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Optimization of ozone decomposition time and its effect on physicochemical and bacteriological quality of table water

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ABSTRACT

Ozone is widely used in water disinfection and the concentration needed for the effective microbial elimination depends on the water source. In many bottled water producing industries, products containing ozone are quarantined after application to allow decomposition into diatomic oxygen molecules and oxygen atoms in order to eliminate any toxic effect. A process optimization was carried out to determine the ozone decomposition time in a table water producing factory in southern Nigeria. To this end, bottled water products injected with the ozone were collected from a bottling line immediately after production and monitored for ozone decomposition. Parameters like total dissolved solids, temperature and pH were determined and bacteriological analyses for total bacteria count and presence of *Pseudomonas* and coliforms were carried out. It was found that the ozone half-life was under 30 minutes and was no longer detectable after two and a half hours. For all analyzed stored products, the pH was in the range of 7.0-7.06, while the temperature was between 23 and 25 °C. The total dissolved solids ranged from 0.05 to 0.09 mg/mL, and there was no significant difference ($p > 0.05$) for the bottled products stored for 24 or 48 hours after the production. No bacteria were detected. The shorter quarantine period allows quicker distribution and highlights the importance of ozone decomposition testing for the process optimization, especially if equipment or water source change over time.

Introduction

Ozone molecule is generally known as a powerful oxidizing agent (Yang et al., 2016). It has been described as a reliable antimicrobial agent that is active against microorganisms (Savabi et al., 2018). Also, it has industrial and medical uses and has been shown to be effective in the reduction of bacterial spores adhered to drinking water infrastructure (Szabo et al., 2017). Ozone plays a major role in public health because its application in drinking water systems prevents the proliferation of water-borne microorganisms which may cause various diseases. It has been shown that the proliferation of microorganisms in a water processing factory can result in shutting down the facility (Nwaiwu and Nwachukwu, 2016). Despite its good uses, ozone can be dangerous if safe limits are exceeded. The safety and hazard statement on ozone shows that the compound is fatal if inhaled and a link between long-term exposure to ozone present in air and an increased risk of mortality from cardiovascular and cerebrovascular diseases has been established (Cakmak et al., 2016).

During bottling of table water, the toxic effect of ozone after ozonation is prevented by the favourable thermodynamic decomposition to diatomic oxygen (Batakliev et al., 2014). To allow the breakdown of the ozone concentration to a safe level, a table water bottling company in southern Nigeria usually sets aside ozonated products for 48 h before they are released for public sale. An increase in demand for bottled water led the company to explore the possibility of increasing product availability by reducing the 48 h quarantine period.

In order to implement a new system of keeping products for only 24 h, a review of the plant's bottling records was

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carried out to confirm the exact time of the ozone decomposition in the bottled products. The records showed that the observed 48 h quarantine period was not based on any empirical research or government's regulation and may have been adopted from the values of water source tested elsewhere. The rate of ozone decomposition varies for each water source (WHO, 2011) and for a water processing facility. This information is important to help monitor equipment and disinfectant performance. In order to establish a scientific basis for the change to a 24 h period proposed for the ozonated water and meet new business needs in the bottling facility, a process improvement was initiated through this study. Therefore, the aims of this investigation were to determine the exact time it takes for ozone in the bottled water to decompose and establish that the physicochemical and bacteriological qualities regularly monitored in the bottling facility would not be affected if bottled products were held for 24 h instead of 48 h before the release.

Materials and methods

Measurement of ozone in table water

To carry out the investigation, 6 ozonized bottled water (750 mL) products were collected from the bottling line at the first and last hour of production in three separate 10 h bottling shifts (6x2x3 = 36 bottles). Water from the bottled products was monitored every 30 min for the ozone decomposition. The ozone concentration was measured using a comparator system (Lovibond 2000, Tintometer Ltd, Salisbury, UK) according to the manufacturer's instructions. Briefly, the comparator (0-1 mg/mL range) has two optical glass cells and they were filled to the 10 mL mark with bottled water after which an indicator tablet was crushed and added to one cell. Two colour fields were matched and read off as mg/L ozone. It was not possible to analyze hundreds of bottles at a time because the of the possibility for the ozone to break down and may no longer be detectable.

Water temperature, pH, and total dissolved solids

In order to ascertain the physicochemical qualities for each investigated production shift, two sets of 100 bottles were collected at random from the bottling line immediately after the ozone application. One set was analyzed after 24 h product storage, whereas analysis of the second set of the bottled products was performed after 48 h. The ozone content was retested after storage for both sets of bottles, and pH, total dissolved solids and temperature were determined simultaneously with a multipurpose meter (Hannah, HI 981504, Woonsocket RI, USA).

