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Development and Operational Implementation of a Novel Method for Production of Ozonated Water

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ABSTRACT
The effectiveness of ozone is well established, yet, not applicable in several treatments due to some limitations. This causes existing industry up-to date is still using ozone gas in several treatment due to the difficulty of ozone to dissolve in water and even if dissolved in water, ozone has a relatively short half-life and the concentration is limited to several treatment. Therefore, in this study a novel system was developed to produce ozonated water with higher concentration and longer half-life by increasing the diffusion efficiency of ozone in water. This system utilizes the parameter with combination of high pressure and flow. The efficiency of mass transfer of ozone into water for both bubble diffuser and venturi injection technique were tested and compared in this research. The concentration of ozone water was examined using dissolved ozone analyzer. It was found that the production of ozone water applying venturi injection technique facilitates the production of higher concentration of ozonated water with higher ozone transfer efficiency. Moreover, the efficiency of the developed system is 2 times higher than the conventional method.

KEYWORDS: Ozone; Ozonated water; Ozone half-life; Ozonated concentration; Ozone treatment

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INTRODUCTION

Ozone is known as trioxygen in which each molecule contains three atoms of oxygen. Ozone is categorized as an organic molecule with chemical formula of O_3 and being a very unstable molecule. The principle behind the production of ozone involves the oxygen bond breaking by applying energy to form single oxygen atom which combines with other oxygen molecules to produce ozone. The ozone is recognized in its purification and disinfection properties and had been used in many industrial application include drinking water treatment, commercial laundry, food preservation, odour control, waste water treatment and many more (Rice & Netzer, 1982; Prabakaran *et al.*, 2012; Bermudez-Aguirre & Barbosa-Canovas, 2012; Nur *et al*., 2015)

Ozone gas can be dissolved into water to produce ozonated water. The solubility of ozone in water is adequate about 10 to 15 times greater than for oxygen under normal drinking water treatment conditions. The ozone gas can dissolve in one litre of water forming an ozonated water solution of about 0.1 to 0.6 litres depending on the solubility (Eagleton, 1999). In general, there are three basic methods to produce ozone water. The first method is bubble diffusers method which used a porous device for breaking the gas into small bubble at the bottom of a water column to allow the bubble to slowly rise to the top of column and dissolve into water. Second method is venturi injector method which requires a pressure differential across the device to create a vacuum to suck ozone gas into the device. Third method is static mixer which is designed for the sole purpose of mixing two flows together (Ozone solution, 2017). In aqueous solution, the ozone has a short half-life of approximately 20 minutes and the ozonated water can only be generated and used on-site when applied in the industrial process (Scholz, 2017). As the industrial demand increase in utilizing ozonated water for purification and disinfecting purposes, requirement in high efficiency of ozonated water system becomes prominent. The parameters that affect the reaction time and decomposition time of ozone water include the purity of oxygen source, size of gas bubbles, water temperature, water PH and water pressure. Theory suggested that ozone bubbles will have to travel further upward prior to escaping from the water surface given larger amount of water used (Ozone solution, 2017). Furthermore, the decomposition of ozone in OH-radicals in natural waters is characterized by a fast initial decrease of ozone, followed by a second phase in which ozone decreases by first order kinetics (Von, 2003). The half-life of ozone is in the range of seconds to hours depending on the water quality (Sharma, 2008; Von Gunten, 2003; Hoigne and Bader, 1994).

This paper discusses the effect of water volume to the dissolved ozone water concentration in the function of reaction time and decomposition time. In this study, two methods to produce ozone water which are bubble diffuser and venturi injection were applied in producing ozonated water. At the later part, the findings and output of the new system was established. The efficiencies of fabricated ozone water system to dissolve ozone gas in water at different volume were investigated.

METHODOLOGY

Experimental Procedure

The experimental work was conducted using two different methods which are bubble diffuser method and venture injection method as shown in Figure 1 and Figure 2 respectively. The experiment for bubble diffuser technique was carried out for 0.5L, 1L, 3L, 5L and 10L. For fabricated system using venturi injection was tested for two different volumes, 10L and 35L. All experiment was carried out using tap water as water source. The temperature of tap water was maintained at room temperature ranging from 24.0 °C to 26.5 °C. The reaction time and the decomposition time of the ozonated water were studied. Each sets of experiment were repeated three times and the data obtained was averaged and analysed.

