Basic Environmental Engineering and Pollution Abatement
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Lecture 34
Advanced Secondary Processes 2

Hello everyone. Now, we will discuss on the topic Advanced Secondary Processes, Part 2.

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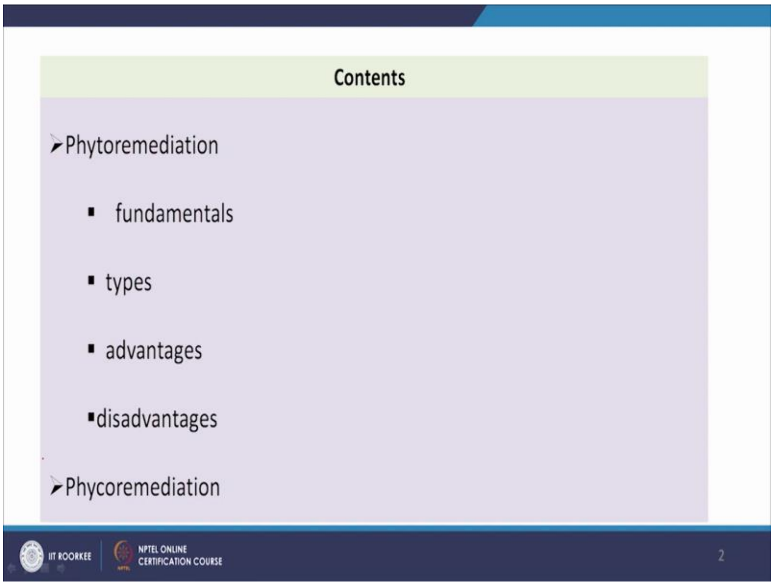

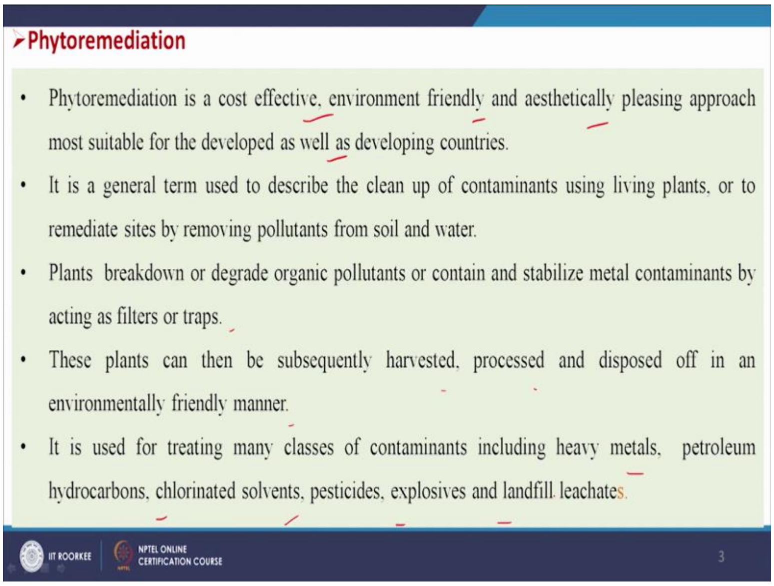

And in this class, we will discuss on phytoremediation, some fundamentals, types, advantages and disadvantages. And also we will discuss phycoremediation. As mentioned earlier that in phytoremediation the living plants are used for the remediation of wastewater and the contaminated soil. We have seen that when we use microbes for the wastewater treatment, then microbes degrade the organic compound, and they can take energy from it that is heterotrophic bacteria or microorganism. There maybe chemoautotrophic microorganisms and autotrophic microorganism, different types of.

So, when we are using the living plant. So, living plant also can take off the organic materials into the cell and that can be metabolized later on. And there are some detoxification mechanism also if the foreign material which is taken up by the plant are having some toxic characteristics, so, there will be some detoxification mechanism. So, the pollutants which are available in the water or in the soil that may be stored locally, or maybe converted to less toxic form, or that may be transmitted from root to shoot to leaves.

So, this way the pollutant will be transmitted and after certain time, the upper parts of the plants can be harvested and can be used to recover this, if it is heavy metal is there or not? If heavy metal is there so that can be recovered, or can we processed with care to eliminate the contamination, the chance of further contamination. So, phytoremediation is a cost effective, environment friendly, and aesthetically pleasing approach most suitable for the developed as well as developing countries. So, phytoremediation is not a very new concept because if we go to villages, we will see that there are many lowlands are there, ponds are there when aquatic plants are there, and they purify the water of the pond.

But this concept we can develop in engineered way and that is called artificial wetland. So, that can be used and people are using it in different parts it can be used in developed as well as developing countries. And it is a general term used to describe the clean up of contaminants using living plants, and or to remediate sites by removing pollutants from soil and water. Plants break down or degrade organic pollutants, or contain and stabilize metal contaminants by acting as filters or traps.

These plants can then be subsequently harvested, processed and disposed of in an environmentally friendly manner. It is used for treating many classes of contaminants including heavy metals, petroleum hydrocarbons, chlorinated solvents, pesticides, explosives and landfill leachates.

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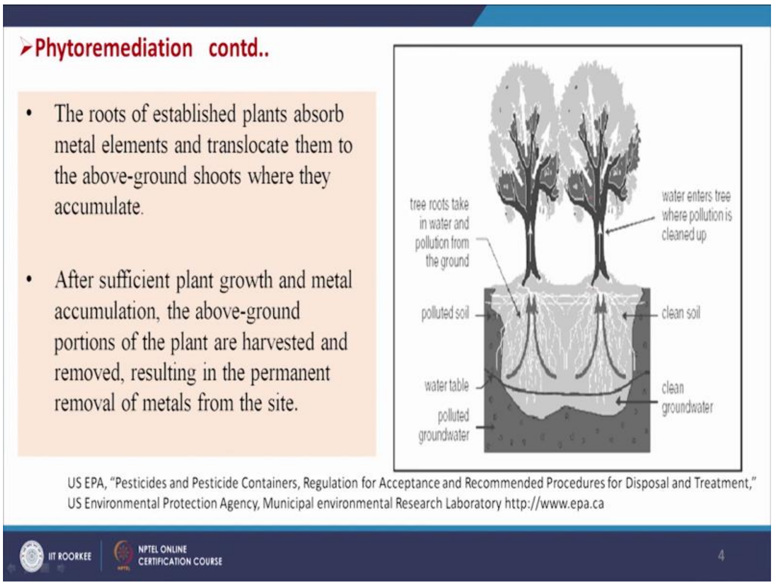

