Study the effect of different types of impellers on the transfer coefficient in photobioreactor.

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Abstract
In this research, study the effect of different types of impellers on the overall volumetric mass transfer coefficient. (determination of KLaO₂ is very important for photobioreactor design and process analysis). Through measuring KLaO₂, the volumetric mass transfer coefficient of carbon dioxide is calculated based on the following relationship klaCO₂ = 0.9 klaO₂ Which is one of the most key factors that depend on it in the design of the photobioreactor. Then, make comparison between them, the impellers type which used in this research is 4-blade propeller, mixed flow impeller, 2-blade propeller (plastic), hybrid photobioreactor-type has been used in this research, which is a mixture of a bubble column and the stirred tank photobioreactor. The variables that studied in this research are the impeller speed (100-500) rpm, the rate of airflow into the reactor (1-4) L/min, and the type of impeller used. KLaO₂ can be measured by static gassing out method. Through practical experiments, it was found that the highest value of KLaO₂ in the 4 blade propeller was at a flow rate of 2 liters per minute and impeller speed 500 rpm, which equals 0.0091 (1/s). As for the impeller (mixed flow impeller), the highest value of KLaO₂ was at a speed of 500 rpm and a flow rate of 4 L/min which equals 0.0118 (1/s). The highest value of KLaO₂ in the impeller 2 blade propeller (plastic) was at a flow rate of 4 liters per minute and impeller speed 500 rpm which was equal to 0.0101 (1/s). A comparison is made between the three impellers on the basis of their efficiency in giving high values of KLaO₂, where it was found that the mean value of the KLaO₂ for the impeller (mixed flow impeller) is higher than the other impellers, where the average value of the KLaO₂ at a speed of (100-500) rpm and the flow rate (1-4) L/min is 0.00806 (1/s). This means that the type of impeller (mixed flow impeller) has a high efficiency of mixing and mass transfer between gas and liquid. In this study, correlation equations were developed for each impeller to see the correctness of the results according to specific exponents and
constants within the range of previous studies and research, and it was found that theoretical volumetric mass transfer coefficient values are close to practical volumetric mass transfer coefficient values.

**Keywords:** volumetric mass transfer coefficient of oxygen; process variable; correlation studies; hybride photobioreactor;microalge
Gas-liquid mass transfer, volumetric mass transfer coefficient of carbon dioxide

1. **Introduction**

Because of their unique properties and multiple applications, algae cultivation has become an important area of study for researchers and various industries. Microalgae They are rapidly growing organisms that convert light, carbon dioxide, nitrates and phosphates into complex organic molecules such as fats, proteins, and sugars through photosynthesis. It can be grown on unproductive land, in saltwater, or in other available wastewater. And they gained popularity as the third generation of biofuels, overcoming minimal competition with food sources and lower biomass productivity associated with the first and second-generation biofuels, respectively.

Microalgae require higher amounts of carbon dioxide from earthly plants, thus helping to sequester carbon. In addition to stabilizing carbon dioxide in the atmosphere, it also uses nitrates and phosphates in the atmosphere and its helps reduce environmental pollution. Microalgae biomass can also be processed to produce medicines, food additives, aquaculture, single-cell proteins, etc. (Bannister 1979). Microalgae have the versatility of being genetically engineered to improve lipid production and carbohydrate stabilization and carbon dioxide (Lindberg, Park and Melis 2010) (Stephanopoulos 2000). Microalgae related experiments require the correct selection of microalgae strains, depending on the purpose for which they are to be used. The selection is usually based on the oil content of the strain and the growth rate. Chlorella Vulgaris It is commonly used for these experiments due to its high oil content and growth rate. (Chisti 2007). Chlorella is commonly known as one of the fastest-growing green algae. The optimal conditions for the growth of Chlorella Vulgaris are a temperature between 20 and 30 ° C and a pH of 4, the biomass of Chlorella Vulgaris when dried consists of approximately 40% protein, 25% oil, 20% carbohydrates, 5% fibers, 10% minerals, and vitamins. Although photosynthesis is very effective it allows producing more oil and proteins than most other plants. The lipid content of Chlorella Vulgaris can be considerably increased between 50% and 70%(Campbell 2008)(Yeh, Chang, and Chen 2010).the design of a photobioreactor plays an important role in affecting the growth of microalgae. One of the main parameters of the design includes efficient transfer of carbon dioxide from the gaseous phase to the liquid phase. This is a crucial parameter as living cells (microalgae) consume only the dissolved carbon dioxide molecules, and carbon is one of the essential nutrients for microalgae cultivation. Therefore, it is essential to design a photobioreator that operates at conditions that will allow maximum transfer of carbon dioxide. The phenomenon of carbon dioxide transfer from the gaseous phase to the liquid phase is dependent on the overall mass transfer coefficient of carbon dioxide. The exact mass transfer coefficient values will help determine the transfer rate of gaseous carbon dioxide to a liquid phase, and the optimal amount of the gas supply needed to increase its consumption by microalgae for maximum possible growth. Therefore, the information about the overall mass transfer coefficient of carbon dioxide is essential for a better feeding control and accurate data of how much carbon dioxide has been consumed by microalgae in comparison to the supplied carbon dioxide. In gas-liquid mass transfer experimental studies, CO2 transfer is often looked as analog to O2 gas-liquid mass transfer, in fact $K_{L}a$ is easier to measure experimentally with O$_2$ using an oxygen probe than with CO$_2$, the overall gas-liquid mass transfer coefficient of CO2 is then often deduced from experiments where O2 transfer is measured with a correction by O2 and diffusion coefficients. The carbon dioxide mass transfer coefficients were calculated (see equation 1) from value determine for oxygen using the equation proposed by blackbbok:

\[
K_{L}a (CO_2)=0.9 K_{L}a (O_2)\]
For this importance of the value of the volumetric mass transfer coefficient $K_{La}$ it is essential to calculate the value of $K_{La}$ ($O_2$).

