Membrane Technology

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Lecture No 5
Membrane Modules and Selection, Flow Types

Good morning, students. Today is the module 2, and Lecture 5.

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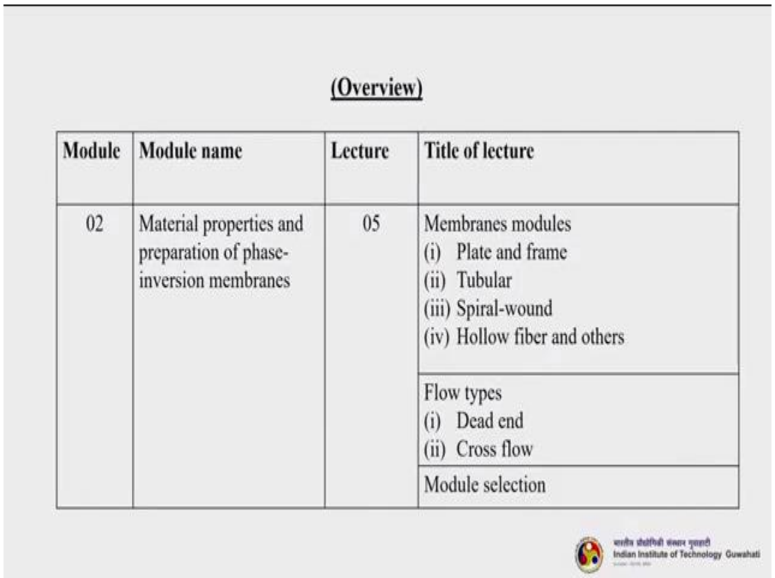

(Overview)

Module	Module name	Lecture	Title of lecture
02	Material properties and preparation of phase-inversion membranes	05	Membranes modules (i) Plate and frame (ii) Tubular (iii) Spiral-wound (iv) Hollow fiber and others
			Flow types (i) Dead end (ii) Cross flow
			Module selection

So here in this class will cover about the membrane modules and different types of member and modules and what are the flow types, and then how we actually select particular module.

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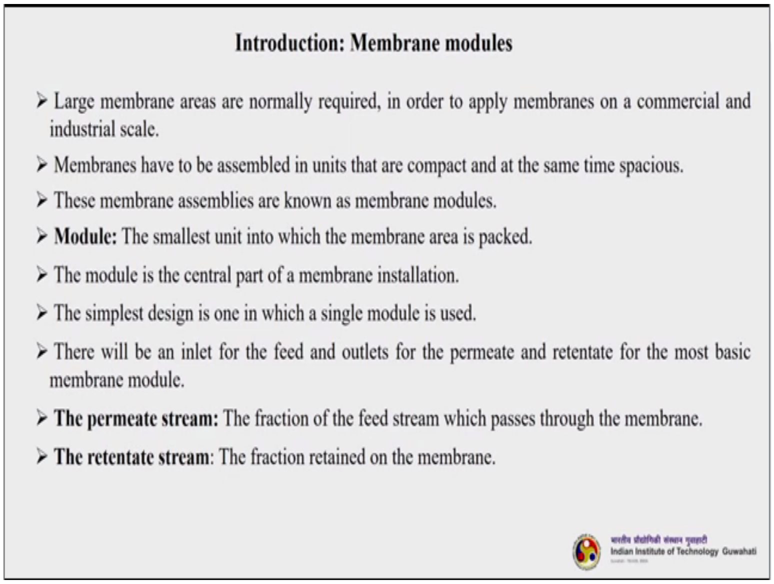

So, you know, large membrane areas are normally require, in order to apply membranes on a commercial and industrial scale membranes have to assemble in units that are compact and at the same time spacious. Now these membrane assemblies are actually called as membrane modules. Module, by definition, is the smallest unit into is the membrane area, each pair, whatever wherever the membrane area.

That what you actually, we get after we have a particular design to achieve a target separation, and the module is the central part of the membrane installation. The simplest design is the one, in which a single module is used. There will be an inlet for the feed and outlet for the permeate and retentate that is the most basic membrane module that can be possible. The permeate stream is a fraction of the feed stream which passes through the membrane and retainted it is the one which is retentate on this surface of the membrane.

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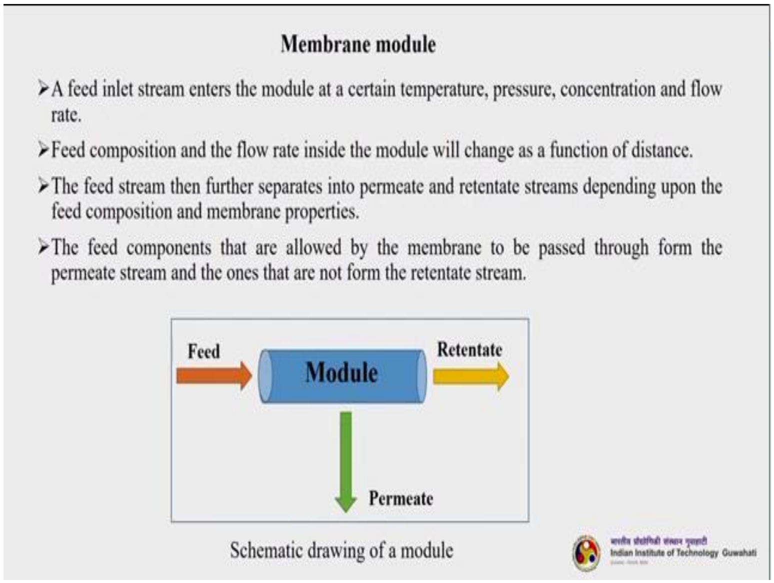

Please look at this particular figure. And you can see a feed inlet stream enters the module, at a certain temperature, pressure, concentration and flow rate another feed composition and the product inside the module will change as a function of distance. Right, so that precisely that means that when the feed is flowing like from the inlet to outlet in this direction. Okay, that the composition of the feed, as well as the flow rate will change because the membrane.

The feed is passing through the membrane. So some permeation is happening, and then whatever the solutions that are not able to pass through the membrane, are retentate so the solute concentration on the surface of the membrane, which are rejected is getting enhanced as the pro progresses, and at the solutes which are rejected through the membrane. That means they are going to this permeate side, okay, their concentration in the feed is continuously decreasing.

So the feed stream, therefore the separates into this permeate and retentate depending upon the feed competition and the membrane properties, the feed components that are allowed by the membrane to be pass through form the permeate stream and the ones that are not from that retentate to this is what we have understood earlier also.

Whatever that is rejected by the membrane, or we can say retained on the surface of the membrane okay that forms retentate, whatever that is passing through the membrane. Okay. That is permeate.

