Innovative Method of Utilising Hydrogen Peroxide for Source Water Management of Cyanobacteria

Jianyin huang (✉ leslie.huang@unisa.edu.au)

University of South Australia <https://orcid.org/0000-0003-1584-9341>

Maximus Ghaly

University of South Australia

Peter Hobson

South Australian Water Corporation

Christopher W.K. Chow

University of South Australia

Research Article

Keywords: algal blooms, algaecides, copper sulphate, hydrogen peroxide, decomposition

Posted Date: August 30th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-741784/v1>

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Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on November 18th, 2021. See the published version at <https://doi.org/10.1007/s11356-021-17511-5>.

Abstract

The treatment and control of cyanobacterial blooms using copper-based algaecides in water reservoirs has historically been used, however, due to the adverse impact of copper on the environment, water authorities have been researching and studying new and innovative ways to control cyanobacterial blooms. Hydrogen peroxide has been investigated as an environmentally friendly alternative and this research aims to determine the impact of water quality on its effectiveness based on the decay characteristics in different water samples. Natural water samples from South Australian reservoirs were used to evaluate hydrogen peroxide decomposition and provide a better strategy for water operators in using it as an algaecide. Our experiments show the dependency of hydrogen peroxide decomposition not only on water quality but also on the initial hydrogen peroxide dose. A higher initial hydrogen peroxide dose can trigger the increase of pH, leading to increased consumption of hydrogen peroxide. In addition, the hydrogen peroxide decomposition is significantly accelerated with the rise of copper concentration in water samples. Moreover, it is found that UV light can also affect the decomposition rate of hydrogen peroxide. The hydrogen peroxide decay is more significant under UV light for the samples with lower hydrogen peroxide concentrations. Our study also shows the impact of DOC on hydrogen peroxide decomposition is not substantial. The study also presents a modelling method to optimise hydrogen peroxide application based on water quality characteristics. Our findings can provide knowledge for the water industry to produce a suitable model which can be used to optimise the application of hydrogen peroxide for the control of cyanobacteria.

1. Introduction

Population increase, urban growth and expansion of agricultural practices have led to the increase of nutrient levels in the environment and waterways (Newcombe et al. 2012). This increase in nutrient concentration and increase in global temperatures, due to the climate change (Jančula &Maršálek 2011, Newcombe et al. 2012), have had an obvious negative impact on the aquatic ecosystem, especially in the mass development of cyanobacteria in water resources (Jančula &Maršálek 2011). Cyanobacteria in waterways has been the focus of many studies over recent decades given the environmental and health risks they pose on humans and other living species, such as livestock, wild mammals, birds and fishes (Dreyfus et al. 2016, García-Villada et al. 2004, Stewart et al. 2008). Humans can suffer from heart and kidney diseases, gastrointestinal irritation, liver failure or even death due to consumption of these toxins (Carmichael &Boyer 2016, Fitzgerald et al. 1999, He et al. 2012, Westrick et al. 2010). This highlights the importance of having access to high quality and appropriately treated drinking water (Antoniou et al. 2013, Chow et al. 1999, Westrick et al. 2010, Xing et al. 2015). Moreover, cyanobacteria pose a challenge for water supply systems due to production of unpleasant taste and odour compounds (García-Villada et al. 2004, Lee et al. 2017). Consequently, this requires more intensive and costly treatment process to eliminate their presence (Hitzfeld et al. 2000).

To improve the effectiveness of treatment, a variety of options have been proposed to control cyanobacteria in the source waters. Stroom andKardinaal (2016) identified two major approaches to

