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Overview on Application of Ozone in the Food Processing Industry

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Abstract
Antibacterial qualities of ozone have been discovered recently and it is being employed as a potent disinfectant in food industry. Ozone is used in liquid and gaseous forms. Ozone in liquid form can treat water, sterilize equipment, and various types of food. In gaseous form it can be used to sanitize instruments and food packaging materials. The history of ozone, ozone generating processes, ozone physicochemical features, and its application in food processing are covered in this study. Ozone can be generated by many artificial methods like silent electrical discharge, electrochemical reactions, UV radiation, and Electrolysis. Ozone is recently applied in many fields of the food industry like, food beverages, seafood, fruit and vegetable industry, meat industry and dairy industry and it has shown significant influence in food processing fields. In addition to this, potential applications concerning the development and application of ozone generation, nutritional and quality aspects of food, and ozone as a disinfectant also have been proposed

Keywords: Ozone, Non-thermal technologies, Application of ozone, Ozone in food.

INTRODUCTION

Consumer demands towards minimally processed safer foods, necessitating innovation and adaptation of novel disinfecting, preserving, and processing methods of food processing. Food spoilage and pathogenic microbes can be reduced using thermal processing technology for many years; however, these technologies might result in undesirable, unwanted modifications in their fresh counterparts. As a result, novel technologies that are effective at inactivating common and emerging pathogens, removing toxic contaminants, reducing product quality loss, adapting to food processes, and being environmentally friendly are required. Consumers are not only concerned about the ingredients in the foods they eat, but also about the processes that take food from farm to fork. Cleaning and disinfection products are the most important aspect of food safety, as they help to produce safe products by reducing pathogenic and spoilage microorganisms. In food processing facilities, sanitizers have been employed to control contaminating microorganisms, particularly those that cause foodborne illnesses. Chemicals affect the composition and cellular activity of the pathogens but those chemicals itself acts like a potential hazard by leaving residues. Hence, the use of some sanitizers has been restricted or banned because of potential health risks.

Ozone treatment is one such novel technology having the ability to meet these criteria and has shown positive prospects in the food industry. Since the early 1900s, Ozone was found to be used as a disinfecting agent in treating water for drinking purposes in Europe [1]. Ozone's bactericidal effects were observed to be effective on gram-positive and gram-negative bacteria, spores, and vegetative cells, among other species. Ozone is a powerful oxidant that has been shown to kill bacteria, remove hazardous compounds, and extend the shelf life of a variety of foods[2].The use of ozone in food processing has gained importance ever since the affirmation

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of ozone as a GRAS chemical in 1997[3]. It has been approved as an antimicrobial additive by the US FDA 2001 for its direct contact with food products of all types. Many countries, such as the United States, Japan, Australia, France, and Canada, have given their approval to the use of ozone in food processing to various extents.

Ozone’s oxidizing effect helps to reduce microbial load, level of hazardous organic compounds, Chemical Oxygen Demand(COD), and Biological Oxygen Demand(BOD) in the environment, hence it can be used to replace the traditional sanitizers [4]. Ozone has a stronger and faster antibacterial effect on spores, feces, pathogenic microorganisms, and viruses than chlorine. Since ozone decomposes spontaneously to oxygen and does not remain in the water for longer timeframes, it can be regarded as a process rather than an additive, with no health concerns associated with consuming leftover ozone in food. The byproducts of ozone food treatment are similar to typical oxidation products and are less likely to cause health problems than chlorine byproducts. Ozone's versatility makes it a promising food processing agent.

PROPERTIES AND CHARACTERISTICS

Ozone is the second most powerful common oxidising agent. Ozone(O_3) is a triatomic oxygen formed by the addition of a free radical of oxygen to molecular oxygen. The three atoms of oxygen in the ozone molecule are arranged at an obtuse angle whereby a central oxygen atom is attached to two equidistant oxygen atoms. The boiling point of ozone is 111.9 ± 0.3 °C, the melting point is 192.5 ± 0.4 °C, the critical temperature is 12.1°C and the critical pressure is 54.6 atm. Ozone exists in the gaseous state at room and refrigeration temperature and it is partially soluble in water. At room temperature, ozone is an unstable gas and also a colourless gas.

