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# Preliminary Study on Biomitigation Green House Gas Carbon Dioxide in Closed System Bubble Photobioreactor: Relationship Among the Mass Transfer Rate and CO<sub>2</sub> Removal Efficiency in High Level of CO<sub>2</sub>

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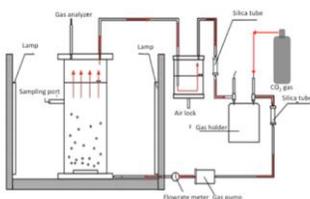
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## Article history

Received :1 January 2014  
Received in revised form :  
15 February 2014  
Accepted :18 March 2014

## Graphical abstract



## Abstract

Emission of carbon dioxide (CO<sub>2</sub>) is a major contributor to global warming. Biofixation of CO<sub>2</sub> by microalgae in photobioreactors seems to be a promising strategy for CO<sub>2</sub> mitigation. The research to determine the overall mass transfer coefficient (k<sub>L</sub>a) has been done to find the way on biomitigation CO<sub>2</sub> emission by using biologically Carbon Capture and Sequestration method. This research was conducted according to green microalgae *Scenedesmus obliquus* activity, which is cultivated in a bubble photobioreactor through the mass transfer process that assumed adequate mixing occurs. Flow rate of CO<sub>2</sub> that supplied to the system were 2 L/min, 5 L/min and 8 L/min, when each rate flowed into the photobioreactor with high CO<sub>2</sub> concentration (v/v) of 2%, 5% and 10%. The highest CO<sub>2</sub> removal efficiency occurred at culture that supplied with an CO<sub>2</sub>-enriched air flow rate of 5 L/min. The k<sub>L</sub>a (CO<sub>2</sub>) value is the highest in 0.3582/day at 2% CO<sub>2</sub> concentration and flow rate of 2 L/min, while the lowest is in 0.0503/day at 5% CO<sub>2</sub> concentration and flow rate of 8 L/min. In terms of solubility is inversely proportional to the flow rate, the less carbon dioxide is dissolved at the rate of 8 L/min as well as the value of the k<sub>L</sub>a. The results showed that the variation of flow rate will affect the amount of mass transfer coefficient, growth rate and cell biomass. Higher flow rate decreases k<sub>L</sub>a value as well as CO<sub>2</sub> removal efficiency.

**Keywords:** Biomitigation; photobioreactor; k<sub>L</sub>a (CO<sub>2</sub>); mass transfer; *Scenedesmus obliquus*

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## 1.0 INTRODUCTION

Removal of carbon dioxide (CO<sub>2</sub>) from industrial flue gases become an urgent necessity in order to reduce the impact of CO<sub>2</sub> on global warming. The researcher [1] explained that the two main CO<sub>2</sub> mitigation strategies commonly used approach is based on chemical reactions and biological mitigation. On the one hand, the chemical reactions based CO<sub>2</sub> mitigation approach is energy-consuming, expensive process to use, and disposal problems due to either carbon dioxide captured and absorbent waste needs to be removed. On the other hand, one interesting method for CO<sub>2</sub> mitigation is the use of biological processes in the utilization of CO<sub>2</sub> directly from the biomass to be converted into a point source of CO<sub>2</sub> emissions in a closed system that is engineered as a photobioreactor. The biological CO<sub>2</sub> mitigation has attracted much attention in recent years because it causes the production of biomass energy in the process of fixation of CO<sub>2</sub> through photosynthesis. Other researcher [2] described the use of photobioreactors for CO<sub>2</sub> absorption by microalgae offers major advantages is the increase in productivity of microalgae for controlled environmental conditions and maintenance space utilization can be optimized so that it is considered more efficient

than using terrestrial plants that require extensive and expensive land.

The fact that most of the flue gases produced by most industries contain 5–15% CO<sub>2</sub> concentration gives microalgae the advantage of being the best candidate for creating a sustainable carbon sink. One of the hydrodynamic variables related to the growth of microalgae, and the effectiveness of the removal of carbon dioxide is the mass transfer of carbon dioxide. The mass transfer of carbon dioxide from air into the media can be growth-limiting in dense algal cultures [3].