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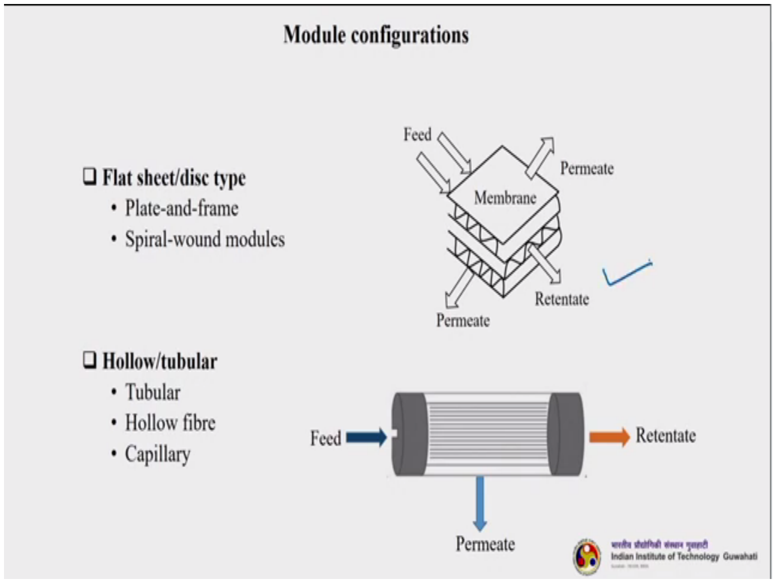

So, let us start discussing the module configurations. There are various types of module configurations that is possible, but broadly, we classify them into two types flat sheet or disc type, under which the traditional plate-and-frame module and spiral-wound modules will come, and then hollow fiber or tubular under which tubular modules hollow fiber modules capillary modules all these are the possible configurations under hollow fiber tubular category.

So, this is the flat sheet, plate-and-frame type flat sheet or disc type membrane, which is the traditional plate-and-frame module, and here this one is the tubular hollow fiber module.

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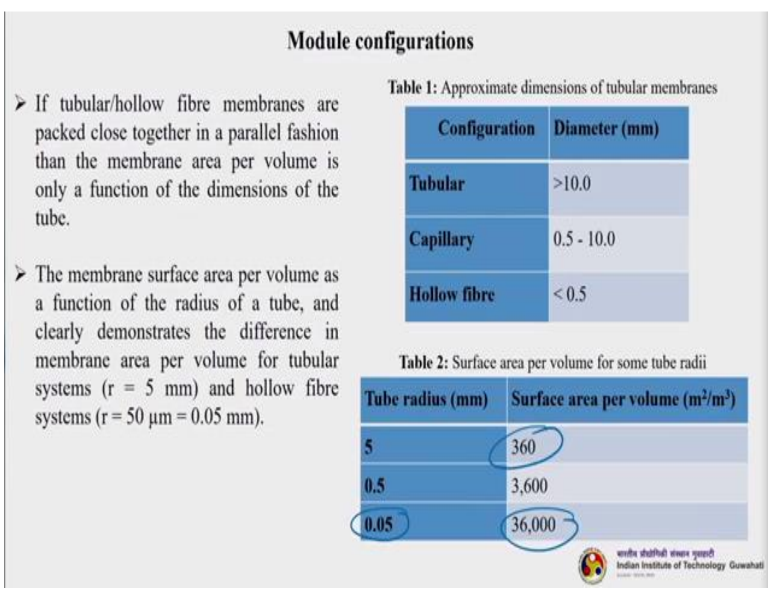

So, if if tubular hollow fiber membranes are packed close together. Okay, in a parallel fashion, then membrane area per volume is only a function of the diamensions of the tube So that means, when the fibers, we can have single hollow fiber membranes, or fibers we can call them fibers also. So, many of them actually have joined a fuse together to form a hollow fiber membrane module. So, the membrane area per volume is only a function of the diamensions of the tube.

So you increase the diamensions of the tube your membrane area for volume gets increased. So you can see the approximate dimensions of tubular membranes. So tubular is usually greater than 10 centimeter at 10. millimeter capillaries .5 to 10 and hollow fiber is usually less than .5. So, the membrane surface area per volume is a function of the radius of the tube and clearly demonstrates the difference in the membrane area per volume particular system.

Usually the radius is about 5mm and hollow fiber system, it is anywhere between 50 micron to .05 mm that is basically, so that you can see the table 2 were we have given surface area volume of some of the activities. So if the tube radius is approximately 5 mm. So you get us a surface area for volumes is almost approximately 360,meter square per metercube, similary for 0.05, We get 36,000 area per volume that is meter square per metercube.

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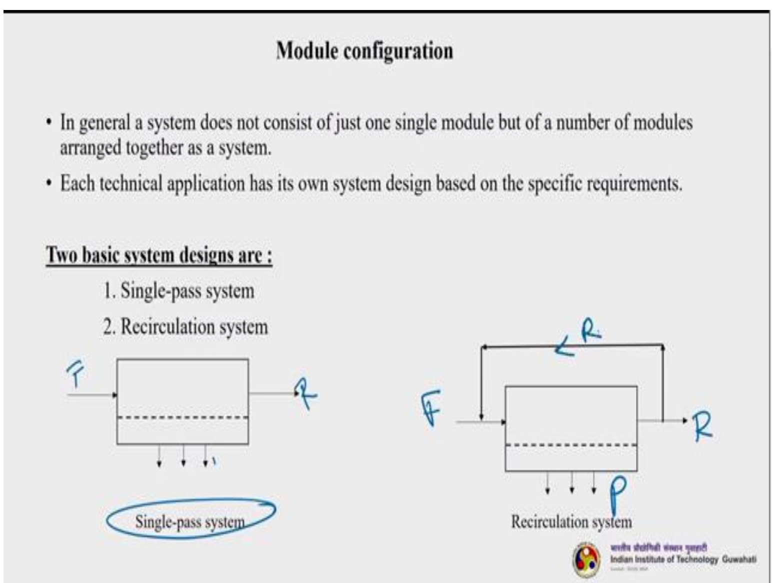

So, in general, a system does not consist of just one single module, but of a number of modules areas together as a system. Now, each technical application has its own system design based on specific requirements. Now please understand that, whether I am going to use a single module, or I can have so many different modules, which are fused together, or combined together. So it all depends upon what is my targeted separation, what I want to achieve what is the feed. What I want to retain what I want to permeate.

And there are so many other process parameters that also affects. Apart from the membrane itself and as well as module configuration. So we have two basic types of design. So one is called the single pass system and another is the recerculation system. So same single pass system. So, you can see this was single pass system, here the feed enters. Okay, and the permeate is that is coming through the membrane, and we get retentate here.

