INTRODUCTION AND SUMMARY

As we observe the advancements in technology, it is evident that microalgae have emerged as a promising solution for sustainable energy. Their exceptional ability to convert sunlight into valuable biofuel has garnered significant attention. One notable invention contributing to this pursuit is the photobioreactor, which creates an optimal environment for microalgae cultivation and facilitates the production of large quantities of biomass. These innovative reactors efficiently harness solar radiation, enabling higher productivity compared to traditional open ponds. The significance of microalgae extends beyond biodiesel extraction, encompassing their potential as sources of other valuable products such as proteins, omega-3 fatty acids, and pigments.

Additionally, the photobioreactor-based production of microalgae has a number of environmental advantages, including the treatment of wastewater and the sequestration of carbon dioxide. Analyzing the value of microalgae has great potential for reaching sustainability goals and diversifying our energy sources, although there are still limitations that need to be overcome, such as cost-effectiveness and scalability of photobioreactor technology. In addition, microalgae's capability goes beyond its capacity to generate high-end goods and positive effects on the environment. These tiny organisms can be extremely important in addressing issues with nutritional safety. Microalgae can be grown as a sustainable source of wholesome nourishment for both people and animals because of their capacity to grow quickly and prosper in a variety of environments. By utilizing their nutritional value and incorporating them into our dietary routines, we could potentially diminish our reliance on conventional food sources and encourage a more resilient and sustainable food system.

Microalgae use in photobioreactors has been identified as a promising approach to help achieve the objectives of sustainable development. Microalgae are photosynthetic microorganisms that can fix carbon dioxide and turn it into useful goods like biofuels, dietary supplements, and medicines. These tiny organisms thrive in controlled environments when grown in photobioreactors, efficiently utilizing nutrients and sunlight while minimizing environmental effects. Regarding our patented Photobioreactor (PBRC) design, which is a technique and apparatus used to cultivate microalgae continuously and effectively separate their oleic and protein components bypassing the limitations from the other methods of cultivation. The process of microalgae cultivation, its value, characteristics of microalgae, the types of methods currently being used for cultivation, and what limitations do companies and industries face in such process, is covered in this detailed study.

When considering the Photobioreactors, there are some restrictions to be taken into consideration. This method and the implementation of device brings us back to phase one by determining the production, cost, and resourcefulness. One could think about using renewable energy to get around these restrictions, but resources are still needed to create photobioreactors that could grow a lot of microalgae for use. However, this specific design cultivates a tiny number of microalgae continuously, from which protein and oleic can be extracted. The development of this design opens up many opportunities for the appropriate cultivation of microalgae and will support a greener environment.

This technology has enormous potential for addressing major global issues like food scarcity, energy security, and climate change. Microalgae provide a sustainable way to lower greenhouse gas levels by capturing carbon dioxide emissions from industries and reducing their release into the atmosphere through photosynthesis. Additionally, because of their rapid biomass production for the production of renewable biofuels, they help to reduce reliance on fossil fuels. Additionally, functional foods and dietary supplements made from microalgae offer an alternative source of proteins and essential fatty acids without putting a strain on the water or land resources needed for conventional farming methods. Overall, incorporating microalgae with our patent photobioreactor continuous offers versatile solutions that promote cleaner energy sources, mitigate the effects of climate change, and improve food security globally.

Let us explore more extensively into microalgae cultivation as a viable energy solution, how Photobioreactor continuous (PBRC) adds value in encouraging cleaner energy sources, and how application of this device can help obtain a cost-friendly and eco-friendly solution to the cultivation of microalgae.

1. INTRODUCTION TO MICROALGAE

Due to their distinctive characteristics and potential uses, microalgae, a diverse group of microscopic organisms, have been capturing a lot of attention lately. These tiny organisms, which tend to thrive in freshwater and marine environments, are vital in multiple facets of the economy, including agricultural commodities, pharmaceuticals, biofuels, and bioremediation. Among the many advantages of microalgae are their high nutritional value, capacity to make biofuels, and effectiveness in removing pollutants from wastewater. However, knowledge of the environmental elements that affect microalgae's growth as well as the use of particular strategies and techniques are necessary for their successful cultivation. This article examines the cultivation of microalgae, going in-depth on their uses, environmental needs, cultivation methods, biomass harvesting and processing, chances for commercialization, difficulties, and prospects for the future.

Let's pause to admire microalgae, the barely noticeable aquatic superheroes. The term "microalgae" refers to microscopic algae that can be found in both freshwater and saltwater environments. They are singlecelled organisms that use the process of photosynthesis to turn light energy and nutrients into energy. These amazing organisms come in an array of hues, from vivid green to calming blue, and they are essential to the ecosystem because they produce oxygen and provide food for many marine animals.

