Chapter 5

Pilot Scale of Microalgal Production Using Photobioreactor

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Additional information is available at the end of the chapter

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Abstract

Microalgal gained much interest as a promising sustainable feedstock for the production of food, feed, bulk chemicals and biofuels. Pilot scale of microalgal is needed to bridge the gap between laboratory scale research and commercial application. Commercial applications of microalgal have been used for a wide array of functions including, pharmaceutical, health sector, nutraceutical, cosmetics and agriculture. Numerous photobioreactors (PBRs) of different volume and shapes have been designed. Cost of PBR has a major influence on production cost for large scale biomass. There are several ways to reduce production cost depends on the type of algal strain, type of PBRs, CO_2 and the production technology of the biomass. Dilution rate is an important factor, which affects the biomass productivity, rate and ultimately what needs to be maximized.

Keywords: photobioreactor, open bonds, biomass production, water sterilization, biofilm, dilution rate

1. Introduction

Microalgal is that the good biotechnological potential for the assembly of huge quantities reasonably compounds like polysaccharides, lipids, proteins, carotenoids and pigments, vitamins, steroids, amongst others. Microalgal species is now used in the manufacture of animal feed, human nutrition, cosmetics, and pharmacy trade parts. Biofuels could also be used to produce biofuels [1–3]. Some authors have faith in microalgal as biodiesel feed stocks [3]. The advantages of microalgal culture compared to superior plants unit listed [4, 5]:

1. Microalgal biological systems square measure thought-about the foremost economical for star lightweight capture and the production of compounds.

2. Several microalgal species manufacture and accumulate compounds of high business value could also be induced, for example, proteins, carbohydrates, lipids, and pigments.
3. The isolation, genetic selection, and strain studies is relatively easy and fewer time intense because microalgal reproduce themselves by a straight forward process and might fulfill their life cycles in precisely several hours or days.
4. Microalgal could also be cultivated with low inorganic nutrients concentration. These make them of express interest as an organic compound provide, encouraging organic compound convenience in regions of low agriculture productivity due to the shortage of water and nutrient-poor soils.
5. Systems for biomass production could also be tailored or scaled up to altogether totally different operation levels, allowing later incorporation of these systems to fully machine-controlled facilities for large scale production.

Microalgal cultivation has received a lot of attention within the past decade [6]. Still, most analysis is completed on the laboratory scale and is geared toward beneath standing the behavior of single cells under controlled conditions. As a central component within the production chain, cultivation ought to even be studied in additional detail beneath business or "large-scale" conditions.

2. Microalgal cultivation systems

2.1. Opens ponds system

Generally, microalgal and true bacteria huge scale mass cultivation is completed in shallow open ponds tanks, of circular or raceway kind, with sun gentle one amongst the vital edges of the employment of open structures is that they are simple to construct, function, and that they have decrease charges than closed systems. Though it's been established that open pool method of life is economically viable, they still have some disadvantages and bounds, they use gentle in a very altogether inefficient method, have evaporation water loses, low dioxide mass transfer value from the system, because of its inefficient mixing mechanisms.

2.1.1. Circular pond

A circular pond is principally used for culturing algal sp. in Asia [7]. The thought of exploitation such a rounded pond with a protracted rotating arm was impressed by the circular reactor in waste matter treatment, so a circular pond is very kind of like the waste matter treatment pond (**Figure 1a**). This type of pool is usually 20–30 cm thorough and 40–50 m in diameter. The long rotating arm is about within the center of the pond that acts sort of a face and performs a paddle wheel perform that is acquainted within the structure to that of a raceway pond. It's obvious that mix of culture media and algal cells square measure additional economical than that in associate ponds, however because the algal is exposed to

Figure 1. Open ponds cultivation system of microalgal cells. (a) Circular open pond and (b) raceway pond.

the surroundings, the contamination is unavoidable. According to the analysis literature, the productivities in circular pond vary between 8.5 g/(m^2 d) and 21 g/(m^2 d) [4].