Oxygen transfer in aerobic bioprocesses is essential and any shortage of oxygen vastly affects the process performance. Therefore, oxygen mass transfer is one of the most important in the design and operation of mixing-sparging equipment for bioreactor. It can be described and analyzed by means of the volumetric mass transfer coefficient $K_{La}$. The value of $K_{La}$ are affected by many factors, such as geometrical and operation characteristics of the reactor (type of impeller, the geometry of the bioreactor, the agitation speed and air flow rate) media composition and properties, concentration and microorganisms morphology and biocatalysts properties. Thus the coefficient $K_{La}$ plays an important role in design, scale-up and economy of the process.

The limiting factor in providing the optimal environment is the oxygen transfer rate (OTR). The mass balance for the dissolved oxygen in the well-mixed liquid phase can be written as:

$$\frac{dc}{dt} = k_{la}(c^*-c) - r_{O_2} = OTR - OUR \quad 1.2$$

When oxygen uptake rate, OUR=0, the oxygen mass balance in the liquid phase can be simplified to:

$$\frac{dc}{dt} = k_{la}(c^*-c) = OTR \quad 1.2$$

Integrating this equation gives:

$$\ln\left(\frac{c^*-c^0}{c^*-c}\right) = K_{La}.t \quad 1.3$$

Then plot of $\ln\left(\frac{c^*-c^0}{c^*-c}\right)$ Vs $t$ shows the result in a straight line of slope $K_{La}$.

From the previous researches and studies that proved that the aeration and agitation provide effective oxygen transfer rate, so will design photobioreactor that contain this specifications (agitation, and aeration).

So will design photobioreactor called bubble column with stirrer photobioreactor which it is from the hybrid type photobioreactor that combine two types of photobioreactor, bubble column and stirred tank photobioreactor photobioreactor. The aim of the experimental studies was to investigate the effect of different types of impeller (4-blade propeller, mixed flow impeller, 2-blade propeller(plastic)) on the values of the overall volumetric mass transfer coefficient, and make comparison between them to investigate the impeller which give the highest value of $K_{La}$, by study the influence of process variable such as impeller speed and flow rate of the three types of the impellers. Later, $K_{La}$ values were analyzed to establish correlations with impeller speed and air flow rate. From the established correlations, the numerical values for the exponents ($\alpha, \beta$) were determined.

1.1 Culture systems for microalgae

Large scale system for phototrophic culture of microalgae can be classified as either open types or closed system.

1.1.1 Open system culture:

Culture is adequately exposed to the environment and has been used traditionally for cultivating microalgae due to its low costs, simplicity, low consumption of energy, and high solar radiation availability. Circular and raceway ponds are the most widely used open systems (Chang et al. 2017).

As shown in the Figure (2-1) below
1.1.2 Closed system culture

The closed system represent the photobioreactors. The photobioreactors are completely isolated from the outside surroundings. Therefore, in this study will chose the photobioreactor type.

1.2 Photobioreactors

These bioreactors are implicated in fermentation processes that are to be performed in the presence of either artificial light or sunlight. This bioreactor is used for the diffusion of light-used microorganisms, which are phototrophic in nature. These microbes have photosynthesis capabilities like microalgae and can produce biomass with light. The structure generally uses glass or clear and transparent plastic. The photobioreactors operate continuously in nature, and the temperature is kept at 35-40 °C. A photobioreactor is a fully closed microalgae culture device that uses natural or artificial light to produce several different algae for aquaculture purposes, but tends to be smaller than an open vessel, a culture vessel illuminated for controlled production of biomass. The photobioreactor refers to closed systems that are environmentally closed and don't have any direct exchange of gasses and pollutants with the environment. In spite of their costs, photobioreactors. Have several major advantages over open systems (Tsoglin et al. 1996)(Carlozzi 2008).

Advantage of photobioreactors

A. Photobioreactors minimize contamination and allow the cultivation of axenic algal monocultures (Carlozzi 2008).
B. Photobioreactors provide greater control over parameters such as pH, temperature, illumination, the concentration of CO₂, etc. (Singh and Sharma 2012).
C. The loss of CO₂ is significantly lower in photobioreactors. (Singh and Sharma 2012).
D. Photobioreactors inhibit the evaporation of water.
E. The photobioreactors produce higher concentrations of cells.
F. Photobioreactors enable the manufacture of complex biopharmaceuticals.
G. allow good heat transfer