So, you see here, this figure you see. So, pollutants are maybe present in the water or maybe present in the soil, so, that will come to the roots into the plant and that is going towards the steam and towards the leaf. So, depending upon the nature of the pollutants, so that will be translocated maybe available here, maybe transmitted to shoots, or maybe transmitted to leaves also. But that will depend upon the nature of the plant, the nature of the pollutants, etc. So, the roots of established plants absorb metal elements and translocate them to the above ground shoots where they accumulate, so maybe shoot, or maybe leaves.

After sufficient plant growth and the metal accumulation, the above ground portions of the plant are harvested and removed, resulting in the permanent removal of the metals from the site. So, from the site the metal is coming, but where it is going? It is going to the biomass. So, we have to handle this biomass with more precaution.

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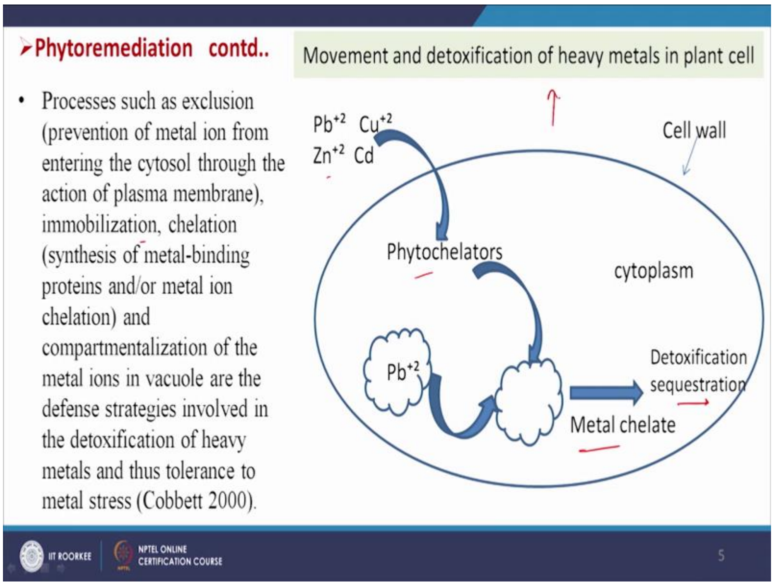

Now we will see how the detoxification mechanism is applicable for plants. So, the processes such as exclusion, that is prevention of metal ion from entering the cytosol through the action of plasma membrane. So, exclusion is one mechanism, and other is immobilization, another is chelation that is synthesis of metal binding proteins and or metal ion chelation, and compartmentalization of the metal ions in vacuole. So, these are the major mechanisms, which work on the detoxification of the heavy metals which are available in the water and soil.

So, here we see these are different metals. So, we have some phytochelators, and then chelate formation is there. So, metal chelates either this can be detoxified, or that will be sequestered. And then from root to shoot it will be translocated.

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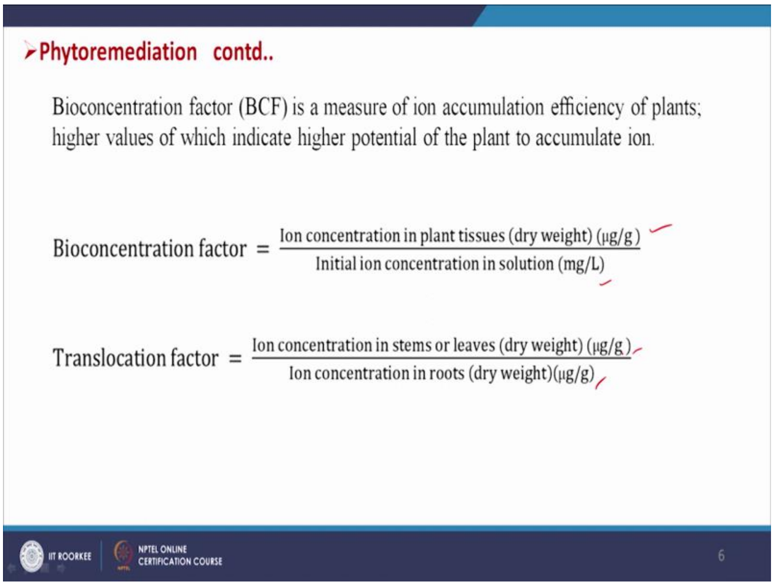

So, there are basically translocation mechanism is there and that will depend upon the nature of the pollutants and the plants we are using as we have mentioned earlier. And we can quantify this term that how the concentration of the pollutants will increase that is bioconcentration factor that will also depend upon the plant species and the pollutant types.

$$\text{Bioconcentration factor} = \frac{\text{Ion concentration in plant tissues (dry weight) } (\mu g/g)}{\text{Initial ion concentration in solution } (mg/L)}$$

$$\text{Translocation factor} = \frac{\text{Ion concentration in stems or leaves (dry weight) } (\mu g/g)}{\text{Ion concentration in roots (dry weight)}(\mu g/g)}$$

Because, the root is in direct contact with the soil, or water, or the contaminants present in the soil and water. And then it is accumulating there, and then it is translocated from root to steam, and steam to leaves gradually. So, these are the formula which are used for the quantification of the pollutants in the steam and leaves.