removing cyanobacteria, namely preventative and control. Preventative measures involve improvement of the chemical and biological health of the system and control encompasses direct actions to stop cyanobacteria proliferation. In reservoirs, one such direct control is chemical treatment using algaecides which have been widely utilised and extensively studied as a way of reducing cyanobacteria numbers prior to conventional drinking water processing (Antoniou et al. 2013, Chow et al. 1994, Fan et al. 2014, García-Villada et al. 2004). This includes the use of copper sulphate, copper chelates, aluminium sulphate, or potassium permanganate algaecides (Fan et al. 2014, García-Villada et al. 2004). Among these algaecides, the toxicity of copper sulphate on cyanobacteria cells and its effectiveness of algae elimination and cell density control has been widely studied and documented (Costas & Lopez-Rodas 2006, Fan et al. 2013, García-Villada et al. 2004). Using copper sulphate is also economical and relatively safe for human health as well as easy to apply (Fan et al. 2013, García-Villada et al. 2004, Jančula & Maršálek 2011). Copper sulphate is generally applied at the early stage of bloom formation. However, this treatment does not totally remove all cyanobacteria and repeat doses are required when cyanobacteria once again return (García-Villada et al. 2004). Furthermore, it has been speculated that the excessive treatment of algae, using copper sulphate, can develop cell resistance, which requires higher concentration and more frequent treatments (García-Villada et al. 2004, Kansole & Lin 2017, Murray-Gulde et al. 2002). The excessive use of copper sulphate can also impact on the biotic and abiotic fresh water characteristics (Song & Wang 2015) and has a serious ecological impact on non-target species (Greenfield et al. 2014, Jančula & Maršálek 2011). For example, copper has a toxic effect on *daphniids*, and the fish, *danio rerio* (Closson & Paul 2014, Jančula & Maršálek 2011, Murray-Gulde et al. 2002). Additionally, copper can be transported from the water supply reservoir in a dissolved organic or inorganic form raising the risk of metal accumulation and toxicity in sediments (Fan et al. 2013, Jančula & Maršálek 2011). The excessive and incorrect use of copper sulphate dosing has also been associated with hepatitis illness of children and adults in Palm Island in Queensland (Kansole & Lin 2017, Prociv 2004).

There have been a number of studies examining the effectiveness of hydrogen peroxide (H_2O_2), the active ingredient of sodium percarbonate (SP) when used as an algaecide. However, there is very little research on the impact of different water types with various chemical characteristics on residual H_2O_2 which acts as the algaecide. The current paper presents results from an investigation of the effects of different water chemistries on H_2O_2 decomposition and development of a models to estimate the H_2O_2 decomposition in water over time. This information will be valuable in understanding the activity of H_2O_2 as an algaecide in natural waters and help operators develop its use to control cyanobacterial blooms.

2. Materials And Methods

2.1 Site selection and sample collection

Experimental waters were sourced from three South Australian locations that have had a history of cyanobacterial blooms and include Happy Valley Reservoir, Torrens River, and Myponga Reservoir. Happy Valley Reservoir is located in Adelaide and supplies drinking water to over half a million people. The

Torrens River is a recreational water course located near Adelaide's CBD. Myponga Reservoir is located about 60 km south of [Adelaide](#) and it is fed by the [Myponga River](#) and other smaller catchment streams, and provides about 5% of [Adelaide's](#) water supply.

Samples collected from these three sites were filtered through a 90 mm glass microfiber filter Gf/C and kept in a refrigerator under 4°C. All glassware and storage containers were washed three times with distilled water, followed by three washes with ultrapure deionised water (Milli-Q element, 18.2 MΩ) before a final rinse with the reservoir water used in each experiment.

2.2 Materials, reagents and solutions

Sodium percarbonate (SP) stock solution was prepared by dissolving 18.382g granulated SP (IXOM Operations Pty Ltd) in 1 L of Milli-Q water to give a final hydrogen peroxide concentration of 5 g/L. This stock solution was used to simulate the same method of H₂O₂ dosing in reservoir water. Copper sulphate solution was prepared by dissolving 9.82 g of CuSO₄·5H₂O (AR, Chem-Supply) in a litre of Milli-Q water. Buffer stock to perform the H₂O₂ concentration measurement was prepared by mixing 18 mL of 0.5 mol/L Na₂HPO₄ and 82 mL of 0.5 mol/L NaH₂PO₄ to achieve pH 6 in tested samples. N,N-diethyl-1,4-phenylenediammonium sulphate (DPD) reagent was prepared by diluting 0.1 g of N,N-diethyl-1,4-phenylenediammonium sulphate, Fluka, in 10 mL of 0.1 N H₂SO₄. Horseradish peroxidase reagent was prepared by diluting 10 mg of horseradish peroxidase, Type II, 181 purpurogallin units/mg, in 10ml of Milli-Q water (Drábková et al. 2007).

