Evaluation of different carbonate sources for bicarbonate-based integrated carbon capture and algae production system using *Spirulina platensis*

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Abstract. *Spirulina Platensis* was evaluated in Bicarbonate-based Integrated Carbon Capture and Algae Production System (BICCAPS) using Modified Zarrouk’s media under three different carbonate solutions, namely, sodium, potassium and an equimolar mixture of sodium-potassium carbonate, as well as a control experiment consisting of only water. All systems mentioned were exposed to carbon dioxide loading in order to produce bicarbonate solutions to be used for cultivation of *Spirulina Platensis* under BICCAPS. Parameters such as pH, biomass productivity, and carbon conversion were analyzed to evaluate the effectivity of BICCAPS as a carbon sequestration technique given the conditions applied in the study. Results determined that the control system produced the highest biomass productivity of 10.42 mg L⁻¹ day⁻¹ despite having the lowest carbon conversion of 0.292 mM due to the limited amount of bicarbonates initially present. The sodium-potassium carbonate system then follows the control experiment, having a productivity of 7.37 mg L⁻¹ day⁻¹ and carbon conversion of 4.192 mM. Sodium carbonate system ranks third with productivity and carbon conversion of 6.56 mg L⁻¹ day⁻¹ and 2.682 mM. Lastly, potassium carbonate system was determined to have the lowest productivity of 4.48 mg L⁻¹ day⁻¹ as well as a relatively low carbon conversion of 0.996 mM.

1. Introduction

Over the past decades, global warming has brought about significant damaging effects on both the environment and human life. An increase in the surface temperature of the Earth is promoted by the phenomenon called greenhouse effect – trapping the radiation from the sun due to the accumulation of greenhouse gases, such as nitrous oxide, methane, and carbon dioxide, in the atmosphere where carbon dioxide plays as the main anthropogenic component [1].

The U.S. Environmental Protection Agency (2016) reported that the total greenhouse gas emissions reached 6,870.5 million metric tons of CO₂ equivalents in 2014 alone. Carbon dioxide accounted for approximately 80.9% of the said total greenhouse gas emissions [2]. As the National Oceanic and Atmospheric Administration Earth System Research Laboratory (2017) reported, the mean CO₂ concentration in the atmosphere has already surpassed the safety limit of 350 parts per million, reaching a mean concentration of about 414.83 ppm as of June 2019 [3]. It is projected that the CO₂ concentration in the atmosphere will be approximately 530 ppm in 2050 and 780 ppm in 2100.

IEA investigated that at least two thirds of carbon dioxide emissions produced were from burning fossil fuels for power consumption for almost 20 years, with 2016 amounting to 45% of total emissions [4]. Therefore, a growing concern on the sustained increase of CO₂ emission arised; hence, various organizations and agencies have proposed ways to address the problem.

Carbon Capture and Storage (CCS) is a technology that captures carbon dioxide from flue gas streams of industrial and energy-related processes, which is then transported to an underground storage location by either a pipeline or ship, preventing CO₂ from entering the atmosphere. CCS can potentially reduce mitigation costs, as well as the CO₂ concentration in the atmosphere [5].

Bicarbonate-based integrated carbon capture and algae production system is a method of using bicarbonates to capture carbon dioxide emissions in the atmosphere. This method was invented to reduce costs in carbon dioxide capture and easily transport and store CO₂ especially upon large-scale application [6,7]. The utilization of bicarbonate maximizes the capacity of the microalga to capture...
more carbon dioxide and eliminates the use of energy for the absorption of more carbon dioxide [7]. The use of bicarbonates is one of the key features of the BICCAPS process. With the use of bicarbonates instead of merely transporting or sorting compressed carbon in order to more accurately measure the amount of inorganic carbon present in a solution is one advantage of BICCAPS [6]. BICCAPS has been applied to other microalgae, such as Chlorella vulgaris, Chlorella sp., Scenedesmus obliquus, and Dunaliella salina, utilizing different concentrations of sodium bicarbonate as their carbonate source [8–10]. As of date, studies to be presented on the field and literature is scarce.