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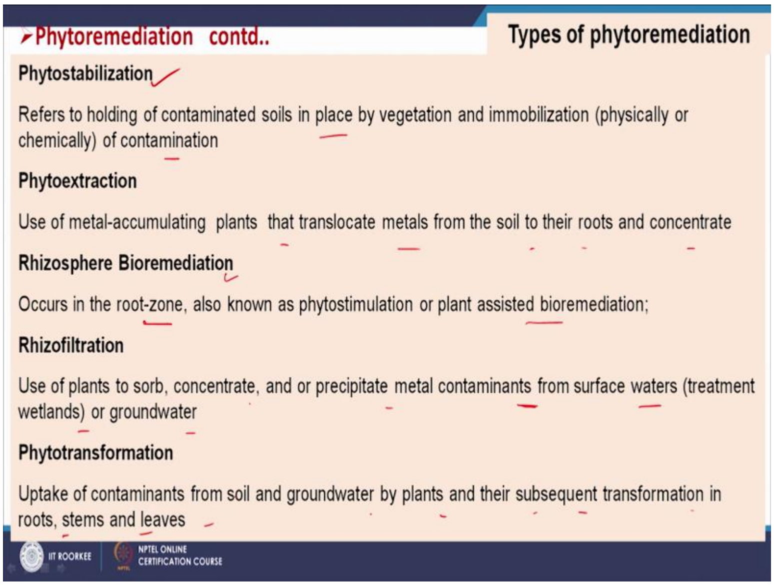

And phytoremediation methods may be of different types, then we will be seeing those types here. So, phytostabilization. So, this refers to the holding of contaminated soils in place by vegetation and immobilization, physically or chemically of contamination. So, for more understanding, we can say that some biochar is also used in soil as a soil conditioner. So, that can also capture heavy metals and other pollutants and remain as such in the soil, but that is not available to the plants for vegetation.

And phytoextractions, the use of metal accumulating plants that translocate metals from the soil to their roots and concentrate. That is those are extracting the metals from the soil or water and that is concentrated on their roots. And rhizosphere bioremediation this occurs in the root zone also known as phytostimulation or plant assisted bioremediation. And these type of plants, the root system is very robust and very huge amount of roots are available, and the pollutants are remediated in this root zone.

And rhizofiltration use of plants to solve, concentrate, and or precipitate metal contaminants from surface waters, the treatment wetlands or groundwater. So, this is the rhizofiltration. So, that use of plans to solve, concentrate, and or precipitate metal contaminants from surface waters. And phytotransformation that uptack of contaminants from soil and groundwater by plants and their subsequent transformation in the roots, stems and leaves. So, these are the different types of phytoremediation methods.

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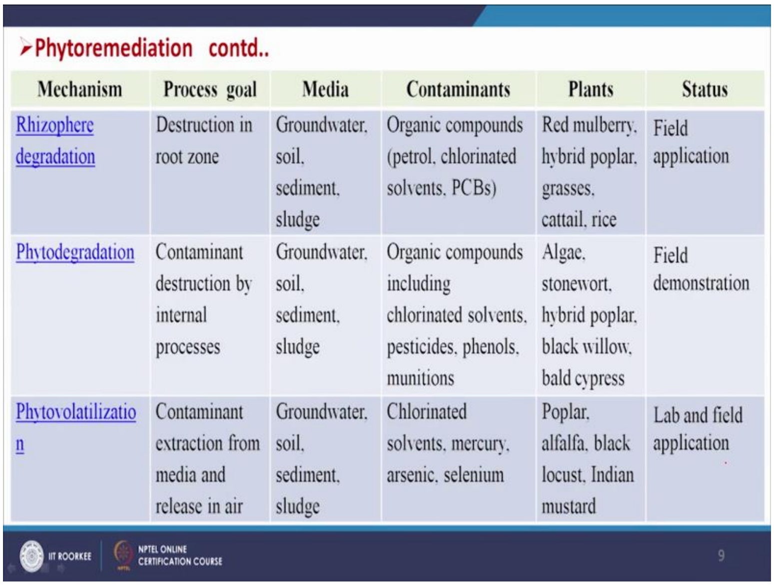
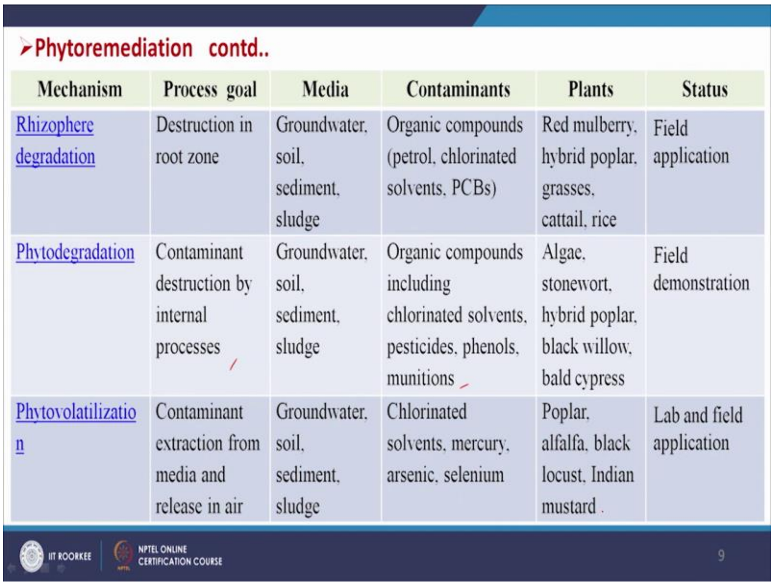


Phytoremediation contd..

Mechanism	Process goal	Media	Contaminants	Plants	Status
Rhizophere degradation	Destruction in root zone	Groundwater, soil, sediment, sludge	Organic compounds (petrol, chlorinated solvents, PCBs)	Red mulberry, hybrid poplar, grasses, cattail, rice	Field application
Phytodegradation	Contaminant destruction by internal processes	Groundwater, soil, sediment, sludge	Organic compounds including chlorinated solvents, pesticides, phenols, munitions	Algae, stonewort, hybrid poplar, black willow, bald cypress	Field demonstration
Phytovolatilization	Contaminant extraction from media and release in air	Groundwater, soil, sediment, sludge	Chlorinated solvents, mercury, arsenic, selenium	Poplar, alfalfa, black locust, Indian mustard	Lab and field application



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And we will compare here say phtoextraction, that is the process goal is contaminant extractions and capture to soil sediment sludge, may be your media where these are available and metals are extracted, and some plants are suitable for this. That is Indian mustard, penny cress, sunflowers, hybrid poplars. And the status is that lab, pilot and field applications. And Rhizofiltration that contaminant extractions and capture is the main objective, and groundwater and surface water is used for this case. And metals, radionuclides are the contaminants investigated. And sunflower, Indian mustard water hyacinth have been used, and lab and pilot scale study has been performed.

