Optimizing microalgae growth in treated flue gas

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NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

SCBE21031 – Optimizing Microalgae growth in Treated Flue Gas

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Introduction

With the continuous greenhouse gas emissions from power plants, climate change has become one of the top global threats[1]. Effects of climate change like rising global temperatures can be felt. Microalgae can help minimise carbon footprint by capturing CO_2, SO_x and NO_x in flue gas for its metabolism, to make biomass. This biomass can have pharmaceutical and nutraceutical applications[2].

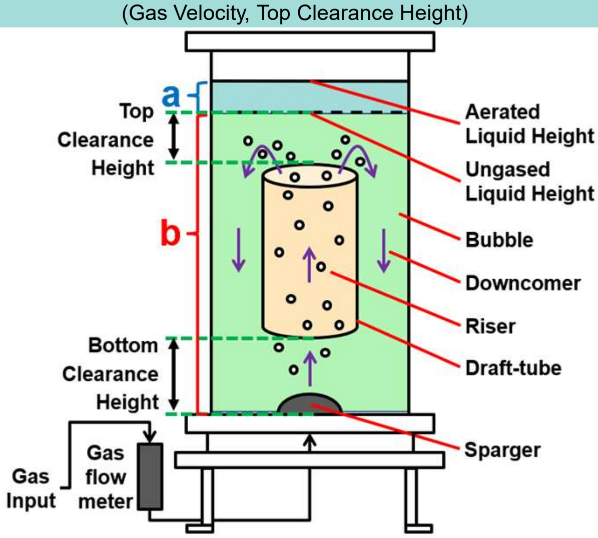
Aim

- To analyse the effects of gas velocity and top clearance height on the gas holdup and liquid circulation rate to control microalgae growth condition.
- To optimise the growth condition of the microalgae culture.
- To investigate the effect of treated flue gas on the microalgae growth.

Methodology

Part 1: Varying Operational Conditions of Air Lift Reactor

(Gas Velocity, Top Clearance Height)



Effect:

1) Gas Holdup, ϕ

$$\phi = \frac{a}{b}$$

Calculated by dividing the difference in liquid height (a) by the ungased liquid height (b).

The average aerated liquid height applied for the calculation uses the minimum and maximum aerated liquid height.

2) Liquid Circulation Rate, J_{Ld}

Measured by observing tracer particles with High-Speed Camera.

To get the highest liquid circulation rate, divide the frame rate by the lowest number of frames taken for a tracer particle to travel 1 cm.

This indicates that the tracer particles are in the annular region

The tracer particles were 3D printed with Polyamide 11, which has similar density to water, using the Multi Jet Fusion process.

3) Residence Time

Calculated by dividing the sum of length of the draft-tube and the bottom clearance height by the liquid circulation rate.

Microalgae Growth

Light/Dark Cycle, which is the time spent in the dark and photic zone by the microalgae culture.

Part 2: Optimization of Microalgae Growth Condition

(Maximizing biomass productivity and its biochemical profile)

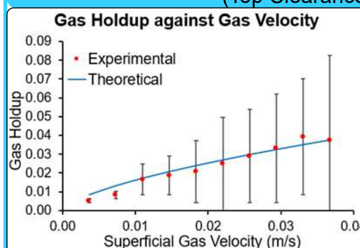
Part 3: Introduction of Flue Gas to Microalgae Culture

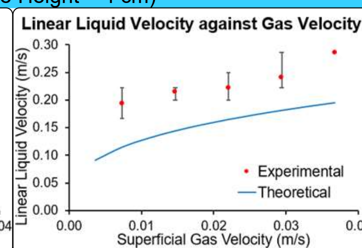
(Evaluate survival of microalgae culture and its biochemical profile)

Results

Effect of Gas Velocity

(Top Clearance Height = 4 cm)





Effect on Gas Holdup:

- Obeys the correlation postulated by Popovic and Robinson (1989)[3]:

$$\phi = 0.465 J_G^{0.65}\left(1+\frac{A_d}{A_r}\right)^{-1.06} \eta^{-0.103}$$

where J_G = Superficial Gas Velocity (m/s), η = Apparent Viscosity (Pa·s), A_r = Cross-section Area of Riser (m^2), A_d = Cross-section Area of Downcomer (m^2)

- Error bar increases with gas velocity due to increasing Reynold's Number.

Effect on Linear Liquid Velocity:

- Obeys the continuity equation for the liquid flow in the riser and downcomer[4]:

$$Q_L = J_{Ld} \cdot A_d = J_{Lr} \cdot A_r (1-\phi)$$

where Q_L = Liquid Flow Rate (m^3/s), J_{Lr} = Linear Liquid Velocity in Riser (m/s), J_{Ld} = Linear Liquid Velocity in Downcomer (m/s)

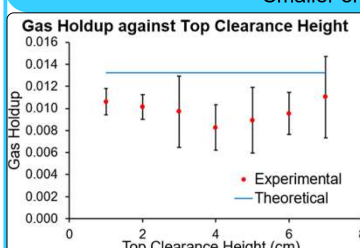
- Deviation from theoretical data is due to the assumption that the liquid flow rate is equivalent to gas flow rate.

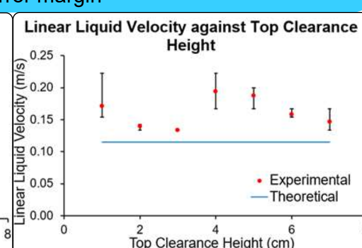
Effect of Top Clearance Height

(Gas Velocity = 0.007 m/s)

Dispersed bubble regime is used to study the effect of top clearance height:

- To prevent cell damage
- Smaller error margin





Effect on Gas Holdup:

- Obeys the same correlation equation as above.
- Fluctuation in gas holdup trend appears statistically insignificant and consistent with operation parameters determined above.

Effect on Linear Liquid Velocity:

- Obeys the same continuity equation as above.
- Discrepancy from the theoretical data is also due to a higher theoretical gas holdup value, causing the linear liquid velocity to be underestimated.

Conclusions & Future Work

- The optimal gas velocity to use is 0.147m/s to achieve stable microalgae growth. At 0.147 m/s, microalgae are in a flow state with a distribution of light intensity, while not causing cell damage.
- The optimal top clearance cannot be obtained as it does not affect the parameters tested in this experiment. However, further studies are required to determine its effects on the residence time in the separator.

Further investigation is required on:

- the effects of treated flue gas on the microalgae culture and its biochemical profile.
- the amount of toxic compounds in the treated flue gas that can be tolerated by the microalgae culture.
- the amount of toxic compounds absorbed by the microalgae and its edible limits.

References

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[2] C. Espro et al., "Sustainable production of pharmaceutical, nutraceutical and bioactive compounds from biomass and waste," Chem. Soc. Rev., vol. 50, no. 20, pp. 11191–11207, 2021.

[3] M. K. Popovic and C. W. Robinson, "Mass transfer studies of external-loop airlifts and a bubble column," AIChE J., vol. 35, no. 3, pp. 393–405, 1989.

[4] X. Wu and J. C. Merchuk, "Simulation of algae growth in a bench scale internal loop airlift reactor," Chem. Eng. Sci., vol. 59, no. 14, pp. 2899–2912, 2004.