Ozone is relatively stable in air but highly unstable in water, decomposes in a very short time. It cannot be stored, hence it requirs continous generation. Ozone has a pungent characteristic odour described as similar to “fresh air after a thunderstorm.” It is readily detectable at 0.01–0.05 ppm-level. Ozone is a blue gas at ordinary temperature when generated from dry air, but colourless when generated from high purity of oxygen. Ozone decomposition is faster in higher water temperatures. Ozone condenses to a dark blue liquid. Liquid ozone is easily exploded if greater than 20% ozone to oxygen mixtures occur. Although in low concentrations ozone is not an extremely toxic gas, at high concentrations ozone may be fatal to humans.

GENERATION

The generation of ozone occurs naturally and is generated artificially as well. Usually, a high energy input splits the oxygen(O_2) molecule present in the atmosphere into 2 single oxygen (O) molecules. Since these single oxygen(O) molecules are unstable, they rapidly combine with the present oxygen (O_2) molecule to form the highly reactive Tri-atomic oxygen known as Ozone(O_3). In nature, the generation of ozone occurs through the UV radiations emitted by the sun entering the earth’s atmosphere and also with an occurrence of lightning discharge. Since its instability, it gets converted back to an oxygen (O_2) molecule. Artificially, there are 3 methods of generating ozone on-site.

Corona discharge/ Plasma technique

This is one of the most widely and commercially methods of generating ozone. Plasma or corona discharge type of ozone generation is shown in the figure 1. In a corona discharge type of ozone generator, there are 2 electrodes, of which one is a high tension electrode coated with a dielectric medium and another one is a low

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tension electrode. A narrow discharge gap separates them both. When oxygen is passed through the gap and presence of a high voltage alternating current, electrons get excited and the oxygen(O_2) molecules get split. After splitting, the atoms from the single oxygen molecule combine with other oxygen (O_2) molecules to form ozone(O_3). The factors which affect the yield of ozone are voltage, property of dielectric material, current frequency, the discharge gap, and pressure inside the generator. Some advantages of this technique are high O_3 concentration, long-lasting generators, best for water applications. [5].

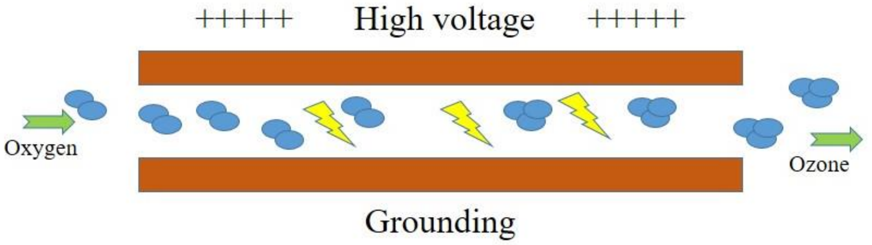

Figure 1: Plasma or corona discharge type of ozone generation

UV Lamp

In a UV lamp type of ozone generator, the UV light from the UV lamp splits the oxygen(O_2) molecules. UV-lamp based ozone generation is shown in the figure 2.These single oxygen molecules combine with other oxygen (O_2) molecules to form ozone(O_3). The ozone produced can be converted back to oxygen(O_2) by UV light from the UV lamp. A wavelength of 188 nm is used for the generation of ozone[1].

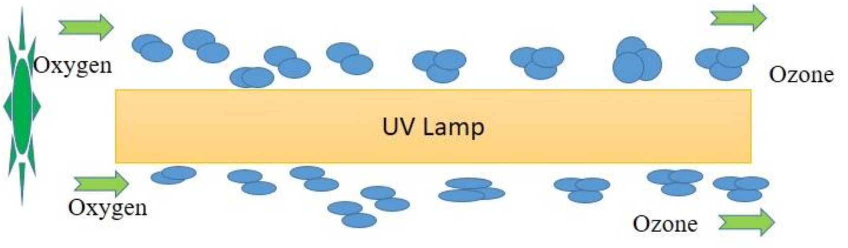

Figure 2: UV Lamp type of ozone generation

Electrolysis

This method of generation of ozone is a small-scale production. It is used in laboratories. Figure 3, illustrate the electrolysis type ozone generation. The electrolytic ozone generator uses pure water directly for the generation of ozone. When a DC voltage is applied across electrodes in a solid polymer electrolyte, with the feed as pure water, the hydrogen atoms generated at the cathode get discharged and O_2 atoms at the anode. The O_2 atoms get recombined to form ozone (28%), oxygen (72%) [6].