And phytpstabilization, contaminant fixation at the root zone and in the roots. So, that is the main objective and metals and brassica, juncea, and poplars have been used in a field application. Similarly, rhizosphere degradation that destructions in the root zone, that is the main objective that means detoxification will take place in the root zone. So, that is rhizosphere degradation and groundwater soil sediment sludge anyone can be used. And then organic compounds are basically degraded in this process, and red mulberry, hybrid poplar, grasses, cattail, rice. So, these are some example of plants which have been used in filed application.

Phytodegradation, the objective is to contaminate distractions by internal processes, and groundwater, soil sediments, anything has been used, and then organic compounds including chlorinated solvents, pesticides, phenols, and munitions have been used Algae, stonewort, and hybrid poplar, black willow, bald cypress have been used in a filed demonstration. And phytovolatilization, the objective is contaminant extraction from media and release in air. So, from groundwater soil sediment has been investigated and chlorinated solvents mercury, arsenic, selenium has been used as a target pollutants. And popular, alfalfa black locust, Indian mustard have been used in lab and filled application.

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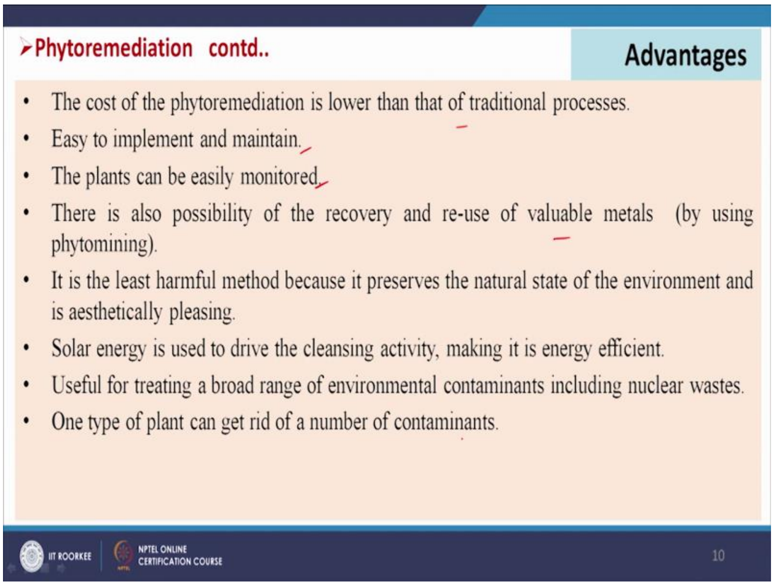

These are the different methods which have been investigated for the phytoremediation of metals and other pollutants. And there are some advantages of phytoremediation, like say the cost of the phytoremediation is lower than that of traditional processes. Easy to implement and maintain, the plants can be easily monitored, there is also possibility of the recovery and reuse of valuable metals by using phytomining So, this new area is also developing that phytomining that means the metal containing plants which we will be getting. So, that will be used for the extraction of the metals once again.

It is the least humble method because it preserves the natural state of the environment and each aesthetically pleasing. Solar energy is used to drive the cleansing activity, making it is energy efficient, useful for treating a broad range of environmental contaminants including nuclear waste, one type of plant can get rid of a number of contaminants.

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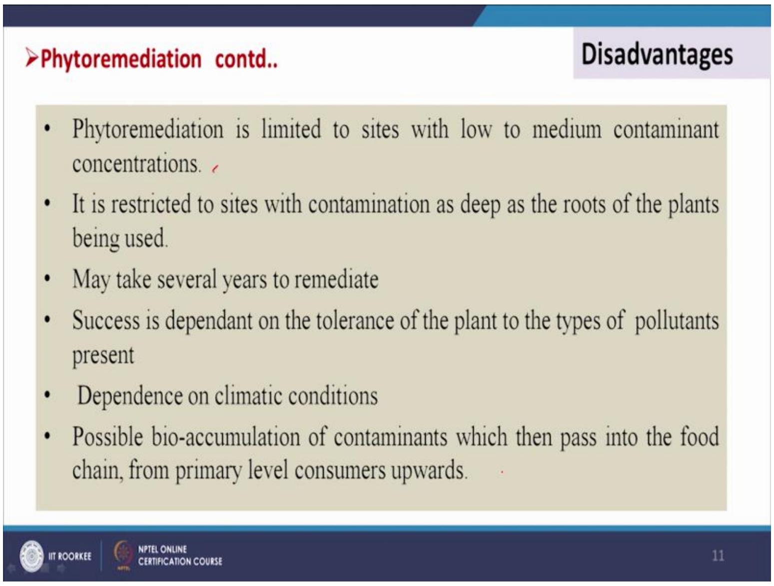

It has some disadvantages also, like phytoremediation is limited to sites with low to medium contaminant concentrations, it is not very suitable for high concentration removal. It is restricted to sites with contaminations as deep as the roots of the plants being used, and may take several years to remediate, success is dependent on the tolerance of the plant to the types of pollutants present, and dependence on climatic conditions, possible bio-accumulation of contaminants which then pass into the food chain from primary level consumers upwards. So, that is also one drawback of this that pollutants may be accumulated and that can be passed upward to the food chain.

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And this slide shows us some photograph, artificial wetland where the plants have been grown and used for the treatment of the wastewater and this is on lab scale setup. So, in the laboratory scale also providing control light and the plants that is Vetiveria Zizanioides have been grown here. So, for the removal of arsenic fluoride, etc. from the contaminated water.

