Research Analysis and Initial Bioreactor Design Development

Introduction

Day 3 and 4 of week 1 focused on understanding different designs of photobioreactors (PBR) systems used for microalgae cultivation, specifically for carbon dioxide capture and biomass productivity. I examined 3 relevant research studies to explore how factors like light distribution, circulation, gas exchange, and low-cost reactor designs influence algal efficiency and sustainable algae growth.

This phase of research aimed to identify weaknesses in current systems and guide the development of a low-cost, efficient hybrid bioreactor suitable for small-scale or resource-limited settings. My notes include summaries of key findings in each study, analysis of recurring disadvantages, and initial conceptual sketches of a new hybrid PBR design (located in the visuals folder) that combines features from thin film and airlift systems.

Note: ***Detailed data and graphs for the studies summarized here are compiled in the file 'Visuals' in the Week 1 folder.***

Study 1 - Development of thin-film photo-bioreactor and its application to outdoor culture of microalgae (2013)

Objective: Developing a thin film photobioreactor made from polypropene sheets.

Materials: Polypropene is light weight, durable and has efficient light transmission

Design: Thin film with a very shallow layer for maximum light exposure. The study tested multiple reactor configurations—flat, vertical, and tilted—to determine which geometry best supported algal growth.

Microalgae species: Chlorella vulgaris is known for robust growth and adaptability outdoors. It is ideal for low-cost, large-scale systems due to efficient CO_2 fixation and biomass productivity. Although the study included other species, Chlorella vulgaris was chosen for its better performance and scalability.

Results: The thin film photobioreactor effectively captures light energy, promoting healthy growth and biomass accumulation of Chlorella vulgaris. A sparger was used to inject CO_2-rich air, which enhanced mixing and gas exchange. Tests were conducted under both indoor and outdoor conditions, confirming the design's effectiveness in real-world settings. This design showed promising potential for efficient algae cultivation by maximizing light utilization.

Application: The design shows promise as a low-cost and scalable solution for efficient microalgae cultivation.

Study 2 - A simple and low-cost airlift photobioreactor for microalgal mass culture (2002)

Objective: The study developed a low cost, simple airlift photobioreactor for microalgae cultivation

Materials: The photobioreactor was constructed using **transparent plexiglass (Plexiglas)** to allow optimal light penetration.

Design structure consisted of 3 major parts:

- Outer tube, which forms the main body of the reactor
- draft tube, an inner tube that helps with the circulation of the culture medium
- Airduct, which introduced the carbon dioxide rich air and facilitates mixing

The system operates by circulating microalgae culture through airlift-driven mixing, enhancing nutrient and gas exchange.

Microalgae species: Chlorella sp. Was used as it is known for its mass production capability

Result: The experiment proved well suited for mass cultivation of algae and application of this set up seemed promising due to its low cost and easy installation.

Application: The study emphasized the photobioreactor's potential for scalable industrial or commercial applications thanks to its simple design. While it focused on demonstrating feasibility and cost-effectiveness, detailed discussion of limitations or areas for improvement was limited.

Gas Holdup and Circulation Time Explained

1) **What is Gas Holdup?**
   It is the fraction of the reactor volume that is occupied by gas bubbles
   ε: Overall gas holdup in the whole reactor.
   εr: Gas holdup in the riser (part where bubbles rise).
   εd: Gas holdup in the downcomer (contains less gas).
   Gas bubbles supply carbon dioxide to algae and allow circulation when the liquid rises.

2) **Why is it important?**
   When there are more gas bubbles, the surface area for carbon dioxide to be transferred to the algae is higher. In addition, it creates liquid movement, provides efficient light absorption, and nutrients.

3) **What is Circulation Time?**
   It is the time taken (tc) for water to complete a loop from the upriser to the downcomer. Residence time in riser (tr) and downcomer (td) is time water spends moving in each section.

4) **Why is circulation time important?**
   Faster circulation improves carbon dioxide reaching algae. Slow circulation could affect some algae not getting enough nutreints and light exposure.

Liquid Circulation Velocity:
This is the speed at which the liquid moves through the reactor loop (riser and downcomer).

- **Why it matters:** Faster circulation improves mixing and helps algae get more CO_2 and light.

Gas-Liquid Mass Transfer Coefficient (Kla):
This tells us **how efficiently gas (like CO_2 or O_2)** is being transferred from the bubbles into the liquid.

- **Why it matters:** A higher Kla means better delivery of CO_2 for photosynthesis, which is critical for algal growth.

Study 3 - Development of a Photobioreactor for Microalgae Culture

Objective: Develop a low-cost, efficient photobioreactor to improve microalgae cultivation and support biodiesel production.

