Materials Used in Photobioreactor Design

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Introduction

Many configurations of photobioreactors have been devised and built. These range from tubular and cylindrical chambers to flat-sided and vertical systems. Each of these systems employs a wide variety of materials for photobioreactor construction. This review deals with the key aspects involved in the material selection for PBR design to ensure cost-effectiveness and high efficiency.

Materials Used in PBR Construction

The materials for the construction of photobioreactors represent a significant practical issue both from the standpoint of the investment cost and biological performance. The materials used for the reactor include glass, plexiglass, acrylic or Poly Vinyl Chloride (PVC) and the most common, polyethylene. The forthcoming section discusses the features and benefits along with the disadvantages of a few prevalent materials utilized for constructing photobioreactor:

- ✓ Glass
- ✓ Low Density Polyethylene (LDPE)
- ✓ High Density Polyethylene (HDPE)
- ✓ Rigid acrylic (PMMA)
- ✓ Poly vinyl chloride (PVC)

1. *Glass*

Glass is most commonly used in tubular photobioreactors meant for biohydrogen production from algae

Features & Benefits

- Reactors for photoautotrophs like microalgae must be fully translucent without any loss in transparency over time for which glass is generally employed

- Among the types of glasses, borosilicate (Pyrex) glass is commonly used in the solar hot water collector of PBR.

- The energy content of glass ranges between 13.0 and 18.6 $MJ.kg^{-1}$ for window glass, to 15.9 $MJ.kg^{-1}$ for float glass and 26.2 $MJ.kg^{-1}$ for toughened glass.
  (Baird G et al,1998)

- The glass tubes have a lifespan equal to the plant service life time of 20 years.

- For a tubular photobioreactor, glass has significantly higher NERs (Net Energy Ratio) than rigid polymers such as polymethyl methylacrylate (acrylic)

- A photobioreactor with low energy content is required, for which glass can be a suitable material in principle

Disadvantages

- The use of glass tubes requires many more connection fittings as lengths of more than a few meters are not produced or, otherwise, are difficult to transport and assemble.

- Glass tubes also require a supporting structure

- The system employing glass is potentially viable, only when specific constraints on photosynthetic conversion rates, microbial H_2 generation phase stabilities, and H_2 collection efficiencies are met

http://bit.ly/99QcWH

2. *Low Density Polyethylene Film (LDPE)*

Tubular photobioreactors made from polyethylene sleeves have been used commercially for algal cultivation.

Features & Benefits

- The variants of basic LDPE plastic film used are single layer LDPE, linear low density polyethylene (LLDPE), fiber-reinforced LDPE

- Estimates of the energy content of LDPE film are 78.1 MJ/kg and 74.0 MJ/kg
  (Lenzen M et al, 1999)

- The benefits of using LDPE include high visible light and near infra red transmission, low UV transmission, and low cost.

- In few PBRs, the chamber material is comprised of a multi-layer composite polymer, comprising one layer of nylon plastic film bonded on either side with a tie layer of bonding agent and a layer of low density polyethylene (LDPE).

- The nylon-LDPE plastic film used in PBR can vary in thickness, depending on the species of algae and the corresponding level of turbulence required for light cycling, shear-stress limitations, etc.

- A preferred size of the LDPE-nylon film is 3.5 thousandths of an inch thick. At this thickness, a moderate amount of turbulence within the photobioreactor chamber would have little effect on the film's structural integrity

Disadvantages

- The main disadvantage of using these materials is their short lifespan as even with the addition of UV stabilizers, the maximum life of LDPE film is only 3 years

- Environmental factors which can affect the film lifetime include UV radiation, temperature, thermal cycling, and contact with rigid surfaces and chemicals (including atmospheric pollutants)

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3. *High Density polyethylene (HDPE)*

High Density Polypropylene is used in bag photobioreactors to overcome the problems in using LDPE for algal cultivation.

Features & Benefits

- HDPE is the most promising plastic used for algal cultivation since it is cheap and commercially viable

- HDPE would cost approximately only one-third that of the current plastic materials used

- The HDPE employed reactors are found to produce algae with oil content 1% higher than that of the reinforced LDPE films.

- The opaqueness of HDPE help prevent photooxidative damage or photoinhibition

- It is also less prone to biofouling (build-up of layer of algae that blocks some of the sunlight from getting through)

Disadvantages

- HDPE is not quite as good as LDPE or the five-layer plastic as it is difficult to weld and hence show less tensile strength

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4. Rigid acrylic (PMMA)

Acrylic, chemically referred as PolyMethyl MethylAcrylate (PMMA) is a common material of construction for most research photobioreactors due to its superior qualities.

Features & Benefits

- The acrylic tubes are also known by the trade names Plexiglas and Perspex
- Clear acrylic tubing has been used in a number of prototype photobioreactor systems, with outer diameters in the range of 30 to 60 mm and wall thickness 3 to 5 mm (Tredici et al,1995)
- The energy content of PMMA is estimated at 131.4 $MJ.kg^{-1}$. The lifespan of acrylic in outdoor conditions is at least 10 years. (Boustead,2005)
- Studies indicate that the acrylic sheet transmit 95% of the incident light from 390 to 800 nm. Based on its excellent transmittance in the PAR, acrylic is suitable construction material for photobioreactors. (Berberoglu et all, 2008)
- Acrylic tubes and coils act as solar collectors, increasing temperature and extending the growing season.
- Other advantages are increased productivity, less water loss from evaporation, screening out contaminant algae, greater control over the culture, and ability to grow a pure culture of algae.

Disadvantages

- Acrylic tubes are used for PBR construction but the installed costs make the system too costly

- Excessive oxygen produced by the algae while growing can reduce growth.