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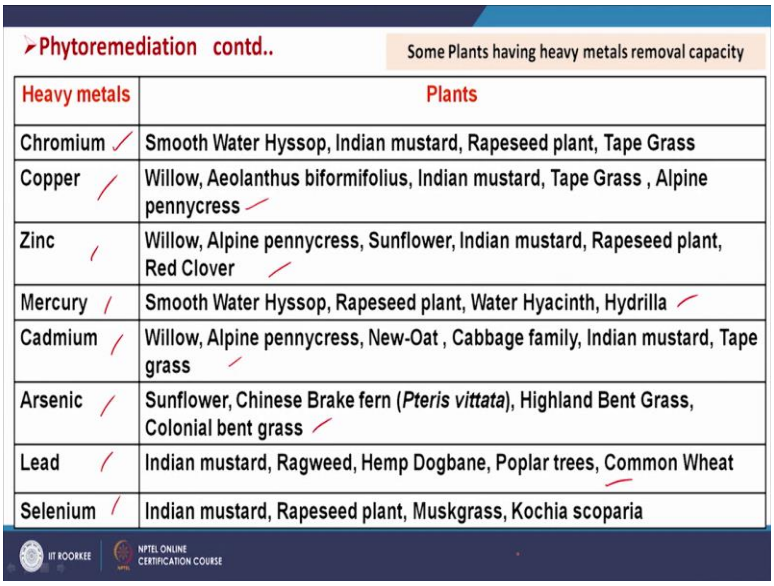

Heavy metals	Plants
Chromium	Smooth Water Hyssop, Indian mustard, Rapeseed plant, Tape Grass
Copper	Willow, Aeolanthus biformifolius, Indian mustard, Tape Grass , Alpine pennycress
Zinc	Willow, Alpine pennycress, Sunflower, Indian mustard, Rapeseed plant, Red Clover
Mercury	Smooth Water Hyssop, Rapeseed plant, Water Hyacinth, Hydrilla
Cadmium	Willow, Alpine pennycress, New-Oat , Cabbage family, Indian mustard, Tape grass
Arsenic	Sunflower, Chinese Brake fern (*Pteris vittata*), Highland Bent Grass, Colonial bent grass
Lead	Indian mustard, Ragweed, Hemp Dogbane, Poplar trees, Common Wheat
Selenium	Indian mustard, Rapeseed plant, Muskgrass, Kochia scoparia

Now, we will see here some plants having heavy metal removal capacity. Let us say chromium, copper, zinc, mercury, cadmium, arsenic, lead, selenium, all these heavy metals have been removed using different types of plant species as mentioned here. For chromium, for these are the for coppers, these are for zinc, these are for mercury, and these were cadmium, these are for arsenic, these are for lead, and these are for selenium.

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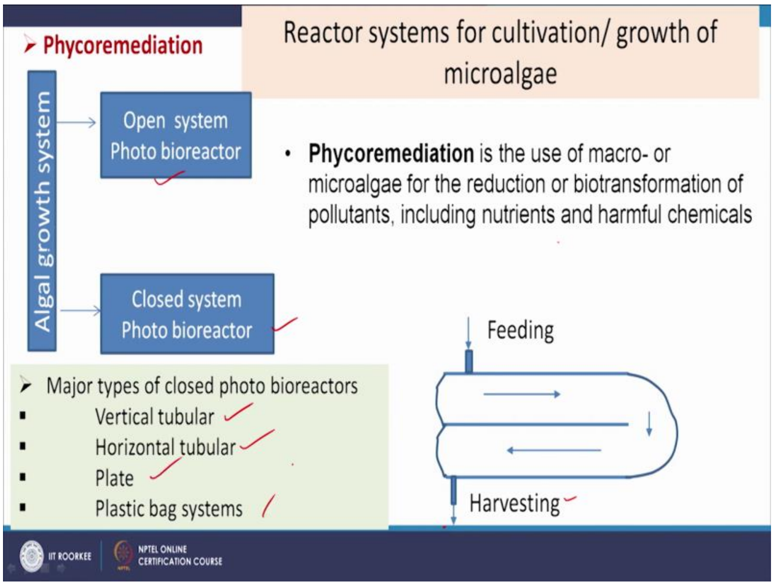

Now, we will discuss on the phycoremediation. So, in case of phycoremediation, algae is used for the removal of the pollutants. So, algae are autotrophic, and some algae are heterotrophic, and in presence of sunlight some algae produces food, but in absence of sunlight, they use organic carbon also. So, the algae both micro and macro can be used for the treatment of wastewater, at the same time it will give us some algal biomass that can be used for bio oil production, or biogas productions, or as a renewable energy feedstock. So, that is the one another advantage of this process also.

And the growth of this microalgae is very fast, so the efficiency of the processes is also very good. If the concentration level is in lower side. And you see here, if we the phycoremediation is the use of macro or micro algae for the reduction or bio transformation of pollutants including nutrients and harmful chemicals. And there are basically two types of phycoremediation system. One is open system photo bioreactor, and closed system photobioreactor. So, why it is photobioreactor? Because, the algae produces food through photosynthesis in presence of sunlight, so, that is photo bioreactor.

And this is one flow sheet of the open system photobioreactor. So, here we are getting the feeding and this is our open pond say. So, wastewater is getting entry here, it is getting some residence time. So, microalgae is growing here, and pollutants are being taken off by the microalgae, and when it is going out we are harvesting the microalgae. So, microalgal concentration we are maintaining, at the same time we are getting treated water here.

We are also getting harvested algal biomass. So, two benefits we are getting. So, this is open system. But in case of closed system, this is not in open in contact to air. So, that will be in a closed vessel, and in that case we can get different types of closed photobioreactors, like vertical tubular, horizontal tubular, plate and plastic bag systems.

