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Tracking metabolic gases in an airlift bioreactor for enhanced microalgae cultivation

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Abstract

Airlift bioreactors have been classified as a promising technology for microalgae cultivation. Several improvements have contributed to increasing the mixing efficiency and production. However, some challenges are still facing this biological process. One challenge is the efficient dissolution and delivery of carbon dioxide to microalgae cells, which remains a limiting factor in the biological processes. On the other hand, sparging the gas in large quantities may lead to gas loss if microorganisms do not completely consume it. In this study, microalgae were cultivated in two stages and compared: the first stage of injecting 5 ml of carbon solution into a conical flask and the second stage of sparging 5 liters/hour in an airlift bioreactor with increasing sparging time this is done by sparging carbon dioxide gas at the same flow rate from day to day, but increasing the sparging time by 30 seconds, starting with sparging the gas for one minute until reaching 7 minutes. The results showed that the airlift bioreactor gives a higher growth rate of microalgae than that produced in a conical flask. The maximum biomass concentration reached 5 g/L in the airlift bioreactor culture with a maximum specific growth rate of 0.324 day^{-1}, while it reached 1.0799 g/L in the conical flask culture with a specific growth rate of 0.187 day^{-1}. This result shows the importance of the airlift bioreactor in microalgae cultivation. Also, the internal composition of the biomass was found that the airlift bioreactor was the best, as the amount of lipids, carbohydrates and protein was (2.06, 1.43, and 18.03 g per 30 g of dry biomass), respectively, while the internal composition of the control cultivation was (0.005386, 0.00428, 0.05754 and g/L), respectively. The volumetric mass transfer coefficient showed that when the sparging time increases, the oxygen gas transfer coefficient increases until it reaches 1.0397 s^{-1}. The pH value was also maintained around 7, which is the appropriate value for increasing the growth rate.

Keywords: Mass transfer; airlift bioreactor; microalgae; sparging; carbon dioxide.

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1- Introduction

Human activities, especially the use of fossil fuels as an energy source, still pose a major threat to the global climate, whereas the reason for this threat is the change in atmospheric gases [1]. while the combustion of hydrocarbon fuels like gasoline and diesel in human industries, such as cars, airplanes, and trains that run on engines. Also, the coal and natural gas used to supply the world with electricity, all these sources are considered responsible for emitting gases that lead to global warming, especially carbon dioxide, which is responsible for 50 % of global warming problems [2]. Therefore, to reduce these emissions, biological methods have been relied upon. As microalgae, due to the importance of carbon dioxide in the process of photosynthesis, thus significantly reduce energy consumption resulting from physical and chemical methods [3].

Binary fission and the doubling of microalgae biomass, as well as its high content of fats, proteins, and carbohydrates, make it a complete industrial value. In addition to the ability of algae to fix carbon and isolate it for use in photosynthesis processes, as well as the possibility of algae growing anywhere, whether in fresh or salt water [4- 6]. All these reasons make algae a promising product in many fields, including energy, food, medicine, and water treatment plants. Furthermore, as its use in the production of fuel, biogas, and other vital processes [7- 9].

While the fixation of carbon dioxide by microalgae makes it a promising technology, its cultivation in open systems such as raceway ponds, recirculation tanks, and other artificial ponds makes it more vulnerable to the loss of carbon dioxide before it can be utilized. In addition, there is a lack of sufficient control over the decrease in pH when carbon dioxide dissolves, and thus, the microalgae cells do not grow well. On the other hand, closed systems such as bioreactors are characterized by a high degree of control over cultivation conditions (temperature, pH, light intensity) and are more efficient in delivering carbon dioxide.

It also has the advantage of reducing pollution and evaporation, which is very common in open systems [10-12]. However, the productivity of these organisms is still far from global requirements due to the high costs

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involved in cultivation and extraction processes. Many studies address some of the sources of these costs by investigating operating conditions or bioreactor designs [13]. Stanimir et al [14] explained that the design of the ALBs plays an important role in the fermentation and growth of microorganisms, as the draft tube, with the help of the sparging from the riser area, circulates the air in the liquid by passing through the downcomer area, thus circulating it and preventing its loss.