Consideration that must be taken while designing the photobioreactor:

a) The reactor should allow the cultivation of various microalgae species on a universal basis.
b) The design of the reactor shall ensure uniform illumination of the culture surface and rapid mass transfer of CO₂ and O₂.
c) Microalgae cells are usually highly adhesive, leading quickly to the fouling of the reactor surfaces transmitting light. This causes the reactors to be shut down frequently for mechanical cleaning and sterilization. The design of the reactor must prevent or minimize the reactor fouling, especially of its light-transmitting surfaces.
d) High mass transfer levels must be accomplished in such a way as not to harm or inhibit the growth of the cultured cells.
e) Photobioreactor will operate under extreme foaming conditions, as often occurs in reactors with high mass transfer rates.
f) The reactor should have a minimum unlighted part. (Tsoglin et al. 1996)
Table 1-1 the comparison between open system and closed system (Carvalho, Meireles, and Malcata 2006)

| parameter                        | Open ponds(raceway ponds) | Closed systems(PBR systems) |
|----------------------------------|---------------------------|----------------------------|
| Contamination risk               | High                      | Low                        |
| Water losses                     | High                      | Low                        |
| CO2-losses                       | High                      | Almost none                |
| Reproducibility of production    | Variable but consistent over time | Possible within certain tolerances |
| Process control                  | complicated               | Less complicated           |
| Standardization                  | difficult                 | possible                   |
| Weather dependence               | High                      | Less because protected    |
| Maintenance                      | Easy                      | Difficult                  |
| Construction costs               | Low                       | High                       |
| Biomass concentrations at harvesting | Low                        | High                       |
| Overheating problems             | Low                       | High                       |
| Super dissolved oxygen concentrations | Low                       | High                       |

Types of photobioreactor

a) Vertical tubular photobioreactor
b) Bubble column photobioreactor
c) Airlift bioreactor
d) Horizontal tubular photobioreactor
e) Helical type photobioreactor
f) Hybrid type photobioreactor

(Carvalho et al. 2006)

1.3 Chosen the type of photobioreactor

Photobioreactor design plays a crucial role in affecting the growth of microalgae, and one of the main limitations of the design includes the effective transfer of carbon dioxide from the gas phase to the liquid phase. Hence CO2 is also a parameter of cultural system design (Sánchez Mirón et al. 2000).

For experimental gas-liquid mass transfer studies, CO2 transfer is often viewed as analogous to O2 gas-liquid mass transfer; for the fact, KLa is extremely easy to experimentally calculate with O2 using an oxygen probe than with CO2. The overall gas-liquid mass transfer coefficient of CO2 is then also obtained from experiments where O2 transfer is calculated with O2 and CO2 diffusion coefficients correction (Langley, Harrison, and van Hille 2012)(Khoo, Lam, and Lee 2016) (Fernandes et al. 2014).

Therefore it is necessary to measure the volumetric mass transfer coefficient of oxygen, so that KLa must increase to perform the photobioreactor. As KLa is dependent on factors such as agitation rate, the flow rate, and configuration of the impeller, so the type of photobioreactor that will choose for this study is hybrid type photobioreactor.

1.4 Hybrid type photobioreactor.

Hybrid photobioreactor type is heavily used that hacks the advantages of the two different reactor types, and one overcomes the disadvantage of the others (Acién Fernández et al. 2001). The type used in this research is combined between bubble column and stirred tank bioreactor.

So that the bioreactor called bubble column with stirrer photobioreactor
1.4.1 Bubble column photobioreactor

In general, the Bubble Column Bioreactor (Fig.(2-3)) is primarily developed for sensitive cells. This consists of a cylinder-type container that has a particular bottom device that is involved in the delivery of gases. The gas is sprayed in a liquid phase or liquid-solid phase in the form of bubbles via this distributor. They are used extensively in the pharmaceutical, petrochemical biochemical, and the metallurgical industries. The upper part of the cylinder remains relatively large, to facilitate bubble release and foam breakage. Aeration is performed by using compressed air using spargers fixed at the bottom of the container.

The cylinder does not contain any other internal components. The gas sparger is significant because it can change the characteristics of the bubbles, such as shape, size, and so on, where the plates have small holes that control the formation of small pores (Ali et al. 2018). Common gas sparger includes porous and perforated plates, membranes, type and arm. The gas holdup is an important key parameter in the bubble column bioreactor. It is described as the volume of the gas phase surrounded by gas bubbles (Luo et al. 1999).

The design and analysis of the bubble columns are based on gas holdup, so it is quite important (Kantarci, Borak and Kutlu O. Ulgen 2005).

Bubble columns are involved in the processing of protein, other enzymes, and antibiotics. Important parameters of the bubble column fermenters include: Ascending speed of bubble, residence time, interfacial space, mass transfer, and hold up value. The advantages of Bubble Column Fermenter are as follows; the gas introduced from below plays an important role in the mixing and aeration, used in wastewater treatment as well as used in the production of citric acid, baker's yeast and beer (Garcia-Ochoa and Gomez 2009).

Bubble column reactors are cylindrical structures with a height more than twice the diameter. It has the advantage of low capital costs, a high area-to-volume ratio, absence of moving parts, adequate heat and mass transfer, a relatively homogeneous cultivation environment, effective release of O₂ and residual gas mixtures. The mixing and transfer of the CO₂ mass are achieved by bubbling the gas mixture from the sparger. For scale-up, perforated plates are used to break up and redistribute coalesced bubbles for the tall bubble column. Light is externally provided. Photosynthetic performance largely depends on the rate of gas flow, which depends on the light and dark cycle as the liquid frequently flows from the central dark zone to the external photic zone at higher gas flow. Circulation flow pattern does not occur due to lack of back mixing. The photosynthetic efficiency may be greatly increased by increasing the amount of gas flow, leading to shorter light and dark cycles (Sánchez Mirón et al. 2000) (Kantarci, Borak and Kutlu O Ulgen 2005). The Figures (2-4) below shows the bubble column bioreactor in general and photobioreactors.
1.4.2 Stirred tank bioreactor

