

Microfiltration Membrane Assisted CO₂ Diffuser for Algae Cultivation

U. A. Muhammad Idris Lutfi, S. M. Hizam, K. S. Lau, N. A. H. Md Nordin*, M. R. Bilad, Z. A. Putra, M. D. H. Wirzal

Chemical Engineering Department, Universiti Teknologi PETRONAS,
Bandar Seri Iskandar, 32610 Perak, Malaysia

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ABSTRACT

The aim of this paper is to cover on the feasibility of using algae as an alternative to capture CO₂. As such, comparison between a membrane diffuser and a bubble diffuser in terms of its performance in the cultivation of algae has been made. This work utilized PVDF flat sheet membrane with only air and pure CO₂ as the feed gas and the diffusion method used was compared between membrane diffuser and a bubble diffuser. In the experiment, the feed gas flows through the membrane diffuser in which the algae suspension utilized the CO₂ for its growth. The biomass contents of four different samples have been determined using the dry weight of the algae suspension samples, which is obtained by drying the samples in an oven overnight at 105°C. The algae suspension with the membrane diffuser was able to remove CO₂ feasibly while showing better performance with respect to algae cultivation in comparison to the bubble diffuser. Results showed the maximum average biomass content of the samples that used membrane diffuser had higher value of 0.325 g/L when a 1:1 ratio of air and CO₂ was used in the feed stream and 0.275 g/L when using pure air as the feed stream. Thus, it has been shown that membrane diffuser is better than a bubble diffuser owing to its larger effective surface area.

Keywords: CO₂ capture, membrane diffuser, bubble diffuser, algae cultivation, biomass content

1.0 INTRODUCTION

Nowadays, climate change is occurring at an alarming rate due to an increase in greenhouse gasses in the atmosphere. Consequently, other environmental effect has been occurring such as frequent heat waves with longer durations, an increase in sea level and warmer ocean and atmosphere [1]. According to the Worldwatch Institute report, the main greenhouse gases that contribute to climate change are carbon dioxide (CO₂), nitrous oxide (N₂O) and methane (CH₄) with CO₂ as the highest contributor at 77% [2]. The combustion of fossil fuels is the major emission source for CO₂, which is also the main contributor for greenhouse gases, and a

third of it comes from fossil fuel based fuel generation [3]. The concentration of CO₂ in the atmosphere has been increasing every year and its global emissions are around 30 Gt/year [4].

Therefore, world leaders have come out with the Paris Agreement on climate change in the December 2015 G20 Summit, in which the main goal is to keep global temperatures from having a rise of more than 2°C by the year 2100 [5]. Therefore, there is a need to reduce the amount of greenhouse gas, particularly CO₂ being released to the atmosphere as well as the amount of CO₂ that is already present in the atmosphere.

There are many new methods and technologies developed which can be

* Corresponding to: N. A. H. Md Nordin (email: nahadi.sapiaa@utp.edu.my)
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used to remove or capture CO₂. Such method includes chemical processes, geological sequestration and bioprocesses [6]. However, the most promising alternative is by using biological systems, namely algae cultivation as it is sustainable, relatively efficient and economically feasible compared to the previously mentioned methods [7]. The method is based on the concept of photosynthesis which includes the transformation of CO₂ into biomass via light energy. Moreover, capturing CO₂ using algae will meet the green technology demand as the algae will be cultivated and biomass can be generated [8]. Furthermore, there is a high interest in using algae to remove CO₂ directly from the atmosphere as there are researches that focus on capturing CO₂ to reduce the amount of greenhouse gases present [4].

To ensure efficient CO₂ capture, the growth of algae and the area of contact for mass transfer would need to be addressed. There are many factors that influence the growth rate of algae including light irradiance, temperature, salinity, dissolved oxygen concentration, qualitative and quantitative profile of nutrients present and the presence of toxic elements [9]. Indeed, light is an important source to the algae for growth and photosynthetic activity. The cultivation of algae can be illuminated by using sunlight, artificial light or a combination of both. For example, the *C. Vulgaris* algae itself is a green algae and it grows better in blue and red light due to its light harvesting pigments are more sensitive to blue and red wavelengths [10]. Meanwhile, the optimum temperature for the cultivation of microalgae ranges from 20°C to 30°C [10]. Furthermore, the concentration of CO₂ in feed stream also influences the cultivation of algae and capture of CO₂. The CO₂ concentration should be high enough so that it can satisfy the algae's need but not exceeding the upper limit

value that will result in high loss of CO₂ [11].