*Spirulina platensis* can be cultivated worldwide however it thrives in temperatures of tropical countries such as the Philippines. It is found in freshwaters including ponds and rivers, an abundant source of sunlight and settles at a moderate temperature. It can also live in extreme conditions due to their high adaptability.

Bicarbonate solutions are products of entrapping carbon dioxide from the atmosphere upon interacting with carbonate solutions. It allows the feasibility of carbon dioxide to exist in a non-gaseous phase making it easier to store or process [11]. Bicarbonate formed is utilized as the carbon source for the BICCAPS to increase biomass productivity and enhance growth rate [7,8]. Higher levels of bicarbonate can aid in the said system by increasing the reaction rate thereby making it more efficient. Moreover, inorganic carbons present in the bicarbonate solutions can be regenerated and recycled to absorb another cycle of carbon dioxide. Bicarbonates are also known as excellent carbon dioxide mitigators. Once the gas has been captured, it is able to regenerate and consume more carbon dioxide as compared to that it emits. In addition, the consumption of bicarbonate results to an increase in the alkalinity of the culture medium [7].

Sodium bicarbonate is commonly used for BICCAPS due to its high availability to exist in high concentrations. The biomass productivities of *Spirulina* in the said process were recorded to fall between 0.15 - 0.43 g L⁻¹ day⁻¹ [7]. Another bicarbonate to be considered, however, is potassium bicarbonate; aside from providing a good amount of energy, it is also composed of an alkali metal which is necessary to survive and function upon HCO₃⁻ exhaustion. In addition, potassium bicarbonate, is known to be more soluble than NaHCO₃ and it is likewise highly tolerant to high concentrations- implying its possibility to serve as an alternative for sodium bicarbonate [7,12]. Furthermore, no studies have been recorded for the use of equimolar. Mixture of sodium bicarbonate and potassium bicarbonate is highly likely to mix well together due to the similarity of its solubilities [13]. With the presence of both K⁺ and Na⁺ ions, the mixture may mirror both its advantages thereby promoting a better environment suitable for BICCAPS.

This study evaluate the viability of *Spirulina platensis* in Bicarbonate-based integrated carbon capture and algae production system for CO₂ mitigation and utilization; more specifically, it determines and differentiates the growth curve, biomass productivity, maximum specific growth rate, and inorganic carbon conversion of *Spirulina platensis* under NaHCO₃, KHCO₃, and equimolar mixture of NaHCO₃-KHCO₃ as carbon source.

## 2. Methodology

### 2.1. Culture Media

*Spirulina platensis* was obtained from SEAFDEC and introduced to Modified Zarrouk’s culture media. Modification on the original Zarrouk’s formula, provided by Zarrouk (1966), with regards to the removal of the NaHCO₃ was done to investigate its effect in BICCAPS. The Modified Zarrouk’s culture medium consisted of 2.5 g-L⁻¹ NaNO₃, 0.5 g-L⁻¹ K₂HPO₄, 1 g-L⁻¹ K₂SO₄, 1.0 g-L⁻¹ NaCl, 0.04 g-L⁻¹ CaCl₂₂H₂O, 0.01 g-L⁻¹ FeSO₄₇H₂O, and 1 mL of A₅ solution. The A₅ trace elements solution is composed of 2.86 g-L⁻¹ H₂BO₃, 1.81 g-L⁻¹ MnCl₂ • 4H₂O, 0.222 0.01 g-L⁻¹ ZnSO₄ • 4H₂O, 0.018 0.01 g-L⁻¹ Na₂MoO₄, and 0.079 0.01 g-L⁻¹ CuSO₄ • 5H₂O [14].

### 2.2. Experiment

#### 2.2.1. Cultivation of *Spirulina platensis* with Continuous Aeration

Experimental runs for the cultivation of the microalgae were performed using 10 L polyethylene terephthalate (PET) bottles with a working volume of 8 L composed of 15% algae and 85% culture media. This was exposed to a 12 hour light-12 hour dark cycle with the use of tubular LED lamp while maintaining a pH of approximately 9 and ambient room temperature. The system was continuously aerated by sparging CO₂ from air with the aid of air pumps. The calibration curve was generated by forming a linear relationship with optical density and biomass concentration. Further analysis was conducted by evaluating the biomass productivity,
maximum specific growth rate, and pH. Sampling was performed thrice a week for 31 days which involved obtaining dry weight, optical density, and pH analysis.