2.3 H₂O₂ analysis / concentration determination

The method used to measure the H₂O₂ concentration was adapted from Drábková et al. (2007), which was modified from Bader et al. (1988). 30% H₂O₂ solution (AR, Chem-Supply) was used to create H₂O₂ standard solutions. Two H₂O₂ standard curves were prepared to determine the H₂O₂ at low and high concentration. The standard curve to determine low H₂O₂ concentration of less than 5 mg/L (0, 0.056, 0.113, 0.226, 0.564, 1.13 and 5.64 mg/L) was prepared by mixing 16.6 µL of H₂O₂ standard solution to 1 L of Milli-Q water, followed by multiple dilutions. The standard curve to measure high H₂O₂ concentration of more than 5 mg/L (0, 0.11, 0.57, 1.13, 2.27, 3.4, 6.8 and 13.6 mg/L) was prepared by mixing 1 mL of H₂O₂ to 1 L of Milli-Q water, then followed by multiple dilutions. Standard solutions were then analysed in Agilent Cary 60 UV-Vis spectrophotometer at 551.0 nm.

For H₂O₂ concentrations up to 5 mg/L, 100 µL of the buffer solution, 50 µL of DPD reagent, and 50 µL of HRP reagent and 900 µL of the water sample were mixed in a polystyrene cuvette by inverting before immediately placing in UV-VIS spectrophotometer and measuring absorbance. Concentration was then determined from the corresponding standard curve. For H₂O₂ concentration greater than 5 mg/L, 100 µL

of the buffer solution, 850 μL of Milli-Q water, 50 μL of DPD reagent, and 50 μL of HRP reagent was used. All measurements were made in triplicate.

2.4 Investigate the effects of different parameters on H_2O_2 decomposition

a. The effects of different water types

A 200 mL volume of either Milli-Q water or experimental water samples were dosed with 40, 200, 400 and 800 μL of SP solution to achieve initial concentration of 1, 5, 10 and 20 mg/L H_2O_2 . All samples were incubated (Thermoline Scientific TRIL-1175-2-SD) at 20 °C in the dark over a 24-hour period to ensure the change in H_2O_2 concentration was not affected by changes in light or temperature. The water samples were collected at the time of initial dosage, and on every hour for a period of 7 hours to determine the H_2O_2 concentrations. At the same time, pH was measured using Oakton pH Meter (510 series) every hour for each water sample across all the four concentrations. Additionally, the H_2O_2 level was again measured 24 hours later from the initial dosage.

b. Additional Control Experiments

i. The effect of UV light

The experiment was conducted in Happy Valley reservoir water using the same method, concentrations and conditions as presented in 2.4a except in the presence of UV light. All samples were kept in the incubator under two UV lamps (Dermfix 3000 phototherapy 310-312 nm spectrum). H_2O_2 concentrations were measured at the time of initial dosage and on every hour for a period of 7 hours, with a final sample taken 24 hours after the initial dosage. pH was also determined over the same period.

ii. The effect of copper sulphate under dark condition

The experiment was carried out in Milli-Q water using same methodology presented in section 2.4a but replacing hydrogen peroxide with 0.5 mg/L Cu^{2+} . pH was determined as described previously.

iii. The effect of DOC under dark condition

The experiment was carried out in Milli-Q water as described in section 2.4a but with inclusion of dissolved organic carbon (DOC) extract as surrogate of natural organic matter (NOM) present in natural water samples. The DOC was added to the samples using the laboratory organic extract adopted from

the Spent Brine of Mt Pleasant, South Australia, MIEX based Water Treatment Plant. 200 µL of the organic compound was dosed into 200 mL samples to achieve 10 mg/L DOC in all samples. H₂O₂ concentrations and pH were also determined using the same procedure as previously described.

2.5 Data analysis and model development

Experimental data was initially processed and analysed using Microsoft Excel. For further data analysis and model assessment, the three-column H₂O₂ concentration, dosage and time data were further analysed using TableCurve3D, Systat Software, Inc., to obtain the equation of best fit. TableCurve3D used the built-in equation types / equations to fit the experimental data and ranked against the r² value. The simple equation option was initially selected, if r² values were good, >0.95, then simple equation will be used to provide the best equation for the decay characteristic of each water sample, which were then used to establish an initial prediction model. By using the coefficients which were determined by the fitting procedure, the H₂O₂ decay behaviour can be established for each water source, thus, the CT (contact time x concentration) value can be determined.