2.1.2. Raceway pond

During the past 40 years, the raceway pond (**Figure 1b**) has been the foremost common and wide used open system reactor for the large-scale cultivation and business production of microalgal merchandise. The raceway pond was initial raised by Lee [7] and Oswald and Goleuke [8] within the sixties and its look and structure have not been modified a lot of compared with 40 years past till today [8].

2.1.2.1. Challenges in open pond cultivation systems

2.1.2.1.1. Light penetration

Light is the sole supply of radiant strength, bad light penetration into the pond becomes a hassle. Light is regularly considered to be one of the most vital factors that decide algal increase. The critical troubles that are confronted are: the open pond device, mild penetrates most effective the top 3–4 in. (76–100 mm) of the water. Because the algal grow and multiply, the way of life becomes so dense that it blocks mild from reaching deeper into the water. Low intensities might not promote algal boom at the lowest of the pond. Direct sunlight is simply too strong for most algal, which need most effective about 1/10 the quantity of light they acquire from direct sunlight. Excessive intensity may additionally cause picture inhibition and image-oxidation. Lengthy exposure to light may additionally result in minor damage of algal series antenna that may be fast repaired via the cell if placed within the darkish.

Studies have tried that it should be powerful to realize high productivity in open ponds because of the actual fact the temperature and light-weight intensity vary at some purpose of the day and 12 months. Further, even at some purpose of bright summer season days, out of doors algal cultures were shown to be light-limited, to get most productivity, it has been cautioned that it is acceptable to possess artificial resources of sunshine for nights and cloudy days [9]. The sunshine saturation result accounts for the truth that a twenty-fold growth

within the incident energy consequences in simplest a four-fold increase within the amount employed by the algal [10].

2.1.2.1.2. Odor troubles

Developing algal cultivation in open ponds will cause malodour within the ponds. This downside is specially thanks to lack of gas. Alga that square measure suspended below the surface cannot photosynthesize and as a result, they decompose. The decomposition technique consumes dissolved gas, and as a conclusion, gas ranges within the water column decrease, main to the mal-odor to unravel this example deliberate cultivation and harvest home have to be compelled to upset this on this context, right designing refers to harvest home the alga on the right time, before they die and decay.

2.1.2.1.3. Culture infection

Open ponds can get contaminated. Infection of ponds may be a result of: infiltration from other algal strains and alternative organisms, dirt scrap, leaves and alternative mobile materials. as associate instance, though the algal species adult commercially in outside ponds normally grow underneath tremendously selective things *(Nannochloropsis*, *Chlorella* Spp., and *P. tricornutum* adult at excessive nutrient concentrations, *Spirulina* is adult at high hydrogen carbonate concentrations and *D. Salina* is adult at terribly high salinity) contamination by means that of various undesirable algal species isn't uncommon.

Hence, while the capital fees for fixing associate open lake algal farm are low, the chance of contamination of the proper algal oil generating species, with the help of invasive species remains high. The contaminants not solely belong to non-organic sources but to boot from the varied biological and completely different alga species that might come back to be invasive.

Contaminants may have an effect on the hydrogen ion concentration and pH scale of social group medium. Principal contaminants that have an effect on the algal cultivation in open ponds are indexed as follows: protozoans completely different algal species—fauna—insects—different organic resources like bacterium, virus and fungi. The result, the enterprise is to confirm careful tradition protection and things that favor the rise of desired algal species over the contaminating species.

Open ponds, massive contaminants are also removed often by means that of golf stroke appropriately sized show within the water glide. Serious contaminants that sink to the lowest is cornered in pits organized at correct angle to the escort the flow and should then be off from those sediment traps. Those area units controlled through effectively operative the tradition widget as a batch tradition and restarting the social group at regular durations with contemporary, algal matter. That's the first system used for the culture of algal in Japan and H. bird genus in Hawaii. Cautious method of life preservation, presenting things that favor the popular species over the contaminating species conjointly permits lengthy-time amount non-stop method of life. Instance, infection of *Spirulina* cultures with alga is also reduced with the help of holding the hydrogen carbonate concentrations on top of 0.2 m and also the hydrogen ion concentration on top of 10 and running at excessive mobile densities [11]. Raceway cultures of *P. tricornutum* have conjointly been maintained with efficiency in labs for additional than 1 year throughout

trials, by method of holding high concentrations of gas and phosphorus. Contamination of *D. Salina* ponds by method of different algal species of *Dunaliella* (e.g.*D. verdict*, *D. parva*, *D. bioculata*) is controlled significantly by protective high salinities.