The setup of the bubble diffuser method was as shown in Figure 1. Ozone generator which ionized oxygen molecule using corona discharge was applied to produce ozone gas. The cylindrical bubble diffuser stone was used to dissolve ozone gas into water. The diffuser has maximum flow rate at about 1 LPM with maximum pores size, 80 microns.

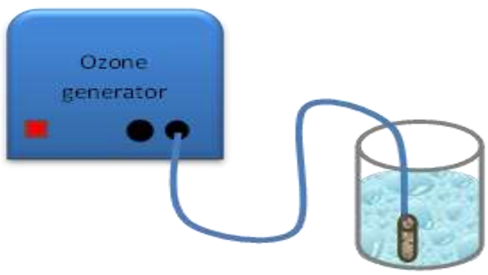

Figure 1. Schematic diagram of ozone water production by using bubble diffuser method.

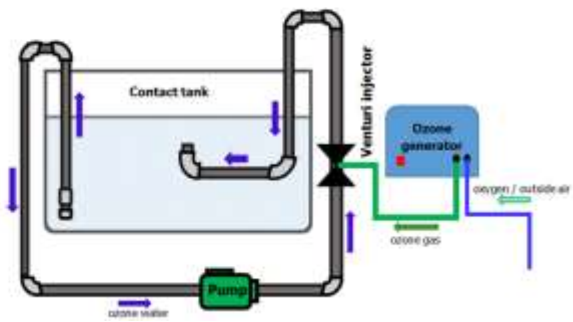

Figure 2. Schematic diagram of developed ozone water system by using venturi injection method.

Figure 2 shows the schematic diagram of the new developed system using venturi injection technique. This technique utilizes the combination of a pump and a contact tank. The main components of this system are ozone generator, contact tank, venturi injector, oxygen source and electric water pump. In this work, the same ozone generator is utilized to produce ozone gas. All experiments are conducted by using pure oxygen source as the input gas. Previous study had revealed that ozone concentration and ozone yield increases as oxygen pressure decreases (Boonduang *et al.*, 2012). In this research, oxygen gas is made constant at pressure of 0.5 psi which this pressure is observed to yield the optimized ozone concentration at a given time.

MK684 Kynar Injector Venturi is utilized in this new developed system. Venturi injection is a popular method to produce ozonated water as the ozone mass transfer rate is very high which is up to 98% if pressurized (Ozone solution, 2014). The ozone gas that was produced from the ozone generator was vented into the venturi injector, will diffuse into the water which will form the ozone water. The contact tank is used to store tap water or ozonated water after the reaction. This contact tank helps the ozone gas to dissolve better and improve the solubility of ozone gas in water. The tank is fully covered to avoid the ozone gas directly escape into the air. XILONG Submersibles power pump model xl-370 is used to produce the pressure differential required to maximise mixture of ozone gas with water in the venturi injector as it requires a constant pressure differential to initiate ozone injection. Also, the water pump allows a continuous circulation in the system to ensure that the water has maximum dissolved ozone concentration at the end of the reaction.

To measure the ozone concentration in water, Ozone Analyzer KRDRY-2056 is used in this research. The ozone meter used has a measuring range of 0-20mg/L which corresponds to 4-20 mA current output and a precision better than ±1%. During the experiment, the probe is immersed into ozone water for measurement.

$$\text{Output current (mA)} : I=16\times(C-A)/(B-A)+4 \quad (1)$$

where I is current output, C for instrument current measuring dissolved ozone, value A for setting of 4 mA and B for setting 20mA.

RESULT AND DISCUSSION

Analysis of Ozonated Water Concentration using Bubble Diffuser Technique

The data obtained is analysed and the relationship graph between reaction time and concentration of dissolve ozone is established to study the ozone water concentration. Figure 3 show the reaction time of ozone gas to dissolve in water against the concentration of ozone water.