And in case of the recirculation system. Okay, so feed that is entering the membrane and module permeate we are getting here, and we are getting retentate here, but the path of the retented is getting recycled back. Okay, so this is called the recirculation system. This is actually being done to achieve a particular separation or targeted inter separation. Okay.

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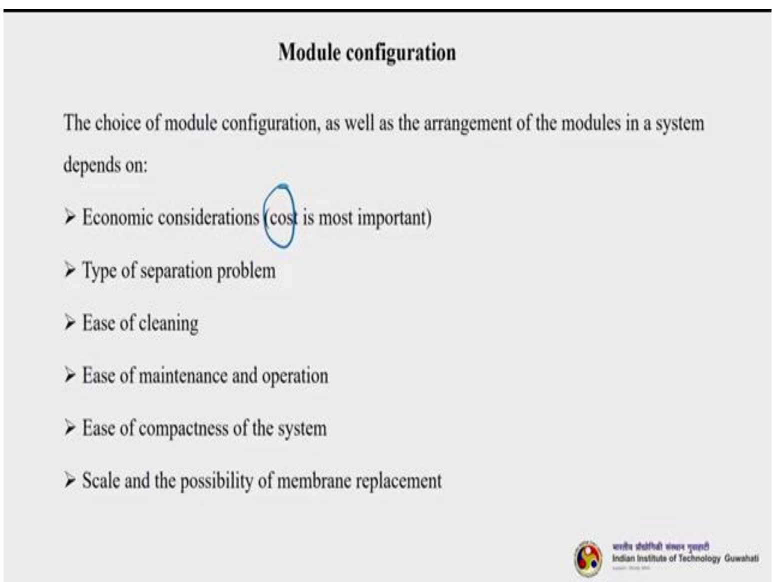

The choice of module configuration as well as the arrangement of the module in a system depends on several characteristics features. So the first and foremost important thing is of course cost, cost is the most important thing. Then type of the separation problem what you are going to separate that is very important. Okay, you may be given a task of separating or purifying water, it may be desalination. Okay. brackish water of seawater.

So it can be removal of organics or heavy metals from wastewater stream, or it can be purifying proteins or monoclonal antibodies so the list is endless. So that is one of the most important consideration, while deciding a module configuration. Then, ease of cleaning is one of the another parameter, which also should be consider while designing a module, how easily I can clean the membrane, because Anyway, after a certain time either time progresses, or time elapsed.

So what will happen that there will be concentration polarization and fouling. So to get rid of these things we need to clean the membrane, either by using by backflushing or some other techniques. So to do that, I must disassemble the membrane module and modules should be in such a way that is easy to assemble and easy to disassemble them cleaning will not a problem. So, is maintenance and the operation. So an ease of compactness how compact it is, in a small area how much area is actually occupying, in industry space is also a cocern.

So, in the less area, less space that is available pore space basically. How can I configure a module so that we do less pore area you can have more membrane in area them scale and possibility of the membrane replacement.

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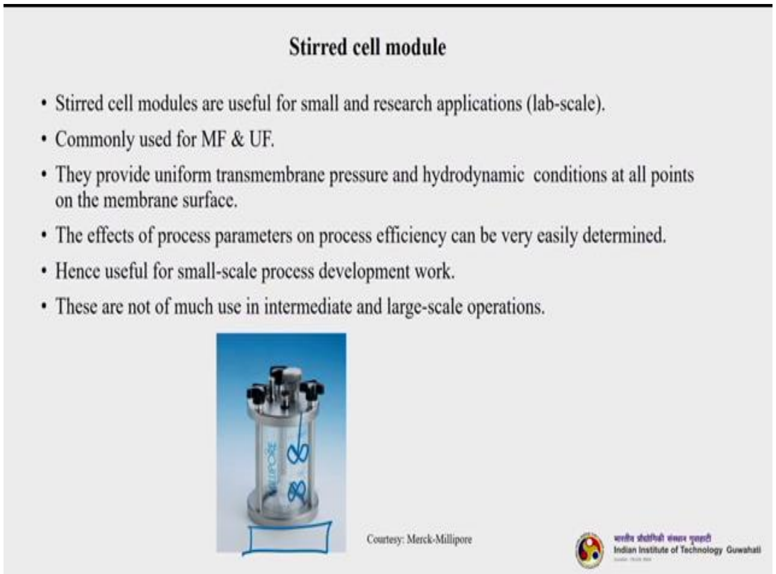

And now students, let us see one by one different types of configurations. The first most important membrane module configuration that has been actually discovered is nothing but the stirred cell module so you can see the picture. Exactly. It looks like this this is a dead end filtration module it is called Stirred cell because there is a stirred here inside which is not visible. Okay, so it is mechanical it is getting stirred here also okay.

So I can have it mechanical stirred from here, or I can have a magnetic stirred here okay and I have a magnetic plate here, so that the module will be stirred. So the material inside the module will be stirred. So, these are useful for small and research applications usually large scale, no there is no commercial application of this in large scale operations, commonly used to characterize actually microfiltration and ultrafiltration membranes.

So they provide the beauty of this module is that the provide uniform transmembrane process, and had a dynamic condition set all parts of the membrane surface. That is because it is dead end filtration and, you feed the module, then close it and start it. So then separation is occurring so continuously permeate is being drawn out. Okay, and however, the retentate is the feed remains inside and above the surface of the membrane okay.

And effects of process parameters on process efficiency can be very easily determined, hence useful for small scale process development work. These are not of much use in intermediate and large scale so basic uses that let us say you design a membrane and you fabricate it. So then you have to test the membrane so to testing that membrane and finding out is performance in the lab scale actually it is being used.

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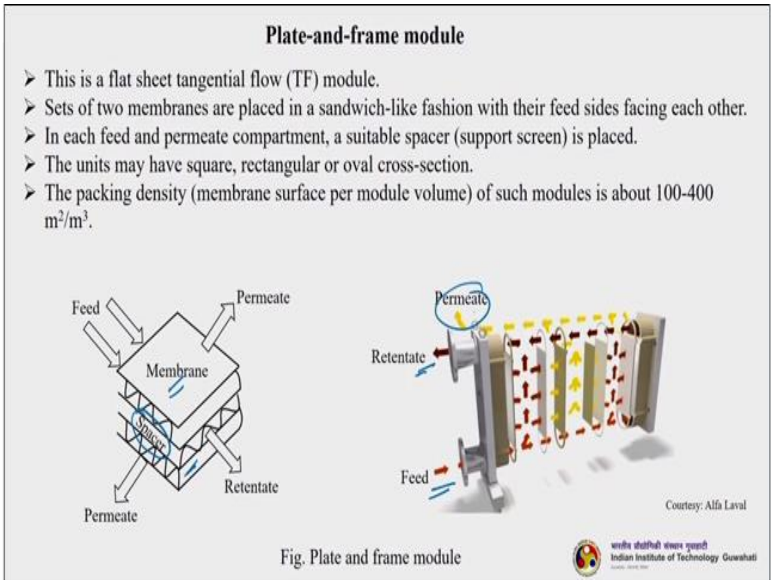

The next one is plate-and-frame module. So the actually this is also, these are also called flat sheet tangential flow module, so in many books, you will see that it is called TFF system or TF systems or TF modules. So what happens actually here the sets of two membranes are placed in a sandwich-like fashion with their feed sides facing each other. So you can see here in this particular scheme.