The stirred tank reactor (Fig 2-5) is more traditional when the stirring is mechanically supplied with the help of a propeller of different shapes and sizes. Baffles are used to reduce vortex. CO₂-enriched air is bubbled to the bottom to provide a carbon source for the growth of algae. This bioreactor design is a photobioreactor when illuminated externally by fluorescent lamps or optical fibers, but the major disadvantage of this device is the low surface/volume ratio that reduces light-harvesting efficiency. Use of optical fibers has also been attempted, but the use of optical fibers for illumination has a disadvantage due to its interference in the mixing pattern. New Brunswick Bioflo 115 and Bioengineering Fermenters are commercially available photobioreactors with external lighting systems (Kumar et al. 2011). The high disengagement zone removes the unused sparged gas and transfers oxygen from gassed liquid to gas during photosynthesis (Singh and Sharma 2012).

The performance of this bioreactor depended on the value of $K_{La}$ of $O_2$ and $CO_2$. 

Figure 1-3 bubble column bioreactor

Figure 1-4 bubble column photobioreactor
1.5 Overall Volumetric Mass Transfer Coefficient of CO$_2$ in a Microalga Solution

In general, the transfer of carbon dioxide mass from a gas bubble to a microalga cell occurs in the next seven steps.

a) The bubble contains a bulk gas phase

b) Gas travels to the interphase between gas and liquid

c) Crosses the liquid layer that around the bubble

d) The gas enters the bulk liquid culture medium

e) It flows through the liquid layer around the microbial cells

f) The gas reaches the interface between the cells and liquids

g) The gas eventually crosses resistance of intracellular gas transfer

It is relevant to note that the liquid film around the bubble actually causes more of the resistance to the transfer of gas from the gas phase to the liquid phase. Whereas the liquid film around the microbial cells is negligible because of the cell's extremely small size and therefore does not cause any resistance. (Kazim 2012b)

The carbon dioxide mass transfer coefficient in the algal suspension has been calculated using Equation (1.5), which is similar to the reported equation (1.4) for determining the mass transfer of CO$_2$ in a fermentation broth.

$$\frac{K_{LCO_2}}{KL_{CO_2}} = \left(\frac{D_{CO_2}^L}{D_{CO_2}}\right)^2 = \left(\frac{2 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}}{2.4 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}}\right)^2 = 0.89 \quad 1.4$$

$$\frac{K_{LCO_2}}{KL_{CO_2}} = \left(\frac{D_{CO_2}^L}{D_{CO_2}}\right)^2 = 0.9 \quad 1.5$$

The same equation as the above was used in an experiment carried by (Babcock, Malda, and Radway 2002) to determine the overall carbon dioxide transfer coefficient in the tap water, seawater and algal culture medium within the near-horizontal tubular reactor. But, the mass transfer coefficients of O$_2$ and CO$_2$ in (2.2) were replaced with the volumetric mass transfer coefficients of the gases, and the equation was simplified as:

$$(KLa)_{CO_2} = 0.9(KLa)_{O_2} \quad 1.6$$

The overall volumetric mass transfer coefficient of CO$_2$ has been first measured experimentally by the overall volumetric mass transfer coefficient of O$_2$ to see the document for (Babcock et al. 2002) to obtained details on the method used for the determination.

2. Material and methods

Experiment were performed in cylindrical vessel, the cylindrical vessel was made from acrylic material with internal diameter 18 cm. the experiments were performed in semi batch condition at a temperature 30 $^\circ$C and atmospheric pressure. The liquid phase was deionized water with microalgae and air, nitrogen were the gas phase. The vessel was filled with the liquid up to height H=2Ti, liquid
volume in the vessel was equal to 8 Liter. Filtered air was fed to the system through the sparger located 9cm(Ti/2) below the impeller, the sparger used to dispersed the gas through the liquid, the sparger which used in this work was porus sparger type. The experimental condition have been selected inorder to generate normal flow patterns inside the tank. Figure(1) and table (1) give the schematic and dimensions of the photobioreactor designed,constructed and utilized in this study. three types of impeller are used in this research, 4-blade propeller,mixed flow impeller,2-blade propeller (plastic), the impeller was mounted on the common shaft at distance 9 cm (Ti/2) from the sparger the measurement were carried under different value of gas flow rate(1-4)L/min and agitation speed (100-500)rpm, volumetric gas-liquid mass

The design of the photobioreactor

The transfer coefficient were measured using static gassing out methods. the sensor used to measure the change of oxygen concentration in the liquid phase was immersed in the liquid. the amount of gas that introduced to the vessel can be control by flow meter.