Despite the simplicity and efficiency of the design of bioreactors, comparing hydrodynamic mass transfer processes in general and mass transfer, in particular, is the most difficult, especially when there is a living organism, as the dissolution of gas in the ALBs does not match the organism's consumption of the same gas. Therefore, using these reactors to cultivate microalgae requires efficient transfer of carbon sources that constitute 50 % of the microalgae biomass. This is done by providing enough carbon dioxide gas in the form of bubbles to be fixed by microalgae through photosynthesis, thus isolating the oxygen produced to ensure the growth of microalgae in the ALBs. To express the gas mass transfer is done through the volumetric mass transfer coefficient $K_L a$ is used, which is one of the most important factors used in the design of bioreactors [15, 16, 12, 17].

Consequently, any increase or decrease in the gas can affect microalgae growth. The increase in the amount of gas may lead to the waste of gas and thus not reaching the cells. The decrease may not be sufficient for the growth and reproduction of cells, as the process of transporting gas from the bubble and then to the cells of the living organism is a complex process that goes through several stages until it reaches the cell, and then goes through other stages and reactions inside the cell. So, any difference in the supply of carbon dioxide and the uneven distribution of gas affects the performance of the vital process [8, 16, 12]. Accordingly, this study aims to provide a sufficient and optimal amount of carbon dioxide gas as a carbon source and adjust the pH value to achieve the highest levels of efficiency in the growth of microalgae by using the ALBs.

2- Experimental work

2.1. Materials and methods

Microalgae cultivation was tested in two stages, the first stage using a 500 ml conical flask and the second stage using a 10-liter rectangular Airlift bioreactor designed with dimensions of (28,18,30 cm) in length, width, and height respectively to fit the dimensions of the flat ceramic diffuser plate which has dimensions of (18,7.8,5.2 cm) in length, width, and height respectively. Chlorella Sorokiniana MH923013 is the type of microalgae used in cultivation.

2.2. Microalgae culture medium

Chlorella Sorokiniana MH923013 is the type of algae used in this research, which belongs to the Chlorophyta section, a green alga that grows in freshwater. It was isolated in the Department of Biology, College of Science, University of Baghdad [18]. BG11 is the nutrient used to feed the culture, which consists of Sodium Nitrate (NaNO3) 1.5 g, Dipotassium Hydrogen Phosphate (k2HPO4) 0.04 g, Magnesium Sulfate (MgSO4. 7H2O) 0.075 g, Calcium Chloride Dihydrate (CaCl2. 2H2O) 0.036 g, Disodium Magnesium EDTA 0.001 g, Citric Acid 0.006 g, Ferric Ammonium Citrate 0.006 g, and Sodium Carbonate (Na2CO3) 0.02 g. The medium was prepared by dissolving 1.627 g per 1000 ml (1 liter) of distilled water. The medium was sterilized using an autoclave at 121 ℃ under a pressure of about 2 bar for 15 minutes. 2 ml of microalgae was added to 500 ml of medium [19].

2.3. Experimental setup

The work was divided into two stages to understand the mechanism and dynamics of algae growth. The first stage involved culturing algae in a conical flask, where 5 ml of the carbon solution was injected [20]. A control flask was left to grow naturally with two repetitions for each cultivation, making three repetitions for the error bar. The dissolved oxygen and pH of the cultures were measured before the injection process once and after the injection process three times a day. The optical density was measured from day to day to maintain the quantity using a spectrophotometer with a wavelength of 680 nm.

The second stage was carried out using 5.5-liter ALBs and by sparging carbon dioxide gas through a microbubble diffuser installed in the middle of the bottom of the ALBs 2 cm from the draft tube to facilitate gas circulation and connected to a nozzle at the top of the ALBs to enter the gas at a flow rate of 5 liter/hour. The spraying operations were carried out from day to day with a constant flow rate, and the time changed, starting from one minute up to seven minutes of spraying to adjust the pH value and keep it from falling below 7. The dissolved oxygen and pH were recorded before, during, and after sparging. When the pH dropped below 7, the solution was neutralized with 2 M sodium hydroxide. A 1-liter control conical flask was left to grow normally. The optical density was measured daily to monitor growth. Both stages were carried out at a constant temperature of 25 to 30 ℃, with continuous light for 16 hours and darkness for 8 hours [21]. Fig. 1 shows a schematic diagram of the ALBs and an illustrative image of the Chlorella Sorokiniana MH923013 cultures.