2.2.2. Carbonate Dissolution and Carbon Dioxide Absorption. For the control system, 6.3 L of water was bubbled with carbon dioxide at a flow rate of 1 L min⁻¹, with constant stirring by utilizing a magnetic stirrer, in order to produce carbonic acid which is portrayed in equation (1). The resulting solution then dissociates in order to produce both a hydrogen ion and bicarbonate molecule as seen in equation (2). This solution represents a system with no bicarbonate derived from carbonates as carbon source.

\[
\text{CO}_2(g) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3(aq) \quad (1)
\]

\[
\text{H}_2\text{CO}_3(aq) \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \quad (2)
\]

In BICCAPS, two carbonates – Na₂CO₃ and K₂CO₃ – and an equimolar mixture of these carbonates were each diluted in 6.3 L of water in separate 8 L erlenmeyer flasks to produce 0.1 M solutions. The resulting dissolved carbonate solutions were then loaded with carbon dioxide at 1 L min⁻¹ with constant stirring in order to produce bicarbonate solutions, satisfying the reaction presented in equation (3).

\[
\text{H}_2\text{CO}_3(aq) + \text{NaCO}_3(s) \rightarrow \text{Na}_2\text{CO}_3(aq) + 2\text{HCO}_3^- \quad (3)
\]

2.2.3. Cultivation in BICCAPS. The resulting solutions are evaluated under a closed system cultivation where the bicarbonate mixtures were mixed with culture media and the microalgae in 6 L PET bottles with a working volume of 5 L; each system having a composition of 15% *Spirulina platensis*, 40% Bicarbonate solution, and 45% culture media. This was continued for approximately 30 days or until the stationary phase was observed. Sampling was performed thrice a week until approximately 30 days or until the stationary phase is observed in order to evaluate its pH, optical density, carbonate, bicarbonate, and dissolved CO₂ content.

2.3. Analytical Method

2.3.1. Cell Growth Measurement. 0.45 µm sterilized membrane filter is initially oven-dried in order to remove remaining moisture. A 30-45 mL sample is obtained from each system and vacuum filtered and oven dried with the membrane filter. The difference between the weights divided by the sample volume is calculated as the biomass concentration which is expressed in equation (4). Analysis such as biomass productivity, equation (5), is obtained by dividing the difference of the final and initial biomass concentrations under the exponential phase with time. Also, equation (6) obtains the maximum specific growth rate of the microalgae by forming a linear relationship of biomass concentration under exponential phase and time.

\[
\text{Biomass concentration} = \frac{\text{dried filter with biomass} - \text{dried filter}}{\text{sample volume}} \quad (4)
\]

\[
\text{Biomass productivity} = \frac{X - X_0}{t} \quad (5)
\]

\[
\ln(X) = \mu_{\text{max}} t + \ln(X_0) \quad (6)
\]

Where X represents the final biomass concentration in g L⁻¹, X₀ as the initial biomass concentration in g L⁻¹, \(\mu_{\text{max}}\) as the specific growth rate in day⁻¹, and t as time in days.

2.3.2. Optical Density A UV-1700 spectrophotometer with a wavelength of 530 nm was used for optical density analysis. Sampling was performed every 2 days in duplicate analysis. Utilizing the Beer-Lambert’s Law, as displayed in equation (7), a linear relationship between absorbance and concentration is observed.

\[
A = \log_{10} \frac{1}{T} = \varepsilon c l \quad (7)
\]

Where A is the absorbance, T is the transmittance, \(\varepsilon\) is the absorptivity in M⁻¹cm⁻¹, c is the concentration in M, l is the path length in cm

2.3.3. Carbonate and Bicarbonate Concentrations. Double titration is performed in order to identify carbonate and bicarbonate concentrations A 5- mL sample was first titrated with approximately 0.1M HCl up to phenolphthalein endpoint in order to account for carbonate concentration in each sample, as
seen in equation (8); amount of bicarbonate then was obtained by a second titration utilizing bromocresol green indicator with the same acid, as illustrated in equation (9).