THE APPLICATIONS OF MICROALGAE IN NUMEROUS INDUSTRIES

Even though microalgae are tiny, their influence is enormous. Due to their remarkable characteristics, these little powerhouses have attracted interest from a variety of industries. They are frequently utilized in cosmetics, pharmaceuticals, and even as a food source. Certain microalgae species are a desirable option for dietary supplements and functional foods due to their high protein content. Microalgae have also been taken into account for the production of biofuels because they are effective at converting carbon dioxide and sunlight into lipids that can be converted into biodiesel. Overall, these amazing microorganisms are paving the way for creative and long-lasting solutions across many industries.

Microalgae can be used as a renewable energy source in a variety of industries, which is one of their most promising applications. Due to their exceptional capacity for photosynthesizing and converting light energy into biomass, microalgae have a high potential for producing significant quantities of algal biomass that can be used for energy production. By converting this biomass into biofuels like biodiesel and bioethanol, we can lessen our reliance on fossil fuels and cut down on greenhouse gas emissions. Due to their ability to consume CO2 during growth and their capacity to remove pollutants from effluents, microalgae can also be used in other energy-intensive industries like wastewater treatment facilities and power generation facilities. Additionally, because microalgae require less land than traditional crops do, their quick rate of growth makes them a very appealing option for the production of sustainable energy. Overall, the use of microalgae for the production of algal biomass holds enormous promise for transforming numerous industries by offering a reliable, efficient source of renewable energy.

2. MICROALGAE BENEFITS AND APPLICATIONS

Nutritional Value and Human Consumption

Microalgae are the newest popular superfoods, so say goodbye to quinoa and kale. When it comes to nourishment, these little creatures are incredibly potent. Essential amino acids, vitamins, minerals, and antioxidants are abundant in some microalgae species. They are a particularly good source of the heart- and brain-healthy omega-3 fatty acids. Microalgae have the potential to be produced on a huge scale, making them a sustainable and wholesome food source for a growing world population.

Although microalgae have a taste somewhat akin to grass, they could be used as a source of energy for our cars. Microalgae-based cellular agriculture has been identified by researchers at an Australian university as a novel and potentially sustainable method of producing healthful "superfoods" and plant-based "meat" in the future.

Microalgae have been extensively researched for the manufacture of biofuels because of their high lipid content. These small creatures can produce oils that can be used to make biodiesel when grown in big amounts. Microalgae are a more environmentally responsible and sustainable alternative to conventional biofuel crops since they may be cultivated in locations where food crops cannot.

Although these microbes are tiny, they are excellent cleaners. Bioremediation, the process of utilizing living organisms to remove or neutralize toxins from the environment, has been carried out using these little green machines. Microalgae may detoxify and absorb a variety of toxins from contaminated water sources, including heavy metals and organic chemicals. They can also be used to treat and clean water in wastewater treatment facilities before it is discharged back into the environment. As a result, the next time you see a patch of brilliant green algae in a filthy pond, be aware that it is doing its lot to keep the environment clean.

Microalgae like chlorella and spirulina are very good at absorbing nitrogen and phosphorus, which are frequent water contaminants that cause toxic algal blooms and eutrophication. Microalgae's development is accelerated while the number of contaminants in the water is decreased when wastewater rich in these nutrients is provided to them. Additionally, by using biosorption processes, microalgae effectively remove heavy metals and organic substances from the water by attaching them to their cell walls. Furthermore, some types of microalgae contain extremely active enzymes that, via a process known as biodegradation, convert complicated organic molecules into less complex ones that can be quickly broken down by bacteria or other microbes. Therefore, using large-scale microalgae growth systems shows significant promise in treating contaminated water sources, providing an environmentally acceptable method for water filtration while utilizing the potential of these tiny organisms for sustainable resource management.

Additionally, the production of microalgae can be extremely important in reducing greenhouse gas emissions and halting climate change. Microalgae serve as organic carbon sinks by absorbing carbon dioxide from the environment and releasing oxygen when they photosynthesize. This procedure improves air quality while also assisting in the reduction of this strong greenhouse gas. Additionally, microalgae's biomass can be used as a renewable energy source. Microalgae may be transformed into biofuels like biodiesel or biogas through pyrolysis or anaerobic digestion, offering a sustainable alternative to fossil fuels. This lessens reliance on non-renewable resources and also aids in lowering carbon emissions linked to the generation of conventional energy.

3. Environmental and Financial Elements Affecting Microalgae Cultivation

Microalgae depend entirely on sunshine to survive, just like plants. Since light is the primary catalyst for photosynthesis, light is an essential component in the growth of microalgae. The rate of development and lipid production of microalgae can be greatly influenced by the amount and length of light exposure. Optimizing microalgae cultivation and increasing output require finding the ideal balance between light intensity and photoperiod. Therefore, you might say that having a positive outlook is a necessity when it comes to microalgae farming.

Despite their small size, microalgae are heat-sensitive. Due to the fact that different species of microalgae prefer particular temperature ranges, temperature is crucial to their growth. Temperature extremes can be stressful and possibly result in cell death or reduced development. For each strain of microalgae, it's critical to determine the temperature that falls into the Goldilocks zone. As a result, microalgae prefer a cool environment that's not too cold.