2.4. Volumetric mass transfer coefficient measurement

To measure the quality of the mass transfer of gas entering and exiting from to the biological process, it is necessary to measure the volumetric mass transfer coefficient ($K_L a$, s^{-1}) for both carbon dioxide gas and oxygen gas resulting from photosynthesis. The dissolved oxygen concentrations (mg/L) were used to measure the ($K_L a$, s^{-1}) for oxygen gas and the carbon dioxide concentrations extracted from the value of pH were used

to measure the (K_La, s^{-1}) for carbon dioxide gas [22]. Using Eq. 1 to estimate the volumetric mass transfer coefficient (K_La, s^{-1}) for both gases [23]:

$$K_La, s^{-1} = \frac{\ln\frac{C[Gas]^* - C[Gas]_0}{C[Gas]^* - C[Gas]_t}}{t_2 - t_1} \quad (1)$$

Where $\ln\frac{C[Gas]^* - C[Gas]_0}{C[Gas]^* - C[Gas]_t}$ is plotted against $t_2 - t_1$ and the slope representing KLa, s^{-1} is extracted.

Where $C[Gas]^*$ (mg/L) is dissolved gas concentration after stabilization (in steady state), $C[Gas]_0$ (mg/L) is the initial dissolved gas concentration, $C[Gas]_t$ (mg/L) is the dissolved gas concentration at any time ($C[Gas]_1$, $C[Gas]_2$, $C[Gas]_3$,……etc.).

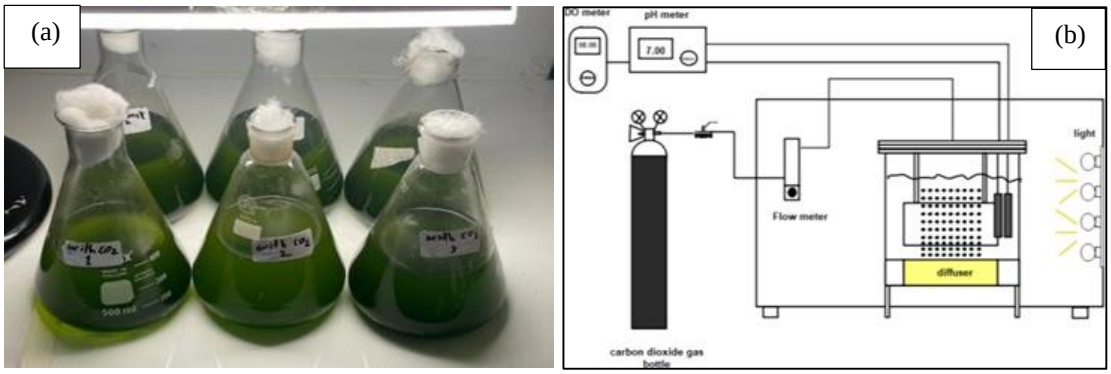

Fig. 1. The figure shows a) An illustrative image of the chlorella sorokiniana mh923013 cultures, b) A schematic diagram of the ALBS

2.5. Parameters to the measurement of the growth of microalgae

Microalgae and other microorganisms, when grown and cultivated in a specific system, must be verified to respond to this system and the factors affecting the system. Therefore, it was necessary to know and calculate the specific growth rate (μ, d^{-1}) by using the spectrophotometric analysis method and thus knowing the time required and sufficient to double the biomass during the exponential phase (t_d, day). The specific growth rate was calculated using Eq. 2 [24, 25].

$$\mu = \frac{\ln(OD_f) - \ln(OD_i)}{\Delta t} \quad (2)$$

Where OD_f is the final optical density, OD_i is the initial optical density, and Δt is the difference between cultivation time in a day during the logarithmic exponential growth phase [26]. While the biomass doubling time (t_d, day) was determined by Eq. 3 [27, 28].

$$t_d = \frac{\ln 2}{\mu} \quad (3)$$

3- Results and discussion

3.1. Ph response

An important factor affecting the efficiency of microalgae growth is the pH factor, which must be alkaline or neutral to ensure microalgae growth. An acidic pH inhibits growth and, thus, the death of microalgae [29]. Injecting or sparging carbon dioxide gas increases the acidity due to the decomposition of carbonic acid and its ionization in the water into bicarbonate and carbonate ions, thus increasing hydrogen ions. Therefore, in this study, the amount of added gas was reduced to control the pH by stabilizing the flow rate and controlling the time factor by increasing the sparging time. Initially, a preliminary study was conducted on the ability of microalgae to absorb carbon when reducing the amount of gas and its effect on the pH. As shown in Fig. 2, the pH value before and after injection shows that 5 ml of carbon solution can maintain the pH at the required levels and thus increase it during the growth days due to the fixation of carbon dioxide gas and the algae's carbon absorption during photosynthesis.