Tradition renovation requires continuous watching the utmost primary sort of pursuit is that the everyday microscopic examination to observe any eccentric morphological changes and therefore the presence of contaminating organisms inclusive of various algal and protozoa. Habitual checks of nutrient awareness of the pool should even be completed to stay aloof from sudden nutrient deficiencies. Standard pursuit of modifications in pH and O_2 ranges within the pool over the day can even be a helpful early alarm. Pursuit of O_2 and pH has the gain of obtaining the flexibility to be computerized. Recently, a replacement approach, pulse amplitude modulated fluorometry (pam) has emerge on be had and appears to be terribly touchy to deciding the physiological nation of algal [12].

The contamination with totally different alga can be overcome by employing a gradual population build-up of the required organism. Overlaying ponds with clear membranes or the usage of greenhouses overcomes this bother, permitting the additional effective strains to be fully grown freed from part infection.

2.1.2.1.4. Evaporation associated demanding situations

Cultivation in dry, tropical areas is that the excessive value of evaporation from open pool floor (up to 10 l/m^2/day). This poses a problem each from the purpose of skyrocketing the salt attention within the medium and within the acquisition of sufficient water to form up the water loss. Algal cultivation system locations should be selected in one amongst these manners that they need got a substantial offer of water to form up for evaporation losses.

2.2. Closed system

Photobioreactors (PBR) could also be delineated as an internal, lighted culture vessel designed for controlled biomass production. PBR refers to closed systems that area unit closed to the surroundings having no direct exchange of gases and contaminants with the setting. PBRs, despite their costs, have many major blessings over open systems:

- PBRs minimize contamination and allow axenic microorganism cultivation of monocultures.
- PBRs provide higher management over conditions like pH, temperature, light, greenhouse emission concentration etc.
- PBRs lead to less greenhouse emission loss.
- PBRs stop water evaporation.
- PBRs enable higher cell concentrations.
- PBRs enable the assembly of advanced biopharmaceuticals.

Troubles detected in open systems it has been planned the utilization of closed PBRs. The previous further acceptable for strains which cannot tolerate intense environments or once previous product is noticeably at risk of degradation or infection. Closed systems as well permit

the interference of contamination, permitting the operation in issues for PBR vogue and operation for mass cultivation of microalgal culture modes like photoautotrophic, heterotrophic, or mixotrophic. To boot, closed structures will achieve up to variety of instances larger biomass than open structures, consequently lowering harvest fees [13]. Notwithstanding the excellent advances that area unit done inside the assembly and operation of PBRSs, its generation continues to be in improvement. Around ninety-eight of current biomass production international is obtained in open systems, however the actual undeniable fact that PBRS technology provide an excellent deal of potential in phrases of productivity, manipulate of culture conditions, and pertinences to cultivate numerous traces. Numerous closed BPRS styles that operative in laboratory, pilot plant degrees, and even few had been effectively scaled up to associate in nursing industrial degree. Thought of amongst this made closed BPRS design is that the hollow kind, on this the tubes configuration whereby suggests that of life is hold is taken into consideration one amongst the primary factors touching productivity of chemical process biomass [14]. BPRS built with plastic materials like inflexible clear synthetic resin (p.c), polycarbonate flexible plastic baggage, amongst different substances. They're going to be organized in vertical, horizontal, conical, and willing type, with degasifying devices that allow the elimination of the O_2 created at some stage in chemical process [15]. The tubes could also be organized in photoreactors type comparison of individual open lake or closed PBRSS cultivation appliance each, closed PBRS and open raceway lake cultivation semiconductor diode to 3 primary boom cycles and harvest activities.