The availability and makeup of nutrients are also important factors in microalgae cultivation and have a big impact on growth rates and the lipid production of the microalgae. For their growth, critical nutrients including nitrogen, phosphorus, and potassium are required. A thriving microalgae production and a subpar one can be distinguished by striking the proper balance and offering the required nutrients in the proper amounts. It's like being a chef, but instead of producing a delicious dish, you get to take home a thriving microalgae farm.

Microalgae farming is heavily impacted by a number of economic factors. First off, establishing a facility for the growth of microalgae can need a sizable initial expenditure. This introduces the price of investing in machinery like photobioreactors, bioreactors, and harvesting systems as well as the expense of building specialized infrastructure for optimum growth conditions. In addition, a key factor in the cultivation of microalgae is operating expenses.

Not to mention the costs entailed to purchasing and keeping up-to-date strains of algae from pond water, rivers, and lakes, supplying sufficient nutritional inputs, assuring effective light sources and control systems, keeping track of water quality parameters, and carrying out routine analytical tests to assure optimal growth. The financial feasibility of microalgae cultivation is also heavily dependent on labor expenses. A skilled workforce is required to manage the numerous facets of algae production, such as biomass harvesting and downstream processing for value-added products like biofuels or dietary supplements. Lastly, market variables such as fluctuating customer demand for items made from microalgae and competition from different suppliers of raw materials or finished goods have an impact on the overall profitability of microalgae-based firms. In the microalgae sector, effective planning and execution depend greatly on a grasp of these financial factors.

Costs for sustaining ideal growth conditions, such as nutrient supplementation and quality assurance, can mount up quickly. Further improvements in microalgae production are hampered by these financial obstacles that make it difficult for academics, business owners, and even established firms to enter the industry. Furthermore, the scalability of microalgae culture is constrained by its high cost. The ability to produce microalgae on a commercial scale is still constrained by a number of issues, despite technical developments aimed at lowering prices. For instance, compared to other crops, the yield per unit area is relatively low, necessitating bigger cultivation areas to produce commercially feasible quantities. Furthermore, the price of harvesting and processing microalgae can be prohibitive, especially for uses like the extraction of nutraceuticals and the generation of biofuels. These restrictions prevent microalgae production from being widely used as a sustainable and profitable solution for several businesses.

4. HARVESTING AND PROCESSING MICROALGAE BIOMASS

In order to concentrate the microorganisms while limiting energy and expense inputs, efficient separation procedures are needed while harvesting microalgae biomass. Filtration, flocculation, centrifugation, and sedimentation are typical processes. While filtration requires sieving via membranes to remove bulk water, centrifugation uses centrifugal force to separate denser microalgae from the liquid medium. Flocculation, which entails the injection of a chemical agent that groups microalgae into bigger particles, makes subsequent separation easier. Gravity is utilized by sedimentation to cause the microalgae cells to settle. However, because each approach has specific advantages and disadvantages, a mix of techniques is frequently used to get the best harvest efficiency.

Microalgae are mostly processed using the wet and dry methods after being harvested. When microalgae are in a liquid form, wet processing is used to disrupt them and extract important components. This is commonly done using methods including sonication, high-pressure homogenization, and enzymatic treatments. Lipids, pigments, and proteins can be extracted using this technique and used to create nutraceuticals, biofuels, and other goods with added value. In contrast, dry processing uses methods like spray drying, freeze drying, or pneumatic drying to extract moisture from the biomass.

Sedimentation and Flocculation

Water treatment techniques such as sedimentation and flocculation are essential for eliminating suspended particles and pollutants from water sources. These particles settle under the effect of gravity during sedimentation, separating from the water due to their size and density. The inclusion of chemicals known as flocculants, however, which enable tiny particles to aggregate into bigger clumps known as flocs, aids flocculation improves this settling process. After that, during sedimentation, these flocs sink more quickly, assisting in the removal of turbidity and other undesirable materials. Water treatment facilities can successfully attain the appropriate quality requirements and make a contribution to preserving public health and environmental sustainability by comprehending and maximizing these systems.

Filtration and Centrifugation

In many scientific domains, filtration and centrifugation are two crucial separating processes. In filtration, a porous substance called as a filter is used to separate solid particles from a liquid or gas. Smaller particles pass through the filter while larger ones are held using this technique, which is dependent on the size and shape of the particles. Centrifugation, on the other hand, uses the concepts of density and centrifugal force to separate components according to their various densities. When a combination is spun at a fast speed, the less dense materials stay at the top while the denser particles move to the bottom, forming a pellet.