2.1 Instruments and measuring devices

2.1.1 Column:

Column: The reactor consists of a transparent cylinder of 60 centimeters in length, 18 centimeters in diameter and 3 millimeters thick. The column is filled with 8 liters of algae with distilled water to the height of 35.4 centimeters. The container is made of acrylic material, and Acrylic material has been selected as a raw material because it is not toxic, where it does not affect the algae within the column, providing a soft texture and a smooth appearance. While the glass is very thick and decomposes the exposure to the sun, acrylic is apparent and retains its clarity over the years without turning yellow when exposed to sunlight or corroding when exposed to moisture. It is lighter in weight than glass.

| description                        | unite | value         |
|------------------------------------|-------|---------------|
| Body of vessel (material)          | ------| acrylic       |
| Internal diameter of vessel        | cm     | 17.6          |
| External diameter of vessel        | cm     | 18            |
| Thickness of vessel                | mm     | 3             |
| Vessel height                      | cm     | 60            |
| height of liquid                   | cm     | $H_L = 32$    |
| Clearance between impeller and sparger | cm | 9             |
| Working volume                     | liter  | 8             |
| Impeller type                      | ------| 4 blade propeller, 2 blade propeller (plastic), Mixed flow impeller |
| Type of sparger                    | ------| Porus sparger |
Figure 2-1 the flow diagram of the experimental work

1. Filter
2. Air pump
3. Flowmeter
4. Air sparger
5. Dissolve oxygen meter
6. Microalgae
7. Motor
8. Impeller
9. Nitrogen vessel
10. Valve
11. Electric lamp
2.1.2 Air pump:
Is used to pump clean air, is pumped into the bioreactor to grow algae inside and stay alive through the sparger that diffuses air in the form of bubbles to the reactor. Where the air is pumped at a flow rate from 1 liter to 4 liters per minute. And it connected to a filter to clean the air entering the reactor to prevent contaminants. It is also connected to the flow meter to control the amount of air entering the reactor. As shown in the Figure (2-3):

2.1.3 Flowmeter:
A flow meter is used by measuring the gas that flows through the sensors of the flow meter. Flowmeter sensors operate in several various ways, but with the same end goal: to provide the most accurate and repeatable flow measurements for a specific application, whether for process control, general research or semiconductor processing. Flow meters measure either mass or volume. The flow (Q) is equal to the cross-sectional area of the pipe (A) in a volumetric flow meter, and the velocity of the flowing fluid (v): Q = A * v. The mass flow can be expressed in a mass flow meter as follows: \( \dot{m} = Q \cdot \rho \) (where Q is the volumetric flow rate and \( \rho \) is the fluid density.
2.1.4 Agitator:
It is desired to achieve a number of mixing key objectives, for example, bulk fluid and gas-phase mixing, air dispersion, transfer of oxygen, transfer of heat, suspension of solid particles and maintenance of uniform environments throughout the container content. The agitator consists of a shaft, a 4-6 blade impeller and a motor to drive it. The main function of the agitator is to mix the contents, aeration. The mixer shall consist of the following accessories:

2.1.5 Motor:
Overhead stirrers advantage brushless motors that are quiet and long-lasting. Overload safeguard prevents damage to motors that are fully enclosed to stop liquids penetrating the casing. Our overhead stirrer line includes a number of high torque units that are specifically designed for stirring viscous liquids. A wide range of impellers and other accessories are available for these instruments as shown in the Figure (2-5):
2.1.5.1 Shaft:
It is made of stainless steel so that it does not corrode because of the solution. The shaft is placed 9 cm from the diffuser and connects from the top to the motor and connects from the bottom to the impeller.

2.1.5.2 Impeller:
The impeller is the important part of mixer, which accomplishes three main tasks, solid suspension, mixing and dissolution of the necessary atmospheric oxygen into the liquid phase and to increase the interfacial region between the gaseous and aqueous phases. The purpose of impeller to increase the rate of oxygen transfer from air bubble to the liquid medium, increase the rate of oxygen and nutrients transfer from the medium to cells, to inhibit the forming of clump of cells, aggregates of mycelium. In this research was used three type of impeller, 4 blade propeller, mixed flow impeller, 2 blade propeller (plastic)

4-blade Propeller
The impeller used has dimensions, diameter is 5 cm, paddle length is 2 cm and thickness is 2 mm, made from stainless steel. As shown in Figure (2-6)

Mixed flow impeller:
The dimensions of the used impeller, the diameter of 6 cm and the length of the blade 2.5 cm
and thickness 2 mm are used in the high volumes of solutions. As shown in the Figure(2-7)

![2-blade propeller (plastic)](image)

**2-blade propeller (plastic)**

The dimensions of the impeller used, the diameter 8 cm, blade length 3.5 cm and thickness 2 mm and consist of 2 blades only. The Figure (2-8):

![2-blade propeller (plastic)](image)

**Figure 2-8 2-blade propeller (plastic)**

**2.1.6 Spargers**

Provide for thousands of tiny pores to distribute gases in liquids. As a result, there is more gas / liquid contact surface area, which reduces the time and amount needed to divide the gas into the liquid. The sparger has lots of tiny pores on the surface, causing large quantities of gas to enter the solution or medium in the form of bubbles that it penetrate to transfer the oxygen from the gas phase to the liquid phase. The diffuser is better when the diameter of the bubble is small, and it depends on the diameter of the diffuser pores. The diffuser is placed at the bottom of the column and is connected to the air pump by a tube, as well as a flow meter to control the amount of gas that enters the reactor. There are many types of sparger, porous, orifice, and nozzle sparger. As shown in the Figure(2-9)
2.1.6.1 Porous sparger

The porous sparger (Figure 2-10) of sintered glass, ceramics or metal has been used mainly on a laboratory scale in agitated vessels. The size of the bubble created from such sparger is really very small, resulting in the formation of small bubbles and the smaller the bubbles has high surface area, which leads to an increase in the rate of mass transition between gas and liquid. The problem of the sparger, the fine porous, will be blocked by the growth of the microbial culture.