Handiest biomass incontestable to be rich in lipids becomes harvested pondering the boom curves for closed PBRS and open raceway lake, a doable forth harvest regarded possible whereas mobile concentrations reached a pair of 106/ml at days 28 and 29, severally, however the biomass throughout this excessive irradiation section become not made in lipids and had, consequently, be harvested some days later. The hybrid cultivation machine light-emitting diode to 6 most significant boom cycles and harvest activities. For that reason, the common increase rate of the hybrid system becomes drastically more than that of every widowed structures. The first cause for this appears to be that biomass increase and lipoid induction levels primarily impartial from each alternative whereas the employment of the hybrid cultivation device. This permits to take care of the life-style in speedy boom at awfully high cellular density. As an alternative, microalgal cultures in character cultivation systems (PBRS or open raceway pond) undergo phases of exponential boom and nutrient starvation to allow lipoid accumulation, discovered through a brief lag section before the subsequent growth phase, resulting in diminished typical growth prices. To work out productivity of all structures, biomass harvests (offered as gram/rectangular meter/day).

2.2.1. Tubular (TPBRs)

Tubular PBRs product of clear tube through that the media is circulated at liquid velocities of usually 0.5 m s^{-1} [16]. To prevent high gas concentrations the clear tubes area unit connected to a degasser or stripper vessel, where gas is removed by air injection. Hollow systems are usually found in varied orientations; horizontal tubes organized throughout one plane and multiple planes of vertically stacked horizontal tubes (fence-like systems). Diameters of the tubes vary with system orientation, diameters larger than 3 cm and smaller than 10 cm area unit usually used [17]. Tubular PBRs area unit costlier to construct than open raceway ponds,

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notably vertically minded hollow PBRs. Investment costs for 100 ha horizontal tubular plant were calculable to be 0.51 M€/ha by Norsker et al. [16].

For the selection of a PBR for giant scale production, info on the actual productivity and chemical action efficiency of varied PBR designs is required. Norsker et al. [16] reported outline of chemical action efficiencies obtained with fully totally different reactors, locations and microalgal species; one. You take care of open raceway lake, you take care of horizontal hollow PBRs and you take care of flat panel PBRs [18]. However, for the next comparison of PBR designs information have to be compelled to be gathered at one location with the same microalgal species. Throughout this study, we have a tendency to tend to at identical time compared the performance of pilot-scale out of doors PBRs with *Nannochloropsis* sp. beneath identical climatological conditions at intervals The Netherlands. Four PBRs were place in at the Algal PARC pilot facility; academic degree open raceway pool (OPR), a horizontal annular PBR (HT), a vertical hollow PBR (VT), and a flat panel PBR (FP) [19]. The impact of daily dilution rates and boson flux densities on region productivity and activity efficiency was evaluated for each cultivation system.

2.2.1.1. Helical photobioreactor (HPBR)

HPBR contain of wound clear and versatile tube of very little diameter with separate or connected degassing unit. A pump is utilized to drive the culture through long tube to the degassing unit (**Figure 2**). Travieso et al. [20] technique with fully completely different micro-organism strains. Greenhouse emission gas and matter are circulated from either direction but injection from bottom offers higher natural process efficiency [21]. Tredici and Zittelli [10]

