Preliminary AutoCAD design

Overall Goal: To create a conceptual layout drawing of the hybrid flat panel and airlift bioreactor on AutoCAD. It should explicitly be able to facilitate wastewater treatment by removing nitrates, phosphates, and help with carbon fixation.

Summarized Phosphorus Notes:

- Critical ratio of nitrogen: phosphorus should be maintained for removal of phosphorus and continue contributing to growth
- Concept of luxury uptake (algae taking in more phosphorus than immediately required when nitrogen levels are low)
- 45.16 milligrams of phosphorus uptake per day – this is a key component to consider when sizing the bioreactor
- The cells can store 3.5% of dried biomass – crucial for phosphorus recovery
- 25°C, 127 μmol photon m^{-2} s^{-1} continuous illumination, 10% CO_2 (v/v) in aeration gas, and the idea of pulsed/staged $NaNO_3$ addition.

Summarized Nitrogen Notes:

- Nitrogen assimilation pathway: $NO_3^- \rightarrow NO_2^- \rightarrow NH_4^+ \rightarrow$ Organic N (Biomass).
- Key enzymes: Nitrate Reductase (NR), Nitrite Reductase (NiR), Glutamine Synthase (GS), Glutamate Synthase (GOGAT).
- Light dependence: Light is essential for nitrate uptake and NiR activity.
- Ammonium (NH_4^+) acts as a repressor of nitrate uptake and enzyme activity.
- Optimal nitrate concentration: 1800–2400 mg/L for maximum biomass production.
- Optimal nitrite concentration: 400 mg/L for maximum biomass production.
- The benefit of combining nitrate and nitrite for higher biomass yield.
- Hydraulic Retention Time (HRT) of 6-7 days for nitrogen removal.
- CO_2 supply: Crucial link between nitrate assimilation and carbon metabolism.
- Molybdenum (Mo) supplementation: Essential cofactor for NR.
- Biomass harvesting: The ultimate step to physically remove nitrogen.

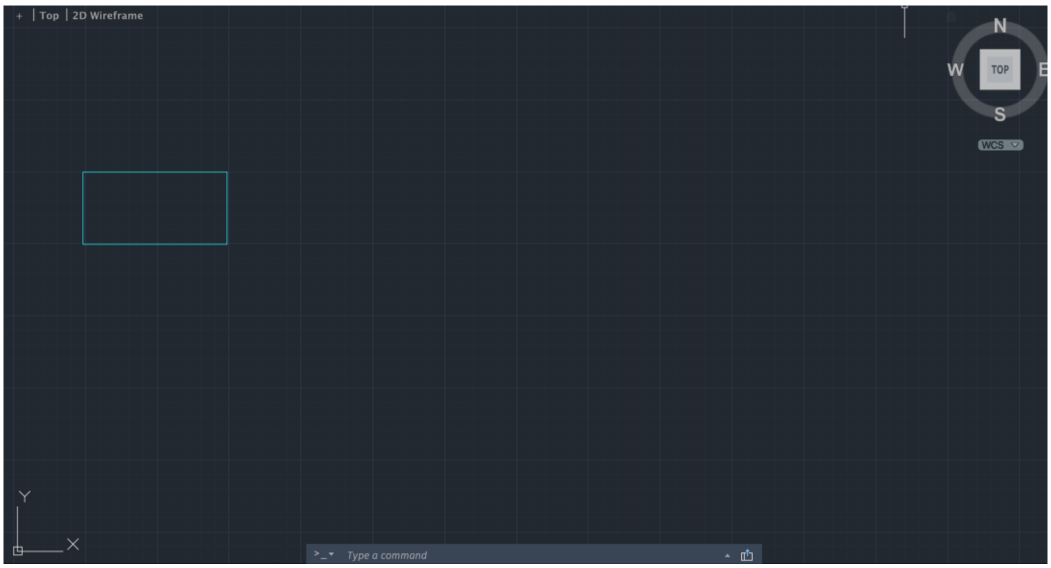
Each point should be highly considered when making the bioreactor design

AutoCAD Setup - Drawing Environment

- Date & Time of Setup: 12th June 2025, 9:31PM
- Units Selected: Decimal, Meters (m), 0.00 Precision.
- Layers Created (and their chosen colors):
- - Walls_Structure - Cyan
- - Pipes_Flow - Blue
- - Equipment_Components - Red

- - Text_Labels - Yellow
- - Light_Sources – Light orange
- Using layers provides organization for visibility and assigning colors helps with modification of different components.