Dissolved oxygen meter:

2.1.7 Dissolved oxygen meter:

There are several kinds of oxygen meter, in this work we have chosen the microprocessor-controlled SensoDirect Oxi 200 handheld meter from Lovibond DO meter, oxygen meter, determine the amount of oxygen dissolved in an aqueous solution. There are two main types of dissolved oxygen sensing technologies available: the optical-based sensing system usually referred to as luminescent, and the Clark electrochemical or membrane-covered electrode. There are slight variations within these two types of technology. Polarographic and galvanic are the two types of electrochemical sensors available. Dissolved oxygen is usually described in milligrams per liter (mg / L) or as a percentage of air saturation. However, some studies will report DO in parts per million (ppm) or micromoles (mmol). 1 mg / L is the same as 1 ppm. As shown in Figure 2-11:
2.1.8 Electric lamp:
The illumination used is a light bulb, and the light intensity is high 24 hours. Microalgae use light as a source of energy to turn CO$_2$ and water into carbohydrates and O$_2$ in the process of photosynthesis. Three essential light variables for proper photosynthesis are intensity, spectral quality, and photoperiod. Depending on the contemplation of the algae, the light of the appropriate wavelength should be chosen. Although the photoperiod varies from organism to organism, 12-15 h of illumination is considered to be the optimal timeframe. Algal growth is strongly proportional to light intensity. As shown in Figure 2-12.

2.1.9 pH value tester
The concentration of the solution should be neutral, so the acidity of the solution should be checked from time to time. When the base of the solution increases, a few drops of hydrogen chloride solution are added, but if the solution pH increases, a few drops of sodium hydroxide solution are added. Because the acid or basal solution affects the mass transition.
2.2 Determination of the $K_{La}$ values

The static gassing-out method was used for the determination of $K_{La}$ values. This method has advantages over chemical methods in that it can be carried out in many different media and does not involve a chemical reaction which could affect the liquid film resistance. The limitations of the gassing-out method lie in the fact that a non-respiring system is involved, which may differ from the actual fermentation condition with fast responding oxygen electrode. The oxygen solution rate was determined by direct measurement of the rate of increase in dissolved oxygen concentration after it was lowered by passing nitrogen gas. The nitrogen gas flow was stopped and this was followed by passing various rates of dry air as a source of oxygen through the air sparger at the bottom of the agitated bioreactor. It is assumed that the response of the oxygen electrode to a change in the dissolved oxygen concentration is sufficiently fast in the analyzer. Most investigators did not take the response time of the electrode into account.

2.3 NPK:

It represents one of the most important and most effective foods for algae. NPK represents the following nutrients: nitrogen (N), phosphorus (P) and potassium (K). The higher the number, the greater the nutrient concentration in the fertilizer.

Procedure for used NPK:

a) An amount of NPK about 40 mg per liter of solution is used
b) We put in the sensitive balance a quantity of NPK (320 mg) because we have 8 liters of algae and distilled water.
c) Take this amount of NPK and put it in a glass beaker containing 10 ml of distilled water and then shake the solution to occur homogeneity between them.
d) The output is taken from the filtration and placed in the electric oven until the temperature becomes 40 or 35°C
e) The solution is then taken and placed in the vessel

Figure 2-13 pH value tester
3. Results and discussion

3.1 The effect of impeller speed on the value of $K_\alpha$ for the impeller type (4 blade propeller)

The speed of impeller was investigated using the speed in the range (100-500) rpm and working volume is 8 liter at various flow rate (1-4) L/min and the average temperature $33\, ^\circ C$ and pH 7. When the flow rate of air is 1 L/min the value of the volumetric mass transfer coefficient increased from 0.0041 1/s at speed 100 rpm to 0.0048 1/s at speed 500 rpm. And when the flow rate is 2 L/min the value of $K_\alpha$ increased from 0.0046 at agitation speed 100 rpm to 0.0091 rpm at speed 500 rpm. At flow rate 3 L/min the value of $K_\alpha$ is 0.0062 1/s at impeller speed 100 rpm and this value increased linearly to become 0.0082 1/s at speed 500 rpm. At flow rate 4 L/min and agitation speed 100 rpm the value of $K_\alpha$ is 0.0063 1/s and this value increased to 0.0086 1/s at agitation speed 500 rpm. It can be noticed that the value of volumetric mass transfer coefficient increased with increase the speed of impeller. The effect of agitation speed is considered the key factor that influence the volumetric mass transfer coefficient of the bioreactor. This effect can be attributed to the faster breakage of the gas bubble at a smaller size with an increase in the speed of impeller and thus increase the gas–liquid interfacial area for the mass transfer. This also resulted in the largest gas hold–up and therefore the highest $K_\alpha$ value (Özbek and Gayik 2001).

Figure 3-1 The effect of impeller speed on the value of $K_\alpha$ at flow rate 1 L/min

Figure 3-2 The effect of impeller speed on the value of $K_\alpha$ at flow rate 2 L/min
The effect of impeller speed on the value of $K_{La}$ at flow rate 3L/min

![Figure 3-3](image)

The effect of impeller speed on the value of $K_{La}$ at flow rate 4L/min

![Figure 3-4](image)

3.2 The effect of air flow rate on the $K_{La}$ values

The effect of flow rate on $K_{La}$ was investigated at a flow rate of air from 1 liter/min to 4 liter/min in the vessel that contains 8 liter of mixture that consisted distilled water and microalgae and study the effect of flow rate on the value of $K_{La}$ at each speed (100-500) rpm.

