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Economical Pond Water Treatment Technology based on Self-supplying Oxygen Material and Advanced Oxidation Process to Support The Blue Economy in Indonesia

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I. IDENTITY PAGE

1. Title : Economical Pond Water Treatment Technology based on Self-supplying Oxygen Material and Advanced Oxidation Process to Support The Blue Economy in Indonesia

2. Relevance of Topic :

- Smart Aquaculture

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Executive Summary

The Government of The Republic of Indonesia through Presidential Regulation No. 18 of 2020 designed a sustainable revitalization of national shrimp ponds where the blue economy concept of shrimp ponds could realize economic growth and community welfare. However, disease outbreaks in shrimp ponds had become more frequent in recent years and had caused the declining of productivity in shrimp aquaculture. Various methods had been used biologically by adding probiotics, but it was still not optimal for preventing disease. Water quality management was the main key to disease control in shrimp ponds. Physicochemical water treatment technology had not been widely used in ponds because it was felt to be quite expensive. The aim of this research was to develop an economical pond water treatment technology using self-supplying oxygen material and an advanced oxidation process to degrade waste and prevent disease in shrimp ponds. The method used was divided into three stages, where there was a production stage, a characterization stage and a laboratory scale test stage. Material production was made from hydrated lime ($Ca(OH)_2$) which was reacted with hydrogen peroxide (H_2O_2) and composited with peracetic acid. Those material were pro analyte standard. The products made into two variation, granule and powder. Next, the material was characterized using Fourier transform infrared spectroscopy (FTIR), X-ray Diffraction (XRD), scanning electron microscope (SEM), and active oxygen measurement. Preliminary results indicate that the current product has successfully achieved the desired composite targets and is ready to proceed to laboratory-scale testing. Owing to temporal limitations, the laboratory-scale testing stage has been postponed. Nevertheless, this research endeavor will continue, and interim results are presented herein.

1. Introduction/Background

The Government of the Republic of Indonesia, through Presidential Regulation No. 18 of 2020, has embarked on a sustainable revitalization of national shrimp farms, aiming to harnessthe blue economy concept to drive economic growth and enhance community welfare. In the realm of aquaculture, managing water quality is a fundamental task that continually evolves with various treatments. Water quality in shrimp ponds can deteriorate quickly due to factors such as feed supply, waste disposal, and biota respiration. Critical water quality parameters include dissolved oxygen and organic matter, which merit close monitoring [1]. The decline inwater quality, driven by fluctuations in these parameters, is a significant factor in the spread ofmicrobial pathogens transmitted via water [2]. Presently, there is an observed rise in diseases in shrimp ponds, leading to widespread shrimp mortality and reduced productivity in cultivation[3].

Various strategies for disease control in shrimp ponds, centered around water quality management, have been explored. The biosecure zero-exchange system, which minimizes water exchanges and utilizes in-situ microorganisms combined with probiotics, is one approachto disease control [4-6]. This method is popular due to its cost-effectiveness and ease of implementation, thus finding broad application in the shrimp farming industry. Physical and chemical technology for water management in shrimp ponds has not been widely used for various reasons, including technical challenges in site selection, design, infrastructure and technician skills [7]. The many pond conditions currently owned by traditional farmers make various previous challenges difficult to solve, especially as adjustments to physical andchemical technology will require expensive costs [7].

Self-supplying oxygen materials are recognized for their capacity to release oxygen over time. Calcium peroxide (CaO_2), for instance, effectively maintains dissolved oxygen levels in shrimp ponds, thereby ensuring that both biota and bacteria have adequate oxygen for decomposing organic matter [10]. The efficiency of self-supplying oxygen materials can be enhanced through reactive oxygen generators engaging in an Advanced Oxidation Process (AOP). AOP is a water treatment technology employing physicochemical procedures togenerate reactive species, particularly hydroxyl radicals, which can degrade pollutants and disinfect pathogenic bacteria [8-9]. This reaction can be carried out with strong oxidants and ultraviolet light photocatalysis. Disinfection of pathogens is carried out using a series of free radical formation from AOP which is carried out with the production of reactive oxygen species(ROS) to rotate the utilization of oxygen from the self-supplying oxygen material with the production of the free radical superoxide anion, O_2⁻•. Superoxide is then quickly converted to H_2O_2 by superoxide dismutase. These free radicals can destroy microorganisms or other foreignobjects in biota through the activation of NADPH oxidase (NOX) in cells [11-13]. In addition,O_2⁻• and H_2O_2 react to produce OH• which can simultaneously and directly break the bonds oforganic matter in waters through primary, propagation and termination reactions. [14]. Reduction of organic materials through AOP treatment can occur as a form of abstraction reaction from hydroxyl radicals against covalent bonds to become water [15].

