



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

CULTIVATION OF ALGAL BIOMASS AND TREATMENT OF WASTE WATER-2

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Contents

- Why algal cultivation?
- Algal metabolism and synthesis of fat and protein
- Classification of algae
- Lipid content in algal cell
- Algal lipids and bio oil quality
- Conditions influencing algal lipid quality and quantity
- Enhanced lipid accumulation
- Cultivation/ growth of microalgae as an important step for algae to oil
- Reactor systems for cultivation/ growth of microalgae
- Harvesting of algal biomass
- Treatment of wastewater using microalgae



Reactor systems for cultivation/ growth of microalgae

Algal growth system

Open system
Photo bioreactor

Closed system
Photo bioreactor

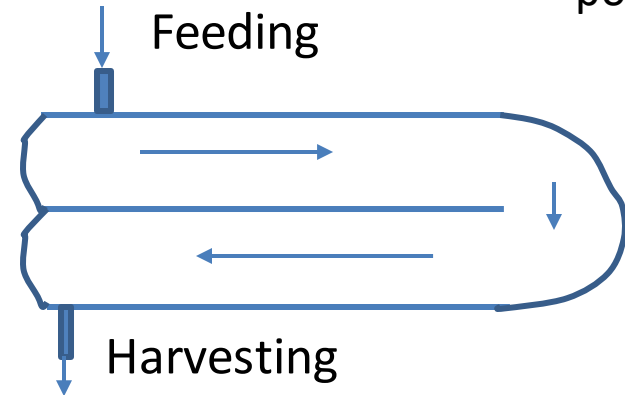


<http://ecoholly.livejournal.com/2595.html>

Open
system/
Raceway
pond

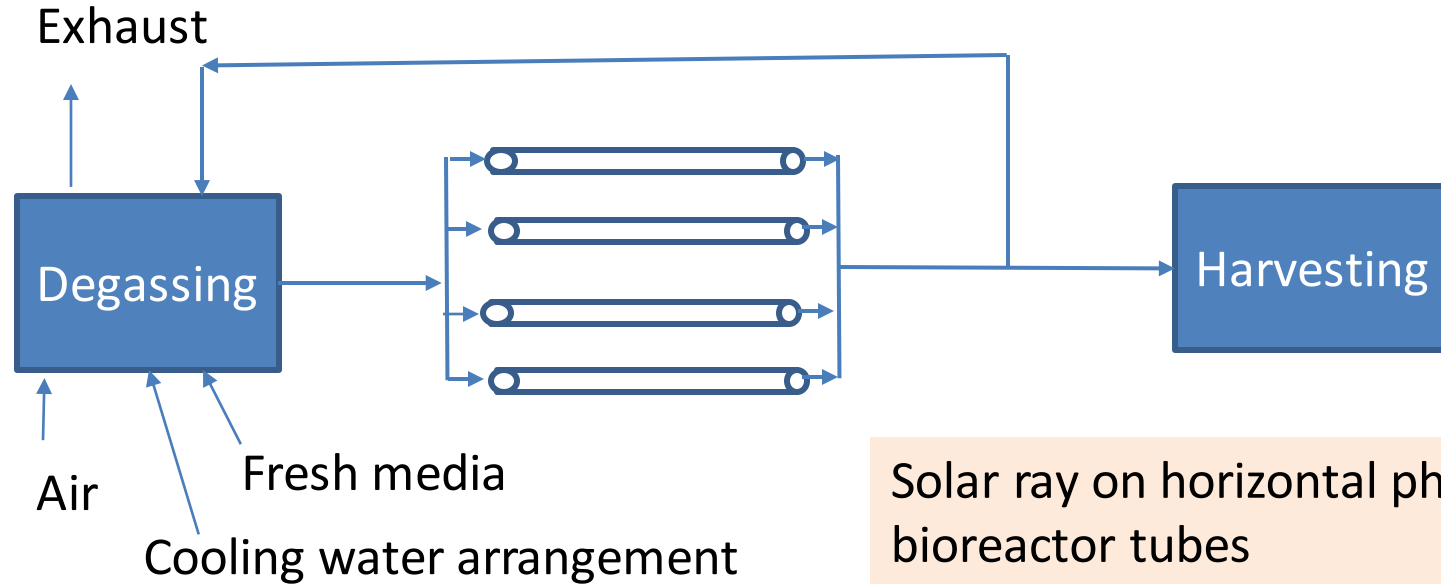
➤ Major types of closed photo bioreactors

