thus enables efficient cleaning and disinfection/sanitation.

The equipment components required for generating and applying ozone in the gas phase are fairly simple compared to aqueous ozone applications, primarily because mixing a gas (ozone) with another gas (air) is much less complicated than dissolving ozone gas in water. Typical components are a feed gas, which will both dry the air and pressurise the ozone entering the storage room, an ozone generator, preferably with 4/20 mA control for realtime variable output, and finally a gas phase ozone monitor, for achieving and maintaining a desired ozone level in the room. One design note: it is advisable to interface the system with the cooling fans so there is no build up (or localisation) of ozone without air movement anywhere in the room (O'Donnell *et al.*, 2012).

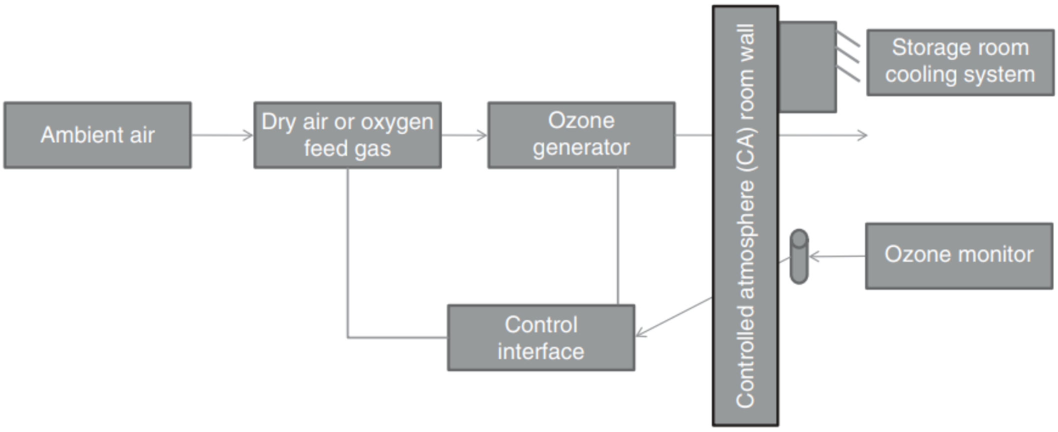

Fig. 2 Components of ozonizer

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