This research aimed to explore the synergistic effects of self-supplying oxygen materials alongside advanced oxidation process generators in seawater environments tailored for shrimp farming. Our primary objectives were to optimize dissolved oxygen saturation, enhance the breakdown of organic material, and inhibit the proliferation of pathogenic bacteria. The significance of this study lay in its potential to yield a prototype with practical applications—poised for commercialization—to bolster shrimp pond productivity. This venture aligned with Indonesia's blue economy initiatives which emphasized sustainable economic development through marine resources.

2. Methodology

2.1. Experimental

This research was carried out experimentally with four stages, where there was a production stage, a characterization stage, a laboratory-scale test stage, and economical feasibility. Illustration of the stages of research can be seen in Figure 1. The explanation of the various stages is explained as follows.

The production stage aimed to prepare various kinds of products to be studied. This stage was carried out by selecting raw materials for making self-supplying oxygen material consisting of $Ca(OH)_2$, H_2O_2, and CH_3CO_3H. Quality control of raw materials was adjusted to pro analytical standards, where $Ca(OH)_2$ ACS reagent Sigma-Aldrich ≥95.0%, H_2O_2 Sigma-Aldrich 30 % (w/w), and acetic acid 100%. The target products were CaO_2 and CaO_2-CH_3CO_3H with the ratio of CaO2 manufacturing referring to Cai-Xia[18] and for other target products is 10:1. Each target product was made as much as 2 kg. At this stage, powder product was also made using milling process. Some of the target products were then carried out a dry granulation process. The target product that had been created was then characterized in the next stage of research.

The characterization stage aimed to examine the crystal structure, chemical composition, and physical properties of the product which was then monitored for quality and evaluated from the performance of the target product. Characterization in this stage included surface morphology studies using scanning electron microscope (SEM), X-ray diffraction (XRD) analysis, functional group analysis using fourier-transform infrared spectroscopy (FTIR), and analysis of active oxygen. Methods for studying surface morphology studies, FTIR analysis, and XRD analysis used references Piyarat et al. [23]. While for electron spin resonance analysis referred to ASTM [24].

The laboratory-scale test stage aimed to examine various target products as precursors to optimize oxygen solubility, minimize organic matter levels, and suppress the growth of pathogenic bacteria in pond water media. There were several measurements made, as can be seen in Table 1. Tools and materials used at this stage include an aquarium 40 cm x 15 cm, x 15 cm. The bottom layer of the aquarium filled by alluvial soil taken from traditional ponds originating from the Bekasi Regency, West Java, Indonesia. Aquarium water uses filtered seawater [31]. The shrimp will use *Litopenaeus vannamei* PL 12 with a density of 10 heads per aquarium and given Irawan 681V crumble feed twice a day with 20% of body weight. The aerator used was the AM-Q6 ARMADA used during the test. The target product to be used in this study is 5 ppm every two days. The UV lamp will use a Philips UV-C Hg low pressure 4 W which was used during the test and installed inside the cover with illustrations such as Figure 1.