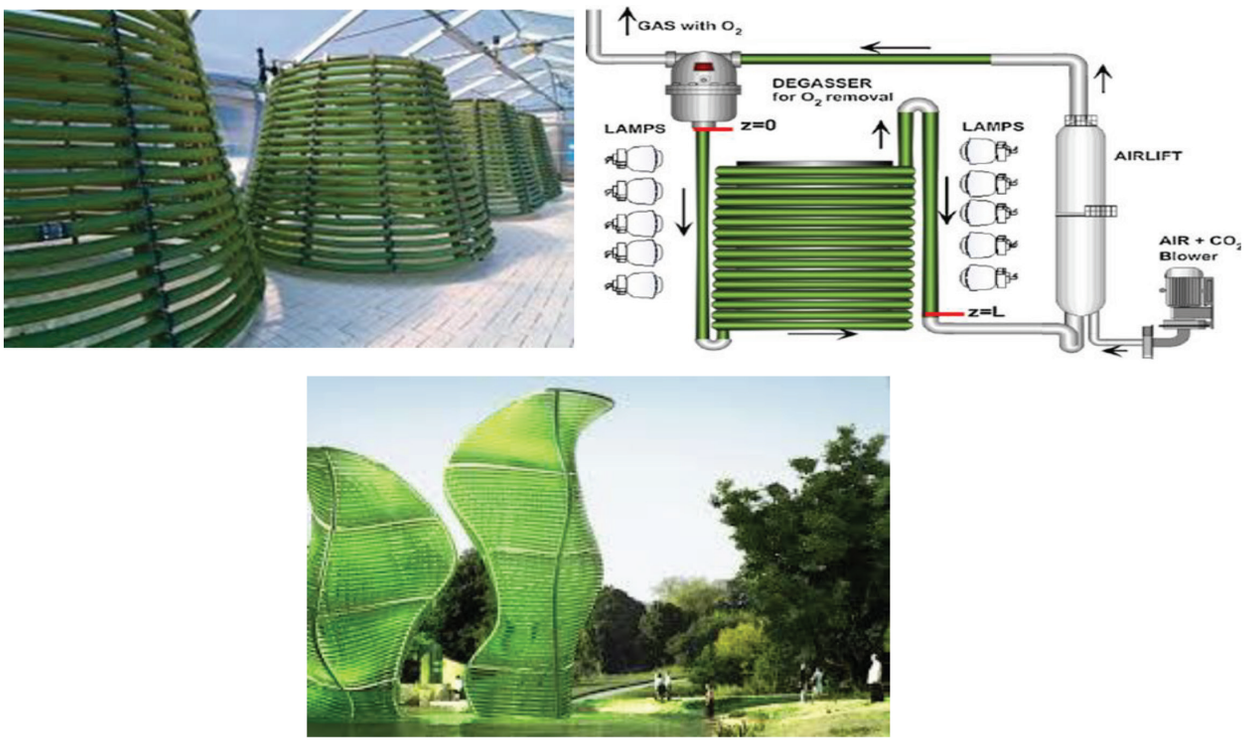

Figure 2. Helical photobioreactor.

designed PVC PBR with 3 cm diameter and vertical structure rigid with 2° with horizontal. It contains a degasser to remove oxygen and gases. Biomass production and photosynthetic potential were found to be 0.9 g L^{-1} d^{-1} and 6.6%, respectively. Light absorption of PVC is important for its higher photosynthetic potential and biomass production. Tredici and Zittelli [10] reported that "the HPBR had surface area to volume ratio of 53 m^{-1} with 23% of total volume was occupied by the gas bubbles" HPBR had advantages:

- Long tubes placed at small rise occupying small ground area,
- Large CO_2 absorption
- Essay scaling-up
- It use a stress limits commercial centrifugal pump [22].

Morita et al. [23] designed a PVC cone shape PBR with angle of 60°, and using air pump for aerated and recirculation of the algal culture, and optimize the temperature by controlling. At angle 60° increase the photosynthetic (6.84%) productivities and biomass productivity.

2.2.1.2. Vertical (VPBRs)

VPBRs are using for outside biomass production, as a result of their giant expanse (**Figure 3**). These PBRs are created from clear VPBRs enable to absorption of the sunshine. The algal media are circulated and aerated with air pump. VPBR**s** are often additional sorted into bubble column and air, based on their mode of algal media flow rate.