3. Results And Discussion

3.1 Characteristic of water sources

The filtered water samples from three field sites were analysed to determine chemical characteristics. The results in Table 1 show that the total iron concentrations in filtered water samples were between 0.11 and 0.21 mg/L, TKN was between 0.69 and 0.97 mg/L, and pH between 7.6 and 8 from three field sites. Torrens River and Happy Valley have similar total manganese levels of approximately 0.045 mg/L which is much higher than Myponga, with only 0.0017 mg/L. Happy Valley has the lowest total phosphorus concentrations compared to others.

Table 1
Measured water quality parameters for water samples collected from three field sites.

	Torrens River	Myponga	Happy Valley
pH	8.0	7.6	7.9
Iron-Total (mg/L)	0.108	0.208	0.196
Manganese-Total (mg/L)	0.045	0.002	0.049
Phosphorus-Total (mg/L)	0.036	0.035	< 0.003
TKN (mg/L)	0.97	0.83	0.69
Copper-Total (mg/L)	0.003	0.025	0.435
DOC (mg/L)	5.9	13.8	7.1

However, total copper and DOC concentrations showed large differences amongst the samples, Happy Valley water had a significantly higher total copper level compared to Torrens River (136 times higher) and Myponga Reservoir (17 times higher). Myponga Reservoir water had the highest DOC level of 13.8 mg/L among the three water sources (Table 1). The rest of study will be concentrating on the impact of copper and DOC.

3.2 The effects of different water types on H_2O_2 decomposition

Figure 1 shows the effect of H_2O_2 dosages on pH, two trends, low doses (1 mg/L and 5 mg/L) and high doses (10 mg/L and 20 mg/L), were observed. For low H_2O_2 dosages, an observable trend of pH decreased slightly after the addition of H_2O_2 then increased after 24 hours. For high dosages, pH initially increased then decreased after 24 hours. There is also another general trend of pH increased with the increasing H_2O_2 concentration. Milli-Q water has the highest pH increase (to pH 10) after addition of H_2O_2 compared to the field water samples (increased to about pH 9), the final high pH in Milli-Q after addition of H_2O_2 is likely caused by the low buffering capacity of Milli-Q water. For the Myponga samples and Milli-Q water with low doses of H_2O_2 , pH remained relatively constant over 24 h after addition of H_2O_2 . The initial increase in pH after high H_2O_2 may explain the initial rapid loss of H_2O_2 concentration in high dose situations (will be discussed later in the manuscript).

Figure 2 presents the H_2O_2 decomposition (decay) for different water types over 24 hours. Our results show that there is no observable change in H_2O_2 concentration (decomposition) in Milli-Q water at different concentrations after 24 hours compared to other water types for low H_2O_2 concentration (1 mg/L). However, for high doses, a rapid initial drop in H_2O_2 concentration is observed (all four water types), this could be related to the initial increase in pH after H_2O_2 addition reported earlier. Torrens River samples showed a slow decomposition of H_2O_2 . The H_2O_2 concentration decreased by 41%, 30%, 33%,

and 33% of the initial H_2O_2 concentrations of 1, 5, 10, and 20 mg/L, respectively after 24 hours. The results of Myponga Reservoir water samples presented a similar trend compared to Torrens water. The H_2O_2 concentrations in the samples reduced by 23%, 22%, 24% and 22% compared to initial concentrations of 1, 5, 10, and 20 mg/L, respectively. Conversely, the results of Happy Valley water samples showed a significant variation in H_2O_2 decomposition over the 24-hour period across all four concentrations. The results shown in Fig. 1 demonstrate a significant drop in the concentration with 100% loss of H_2O_2 at high H_2O_2 dosages (10 and 20 mg/L), 95% was lost at 5 mg/L dosage while 67% was lost at 1 mg/L dosage after 24 hours. The results also showed a rapid decomposition in the early stage for the Happy Valley water samples where 24% was decomposed at 1 mg/L, 45% at 5 mg/L, 72% at 10 mg/L and 81% at 20 mg/L after the first hour. In general, for all water samples, the percentage lost has a direct relationship with the H_2O_2 dose i.e. higher the H_2O_2 dose the higher the percentage reduction. Studies showed that H_2O_2 was more stable in low and moderate pH. However, when the pH continued to increase and reached alkalinity condition, it could lead to high consumption of H_2O_2 in solutions (Lee et al. 2013, Pędziwiatr 2018, Yazici & Deveci 2010). From Fig. 1, we can see that higher initial dose of H_2O_2 triggered a significant change of pH after H_2O_2 was added. The increased pH can result into a rising rate of reaction for H_2O_2 , leading to higher the percentage reduction of H_2O_2 (Fig. 2). From this result, higher H_2O_2 dose does not necessarily mean the H_2O_2 will perform better than lower H_2O_2 dose. If the system's pH increases significantly after initial doses of H_2O_2 , it could cause rapid consumption of H_2O_2 , affecting its performance as an algaecide. In addition, over-application of H_2O_2 is not economic for the water authorities.