In 2009, [4] stated that the transfer of CO<sub>2</sub> from a gas to a liquid depends on many parameters such as gas flow rate, CO<sub>2</sub> partial pressure, bubble diameter and lifetime can have large influences on the rate of transfer. Mass transfer coefficient of CO<sub>2</sub> or k<sub>L</sub>a (CO<sub>2</sub>) could reflect the condition of the mass transfer that occurs in the photoreactor. The k<sub>L</sub>a term generally used to describe the overall volumetric mass transfer coefficient photobioreactor. Volumetric mass transfer coefficient (k<sub>L</sub>a) is characteristic of a photobioreactor in determining the ability of a photobioreactor to maintain optimal cell growth. The k<sub>L</sub>a value (CO<sub>2</sub>) is a general hydrodynamic parameter that is often used to assess the performance of the bioreactor in the cultivation of microalgae. For microalgae cultivation process is necessary k<sub>L</sub>a

optimal value. The high value of  $k_L a$  indicates the mass transfer of  $\text{CO}_2$  better in microalgae culture [3], [4], [5], [6].

Behavior of  $k_L a$  and cell growth rate varies in different regions in a fluid stream. Region fluid flow in the photobioreactor can be divided into streams of bubbles, and heterogeneous transition zone depends on the gas velocity, the flow area of the bubble, the gas hold-up, the interface area and the  $k_L a$  proportional to the superficial gas velocity [5]. Despite the reduction in interface area start moving from the transition zone to zone heterogeneous but the gas continues to rise and reaches a high value of the  $k_L a$ . The  $k_L a$  values, a specific increase in the initial growth but at the end of the transition zone begins to decline [7].

This study examines the effect of the concentration of carbon dioxide on  $\text{CO}_2$  removal by microalgae *Scenedesmus obliquus*, biomass concentration, and the rate of mass transfer in a bubbles photobioreactor.

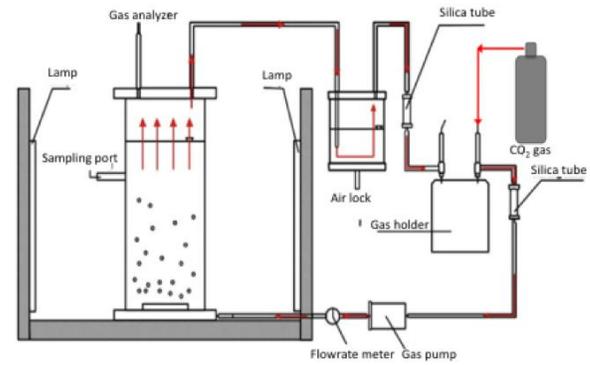
## 2.0 MATERIAL AND METHODS

### 2.1 Culture of *Scenedesmus obliquus*

Microalgae used in this study is green microalgae *Scenedesmus obliquus* isolated from Wastewater Treatment Bojongsoang, Bandung, Indonesia previously been performed screening of the types of microalgae found in the installation of a pool [8]. Provasoli Hematococcus Media (PHM) chosen as growth medium because the medium is suitable for freshwater microalgae, such as *Scenedesmus obliquus* [9]. In the activation process, *Scenedesmus obliquus* put in PHM medium in glass bottles, aerated with air at a rate of 800 ml/min, at 2500 lux light intensity and ambient temperature. The activation process is a growing process of microalgae cells to be used directly in the photobioreactor cultivation. This process also serves to prevent long a lag phase in the photobioreactor cultivation.

### 2.2 Operational Experimental Condition of Closed System Photobioreactor

This study used a vertical type with a bubbles photobioreactor to distribute  $\text{CO}_2$ -enriched air (Figure 1A) whereas sparger placed at the bottom of the photobioreactor to distribute carbon dioxide (Figure 1B). One of the parameters that determine the growth and biofixation  $\text{CO}_2$  by microalgae is the rate of mass transfer in a photobioreactor gas. In order to enhance the mass transfer, a Sparger as gas converter into small bubbles is fitted at the bottom of the reactor. Sparger used has a diameter of between 100-160  $\mu\text{m}$ . Sparger is mixing condensed gas with a flow rate of 2 L/min, 5 L/min and 8 L/min to increase the mass transfer of  $\text{CO}_2$  and also eliminates the  $\text{O}_2$  produced during photosynthesis. The size of the bubbles are formed also affect  $\text{CO}_2$  fixation by microalgae.



**Figure 1** Schematic design of closed system bubble photobioreactor microalgae

Advantage of using the photobioreactor microalgae cultivation process is providing culturing conditions that can avoid contamination as well as presence of competitors or culture in a state that has been adjusted in order to obtain the optimum results for then can be done to scaled up. Environmental conditions for the study were light intensity of 4000 lux, the periodicity of 16 light hour and 8 dark hour and temperature of  $30^\circ\text{C}$ .

