A Critical Review of Wastewater Treatment in Photobioreactors for Improving Microalgae Growth

Habiba AL-Hadabi, Talal Al-Balushi *Member, IAENG*, Shinoona Al-Aisri Sahar Talebi, Tahir Al-Barwani

Abstract— **In order to enhance micro-algal growth in photobioreactors (PBRs), light requirement is one of the most important parameter to be addressed; light should indeed be provided at the appropriate intensity, duration, and wavelength. Excessive intensity may lead to photo-oxidation and -inhibition, whereas low light levels will cause growth-limiting. The constraint of light saturation may be overcome by either of two approaches: increasing Photosynthetic efficiency by genetic engineering, aimed at changing the chlorophyll antenna size; or increasing Flux tolerance, by tailoring the photonic spectrum, coupled with its intensity and temporal characteristics. These approaches will allow an increased control over the illumination features, leading to maximization of micro-algal Biomass and metabolite productivity. This review introduces the nature of light, and describes its harvesting and transformation by microalgae, as well as it is metabolic effects under excessively low or high supply.**

Index Terms— **PBRs, photosynthesis, light sources, Photo-acclimation.**

I. Introduction

Microalgae are microorganisms characterized by a high productivity per unit area when compared with such other photosynthetic organisms as higher plants. This outstanding photosynthetic efficiency results from reduced number of internally competitive physiological functions, fast reproduction cycles, limited nutrient requirements, and adaptation to a broad range of temporal and spectral irradiances. Furthermore, a few micro-algal cultures (e.g., Dunaliella, Spirulina, and Chlorella spp.) are relatively prone to scale-up in photobioreactors (PBRs), where it is in principle possible to provide optimal nutrient levels on a continuous basis.

Manuscript received April 4, 2012; revised April 18, 2012. This work was supported in part by The Research Council, Oman and Sohar University, Sohar, Sultanate of Oman.

Habiba Al-Haddabi is with the Faculty of Engineering, Sohar University, Sohar, Sultanate of Oman. (Phone: 00-968-98029250; fax: 968-26720101; E-mail: al-baroona990@hotmail.com).

Talal Al-Balushi is with The Research Council, Oman, Sultanate of Oman. (E-mail: talal.albalushi@trc.gov.om).

Shinoona Al-Aisri is with the Faculty of Engineering, Sohar University,Sohar,Sultanate of Oman. (E-mail: Shinu 16.2@hotmail.com).

Sahar Talebi is with the Faculty of Engineering, Sohar University, Sohar, Sultanate of Oman. (E-mail: leo_sahar_t@yahoo.com).

Tahir Al-Barwani is with the Faculty of Engineering, Sohar University, Sohar, Sultanate of Oman. (E-mail: tahir-1989@hotmail.com).

II. Literature Review

Khoeyi et. al., 2011 described the effects of irradiance and photoperiod on the biomass and fatty acid (FA) composition of Chlorella vulgaris which were examined in the exponential growth phase. Light regime had an effect on the biomass of C. The longer duration of light brought about increased biomass of C. However, light intensity showed different effects on biomass; increase in light intensity from 37.5 to 62.5 mol photons m^{-2} s^{-1} resulted in increased biomass, but at 100 mol photons m^{-2} s^{-1}, biomass decreased [5].

Carvalho et. al., 2010 in their studies about light requirements in micro-algal photobioreactors, the constraint of light saturation may be overcome by either of two approaches: increasing photosynthetic efficiency by genetic engineering, aimed at changing the chlorophyll antenna size; or increasing flux tolerance, by tailoring the photonic spectrum, coupled with its intensity and temporal characteristics. These approaches will allow an increased control over the illumination features, leading to maximization of microalgal biomass and metabolite productivity [2].

Walker et. al., 2005 discussed in their article and compared the current commercially viable bioreactor systems, outline recent progress in micro-algal biotechnology and transformation, and discuss the potential of microalgae as bioreactors for the production of heterologous proteins. Bacterial fermentation is limited in application as bacteria are unable to perform post-transcriptional and post-translational modifications essential for the production of functional eukaryotic proteins. Such modifications include intron-splicing, glycosylation and multimeric. An additional complication is that high intracellular levels of heterologous proteins tend to result in the formation of protein aggregates as insoluble inclusion bodies [11].

Johnson et. al., 2009 wrote about, “Development of an attached microalgal growth system for biofuel production”. The objective of this study is to explore a novel attached culture system for growing the alga chlorella sp. The biomass harvested from the attached growth system (through scraping) had a water content of 93.75%, similar to that harvested from suspended culture system (through centrifugation). Collectively, the attached algal culture system with polystyrene foam as a supporting material demonstrated a good performance in terms of biomass yield, biodiesel production potential, ease to harvest biomass, and physical robustness for reuse [4].

Fun et. al., 2011 discusses the unit processes required for algal biofuels production (i.e., growing the algae, harvesting, dewatering, extraction and conversion to biofuel). The production of biofuels from microalgae, especially biodiesel, has become a topic of great interest in recent years. And there are two basic types of culture systems were recognized and developed at that time: 'open' pond systems and 'closed' photobioreactors.