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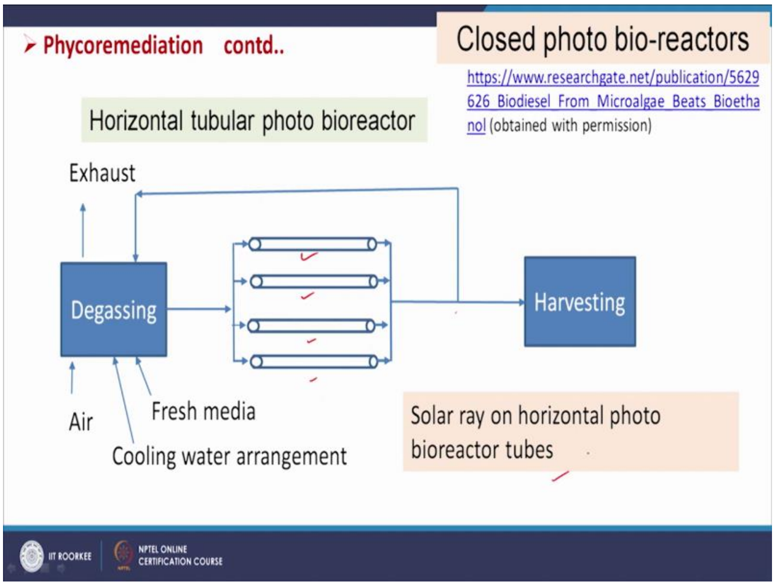

Now, here we see the horizontal tubular photobioreactor. These are the photobioreactors in parallel arrangement. So, here the wastewater is going through it and algae is growing. So, then it is coming out, then we are doing some harvesting. So, after harvesting, we are getting some algal biomass, we are getting wastewater. So, some part of that wastewater and this harvesting biomass is recycled here. So, this is used for degassing, because here the algae is working on it. So, this algae is generating oxygen in presence of sunlight.

So, this water we are sending here. So, that will be having some oxygen that needs to be removed. So, that is the air is sent. So, oxygen will be removed, and that is degassing section is there and cooling water arrangement is also needed to maintain the temperature. Because due to the presence of sunlight the temperature will be higher, with raise, and that temperature will be reduced by the cooling water arrangement. So, this is a flow sheet of a solar ray horizontal photobioreactor tubes.

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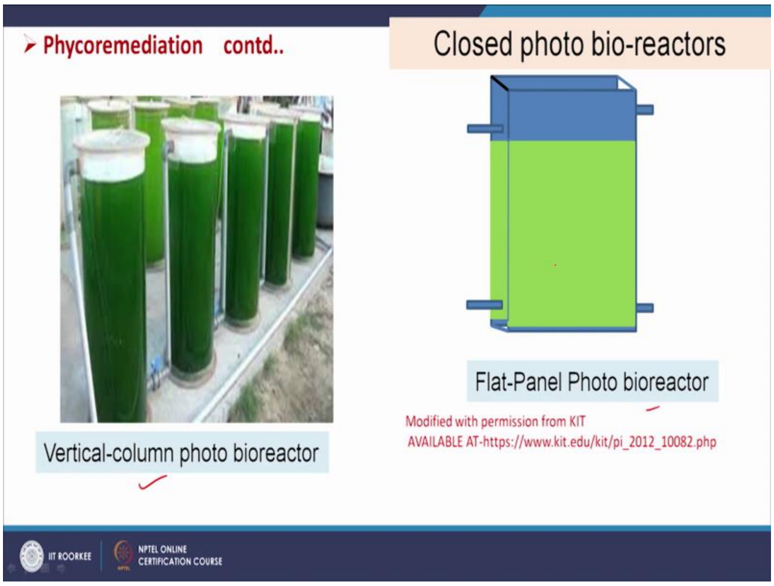

Now, this is a vertical column photobioreactor you see here the vertical columns are there. So, this is the entry from that side water is coming and then. So, this is getting out, that is in, out, in like this. So, this is our first column out is the into the second column, second column out into the third column, third column out, fourth column, fourth column out into the fifth column. So then from fifth column, it is going as a final treated water. So, after harvesting, we will be getting the treated water. So, this is your vertical column photobioreactor. And similar a flat panel photobioreactor which looks like a flat panel. So, inlet and outlet will get. So, these are closed photobioreactor.

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Phycoremediation contd..

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)

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Now, we will see the difference between the open and closed photobioreactor. So if we compare these two types of photobioreactor with respect to some parameters like say required space, so for open ponds it is high space required, but in case of closed photobioreactor, lesser space is required. And water loss is very high in case of open ponds, but it is less in case of closed photobioreactor. And carbon dioxide is loss is also again high in case of open ponds and low in case of closed photobioreactor. Oxygen concentration usually low enough because of continuous spontaneous outgas in case of open pond.

And for close photobioreactors it requires gas exchange devices that is oxygen must be removed to prevent inhibition of photosynthesis or photooxidative damages that we have already mentioned. And then temperature, that highly variable some control possible by pond depth only. And for closed photobioreactor cooling often required and temperature control can be done more precise. And low shear is experienced in case of open pond and high shear is experienced in case of closed photobioreactors.

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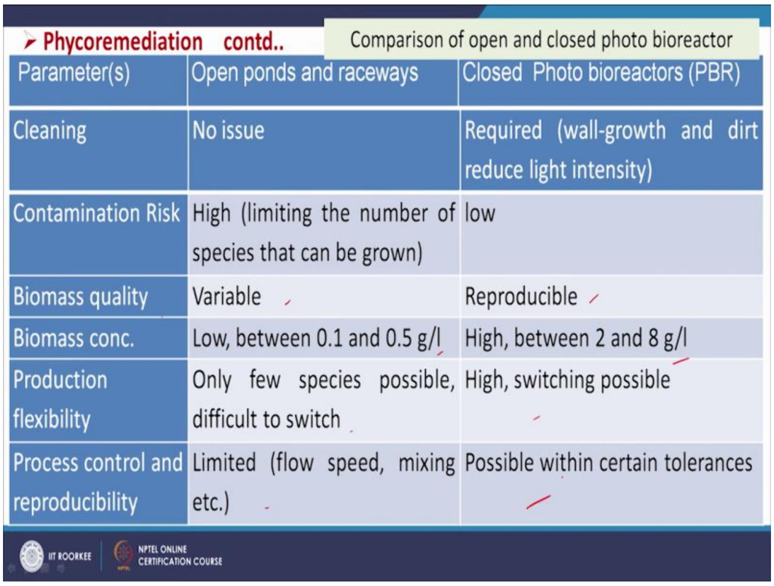

Parameter(s)	Open ponds and raceways	Closed Photo bioreactors (PBR)
Cleaning	No issue	Required (wall-growth and dirt reduce light intensity)
Contamination Risk	High (limiting the number of species that can be grown)	low
Biomass quality	Variable	Reproducible
Biomass conc.	Low, between 0.1 and 0.5 g/l	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

Cleaning in case of open ponds, no cleaning, no issue. But closed pond, it requires cleaning and wall-growth and dirt reduce light intensity. And contamination risk there is good risk for open pond, but there is low risk for closed photobioreactor. Biomass quality again open ponds variable, and is better and it is reproducible in closed photobioreactor. Biomass concentration low between 0.1 and 0.5 g/L for open pond system, where have this is high between 2 to 8 g/L for closed photobioreactor.