When the agitation speed equal to 100 rpm the value of the volumetric mass transfer coefficient when the flow rate of air is 1L/min is 0.0041 and this value increase a little when the flow rate become 2 L/min, at the flow rate 4 L/min the value of $K_{La}$ increase to 0.0063 1/s (Kielbus-Rapala and Karcz 2009).
When the speed of impeller is 200 rpm the value of $K_{La}$ is 0.0044 when the flow rate 1 L/min and this value increase to 0.005 at flow rate 2 L/min ,and this increase continue to the flow rate 3 L/min where the value of $K_{La}$ is 0.0066, but when the flow rate is 4 L/min observed there is a decrease in the value of $K_{La}$.
At the agitation speed 300 rpm the value of $K_La$ at flow rate 1L/min is 0.0046 and this value increases to 0.0077 1/s at flow rate 3L/min, but when the flow rate of air becomes 4L/min the value of the volumetric mass transfer coefficient decreases.

When raising the speed of impeller to 400 rpm, it can be observed that the value of $K_La$ is 0.0047 at flow rate 1L/min and this value continues increasing where the value of $K_La$ becomes 0.0079 at flow rate 3L/min, but at flow rate 4L/min the value of $K_La$ decreases to 0.0071.

When the agitation speed is 500 rpm, the value of $K_La$ at flow rate 1 L/min is 0.0048 1/s, and this value increases dramatically to 0.0091 1/s when the flow rate of air is 2L/min. Then the value of $K_La$ decreases to 0.0082 1/s at flow rate 3L/min, this thing is natural as gas hold-up increases. Then the value of $K_La$ increases to 0.0086 1/s at flow rate 4L/min.
fractional gas hold-up, at higher gas flow rates gas hold up in the bioreactor increase, leading to high a (surface area of the bubble) which increases the $K_La$ value and hence the gas-liquid interfacial area it was observed that with increasing the gas flow rate there will more gas bubble and larger gas-liquid interfacial area, therefore, the volumetric mass transfer coefficient value increased (Sivaprakasam, Mahadevan, and Gopalaraman 2008) (Park et al. 2002) (Özbek and Gayik 2001). But the further increasing airflow has a negative effect on its value, due to the bubbles coalesce to form large bubbles which leads to a decrease in gas residence time, and then it reduces the rate of oxygen stay, which leads to a decrease in $K_La$ which that show when the speed of impeller 200, 300, 400 rpm it can be notice that decrease in the value of $K_La$ at flow rate 4 l/min.

3.3 Correlation

Several empirical correlations for the rate of oxygen transfer in a bioreactor are established with three kinds of impeller, the values of $K_La$ obtained from the experimental data are plotted against the operational variables and mathematical correlations which describe the influence of the studied parameters on the $K_La$ have been established in order to predict biodegradation performances from viewpoints of oxygen mass transfer when using models that account for the effect of dissolved oxygen.

Correlation for the volumetric mass transfer coefficient:

Predictions of the absorption rate of a gaseous material in a stirred tank are generally based on correlations between the overall volumetric mass transfer coefficient ($K_La$) with mechanical agitation power per unit volume ($P / VL$) and the gas sparging rate expressed as the superficial velocity ($u_g$). Power input per unit volume ($P / VL$) and superficial gas velocity $u_g$ are key factors in these $K_La$ correlations. There are many proposed equations for the volumetric mass transfer coefficient as a function of various variables in previous studies. In literature, the following equation is frequently found in (Kapic and Heindel 2006) (Kazim 2012b) (Puthli, Rathod, and Pandit 2005).

$$kLa = A \left(\frac{P}{VL}\right)^\beta (u_g)^\alpha$$

Where $A$, $\beta$, and $\alpha$ are constant values that depend on the type of gas used and the operating conditions of the reactor.

$P$ is the power generated by the stirrer to the aerated liquid that determined by the electrical measurement method, using a circuit control system that controlled the electrical current (A) and the voltage (V) of the DC stirrer motor placed on the bioreactor. $VL$ as the working volume of the bioreactor, in this study, was 8 liters and $u_g$ was determined by dividing the gas flow rate (m$^3$/s) by the internal column area (m$^2$).

Until now, various values of $A$, $\beta$ and $\alpha$ are identified for the determination of the volumetric oxygen transfer coefficient in the agitated vessel under different operating conditions. On the other hand, there is not enough available information about the constant values for oxygen to measure the $K_La$ of $O_2$. Therefore, based on experimental results, constant values of $A$, $\beta$ and $\alpha$ were produced.
using Microsoft Excel. And correlations were developed to directly calculate the overall volumetric mass transfer coefficient of oxygen.

It was necessary to validate correlation for each gas flow rate (1-4) L/min that represented by the superficial velocity \( u_g \) and agitation rates ranging from (100-500) rpm that represented by \( \frac{P}{V} \), then the \( A, \beta, \) and \( \alpha \) for each correlation they were average in this research developed correlation equation for each impeller (4-blade propeller, mixed flow impeller, 2-blade propeller (plastic)).