Almost all commercial producers use open ponds where the algae culture is mixed either by paddle wheels (raceway ponds) or by a centrally pivoted rotating arm. The energy contained in the algal biomass can be recovered in a number of ways including direct thermo chemical liquefaction. However the current main interest in algae is the production of liquid fuels, especially biodiesel and jet fuel, from the algal lipids [3].

Kumar et. al, 2010 in their research, " Waste water treatment and metal (Pb^{2}+, Zn^{2+}) removal by micro-algal based stabilization pond system", the growth inhibition in microalgae is related to the amount of heavy metal ions bound to the algal cell surface, and also, to the amount of intracellular heavy metal ions. Presently, the application of conventional wastewater treatment systems in countries with low GNP is limited because of high cost and technological complexity. Worldwide, there is a continuous interest in algal-based waste stabilization pond systems that are inexpensive and are known for their ability to achieve good removal of pathogens and organic pollutants [6].

III. WASTEWATER TREATMENT

Studies on stabilization ponds used to treat wastewater show that the most probable cause of microbial death and reduction in these ponds is the pH increase caused by the multiplication of microalgae and its energetic photosynthesis. A pH of over 9 considerably reduces the presence of bacteria in water. The light source was also used at illumination of an incandescent lamp of-400(W/m', 8hours/day). Microalgae are equivalent to 0.15 g/l (dry weight).

In the first pond, the microalgae are kept in the tank overnight affected by the light. In the morning, the concentrated alga, floating in saline water is poured into the wastewater pond in which, through one day, the lively alga enhances a dramatic rise in the pH. On the following night after the wastewater treatment occurred, the algae are recovered in the intermediate tank again using the light as attractor and poured, at the next morning, into the original algae growing pond where proliferation continues while the treated wastewater is poured out from the pond no. III. This dynamic procedure improved the time spent in the wastewater treatment [10].

IV. PHOTO-BIOREACTOR DESIGN

The light attenuates exponentially as it penetrates into the culture medium is one major problem in designing efficient bioreactors for photoautotrophic microorganisms arises from realization. A plate configuration can be employed and light comes from a normal direction thereto by the average light intensity at any given point within a culture assuming. In order to overcome short light penetration depth, the distance can be reduced as much as possible between the innermost region of the culture and the light source. Usually via a thin tubular structure, or strong stirring (to increase the efficiency of light usage). However, the former approach leads to inept transfer of gases (i.e., supply of CO_2 and removal of O_2), whereas the latter has a maximum limit set by the excessive shear stress imposed on the culture (that may eventually cause cell disruption) [1].

V. LIGHT SOURCE

They are several criteria to be kept in consideration when selecting the type of light source. There are high electrical efficiency, low heat dissipation, good reliability, high durability, long lifetime, reasonable compactness, low cost and spectral output falling within the absorption spectrum of the microorganism of interest. In table I, different types of light are mentioned. It also shows the photonic features of major types of artificial light. Among all types of light , Laser diodes found to be having the extra advantage as it has an ability to conduct light in the optical fiber which has special sensing probes can be made-up to check chosen chemical parameters [5].

Table I, Light Sources and Characteristics [5].

Light Type	Generation of light	Intensity (w/m^2)	Energy Emission 400-500 nm (%)	600-700 nm	Energy Conversion	Lifetime hours	Luminous Efficacy (lm/W)
Incandescent Bulbs	Heating of tungsten-wire in a vacuum or inert gas environment	5.1	0.5 %	3.8 %	Very High	750–2.00	10–18
Incandescent Bulbs	Heating of tightly coiled Tungsten filament surrounded by halogen gas	1.6	0.3 %	3.3%	High	3.00–4.00	15–20
Fluorescent Lamps	Production of electric arc leading to mercury vapor ionization radiating energy.	5.9	25.0 %	20.7%	low	10.00	35–100
Light emitting diodes (LEDs)	Semiconductor light source releasing energy in the form of photons.	14.7–55.5	0.04–0.08%	87.6–98.3%	Below 10%	35.00–50.000	25–64
Laser diodes	Based on doping of a very thin layer on the surface of a crystal wafer.				Nil	100.00	30–45

ISBN: 978-988-19252-2-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

VI. SELCTION OF LIGHT SOURCE

As it is known that light with wavelengths within 600-700nm is the most proficient for photosynthesis , utilizing to irradiance between 400 and 500 nm may give an increased overall rate of microalgae, because light serves other purposes in addition to photosynthesis. The design and choice of effective light source for microalgae farming depends on the microalgae at stake because there are different sorts of microalgae which necessitate dissimilar light Spectra, depending on the pigments present in and the kind of light as well as the intensity of light source. Spectral quality and quantity of light are crucial elements for microalgae growth and metabolism [5].

VII. INTENSITY OF LIGHT SOURCE

The measurement of the availability of photons for photosynthesis process is the intensity of light source. In every type of the microalgae, there is a specific curve that correlates its growth rate with incident light intensity at given temperature. That means if there is an increase in the temperature, there will be an increase in the light intensity [2].