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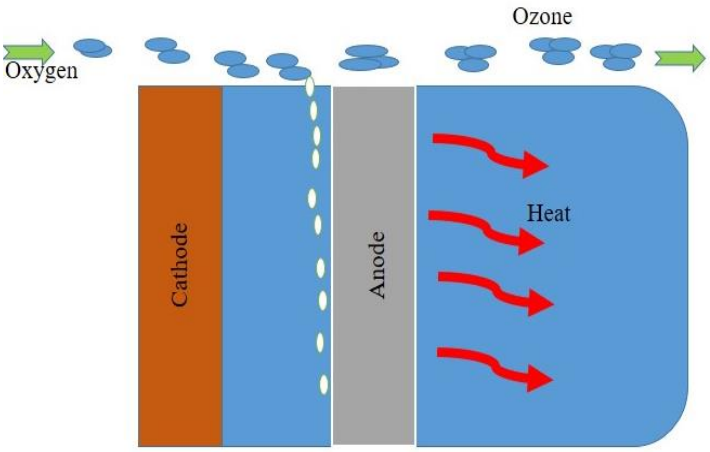

Figure 3: Electrolysis type of ozone generation

METHODS

Ozone can be used in food processing in the gaseous state as well as the liquid state.

Gaseous state: Ozone is used in the gaseous state by using a required concentration of ozone(eg: 0.3ppm to 2ppm)(Volume/volume) for the required amount of time (eg: 24 hours to 6 weeks) to treat fruits like peaches, grapes; vegetables like potatoes; whole meat; Liquids like fruit juices, liquid dairy products, drinking water; and grains.

Produce	**Treatment**	**Microbial Quality**	**Results**
Fresh carrots	1–5 mg L^{-1} of ozone at 3.9–24.1 °C for 9.5–110.5 min	Not determined	Increase the shelf-life of carrots [7].
Green tomatoes	25 or 45 mg m^{-3} for 2 h day^{-1} for 16 days	Reduction of spoilage apparition only 14% of damaged fruit versus 54% for the control	No significant impact on pH, titratable acidity, and soluble solids.Firmness, weight preservation[8].
Figs (dried)	5 ppm of ozone - 3 hours and 10ppm of ozone - 5 hours	Decrease in total aerobic mesophilic microorganisms and yeast/mould counts	All coliforms were inactivated[9].
Blackberries	Storage for 12 days at 2°C in an atmosphere containing ozone (0.1 and 0.3 ppm).	Not Determined	Ozone storage suppressed fungal development for 12 days[10].

Table 1: Ozone treatments in the gaseous state for various products.

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Liquid state: Ozone is used in the liquid state by using ozonated water/bubbling of ozone in water to wash or immerse for a required amount of time to treat fruits like apples; vegetables like green leafy vegetables, broccoli, beans, celery, bell peppers, and other vegetables and ready to eat salad mixes; cut meat, salmon. Also, seafood can be stored in ozonized slurry ice.

Produce	Treatments	Microbial Quality	Results
Fresh carrots	Spray ozonated water(1.9 mg L^{-1}) -2 min	Significant decrease of moulds after the treatment and smaller concentration after 28 d storage	Preservation time increased by 1.8 times than control[11].
Shredded Iceberg Lettuce	10 to 20 mg L^{-1} of ozone, 3 to 5 min	Reduction of 1.6 log CFU g^{-1} of total microorganisms and 3 log CFU g^{-1} of coliforms	Slow microbial growth throughout 13 days of storage. Conservation of vitamin C content[12].
Apples (inoculated with *E. coli* O157:H7)	Bubbling of ozone during apple washing and dipping apples in pre-ozonated water.	Decrease in E.coli counts	The bubbling method was more effective[13].