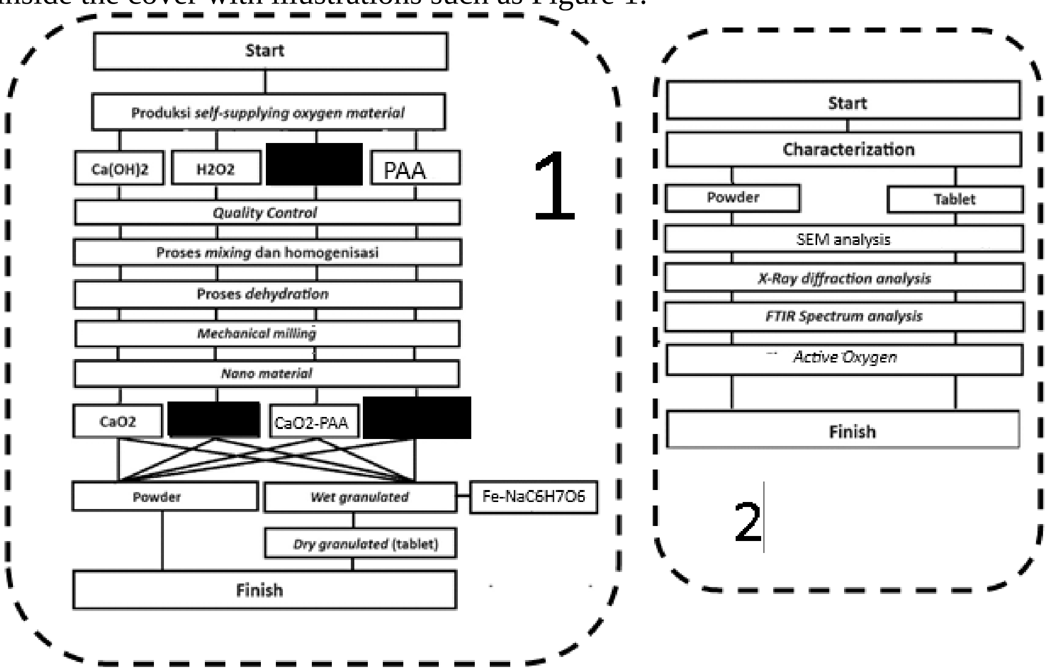
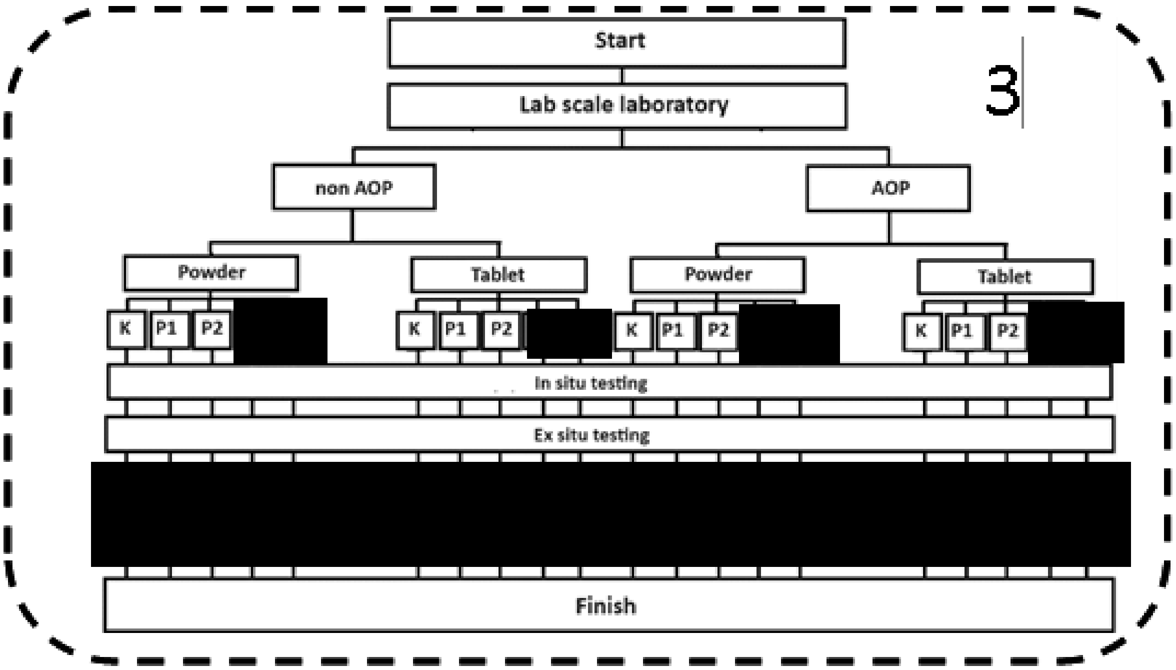


Figure 2. Research Stages (1) production, (2) characterization, (3) laboratory scale research.