Here the top person is also membrane here the bottom person is also a membrane. And what is provided here is a spacer. Okay, the spacer is a support screen actually it is a support screen. So, which is dividing the feed and permeate compartments into two separate divisions. The units may have square, rectangular or oval cross-section. So you can have either squared. plate-and-frame module or we can have a rectangular TF system, or we can have a oval cross section.

TF system also the packing density which is nothing but the membrane surface per module volume of such module is about hundred to 400 meter square per meter cube. So you can see this is another figure here, the feed is entering here. Okay. And we are getting the overall retentate here, so you can have so many different types of membranes arragments here. Okay and the permeate we are getting here. So, actually. This is one of the oldest type of system, and quite good also.

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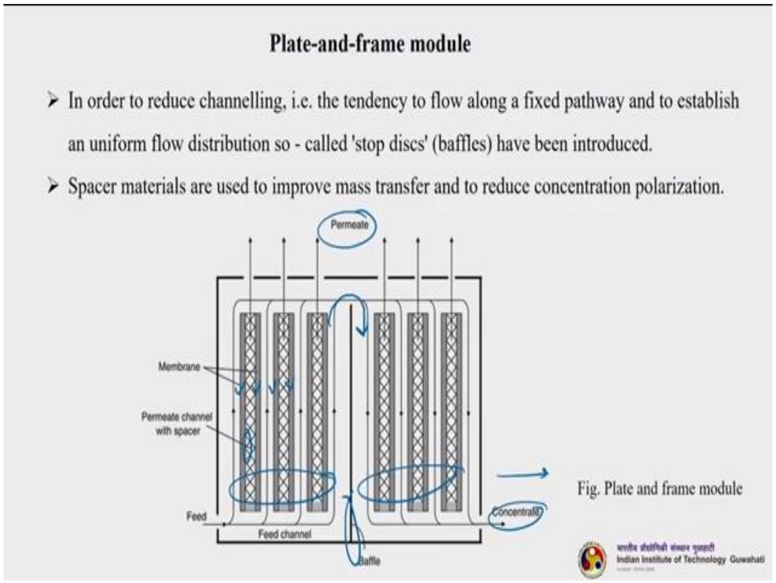

And in order to reduce channeling the tendency to flow along a fixed pathway, and to establish and uniform flow distribution. The stop discs or baffles have been introduced so please look at this particular figure, so you can understand that. So, there is a baffle here. Right. This is also called stop disc. So this is being introduced, okay, and to separate two different compartments. So this is one particular section.

This is another section. So you can have more section here also we can add on more section. Okay, the spacer materials are used to improve mass transfer, and to reduce concentration polarization. So you can see how the flow is happening actually. So the feed is coming here. Okay and then it is entering here, here, and here, and here. Okay. And again, that is getting circulated here, then again coming to the second compartment.

Again the feed is flowing through from the top here, we get overall concentrated attended here, and we will get the permeate here. Okay, this is the permeate channel. Okay, this is these are membranes, so this is a membrane. This is another membrane. Similarly, this is a membrane and this is a membrane, what you are seeing in the cross section, actually. So, that is actually the permeate channel with spacer, and the place to place for the permeate to flow through.

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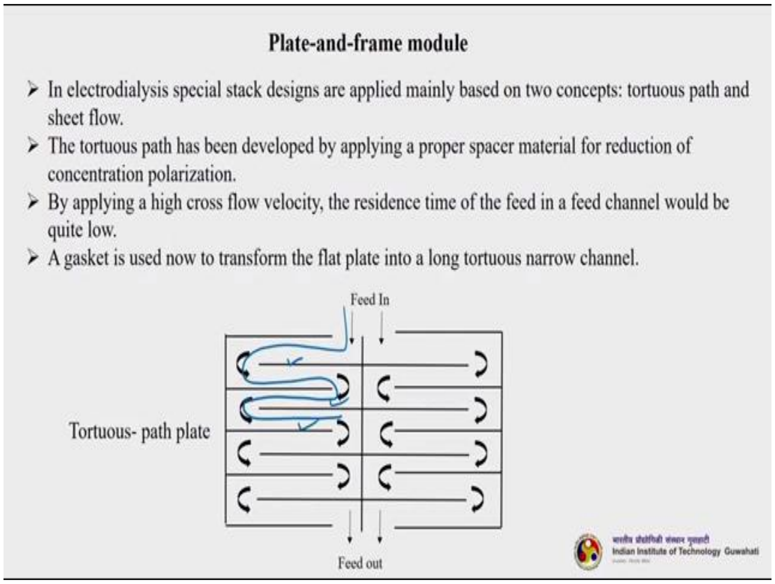

So, in electro dialysis special stack designs are applied, mainly based on two concepts. One is torturous path and another is seat flow. So the torturous path has been developed by applying a proper special material for reduction of concentration polarization. The aim of developing this torturous path is to reduce the concentration polarization, so as to minimize fouling by playing a high cross flow velocity.

The residents time of the feed in the feed channel would be would be quite low. So a gasket is used to transform the flat blood into the long torturous narrow channel, so you can see how the flow is happening. So feed is coming here. Okay, it is going here going here like this in a circular motion. So this is that is why it is called a torturous path. So, seems, and we have this baffels here okay.

So these baffels are providing to the tortuous are helping that establishing that tortures flow. Okay. So, if the flow will be like this that the concentration polorization on the surface of the membrane will be minimized. So that is the aim to have such type of flow.