2.2.1.3. Horizontal (HPBRs)

HPBRs are the foremost standard PBRs. HPBRs disagree from the vertical tubes in many ways, significantly with tube surface and volume quantitative relation [24]. HPBRs (**Figure 4**) are primarily recognized of tubes organized in multiple potential orientations, like horizontal and helicoidally however all orientations basically add same method. Except for the arrangement

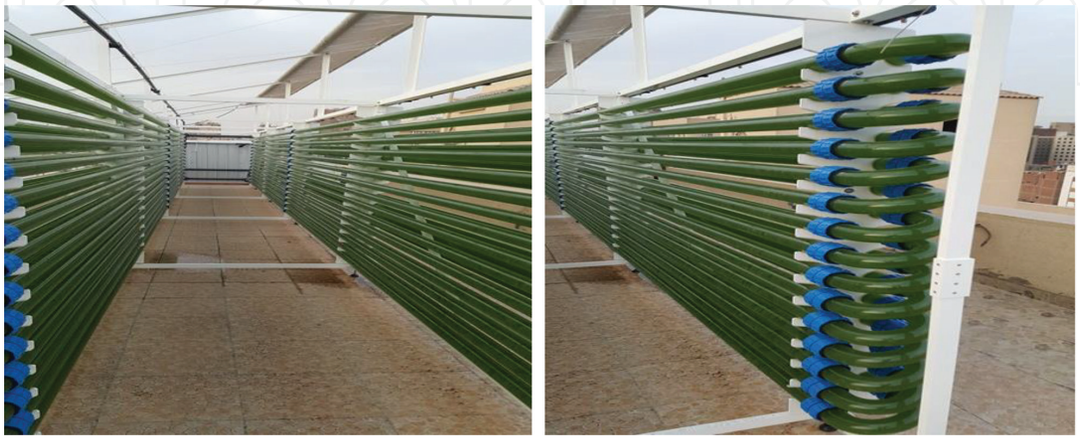

Figure 3. Vertical tubular PBRs.

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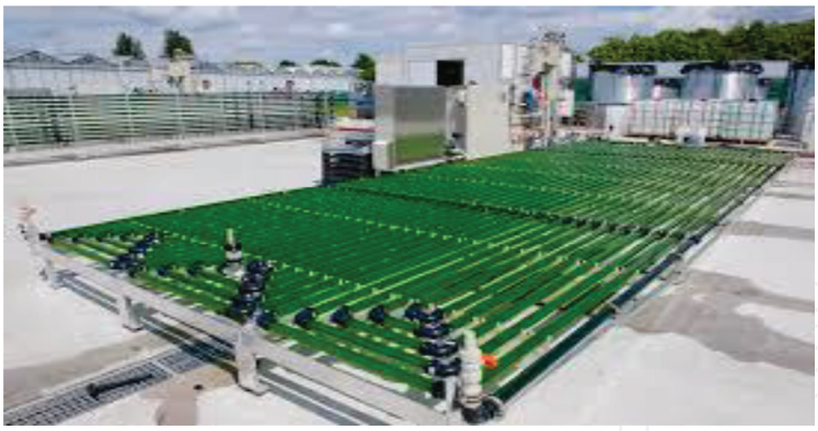

Figure 4. Horizontal tubular PBRs.

of tubes, hollow PBRs disagree within the tube length, flow speed, circulation system, and geometric configuration of the sunshine receiver. Mostly, these tubes have diameters of 10 metric linear unit to maximum 60 metric linear unit, and lengths of up to many 100 m. The utilization of such tubes helps in achieving high surface to volume quantitative relation (above 100/m), that is one amongst them in blessings of this style [25]. Sanchez Miron et al. [24] reported that "the increasing the tube diameter leads to a decrease within the surface/volume ratio, and this issue features a sturdy impact on the culture growth". Moreover, the thus referred to as "lens" or "focusing effect" helps to distribute the sunshine homogenously. In the "focusing effect" the incident light-weight is diluted on the circumference and is, during a radial direction, targeted onto the axis of the tube, so leading to preventing mutual shading and increasing of radiation intensity [25]. One of the main disadvantages of horizontal PBRs includes the buildup of O_2 to repressive levels, oxygen concentrations on top of air usually reduced chemical action in algal strains. HPBRs area unit usually can be the foremost ascendable culture. HPBRs do not seem to be economical possible for giant scale production due to demand of cooling as they need high surface to volume quantitative relation Sanchez Miron et al. [24]. Moreover, picture inhibition due the accumulation of O_2 and high strength leads to reduce production rates.