(cont) Figure 2. Research Stages (1) production, (2) characterization, (3) laboratory test.

Table 1. Parameters measured at the laboratory test stage.

No.	Parameters	Units	Method/Reference
Water quality in situ parameter			
1	Temperature	°C	Instruments [25]
2	pH	-	Instruments [25]
3	Dissolved oxygen	mg/L	Titrimetry [25]
Water quality ex situ paremeter			
1	Ammonium-Nitrogen	mg/L	Spectrophotometers [26]
2	Nitrate nitrogen	mg/L	Spectrophotometers [26]
3	Ammonia nitrogen	mg/L	Spectrophotometers [26]
4	Nitrite nitrogen	mg/L	Spektrofotometri [26]
5	Total organic carbon	mg/L	Instruments [27]
6	Chemical oxygen demand	mg/L	Spektrofotometri [26]
7	Turbidity	NTU	Instruments [26]

2.2. Data analysis

Statistical testing of each treatment will be tested separately for each sampling time (i.e. week) using bidirectional ANOVA for correlation between sampling results. The statistical test is calculated using the SPSS 26 statistical package. The fingerprints used in this study to see the experimental factors in the treatment given can provide changes. If the results of the fingerprints show a rejection of H0, then further tests are carried out. This further test is needed to determine the factors that strongly influence the occurrence of rejection of H0 in the study treatment [32]. The next test used is called the Duncan Multiple Range Test (DMRT). Further DMRT tests were conducted using IBM SPSS 6 applications.

3. Results

3.1. Sample Production

The samples produced for this study consisted of two products: calcium peroxide (CaO_2) and a CaO_2/peracetic acid (PAA) mixture at a 3:1 ratio. Each product was prepared in both powder and granule forms. The granule samples were encapsulated using Fe-alginate. These samples are shown in Figure 2 and were subsequently subjected to characterization.

Gambar 2. Produksi sampel (A) CaO_2 powder, (B) CaO_2-PAA powder, (C) CaO_2 granul, (D) CaO_2-PAA granul

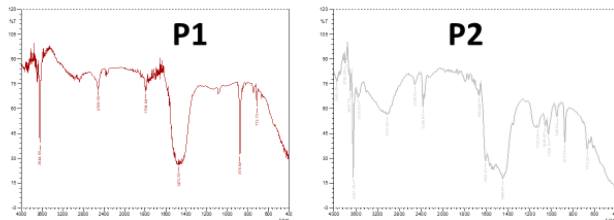
3.2. Characterization

The characterization in this study comprised Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), and active oxygen analysis. Based on Figure 3, the FTIR analysis indicates that powdered CaO_2 typically exhibits distinct peroxide (O–O) stretching vibrations and Ca–O vibrations. The obtained spectrum is consistent with these characteristic features; however, the potential presence of impurities, such as moisture or carbonates, should be considered. In the CaO_2-PAA sample, components attributable to methyl and carbonyl groups, characteristic functional groups of PAA, were observed. Furthermore, the FTIR spectra of the tablet products of both materials revealed a prominent peak, likely originating from carbonyl groups, possibly from the sodium alginate polymer.

Based on Figure 4, the SEM and XRD analyses demonstrate that both powdered CaO_2 and CaO_2-PAA possess the potential to generate active oxygen but lack the structural complexity observed in the granule product. Conversely, the granule product, particularly the samples coated with alginate and ferrous sulfate, exhibits complex characteristics. The formed granular structure, along with the presence of multiple crystalline phases, influences the active oxygen production potential.

Based on Figure 5, the highest active oxygen content was observed in the powdered CaO_2-PAA sample, followed by the powdered CaO_2 sample. The tablet products exhibited lower active oxygen values, suggesting effective sustained release of oxygen. These results will be complemented by electron spin resonance (ESR) analysis using a spin trap. The corresponding data will be presented in the supplementary information/in a subsequent publication.

