

Preparation of the Second-Generation Oxygen Release Compound and Assessment of its Oxygen Release Performance in Water

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Abstract. The objective of this study was to prepare a long-lasting high performance oxygen-releasing agent (called 2G-ORC, the second-generation oxygen release compound in this study). The lab-prepared 2G-ORC is comprised of sustained-release catalase and high stability sodium percarbonate. In this study, catalase was embedded in chitosan to control its water solubility and prolong its effectiveness, whereas PLGA (Poly (D,L-lactide-co-glycolide)) was coated with nanoscale sodium percarbonate to reduce its solubility to achieve its stable release. Test results showed that sustained-release catalase (added only once) has the ability to catalyze hydrogen peroxide and produce oxygen for 15 days while maintaining the dissolved oxygen concentration in the range of 13.84-15.17 mg/L in water. When sustained-release catalase was further combined with high-stability sodium percarbonate, it could maintain the dissolved oxygen concentration (6.24 mg/L) higher than the dissolved oxygen concentration of deionized water (5.43 mg/L) even after 7 days of application. Test results are really promising in enhancing the degradation of organic pollutants by indigenous microorganisms.

Keywords: 2G-ORC, sustained-release catalase, high stability sodium percarbonate

1. Introduction

It is well known that microorganisms degrade contaminants faster and more completely under aerobic conditions than anaerobic conditions. More importantly, how to maintain a sufficient level of oxygen content in the system is crucial for the growth of aerobic microorganisms and their ability to degrade the neighbouring organic contaminants. To meet this need, many research and engineering efforts have been made aiming at converting commonly found anaerobic conditions in contaminated sites to aerobic conditions. Among these efforts, addition of an oxygen release compound (ORC) to groundwater for bioremediation is widely practiced over the world.

Generally, ORC is designed specifically for enhanced, *in situ* aerobic bioremediation of organic contaminants in the subsurface. The remediation effectiveness of ORC has already been confirmed in the lab-scale studies and field applications. In the literature, different ORCs have been tested for bioremediation of various organic contaminants in different environmental media as shown below. MgO₂ has been used as an ORC to increase the dissolved oxygen level and to strengthen the microbial activity of indigenous microorganisms for the remediation of MTBE (methyl tertiary butyl ether) polluted groundwater. After 148 days of biological treatment, a removal efficiency of 96% was obtained [1]. MgO₂ has also been used for *in situ* bioremediation of BTEX (benzene, toluene, ethylbenzene and xylenes) contaminated groundwater yielding a removal efficiency of over 95% for each target contaminant after 120 days of treatment [2]. As another ORC, CaO₂ has been studied by other researchers for enhancing the bioremediation of sediments from intensive aquaculture shrimp farms. After seven days of microbial reaction, the following removal efficiencies were obtained: (1) BOD (biochemical oxygen demand), 95%; (2) organic carbon, 17.6%; and (3) organic nitrogen, 75% [3]. In another study, H₂O₂ (as an ORC) and nutrients were applied to the hydrocarbon polluted soil for the enhancement of the microbial activity of microorganisms to remediate

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target contaminants therein. After 7 days of bioremediation, 37.5% of TPH (total petroleum hydrocarbon) removal was found [4]. A synergistic effect of applying CaO_2 and MgO_2 together has also been studied for bioremediation of soil contaminated by PCB (polychlorinated biphenyls) and electrical insulating oil. After 21-day treatment, 96% of removal efficiency was obtained [5].

Although ORC can promote the aerobic biodegradation effectively, there are some disadvantages. For example, the oxygen release rate of oxygen release powder is too fast so that microorganisms cannot use it effectively [6]-[7]. Besides, due to its insoluble nature, oxygen release powder would aggregate in water of low flow velocity rendering a poor release of oxygen and further becoming residues in the environment. Moreover, an increased pH after the release of oxygen would cause the formation of metal precipitates in the soil pores resulting in a clogging phenomenon [8]. In the case of applying diluted H_2O_2 solution, there would be a poor utilization of oxygen by microorganisms due to its low transport velocity and ease of loss in the remediation process [9]. To tackle this problem and meet the remediation goals, a practice of multiple additions of ORC is generally needed. Thus, this study aimed at preparing an environmentally benign 2G-ORC, which is long-lasting and capable of markedly increasing the concentration of dissolved oxygen in aqueous solutions to enhance bioremediation performance.