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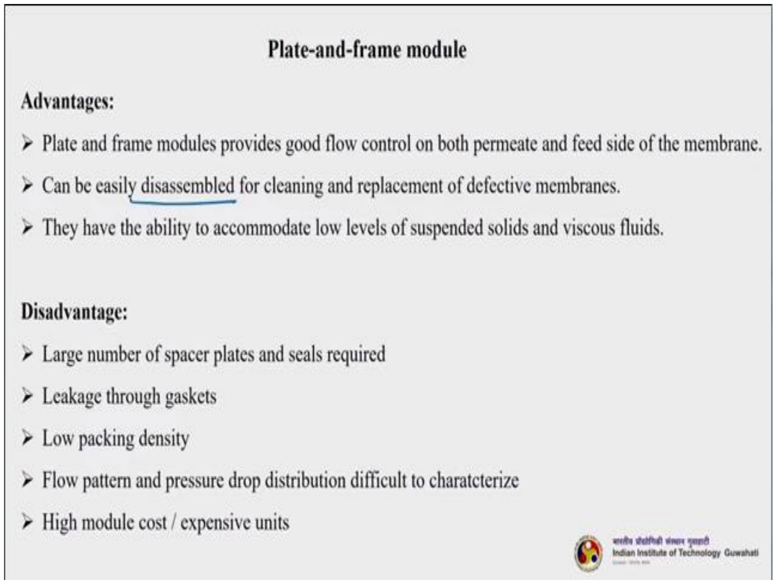

So the advantages of such modules which is the plate-and-frame module is that, So they provide good content on both permeate and feed side of the membrane, and they can be easily dissemble so this is one of the most important thing, while designing the module actually for cleaning and replacement of defective membranes, so they have the ability to accommodate lower levels of suspended solids and viscus fluids.

This is also important because, in many times it may happen that the levels of suspended solids are very low. And so that other module configurations may not help it so in that time, we can use plate-and frame type, and if the fluid or the period whisker because it is very high, then you can use plate-and-frame module. They have so many disadvantages also the first and foremost disadvantages large membrane of spacer plates and seals required.

So we are complicating the flow design actually basically the flow path and leakage to the gaskets, there are so many gaskets that is has been utilized for this type of membrane module. So that is why you have to take sufficient care, so that there is no leakage but instead of that and pressure gets developed inside the membrane module. So leakages happens. And the packing density is very less compared to other types of our modules and flow pattern and pressure drop distribuion is very difficult to characterize, and the cost of the module is actually high.

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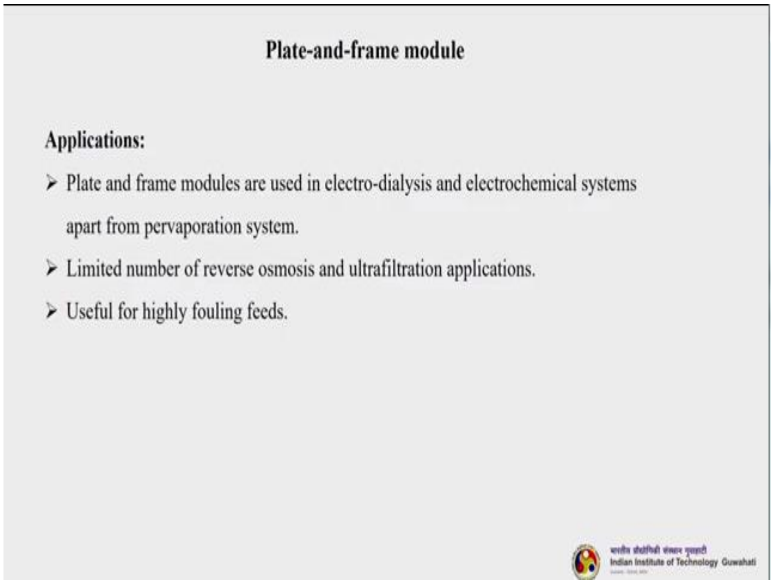

So the applicantions, they are used in electro dialysis and electro chemical systems, apart from nowadays they are also being utilized for the pervaporation system also have that limited membrane of reverse osmosis and ultrafiltration application is there. But then, another important thing I forgot to mention early slide is they are,they are very useful for highly fouling feeds, it might happen to them sometimes the feed content certain solutes so, which are very highly foulable, so that time, actually, This type of module will help us.

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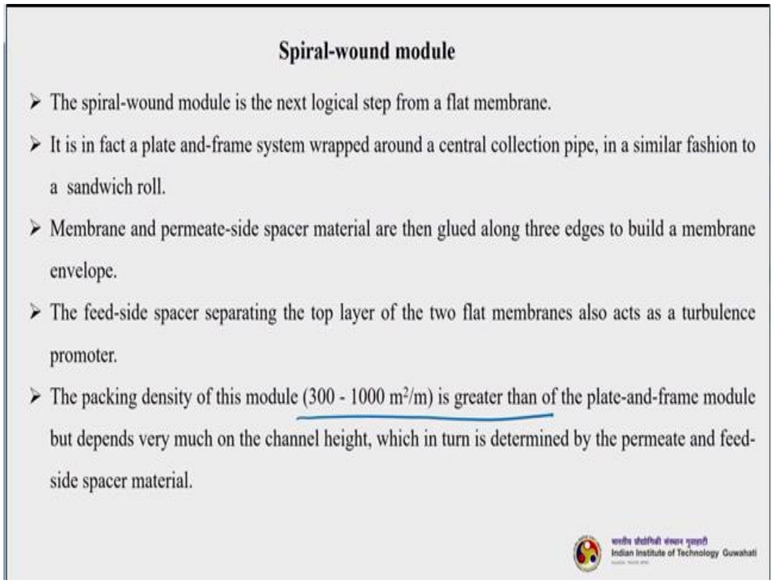

Students, The next one is the spiral-wound module, spiral-wound module is the next logical step from the flat sheet membranes and development. So it is in fact a plate and frame system, wrapped around a central collection pipe, in a similar fashion to a sandwich roll. You can imagine there are so many flat sheet membrane modules, and I am wrapping them on the surface of the tube. So that is how it really spiral-wound look like, so you figure in the next slide.

So membrane and for permeate-side spacer material and then glued along three edages to build a membrane envelope. And now the feed side spacer separating the top layer of the two flat membranes also acts as turbulence promoter. Here there will be spacer in the feed side also as well as in the permeate side also, and the feed side spacer is acting as a turbulence promoter so basically spacers are screens or messes.

Okay, maybe either up stainless steel or any other metals and alloys, and the packing density is greater than that of the plate and frame module, so packing density is higher than that of the tangential systems, but depends very much on the channel height, which in turn is determined by the permeate and feed side spacer material.