Drying and Extraction Methods

The obtained microalgal biomass should effectively be dried without losing its biochemical makeup in the process. Techniques that are frequently used include sun drying, freeze drying, and spray drying. Through the atomization of the biomass into tiny droplets and subsequent exposure to hot air, spray drying allows quick water evaporation, culminating in the creation of dried powder. By first freezing the biomass and then sublimating it under lower pressure, heat-sensitive chemicals can be preserved without losing their integrity. Sun drying is a low-cost and energy-efficient technique that uses solar radiation to naturally evaporate moisture, however it takes longer to complete. Following that, other solvent-based procedures, such as Soxhlet methods or supercritical fluid extraction, are used to extract the desired chemicals from dried microalgae, ensuring a high yield and purity of the end products. In order to maximize productivity while keeping the bioactivity of microalgal-derived compounds in industrial applications, careful drying and extraction procedures must be chosen.

5. TECHNIQUES AND METHODS FOR MICROALGAE CULTIVATION

Open Pond Systems

A popular technique for growing these tiny organisms is the open pond cultivation method for microalgae. In open-air ponds, microalgae are grown using this conventional method. Open ponds are the systems currently employed on an industrial basis. They typically have relatively simple designs. These tanks are typically underground, with a wide surface area and a depth of up to 0.5 meters, and they are mechanically churned using a paddle agitator. Through straightforward diffusion, carbon dioxide is immediately taken in from the atmosphere. This technological solution has the benefit of being simple and affordable to build, but it has disadvantages as well, such as high-water losses due to evaporation, low biomass yield, and limited opportunities for cultivating particular species of algae that are vulnerable to various parasites, infections, and diseases. To assist the development of microalgae, these ponds frequently contain fertilizers like nitrogen and phosphorus. This approach is still being investigated and improved upon by researchers in order to make full use of its future potential and get beyond its drawbacks.

Closed Photobioreactor Systems

In the field of growing microalgae, closed bioreactor applications have become a game-changing invention. Compared to conventional open pond cultivation techniques, these cutting-edge systems have many advantages. Closed bioreactor systems give precise control over factors affecting the environment like temperature, light intensity, and supply of nutrients, enabling the maintenance of ideal growth conditions. Furthermore, they shield the microalgae culture from outside contamination, ensuring its purity. Due to their capacity to maximize light utilization and enable effective nutrient uptake, these closed systems also have the benefit of increased efficiency and biomass concentration. Closed bioreactor systems lessen the amount of land and water needed for microalgae cultivation while also lowering the carbon footprint. Overall, the application of closed bioreactor systems heralds a major milestone in the production of microalgae, with considerable promises of increased productivity, efficiency, and environmental sustainability.

Mixotrophic Cultivation

Microalgae occasionally choose to be able to photosynthesize and ingest organic carbon sources. Mixotrophic cultivation can help with that. In this technique, organic carbon substances like glucose are combined with light energy and given to microalgae. It offers an appealing alternative for large-scale cultivation since it permits improved growth rates and lipid production.

In conclusion, microalgae are remarkable organisms with a wide range of purposes. These little beacons are causing a stir across a range of industries, thanks to their nutritional value, potential for biofuel production, and wastewater treatment capabilities. However, careful consideration of environmental aspects including light, temperature, and nutrient availability is necessary for effective microalgae development. Finding the correct method is essential for maximizing the potential of microalgae, whether it be through open pond systems, closed photobioreactors, or mixotrophic cultivation.

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7. USE OF PHOTOBIOREACTORS IN THE GROWTH OF MICROALGAE

The most potential technological advancement for the development of third generation biofuels now being researched and developed are photobioreactors. Photobioreactors allow crops to grow uncontaminated, in contrast to outdoor systems. Photobioreactors provide a promising solution for a variety of industries, including biofuel generation, wastewater treatment, and pharmaceutical discovery, by utilizing light energy and photosynthetic bacteria. Using this technology, it is possible to grow and cultivate microorganisms that photosynthesize in a controlled setting, including microalgae and cyanobacteria. These reactors supply the right lighting, temperature, and food availability for healthy growth. Utilizing these microbes' photosynthetic powers in photobioreactors will enable the production of useful goods including biofuels, medicines, and food supplements. Ancient civilizations that cultivated microalgae in ponds and other shallow structures for food and fertilizer are where photobioreactors first emerged. However, more advanced photobioreactors didn't start to appear until the middle of the 20th century. In order to address the issues of pollution and unstable conditions in open ponds, closed-system photobioreactors were developed with improvements in technology and our understanding of the development of algae. Photobioreactors provide a sustainable and effective method for producing renewable fuels like biodiesel and bioethanol in the biofuel sector. In addition, the use of photobioreactors for the sewage treatment, carbon dioxide sequestration, and even as potential sources of protein for livestock nutrition is being researched.

Since the culture is not in close contact with the environment and gas exchange with the outside environment takes place through sterilized filters, the risk of contamination is greatly diminished in photobioreactors, which are typically defined as closed lit vessels. In addition, this configuration results in less CO2 and water loss during the process, and overall productivities are significantly greater than in an open system. PBRs come in a variety of forms with numerous ways to categorize them. In this section, they are split into two groups: conventional PBRs, which are the most well-known and traditional, and the so-called unconventional PBRs, which have radical designs and have only been employed up to this point in laboratory settings.