### 2.3 Measurement of Biomass Concentration and Growth Rate of *Scenedesmus obliquus*

Biomass concentration (dry weight) according to [10] calculated by the formula: dry weight ( $X$ ; mg) =  $y$  (mg) -  $x$  (mg). Specific growth rate ( $\mu$ ;  $\text{d}^{-1}$ ) was calculated as follows:

$$\mu = \frac{1}{X} \cdot \frac{dX}{dt} \quad (1)$$

Dry weight cell biomass of microalgae was obtained by evaporating the liquid in the cell culture. A total of 100 mL culture tube inserted into centrifuges, and then centrifuged at 3500 rpm for 10 minutes [11]. Supernatant was then removed from the tube pasta until just earned cells. Pasta cells were then put into a petri dish that had previously been weighed ( $x$ ). Samples were put in the oven with a temperature of  $105^\circ\text{C}$  for one night to get a constant weight ( $y$ ), and then stored in a desiccator for 30 minutes before re-weighed.

### 2.4 Measurement of $\text{CO}_2$ Concentration and Determination of $\text{CO}_2$ Removal Efficiency

Efficiency of  $\text{CO}_2$  removal can be calculated by the following formula:

$$\frac{\text{Influent of } \text{CO}_2 - \text{Effluent of } \text{CO}_2}{\text{Influent of } \text{CO}_2} \times 100\% \quad (2)$$

The  $\text{CO}_2$  concentration in the influent gas and effluent gas was measured by Portable Combination Gas Detector RIKEN Model RX-515.

### 2.5 Measurement of Overall Mass Transfer Rate

The rate of  $\text{CO}_2$  absorption associated with the mass transfer of  $\text{CO}_2$  and the overall rate of carbon dioxide by microalgae biofixation.  $\text{CO}_2$  absorption rate is temperature dependent. In the overall mass transfer rate equations contained in the Equation 3.

$$Na = k_L a (C^* - Ct) \tag{3}$$

Na is the rate of transfer of carbon dioxide per unit of time. The equation shows that the rate of transfer of carbon dioxide per unit time is proportional to the difference between the concentration of the injected carbon dioxide saturated with dissolved carbon dioxide concentration. In accordance with the theory of the reaction order and reaction rate, the rate of mass transfer of CO<sub>2</sub> is included in the reaction order 0 [3], [5].

### 3.0 RESULTS AND DISCUSSION

#### 3.1 CO<sub>2</sub> Removal Efficiency

Figure 2 shows the profile of CO<sub>2</sub> removal efficiency at various flow rates during 12 days of observation. At each slow flow rate (2 L/min), moderate (5 L/min), and rapid (8 L/min), the CO<sub>2</sub> removal efficiency is higher in cultures were flowed with 2% CO<sub>2</sub>, followed by culture that flowed with 5% CO<sub>2</sub> and 8% CO<sub>2</sub>. Low flow rates allow CO<sub>2</sub> gas stuck longer in the system, while the rapid flow rate causes turbulence, and CO<sub>2</sub> is rapidly moving out of the system so that CO<sub>2</sub> removal could not occur. In other words, the longer of detention time at a lower flow rate (2 L/min) causes the higher of CO<sub>2</sub> removal efficiency.

Although high CO<sub>2</sub> removal efficiency generally occurs in cultures were flowed with a slow flow rate (2L/min) but the highest removal efficiency of the CO<sub>2</sub> occurred in the reactor with a flow rate of 8 L/min i.e the CO<sub>2</sub> removal efficiency was 16% in cultures supplied with 2% CO<sub>2</sub> (Figure 2c). The researcher [10] reported that 24% CO<sub>2</sub> has been sequestered in microalgae cultures that supplied with 5.5% pure CO<sub>2</sub>. Thus the efficiency of CO<sub>2</sub> removal in this study is low, although the efficiency is still greater than the volume of carbon dioxide in the ambient air.

Average of CO<sub>2</sub> removal efficiency at various flow rates can be seen in Figure 3. For every input of CO<sub>2</sub> concentration with variations of flow rate, has the same efficiency profile, whilst the higher the concentration of CO<sub>2</sub> the smaller the average removal efficiency of CO<sub>2</sub>.

Reduced amount of CO<sub>2</sub> that captured in the medium of microalgae in a photobioreactor will be used for the photosynthesis process by microalgae. CO<sub>2</sub>-enriched air that flowed into the photobioreactor is a potential gas to perform mass transfer. In hydrodynamic aspect, its purpose is to ensure the more gas hold in the system then the mass transfer process will be optimal.

In the water, the carbon dioxide will dissolved and formed a carbonate compound depends on the pH conditions. Microalgae will use the carbon dioxide dissolved in water to perform photosynthesis process and store it in the vacuole. Furthermore, by using Rubisco enzymes used in photosynthesis process which will naturally produce oxygen, so that the carbon dioxide out of the photobioreactor will be less than the amount that supplied.