Component Design - Main Growth Panel

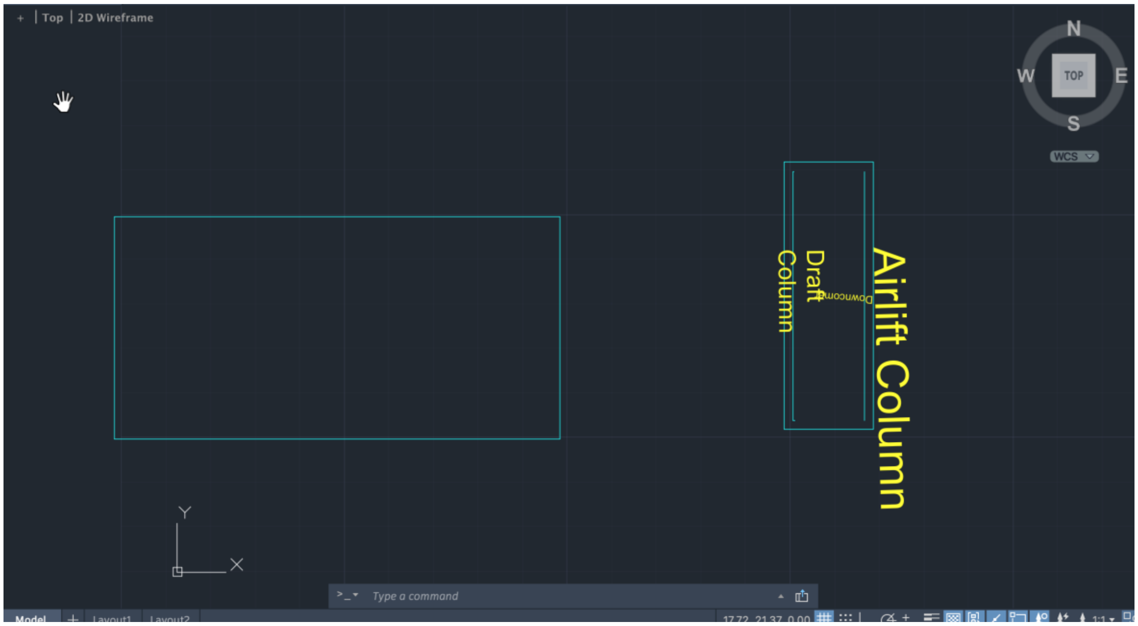


Dimensions: 5m long in width and 2.5m in height (side view)

Design Rational and Explanation:

- The panel is a zone where algae growth occurs. It is narrow in depth, and the flat panel design is used for maximum light exposure, CO_2 capture, and nutrient assimilation.
- The initial dimensions are the overall bioreactor volume that can accommodate 6-7 days Hydraulic Retention Time (HRT) needed for efficient nitrogen removal. In addition, 45.16 mg P L^{-1} d^{-1} phosphorus uptake rate to remove phosphorus efficiently.

AutoCAD Drawing Progress - Labels & Airlift Column Completion



How does the airlift column work?

This separate **airlift column**, containing a **draft column** and **downcomer**, is designed to create a continuous and vigorous circulation of the algal medium. This separation from the main panel allows for optimized gas exchange without interfering with light penetration into the panel. The continuous mixing provided by the airlift is vital for uniform distribution of algae, nutrients, and supplied CO2. This robust mixing supports the 10% CO_2 (v/v) rich air injection (from phosphorus paper) which is crucial for CO2 capture and provides the necessary carbon skeletons for algal growth and efficient nitrogen assimilation.

Airlift Column Internal Structure Completion:

- Description: Successfully completed the internal structure of the airlift column.
- The inner rectangle representing the **draft tube** was created using the OFFSET command (0.1m offset from outer walls),
- then **EXPLODED and** its top and bottom horizontal lines were **BROKEN** to create open passages for water flow (0.1m top and bottom openings).