And production flexibility only few species possible difficult to switch in case of open ponds, but this is production flexibility very high in case of closed photobioreactor. And process control and reproducibility is limited in case of open ponds, and more control and reproducibility is possible for closed photobioreactor.

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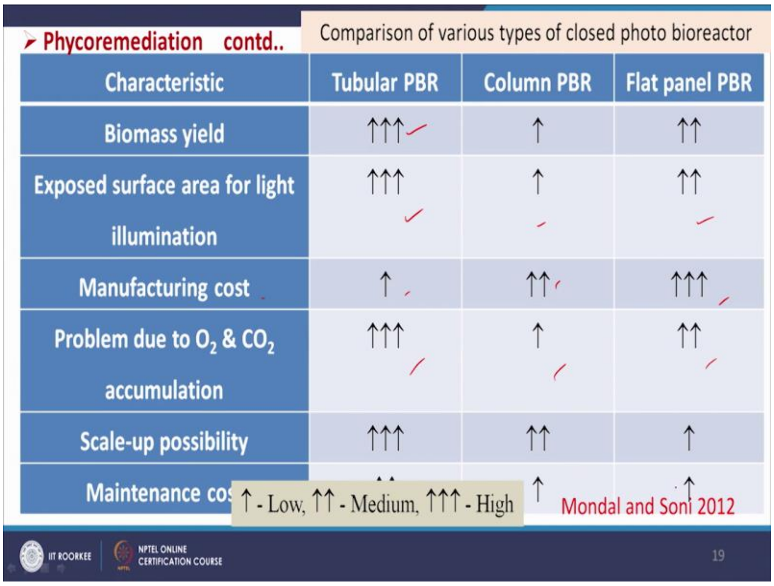

Now, we will compare different closed photobioreactor, like say tubular photobioreactor, column photobioreactor, and flat panel photobioreactor. So here we will see that biomass yield it maximum in case of tubular PBL followed by flat panel and then column PBR. The exposed surface area of light illumination, maximum in tubular followed by flat panel, and column PBR. Again, manufacturing cost is maximum in flat panel PBR, followed by column, and then tubular PBR.

Problem due to O_2 and CO_2 accumulation maximum in case of tubular PBR, followed by flat panel, and then column PBR. And scale up possibility very high in case of tubular PBR, followed by column PBR, and then flat panel PBR, it is very low possibility. And maintenance cost is medium in case of tubular, and low in case of column PBR and flat panel PBR.

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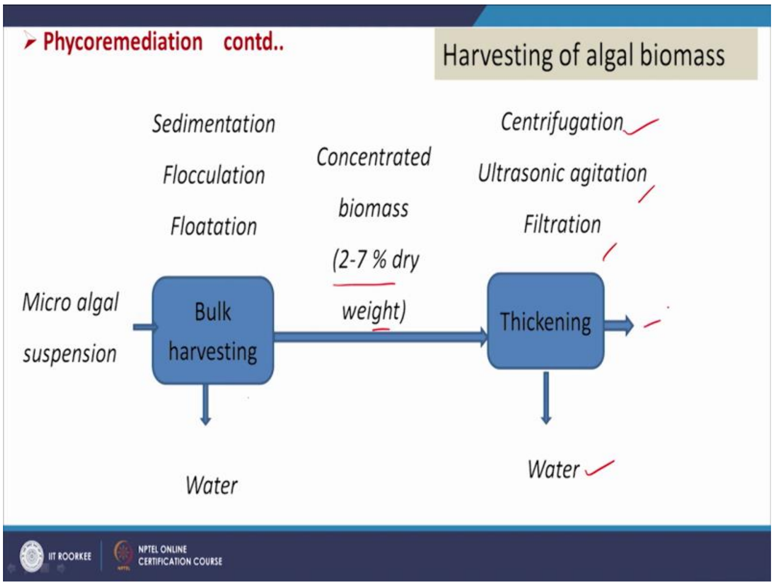

Now, we will discuss on the harvesting of algal biomass. So, algal growth is taking place in the photobioreactor and when the wastewater is going out, we are harvesting the algal biomass. So, in the treated water the concentration of algal biomass is very, very less. So, then we have to concentrate it. So, there are basically two steps for its concentration. The first step there is bulk harvesting, where microalgal suspensions, and then it is concentrated through the sedimentation, flocculation, and flotation.

So that water is separated and we are getting condensed microalgae, that is 2 to 7 % dry weight, concentrated biomass you are getting. Then this will be thicken further by using centrifugation, ultrasonic agitation, filtration or any of these or any combination, then we will be getting pure water, and we will be getting the concentrated algal biomass.

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Phycoremediation contd..

Some techniques used for harvesting microalgae

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

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Phycoremediation contd..

Some techniques used for harvesting microalgae

Microalgae sp.	Method	Effectiveness	Condition
B. braunii	Dispersed air flotation	93.6% recovery	-
Chlorella minutissima	Flocculation followed by sedimentation	60% Recovery efficiency	1g/L of $Al_2(SO4)_3$ and $ZnCl_2$ and took 1.5 h and 6 h,respectively
Dunaliella salina	Micro bubble flotation	99.2% recovery	Using microbubble generation at a pH of 5 with the aid of ferric chloride coagulant (150 mg/L)

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Phycoremediation contd..