- Vertical tubular
- Horizontal tubular
- Plate
- Plastic bag systems



Closed photo bio-reactors

Horizontal tubular photo bioreactor

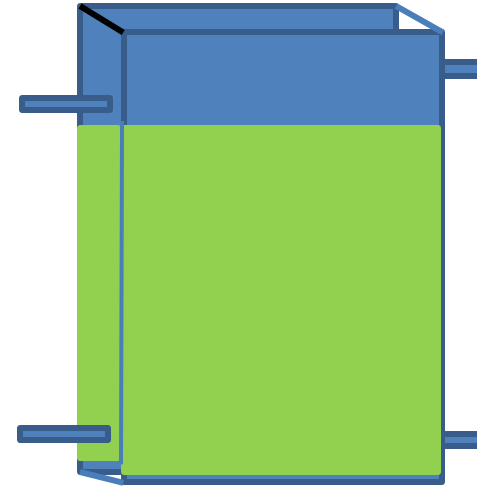


Modified from Chisti Y, Biodiesel from microalgae beat Bioethanol; Trends in Biotechnology, 2008, 126, 1-6

Closed photo bio-reactors



Vertical-column photo bioreactor



Flat-Panel Photo bioreactor

Modified from

https://www.kit.edu/klt/pi_2012_10082.php

<http://users.wpi.edu/~bwolfson/Final%20Poster.pdf>

Comparison of open and closed photo bioreactor

Parameter(s)	Open ponds and raceways	Closed Photo bioreactors (PBR)
Required space	High	For PBR itself low
Water loss	Very high, may also cause salt precipitation	Low
CO ₂ loss	High, depends on pond depth	Low
Oxygen concentration	Usually low enough because of continuous spontaneous outgas.	Requires gas exchange devices (O ₂ must be removed to prevent inhibition of photosynthesis or photo oxidative damage)
Temperature	Highly variable, some control possible by pond depth	Cooling often required (immersing tubes in cooling baths)
Shear	Low (gentle mixing)	High (fast and turbulent flows required for good mixing, pumping through gas exchange devices)



Comparison of open and closed photo bioreactor

Parameter(s)	Open ponds and raceways	Closed Photo bioreactors (PBR)
Cleaning	No issue	Required (wall-growth and dirt reduce light intensity)
Contamination Risk	High (limiting the number of species that can be grown)	low
Biomass quality	Variable	Reproducible
Biomass conc.	Low, between 0.1 and 0.5 g/l	High, between 2 and 8 g/l
Production flexibility	Only few species possible, difficult to switch	High, switching possible
Process control and reproducibility	Limited (flow speed, mixing etc.)	Possible within certain tolerances



Comparison of various types of closed photo bioreactor

Characteristic	Tubular PBR	Column PBR	Flat panel PBR
Biomass yield	↑↑↑↑	↑	↑↑
Exposed surface area for light illumination	↑↑↑↑	↑	↑↑
Manufacturing cost	↑	↑↑	↑↑↑↑
Problem due to O ₂ & CO ₂ accumulation	↑↑↑↑	↑	↑↑
Scale-up possibility	↑↑↑↑	↑↑	↑
Maintenance cost	↑↑	↑	↑