Furthermore, Happy Valley water showed a substantial and rapid loss of H_2O_2 concentration across all samples in comparison to Torrens River and Myponga Reservoir water. It was reported that the amount of copper was much higher in Happy Valley compared to Torrens River and Myponga Reservoir water and it is assumed that this is the reason for high H_2O_2 decomposition in Happy Valley water. To confirm whether the metal contents influenced the results, as assumed, further experiments were conducted using Milli-Q water with a similar concentration of copper sulphate found in Happy Valley water.

3.3 The effect of copper sulphate on H_2O_2 decomposition

The results of adding copper sulphate to the Milli-Q water samples were similar to Happy Valley water (Fig. 3). 1 mg/L H_2O_2 test solutions showed a slower reduction with only 42% of H_2O_2 loss after 24 hours, while the 5 mg/L H_2O_2 samples showed a 97% loss after the same duration. The samples with both 10 and 20 mg/L H_2O_2 (high dosages) showed a rapid loss of H_2O_2 with 100% removal after 24 hours.

The results of the Milli-Q water mixed with similar copper concentration found in Happy Valley water samples of 0.5 mg/L, showed very similar behaviour to the H_2O_2 decomposition of the Happy Valley water experiment conducted in the dark. This was in complete contrast to the Milli-Q water alone. These results suggest the rapid decay observed in the Happy Valley water samples was due to the presence of copper in the reservoir water. These results are consistent with the study of Akagawa and Suyama (2002),

which indicated that Cu^{2+} was more effective than Fe^{3+} in catalysing the H_2O_2 and could generate hydroxyl radicals at a much higher rate than Fe^{3+} . Others studies from Yazici and Deveci (2010) and Mlasi (2015) of H_2O_2 decomposition in the presence of copper also confirmed that the copper acts as a catalyst, which could accelerate H_2O_2 decay. Yazici and Deveci (2010) and Mlasi (2015) showed the H_2O_2 decomposition was also significantly accelerated as the amount of copper was increased. In addition, Lee et al. (2013) indicated that the catalytic decomposition of H_2O_2 by Cu^{2+} could be accelerated when pH increased. This is because the deprotonated form of H_2O_2 could act as the major electron-donor for the reduction of Cu^{2+} . Therefore, the pH increase in solutions caused by higher initial H_2O_2 dose can also accelerate H_2O_2 decay under the presence of Cu^{2+} .

Based on the experimental results, it has been confirmed that H_2O_2 decomposition is dependent on water quality, especially the amount of metals present. It was also confirmed that water types consisting of low metal contents, such as Torrens River and Myponga Reservoir water, can maintain H_2O_2 residual for over a 24-hour period. However, if metal content is high, such as observed in the Happy Valley samples, the algicidal activity of H_2O_2 could be impacted. In addition, the pH changes after the initial dose of H_2O_2 could further affect the H_2O_2 decomposition with the presence of metals (Lee et al. 2013). Therefore, determining the optimum initial dose of H_2O_2 in the water bodies under laboratory condition is recommended before any large-scale application of H_2O_2 in the natural waters.

3.4 The effect of UV light on H_2O_2 decomposition

H_2O_2 combined in the presence of UV light for same sample conditions showed an increased decomposition rate compared to samples tested in the dark. 100% of the initial H_2O_2 concentration was decomposed in the higher concentration samples of 10 and 20 mg/L in an 8- and 4-hour period, respectively. This is compared to 24 and 6 hours of total H_2O_2 lost in the dark for the same concentration. In addition, the loss of the H_2O_2 in the first hour was greater than samples in the dark for 10 and 20 mg/L concentrations. The H_2O_2 was also 100% decomposed in all H_2O_2 doses after a 24-hour period. This showed a higher decomposition rate in comparison to the same water samples and concentrations when incubated in the dark. In Fig. 4, the side by side comparison of H_2O_2 decomposition in the dark and in the presence of UV light, it is more clearer in the low dose cases that the decay curve for samples in the dark has a higher corresponding H_2O_2 concentration than those with UV light.