Some techniques used for harvesting microalgae

Microalgae species	Method	Effectiveness	Condition
Chlorella vulgaris	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
Chlorella vulgaris	Flocculation	85%–95% of biomass was recovered	Above 25 m mol/L aluminum sulfate was used as flocculant.
		95% of biomass was recovered	Sodium hydroxide was used as flocculant at pH between11and 12

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And here we will see some comparison. So, these are the different microalgae species used for different study. Like say vacuum filtration, and then tangential flow filtration, centrifugation, centrifugation. So, here we will see the effectiveness. So, it is not mentioned here, but 70 to 89 % for tangential flow filtration, and centrifugation greater than 95 %, here greater than 90 %. And these are the conditions which have been investigated. So, it is seen that for centrifugations we will be getting more effectiveness.

And some other examples different microalgal species used, and different methods like dispersed flotation, flocculation followed by sedimentation, micro bubble floatation, etc. Here also the effectiveness are given. So somewhere it is 93.6 %. Here it is 60 %. Here 99.2 % recovery, and these are the conditions which have been used for this harvesting process.

Another two examples are here that is these are the microalgal species used, and this is the method, gravity discriminations and flocculation. Again, the effectiveness are given and conditions are also given. So, here it is 60 % effectiveness here 85 To 90 % biomass recovered, and 95 % biomass was recovered. So, these are having sodium hydroxide was used as flocculant at pH between 11 and 12. So, these are the different methods which have been investigated for the harvesting of the algal biomass.

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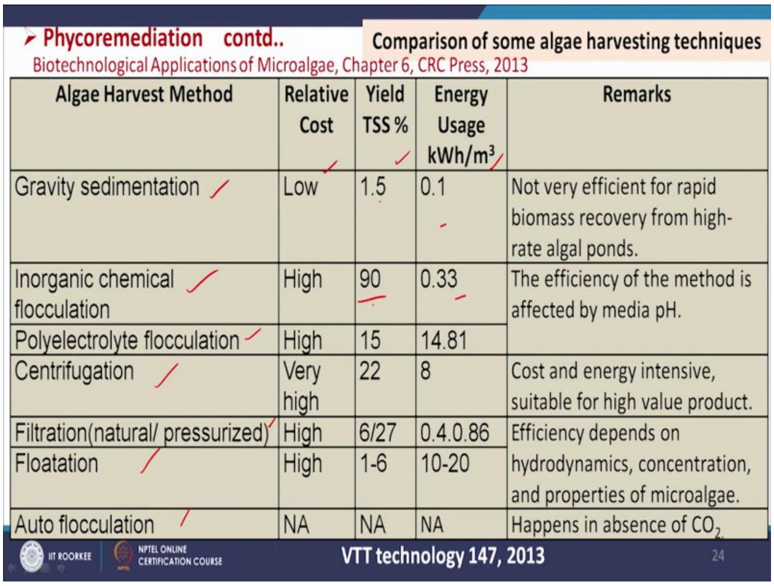

Algae Harvest Method	Relative Cost	Yield TSS %	Energy Usage kWh/m^3	Remarks
Gravity sedimentation	Low	1.5	0.1	Not very efficient for rapid biomass recovery from high-rate algal ponds.
Inorganic chemical flocculation	High	90	0.33	The efficiency of the method is affected by media pH.
Polyelectrolyte flocculation	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

And this slide gives us some comparison of some algal harvesting techniques. Let us say gravity sedimentation, in organic chemical flocculation, polyelectrolyte flocculation, centrifugation, filtration, natural/pressurized, and flotations, and auto flocculation. If we compare the relative cost and yield TSS percentage, what is the percentage of solid we are getting or energy uses. Then we see this is the scenario, different methods, different relative cost, different TSS yield, different energy uses. So, here maximum is 90 % TSS, through inorganic chemical flocculation, and here energy usage is 0.33.

So, this we see, lower side you see energy usage, and higher size TSS, but gravity sedimentation is having the lowest energy uses, but the TSS yield is very very less with respect to other method. So, we can select one on the basis of our situation or type of microalgae we are using, type of density of the microalgae cells etc. And we can select any one suitable process for the harvesting purpose.

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Some example of Waste water treatment using algae

Wastewater	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±2°C, Light intensity-50µmol/m²s ; 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±2°C, Light intensity-50µmol/m²s Batch ,14 days	Li et al; 2011

Some example of Waste water treatment using algae

Wastewater	Algal Strain	Nutrient Removal (%)	Process condition	Ref.
Soyabean processing wastewater	C. Pyrenoidosa	N-89.9 P-74.5 COD-84.0	Initial N, P and COD : 190, 46 and 8087 mg/l respectively ; Temp-27±1°C, Light intensity-40.5µmol/m²s, Light:dark=14:10 Batch, 5 days	Su et al; 2011
Piggery wastewater (Raw)	Chlorella Zofiengensis	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±1°C, Light intensity-230±20 µmol/m²s , pH=6.8 Batch, 10 days	Zhu et al; 2013

And now, we will see some example of wastewater treatment using algae. Like say, municipal wastewater have been used and chlorella species has been used, and municipal wastewater raw and some autoclaved have been used. So, people have tried to find out whether there is an effect of the other microorganisms present in it. So, that is autoclaved means no other microorganisms. And here raw means many other microorganisms are present. So, that way the investigations have been carried out for the nitrogen removal, phosphorus removal, and COD removal, and different conditions have been used.

That is initial N, P and COD concentration is given here, light intensity and batch days. Inoculation, what is the percentage of inoculation that is also given. So, these are the different conditions which have been used by different researchers for the removal of nitrogen, phosphorus, and COD using different microalgaes, and different wastewater sources. Some other examples are. So, I have been processing wastewater, piggy wastewater. So, industrial wastewater also has been used.

So, different microorganisms have been tested and nitrogen, phosphorus, COD removal has been investigated. So, these are very old literature, that is 11 and 2013. By the meantime many other research have come up, and this area is being developed gradually. And it has been found that this algal treatment may be very promising for the treatment of low organic load municipal wastewater treatment purpose. Up to this in this class, thank you very much for your patience.