Table 2 : Ozone treatments in the liquid state for various produce

APPLICATIONS OF OZONE IN FOOD PROCESSING

Now a days, ozone is considered as an universal disinfectant since it oxidises many inorganic and organic impurities, and it is also significant in destroying bacteria, viruses, and other harmful pathogens. Ozone has been utilised as disinfecting agents, sanitising agents in the drinking water treatment plants for many years in the US, Europe, Russia, and Japan. Ozone has also been approved for its use as a disinfectant in fresh fruits, vegetables, meat, poultry, seafood, fluid foods (including dairy), grains, and many other food processing industries. Ozone is a multi-functioning agent i.e., it has disinfecting, oxidising, sanitising, preservative, and bactericidal properties. Hence Ozone is one of the promising agents that can be used in food industries. The prominent applications of Ozone in food industries include food surface hygiene, food plant, and equipment sanitising, treating wastewater for reusing purposes, lowering BOD and COD.

Fresh produce has been recognized as a healthy food since there is increasing consumer demand. Their shelf-life is relatively short and is limited by microbial contamination or visual, textural, and nutritional quality loss. There are many methods to reduce or eliminate microorganisms present in food and ozone treatment is one of them. The use of ozone by the fresh produce industry is a good alternative to chemical treatments, e.g., the

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use of chlorine. Consumer preference for minimally processed foods and foods free from chemical preservatives, as well as recent outbreaks of foodborne pathogens, identification of new food pathogens, have all stimulated demand for novel food processing and preservation systems. For this purpose, the incorporation of ozone resulted either in improved product quality, significant costs savings, or both.

Consideration of fresh food requirement standards for consumers should assure fresh and safe food products. Ethylene formation on the food surface is responsible for the food ripening and spoilage. By virtue of its chemical properties, ozone prevents ethylene formation and thereby retards ripening and spoilage by microorganisms these intern enhances the shelf life of food.

Ozone in fruits and vegetables

Fresh fruits and vegetables have been treated with ozone in the food sector, either through gaseous treatment or washing with ozonated water. To minimize microbial counts on the surface of produce, two types of cleaning methods can be used: spray and fume[14]. Several studies have found that ozone treatment extends the storage life of fresh fruits and vegetables such as broccoli, cucumber, apples, grapes, oranges, pears, raspberries, and strawberries by lowering microbial populations and oxidizing ethylene [6]. Storage of fruits and vegetables in ozone-rich atmospheres has been found to minimize microbial and fungal diseases, in addition to surface decontamination. Continuous exposure of fresh commodities to ozone during storage reduces the postharvest decay and reduces the microbial spoilage of fruits and vegetables [10]. It has now been proven that using ozone to extend the shelf life of many agricultural products is a promising technique, not only because of its great performance, but also because of its low cost and convenience of use. In particular strawberry fruits are highly perishable and need special attention and great care. Ozone not only preserves the fruit from mold and bacterial colonies, but it also keeps the surrounding areas clean. Ozone slows the maturation process by 20 to 30 percent in fruits such as apples, cherries, carrots, kiwi, onions, peach, plum, potatoes, table grapes, tomatoes, blackberries, and strawberries. It was proven that ozone can be used as a quick pre-storage treatment in air or water, or it can be introduced to the storage room atmosphere constantly or sporadically throughout the storage time to prevent fruit rot. Hildebrand et al. (2008) noticed a reduction in postharvest deterioration[15]. According to published research, the effect of ozone during storage varies greatly depending on the kind of microbe, commodities, and storage conditions. For example, Forney et al. (2003) observed a decay resistance towards *B. cinerea* in carrots treated with 1000 ml/L ozone for 2 or 4 days, however they did not observe a decay resistance towards S. sclerotiorum[16]. According to Skog and Chu (2001), an ozone concentration of 0.04 l/L can increase the storage life of broccoli and cucumbers stored at 3 °C[17]. According to Ogawa et al. (1990)**,** *B. cinerea* spores were inactivated in tomato fruits after ozone treatment[18]. Sharpe et al. (2009) investigated the effects of gaseous ozone on the viability of *B. cinerea* spores and the growth of *B. cinerea* and *S. sclerotiorum mycelium* in apple, grapes, highbush blueberries and carrots[19]. They discovered that B. cinerea spore viability was reduced by nearly 99.5 percent after 48 hours of exposure to 450 or 600 ppb ozone at 20 °C, and aerial mycelium was reduced from 4.7 mm in the control to less than 1 mm. Furthermore, excessive ozone concentrations during storage may cause surface discolouration. Continuous ozone therapy has been shown to reduce blackberry deterioration, as well as mold suppression and onion degradation [10]. The growth of green and blue mold was delayed in ozonated citrus fruit. Apart from minimizing microbial damage, ozone has been found to be an excellent agent for removing ethylene from the atmosphere without compromising quality during apple and pear storage. During storage, ozone-containing water treatment had no effect on the total sugar level of celery and strawberries [20].