\[
\begin{align*}
  \text{CO}_3^{2-} + \text{H}^+ &\rightarrow \text{HCO}_3^- \quad (8) \\
  \text{HCO}_3^- + \text{H}^+ &\rightarrow \text{H}_2\text{CO}_3 \quad (9)
\end{align*}
\]

2.3.4. Dissolved CO\(_2\) Concentration. Another 5-mL sample was first vacuum filtered then added with excess 0.1M NaOH, allowing a full conversion of dissolved carbon dioxide into sodium carbonate as seen in equation (10). Afterwards, excess 1M BaCl\(_2\) was added in the same sample, precipitating carbonates to a white-opaque solution, BaCO\(_3\), as expressed in equation (11). Unreacted NaOH is back titrated with 0.1M HCl to a phenolphthalein endpoint as shown in equation (12).

\[
\begin{align*}
  \text{CO}_2 + 2\text{NaOH} &\rightarrow \text{Na}_2\text{CO}_3 + \text{H}_2\text{O} \quad (10) \\
  \text{Na}_2\text{CO}_3 + \text{BaCl}_2 &\rightarrow 2\text{NaCl} + \text{BaCO}_3 \quad (11) \\
  \text{NaHCO}_3 + \text{NaOH} &\rightarrow 2\text{NaCl} + \text{H}_2\text{O} \quad (12)
\end{align*}
\]

Amount NaOH that reacted in the solution is then regarded as the total amount of CO\(_2\) and bicarbonate. Hence, to calculate for the dissolved CO\(_2\) content in the sample, the difference between total carbon dioxide reacted and known bicarbonate determines amount of dissolved CO\(_2\), as displayed in equation (13).

\[
\text{moles dissolved CO}_2 = \frac{\text{moles CO}_2 \text{ reacted} - \text{moles HCO}_3^- \text{ reacted}}{2} \quad (13)
\]

2.3.5. Inorganic Carbon Conversion. The amount of CO\(_2\) converted into biomass per volume of culture per day is termed as the inorganic carbon (Ci) conversion, as shown in equation (14). In BICCAPS, the total amount of CO\(_2\) utilized include the quantity of carbonate produced after the cultivation period, as well as the quantity of dissolved CO\(_2\) present in the culture medium consumed, as seen in equation (15).

\[
\begin{align*}
  \text{Ci conversion} &= \frac{\Delta \text{Ci}}{\text{culture time}} \quad (14) \\
  \Delta \text{Ci} &= \text{[CO}_3^{2-}]_{\text{produced}} + \text{[dissolved CO}_2]_{\text{consumed}} \quad (15)
\end{align*}
\]

3. Results and Discussion

3.1. Spirulina Platensis Cultivation

The cultivation of microalga \textit{Spirulina platensis} under an open system was regularly analyzed and monitored in order to maintain proper operating conditions. Optical density and dry weight were measured three times a week for approximately 30 days to produce a calibration curve. Two trials for each media for the cultivation of the microalgae were performed. From this, a calibration curve (Fig 1a) was generated with a linearity value of 0.7817; this value is considered close to the value of 1 and is in accordance with Beer- Lambert Law. This curve was then used in the calculation of biomass concentration from an obtained absorbance under the closed system. Furthermore, a growth curve (Fig 1b) is displayed by relating obtained biomass concentration with time. Once the stationary phase was observed, further growth was halted. It could also be seen that the exponential phase occurred from the second until the 26\(^{th}\) day producing a maximum specific growth rate (\(\mu_{\text{max}}\)) of 0.0469 day\(^{-1}\) as seen in figure 1c and a biomass productivity of 11.19 mg L\(^{-1}\) day\(^{-1}\).

![Figure 1](image-url)
The obtained growth curve and biomass productivity can be compared with the study presented by Soni, Sudhakar, & Rana [15]. The said study was able to produce a biomass productivity of 8.57 g L\(^{-1}\) day\(^{-1}\) while this study produced 0.01119 g L\(^{-1}\) day\(^{-1}\); although the system was able to grow successfully, the removal of NaHCO\(_3\) from the initial culture medium could have been a factor in the significant difference between the biomass productivities of both studies especially since the original formulation of Zarrouk’s medium is specifically formulated for optimal *Spirulina platensis* growth.