- The algae may stick to the inside of the tubes and block sunlight, and tubes may get too hot.

http://bit.ly/dnmOnD

5. *PolyVinyl Chloride (PVC)*

The basal and helical photostage of a helical photobioreactor are generally made of a transparent polyvinyl chloride (PVC) tube

Features & Benefits

- Polyvinyl chloride membranes containing immobilized agents have been widely documented and used to prepare membrane sensors in photobioreactors

- The unique UV blocking technology prevents harmful ultraviolet light wavelengths from penetrating the PVC while allowing beneficial light wavelengths to pass through the PVC clear pipe.

- The advantages include corrosion resistance, non-conductivity and light weight construction.

- Using specialty clear PVC piping is beneficial in the use of photobioreactors since clarity is critical in allowing as much light into the process to allow the algae to grow and feed.

Disadvantages

- Flexible PVC tubing has been used, but because of the damaging UV rays the PVC tends to break down and get brittle.

- PVC when attacked by UV rays on conventional PVC will discolor the surface of the pipe preventing or limiting the light from getting to the medium.

http://bit.ly/bNdJ7n

Choice of Favourable Materials for PBR Design

As illustrated in the previous section, a range of materials is available for photobioreactor construction which not only possesses significant benefits but also show a few disadvantages. It is thus critical to select the best material that satisfies all the criteria of an efficient PBR design.

The following table provides the characteristics of a few photobioreactor materials and the energy content of tubular photobioreactors.

Material	Material Energy Content ($MJ.Kg^{-1}$)	Material Life Span (y)	Material Density ($kg.m^{-3}$)	Proposed Wall Thickness (mm)	Energy Content (MJm^{-2})	Life Span Weighted Energy Content ($MJjm^{-2}y^{-1}$)
Glass	25	20	2470	1.6	310	15.5
LDPE	78	3	920	0.18	40.5	13.5
Acrylic	131	20	1180	3.0	1456	72.8

- The table infers that the acrylic tubes involve the highest energy content per aperture area, whereas LDPE tubes the lowest.
- Using a hypothetical improved microalgal H_2 generation efficiency of 5%, a Net Energy Ratio (NER) ∼6 can be obtained for LDPE film and for glass.
- After normalization by the expected lifetime, glass and LDPE tubes share a similar lifespan weighted energy content, around 5-fold lower than for acrylic tubes.
- The choice of favourable values for the lifetime, wall thickness, and mechanical & assembly reasons strengthens the conclusion that LDPE is the preferred material of choice. (International Journal of Hydrogen Energy, Volume 32, Issue 9, June 2007, Pages 1225-1234)

http://bit.ly/99QcWH

Innovations in PBR Design Materials

NASA's OMEGA System as bioreactor

Features & Benefits

- The NASA bioreactor that grows algae is an Offshore Membrane Enclosure for Growing Algae (OMEGA) in municipal wastewater to produce biofuel
- The OMEGA system consists of large plastic bags with inserts of forward-osmosis membranes that grow freshwater algae in processed wastewater by photosynthesis.

- The flexible bag-like reactor is formed of two rectangular plastic films attached together along their edges. The reactor is floated on water, exposed to sunlight.

- Using energy from the sun, the algae absorb carbon dioxide from the atmosphere and nutrients from the wastewater to produce biomass and oxygen.

- As the algae grow, the nutrients are contained in the enclosures, while the cleansed freshwater is released into the surrounding ocean through the forward-osmosis membranes.

- The technology employing plastic bags is thus simple and scalable enough to support the commercial development of a new algae-based biofuels industry and wastewater treatment.

(November 2009)

http://bit.ly/U9ssg

Fibrous Geo-textiles

Features & Benefits

- The material comprising the integrated unit of the photobioreactor will be strengthened against punctures with fibrous reinforcement named the geo-textiles

- The fibrous geotextile will be laminated or glued to the outside of the photo-bioreactor

- Including geotextile flaps that are flexibly connected, and extend beyond, the outside edges of the photo-bioreactor helps secure the photo-bioreactor to the angled site

- It avoids the need, in the case of an angled earthen berm, to employ other erosion control methods on surrounding ground areas when installed.

- The geo-textile also ensures resistance to factors that disturb algal growth in the photo-bioreactor

(March 2009)

http://bit.ly/a6D2Ty

Ternion Bio's BioBlade system for Photobioreactor

Features & Benefits

- Ternion Bio's BioBlade system uses Harvel® EnviroKingUV® pipe to create state-of-the-art photobioreactor systems.

- California's Ternion Bio Industries utilizes specialty clear PVC piping combined with scalable technology that provides the backbone of both BioBlade unit and photobioreactor unit as a whole.

- The photobioreactor is constructed of steel framing, specialty clear pipe, and pumps in which carbon dioxide is mixed with other nutrients to feed algae.

- The inner workings of Ternion Bio's photobioreactor are contained in smaller BioBlade™ units, open metal frames containing stacks of interconnected horizontal runs of specialty clear PVC pipe that circulate the algae.

- Each BioBlade slides into the photobioreactor structure in a fashion similar to a computer server "blade" sliding into a chassis.

- The photobioreactor system uses more than 700 gallons of treated water per BioBlade unit, and each BioBlade has its own 250-gallon water tank and pump.

- If one BioBlade experiences mechanical problems, its isolation from the other BioBlade reactors means that the rest of the photobioreactor system will not be affected thus operating independently, while supporting the entire PBR system as well.

(Jan 2010)

http://bit.ly/9h3Plj

Conclusion

The review clearly interprets the criticality of the material selection in determining the efficiency of photobioreactor. The choice of materials and the construction design of the photobioreactor should thus consider the material's efficiency including light transmission, lifespan and recyclability.