2. Experimental

Figure 1 is a schematic diagram showing the components of 2G-ORC and its ideal appearance in aqueous solution.

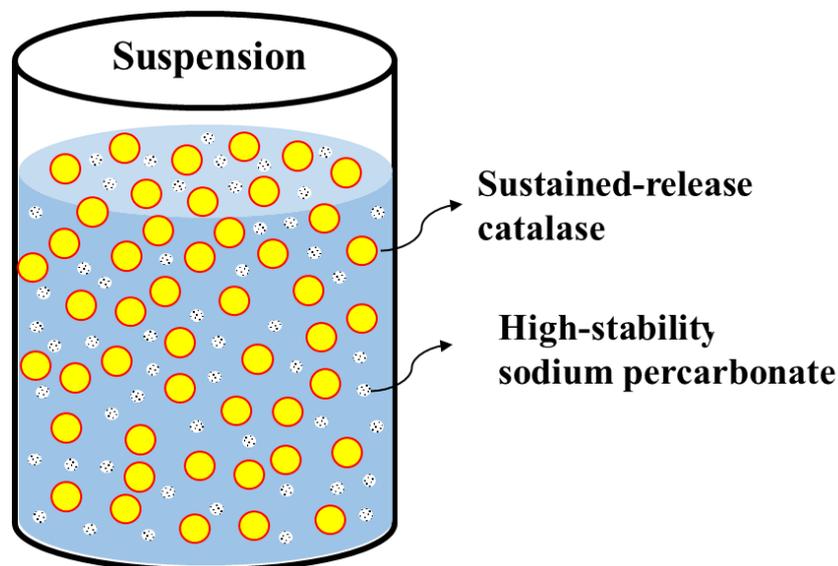


Fig. 1: Schematic diagram of 2G-ORC in aqueous solutions

In this work 2G-ORC was prepared in the lab via the following two steps: (1) coating of catalase with chitosan; and (2) coating of synthesized nanoscale sodium percarbonate with PLGA. Figure 2 shows the key experimental steps employed for 2G-ORC preparation, characterization, and performance evaluation. More details are revealed below. Sustained-release catalase and high stability sodium percarbonate obtained above were characterized by environmental scanning electron microscopy (ESEM), energy dispersive X-ray spectrometer (EDS), Fourier transform infrared spectrometer (FTIR) and X-ray diffractometry (XRD) whenever necessary. In this work sustained-release catalase was evaluated for its catalytic oxygen release ability toward hydrogen peroxide and high stability sodium percarbonate, respectively.

3. Results and Discussion

In this work the lab-prepared sustained-release catalase was characterized by FTIR analysis alone. FTIR transmittance spectra of sustained-release catalase showed that chitosan was indeed bound to the catalase exhibiting various absorption bands of both compounds. The absorption peaks at 1654 cm^{-1} , 1456 cm^{-1} , 1394 cm^{-1} , 1150 cm^{-1} , 989 cm^{-1} and 668 cm^{-1} are for catalase, whereas 3450 cm^{-1} , 1650 cm^{-1} and 1590 cm^{-1} are for chitosan.