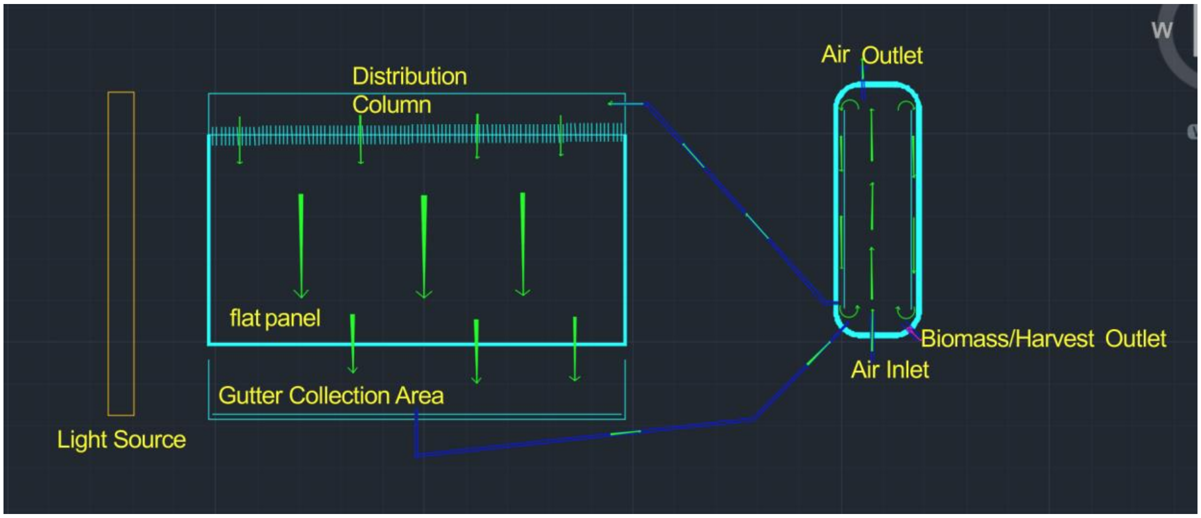
Design Rationale & Research Link

- Continuous circulation takes place in the airlift column including its internal draft tube and downcomer for continuous circulation of the algae medium.
- Efficient mixing ensures that algae is distributed evenly, nutrients are spread evenly, and gases like carbon dioxide are dispersed consistently.
- Efficient fluid dynamics: The 0.1m downcomer gaps and open ends of the draft tubes are designed for smooth movement of the liquid.
- Critical for CO_2 Transfer: The circulation provided by the airlift is vital for the effective transfer of 10% CO_2 (v/v) rich air into the culture.

- The CO_2 supply provides the essential carbon skeleton for growth of algae cells and nitrogen assimilation
- Continuous mixing also ensures all algae cells get efficient light absorption, because nitrate uptake is a light-dependent process.

<u>Friday June 14th, 2025</u>

Saturday, June 14th, 2025 - Current Project Status: Completed AutoCAD Drawing



- The Conceptual AutoCAD drawing phase for the bioreactor system is now complete.
- Design represents a re-engineered hybrid system.
- All major components (airlift column, flat panel, interconnecting piping, lighting rigs) are drawn.
- All flow paths and key components are now clearly represented and labeled.
- This comprehensive drawing forms the foundational visual for further research and optimization.

Airlift Column: Comprehensive Design & Detailing

- **Structural Layout:** Capsule-shaped outer vessel with rounded ends; internal draft tube (parallel lines) with consistent thickness.
- **Internal Dynamics:** Draft tube's top/bottom horizontal lines were EXPLODED and BROKEN (0.1m gaps) to create open passages for fluid circulation between draft tube and downcomer.
- **Internal Flow Visualization:**
  - Green arrows (polylines with arrowheads) strategically placed.