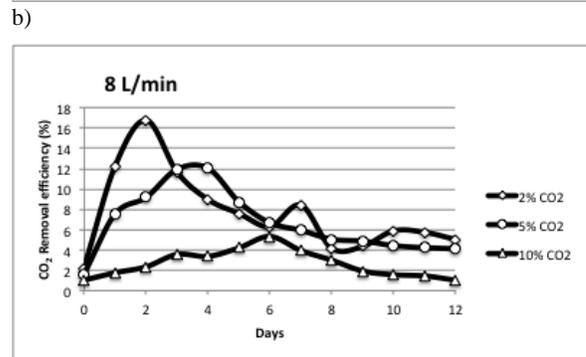
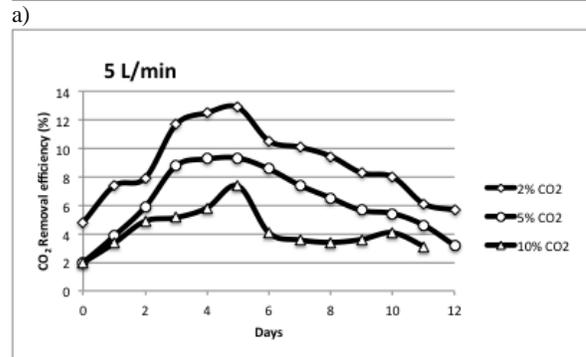
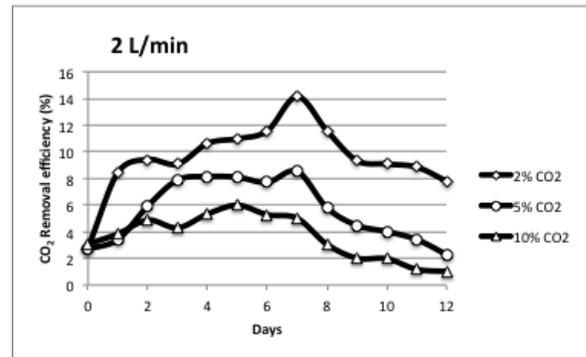


Figure 2 Profile of CO<sub>2</sub> removal efficiency with high level concentration of CO<sub>2</sub> at variation of flow rate a) 2 L/min, b) 5 L/min, c) 8 L/min

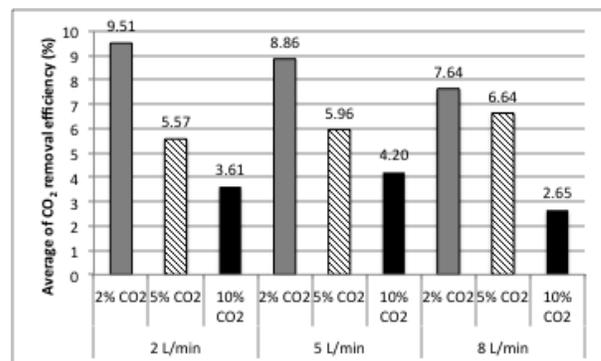


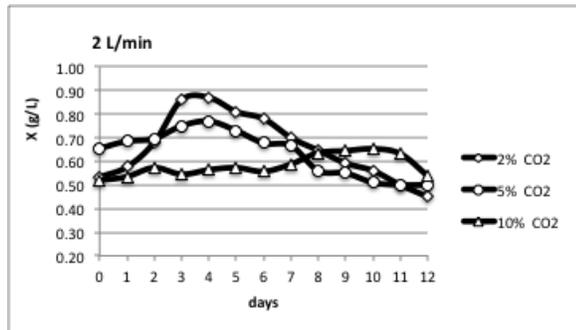
Figure 3 Average of CO<sub>2</sub> removal efficiency with variation flow rate and concentration (v/v) of CO<sub>2</sub>

#### 3.2 Organic Biomass of *Scenedesmus obliquus*

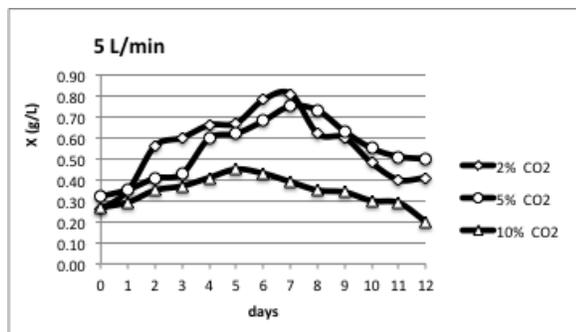
According to research by [12], microalgae *Scenedesmus obliquus* is appropriate to reduce the concentration of CO<sub>2</sub> for biomass

productivity and high lipid and carbon fixation ability is higher than other microalgae. Or fixation of CO<sub>2</sub> removal efficiency depends on the physiological condition of microalgae, such as the potential for cell growth and metabolic capabilities of CO<sub>2</sub>.