Materials: Constructed with readily available materials such as aluminum tubes, Plexiglas, PVC couplers, and dry batteries for fluorescent lighting

Design:

- A 12-chamber vertical bioreactor, each chamber is approximately 122cm tall and has a 3.6cm diameter, arranged around a central fluorescent lamp

- Had a dual light setup meaning natural sunlight and a 36W fluorescent lamp that operated on dry batteries
- Chambers sealed with Plexiglas to prevent contamination

Key Findings:

- Achieved uniform illumination across all 12 chambers
- Cultivated algae using poultry dung. Yielded 430g of algae over 14 days using 2.4L of poultry waste

Conclusion:

- The reactor was inexpensive and easy to build and promised high efficiency of microalgae cultivation.
- It addressed major disadvantages of using open pond systems, offering better carbon dioxide capture and economic feasibility for biodiesel production.

Below is a picture of the set up used:

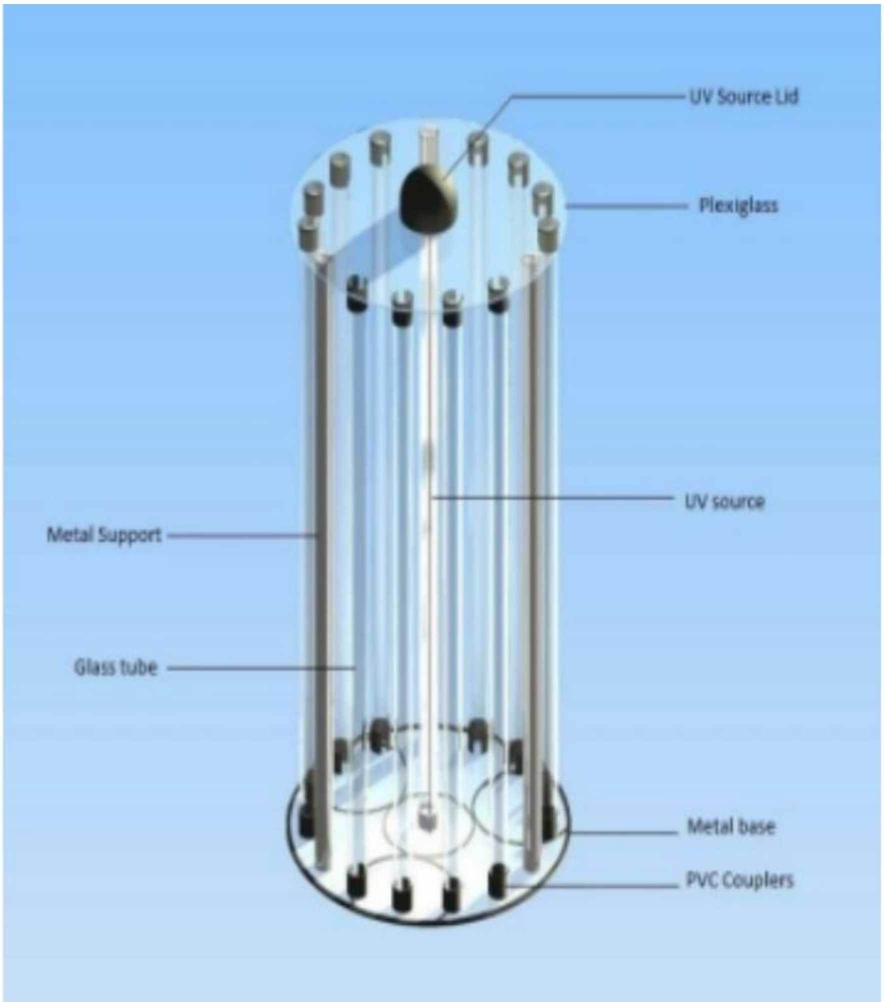

Figure 1: General arrangement of the photobioreactor.

Study	Key Disadvantages	Most Common Issues
Yoo et al., 2013 (Thin-Film Photobioreactor)	- Requires frequent cleaning to prevent biofilm buildup - Limited volume capacity, not ideal for large-scale use - Gravity-fed flow can be slow or uneven	Scalability limitations due to size and biofilm buildup
Xu et al., 2002 (Airlift Photobioreactor)	- Limited light exposure due to vertical design - CO_2 distribution can be uneven without optimization - Basic setup may not scale well	Insufficient light exposure, especially in dense cultures

Ugwuishiwu et al., 2016 (General PBR)	- Bulky and space-consuming structure - Complex sealing needed to prevent contamination - Lacks design for continuous flow operation	Operational complexity and maintenance issues

Most Common Issue Among All:

Scalability and maintenance challenges (e.g., biofilm buildup and light limitations) were the most common disadvantages seen among all three studies.

Conclusion

I chose the first two setups because of their simpler structure. A disadvantage in one - such as the limited mixing in the thin-film reactor - is addressed by an advantage in the other, namely the airlift photobioreactor's efficient circulation and gas exchange. Likewise, the airlifts design's limited light exposure is improved by the thin film photobioreactor's high surface to volume ratio. Combining both allows for optimized light distribution and effective mixing, making the hybrid system more efficient and scalable.