Additionally, when H_2O_2 was combined with UV under the same conditions and concentrations, it was found that UV light affected the decomposition rate. This was especially evident with lower concentration samples, which maintained higher H_2O_2 residuals after a 24 h period compared to the same water tested in the dark. These results are consistent with the study of Drábková et al. (2007), which proved that low concentrations of H_2O_2 of 0.6 and 2.5 mg/L were decomposed in three hours of exposure to UV light. Drábková et al. (2007) argued that this proved the effect of UV on improving H_2O_2 toxicity. This was

explained by the rapid decomposition in the presence of UV, which produced more hydroxyl radicals and enhanced the H_2O_2 toxicity on cyanobacteria cells.

3.5 The effect of DOC on H_2O_2 decomposition

To understand the impact of NOM, the higher DOC concentration on H_2O_2 decomposition in Myponga Reservoir water (highest DOC concentration compared with the other samples), further experiments were conducted using Milli-Q water at similar concentration of the DOC found in Myponga Reservoir water. The Milli-Q water samples with added DOC did not show a significant loss of H_2O_2 after 24 h, a similar result to Milli-Q water without added DOC concentrations when incubated in the dark (Fig. 5).

The results shown in Fig. 5 were in line with the study of Bissey et al. (2006), which found the same decomposition rate of H_2O_2 in natural soils with organic carbon content of 1.6% and 0.2%. Huling et al. (2001) also confirmed that the decomposition of H_2O_2 was independent from organic matter and the decomposition occurs by catalytic reaction with metals rather than the organic component. However, Autin et al. (2013) explained that DOC can compete with cyanobacteria cells to react with the hydroxyl radicals produced by H_2O_2 decay. While the current study showed no impact of DOC on H_2O_2 decay the interaction of DOC with H_2O_2 in the presence of algal cells will need further investigation to understand any changes in algicidal activity in natural waters.

3.6 Using curve fitting technique to model decay in the presence of copper

From our findings, the cause of decay was mainly due to the presence of copper in the water. In this section, a curve fitting technique was applied to understand the decay behaviour of H_2O_2 in the presence of copper. The copper concentrations of Torrens River, Myponga Reservoir and Happy Valley water samples determined by copper analysis showed the results are in the order of magnitude difference of $\mu\text{g/L}$, 10 $\mu\text{g/L}$ and 100 $\mu\text{g/L}$ range, respectively. The autofit function in TableCurve3D was used to get the best fit equation i.e. highest r^2 value. As explained earlier in the Materials and methods section, TableCurve3D used its equation library to find the best fit equations and ranked them based on the r^2 value from high to low. For the Happy Valley water decay data, the top ranked equation is Eq. 302461513: $z^{-1} = a + bx + c/y$, $r^2 = 0.97$, z is H_2O_2 concentration in mg/L , x is time and y is H_2O_2 dose. The same fitting procedure was conducted for Myponga and Torrens River decay data sets, Eq. 151232881 $\ln z = a + b e^{-x} + c \ln y$ is the top ranked equation for both waters, $r^2 = 1.00$ and 0.99 for Myponga and Torrens River waters, respectively. Despite the order of magnitude difference for Happy Valley, Myponga and Torrens River, the same equation / equation family was listed as the best fit for the decay curves for Torrens River and Myponga, while Happy Valley has a different equation. This indicates that the impact of copper on H_2O_2 decay may only occur when a threshold level is reached. Both the copper concentrations in Myponga (0.025 mg/L Cu) and Torrens (0.003 mg/L Cu) would be below the threshold level thus the

same best fit equation was found to represent the decay characteristics. While in Happy Valley the copper concentration is in 100 ug/L range and a different equation was found to represent the decay characteristics.

Table 3
Coefficients for the best curve fitting equation for Happy Valley, Myponga and Torrens River.