    - Upward flow within central draft tube, downward flow in outer downcomer sections.
    - Curved arrows at top/bottom transitions show a continuous circulation loop.
- **Integrated Inlets & Outlets:**
    - "Air & CO_2 & nutrients in" Pipe: At the very bottom center.
    - "Waste Gas out" Pipe: At the very top center (with T-shaped cap).
    - "Biomass/Harvest Outlet" Pipe: Exits lower-right side (includes integrated valve symbol for final product harvest).
    - Seamless Wall Penetrations: Achieved using the TRIM command for clean pipe connections.
- **Design Rationale:**
    - Ensures continuous, vigorous circulation for uniform distribution of algae, nutrients, and CO_2.
    - Optimal fluid dynamics through 0.1m downcomer gaps and open draft tube ends.
    - Critical for efficient 10% CO_2 transfer (supports growth and nitrogen assimilation).
    - Guarantees consistent light exposure for all algae cells (essential for nitrate uptake).
    - Harvest valve allows controlled product removal without disrupting circulation.

Interconnecting Piping System

- **Connection Design:** All major pipes use straight line segments for visual clarity and functional connection.
- **Pipe from Airlift to Top Distribution Gutter:** Connects from airlift downcomer to flat panel top distribution gutter.
- **Medium Return Pipe:** Completes the circulation loop, connecting from the flat panel's bottom collection gutter outlet to the lower side of the airlift column.
- **AutoCAD Techniques:** LINE for segments, OFFSET for thickness, TRIM for clean intersections.
- **Layer Used:** Pipes_Flow.
- **Design Rationale:** Efficiently transfers algal medium between the gas-exchange-optimized airlift and the light-capture-optimized flat panel, ensuring sustained system operation.

Flat Panel: Design & Flow

- **Structure & Internal Flow:** Primary algae growth zone (narrow depth for max light exposure). Green downward arrows indicate medium flow for absorption and purification.
- **Top Distribution Gutter:** Horizontal trough atop panel; includes small vertical dashes indicating medium inflow from the airlift, ensuring even distribution.

- **Bottom Collection Gutter:** Horizontal rectangular trough directly beneath flat panel. Collects fluid post-panel, with wall thickness, open top, and a central outlet for the return pipe.
- **Layer Used:** Walls_Structure.

Lighting Rigs

- **Description:** A long, thin rectangular element, positioned vertically alongside the left side of the flat panel.
- **Purpose:** Represent artificial lighting units providing continuous illumination for algal culture.
- **Layer Used:** Light_Sources.

Labels

- **Description:** All key components, inlets, outlets, and flow paths are now clearly identified with text labels.
- **Purpose:** Enhances overall readability and understanding of the design.
- **Layer Used:** Text_Labels.

Future Research & Design Considerations:

As this is not the final design, several key questions and areas for further research will be explored to refine and optimize my bioreactor system:

- Fluid Dynamics in Return Pipes: How would the medium be efficiently moved through the pipes when returning from the flat panel's collection gutter back to the airlift column? Should detailed fluid dynamics analyses be conducted to determine optimal pipe diameters, flow rates, and potential pump requirements, ensuring smooth and consistent recirculation without excessive energy consumption or shear stress on the algae?
- System Cleaning Protocols: What are the most effective and practical methods for cleaning this bioreactor system in an operational setting? This would involve researching suitable cleaning agents, identifying accessible cleaning ports, and establishing a robust cleaning-in-place (CIP) or cleaning-out-of-place (COP) protocol to prevent biofilm formation and maintain bioreactor hygiene.
- Material Selection for Low-Income Areas: Given the potential application in low-income regions, what alternative, cost-effective, and locally sustainable materials could be utilized for the construction of this bioreactor system, particularly for the main structures and piping, without compromising performance or durability?

- Nitrate Dosing System**:** How to design and integrate a controlled system for the precise and frequent addition of sodium nitrate, especially to supplement low initial nitrate concentrations, and optimize its delivery for enhancing algal growth and phosphorus luxury uptake?
- Temperature Control System: What are the most energy-efficient and practical methods to maintain the bioreactor's optimal operating temperature (e.g., 25°C) in varying environmental conditions? This involves exploring options like external heat exchangers, jacketed vessels, or direct heating/cooling elements, considering their energy consumption and cost.
- pH Monitoring and Control: How to implement a robust system for continuous pH monitoring and automatic adjustment to maintain the optimal pH range for *Chlorella vulgaris* growth and efficient CO2 absorption? This would involve researching suitable pH sensors and automated acid/base dosing mechanisms.