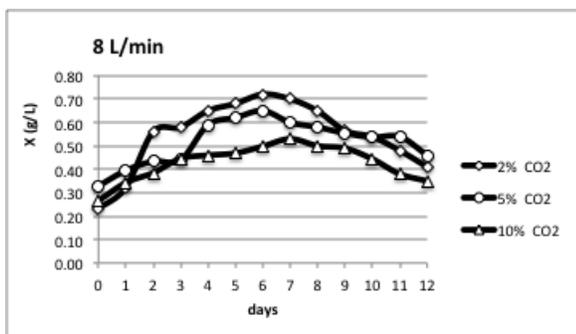
Microalgae growth can be seen in Figure 4. In the cultures supplied with CO<sub>2</sub> of 2 L/min, growth tends to be more stable than other flow rates. Microalgae growth rate increased until at the height of growth, then the growth rate slows. At each flow rate variation, the same phenomenon occurs but in different days, such that the flow rate becomes a factor that limits the growth of microalgae.



a)



b)

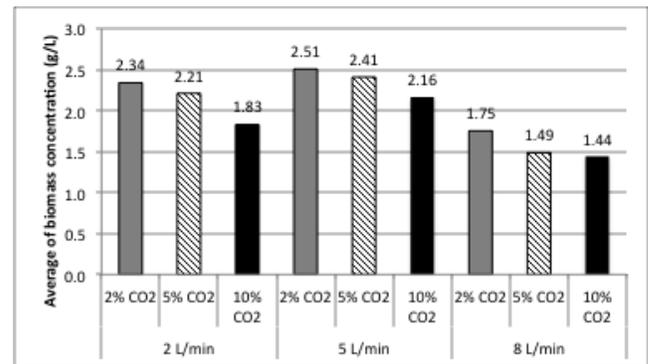


c)

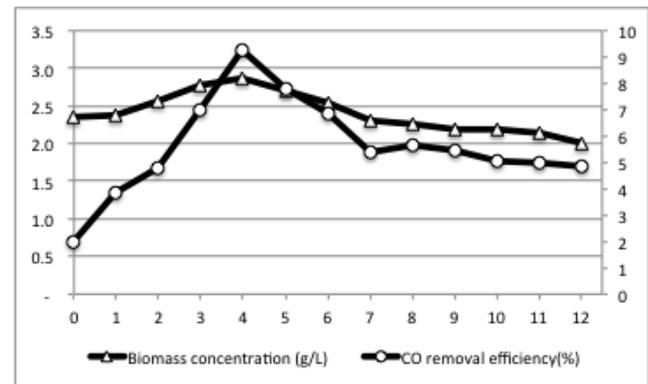
**Figure 4** Profiles of organic biomass concentration (g/L) of *Scenedesmus obliquus*

Figure 4 shows the growth response of microalgae *Scenedesmus obliquus* at elevated flow rate and concentration (v/v) of CO<sub>2</sub>. These profiles indicate that the dry weight of biomass as growth response is affected by the flow rate and concentration of CO<sub>2</sub> that injected into photobioreactor. In each culture were be flowed with 10% CO<sub>2</sub>, at condition a slow flow rate (2 L/min) to fast flow rate (2 L/min), all cultures showed poor

growth response compared with cultures were be flowed with a lower CO<sub>2</sub> concentration than 10%, i.e 2% and 5% CO<sub>2</sub>. The average biomass concentration in culture were fed with the 10% CO<sub>2</sub> was about 30% compared with an average biomass obtained from cultures were fed with 2% CO<sub>2</sub> and 5% CO<sub>2</sub> (Figure 5).



**Figure 5** Average of biomass concentration(%) with variation flow rate and concentration (v/v) of CO<sub>2</sub>



**Figure 6** Profiles of CO<sub>2</sub> removal efficiency and concentration of biomass at condition of 5% (v/v) CO<sub>2</sub> and Flow rate of 5 L/min

In this study, *Scenedesmus obliquus* still could grow at concentration of 10% CO<sub>2</sub>, with flow rate of 8 L/min or 27.16 m/hour although it is potentially cause the shear stress. The shear stress occurs when superficial velocity exceeds the ability of microalgae to withstand the stress.