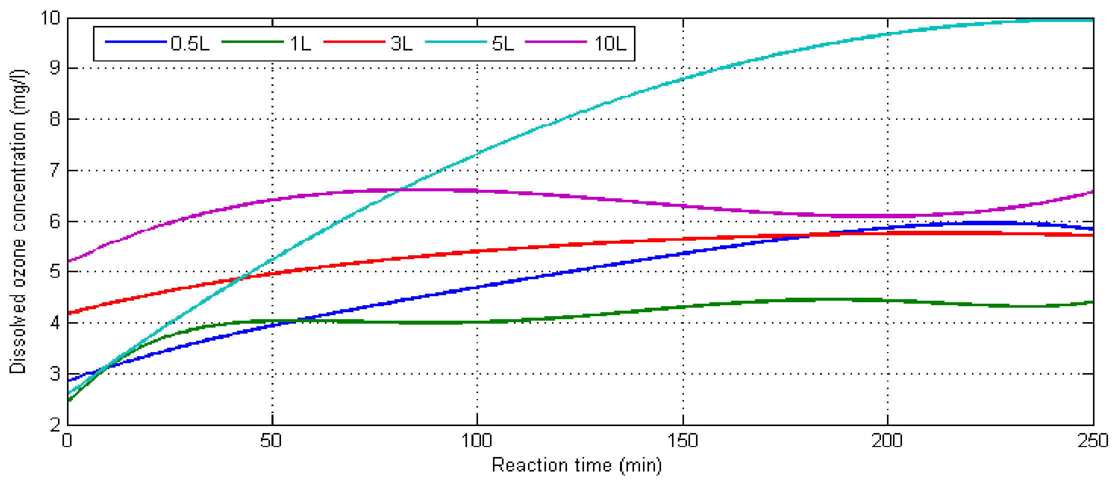

Figure 3. The saturation curve of ozonated water using bubble diffuser technique at different volume of water.

The graph shows that the concentration of dissolved ozone increases with the time reaction for all the varied volumes. As this experiment were carried out using tap water, the initial reading of is at approximately 3.00 mg/L. The maximum dissolved ozone which is achieved for 0.5 L, 1 L, 3 L, 5 L, and 10 L volume of water are 6 mg/L, 4.4 mg/L, 5.7 mg/L, 10 mg/L and 6 mg/L respectively. Moreover, the graphs trend show gradual increase of ozone dissolved concentration except for 10L where the graph trend shows increase at the first 40 minutes and then stabilizes at approximately 6 mg/L of ozone dissolve concentration over the period of 250 minutes. From this result, it clearly showed that the 5L water volume yields the highest concentration of ozonated water which is 10mg/l and the lowest dissolved ozone concentration was 4.5mg/L at volume 1L.

Table 1 tabulated the results of decomposition of ozonated water with time. The decomposition time indicates the time for the ozone gas to decompose from water, transforming back into oxygen molecule by approaching the value for distilled water which is approximately 0 mg/L. The data proves that ozone can destroy viruses and bacteria, and reduces the concentration of iron, manganese and sulphur in water (Prabakaran *et al.*, 2012). This also shows that ozone can be a good substitution for chlorine in water treatment. The reading is taken directly right after the ozone generation activity is stopped. The slower decomposition rate of ozone water is at volume of 3L where the decomposition takes duration of approximately 50 minutes. The higher decomposition rate is observed at the volume of water is 0.5L and 1L with a duration of 25 minutes and 18 minutes respectively. This may be caused by the lower level of water height that allows the ozone gas from water surface to easily escape.

Table 1. Decomposition of Ozonated Water with time

Volume of water (L)	Max. Dissolved O_3 concentration (mg/L)	Decomposition time (min)
0.5 liter	6	25
1 liter	4.4	18
3 liter	5.7	50
5 liter	10	40
10 liter	6	35

Analysis of Ozonated Water Concentration utilizing New Developed System

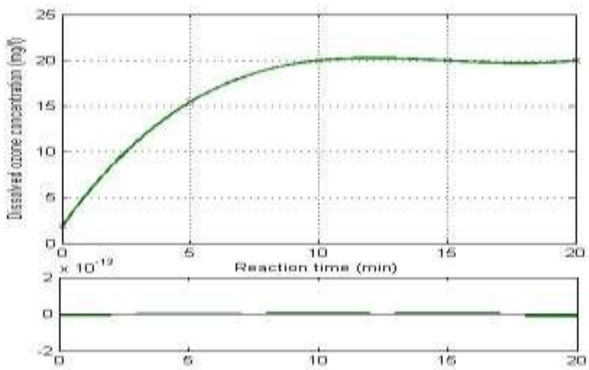

Figure 4. The reaction time against dissolved ozone for volume of 10 L.