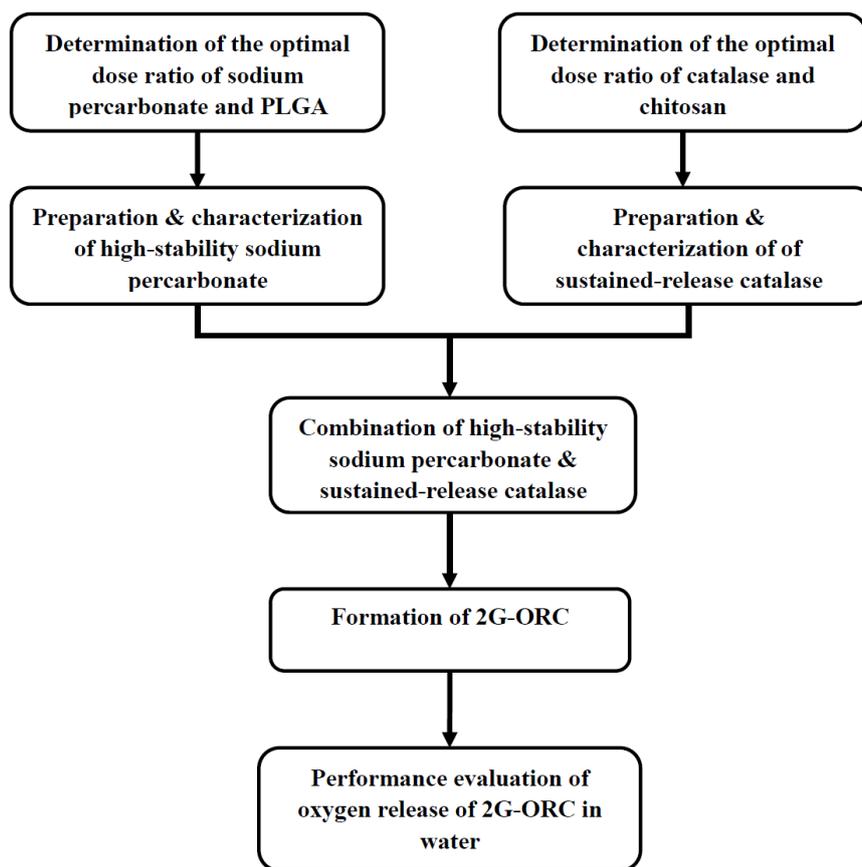


Fig. 2: Flowchart of 2G-ORC preparation, characterization, and performance evaluation in water

Test results concerning the catalytic oxygen release ability of hydrogen peroxide by sustained-release catalase under various pH conditions are presented and discussed below. It was found that no significant catalytic effect of sustained-release catalase toward hydrogen peroxide in raising the dissolved oxygen (DO) level under pH 2. Generally, it is not easy to break down hydrogen peroxide under acidic conditions and catalase reveals its optimal activity under neutral conditions. Thus, under such an acidic condition hydrogen peroxide was not completely decomposed into water and oxygen even it was in contact with catalase. When the test condition was switched to neutral pHs, a significant catalytic effect was found in terms of DO level. During the test period of 15 days studying the catalytic ability of sustained-release catalase toward hydrogen peroxide the DO concentration was maintained in the range of 13.84-15.17 mg/L, which is greater than 5.43 mg/L DO for de-ionized water in a control test. A remarkably catalytic effect of this kind was also noticed when the relevant test was conducted at a high alkaline condition like pH 12. DO concentration of 24.8 mg/L was found even a test period of 26 days has elapsed. This is ascribed to that the chitosan coating on the sustained-release catalase can maintain the activity of catalase even under the alkaline conditions. In addition, under the alkaline conditions the hydrolysis rate of hydrogen peroxide increase. Thus, the combined effect yielded the above inspiring experimental finding.

As indicated above, high-stability sodium percarbonate (HSSP) was obtained by coating lab-prepared sodium percarbonate with PLGA in this work. ESEM analysis showed that the particle size of HSSP was ranging from 70.4 nm to 99.1 nm. ESEM-EDS analysis further indicated that HSSP mainly contained the compositional elements of sodium percarbonate. The characteristic peaks in the XRD pattern of HSSP further confirmed the crystalline structure of sodium percarbonate in the test specimen. HSSP thus prepared was further mixed with the above-indicated sustained-release catalase to form the novel 2G-ORC in this work.

The performance of 2G-ORC in oxygen release was evaluated using deionized water as the control. Some significant experimental findings obtained were given below. The dosage of PLGA used to form

HSSP was found to have a negative impact on final concentration of dissolved oxygen in water when sodium percarbonate reaches its end of life. An increased DO concentration and extended sustained-release of oxygen was found when the applied dose of 2G-ORC increased. By applying 0.17 g of 2G-ORC to 20 mL of deionized water, the DO level was found to maintain at 6.24 mg/L even a test period of seven days has elapsed. The test result is promising for future field application.

4. Conclusion

In this work a novel 2G-ORC was successfully prepared by combining sustained-release catalase and high-stability sodium percarbonate. Test results have demonstrated its long-lasting ability for higher oxygen release in water. Thus, further studies will be carried out to evaluate its feasibility in enhancing the degradation of organic pollutants by indigenous microorganisms.

5. Acknowledgement

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6. References

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