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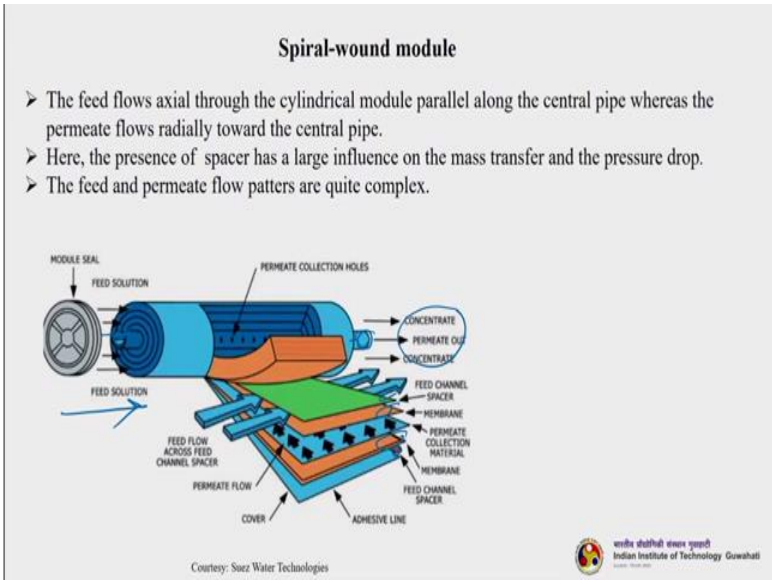

So let us now see how it looks like. Okay. You can see this particular figure. So you can see there is a tube here, this tube. Okay, so you can imagine that so many of membranes, materials, as well as. This is the membrane. Okay. And this is the Feed spacer. Then there is another membrane in here. This is another spacer here. So as feed spacer, a membrane, permeate spacer another membrane.

So they are all glued together and rolled on on a particular tube, which is, which may be this tube. Okay, protective tube of course, and this is being prepared actually. So the under feed flows axial through the cylindrical module parallel along the central pipe, were is the permeate flows readily towards the central pipe. So feed is flowing like this. Okay in this direction. Right. And we are getting concentrate out here.

Where it is here permeate is getting collected through this particular tube over which the membrane and the spacers are actually rolled on. So here the presence of spacer as a large influence of the mass transfer, and the pressure drop. The feed and permeate flow patterns are very complex because you can understand this very compact system. And the beauty of the system is that in a very less space we can have more membrane in area, there is the only thing. However, the flow type are very complex and difficult to characterize.

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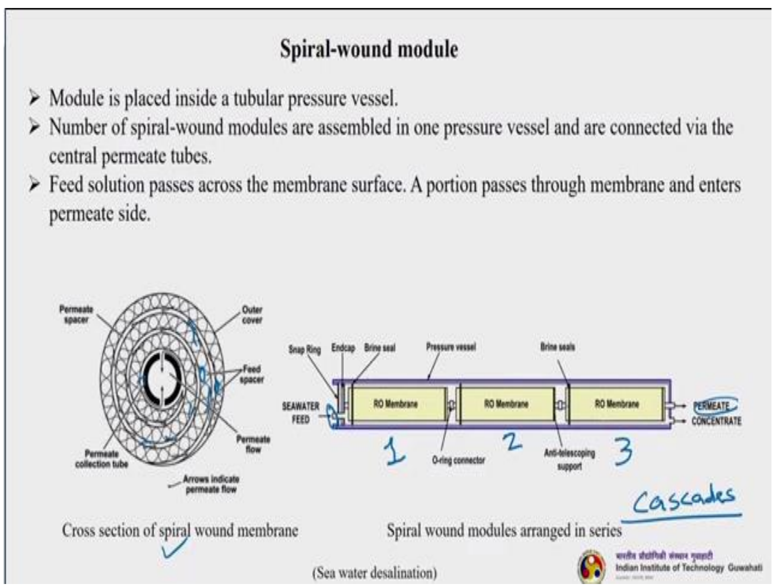

So, our module is placed inside a tubular pressure vessel usually. Okay, membrane of spiral modules are assembled in one pressure vessel, and are connected via the central permeate tubes. So feed solution passes across the membrane surface. A portion passes through membrane and enters the permeate side, this is actually the cross section of the spiral-wound membrane. Okay, so the arrows indicate the permeate flow. So you can see these arrows, this is an arrow, This is an arrow this is an arrow. This is how the permeate is getting collected. Okay. And these and these, these are actually feed spacers. Okay. And this is the permeate collecting tube. Okay. You can see in this particular figure here. This is spiral-wound module arranged in series, so you can have separate more than one spiral-wound membranes, and then place them in series, we can call them either in series, how many times we call them caskedes also.

So, This is what it is actually, cascades here in this particular figure we can see that there are three systems or three spiral-wound modules. So, in this particular figure these are RO modules, actually, so it can be anything. It can be up a map or any other systems. Okay, so Feed is entering in one place here, then it is passing through the membrane, and we are getting permeate from the central collection tubes. Okay, so this, these are the tubes which is collecting okay permeate and then we get concentrate here.

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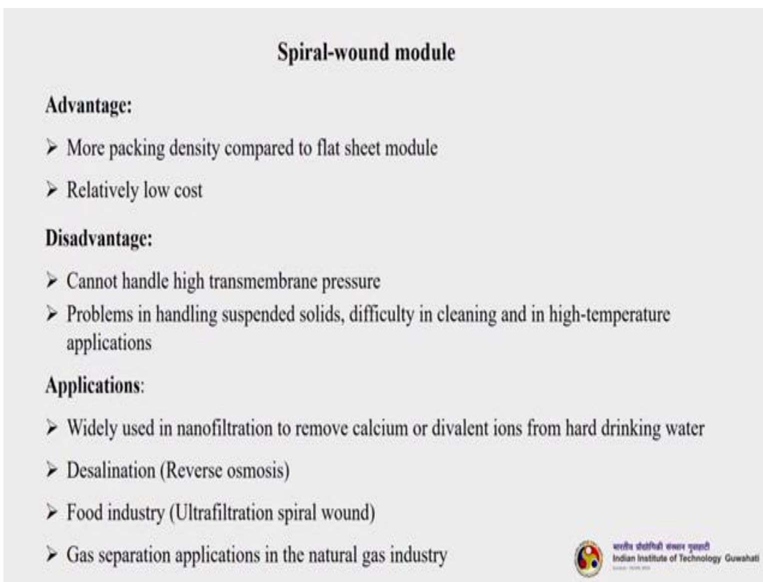

So the advantage here is this, the more packing density compared to flat sheet module, that is what I told in a small space, I can have more membrane area, and the relatively cost is lower than other membrane of modules, a disadvantage is that it cannot handle high transmembrane pressure, because if the transmembrane pressure becomes high the pressure devolopment will be built up in such a way inside the membrane module that it is not good for the separation.

And you will not eventually get whatever the targeted separation. Then, another problem is handling suspended solids, so it cannot handle good amount of suspended solids and difficulty in cleaning and high temperature applications. So since they are actually rolled on, and they are glued to each other so cleaning is a big problem. And then they cannot be used for high temperature applications also because it happens many times in process industries.

The water that is coming out of the other streams that is coming out of the various process units are at elevated temperature needs to be separated or purified for certain targeted separation. So in that time, the feed will be at higher elevated temperature. So, either you can cool the feed by passing through some selective heat exchangers and get the heat takeover for them so that the heat actually is also in process industries.