2.2.2. Flat panel photobioreactors (FPPBR)

FPPBR (**Figure 5**) may be a reasonably common PBR with a rectangular box look that is employed either in algal pure cultivation or alga waste matter cultivation. It can be placed either inside exposed to artificial light weight sources or outside exposed to daylight. Flat panels area unit made by clear or semi-transparent materials (glass, plexiglas, polycarbonate and plastic baggage, etc.). Flat panels have a very-short lightweight path that permits lightweight to easily penetrate the culture liquid. Compounding is principally driven by air bubbles that area unit generated from the air sparser. A pump is typically accustomed supplement air bubbles through the air sparser, current the alga cell suspension. The exhaust gas emission happens at the gas and liquid junction. The reactor is inclined at a precise angle to get the simplest intensity of incident lightweight once the reactor placed outdoors. The main blessings of flat panels include:

a. High surface area to volume ratio

b. Not-too-serious accumulation of dissolved oxygen

c. Convenient to clean

d. The international organization it is versatile and it's suit for scale-up

Meanwhile, the most limitations of flat panel include:

a. It's high-ticket to regulate the temperature

b. Fluid mechanics stress that is generated by aeration

c. Biofoul close to the inner surface

2.2.2.1. Optimizing of PBR growth conditions for a microalgal production

2.2.2.1.1. Major PBR production factors

The following parameters were investigated to optimize the vertical PBR: compounding (intensity of compounding of blending, and mixing pattern), superficial speed, gas holdup, and light-weight availableness. Lightweight availableness within the reactor plays a very important role in increasing the algal density. Lightweight availableness in bubble column is influenced by aeration rates, gas holdup, and liquid speed (mixing and turbulence) [26].

2.2.2.1.2. Light

Light utilization may be an essential issue moving the production of algal biomass. FPPBR area unit usually additional economical in daylight utilization than hollow PBRs as a result

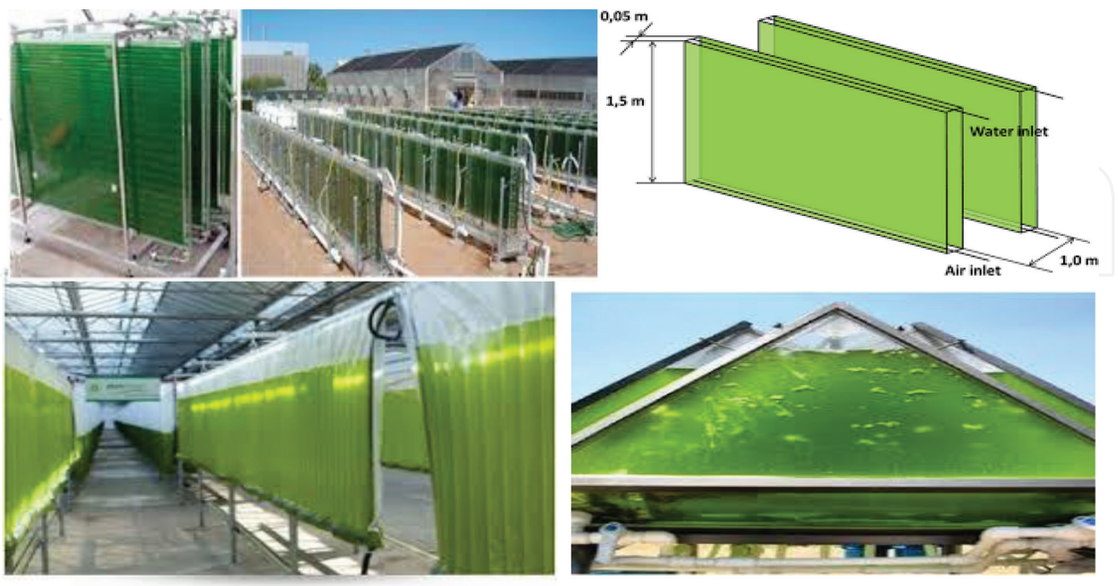

Figure 5. Flat panel photobioreactors.