↑ - Low, ↑↑ - Medium, ↑↑↑ - High

Mondal and Soni 2012

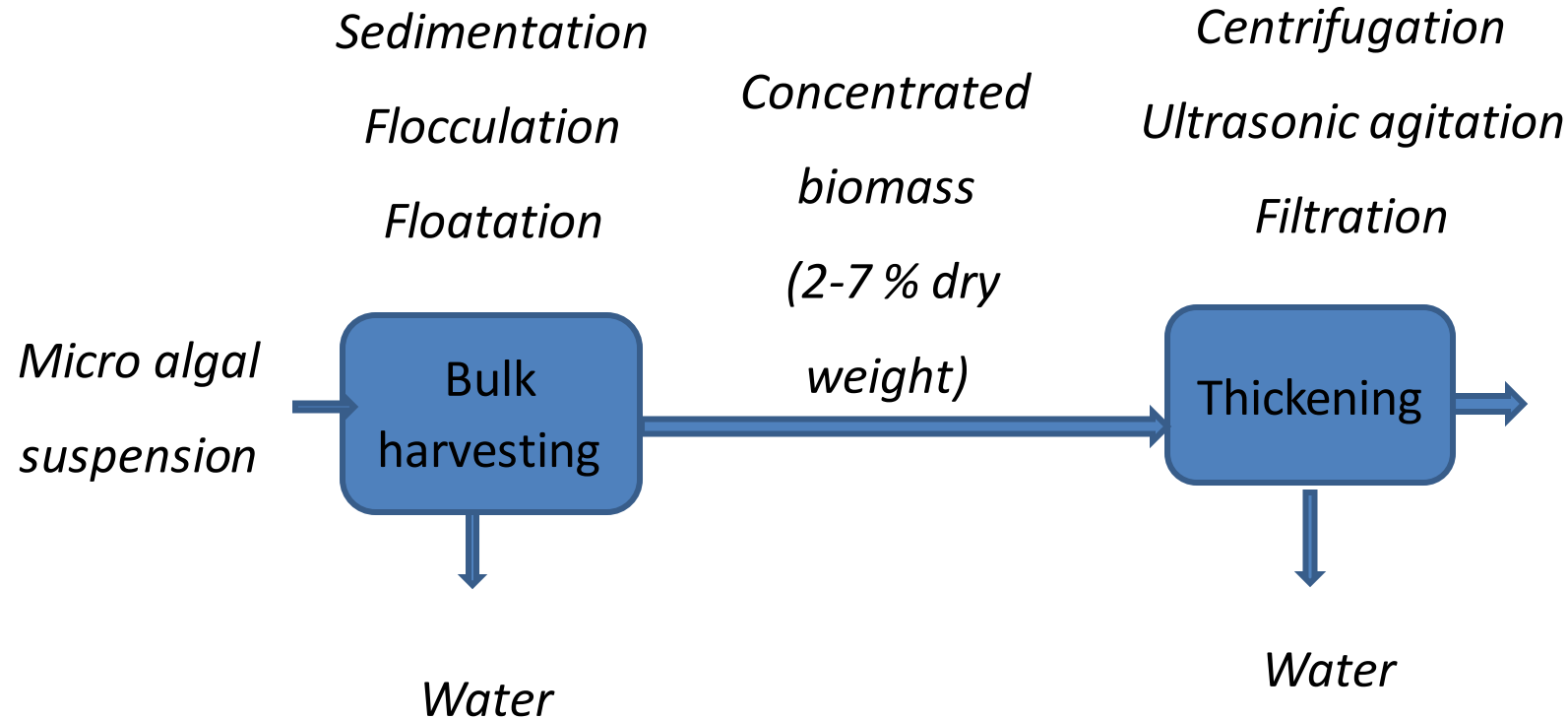


Dimension of various types of photo bioreactor (research scale) Soni, 2012

Photo bioreactor type	Typical dimension
Open Pond	Depth: 1-15 cm
Horizontal tubular photo bioreactor	Tube internal dia. : 2.5 cm
Vertical Column photo bioreactor	Column internal dia. : 2.6 cm
Flat Panel photo bioreactor	Width: 3.2 cm



Harvesting of algal biomass



Flocculation:

Flocculation is used to aggregate the microalgae cells to increase the effective particle sizes. However, the cell wall is a big barrier to facilitate the extraction and the thickness of the cell wall is affected by the conditions of the cells at the time of harvesting.