Microalgae growth in the medium supplied with carbon dioxide-enriched air will be hampered due to lack of other substrates than carbon dioxide. In this study, CO<sub>2</sub>-enriched air is the only addition compounds that injected into the system. CO<sub>2</sub> removal efficiency at flow rate of 2 L/min did not differ significantly with culture were be flowed with flow rate of CO<sub>2</sub> 5 L/min for each concentration of CO<sub>2</sub> is put into the system (Figure 3) but we recommend the flow rate of 5 L/min as the best flow rate, not too slow (2 L/min) nor too fast (8 L/min), since generally the maximum biomass concentration (g/L) of all elevated CO<sub>2</sub> level occurred in cultures supplied with CO<sub>2</sub> flow rate of 5 L/min. When compared with the findings of [15], the maximum cell concentration of 2.02 g/L was found in cultures supplied with 5% CO<sub>2</sub> and a minimum cell concentration of 1.16 g/L was found in cultures supplied with 0.5% CO<sub>2</sub>. It is therefore advisable to maintain the concentration of CO<sub>2</sub> is lower than 5% because higher CO<sub>2</sub> concentrations can inhibit the growth of microalgae. In addition, they reported a gradual increase in the concentration of the cells when the concentration of CO<sub>2</sub> increases. Therefore,

the concentration of CO<sub>2</sub> is directly related to the cells concentration and microalgae biomass.

Related to the growth of microalgae, the concentration of carbon dioxide in the culture medium could not below the requirement for maximum growth rate culture but should not exceed the maximum that can be tolerated by a particular microalgae. In comparison with the study of [14], 5% to 20% concentration of CO<sub>2</sub> from flue gas is the optimum carbon source that is beneficial to the growth of biomass. At higher CO<sub>2</sub> concentrations of 20% will cause the pH and carbonate anhydrase activity is reduced, so that will inhibit growth. The researcher [14] also concluded that the microalgae growing well below 5% to 20% of CO<sub>2</sub>, despite the best growth potential at 10% CO<sub>2</sub>.

In this study, microalgae could grow in culture that injected 10% CO<sub>2</sub> concentration with a flow rate of 8 L/min, although the growth rate tends to be stable during this phase according to a constant number of cells. It can be caused by reduction in the nutrient medium or by the accumulated toxic products of metabolism resulting in impaired growth. In most cases, cell turnover occurs in the stationary phase, the cell loss occurs slowly because death is balanced by the formation of new cells by division. If this is the case then the number of cells will increase slowly even though the number of living cells remained constant. The optimal growth can be determined by calculating the microalgae growth rate ( $\mu$ ) in the exponential phase. The fastest growth rate occurs in the cultures supplied with CO<sub>2</sub> flow rate of 5 L/min, which is the highest growth rate achieved by microalgae at 0.34 day<sup>-1</sup> for 8 L/min flow rate and concentration of 2% CO<sub>2</sub>, when compared with the experiment was done by [13] also exploited *Scenedesmus obliquus* at a specific growth rate of 0.44 day<sup>-1</sup>, then the result is not much different.

Comparison of microalgae growth rate is influenced by the design of the photobioreactor that used, the flow rate is high with larger bubbles and high superficial velocity that can inhibit growth, in addition to the optimum conditions can accelerate the mass transfer, so that this value will be compared with the rate of overall mass transfer.

CO<sub>2</sub> transfer efficiency is one of the most important parameters to improve the level of CO<sub>2</sub> removal efficiency and biofixation by microalgae in a photobioreactor culture system. To determine the relationship between the biomass concentration by dry weight and removal efficiency of CO<sub>2</sub>, linked to the purpose of this study, the data used flow rate of 5 L/min and 5% CO<sub>2</sub> (Figure 6). The CO<sub>2</sub> removal efficiency increase as well as biomass concentration, on the contrary when the CO<sub>2</sub> removal efficiency decrease, the biomass concentration will decrease also. CO<sub>2</sub> absorption by microalgae cells allegedly stimulated by an increase in dissolved of CO<sub>2</sub> in the culture media, so that the culture without the addition of CO<sub>2</sub> will make absorption rate of CO<sub>2</sub> is low.

This is consistent with [13] who described when CO<sub>2</sub> added to the growth medium, the growth rate of the photosynthetic microorganism will be increase, otherwise when there is no CO<sub>2</sub> is added to the culture then there is no growth rate. Described in the experiment that uses microalgae *Scenedesmus obliquus* and *Spirulina Sp.*, microalgae can be grown in a growth medium with a given CO<sub>2</sub>-enriched air. This indicates that *Scenedesmus obliquus* can fix CO<sub>2</sub>, and so that CO<sub>2</sub> is a limiting factor of growth of *Scenedesmus obliquus*.