The effectiveness of CO₂ capture also depends on the type of diffuser. Basically, a membrane is described as a selective barrier that is in between two different phases and is commonly used for separation purposes that are affected by a driving force [12, 14]. The driving force can either be temperature, pressure or concentration, while two primary parameters that are usually used to determine the performance of a membrane are rejection and permeability. Additionally, transport across the membrane itself can be influenced by a few factors such as the membrane's size or shape, temperature of the solution and the solution's viscosity [12, 13]. However, for a gas-liquid membrane contactor, the driving force relies more on concentration difference rather than the pressure gradient [15]. It is reported that by using algae suspension and a membrane contactor, the CO₂ fixation rate was able to rise from 80 to 260 mg l⁻¹ h⁻¹ which shows that the use of membrane contactor can enhance the efficiency of CO₂ removal using algae suspension [11].

Additionally, the carbon availability, which can affect the cultivation of algae depends on the efficiency of CO₂ delivery itself. The use of hollow fibre membranes or silicon membrane as a diffusion method for CO₂ can decrease the loss of CO₂ in the process although it is more exposed to biofouling [16]. However, bubble columns can decrease the loss of CO₂ not more than 20% and it also has a low cost and is fairly a simple method to use.

Meanwhile, the efficiency of CO₂ mass transfer in a column for gas exchange can be affected by a few parameters such as the content of CO₂ in the gas bubbles, the size of the gas bubbles which also determines the contact area for mass transfer, the

height of liquid column used as it determines the gas bubbles period of contact and lastly the receiving liquid's pH value [16]. It is reported that by having smaller sized bubbles and taller liquid column would improve gas transfer as it provides greater surface to volume ratio and higher contact time for the rising bubbles [16].

Typically, algae have proven to have a high potential in the process of CO₂ removal and have been integrated into membrane processes. However, some of the problem that may arise from using algae to capture CO₂ is that, when used as a standalone method in a column, the gas feed being supplied directly produces large bubbles which can increase shear stress and inhibit the growth of algae [17]. This can influence the efficiency of the algae suspension in capturing or utilizing CO₂. Thus, using a membrane diffuser may solve this problem as it produces bubbles that are theoretically smaller in size, reducing the negative effect on algae growth.

Therefore, this paper aims to combine the membrane diffuser technology and algae in wastewater as a method to remove CO₂ and study its feasibility due to time restriction. A combination of membrane diffuser and algae may give more advantages such as having a less toxic product. This concept will utilize the use of membrane diffuser technology to assist CO₂ utilization by algae suspension.

There are two objectives concerning this paper that need to be achieved. Firstly, to investigate the feasibility of using wild algae suspension with membrane diffuser to capture CO₂. Next, is to compare the performance between using a membrane diffuser and a bubble diffuser in terms of the cultivation of algae and CO₂ removal. The feed gas that will be used in this project will be air and pure CO₂ while the membrane used will be

polyvinylidene fluoride (PVDF) flat sheet membranes and the diffusion method are both the membrane diffuser as well as a bubble diffuser.

2.0 METHODS

2.1 Experimental Setup

Firstly, algae were cultivated in four different containers, where each of the containers was filled with 6L of water that were added with the same amount of nutrients before 30ml of algae seed was injected into each of the containers. The containers were then left under different experimental conditions to be observed and the containers were labelled as sample A, B, C and D respectively.

Meanwhile, there were two parameters that were mainly being focused on in this experiment, which were the concentration of CO₂ in the inlet feed stream and method being used to provide contact between the inlet feed stream, specifically CO₂, and the algae suspension. This was done either by using the bubble diffuser or the membrane diffuser. For sample A, a membrane diffuser was used to transfer the feed inlet gas stream which contained both air and pure CO₂ with a 1:1 ratio for flowrate, which was 2L/min for each stream while sample B contained the same composition and flowrate ratio of feed inlet gas stream, but it used a bubble diffuser. Moreover, sample C also used a membrane diffuser, but its feed inlet gas was only composed of air at 4 L/min. Sample D used a bubble diffuser instead although it had the same composition for inlet gas feed stream as sample C. The summary for conditions and method used for each sample is shown in Table 1.

