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Research Article

Utilization of *Spirulina Sp*. Microalgae for Oxygen Production

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Abstract. Global warming, largely driven by rising CO_2 levels, poses a serious environmental threat. Meanwhile, the decline of green spaces, especially in cities, reduces natural CO_2 absorption. In response to this issue, this true experimental research introduced an innovative approach called Smart Microalgae Reactor, which utilizes *Spirulina Sp.* as an alternative CO_2 absorber to produce oxygen. This study aimed to evaluate the effectiveness of microalgae *Spirulina Sp.* in capturing CO_2 through three experimental setups: Reactor 1 (2000 mL *Spirulina Sp.*+ 2 L/min CO_2), Reactor 2 (1500 mL + 2 L/min CO_2), and a Control (2000 mL, no CO_2). CO_2 was injected daily for 1 minute, and key parameters Dissolved Oxygen (DO), Optical Density (OD), and growth rate (μ) were measured over 13 days. The results showed Reactor 2 had the highest DO increase (12.6 mg/L, 63.64%) and fastest early growth (0.0904 day^{-1}), while Reactor 1 achieved the highest OD (1.550, 111.48%) but slower growth. The control performed weakest, confirming that added CO_2 boosts photosynthesis. The study proves that smart microalgae reactor is an effective, sustainable solution for urban CO_2 reduction, offering a viable alternative where traditional greenery is limited.

Keywords: Climate Change, CO_2 sequestration, Microalgae, *Spirulina* sp.

1. Introduction

Climate change is one of the phenomena currently being faced not only in Indonesia but also around the world. This phenomenon is characterized by rising temperatures and declining oxygen concentrations, in tandem with increased production of greenhouse gases. Previous research indicated that CO_2 emissions generated by transportation activities in the city of Pekanbaru amount to 57,495.23 tons per year, with the existing green space absorption capacity standing at 29,013.3 tons per year (Sasmita et al., 2021).

Moreover, the increase in CO_2 levels contributing to global warming also impacts public health, as changes in Earth's temperature affecting humidity trigger the proliferation of disease vectors. On the other hand, poor air quality contributes to the spread of airborne diseases such as respiratory infections, asthma, bronchitis, and tuberculosis (TB) (Eldos et al., 2025).

Plants, which are the primary CO_2 capture agents contributing to oxygen production, have experienced a decline in quantity due to massive land conversion (Skrzypczak et al., 2025). One solution to this problem is to utilize microalgae. Microalgae are autotrophic microorganisms in aquatic environments that have the potential to capture and utilize CO_2 as a source of oxygen and renewable energy (Klinthong et al., 2015).

The utilization of microalgae is a promising technology for large-scale CO_2 absorption from industrial sources and the atmosphere (Politaeva et al., 2023; Zhao & Su, 2020). Thousands of microalgae species inhabit Indonesian waters, but *Spirulina Sp.* is one of the easiest to cultivate and contains a significant biomass (H. Hadiyanto et al., 2012).

The novelty of this research lies in the development and application of a small-scale Smart Microalgae Reactor designed for urban environments with limited green space, which integrates controlled CO_2 injection, artificial lighting, and active aeration in one simple system. Unlike previous studies such as those conducted by Suciati and Aviantara (2020).

Which generally focused on industrial-scale photobioreactors or open ponds, this study emphasizes the ecological function of microalgae as an alternative for CO_2 absorption and oxygen production in urban areas. This approach provides a new contribution to the application of microalgae as a solution for local-scale climate change mitigation.

The main hypoteshis in this study is controlled CO_2 injection in the photobioreactoreactor will increase the growth of Spirulina sp. and dissolved oxygen production compared to a system without CO_2 supply.

This research does not aim to replace trees, but rather to complement the function of green spaces, particularly in areas with limited land. Previous studies have shown that microalgae can have higher CO_2 fixation rates per unit area than terrestrial plants, especially in controlled systems. A microalgae-based system capable of fixing approximately 50 kg of CO_2 per year. Its main advantage lies in its carbon capture efficiency, which is 4.6 times the capacity of a 35-year-old mature tree (Cervera et al., 2024)

2. Method

2.1. Preparation Sample

The microalgae used in this study was *Spirulina Sp.* microalgae obtained from cultivation at the C-Biore Laboratory of Diponegoro University. A total of 6000 mL of *Spirulina Sp.* was cultivated in 6 reactors with Spirulina sp. is cultivated using standard C-Biore laboratory medium, which generally contains a nitrate, phosphate, bicarbonate, and essential minerals for an adaptation period, during which OD measurements were taken every 2 days using a DLAB type SP-UV1100 spectrophotometer. After an increase in OD values was observed, it was determined that *Spirulina Sp.* was stable and ready for treatment in the bioreactor.