	Equation	r ²	Coefficients
Happy Valley	$z^{-1} = a + bx + c/y$	0.97	a=-0.004, b = 0.195, c = 1.071
Myponga	$\ln z = a + b e^{-x} + c \ln y$	1.00	a = 0.296, b = 0.177, c = 1.020
Torrens River	$\ln z = a + b e^{-x} + c \ln y$	0.99	a = 0.355, b = 0.267, c = 0.998

Additionally, the coefficients, a, b, c values, presented in Table 3 can be used determine the H₂O₂ concentration for a particular dose at a particular time to estimate the efficiency. The equation developed by this research can be used as a model to estimate the required initial H₂O₂ dose for a set contact time in a particular water type. Furthermore, a CT value can also be determined.

4. Conclusion

This study investigated hydrogen peroxide decomposition in different natural water samples from South Australia, including two reservoirs and a river, to provide a better understanding of its activity as an algaecide. Cyanobacteria is an ongoing problem in water reservoirs, wastewater systems, and recreational waters in South Australia (Baker &Humpage 1994). During the period of late 1990s until 2011, Torrens River was closed for some time during summer periods because of algae growth, which formed scums, produced unpleasant odours, and released toxins that could impact both the human and the natural environment. Copper sulphate has been used in South Australia for more than 50 years to control algal growth in some of the state’s reservoirs. However, its harmful impact on the environment and increasing cost of the chemical, has driven our local water utility, SA Water, to identify and develop innovative alternative algal control methods. One of the potential alternatives, sodium percarbonate, is considered a more environmentally friendly option than copper sulphate.

The results from our research have shown that water quality and chemistry can play an important role in hydrogen peroxide decomposition in water and in turn its toxicity to cyanobacteria. It is evident that water components, especially metals, such as ambient level of copper in the reservoir, can impact the rate of decomposition of H₂O₂ in natural waters. Additionally, the pH changes related to the initial H₂O₂ does can affect the rate of decomposition of H₂O₂ in water. Moreover, this work highlights the effect of UV light availability on the decomposition of H₂O₂. The knowledge gained from this research will be important for constructing a model explaining the interactions of hydrogen peroxide in natural systems and developing

formulae to help reservoir operators determine the required algaecide dose for removal of problem cyanobacteria.

Declarations

Acknowledgments

The authors would like to thank UniSA STEM and SA Water to support Maximus Ghaly's Master study.

Ethical Approval

Not applicable.

Consent to Participate

Not applicable.

Consent to Publish

Not applicable.

Authors Contributions

Jianyin Huang: experimental design, data analysis, manuscript writing and supervision. Maximus Ghaly: experiment, data analysis and manuscript writing. Peter Hobson: experimental design, manuscript writing and supervision. Christopher W.K. Chow: experimental design, data analysis, manuscript writing and supervision.

Funding

Not applicable.

Competing Interests

The authors declare no competing interests.

Availability of data and materials

Not applicable.

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Tables

Table 2 is not available with this version.

Figures

Figure 1

pH changes in the water samples at different dosages, 1 mg/L, 5 mg/L, 10 mg/L and 20 mg/L, of H₂O₂ over 24 h in a) Milli-Q, b) Torrens River, c) Myponga and d) Happy Valley.

Figure 2

The H₂O₂ decomposition (decay) in different water types, a) Milli-Q, b) Torrens River, c) Myponga and d) Happy Valley with different H₂O₂ dosages, 1 mg/L, 5 mg/L, 10 mg/L and 20 mg/L. Measurements were done in triplicates, standard deviations were determined to be within 5% error, for clarity of the figure, error bars were not shown.

Figure 3

The H₂O₂ decomposition in Milli-Q water with 0.5 mg/L of Cu²⁺ and Happy Valley water dosed by various H₂O₂ dosages, a) 1 mg/L, b) 5 mg/L, c) 10 mg/L and d) 20 mg/L. Measurements were done in triplicates, standard deviations were determined to be within 5% error, for clarity of the figure, error bars were not shown.

Figure 4

H₂O₂ decomposition curve for Happy Valley water with UV light and in the dark with various H₂O₂ dosages, a) 1 mg/L, b) 5 mg/L, c) 10 mg/L and d) 20 mg/L. Measurements were done in triplicates, standard deviations were determined to be within 5% error, for clarity of the figure, error bars were not shown.

Figure 5

H₂O₂ decomposition curve for Mill-Q and Mill-Q with added DOC with various H₂O₂ dosages, a) 1 mg/L, b) 5 mg/L, c) 10 mg/L and d) 20 mg/L. Measurements were done in triplicates, standard deviations were determined to be within 5% error, for clarity of the figure, error bars were not shown.