of they need a wider expanse [10]. Hence, lightweight utilization will be optimized effectively by victimization flat clear panel tubes in numerous configurations and introducing lightweight via fiber optics, and crystal rectifier [27]. Future photo bioreactors have to be improved to realize most chemical action efficiencies near to the theoretical values for achieving higher biomass concentrations with stripped energy and low investment price [18, 28]. The open pond methodology used 1.5 nada alphabetic character with algal productivity 21 ton/ha, whereas hollow PBRs used three nada PE with algal productivity 41 ton/ha and flat panel bioreactor achieved the very best at five nada alphabetic character with algal productivity of 64 ton/ha. This clearly suggests that reducing the light path length (as just in case of hollow and flat panel) is useful for the economical utilization lightweight of sunshine. The orientation of PBRs with relevance the sun is additionally vital, so that the algal receive the utmost quantity of sunshine throughout the day once operated outdoors in step with Sierra et al. [29], for latitudes higher than 35°N the east-faced/west-faced orientation is favorable over north/south orientation. On the contrary, for latitudes underneath 35_N the north/south oriented reactors intercept additional radiation and the distinction is additional pronounced once nearer to the equator.

2.2.2.1.3. Mixing

Mixing keeps algal cells suspended in the nutrient media distribution, and increase gas/liquid/mass transfer to forestall oxygen accumulation, especially in hollow PBRs [18]. The role of blending is suspending algal cells in the sunshine area close to illumination [18, 30]. It will be avoided the harmful effect on the microalgal cells [31]. Mixing effectiveness of makes oxygen transfer in all PBR. There's a general accord that bubble columns and airlift systems supply tight compounding, with low shear stress. However, the sparger and baffles troublesome to clean and repair as a result of baffles connected directly with the reactor wall and hollow fibers gift in sparger create a high risk of biofouling. Circulation is another way to ensure good mixing. Masojidek et al. [32] reported that "the applied a peristaltic pump as circulation equipment to cultivate *Spirulina platensis* and obtained a cell productivity of 0.5 g/L/day, that was thought-about a comparatively high worth by the authors". Ferreira et al. [33] reported that "the utilized three completely different systems for cell circulation, specifically associate in nursing airlift, a motor driven pumping, and a pressurized system, and all over that the normal airlift system might be substituted by the other systems to cultivate *Arthrospira platensis* in hollow PBRs".

2.2.2.1.4. Economics

The PBRs cost is the man influence factor on cost for large scale biomass. The reduction of the PBR value reduced the biomass cost. Acien et al. [34] reported that "the ways to reduce value depends on the sort of algal strain, the sort of PBRs, and therefore the production technology of the biomass". The major value factors square measure irradiation conditions, mixing, photosynthetic potency of the alga, the medium and carbon-dioxide prices. The connectedness consider reducing the cost of PBR is that the consumption of raw materials. The CO_2 is the costliest expendable in production of biomass. Using flue gases from industrial sources

will scale back the cost of greenhouse emission to values as low as zero if flue gases square measure readily on the market [34]. Acien et al. [34] said "that "the bottleneck for the low cost production of microalgal is to develop a lot of productive PBR systems".

3. Conclusion

Production of microalgal at large scale is needs high giant investment and operational prices. The use of open ponds, like raceway ones, may be cheaper to create and operate than other methods, but need giant land area. On the other hand, the restrictions condition for operation of open ponds, such as high condition for temperature limitations, and light intensity, it's value lead to accentuate the efforts in developing outside PBRs. Many research has been done to develop PBRs for protects cultures from contamination, enhance PBRs technologies and enhance mass production. Also, from the economical PBRs view point, the major concerns developing new design of PBRs model have clear and high illumination surface, thus use low energy input and utilizing maximal solar energy. The good PBR models, should be possess high mass transfer rates and high biomass yields within short time of incubation. Other factors like sort of strain, the target product, geographical location, and cost of production are required.

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Conflict of interest

Authors declare no conflict of interest.

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