It is called waste heat recovery, where we recover the heat from the process trims okay and again, use the heat in the form of steam or some other form to supply to other things other units. So, they cannot withstand this type of modules, cannot withstand high temperature. So the applications are widely restricted to nanofiltration. To remove calcium, or divalent ions from hard drinking water.

Desalination, the reverse osmosis, RO actually which I saw you the previous slide, and food industry, in which, ultrafiltration usually the spiral-wound membranes are actually UF membranes and gas separation application in natural gas industries.

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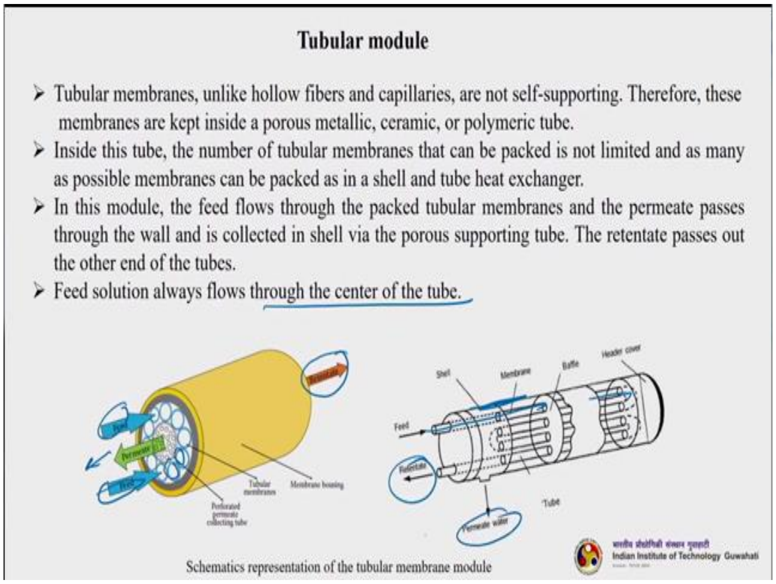

Schematics representation of the tubular membrane module

Students The next one is the tubular module. These are one of the most commercially adapted and industrially adapted actually technology. So tubular membranes unlike hollow fiber and capillaries and not self supporting so they are not self supporting membranes, so therefore these membranes are kept inside a porous metallic ceramic or polymeric tube. So they are not self supporting.

So they have to be kept inside some support, which can be a metallic ceramic or polymeric tube. So inside this tube a number tubular of membranes that can be packed is not limited. And as much as possible can be packed in a shell and tube heat exchanger type actually also in this module, feed flows through the packed tubular membranes and the permeate passes through the wall, and is collected in shell via the porous supporting tube. The retentate passes out the other side of the tube.

Feed solution always flow through the center of the tube. So you can see here. So these things you can, you are seeing that here. So these are actually the tubular membranes. Okay. And then, here the feed is flowing. Okay, here, and here. Right, so the feed is actually entering and flowing through the center of the tube. Okay. And we are getting the retentate here of over all retentate. Okay, and the permeate, that is passing through the membrane.

And passing out of the membrane basically are getting collected in the central space or the tube. Okay, which is supporting this tubes tubular membranes, and are getting collected here. So, this particular figure you can see this is a little more clear. So feed is entering like this here, passing. Okay, and then again it is getting circulated and coming here. So we are getting overall retentate here.

Okay, so this is since I told her this is a shell and tube heat exchanger actually type. Right? So this is the shell side. Okay. and these are tube side, so we can have a baffels inside also. Right. And the permeate is coming here. So these are the tubes, tubular membranes.

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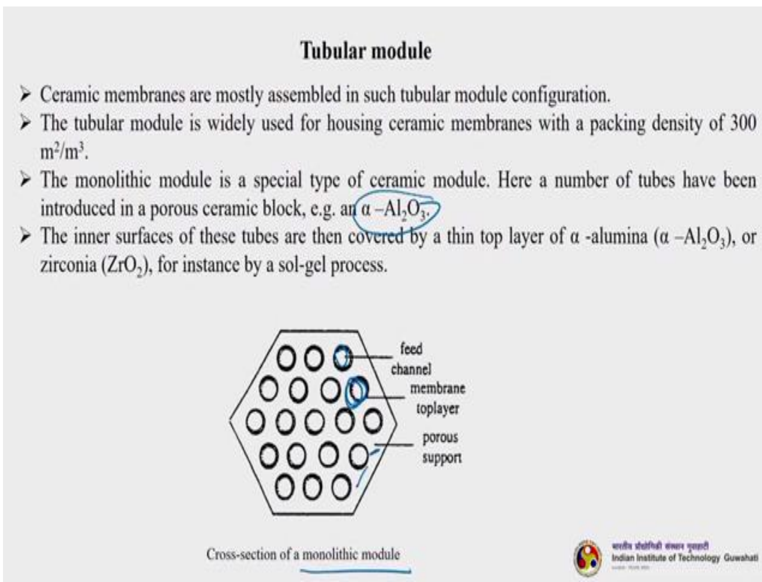

So, ceramic membranes are mostly assembled in tubular module configuration, but this is easy to fabricate also, and the tubular module is widely used for housing ceramic membranes with the packing density of 300 meters square per meter cube. It is a good, actually packing density, not very high not very low also the monolithic module is a special type of ceramic module so I am specifically talking about ceramic membranes.

And tubular ceramic membranes and the module. Okay, here a number of tubes have been introduced in a porous ceramic block. Okay, so for an example in alpha alumina, this is, this is one of the ceramic membrane component Okay, and the inner surface of these tubes are then covered by thin top layer of alumina, or is it zirconia, for instance by sol-gel processes, by making a composite membrane actually,

So you can see this is a monolithic module design okay. So this is the feed channel, right, this is the this is the membrane layer top layer. And this is the porous support whatever you are seeing here. This is porous support.

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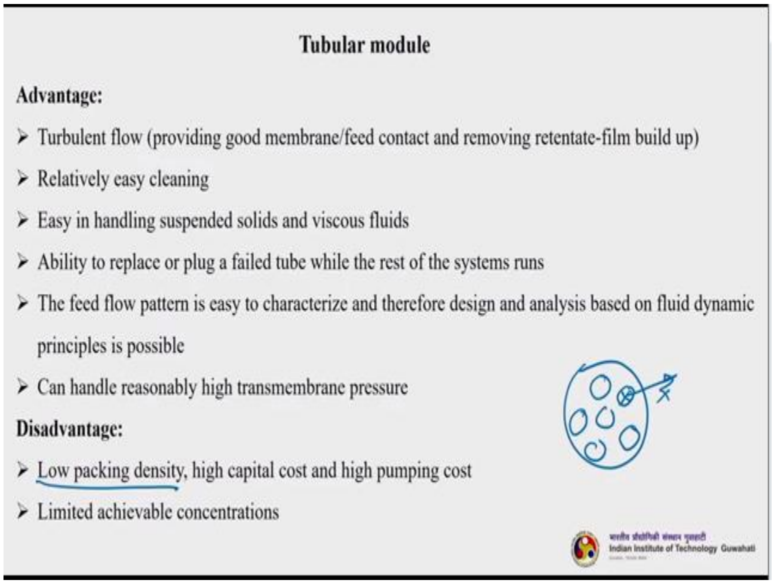

So the advantages of using this development module is that the turbulent flow. Okay, so why the turbulent flow is good because it is providing good membrane and feed contact that is very important. Then the feed, whatever that you are processing suit come in contact with the entire membrane and area that is available, or that is being supplied through membrane module that only we get as a seperation that is what we are targeting actually.