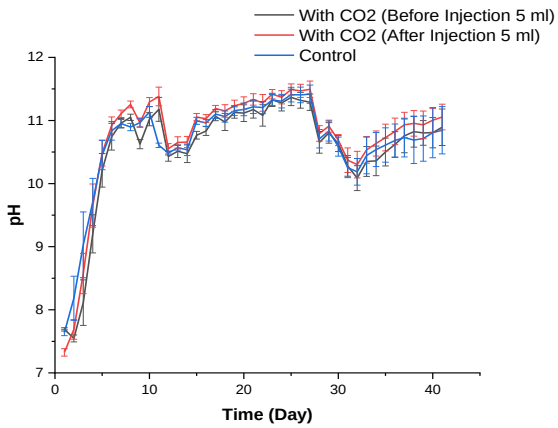

Fig. 2. The pH response to injection of 5 ml of carbon dioxide solution before and after injection

However, cell growth decreases or is inhibited at high pH values due to the lack of distribution of carbon sources and their accumulation, and thus the difficulty of their absorption by microalgae [30, 31]. Therefore, carbon dioxide gas was sparged every other day at a flow rate of 5 L/h with an increase in the sparging time of thirty

seconds starting from one minute. When comparing before and after the sparging process, it was observed that the pH value dropped to approximately 7, regardless of its value before sparging, and then increased the next day to the normal level suitable for the growth and increase of cells, as shown in Fig. 3. This indicates that dissolution of carbon in the bioreactor and its arrival suitable for microalgae. According to [32], the increase in the concentration or flow of carbon dioxide gas brings the pH closer to acidity. Therefore, reducing the sparging carbon dioxide gas controls the pH, which is an effective factor in the process, as well as reduces the amount of gas that microalgae cannot use.

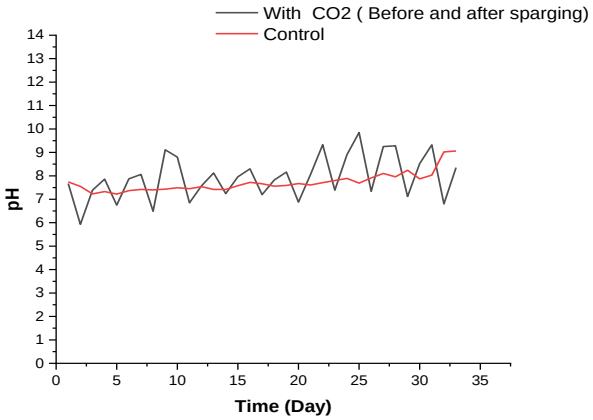

Fig. 3. The pH response to sparging of 5 L/h of Carbon dioxide before and after sparging

3.2. Dissolved oxygen response

Although the oxygen produced from the reaction and decomposition of carbon dioxide in water and its conversion into sugars using light energy is considered a secondary product. It is an important indicator to ensure that the cultivation process is proceeding well [33]. Therefore, the dissolved oxygen produced during the growth of microalgae was studied and monitored, as shown in Fig. 4 and Fig. 5.

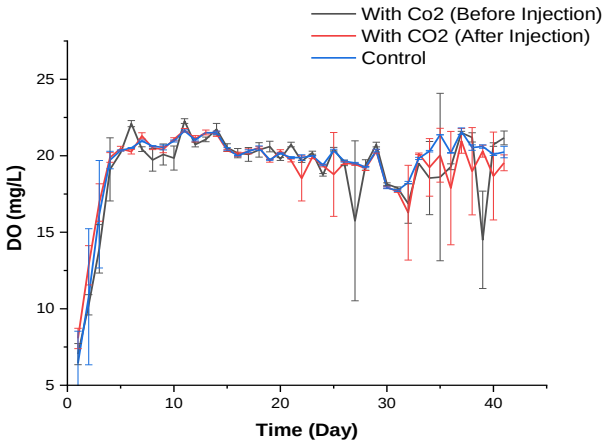

Fig. 4. Dissolved oxygen response to injection of 5 ml of carbon dioxide solution before and after injection

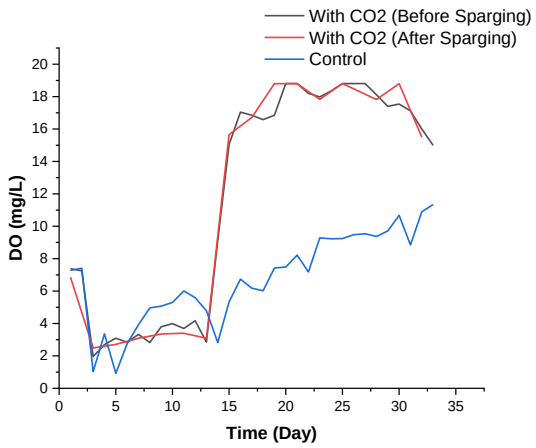

Fig. 5. Dissolved oxygen response to sparging of 5 L/h of Carbon dioxide before and after sparging