2.2. Production of Dissolve Oxygen in Microalgae Spirulina Sp. Bioreactor

Three bioreactors were prepared as controls, R1 and R2. Figure 1 illustrates the sample testing process for analysis, where each reactor has a different *Spirulina Sp.* volume: reactor 1 (R1) has a volume of 2000 ml, reactor 2 (R2) has a volume of 1500 ml, and the control has a volume of 2000 ml.

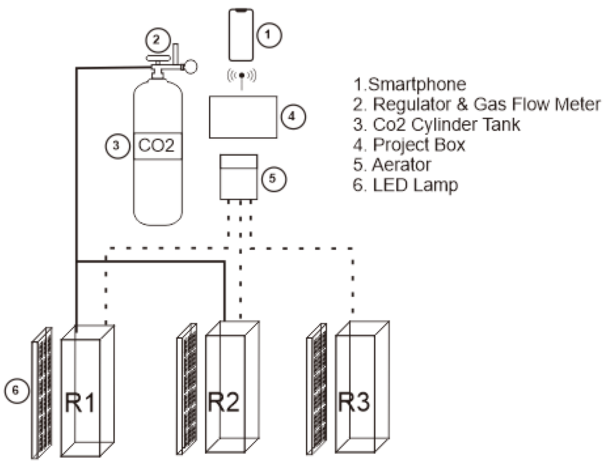

Figure 1. Ilustration the sample testing process for analysis

As in the study conducted by Suciati and Aviantara (2020) Compared with the linear fluid flow rate in the FBR tubular column system, CO_2 gas injection had a greater impact on microalgae productivity. Variation of CO_2 injection flow rate from 0.11 to 0.61 mL/s showed that CO_2 injection produced the most microalgae. The testing method itself involves adding CO_2 from a CO_2 gas cylinder and setting the input to 2 L/minute, which is then fed into reactor 1 and reactor 2 for 1 minute.

Then, the optical density (OD) of each reactor is measured using a UV-Vis Spectrophotometer SP-UV1100 DLAB. Dissolved oxygen (DO) is measured using a DO Meter Dissolved Oxygen Meter | Lutron DO-5510, and the growth rate is determined using exponential regression. The reactor will supply CO_2 from a food-grade CO_2 cylindrical tank with a purity of 99.9% inside and channel it through a hose into a bioreactor containing Spirulina Sp. In addition, the Smart Microalgae reactor itself is equipped with a 6000 lux LED light and an aerator. From this treatment, tests were conducted on the CO_2, DO, and OD concentration levels in the microalgae inside the bioreactor.

The study's findings demonstrate the great photosynthetic efficiency and rapid growth rates of microalgae, which make them a promising carbon sequestration technique. Additionally, the study demonstrates that microalgae may flourish under a variety of conditions, such as low light levels and high CO_2 concentrations. According to the study, microalgae may be utilized to extract CO_2 from wastewater and flue gas, offering a viable substitute for existing CO_2 capture techniques (Singh & Ahluwalia, 2013).

In this study, oxygen production was not used as the sole indicator, but as an indirect indicator (proxy indicator) of microalgae photosynthetic activity, therefore, a significant increase in DO, combined with an increase in Optical Density (OD) and growth rate (μ), scientifically indicates that CO_2 has been absorbed and converted into biomass and oxygen.

The innovation of the Smart Microalgae Reactor lies in the integration of several key components into a single system. While most previous studies have used natural lighting or complex and expensive photobioreactor systems, the system developed in this study is simpler and has potential for urban application, thus offering innovative design value. In this study, an Internet of Things (IoT)-based device was developed to automatically and controllably manage oxygen production through a microalgae reactor.