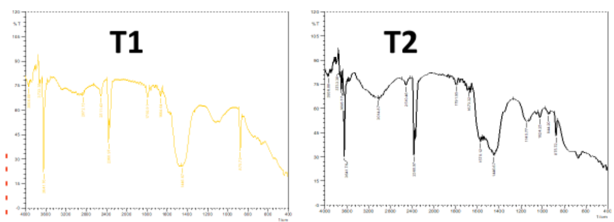
P1= powder of CaO2; P2= powder of CaO2-PAA;



Wavenumber (cm⁻¹)	Assignment P1
3644.65	O–H stretching, likely due to adsorbed moisture or hydroxyl groups.
2509.50	Possibly related to peroxide O–O stretching or overtones (less common).
1794.84	Could indicate carbonate impurity (C=O stretch), though unexpected for pure CaO_2.
1470.79	Possible bending of adsorbed water or carbonate (CO_3^{2-}) stretching vibrations.
876.68	Likely O–O stretching vibration from the peroxide group.
712.73	Metal-oxygen bond vibrations, likely Ca–O stretching.

Wavenumber (cm⁻¹)	P2
3690-3580	O-H stretching (hydrogen-bonded hydroxyl groups) from peracetic acid or adsorbed water on calcium peroxide.
3050-3000	C-H stretching of aromatic or aliphatic C-H bonds, likely from the peracetic acid component.
2360-2300	O=C=O stretching, possibly indicating CO_2 presence or carbonate impurities in calcium peroxide.
1860-1840	O-O stretch, characteristic of peroxide groups in calcium peroxide.
1680-1650	C=O stretching from the carbonyl group in peracetic acid.
1440-1400	C-H bending, likely from the methyl group in peracetic acid.
1100-1050	C-O stretching in peracetic acid, or symmetric stretching of O-O in peroxides.
950-900	O-O stretching in calcium peroxide or peracetic acid's peroxide bond.
870-850	C-H out-of-plane bending, possibly from small organic residues.
675-670	O-H bending from water or hydroxyl species.

T1= granule of CaO2; T2= granule of CaO2-PAA;

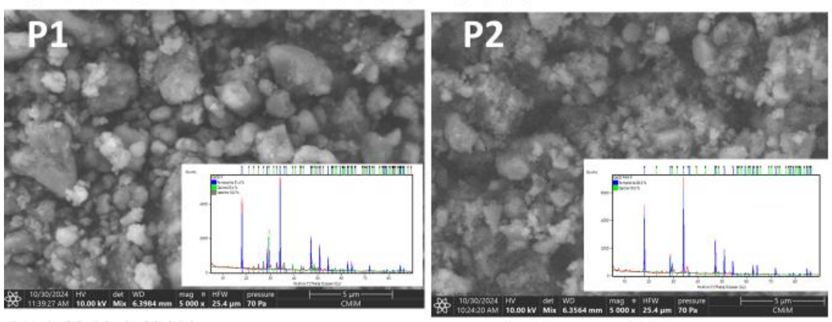


Wavenumber (cm⁻¹)	Assignment T1
3693.98	O–H stretching (likely from residual moisture or hydroxyl groups)
3411.78	Broad O–H stretching (hydroxyl groups, possibly from alginate or absorbed water)
2972.13	C–H stretching (from organic components such as the sodium alginate)
2511.40	O–H stretching (acidic O–H group, possibly from the alginate or sulfate)
2003.97	Possibly overtones or combination bands
1729.91	C=O stretching (likely from carbonyl groups in sodium alginate or carboxylates)
1584.04	C=C stretching (possibly from carboxylate groups or alginate components)
1448.67	C–H bending (from organic compounds, alginate)
877.72	O–O stretching (indicative of peroxide groups in calcium peroxide)