The amount of oxygen dissolved in the conical flask culture reached 22 mg/L after 6 days of cultivation when 5 ml of carbon solution was injected and remained at the same value for the remaining days, i.e. it reached the supersaturation stage, which led to the accumulation of dissolved oxygen, as saturating the solution with oxygen may lead to inhibition of the vital process[34]. Therefore, the accumulated oxygen must be removed to increase productivity.

In the biomethane process, for example, the produced gases were stripped by sparging with pure nitrogen gas in the form of microbubbles. This approach can be worked with a microalgae process to remove dissolved oxygen and thus reduce inhibition of the vital process [19]. In the bioreactor culture, when sparging 5 L/h, the amount of dissolved oxygen became 9 mg/L after 14 days of cultivation. This period is suitable for the microalgae to reach the exponential growth phase. Then, the dissolved oxygen begins to increase gradually until it reaches 18.8 mg/L and begins to stabilize, and then gradually decreases. This indicates that the small amount of gas helped prevent the accumulation of carbon dioxide gas and thus control of oxygen production in this aspect, and increased microalgae biomass productivity in another aspect [35].

3.3. Volumetric mass transfer coefficient

In general, the transfer of gas from the bubble to the cells of the organism takes place in several stages and levels. To understand and analyze these stages, an essential parameter must be studied: the volumetric mass transfer coefficient, which explains the use of dissolved carbon by microalgae and the oxygen produced from the process [36, 37]. Through Fig. 6, the difference between the dissolution or diffusion of carbon dioxide gas and the release of oxygen gas resulting from photosynthesis was observed. As the length of the sparging time increased, the values of the volumetric mass transfer coefficient for carbon dioxide gas decreased, and the values for oxygen gas increased.

This is due to the consumption of sparging gas completely by the algae in the process of photosynthesis and the production of oxygen gas as a secondary product. The maximum volumetric mass transfer coefficient of 1.0397 s^{-1} is achieved by oxygen gas sparing for 6:30 minutes, due to the increased amount of oxygen produced. This is because oxygen gas does not chemically react with water upon release, in addition to its low solubility compared to carbon dioxide, which leads to its presence and free transport. Meanwhile, carbon dioxide gas achieves the maximum volumetric mass transfer coefficient of 0.05885 s^{-1} during sparging for 1:00 minutes at the beginning of the sparging process, before the microalgae grow and completely consume the gas. The decomposition and dissociation of carbon dioxide into bicarbonate ions $HCO^{-3}$and carbonate ions CO^{-3} upon interaction with water reduces its presence as free gas, thus reducing its transport and leading to its complete dissolution when the microalgae biomass increases. Reducing flow rates converts bubbles from fine bubbles to microbubbles, especially in media containing quantities of minerals and organic elements, thus increasing transport efficiency [38- 40], meaning that the sparging gas has reached the vital process with high efficiency.

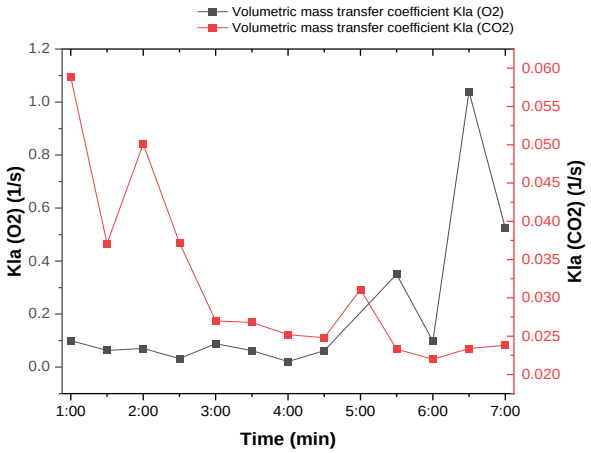

Fig. 6. Volumetric mass transfer coefficient (K_La, s^{-1}) of CO_2 decomposition and O_2 released from photosynthesis by microalgae