Alum and ferric chloride are chemical flocculants used to harvest algae. This method is often too expensive in large dimensions.

Interrupting carbon dioxide supply to an algae system can cause microalgae to flocculate on its own, which is called “auto-flocculation”.

Mechanism of flocculation

Flocculation is a process wherein colloids come out of suspension in the form of floc or flake; either spontaneously or due to the addition of a clarifying agent.

Perikinetic flocculation refers to flocculation (contact or collisions of colloidal particles) due to Brownian motion of colloidal particles. Orthokinetic flocculation refers to contacts or collisions of colloidal particles resulting from bulk fluid motion, such as stirring.

Flocculants promote flocculation by causing colloids and other suspended particles in liquids to aggregate, forming a floc.

Many flocculants are multivalent cations such as aluminium, iron, calcium or magnesium. These positively charged molecules interact with negatively charged particles and molecules to reduce the barriers to aggregation. In addition, many of these chemicals, under appropriate pH and other conditions such as temperature and salinity, react with water to form insoluble hydroxides which, upon precipitating, link together to form long chains or meshes, physically trapping small particles into the larger floc.

Long-chain polymers such as modified polyacrylamides also act as flocculants



Unit operations in harvesting algal biomass cont..

Flotation

- Usually flotation is used in combination with flocculation for algae harvesting in waste water. It is a simple method by which algae can be made to float on the surface medium and then removed. It is used alum to flocculate algae/air mixture, with fine bubbles supplied by an air compressor.

Sedimentation

- The flocculation of algal biomass is generally followed by gravity sedimentation for settling of algal flocs, thus enhancing the efficiency of this process . Gravity sedimentation gets (1% to 5% solids) algae biomass harvesting (Girma et al., 2003)
- The sedimentation rates of algae are influenced by the settling velocity of microalgae, which can be increased by increasing cell dimensions (i.e., by aggregation of cells into large bodies)



Centrifugation:

- Centrifugation is a method of separation algae by using a centrifuge to settling it into the bottom of the tank. This method may prove useful on a commercial and industrial scale, but is expensive for personal use.
- This method is reasonably efficient, but sensitive algal cells may be damaged by granulation against the rotor wall.

Ultrasonic agitation

- The ultrasonic field concentrates the cells due to acoustic forces, but the final separation is based on gravity forces.
- This technique is non-fouling, arouses no shear, has the absence of mechanical failures because this device has no freely moving parts and has the possibility of continuous operation.



Filtration:

This method is carried out commonly on membranes of modified cellulose with the aid of a suction pump. The greatest advantage of this method is that it is able to collect microalgae cells with very low density.

However, concentration by filtration is limited to small volumes with eventual clogging in the filters by the package cells when vacuum is applied.

Filtration is best suited for large microalgae, normally ($>70\text{ }\mu\text{m}$), such as *Coelastum proboscideum* and *S. platensis*, but cannot recover organisms with smaller dimensions such *Scenedesmus*, *Dunaliella* or *Chlorella*.

Some techniques used for harvesting microalgae

Microalgae species	Method	Effectiveness	Condition
<i>Spirulina Platensis</i>	Vacuum Filtration	-	Vacuum filtration equipped with regenerated cellulose membrane with a pore size of 0.45 μ m
<i>Stephanodiscus hantzschii</i> , <i>S. astraea</i> and <i>Cyclotella Sp</i>	Tangential flow filtration	70-89% recovery	Cross filtration with a membrane pore size of 0.45 μ m is used
<i>Tetraselmis spp.</i> And <i>Chaetoceros calcitrans</i>	Centrifugation	Greater than - 95% recovery	
<i>Chlorella + Oocytis</i>	Centrifugation	90% recovery	-