Wavenumber (cm⁻¹)	T2
3938.58, 3793.33	Possibly O-H stretching vibrations (likely from moisture or surface-bound hydroxyl groups)
3641.78, 3605.77	O-H stretching (indicating free or bound hydroxyl groups)
3014.87	C-H stretching (sp^2 hybridized C-H bonds, likely from organic components or peracetic acid)
2506.48, 2300.97	Potential O-H stretching (hydrogen bonding) or indicative of peroxide groups
1791.95	C=O stretching (likely from peracetic acid or related carbonyl groups in the structure)
1673.32	C=O stretching (possibly alginate or $FeSO_4$ complex, related to coordinated carboxyl groups)
1570.12	C=C stretching (may correspond to carboxylate or aromatic ring structures in sodium alginate)
1446.97	C-H bending (likely from the alginate or organic components)
1146.77	C-O-C stretching (from ester linkages, possibly in the polymer)
1024.25	C-O stretching (common in polysaccharides, associated with sodium alginate)
944.20, 875.72	Skeletal vibrations or out-of-plane bending (likely from polysaccharides or inorganic coordination complexes)

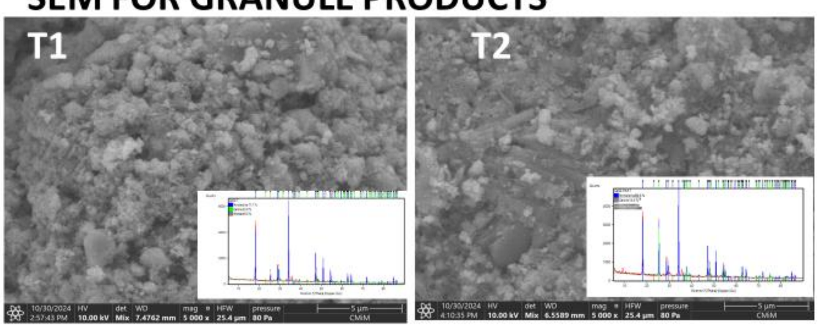
Figure 3. FTIR Analysis Results of Product Samples

SEM FOR POWDER PRODUCTS



P1= CaO2; P2=CaO2-PAA

SEM FOR GRANULE PRODUCTS



T1= CaO2; T2=CaO2-PAA

Figure 4. SEM and XRD Analysis Results of Product Samples

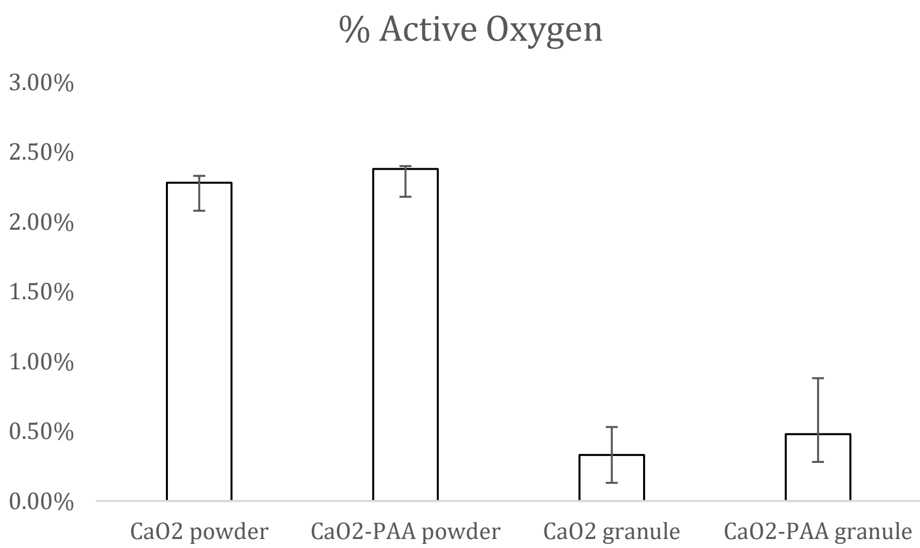


Figure 5. Active Oxygen Content Analysis of Each Product Sample

7. Conclusions

Our current research has thus far yielded data pertaining to product sample characterization. Data collection for this study is ongoing and will continue until February 2025. Subsequent to this period, the complete dataset will be available for comprehensive interpretation to derive meaningful conclusions from this research.

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