High CO<sub>2</sub> concentration in the closed system proved to be effective to increase the growth rate, using the CO<sub>2</sub> bubbles as the transfer medium, rather than doing the same thing in the ambient air. However, the growth rate drops when the culture is conducted with very high concentrations and flow rates of CO<sub>2</sub>. Extreme high flow rate of CO<sub>2</sub> can increase carboxylation microalgae and

suppress the activity of rubisco oxygenation, thus increasing photosynthesis.

### 3.3 Carbon Dioxide Mass Transfer Coefficient

Mass transfer of carbon dioxide in the photobioreactor will also be influenced by the hydrodynamic aspects, one of which is the superficial velocity of the gas in the photobioreactor. Superficial velocity ( $U_g$ ) also called volumetric flux, the gas volumetric flow rate divided by the cross-sectional area of the fermenter [16]. Photobioreactor diameter used is 15 cm, then the surface area of the tube cross section  $1.767 \times 10^{-2} \text{ m}^2$ , while the injected air flow rate of 2 L/min, 5 L/min and 8 L/min so that the value obtained using Equation 3.3 superficial velocity for each flow rate of  $1.9 \times 10^{-3} \text{ m/s}$ ,  $4.7 \times 10^{-3} \text{ m/s}$  and  $7.5 \times 10^{-3} \text{ m/s}$  (Table 1).

**Table 1** Variation of flow rate of carbon dioxide and superficial velocity

Flow rate (L/min)	Surface are of photobioreactor (m <sup>2</sup> )	Superficial velocity (m/s)	Superficial velocity (m/hour)
2	$1,767 \times 10^{-2}$	$1,9 \times 10^{-3}$	6,76
5	$1,767 \times 10^{-2}$	$4,7 \times 10^{-3}$	16,98
8	$1,767 \times 10^{-2}$	$7,5 \times 10^{-3}$	27,16

In Indonesia, [17] describes the use of both superficial gas flow rate which indicates ideal mixing is between  $1.2 < U_g < 12$  m/hour. When referring to this, the flow rate of 2 L/min was included in the ideal mixing, while the flow rate of 5 L/min and 8 L/min excluding superficial velocity ideal for mixing, but this will be assessed by observing the growth of microalgae, the rate of transfer mass and carbon dioxide fixation by microalgae.

Mass transfer of carbon dioxide is affected by mass transfer rate of carbon dioxide. Determination of carbon dioxide transfer rate is very important given the close relationship between biological and physicochemical processes and the concentration of CO<sub>2</sub> in solution. Low pH values and high aeration conditions led to a decrease in available inorganic carbon as CO<sub>2</sub> stripping. A study shows the importance of pH on inorganic carbon limitation for algae biofilm growth. Conversely, when the level of the lower CO<sub>2</sub> stripping, for example, using a low agitation and / or aerated culture conditions, the concentration of dissolved CO<sub>2</sub> will rise above the saturation value (saturation concentration) [18].

The rate of mass transfer coefficient is determined by the concentration of carbon dioxide saturation that is injected CO<sub>2</sub> concentration and calculated concentration in water using Henry's constant, which Henry constant gas into a liquid that is used is from 10 to  $1.5 \text{ mol.L}^{-1}.\text{atm}^{-1}$  [19]. When there is a mass transfer of carbon dioxide from the gas phase to the liquid phase, only dissolved CO<sub>2</sub> of all species of CO<sub>2</sub> is responsible for the mass transfer of carbon dioxide through the gas-liquid interface [3].

The concentration of dissolved carbon dioxide is obtained by using the calculation of acidity and alkalinity, and put it into the Equation 2.21. The results were plotted on a graph between  $\ln [(C^*-C_0)/(C^*-C_t)]$  at intervals (days), and the gradient of the curve is a line of mass-transfer coefficient (Figure 7).

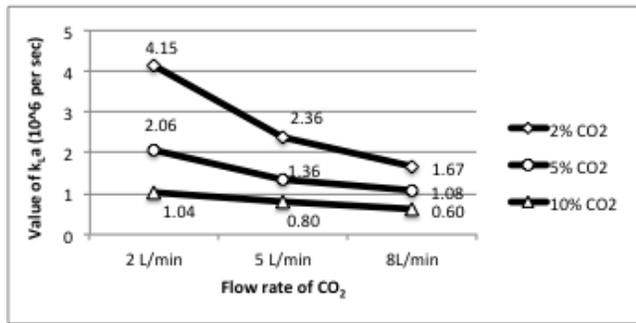


Figure 7 The  $k_{L,a}$  values in variation of flow rate of CO<sub>2</sub>

The  $k_{L,a}$  highest value of  $4.15 \times 10^6 \text{ sec}^{-1}$  occurs in cultures were fed with 2% CO<sub>2</sub> with a flow rate of 2 L/min. With a flow rate of 2 L/min then the diameter of the bubbles that form tend to be small and the detention time within the photobioreactor to be longer. Figure 7 describes any increase in the flow rate will decrease causing the value of the  $k_{L,a}$ . Similarly, at the same flow rate then any increase in concentration led to a decrease in the value of the  $k_{L,a}$ , except at a flow rate of 8 L/min. The  $k_{L,a}$  values generally increased with increasing flow rate of the fluid tangential, because the depletion layer liquid limit.