VIII. PHOTOSYNTHESIS

"Photosynthesis is a process that utilizes the light energy to chemically synthesize molecules". The basic chemical equation can be summarized as:

$$6CO_2 + 6H_2O + 6O_2 \rightarrow C_6H_{12}O_6 + 6O_2$$

It's Endothermic Reaction (2,814 kJ) indicates that energy is required for the reaction to proceed, which is provided by incident radiation. Microalgae seem to absorb light much more land plants. It has Ca and other pigments. The light will be blocked up by the absorbing substances; since chlorophyll and other pigments differ in their absorption spectra in microalgae cell will be more efficient because it happen in a far broader spectral range [8].

IX. PHOTO-ACCLIMATION

Microalgae have a remarkable capacity for photo-acclimation because of the relatively rapid and large change in Ambient light to which they are subjected. This change process includes series of interrelated physical, Biophysical, biochemical and physiological changes that help microalgal cells optimize their use of available light. Damage of microalgae by excess light depends on a certain degree on the state of photo-acclimation. If the cell acclimated to relatively low light (i.e., shade-adapted) before it is exposed to high intensity radiation, it will cause photo damage at a lower irradiation dose which is the opposite if the cell have been high light-acclimated. Therefore, in batch cultures grown outdoors, it is advisable to previously acclimate the inoculums to high light values. On the other hand, when the cellular inoculums are small, initial irradiance should also be low; otherwise photo-damage may cause culture collapse [7].

X. PHOTOSYNTHITIC EFFICIENCY

Characterizing photosynthetic processes can be divided in three ranges: primary photochemistry, electron shuttling and carbon metabolism. These three processes can be intentionally uncoupled by providing pulses of light characterized by the appropriate length within the time range of each process. Once a photon is absorbed, 1-5 ms was needed of the system to reset it, prior to being ready to receive another photon. Absorption of a photon is almost instantaneous, so the time necessary for micro-algal cell to remain in the lit region of a PBR is a function of how long it takes for photon force the absorbing pigment in its antenna. Such a situation is a function of the incident light flux. The depth within the PBR and the amounts of absorbing pigments available in the antenna region [8].

XI. CONCLUSION

In my opinion to increase micro-algal biomass and specific metabolite productivity, long-term strategies of research in the field should include design and development of Innovative PBRs, coupled with genetic engineering of strains. To attain maximum productivity in said PBRs, several parameters are to be accurately controlled; however, none of the many reactor configurations built to date is able to effectively handle all those parameters simultaneously.

ACKNOWLEDGMENT

This article is a part of The Research Council, Oman funded project entitled "Harnessing clean and green energy via integrated treatment of industrial and domestic wastewater". The authors express their gratitude and thanks to the Faculty of Engineering, Sohar University and The Research Council, Oman for their support, cooperation and help in successfully conducting the research.

REFERENCES

[1] Anderson G., “Photobioreactor design”, ASAE/CSAE North Central Intersectional Meeting Presentation MBSK02-216, Saskatoon, Canada, 2002.
[2] Carvalho A. P., Silva S. O., “Light requirements in micro-algal photobioreactors an overview of biophotonic aspects”, Portuguesa, 2011.
[3] Fun S., Sing A., Isdepsky M., Borowitzka A., Moheimani N.R., “Production of biofuels from microalgae”, Ausralia, 2011.
[4] Johnson M. B., Wen. “Development of an attached microalgal growth system for biofuel production”, 2009.
[5] Khoeyi Z. A., Seyfabadi J., Ramezanpour Z., “Effect of light intensity and photoperiod on biomass and fatty acid composition of the microalgae”, Chlorella vulgaris). Noor, Iran, 2011.
[6] Kumar R., Goyal D.,“Waste water treatment and metal (Pb2+, Zn2+) removal by microalgal based stabilization pond system”, Punjab, India, 2010.
[7] Lee C.G., Palsson B.O., “Photoacclimation of Chlorella vulgaris to red light from light-emitting diodes leads to autospore release following each cellular division”, Biotechnology Prog 12:249–256, 1996.
[8] Pirt S. J., Lee Y. K., Walach M. R., Pirt M. W., Balyuzi H.H.M., Bazin M.J., “ A tubular bioreactor for photosynthetic production of biomass from carbon-dioxide—design and performance's Chem Technol Biotechnology 33:35–58”, 1983.
[9] Singh A., Ward O., “Microbiology of bioreactors for wastewater treatment”, Berlin Heidelberg, 2005.
[10] Toha J., Soto M. A. and Cuadros X., “Waste water treatment using saline culture of microalgae. Santiago-Chile. Survival of microorganisms is affected by a combination of salinity and high pH induced by the active photosynthesis of marine microalgae”, 1990.
[11] Walker T. L., Becker D. K., Collet C., “Microalgae as bioreactors”, Brisbane, QLD Australia, 2005.

ISBN: 978-988-19252-2-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)