7.1 Conventional PBRs

Stirred Tank PBR

A complex device used to grow algae or other microorganisms in a controlled environment is a stirred tank photo-bioreactor (PBR). The continual stirring of the culture medium is essential to a stirred tank PBR's operation because it ensures enough mixing and exposes microorganisms to light, nutrients, and gas exchange. A cylindrical vessel with an impeller that creates turbulence to preserve homogeneity inside the reactor normally makes up a PBR. Light is produced either internally by light-emitting diodes (LEDs) or externally through optical fibers. Nutrient supply is regulated by carefully controlling the composition and flow rate of the culture medium. Furthermore, gas exchange occurs through sparging air or carbon dioxide into the reactor, enabling photosynthesis by providing carbon dioxide and oxygen removal. This efficient mixing system supports high cell growth rates while achieving optimal conditions for biomass production in various applications such as biofuel production, wastewater treatment, and pharmaceutical synthesis.

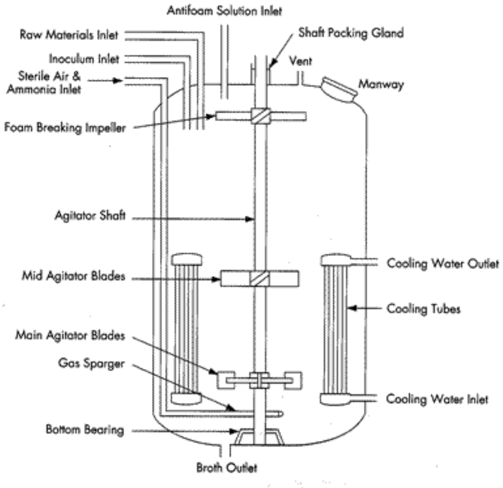

Figure 1. *fig.1.1 A schematic diagram of a stirred tank bioreactor. Adopted from NCBC 22*

fig.1.1 A schematic diagram of a stirred tank bioreactor. Adopted from NCBC 22

Axial, radial, or mixed agitation is carried out mechanically in stirred tank PBRs using one or more impellers that can have various sizes and shapes, ranging from lab scale up to 250 L [20]. Primary benefits of stirred tank photobioreactors are their ability to assure effective heat and mass transmission, as well as uniform nutrient dispersion, when the stirring mechanism is at its best (Sero et al. 2019). However, this kind of bioreactor also has a number of drawbacks, including a high-power requirement, significant shear, and issues with sealing and shaft stability in tall bioreactors. Due to such limitations, the cultivation of microalgae comes with challenges which can be difficult to overcome during more frequent extractions.

Flat Panel Photobioreactor

A common reactor form for the bulk production of several algae species, flat panel photobioreactors provide significant benefits for the large-scale production of photoautotrophic microorganisms. It is made out of a flat, rectangular chamber with a see-through window that enables visual observation of the inner culture. The movement and exchange of nutrients and waste materials constitute the fundamental

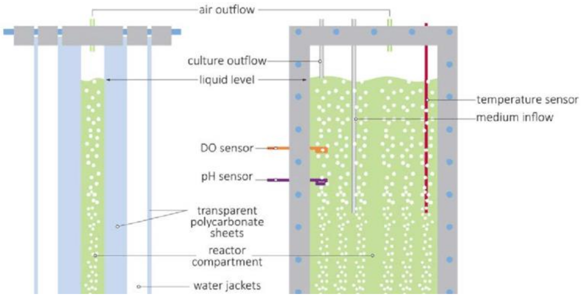

Figure 2*. A flat panel photobioreactor (Singh and Sharma, 2012)*

operating basis of it. Through an inlet port, and a rich source of medium containing vital growth ingredients and oxygen is continuously pumped into the chamber. While preserving the ideal pH and temperature, this medium encourages cell growth and metabolism. The panel alignment, which can be horizontal, vertical, V-shaped, slanted, or in an accordion configuration, must be considered when constructing a flat panel PBR. In every case, the goal aims to optimize photosynthetic efficiency while also accounting for the balance between it and the area required to set up the PBR and the potential photoinhibition, which is in fact the main drawback of a flat panel to produce large amounts of biomass (Sero at al. 2019). The first flat plate reactors were built in the early 1950s. Samon and Leduy employed flat, transparent plates that were lit from both sides and agitated with aeration. This concept was proposed by Tredici and Materassi, who suggested a stiff alveolar panel (E. Sierra, 2007).