Table 1 Summary of experimental condition for each sample

Sample	Method		Inlet Feed Stream (L/min)	
	Membrane Diffuser	Bubble Diffuser	Air	Pure CO ₂
A	/		2	2
B		/	2	2
C	/		4	-
D		/	4	-

Furthermore, all the samples were provided with the same inlet gas feed flowrate, which was at 4 L/min and the amount of nutrients and water were kept at constant as they were being added over certain periods of time regularly to make sure that the nutrients were not limited during the period of the

experiment. The algae suspensions were exposed to same light and room temperature of about 25 ± 1 °C for 20 days until the biomass content values that were needed for the experiment were obtained. The setup of the experiment is as shown in Figure 1.

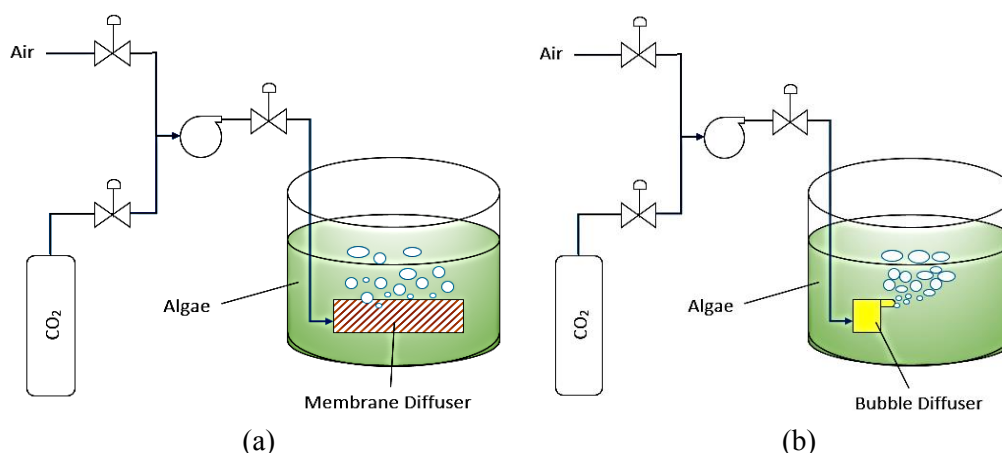


Figure 1 Experimental setup for CO₂ capture via algae cultivation. The inlet feed in Figure 1(a) is connected with a membrane diffuser while in Figure 1(b) is connected with a bubble diffuser

2.2 Materials and Equipment

The Shanda SD-2000 pump used had a maximum flow rate of 4L/min which was used as a basis in this experiment and was set as the constant variable for every sample in this experiment. Meanwhile, the membrane material used for microalgae cultivation in this project was an organic membrane material, which was PVDF membrane. The membrane used was a commercial

product from Merck and the pore size of the organic or polymeric membrane was around 0.45 micron. Memmert Universal Oven UF 110 was used to obtain the dry weight of samples by drying at a temperature of 105°C overnight. A standard fluorescent lamp was used as a constant light source needed in algae cultivation for all the samples while nutrients were replaced by adding it daily into all of the cultivation medium, and tap water was

also added to replace the amount of liquid being taken every day for sampling and experiment purposes.

2.3 Biomass Determination

In this project, the measurement of dry weight was used to estimate the concentration of dry weight in the growing algae cultures and thus their growth and the effect of different methods of providing contact between the algae suspension and CO₂. Generally, 50ml of algae suspension was taken from each sample every day using a pipette. Next, for each sample, 20ml out of the 50ml sample of algae suspension was transferred into an aluminium dish and finally all the samples of algae suspension were dried in an oven overnight at a temperature of 105°C. The dry weight or biomass content of each of the samples was then determined by calculating the

difference between the weight of the empty aluminium dish before drying and the weight of the aluminium dish containing algal biomass after an overnight drying

2.4 Determination of Bubble Size and Amount per Unit Time

Typically, to determine the effective contact area between the algae suspension and the inlet gas feed, it was important to evaluate the size of the bubbles produced by both the bubble diffuser and the membrane diffuser as well as the total amount of bubbles that they produced over a certain period. Therefore, a few images of the bubbles being produced by the bubble diffuser and membrane diffuser together with ruler as a scale were captured as shown in Figure 2 and these images were then analyzed by using the 'ImageJ' software to determine the bubble size.