3.4. Specific growth rate

When comparing the injection cultures with the bioreactor culture, as shown in Fig. 7 and Fig. 8, it was observed that the bioreactor culture gave an optical density of 2.049 after 33 days of sparging. The biomass production in the bioreactor was estimated at 30 g, or 5 grams per liter, while the biomass of the control culture of the bioreactor was estimated at 0.1317 g/L. The injection culture did not give any increase in optical density after 41 days of cultivation, as it showed an optical density of 1.35 and a biomass of about 1.0799 g/L. This remarkable increase in biomass is due to the success of the sparging process in improving the solubility and transport of carbon dioxide gas in the airlift bioreactor, and thus the complete consumption of carbon ions by microalgae and their exploitation in the photosynthesis process to produce carbon dioxide gas inside the cells, which leads to the production of oxygen [41].

Therefore, it is necessary to remove excess oxygen, especially in the conical flask cultures, to prevent inhibition of the vital process and thus affect the amount of biomass. The specific growth rate (μ, d^{-1})was also calculated, which shows the extent of the culture's response to the quantities of carbon used and the doubling time (t_d, day). were calculated. The maximum specific growth rate was (0.324, 0.187) $d^{-1}$for the sparging culture and the injection culture, respectively, while the control cultures showed a specific growth rate of (0.184,0) d^{-1}, respectively. The doubling time of the biomass was 2 days for the sparging culture and 3.7 days for the injection culture, while the doubling time for the two control cultures was (3.7,0) days from the above results, it can be verified that the sparging process used in this study and using the ALBs is more efficient for microalgae cultivation. After the cultures reached the stationary growth phase, the cultures were settled, and then the excess medium was removed, and the biomass was dried at a temperature of 30-40 ℃ to avoid damage to the biomass.