The system was designed using an ESP8266 (Node MCU) microcontroller equipped with an internal WiFi module, enabling the device to connect directly to the internet without additional equipment (Satriadi et al., 2019). IoT integration was implemented through the Blynk IoT platform, which allows users to perform remote control and automatically schedule on/off times via a mobile app (Wahidin et al., 2013).

3. Result and Discussion

In this study, two parameters were used to determine the success of bioreactor use. These two parameters indicate the ability of *Spirulina Sp.*microalgae to capture CO_2 and synthesize it into dissolved oxygen.

3.1. Optical Density

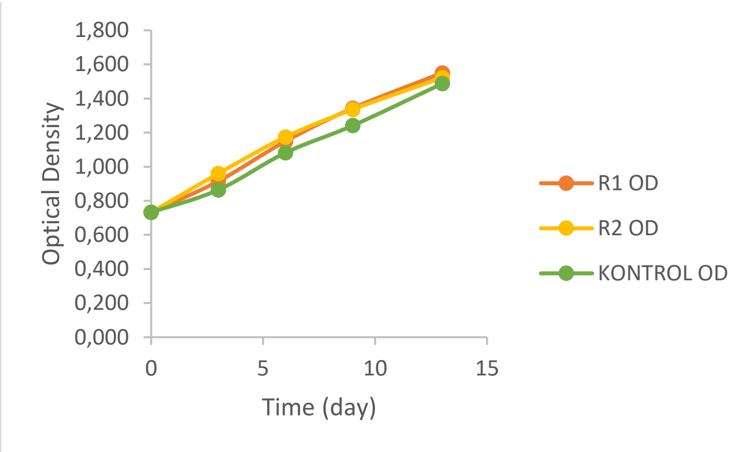

Figure 2. Increasing of Optical Density

Figure 2 shows an increase in optical density on day 13 in all reactors. Reactors 1 and 2 with CO_2 treatment showed a significant increase in optical density compared to the control. This indicates that the CO_2 supply in reactors R1 and R2 is optimally utilized as a carbon source by the microalgae *Spirulina Sp.* The increase in OD also indicates the formation of optimal biomass over time, surpassing the stationary phase. The percentage increase in optical density in the microalgae can be seen in the following table:

Table 1. The result of Increasing Optical Density in Percentage

Hari	R1 OD	%	R2 OD	%	KONTROL OD	%
0	0,732	0	0,732	0	0,732	0
3	0,915	25	0,960	31,15	0,864	18,03
6	1,149	56,97	1,174	60,38	1,082	47,81
9	1,343	83,48	1,336	82,51	1,241	69,64
13	1,550	111,48	1,522	108,2	1,487	103,17

Table 1. shows that the increase in Optical Density (OD) in each reactor indicates that CO_2 availability and environmental conditions play an important role in microalgae growth. In Reactors R1 and R2, which received a CO_2 supply, there was a higher increase in optical density. On the other hand, the Control reactor showed the lowest OD value

compared to the other reactors (1.487). This is understandable, as microalgal growth in the control reactor is hindered by the lack of a carbon source for photosynthesis. This results in lower biomass accumulation compared to reactors supplied with CO_2. In the previous study it was explained that abiotic factors such as light, temperature, and pH are not sufficiently optimal in supporting the density of *Spirulina Sp.* cells without adequate carbon and nutrient availability (Hadiyanto & Widayat, 2014).

3.2. The Growth Rate of Microalgae Spirulina Sp.

The growth rate of microalgae is a measure of how quickly microalgae biomass increases over a given period of time. The growth rate (μ) is the speed at which microalgae grow, calculated based on changes in OD over a given period of time. The unit of growth rate is day^{-1} or hour^{-1}. The growth rate itself can be calculated using the following formula:

$$\text{Growth rate } (\mu) = \frac{\left(\frac{\ln X2}{Xo}\right)}{\Delta T} \quad (1)$$

With the following explanations:

μ : Growth rate
ln : Natural logarithm of Optical Density
X2 : Optical Density (Cell Density) at a specific time
Xo : Initial Optical Density before treatment
ΔT : Time interval (T) from the initial time (To)