Figure 2 Sample Image of Bubbles Produced from Bubble Diffuser (left) and Membrane Diffuser (right) by using "ImageJ" software

Assuming the bubble was a standard sphere and using the value of radius obtained, the effective bubble-to-algae contact area was calculated using the Equation 1 shown below;

$$A = 4\pi r^2 \quad (1)$$

where A is the effective bubble-to-algae contact area in cm² and r is the radius of the bubble in cm.

Besides that, the total amount of bubbles being produced over a period also needed to be estimated and this was done by using the Equation 2 and Equation 3. A few assumptions were done which includes assuming that the outlet flowrate can be calculated using the volume of a bubble and the bubbles had an equal shape and radius;

$$Q_1 = n \times V_B \quad (2)$$

$$V_B = \frac{2\pi R\sigma}{2\Delta\rho g} \quad (3)$$

where Q_1 is the volumetric flowrate of the bubbles in L/min, n is the number of bubbles produced/minute, V_B is the bubble volume in cm^3 , R is the orifice radius in cm, σ is the surface tension in dynes/cm, g is the gravitational constant in cm/s^2 and $\Delta\rho$ is the difference between density of liquid and bubbles in g/cm^3 .

Thus, from the equation above, the number of bubbles being produced by either the bubble diffuser or membrane diffuser over a minute can be estimated and the estimated total effective contact surface area can be calculated as well.

3.0 RESULTS AND DISCUSSION

3.1 Effective Bubble-to-Algae Contact Area and Estimation of Total Number of Bubbles

Firstly, for the size of bubbles, the size of the bubbles produced from the membrane diffuser is much smaller compared to the bubble diffuser. The mean radius of the bubble produced from the membrane diffuser was 0.3cm while the bubble produced from the

bubble diffuser was 1.2cm. Therefore, the effective bubble-to-algae contact area was 0.28cm^2 for membrane diffuser and 4.52cm^2 for the bubble diffuser. Since the bubble size produced by the membrane diffuser was smaller than the bubble diffuser, the total amount of bubbles produced and the total contact area provided per minute by the membrane diffuser was quite higher than the bubble diffuser. The summary of the bubble sizing and total amount of bubble produced is shown in Table 2. It is worth noting that a larger bubble size will produce higher shear stress at which will be a disadvantage especially for shear sensitive algae [17, 18].

3.2 Biomass Content

Next, in terms of the results for biomass content obtained, for sample A, its biomass content increases before staying constant until the fifth day. Then, it starts to increase until the 8th day, and it continues to increase in value after the 10th day before reaching a constant and maximum value of 0.000325g/ml. Meanwhile, for sample B, the biomass content value only starts to become constant and increase in value after the 8th day, before reaching a maximum value of 0.0002g/ml.

Table 2 Mean size and amount of bubbles produced

Diffusion Method	Mean Radius (cm)	Effective Bubble-to-Algae Contact Area (cm^2)	Total Amount of Bubbles (min^{-1})	Total Contact Area (cm^2/min)
Bubble Diffuser	1.2	18.09	552.55	9995.63
Membrane Diffuser	0.3	1.13	35363.18	39960.39

Besides that, the biomass content of sample C, has only became constant starting from day 8 until day 10, then it starts to increase before becoming constant again after reaching a

maximum value of 0.000275 g/ml on day 14. For sample D, its biomass content varies in value before reaching day 6 of the experiment, then it starts to increase until finally reaching its

maximum value of 0.0002g/ml on day 14. The summary of biomass content for each sample was tabulated in Table 3 and shown in Figure 3.