The  $k_{L,a}$  value of this study are much smaller when compared to research of [6], which uses bubbling CO<sub>2</sub> obtained  $k_{L,a}$  value  $7.0 \times 10^{-3} \text{ min}^{-1}$ . In another experiment conducted [17], using a reactor volume of 18 L and 40 L, a combination of a flat plate and bubble columns, the  $k_{L,a}$  values obtained for  $0.303 \text{ min}^{-1}$  or  $0.005 \text{ sec}^{-1}$ . In other studies, for the bubble column reactor as compared to other types of reactors, has a small value so that the  $k_{L,a}$  can be concluded that although the bubble column reactor is simpler and easier in operation, but provides little value of  $k_{L,a}$ . Photobioreactor design seems to have impacted the ability of mass transfer.

### 3.4 Relationship Among the Mass Transfer Rate, CO<sub>2</sub> Removal Efficiency and Biomass Concentration

Cultivation process of microalgae in closed system require optimal value of  $k_{L,a}$  because this value indicate a high CO<sub>2</sub> mass transfer process well occurred in microalgae culture, but the value of  $k_{L,a}$  is not always a good one for the growth of microalgae culture. The researcher [20] stated that the values of  $k_{L,a}$  that too high may lead to the occurrence of shear stress on the microalgae which could inhibit the growth of microalgae, which cause the biomass content will be reduced, so that should be avoided.

Mass transfer of CO<sub>2</sub> from the air into the growth medium may limit the growth of microalgae. By comparing the growth rates of microalgae and mass transfer, it shows that performance is highly dependent on the bioproduction of microalgae metabolism and magnitude carried microalgae growth rate is influenced by the mass transfer of CO<sub>2</sub> into the cell which would then be used for the sustainability of photosynthetic activity by microalgae. In this study the profile of coefficient  $k_{L,a}$  inversely with the growth rate of microalgae. The higher the flow rate at each increment, the smaller the value of microalgae growth rate, thus the smaller the mass transfer. It occurs in cultures fed by 5 L/min of CO<sub>2</sub>. The magnitude of the growth rate is affected by the mass transfer of CO<sub>2</sub> into the cell which would be used for the sustainability of microalgae photosynthetic activity.

Removal of CO<sub>2</sub> in liquid phase is affected by the volumetric mass transfer coefficient and affects the rate of growth of microalgae biomass. This happens on a large flow rate with the

highest superficial velocity, thus indicating ideal mixing. In other case, [5] explained that the increase in the rate of mass transfer of CO<sub>2</sub> has been described as a result of natural convection, the process of destabilization of the gas-liquid boundary layer caused by the increase viscosity/specific gravity (density) of dissolved CO<sub>2</sub> after CO<sub>2</sub> dissolved in water. In other words, the driving force on natural convection occur when the water with CO<sub>2</sub> moves upward toward the boundary layer (interface) and lower CO<sub>2</sub> viscosity of water moving downward, so as accelerate the mass transfer rate. In addition, changes in the density of the liquid CO<sub>2</sub> is highly dependent on the concentration of CO<sub>2</sub> (initial pressure of the gas) i.e, the higher concentration will make the CO<sub>2</sub> to increasingly dissolve in the water.

## 4.0 CONCLUSION

The relation between CO<sub>2</sub> that flowed into the system, CO<sub>2</sub> solubility in the growth medium and the rate of mass transfer coefficient has been described. CO<sub>2</sub> removal efficiency is affected by flow rate and concentration of CO<sub>2</sub>. The results showed that the flow rate significantly affects the operational conditions of photobioreactor that are observed through microalgae growth rate, biomass concentration of cells and the rate of mass transfer. CO<sub>2</sub> flow rate that supplied to the system is inversely proportional to the mass transfer coefficient. Flow rate is too high (8L/min) causing turbulence that causes shear stress on the cells and CO<sub>2</sub> detention time in the system did not last long. This condition also gives the value of the mass transfer coefficient so low that the inorganic carbon cannot be fully utilized for the growth of *Scenedesmus obliquus*.

## Acknowledgement

We would like to thank DIKTI (Directorate General of Higher Education Indonesia) Programme of Decentralization 2014 for funding some of this research.

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