### 3.2. Carbon Dioxide Absorption of Control System and Sodium Carbonate Salt System

pH, carbonate, bicarbonate, and dissolved carbon dioxide concentrations was first evaluated in the control system where only water was present. Carbonate and bicarbonate response is found in Figure 2a. It can be noted that the carbonate concentration remained constant at zero which implies no conversion. Meanwhile, bicarbonate concentration is seen to peak during the 5th minute with a concentration of 5.69 mM and continued to decrease thereafter; this behavior can be supported by the reversible reaction of carbonic acid and bicarbonate as seen in equation (2). Subsequently, after 15 minutes, the amount of bicarbonate remained constant in accordance with Le Chatelier’s principle which states that a change in the system will cause an opposing change to eventually reach a new equilibrium state [19].

Carbon dioxide absorption under sodium, potassium, and equimolar mixture of sodium-potassium carbonate systems were successful as the amount of bicarbonates increased twice as much as the amount of carbonates. Under a sodium carbonate system (Fig. 2b), carbonate concentration decreased at a constant rate of 1.4186 mM min\(^{-1}\) while the bicarbonate concentration increased at a rate of 2.3677 mM min\(^{-1}\) under ambient room temperature and atmospheric pressure. Potassium carbonate solution (Fig. 2c), on the other hand, consumed carbonate at a rate of 0.9638 mM min\(^{-1}\) and produced bicarbonate at a rate of 2.0113 mM min\(^{-1}\). Lastly, the rate of decrease of carbonate concentration and increase of bicarbonate concentration under sodium-potassium carbonate system (Fig. 2d) showed a stable values of 1.1475 mM/min and 2.1895 mM/min respectively.

From this, further evaluation of percent yield and CO\(_2\) absorption ratio was performed. Percent yield was simply obtained by diving the actual with theoretical bicarbonate concentrations while CO\(_2\) absorption ratio pertains to the amount of carbon dioxide absorbed per mole of carbonate consumed. Table 1 displays a summary of the initial and final concentrations of carbonate and bicarbonate in each solution as well as its percent yield and CO\(_2\) absorption ratio.

| Parameter               | Na\(_2\)CO\(_3\) | K\(_2\)CO\(_3\) | Na\(_2\)CO\(_3\) - K\(_2\)CO\(_3\) |
|-------------------------|-----------------|-----------------|----------------------------------|
| Duration (min)          | 150             | 210             | 195                              |
| CO\(_3^2\) (mM)         | Initial         | 280.046         | 225.96                           | 236.43                           |
|                         | Final           | 54.962          | 41.88                            | 36.64                            |
| Total HCO\(_3^\) (mM)  | 355.881         | 367.91          | 417.02                           |
| HCO\(_3^\) from salt (mM)| 9.597           | 0               | 5.24                             |
| CO\(_2\) captured (mM) | 326.284         | 386.48          | 411.78                           |
| % Yield                 | 70.41%          | 99.76%          | 88.19%                           |
| CO\(_2\) Absorption Ratio | 1.450          | 2.100           | 2.061                            |

Figure 2. Response of (a) Pure H\(_2\)O, (b) Sodium, (c) Potassium and (d) Sodium-Potassium Carbonate in Gas Absorption.
As can be seen in Table 1, sodium carbonate had the lowest percent yield and conversion ratio, while potassium carbonate had the highest. This is consistent with the studies proven by Lee et al. (2007), Park, Sung, Choi, Lee, & Kumazawa (2006), and Park, Sung, Choi, Oh, & Moon (2006) where K₂CO₃ exhibited better reaction kinetics and CO₂ absorption ability. In addition, the sodium-potassium carbonate solution % yield and conversion ratio are found between those of sodium and potassium carbonate due to the presence of both Na⁺ and K⁺ ions. A higher % yield and conversion ratio may be attained with an extended reaction time for both Na₂CO₃ and Na₂CO₃- K₂CO₃ [17–19].