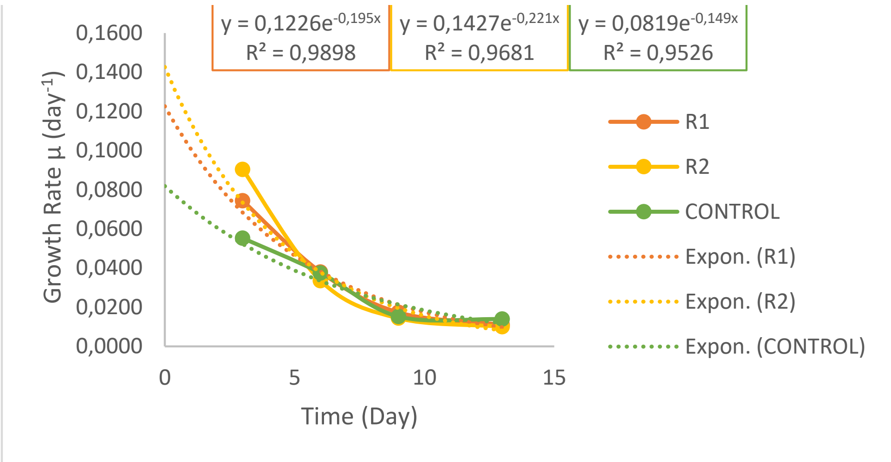

Figure 3. The Growth Rate of Microalgae *Spirulina Sp.*

Figure 3 shows an exponential increase in the growth rate of microalgae with a decrease in differential. On the other hand, on day 10, growth did not experience significant changes until day 13. This condition is understandable because microalgae entered a stationary phase, where cell division slowed down before the microalgae eventually entered a death phase if their density was not immediately reduced. Reactor 1 exhibited the highest growth rate on day 3 (0.0744) and the lowest on day 13 (0.0110). Reactor 2 experienced the highest growth rate on day 3 (0.0904) and the lowest on day 13 (0.0100). The control group also experienced the highest growth rate on day 3 (0.0553) and the lowest on day 13 (0.0139).

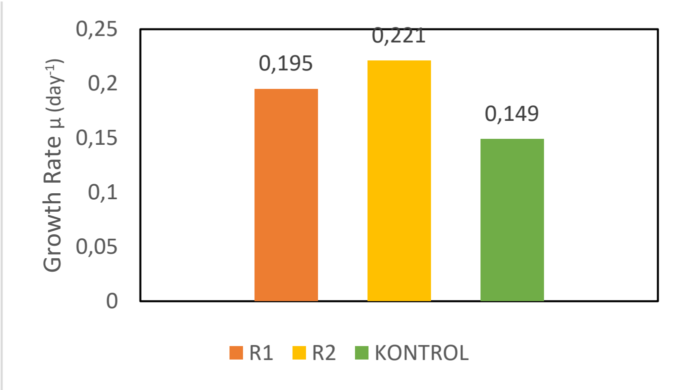

Figure 4. Comparison of Microalgae Growth Rate in Difference Reactor

Based on Figure 4, a comparison of the growth rates of *Spirulina Sp.* microalgae in three different reactors shows that R2 microalgae have a higher growth rate than R1 and the control. CO_2 concentration certainly plays an important role in this regard; the greater the source of carbon and nutrients provided, the faster the microalgae grow.

Furthermore, the measurement results shown in Figure 3 indicate that the highest growth rate occurs on day 3 and decreases over time. On day 3, the highest growth rate occurs in R2 at 0.0904 day^{-1}, followed by R1 at 0.0744 day^{-1}, and the control at 0.0553 day^{-1}. On day 13, the growth rate decreased to 0.0110 day^{-1} for R1, 0.0100 day^{-1} for R2, and 0.0139 day^{-1} for the Control. On the other hand, Reactor 1 experienced a decrease in growth rate from day 3 to day 13, although the total biomass remained high. This decrease may be due to high cell density. Reactor 2 showed the highest growth rate on day 3 compared to the other reactors.

This can be explained by the smaller volume, which allows for better light and nutrient distribution without significant competition for resources. A decrease in growth rate after day 3 was also observed, but the rate of decrease was not as rapid as in Reactor 1. This is also consistent with previous research which found that microalgae undergo specific life phases, with peak growth occurring during the exponential phase before beginning to decline during the logarithmic phase (Hadiyanto & Azim, 2012).