Table 3 Biomass content of each sample at each day

No of Days	Average Biomass Content × 10 ⁻⁴ (g/ml)			
	A	B	C	D
0	0.00	0.00	0.00	0.00
1	1.25	1.25	1.75	1.25
2	1.50	2.00	2.00	1.50
3	1.50	1.50	2.50	1.75
4	1.50	1.25	2.00	1.75
5	1.50	0.40	2.25	1.25
6	2.00	1.75	2.00	1.00
7	2.50	2.00	2.25	1.25
8	2.75	1.50	2.00	1.55
9	2.25	1.50	2.00	1.75
10	2.15	1.50	2.00	1.75
11	2.50	1.50	2.15	1.75
12	2.75	1.75	2.25	1.75
13	3.15	2.00	2.25	1.75
14	3.25	2.50	2.75	2.00

Furthermore, the results are also compared between samples that uses a membrane diffuser, which are sample A and C, as well as samples that uses a bubble diffuser, which are sample B and D. As other parameters are controlled and assumed constant for all four samples, the difference in diffusion method also contributes to the difference in biomass content. Result

shows that using a membrane diffuser results in higher algae growth compared to using a bubble diffuser. This may be due to the membrane diffuser providing a higher and more effective contact surface area, in terms of smaller bubble size and higher amount of bubbles produced per minute, compared to the bubble diffuser [16].

Besides that, there is also a difference in biomass content between sample A and C, as well as between sample B and D. Comparing the maximum value of biomass content of sample that used membrane diffuser, sample A has a higher value at 0.000325g/ml rather than sample C in which its maximum value is 0.000275g/ml. For samples that uses bubble diffuser, sample B also shows a higher value at 0.00025g/ml compared to sample D with maximum value of 0.00020g/ml. This may be due to the difference in CO₂ composition in the inlet feed gas as sample A and B have both air and additional pure CO₂ in the inlet feed gas stream. This shows that the presence of CO₂ enhanced the growth of algae. The concentration of CO₂ is an important factor that can affect the growth of algae itself as a higher concentration promotes algae growth as reported in literature [19], and from this experiment, it was observed that the higher the concentration of CO₂ in the inlet feed stream results in larger maximum biomass content of a sample.

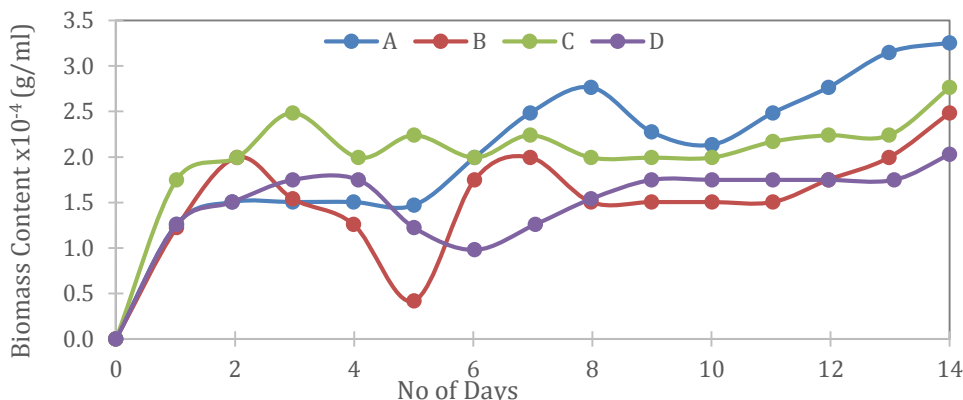


Figure 3 Graph of Biomass Content of each Sample vs No of Days

Apart from that, from the results obtained, it was also shown that sample C has a higher maximum biomass content at 0.000275 g/ml compared to sample B which is at 0.00025 g/ml. Sample B and C both have different CO₂ concentration in their inlet feed stream as sample B have both air and CO₂ in its inlet gas stream while sample C has only air. They also utilize different diffusion methods. Note that sample B has a higher inlet CO₂ concentration compared to sample C while sample C has a higher effective contact area than sample B. Thus, according to the results obtained from the experiment, in which sample C has a higher maximum biomass content than sample B, it shows that having a higher effective contact area gives a higher algae growth even with lower concentration of CO₂ as it provides better gas transfer to the algae suspension [16].

4.0 CONCLUSION

In conclusion, it is feasible to use algae suspension for CO₂ removal. When comparing between bubble diffuser and membrane diffuser, it was shown that the membrane diffuser produces a higher maximum biomass content

owing to higher total contact area provided for gas transfer. It is also worth noting that higher concentration of CO₂ in the feed stream results in higher maximum biomass content. Lastly, when using different gas diffusion methods and having different concentrations of CO₂ in the inlet gas stream, it was shown that having a more effective method for gas diffusion gives a higher impact on algae growth which shows that the gas diffusion method is a more important aspect in algae cultivation.

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