Some techniques used for harvesting microalgae

Microalgae sp.	Method	Effectiveness	Condition
<i>B. braunii</i>	Dispersed air flotation	93.6% recovery	-
<i>Chlorella minutissima</i>	Flocculation followed by sedimentation	60% Recovery by efficiency	1g/L of $\text{Al}_2(\text{SO}_4)_3$ and ZnCl_2 and took 1.5 h and 6 h, respectively
<i>Dunaliella salina</i>	Micro bubble flotation	99.2% recovery	Using microbubble generation at a pH of 5 with the aid of ferric chloride coagulant (150 mg/L)



Some techniques used for harvesting microalgae

Microalgae species	Method	Effectiveness	Condition
<i>Chlorella vulgaris</i>	Gravity sedimentation	60% of biomass was recovered	Biomass with density variation between 0.620 and 0.820 OD at 685 nm are settled and took 1 h
<i>Chlorella vulgaris</i>	Flocculation	85%–95% of biomass was recovered	Above 25 mmol/L aluminum sulfate was used as flocculant.
		95% of biomass was recovered	Sodium hydroxide was used as flocculant at pH between 11 and 12

Comparison of some algae harvesting techniques

Biotechnological Applications of
Microalgae, Chapter 6, CRC Press, 2013

Algae Harvest Method	Relative Cost	Yield TSS %	Energy Usage kWh/m ³	Remarks
Gravity sedimentation	Low	1.5	0.1	Not very efficient for rapid biomass recovery from high-rate algal ponds.
Inorganic chemical flocculation	High	90	0.33	The efficiency of the method is affected by media pH.
Polyelectrolyte flocculation	High	15	14.81	
Centrifugation	Very high	22	8	Cost and energy intensive, suitable for high value product.
Filtration(natural/ pressurized)	High	6/27	0.4.0.86	Efficiency depends on hydrodynamics, concentration, and properties of microalgae.
Floatation	High	1-6	10-20	
Auto flocculation	NA	NA	NA	Happens in absence of CO ₂ .



Some example of Waste water treatment using algae

Waste Water	Algal Strain	Nutrient Removal (%)	Process condition	Ref.
Municipal wastewater (Autoclaved)	Chlorella sp.	N-89.9, P-80.9, COD-90.3	Initial N, P and COD : 132.3, 215 and 2390 mg/l respectively; Inoculation-10%, Temp- $25\pm 2^{\circ}\text{C}$, Light intensity- $50\mu\text{mol}/\text{m}^2\text{s}$; Batch ,14 days	Li et al; 2011
Municipal wastewater (Raw)	Chlorella sp.	N-89.1 P-80.9 COD-90.3	Initial N, P and COD : 116.1, 212 and 2304 mg/l respectively; Inoculation-10%, Temp- $25\pm 2^{\circ}\text{C}$, Light intensity- $50\mu\text{mol}/\text{m}^2\text{s}$ Batch ,14 days	Li et al; 2011



Some example of Waste water treatment using algae

Waste Water	Algal Strain	Nutrient Removal (%)	Process condition	Ref.
Soyabean processing wastewater	C. Pyrenoidosa	N-89.9	Initial N, P and COD : 190, 46 and 8087 mg/l respectively ; Temp- $27 \pm 1^\circ\text{C}$, Light intensity- $40.5 \mu\text{mol}/\text{m}^2\text{s}$, Light:dark=14:10 Batch, 5 days	Su et al; 2011
		P-74.5		
		COD-84.0		
Piggery wastewater (Raw)	Chlorella Zofiengensis	N-89.1	Initial N, P and COD : 116.1, 212 and 2304 mg/l respectively ; Inoculation-10%, Temp- $25 \pm 1^\circ\text{C}$, Light intensity- $230 \pm 20 \mu\text{mol}/\text{m}^2\text{s}$, pH=6.8 Batch, 10 days	Zhu et al; 2013
		P-80.9		
		COD-90.3		

Thanks...