3.3. Dissolve Oxygen Measurement

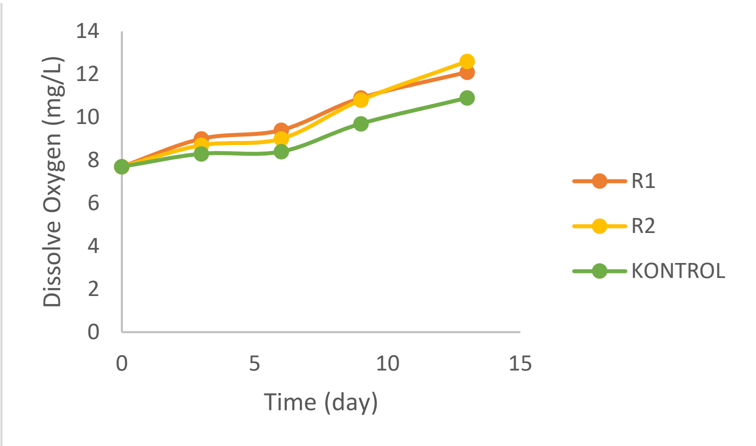

Figure 5. Increasing of Dissolve Oxygen Production

Based on the Dissolved Oxygen (DO) measurement results, as shown in Figure 5, on Day 0, the initial DO value of the three reactors was 7.7 mg/L, which was the initial condition before CO_2 treatment was administered. After CO_2 administration, DO increased significantly, with the highest increase occurring in Reactor 2 (R2) at 12.6 mg/L on day 13, followed by Reactor 1 (R1) at 12.1 mg/L, and the Control at 10.9 mg/L. This increase in DO indicates that the microalgae *Spirulina Sp.* successfully performed photosynthesis by absorbing CO_2 and producing O_2. Furthermore, the oxygen production data over the 13-day treatment period is as shown in the table below:

Tabel 2. The result of Dissolve Oxygen in Percentage

Day	R1	%	R2	%	Control	%
0	7,7	0	7,7	0	7,7	0
3	9	16,88	8,7	12,99	8,3	7,79
6	9,4	22,08	9	16,88	8,4	9,09
9	10,9	41,56	10,8	40,26	9,7	25,97
13	12,1	57,14	12,6	63,64	10,9	41,56

Table 2 shows a significant increase in Reactor 2, where oxygen production increased by 63.64% on day 13. This is consistent with previous studies Gao et al. (2022) such as those conducted the increase in DO concentration over time also reflects the ability of *Spirulina Sp.* to adapt to changing environmental conditions. This microalga can enhance its photosynthetic activity with increased CO_2 levels. This is consistent with previous research which explains how abiotic factors such as light, temperature, and pH significantly influence microalgal growth, thereby affecting the photosynthetic process that produces Dissolved Oxygen (Lage et al., 2021).

4. Conclusion

This study contributes to the development of microalgae-based technology to reduce CO_2 emissions and improve air quality. The use of a smart microalgae bioreactor with *Spirulina Sp.* as an oxygen producer facilitates the production, utilization, and monitoring processes. A significant increase in dissolved oxygen of 63.64% (12.6 mg/L) in reactor 2 compared to the control demonstrates the effectiveness of microalgae in producing oxygen. On the other hand, the significant increase in microalgae growth in R1 and R2 indicates the contribution of CO_2 as an inorganic carbon source in the growth of *Spirulina Sp.* Microalgae.

R2 produced higher O_2 despite having a lower OD value than R1 due to more optimal photosynthetic efficiency under these reactor conditions. The smaller culture volume in R2 allowed for more even distribution of LED light and CO_2 diffusion, resulting in more Spirulina sp. cells being in the active photic zone and capable of photosynthesis effectively. This was reflected in the results of the study, which showed the highest DO increase in R2 of 63.64% to 12.6 mg/L on day 13, as well as the highest initial growth rate (μ = 0.0904 day^{-1} on day 3). Conversely, R1 had a higher OD (1.550; an increase of 111.48%), indicating greater biomass, but the high cell density caused self-shading and competition for light, resulting in lower photosynthetic efficiency and O_2 production compared to R2. The technical limitations of the reactor are the potential CO_2 oversaturation, which can lower the medium's pH if injection is not controlled also this study is lies on laboratory scale, so results may not fully represent field conditions.

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