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Because of its significant oxidizing action, ozonation is likely to result in the loss of antioxidant components. In ozone-rich environments, grapes may acquire thin darker lesions. This injury has been described as sporadic, and it has not always been linked to an ozone dose or cultivar [21].
Gaseous ozone is also successfully applied to onions and potatoes for the prevention of fungal disease spread. Producers who implemented this system were able to increase yields of marketable products enough to recover the cost of equipment investment in the first growing season of use. So far on the use of ozone as a postharvest technology to extend the shelf-life and to maintain the quality of fresh produce. It is apparent from this work that in a number of studies ozone has no adverse effect on the product quality, while some commodities can clearly benefit from ozone exposure. Thus, further research is necessary to determine the optimal dose of ozone for each commodity of commercial importance. This knowledge would clearly benefit the industry and could be incorporated within the supply chain to extend the shelf-life and to improve the quality of the product.

Ozone in Seafood

Haraguchi et al. 1969 reported that the preservation quality of Jack Mackerel (Trachurus trachurus) and Shimaaji (Garanx mertensi) were improved after they were treated with ozone[22]. Fauvel et al. (1979) have contributed to the use of ozone for shellfish depuration from the laboratory stage to full commercial applications in Southern Europe[23]. No mutagens in the shrimp flesh were found after ozonation of shrimp in saline solution. Fishing vessels use ozone in their storage systems to maintain the quality of fish and to increase its shelf life until it is delivered[24,25]. This application of ozone with refrigeration helps the fishing vessels to remain in the sea for up to 14 days [26]. A refrigeration system combined with an ozone generator and ice slurry system developed was recognized to extend the shelf life of the seafood along with maintaining the sensory and microbial characteristics of the product. The synergic effect of ozone treatment and ultraviolet irradiation produce disinfecting effect during the manufacturing process of seafoods [27]. Ozone has also said to suppress the smell characteristics of fresh fish and mollusk. Application of ozone pre-treatment followed by storage at 0°C improves the shelf life, marketability and exportation potential of the fish. Dipping and washing of fish in ozonated water reduces the microflora concentration in the fish without any effect on its quality. Gaseous ozone has found to be potential surface disinfectant of fish and fish fillets. Treatment of peeled shrimp by soaking in ozonated water reduces spoilage bacteria and the level of lipid oxidation [28].

Ozone in Poultry

Ozone has been evaluated for its application in disinfecting hatchery, hatching eggs, contaminated poultry carcasses and contaminated eggs. Ozonation of retail eggs had better quality parameters and keeping characteristics than the controlled eggs [29]. Ozone washing along with refrigerated storage of poultry meat reduced the microbial count and also accounted for extending the shelf life of poultry meat by 2.4 days, this treatment also reduced the gram-negative rods [30]. Treating broiler parts in ice-cold water with gaseous ozone decreases microbial counts and also destroys gram-negative rods [30].
Ozone was successful in inhibiting the growth of surface microflora and destroying the pathogens that cause toxic infection and food poisoning in refrigerated chicken carcasses, without any adverse effect on the quality of the product [27]. Ozonated water is used as a disinfectant for poultry carcasses, since it helps in reducing the microbial concentration. Ozonated water has been evaluated as a successful disinfectant against natural contaminations on the eggs shell that are to be hatched [31].Gas mixture containing ozone was successful in inhibiting the microbial contaminants in poultry meat [6]. Exposure of gaseous ozone followed by modified

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atmospheric packaging can reduce the contamination in the chilled chicken breasts inoculated with Salmonella infantis and also improve its shelf like [32].