3.3. CO₂ Assimilation/Utilization Under Controlled Carbon Dioxide and BICCAPS

Solutions obtained from the carbon dioxide absorption were each combined with Modified Zarrouk’s medium and microalgae as a source of carbon under Bicarbonate-based Integrated Carbon Capture and Algae Production System (BICCAPS). Growth of S. platensis under the said system was first performed under controlled carbon dioxide loading. This was used as a control experiment for comparison with the succeeding systems which involved carbonate sources. The growth of S. platensis under ZC (control system under Modified Zarrouk’s) was successful as it exhibited a biomass productivity of 10.41 mg L⁻¹ day⁻¹ after it was grown for 40 days (Fig. 3a). As for the systems utilizing carbonate salts, the growth displayed by ZS (sodium carbonate under Modified Zarrouk’s) system is presented in Figure 3b and had a biomass productivity of 6.558 mg L⁻¹ day⁻¹. On the other hand, no exponential phase was visible for the ZK (potassium carbonate under Modified Zarrouk’s medium) system as illustrated by Fig. 3c; hence it can be inferred that the microalgae did not grow and was not able to utilize the bicarbonate as carbon source for growth. Furthermore, the growth of S. Platensis was also successful under the ZM (sodium-potassium carbonate under Modified Zarrouk’s medium) system, as seen in Fig. 3d, which resulted to a biomass productivity value of 5.42 mg L⁻¹ day⁻¹. All systems aside from ZK started to display the stationary phase at the 31st day.

Figure 3. Growth Curves of S. platensis under modified Zarrouk’s medium for (a) controlled, (b) sodium, (c) potassium, and (d) sodium-potassium.
Maximum specific growth curves for the systems under Modified Zarrouk’s medium were likewise produced. Exponential phase of ZC system was observed during the 5\textsuperscript{th} day to the 33\textsuperscript{rd} day contributing to a maximum specific growth rate of 0.0655 day\textsuperscript{-1} as seen in Fig. 5.6a. Growth under ZS system was observed to plateau after the 31\textsuperscript{st} day while the exponential phase occurred during the 10\textsuperscript{th} to the 31\textsuperscript{st} day producing a maximum specific growth rate of 0.0632 day\textsuperscript{-1} (Figure 5.6b). The biomass concentration of ZK system, on the other hand, remained constant throughout the cultivation indicating no growth; hence, a maximum specific growth curve for the system could not be generated. Additionally, the exponential phase under ZM system was observed during the 5\textsuperscript{th} until 31\textsuperscript{st} day while the stationary phase was not achieved, indicating that the system was still growing (Fig. 5.6c). All systems, therefore, apart from ZK, depicted similar growths in terms of the exponential phase as with the open system is observed.

The carbonate, bicarbonate and dissolved CO\textsubscript{2} concentrations of the systems under Modified Zarrouk’s were also monitored throughout the cultivation period. For ZC system, bicarbonate produced solely from carbon dioxide was properly utilized by \textit{S. platensis} as depicted in Fig 5a. Bicarbonates are seen to decrease while carbonates increase in concentration from the reversible nature of carbonate-bicarbonate solutions. Dissolved carbon dioxide concentration, as illustrated in Fig. 6a displayed an inverse parabolic trend where it decreased for a short period of time then increased afterwards resulting to an inorganic carbon conversion of 10.94 mM.

In addition, for the ZS system, there was a simultaneous decrease in HCO\textsubscript{3}\textsuperscript{-} at a rate of 1.380 mM day\textsuperscript{-1} and increase in CO\textsubscript{3}\textsuperscript{2-} at a rate of 0.214 mM day\textsuperscript{-1} as can be seen from Figure 5b. Bicarbonate and carbonate concentrations for ZK system are displayed in Fig. 5c where trends of 0.7020 mM day\textsuperscript{-1} and 0.2141 mM day\textsuperscript{-1} were observed, respectively. As compared to ZS, the bicarbonate increase is higher while the carbonate rise is lower. In addition, inorganic carbon concentration was measured at 0.996 mM day\textsuperscript{-1}, also higher than ZS system. It should be noted as well that the carbon dioxide concentration in the solution increased at first then decreased upon achieving a peak value (Fig. 6c). Furthermore, for ZM system, HCO\textsubscript{3} decrease was observed at a rate of 0.1794 mM day\textsuperscript{-1} while CO\textsubscript{3}\textsuperscript{2-} concentration increased at a rate of 0.2848 mM day\textsuperscript{-1} as depicted in Fig. 5d indicating that the system was not able to properly utilize the bicarbonates present in the system. Fig. 6d displays an evident decrease in the
dissolved carbon dioxide concentration of the system which indicates that only CO\textsubscript{2} served as the carbon source of the microalgae; therefore, an inorganic carbon conversion of 4.192 mM day\textsuperscript{-1} was obtained.