Shading and light rays passing through the panels have a significant impact on the biomass output in parallel flat panels. A revolutionary vertical flat panel photobioreactor design has been presented to reduce the overall cost of the equipment. It consists of a transparent bag, such as plastic, mounted on a sturdy frame. The economic viability might be improved as a result (Yen and others, 2014). Brief descriptions of several distinct flat panel photobioreactor designs are provided by Singh and Sharma (2012). Barbosa and others (2005) constructed a flat panel out of a polycarbonate sheet bonded together with stainless steel. While its application brings a number of benefits like high biomass production and easier sterilizing, and low oxygen build-up, it has its own limitations where Flat Panels make it difficult to control temperature. The installation of this PBR requires many compartments and support materials.

7.2 Unconventional PBRs

Hybrid Photobioreactor

In order to create an ideal setup capable of generating high biomass, good oil production yields, decreased energy consumption, and economic sustainability, hybrid photobioreactors integrate various systems,

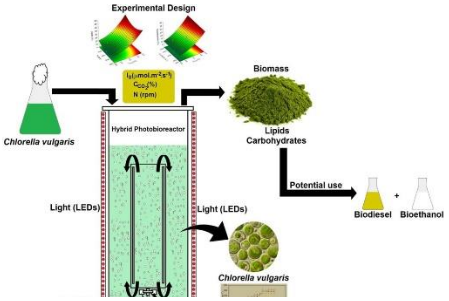

Figure 3.*biomass cultivation shown from Hybrid Photobioreactor.*

which include open and close configurations, or membrane set-ups. To ensure that there is no contamination during the initial closed PBR exposure, maximal production is permitted. The microalgae are subjected to severe conditions in an open system after the required biomass concentration is produced to produce the desired metabolites and lipid products. In comparison to an ordinary open system, illumination and gaseous feed are improved. Due to the large interfacial area that the membrane provides, this form of PBR's principal benefit is its good gas dispersion; nevertheless, these systems are also very permeable to water vapor. Correct equipment selection, control of operating factors, and selection of a culture medium with a high cellular yield are all problems that must be overcome in this particular cultivation method. In general, the expenses and technological difficulties associated with producing biofuel from microalgae biomass are higher than those associated with cultivating crop cultures (Alam et al., 2012).

In Figure 3. Biomass cultivation is shown via this experimental design of Hybrid reactor and the potential it possesses to produce biodiesel and bioethanol. Open-culture systems are often straightforward, require little maintenance, and have cheap operating and energy expenses. The lack of control over water temperature, evaporation, illumination, and low-efficiency CO2 consumption results in low productivity and low biomass concentrations, but they are also more susceptible to weather conditions. Additionally, depending on the medium used, there is a significant risk of culture contamination by other microalgae, bacteria, or even fungi as they are exposed to the atmosphere (Xu et al., 2009).

Large-scale industrial application of this technology may face difficulties due to its complex layout and high capital cost. A gas-liquid contact in the reactor may also cause foaming problems that call for extra control techniques. The complicated flow patterns and multiphase nature of this type of bioreactor can make it challenging to adequately simulate its dynamic behavior. In addition, scaling up the stirred airlift hybrid bioreactor is tough since dealing with higher quantities makes it difficult to maintain continuous operating conditions.

Pyramid Photobioreactor

One of the most recently developed methods for growing algae is the pyramid PBR. Their unique acrylic pyramid design, which enables adding external and/or internal illumination to provide an effective light capture while also keeping a high level of light intensity for the best possible production rate, distinguishes them. They are entirely automated and an airlift system is used to mix the fluid (Dan Kopec & Arsénio, 2020). The fact that pyramid photobioreactors require less space to install than other PBRs may be their principal advantage. These PBRs are, regrettably, still at the experimental stage. Therefore, additional research is required to improve optimization and to assess the design's scalability and economic sustainability. Pyramid photobioreactors' capacity to maximize light availability for microorganisms, optimizing their development potential, is one of their most notable advantages. The biofilm is exposed to more light by shining sunlight through several layers of translucent materials such as plastic or acrylic, which boosts photosynthetic activity. Higher microalgae concentrations and subsequently higher biomass output are made possible by this feature. Pyramid photobioreactors are also excellent for large-scale production within constrained land areas due to their modular design, which maximizes space usage (Z Khoobkar & A Safekordi, 2019).

Figure 4*Experimental set-up of novel pyramid photobioreactor*

In Fig. 4 the schematic illustration of the PBR pyramid as it was built is shown. There are, as can be seen, 12 distinct sections: A power supply unit that can change the voltage and ampere of light sources to ensure that all light sources have the same number of photons.

Despite its many advantages, the pyramid photobioreactor has certain drawbacks. Maintaining a consistent light dispersion throughout the inner layers of the pyramid is one of the fundamental concerns.

Decreased irradiance towards the lower part of the spectrum occurs as a result of the light gradually weakening as it passes through the biofilm. This may result in an uneven development pattern, which would compromise the reactor's overall production. Pyramid photobioreactors can also be expensive to build and maintain since they require specific materials to ensure optimal transparency and insulation, along with a precise monitoring system for temperature and nutrition supply. For the microbes to thrive, this sensitivity may result in considerable changes in biomass output, needing continuous monitoring and adaptation. Pyramid photobioreactor effectiveness can also be impacted by the particular microalgae strains utilized, as some may need various lighting and nutrition amounts.