Ozone in Meat

Many studies have been performed to study the viability of application of ozone in meat processing. While handling meat, beef carcasses have the potential of being contaminated with fecal material that may result in contaminating the carcass. Ozone treatment is effective in decreasing the count of *Pseudomonas spp*. and *C. scottii* on contaminated beef[33]. Ozone treatment has been reported to the decrease in mesophilic aerobes and sulphite reducing anaerobes on meat and increase in the storage quality of meat [34]. Ozone treatment of poultry meat decreased the microflora on its surface at refrigerated conditions [35]. Ozone has been reported to stop the growth of surface contamination during storage of beef in refrigerated conditions and also aids in improving the sensory quality and decreasing the formation of total volatile N compounds [36]. The use of ozonated water as a commercial sanitizer was effective in reducing bacterial contamination on beef briskets that were inoculated with fecal paste [37]. Beef trimmings inoculated with E. coli and S. typhimurium were treated with ozonated water at different exposure levels for their effect on the ground beef microbial characteristics. The results showed that there was a decrease in the microbial count on the ground beef when the beef trimmings were exposed to ozone treatment for 15 minutes, but in the 7-minute treatment, there was a significant reduction in the aerobic plate counts and S. typhimurium. Ozone pretreatment followed by heat treatment/cooking reduced few microbial activities when they were later cooked[38]. Ozone treatment of commercial pork meat reduces microbial contamination and increases its shelf life [39]. Ozone has also been evaluated to be effective in reducing microbial contamination and food-borne pathogens in natural hog casings [40]. New Swiss Ventafresh technology has been using ozone in gaseous and aqueous phases for the preparation of complete meals that will be packaged and sealed in a sterilized manner [41]. Ozone has also been reported to be implemented in treating and processing smoked pork, sausages, bacon, and for many other applications in Pennsylvania (USA) ready-to-eat meat processing plants.

FUTURE OF OZONE

Ozone has wide applications in the various food sectors and in the food industries. Guaranteed natural antimicrobial quality of ozone on various food products as well as a potent sanitizer for plant equipment ozone has a bright future and potential in the food industries. Due to these new emerging techniques as well as improvements and innovations in the ozone generating and application systems the subject will be evaluated more effectively in the future. The following conditions include the effectiveness of ozone is influenced by many factors like the method of use including the temperature, pH, and the quality of water used.

Due to its high oxidation capacity and the inactivation of microbes it is able to prevent various kinds of microbial spoilage in fruits and vegetables. Therefore, more research must be done to demonstrate the concentrations and the methods of application of ozone in different food sectors and in the food industries. So that it can obtain safe and wholesome food products and also maintain good hygienic conditions within the food industry. The high oxidative nature of the ozone or radicals generated during the process of ozonation causes molecular degradation of pesticide residues. Recent studies have suggested that ozone has an exceptional ability to improve the safety and quality of foods thereby attracting interest in the food industries. Overall, ozone is well recognized as a green technology for the food industries because its application causes no toxic traces on the food.

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Conclusion

Ozone is a powerful oxidizing agent and it is the best alternative method for the use of chlorine and hydrogen peroxide in food applications. Ozone is highly effective in cold water which saves our energy and cost. It is an eco-friendly method to use for disinfectants. The current use of ozone helps in the food industry in order to extend the shelf-life of fruits, vegetables, liquid foods, seafood, meat, dairy products, etc. Ozonated water helps in the removal of toxic components from the surface of foods and it also protects the consumers from causing different kinds of diseases. Ozone is used in two different forms mainly in the aqueous and gaseous state whereas in aqueous solution it can be used for disinfecting equipment and process water along with many other foods whereas in gaseous form it can act as a preservative for various food products and can also sanitize food packaging materials. It also enhances the sensory qualities of foods.

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