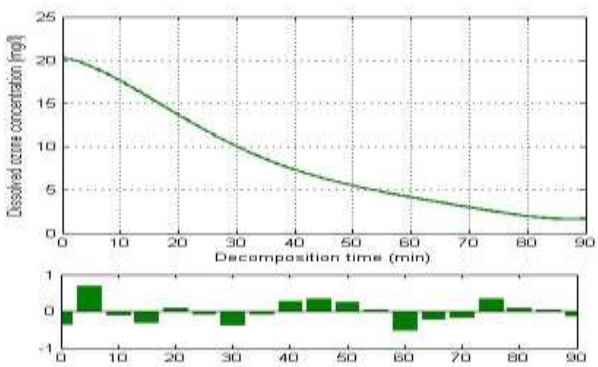

Figure 5. The decomposition time of dissolved ozone for volume of 10 L.

Figure 4-7 represent the findings of the fabricated system that utilizes the venturi injection methods to produce ozonated water. The result for the 10 L of water is shown in Figure 4 in which the trend shows dramatic increase over a period of 20 minutes. For this experiment, the higher dissolved ozone concentration value is measured until 20mg/L as it is the maximum value that can be measured by the ozone meter. The maximum dissolved ozone concentration at 20mg/L is achieved at the first 10 minutes. The decomposition of ozone for 10L is shown in Figure 5. The dissolved ozone concentration decreased gradually over a period of 90 minutes. The outputs of the new fabricated system at 35 L are as shown in Figure 6 and Figure 7. From figure 6, the generation of ozone water escalated over a period of 60 minutes. The maximum dissolved ozone concentration, 20mg/L is completed at 50 minutes while the decomposition time of ozonated water is 50 minutes as shown in Figure 7.

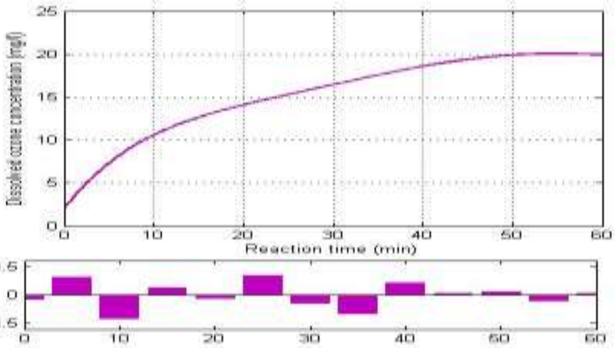

Figure 6. The reaction time against dissolved ozone for volume of 35 L.

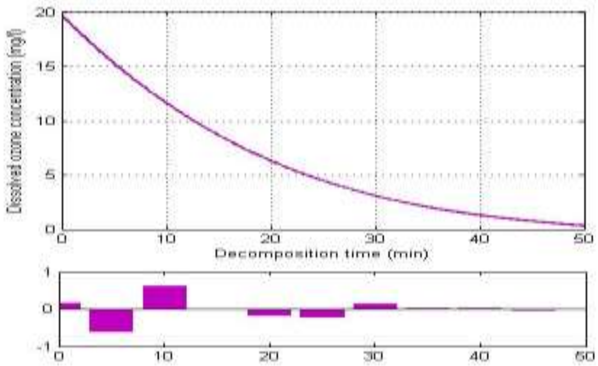

Figure 7. The decomposition time of dissolved ozone for volume of 35 L.

Referring to Figure 4-7, both volume of water show an increasing trend and reached maximum dissolved ozone concentration at 20mg/L. Even though both have similar trend, the reaction time to achieve the maximum ozone dissolved concentration for 10 L is faster than 35L. Meaning that, by using this fabricated system, the increase in volume of water used will slower the reaction of ozone to dissolve into water. The decomposition time of ozone water for 10L and 35L show a slight declining trend over a period of 90 minutes for 10L and 50 minutes for 35L. These trends specify that, the decomposition time of ozonated water for 35L is faster than 10L.

CONCLUSION

The study highlights the ability of the new developed prototype to produce higher concentration of ozone water using venturi injection technique with an integration of other factors to improve the solubility of ozone water. It has been demonstrated that the use of the new developed prototype can produce high concentration of ozone water with longer decomposition time compared to bubble diffuser technique. The maximum achieved ozone concentration for the developed system is 20mg/L, while it is 10mg/L for the bubble diffuser technique. Meanwhile the reaction rate of the new system is 2 times than the conventional system.

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