7.3 Photobioreactor Continuous and Batch Operation Bioreactors

Continuous operation bioreactors, used media is continuously removed and new nutrients are continuously added. This permits a steady flow of nutrients, ensuring ideal circumstances for cell growth. In contrast, a single addition of nutrients and media is made to a batch operation bioreactor at the start of the process, following which the system is left unmodified until the finish. In batch reactors, the culture is grown until it reaches the appropriate level of development or product creation, at which point the entire culture is harvested, and the bioreactor is cleaned and sanitized before beginning a new batch.

The capacity to maintain a steady-state condition, which enables consistent and predictable output rates, is one important benefit of continuous operation bioreactors.

Photobioreactors may run continuously or intermittently. Using photobioreactor continuous (PBRC) as opposed to batch bioreactors has a number of benefits (Williams, 2002). Growth rates in PBRC can be adjusted and kept constant for a longer period of time, and biomass concentrations are controlled by varying the dilution rate. Results prove more reliable and easily reproducible thanks to the constant state of continuous bioreactors, and quality of the desired outcome can be obtained more easily. Continuous reactions offer numerous possibilities for investigation and sizing. The length of time needed for product production is another diverse characteristic. The residence duration is often shorter in continuous operation bioreactors, leading to a quicker production cycle. When working with products that have a brief half-life or are time-sensitive, this is very useful. On the other hand, batch operation bioreactors permit longer cultivation times, which may be required for the creation of complicated or sensitive products that demand exact control over growing conditions. The inoculation stage is the continual technological procedure of a photobioreactor. In this stage, a chosen strain of microbe is added to the bioreactor, which has a culture medium full of growth-promoting nutrients (GP Prpich & A.J. Daugulis, 2005). To maximize production, the procedure should start with a high concentration of microorganisms.

The bioreactor is normally maintained at a particular temperature and pH after inoculation to provide the best conditions for growth.

The cultivation stage, which comes after the first, sees the algae or microbes expand exponentially. Systems of illumination are used to produce enough light and simulate the circumstances found in nature that are necessary for photosynthesis. To maintain ideal growth rates and optimize output, careful monitoring and regulation of temperature, pH, and nutrient levels, including carbon dioxide and nitrogen, are essential. In order to avoid overcrowding and nutrient depletion, the bioreactor is continuously topped off with fresh culture media throughout this phase (A.P. Peter & A.K. Koyande, 2022). Harvested biomass is also continuously removed. The procedure also includes harvesting the biomass and downstream processing. Different methods, including centrifugation, filtering, and sedimentation, can be used to harvest the microorganisms. The biomass is subsequently processed to extract the required component or product after being separated. Methods specific to the intended use may be used for cell destruction, extraction, and purification. Sustainability is further ensured by the proper treatment or recycling of any trash produced during this procedure.

8. Photobioreactor Continuous (PBRC)

Photobioreactor that is the subject of this study is given the name Photobioreactor Continuous (PBRC) precisely because the production process and cultivation of microalgae from this reactor is continuous, and it will be abbreviated PBRC from here on out. The PBRC holds close similarity in terms of design to a Imhoff tank, which is fundamentally made of a sizable watertight container made of vibrated reinforced concrete (parallelepiped), however, the PBRC is built differently. In comparison to other bioreactors there are several limitations that restrict solution to easier mass cultivation of microalgae in which one of them is the cost and usage of energy utilized by photobioreactors. Using fossil fuel as energy source for cultivation is strongly deterred as the world is already suffering from effects of climate change. Hence, PBRC replaces fossil fuels with other renewable energy sources which could be more compatible with the environment. The objective is to obtain dry substance concentrations high enough to justify the high extraction expenses. The decision to shift algal mass, which is a process holding high energy consumption, results being another limitation for actual plants.

The PBRC is a closed system and, similar to current closed photobioreactors, it offers advantages over open systems, including more control over the conditions and growth factors of the culture, higher microalgal densities, higher volumetric productivity, a decrease in microbial contamination, improved photosynthetic efficiency, and less room occupied.

Prepared below is a detailed insight on PBRC, the purpose of said device, its method, and the how it performs differently from other bioreactors in terms of microalgae cultivation to obtain synchronized separation of protein and oleic. This chapter will also discuss how this device is makes use of less space and how it uses renewable energy for its operations rather than relying on fossil fuels.

9. The Purpose for PBRC method

The introduction of PBRC and the continuous technique is intended to promote the culture and development of the modest amounts of microalgae that are present in the watery mixture. Achieving the simultaneous separation of protein and fatty acids with appropriate growth indices in a continuous process, in cramped locations, and in accordance with urban and suburban dynamics. This could be understood as the base-level purpose. Out of all the other designs patented by different groups around the world, including Flat-plate bioreactors, Tubular bioreactors, and Raceway Pond system bioreactors, the PBRC device is meant to get around restrictions related to things like cost, area, cultivation efficiency, the rate of production, consumption of energy, and environmental impact.