Bacteriological analysis

Bacteria count was carried out with the industrial membrane filtration. This was determined with a kit (Sartorius, Göttingen, Germany) according to the manufacturer's instruction using a 0.45 μm membrane filter with various nutrient media pads. The nutrient pads included tryptone glucose extract medium for total bacteria count, tergitol triphenyltetrazolium chloride medium for the isolation of enterobacteria, and cetrimide medium to check the presence of *Pseudomonas* species. Plates containing nutrient pad were incubated after filtration at 37 °C for 72 h and then observed for microbial growth. Statistical analysis (t-test) was performed using Minitab 17 software (Minitab Inc., PA, USA) to determine if there were any differences in the ozone decomposition between the beginning and the end of a bottling production shift. Differences in physicochemical and bacteriological qualities of samples stored for 24 or 48 h were also ascertained. Probability level was set at $p \leq 0.05$.

Results and discussion

The physicochemical parameters analyzed in this study were chosen because they are key indicators of water quality and were the parameters regularly analyzed in the bottling plant. Moreover, these parameters have been reported to have an effect on the decay of ozone in water (Gardoni et al., 2012). The bacteriological tests carried out are common in any water treatment system. The results show that the ozone concentration decreased by 50% (Fig. 1) within 30 minutes and was no longer detectable after two and a half hours. This is close to the ozone concentration in potable water half-life (50% ozone concentration decrease within 24 minutes) reported by the other scientists (Mysore et al., 2012).

It has also been pointed out that the half-life of ozone at 20 °C and pH 7.0 completely dissipates within 5 hours in potable water (Bollyky, 2002). No significant difference ($p > 0.05$) was found between the rate of decomposition at the beginning and the end (Fig. 1) of the investigated bottling shifts, which suggests that the ozone dozing concentration was consistent throughout the monitored production shifts. The residual ozone of less than 0.04 mg/mL after two and a half hours is within the range of 0.04 mg/mL residual limit of the United States of America Food and Drug Administration (FDA, 2016) revised code of federal regulations for bottled water. The observed decomposition in this study differs in 9.2 minutes half-life calculated by Botti et al. (2014). In that study, the starting ozone concentration was ten times the concentration used in this study. It is possible that the higher concentration had an effect on the reported half-life.

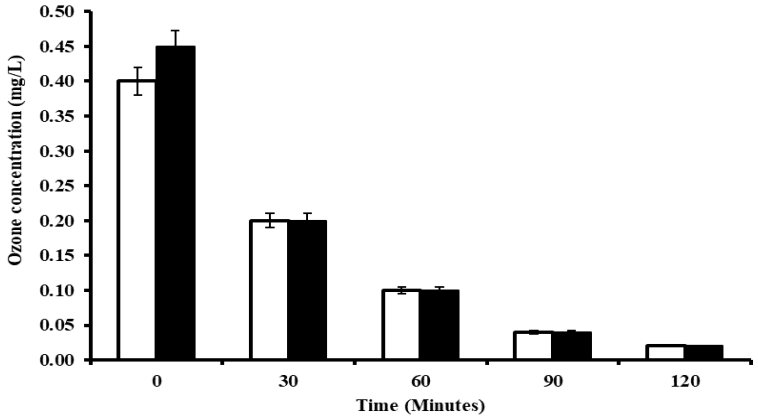

Fig. 1. Ozone concentration over time for table water collected in first (■) and last (□) hour of production in 10 h bottling shifts. Water from the bottled products was monitored every 30 minutes for ozone

Table 1. Descriptive statistics and Student's T-test *p* values for temperature, pH and total dissolved solids of table water samples stored for 24 or 48 hours

Temperature					
Sample	N	Mean	StDev	SE Mean	*p*-value (24 h vs 48 h)
24 h storage	100	23.560	0.715	0.072	0.09
48 h storage	100	23.400	0.620	0.062	
pH					
Sample	N	Mean	StDev	SE Mean	*p*-value (24 h vs 48 h)
24 h storage	100	7.0193	0.0152	0.0015	0.405
48 h storage	100	7.0175	0.0153	0.0015	
Total dissolved solids					
Sample	N	Mean	StDev	SE Mean	*p*-value (24 h vs 48 h)
24 h storage	100	0.0563	0.0123	0.0012	0.216
48 h storage	100	0.0582	0.0914	0.0091	

The physicochemical tests carried out showed that all water samples were within permissible limits (WHO, 2011). The pH was in the range of 7.0-7.06, while the temperature was between 23 and 25 °C. The total dissolved solids ranged from 0.05 to 0.09 mg/mL. No significant difference ($p > 0.05$) was found between the samples stored for 24 h or 48 h (Table 1) after ozonation, which indicates that there was no variation in key product parameters. No ozone was detected in all stored bottled samples and the bacteriological examination revealed no growth in any of the plates, which indicates that the residual ozone was sufficient to prevent organisms from reaching detectable thresholds.

Conclusion

It took two hours for the ozone to dissipate to reach safe levels in the analyzed bottled water and it was established that the physicochemical and bacteriological qualities regularly monitored in the bottling facility will not be affected if bottled products are held for 24 h instead of 48 h before the release for public sale. The bottling plant was advised to implement the proposed 24 h period as planned. The study highlights the importance of re-evaluating water treatment characteristics for process improvement, especially if a change in equipment, water supply or business direction is needed.

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