Figure 5. Concentration profile for carbonate and bicarbonate of \textit{S. platensis} under modified Zarrouk’s medium for (a) controlled, (b) sodium, (c) potassium, and (d) sodium-potassium bicarbonate solutions

Figure 6. Dissolved CO\textsubscript{2} concentrations of \textit{S. platensis} under modified Zarrouk’s medium for (a) controlled, (b) sodium, (c) potassium, and (d) sodium-potassium bicarbonate solutions

3.4. Comparison of Different Culture media Under BICCAPS
A comparison of all systems performed in this study is presented in Table 2. From here, it can be observed that the open system ranks first with regards to its biomass productivity but is closely followed by a closed system under controlled carbon dioxide loading. This deems that a fixed carbon dioxide concentration environment is a suitable alternative for \textit{Spirulina platensis} growth for an open system. However, it can also be observed that under closed systems, the presence of bicarbonate caused a decline in productivity. It is highly likely therefore that the sodium and potassium ions posed inhibiting effects on the microalgae. Furthermore, it can be seen that the system exposed to potassium bicarbonate implied greater inhibiting effects which could be attributed to the increased solubility and kinetics of potassium
ions as compared with that of sodium ions. In BICCAPS, it is a requirement for the organism to thrive at high alkalinity and bicarbonate loadings in order to maximize its use. However, since the growth of *S. platensis* cannot thrive at a carbonate loading of 0.1M or 0.2M bicarbonate loading, the chosen microalgae is not best for the use of BICCAPS thereby implying that another microalgae with a better tolerance for alkalinity should be used. Excluding potassium carbonate, the exposure of *S. platensis* under different media of other carbonate salts may be further evaluated and improved by varying its concentration.

**Table 2. Summary of Different Parameters Under Modified Zarrouk’s Media**

| System | Biomass Productivity | Rank (BP) | Maximum Specific Growth Rate (mM) | Rank (CC) |
|--------|----------------------|-----------|-----------------------------------|-----------|
| ZO<sup>a</sup> | 11.19 | 1 | 0.0469 | - |
| ZC<sup>b</sup> | 10.42 | 2 | 0.0655 | 0.292 | 4 |
| ZS<sup>c</sup> | 6.56 | 4 | 0.0632 | 2.682 | 2 |
| ZK<sup>d</sup> | 4.48 | 5 | N/A | 0.996 | 3 |
| ZM<sup>e</sup> | 7.37 | 3 | 0.0703 | 4.192 | 1 |

<sup>a</sup>ZC- Modified Zarrouk’s Medium, open system.
<sup>b</sup>ZC- Modified Zarrouk’s Medium, control system.
<sup>c</sup>ZS- Modified Zarrouk’s Medium, sodium carbonate system.
<sup>d</sup>ZK- Modified Zarrouk’s Medium, potassium carbonate system.
<sup>e</sup>ZM- Modified Zarrouk’s Medium, sodium-potassium carbonate system.

Furthermore, it is observed that the carbon conversion of the control system is very minimal as compared to those with bicarbonates present. This could be due to the fact that during carbon absorption, only a maximum of approximately 10 mM of bicarbonate concentration and a peak of approximately 6 mM of dissolved carbon dioxide concentration was obtained for the control system while carbonate solutions had bicarbonate values ranging from 0-417 mM and dissolved carbon dioxide concentrations of 0-411 mM. This indicates that the carbon source available for the control system was initially relatively low as compared to those with added carbonate salts. However, if the carbon conversion of the different bicarbonate systems are compared, it can be seen that a direct relationship exists with biomass productivity and carbon conversion value.

Under BICCAPS, it can be seen that *Spirulina platensis* was best grown under a mixture of sodium-potassium bicarbonate system. The behavior of this mixture can be further studied and applied for other microalgae appropriate for BICCAPS.

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