Limitations Faced Due to Energy Consumption

Due to their abundant availability and high concentration of energy, fossil fuels like coal, oil, and natural gas have long been the main source of energy. A serious threat to the climate is posed by the widespread use of these fuels. Large amounts of carbon dioxide (CO2) are released into the earth's atmosphere as a result of burning fossil fuels, which aids the greenhouse effect and causes global warming. The Earth's atmosphere becomes warmer due to the increase in CO2 levels because it retains heat, which also causes weather patterns to shift. The procedures used to extract fossil fuels frequently cause environmental damage and natural resource pollution. It is difficult to ignore the attached negative effects on ecosystems and human health. While efforts are being made to shift to cleaner energy sources, such as renewable energy, decreasing our reliance on fossil fuels is still essential in minimizing the dangers associated with climate change and protecting the world for future generations. Recent observations for growing oil and natural gas prices demonstrate that present supplies will not be sufficient to meet future demand for a number of years, just as climate change threatens our ecosystem. As a result, alternatives must be discovered as soon as feasible (Volker V. Quaschning, 2019).

Various degrees of certainty indicate that the following changes will persist, and that changes will follow, according to climate models and recent and current trends observed by climate scientists (REH Sims, Elsevier - Solar energy, 2004):

• Higher maximum temperatures, more hot days and heat waves across all land areas, increasing the number of deaths among the elderly and the poor in urban areas; heat stress in livestock; a higher risk of crop damage; increased electrical power loads to fulfill air conditioning and cooling demands; and a shift in the most well-liked tourist destinations.

• Lower human fatalities from cold-related causes due to rising minimum temperatures and fewer frosts; decreased risk of crop damage (save for crops that require a cold period); greater range and activity of pests and illnesses; and decreased demand for heat energy.

• Increased flooding, landslides, erosion of soil, and fatalities; risk of infectious disease epidemics; more pressure on the government and insurance providers for flood damage and disaster relief; and potential harm to hydro-power projects. • More severe downpours and intensities that recharge some floodplain aquifers but also result in more floods, landslides, and soil erosion (REH Sims, Elsevier - Solar energy, 2004).

PBRC Overcoming Limitations in Cultivation of Microalgae

It is crucial to power photobioreactors with renewable energy for a number of reasons. Primarily, renewable energy sources pose a positive impact on climate change and are environment friendly. Switching to renewable energy sources for the cultivation of microalgae is essential as the globe struggles to reduce greenhouse gas emissions. Secondly, photobioreactors offer a sustainable substitute for conventional fossil fuels by using algae or cyanobacteria to transform sunlight into biomass or biofuel and that is the primary focus which cultivation method via PBRC proposes. The use of renewable energy to run photobioreactors has both environmental and financial advantages. Infrastructure investments for renewable energy drive job growth and the clean energy sector's economy. The market for photobioreactor technology and related goods is expanding in line with the rising demand for renewable energy. This promotes future research and innovation in the area while also bringing in money and investments. In addition, by using fewer fossil fuels, we can be less vulnerable to changes in oil prices and geopolitical unrest. In addition to advancing a sustainable future, the utilization of clean energy sources for photobioreactors also improves energy security and fosters a steadier economy.

PBRC and the cultivation method this device proposes uses focuses on using renewable energy which overcomes the above-mentioned limitation faced by most other photobioreactors in the cultivation process of microalgae.

The Process and Method of PBRC

The process is distinguished by the fact that it includes the following phases:

Watery mixture, which contains inoculum, moves along a path (B) from an entry point (C) to an exit point (D), during which it is exposed to radiation with a wavelength that is suitable for the growth and development of these microalgae; along this path (B), NPK salts (containing phosphorus, potassium, and azote) and CO2 are added; and finally, this path (B) is completed. The following steps are part of the method's description:

- From its site of entry until its point of exit, the watery combination containing the inoculum is exposed to radiation with a spectrum that is conducive to the formation and expansion of the aforementioned microalgae;
- NPK salts (nitrogen, phosphorus, and potassium) and CO2 are added along the way, and these additions, combined with the diffusion of the radiation spectrum, cause the algae to proliferate rapidly;
- said mixture, which is heavily enriched in microalgae, is flooded by ultrasound to kill the algae and split them into their oleic and protein components, resulting in the production of a new watery mixture that contains both an oleic and a protein fraction;

The naturally gravimetric separation that occurs in the new watery combination results in:

- the lighter oleic portion migrates to the top of new combination;
- the heavier protein component migrates to the lower portion of the new combination;
- the intermediate portion of the aforementioned new mixture still contains a neutral fraction that is virtually entirely constituted of water;

Said three fractions are taken separately.