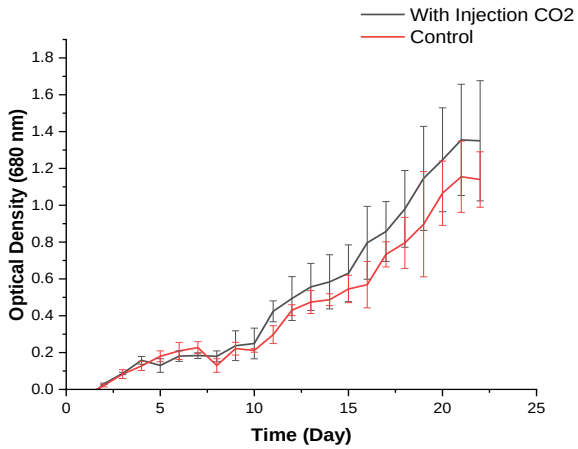

Fig. 7. The optical density of 5 ml of injection culture

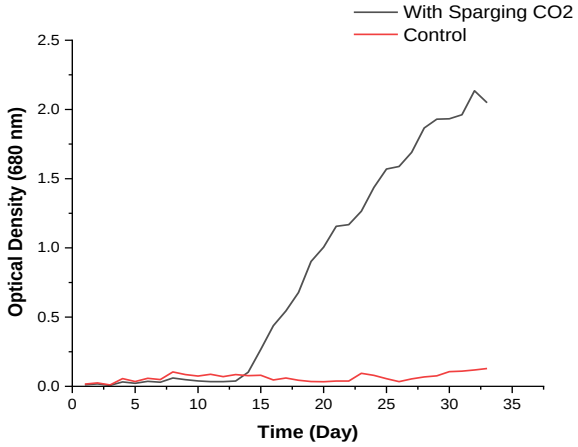

Fig. 8. The optical density of 5 L/h of Sparging culture

3.5. Internal chemical composition and fatty acid

After studying the effect of sparging a small amount of carbon dioxide gas on the pH gradient and the amount of dissolved oxygen produced from the biological process, it was necessary to discuss the effect of the small amount of carbon dioxide on the internal chemical composition of microalgae, as shown in Fig. 9. The bioreactor culture, the number of lipids was 2.06 g per every 30 g of dry biomass, i.e. 0.3 grams per liter, as shown in Table 1, while the lipid produced from the control culture was equal to 0.005386 g/L. As noted, the percentage of lipids decreases, as confirmed in previous studies [20, 42, 43]. This amount of lipids is ideal if the purpose of growing it is to produce nutritional supplements, as this amount is suitable for heart health. However, if the goal of the biomass, especially lipids, is to produce biofuel, the carbon source must be increased to increase the amount of lipids. But this increase requires a deeper study in terms of controlling the pH level and the amount of carbon [44]. Sparging 5 L/h in the bioreactor culture produced (18.03, 1.43 g) per 30 g of dry biomass, i.e., 3.278 and 0.26 grams per liters. This difference in the biochemical composition between the airlift bioreactor system and the control culture is attributed to several reasons, including that the design of the bioreactor provides good light distribution and that the airlift bioreactor contains a draft tube that offers efficient mixing and gas circulation, thus ensuring good distribution of carbon dioxide gas in all corners of the airlift bioreactor. Therefore, this continuous circulation ensures the distribution of all nutrients and thus ensures their access to the cells. This difference declares the superiority of the bioreactor in fermenting algae, even if the carbon source is low, as these quantities are very suitable if the production goal is nutritional due to the low percentage of lipids, and as a high protein source. Chlorella sorokiniana strain is considered a highly important strain for its ability to self-feed and grow in all conditions compared to other strains. This strain has also proven its ability to produce fatty acids that can be used as biological sources and in the production of biofuel [45]. The tests of fatty acids showed 5 forms of saturated and unsaturated fatty acids as shown in Table 2, where the fatty acids are (Palmitic C16:0), (Stearic C18:0), (Linolic C18:2), (Linolenic C18:3), and (Oleic C18:1) acids. Changing the methods of supplying the culture with carbon had a clear effect on the fatty acids, as the percentages of fatty acids injected with 5 ml of carbon solution were (18.9, 6, 22.58, 4.56, 21.08) respectively, while the bioreactor culture showed their percentages (22.15, 7.59, 25.98, 6.99, 24.59) respectively. It was noted that the rate of fatty acids increased when the injection method was replaced by the spray method, as the distribution and fixation of carbon became better and more efficient. Fatty acids are identified in the biodiesel composition, as shown in the previous study [46]. Therefore, this property can be relied upon to produce fatty acids.

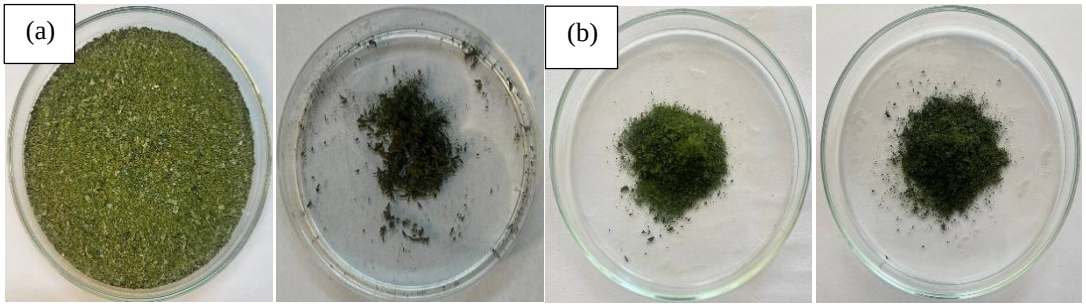

Fig. 9. The biomass of a) Sparging culture, b) Injection culture

Table 1. The amount of biomass composition in the current study

Type of method	Lipids (g)	Proteins (g)	Carbohydrates (g)
Sparging 5 L/h	2.06 g per 30 g of biomass (0.3 g/L)	18.03 g per 30 g of biomass (3.278 g/L)	1.43 g per 30 g of biomass (0.26 g/L)
Control	0.005386 g/L	0.05754 g/L	0.00428 g/L

Table 2. The percentage of fatty acids in the current study

Type of method	Palmitic (C16:0) %	Stearic (C18:0) %	Linolic (C18:2) %	Linolenic (C18:3) %	Oleic (C18:1) %
Injection of 5 ml	18.9	6	22.58	4.56	21.08
Sparging 5 L/h	22.15	7.59	25.98	6.99	24.59
Control	11.58	3.65	16.98	1.25	15.99