**The correlation that developed for (4-blade propeller):**

\[
KLa = 0.005 \left( \frac{P}{V} \right)^{0.127} u_g^{0.154}
\]

\( A=0.005, \beta=0.127, \alpha=0.154 \) this constants that obtained in this investigation are in good agreement with those reported by (Sivaprakasam et al. 2008) (Kapic and Heindel 2006) (Kazim 2012a)

The exponent \( (\alpha=0.154) \) represents the dependence of the volumetric mass transfer coefficient on the superficial gas velocity \( (u_g) \) that compared with the literature value. Previous studies (Sivaprakasam et al. 2008) obtained the value of exponent on the superficial gas velocity in the range \( (0.15-0.67) \) depending on the speed of agitator and the geometry of the equipment. The exponent obtained from this study agree with corroborates the reported values. (Kapic and Heindel 2006) (Hyman and Bogaerde 1960)

The exponent \( (\beta=0.127) \) is within the range reported in the literature \( (0.12-0.68) \) (Kapic and Heindel 2006) (Kazim 2012a). the wide variation of \( (\beta) \) is related to the design of the vessel (the proportionality of impeller diameter to vessel diameter, tank bottom geometry, tank liquid height) employed by different researchers.

The constant \( (A=0.005) \) obtained in this study are in good agreement with those reported by (Yarmush and Pedersen 1995).

The following graphs were created to analyze how well the experimental data fit with the calculated data from the correlation based on the average values of \( A, \beta, \alpha \) for flow rates (1-4) l/min and speed (100-500) rpm.

**At the flow rate equal to 1 l/min**

As for the first Figure (4-16) when the flow rate is equal to 1 l/min observed there that the values of the experimental \( K_{La} \) are close to the theoretical \( K_{La} \) values. See from the chart, at speed 400 rpm the two balls are more overlapping than the rest of the speed, and the same thing is for the remaining balls, but with lower ratios which means that the equation of correlation when the flow rate is 1 l/min will be nearly similar to the experimental results.

As for the second Figure (3-10) when drawing the theoretical \( K_{La} \) with the experiential see that all points are close to the straight line especially at the fourth point.
At the flow rate equal to 2 l/min

In the first Figure (3-12) at the speed of 100 rpm, when the flow rate is equal to 2 l/min note the convergence of the balls with a rate of 40%. Then it decreases when the speed 400 rpm to 80%, after that the percentage drops to 20% at speed 500 rpm.

The second Figure (4-21): Observed from the drawing that the points are close to the straight line. Through the previous three charts, it can be notice that the corrective equation is very appropriate and accurate when the flow rate is 2 liters per minute.
The first Figure (3-13) is at speed 100 rpm, the two balls are identical at 95%, and this means that the experimental and theoretical values at speed 100 rpm are identical. By increasing the speed the balls are approximately 30% converged, but in general, the balls are all overlapping, which indicates that the experimental $K_{La}$ values are close to the theoretical $K_{La}$ values, and this means that the corrective equation is appropriate when the flow rate of air is 3 liters per minute and the speed is from 100 rpm to 500rpm.

In the second Figure(3-14): the points are very close to the straight line and there is a point located on the straight line and another located close to the line and this indicates a similarity between the theoretical and experimental values $K_{La}$.

At flow rate equal to 4 l/min:

The first Figure (3-15) is that at 100,200,300 rpm speed, the two balls are corresponding at 98% which means that the experimental $K_{La}$ values are similar to 98% for theoretical values when the speed is 100,200,300. rpm at 400 rpm the ratio decreases to be 90% which is also close. But at speed 500 rpm is the two balls are identical at 30% meaning that the experimental $K_{La}$ values are somewhat close to the theoretical $K_{La}$ values at 30%.

Through the graph (3-16) between the theoretical $K_{La}$ and the experimental $K_{La}$ observe that almost all points close to the straight line and this means that the practical $K_{La}$ is close to the theoretical $K_{La}$. Notice that the correlation equation is very appropriate when the flowrate equals 4 liters per minute is better than the rest of the rates where the convergence between the theoretical and experimental results of $K_{La}$ is 90%.
3.4 The Effect of Impeller Speed on the Value of $K_La$ for the Impeller Type (Mixed Flow Impeller):

The speed of impeller was investigated using the speed in the range (100-500) rpm and working volume is 8 liter at various flow rate (1-4) L/min and the average temperature 33 °C and pH 7. When the flow rate of air is 1 L/min, the value of the volumetric mass transfer coefficient is increased from 0.0041 (1/s) at speed 100 rpm to 0.0082 (1/s). At flow rate 2 L/min, the value of $K_La$ at speed 100 rpm is 0.0067 (1/s) and then increased linearly to the speed 400 rpm, where the value of $K_La$ is 0.0084 (1/s). After that when the speed of impeller is 500 rpm, the value of $K_La$ is increased dramatically to the value 0.0115 (1/s). At flow rate 3 L/min, the value of $K_La$ increased from 0.0058 (1/s) at speed 100 rpm, to 0.0081 (1/s) at speed 200 rpm, then this increase continues when the value of $K_La$ becomes 0.0083 at speed 300 rpm, 0.0105 (1/s) at speed 400 rpm, and 0.0117 (1/s) at speed 500 rpm. When the flow rate of air is equal to 4 L/min, the value of $K_La$ increased from 0.0054 (1/s), 0.0077 (1/s), at speed 100 rpm, 200 rpm respectively to 0.0094 (1/s), 0.0101 (1/s), and 0.0122 (1/s) at speed 300 rpm, 400 rpm, 500 rpm respectively.
Figure 3-17 the effect of impeller speed on the value of $K_La$ at flowrate 1L/min

Figure 3-18 the effect of impeller speed on the value of $K_La$ at flowrate 2L/min

Figure 3-19 the effect of impeller speed on the value of $K_La$ at flowrate 3L/min