4- Conclusion

This study hypothesized that bioreactor designs may need to be reconsidered through several approaches to reduce operating costs and increase production. One such approach is to track the gas delivery to the microalgae by reducing the amount of gas sprayed or injected. Overall, the investigation found that this type of study demonstrated that the continuous introduction of carbon dioxide into bioreactors equipped for microalgae production, several hours a day, does not necessarily increase production, and may even increase operating costs. The results showed an improvement in microalgae production growth rate when 5 L/h of gas was sprayed into the airlift bioreactor, which is higher than when 5 ml of gas was injected into a conical flask. The growth phase after 33 days, when injected, the growth rate reached the exponential growth phase after 41 days. The results showed that the sparging culture was superior to the injection culture, as the specific growth rate was 0.324 day^{-1} for the bioreactor culture, while the conical flask culture showed a lower specific growth rate of 0.187 day^{-1}. The internal composition, such as lipids, carbohydrates, and proteins, of the bioreactor culture (2.06, 1.43, and 18.03 g per 30 g of dry biomass), respectively, showed higher quantities than the control culture (0.005386, 0.00428, and 0.05754 g/L). in addition, the volumetric mass transfer coefficient achieved the highest value, which is 1.0397 s^{-1}, through the transfer of oxygen gas resulting from the photosynthesis process, and the pH value was maintained neutral, i.e. at around 7.

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Nomenclature

ALBs	Airlift bioreactors
K_La	Volumetric mass transfer coefficient
μ	Specific growth rate
t_d	Doubling time
Δt	Cultivation time in the day during the exponential growth phase
OD	Optical density
DO	Dissolved oxygen

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تتبع الغازات الأيضية في مفاعل الرفع الهوائي الحيوي لتحسين زراعة الطحالب الدقيقة

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الخلاصة

تم تصنيف المفاعلات الحيوية الهوائية على أنه تقنية واعدة في زراعة الطحالب الدقيقة. و قد ساهمت العديد من التحسينات في زيادة كفاءة الخلط و الانتاج. و مع ذلك، لا تزال بعض التحديات تواجه هذه العمليات البيولوجية. ان أحد التحديات هو الذوبان الفعال و توصيل ثاني أكسيد الكاربون الى خلايا الطحالب الدقيقة، و الذي لا يزال عاملاً مقيداً في العمليات البايولوجية. من ناحية أخرى، قد يؤدي ضخ الغاز بكميات كبيرة الى فقدانه إذا لم تستهلكه الكائنات الدقيقة بالكامل. في هذه الدراسة، تمت زراعة الطحالب الدقيقة على مرحلتين و مقارنتهما: المرحلة الأولى تم حقن ٥ مل من المحلول الكاربوني في دورق مخروطي، و المرحلة الثانية تم ضخ ٥ لتر/ساعة في مفاعل الرفع الهوائي الحيوي مع زيادة وقت الضخ، حيث يتم ذلك عن طريق ضخ غاز ثاني اوكسيد الكاربون بنفس معدل التدفق من يوم لأخر، و لكن مع زيادة وقت الضخ بمقدار ٣٠ ثانية، بدءاً من ضخ الغاز لمدة دقيقة واحدة حتى الوصول الى ٧ دقائق. أظهرت النتائج ان مفاعل الرفع الهوائي الحيوي يُعطي معدل نمو أعلى للطحالب الدقيقة مقارنةً بالمُنتج في دورق مخروطي. بلغ أقصى تركيز للكتلة الحيوية ٥ غرام/ لتر في مزرعة مفاعل الرفع الهوائي الحيوي، بمعدل نمو نوعي أقصى قدره ٠،٣٢٤ يوم$^{-١}$، بينما بلغ ١،٠٧٩٩ غرام/لتر في مزرعة الدورق المخروطي بمعدل نمو نوعي قدره ٠،١٨٧ يوم$^{-١}$، مما يُظهر أهمية مفاعل الرفع الهوائي الحيوي في زراعة الطحالب الدقيقة. كما وجُد أن تركيب الداخلي للكتلة الحيوية في مزرعة مفاعل الرفع الهوائي الحيوي هو الأفضل، حيث بلغت كمية الدهون و الكاربوهيدرات و البروتينات (٢،٠٦؛ ١،٤٣؛ و ١٨،٠٣غرام لكل ٣٠ غرام من الكتلة الحيوية الجافة) على التوالي، بينما بلغ التركيب الداخلي لمزرعة التحكم (٠،٠٠٥٣٨٦؛ ٠،٠٠٤٢٨؛ و ٠،٠٥٧٥ غرام/لتر) على التوالي. أظهر معامل نقل الكتلة الحجمي أنه مع زيادة زمن الضخ، يزداد معامل نقل غاز الأوكسجين حتى يصل الى ١،٠٣٩٧ ثانية $^{-١}$. كما تم الحفاظ على قيمة الرقم الهيدروجيني عند حوالي ٧، و هي القيمة المناسبة لزيادة معدل النمو.

الكلمات الدالة: انتقال المادة، مفاعل الرفع الهوائي الحيوي، الطحالب الدقيقة، ضخ، ثاني اوكسيد الكاربون.