And not only that, so turbulence also helps in developing the retentate build up that the solute concentration whatever it is developing on the membrane surfaces. If there is a turbulent flow, it will be lesser. So, and the cleaning is very easy in tubular membrane. Easy in handling suspended solids and viscous fluids. Okay, and ability to replace or plug a failed tube while the rest of the system runs. So the meaning is that since we have.

Let us say, because we have seen that we have so many membranes and modules here. Okay. So these are all one one membrane and module. So I can I am showing you 123456. Here. Let us see this particular membrane is not working. It fail due to whatever maybe it is broken or cracks developed or whatever it happens it is not work, so I can either. Usually, I can open the membrane module and replace this particular tube. Okay.

With the new one, or I can plug it, so I can seal it from both sides, both end. Okay, so that that particular membrane module is not taking part in separation. So that is why it is very important that this type of tubular systems are really advantages. When we are using them in industry, or a large scale applications. So Feed flow pattern is easy to characterize okay and therefore design and analysis.

Based on fluid dynamics principle is also possible. Can handle reasonably high transmembrane pressure. Okay. And of course with the use of, if we use ceramic membrane and then the transmembrane pressure can withstand more also. However, the disadvantage is that low packing density the packing density, that is the membrane area for volume is less capital cost is little high, and pumping costs that is required to pump the feed also, is also relatively higher than other modules that achievable concentrations the targeted concentrations is also less.

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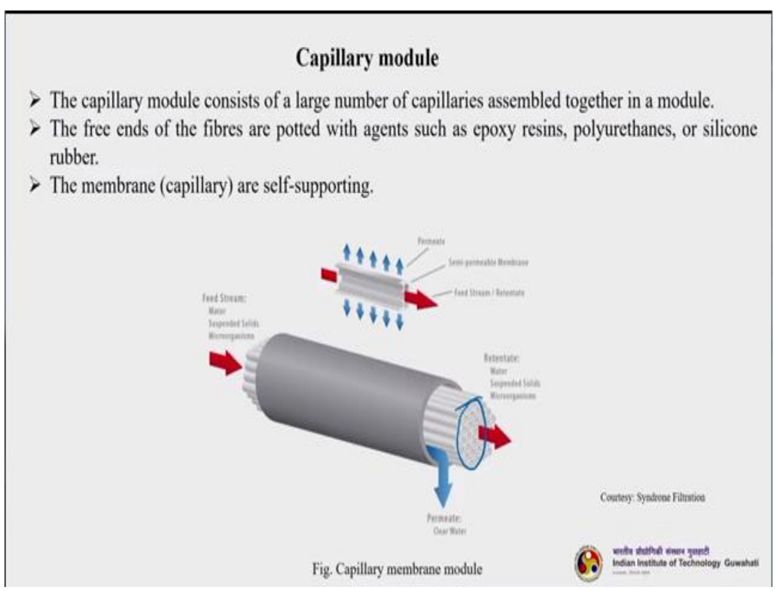

So, the next one is capillary module. So the capillary module consists of a large membrane of capillaries, assemble together in a module. So, you can see so many different so many capillaries here. Okay, and the free ends of these fibers have potted with agents, such as epoxy resins polyurethanes or silicone rubber. Okay, the membrane are self supporting here, we have seen in the tubular systems.

The membranes are not self supporting however here, The membranes are self supporting they do not need any intermediate support to hold them. Okay, so Feed is entering here. As you can see, and we can get the overall return to it here, and the permeates are getting collected out of the membrane. Right. And we can get a permeate here.

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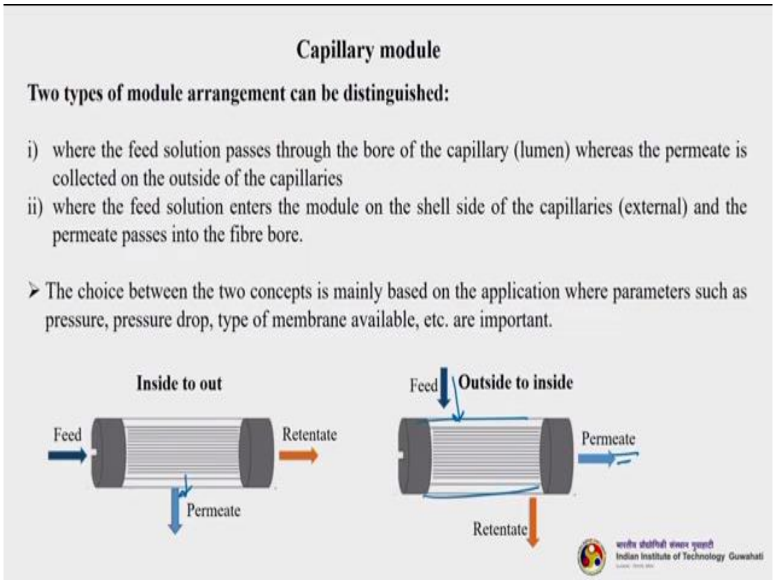

So, two types of module arrangement can be distinguished for capillary modules. So the first one is inside out. The second one is outside to inside. Let us understand what are these. So the first one is the insight to out that means the feed solution passes through the capillary out lumen, where is the permeate is collected on the outside of the complex. So the feed is passing through the membrane, or capillaries and the permeate is getting collected here from the outside of the membrane.

Whereas in outside to inside is that the feed solution enters the module from the top so if you can imagine this is a particular side. Okay, so the feed is entering from outside the membrane basically, right, and the permeate is getting collected from the inside of the membrane. So the field solute are ener the module on the shell side. Okay, an external and the permeate passes through the membrane. So, inside the capillary the permeate is getting collected. Right?

In the first case, the feed is flowing inside the capillary and permeate is getting out from the membrane from the outside, from the external side or the outside to inside it is the reverse. So actually, what type of this arragments you are going to use or recommend, so that depends upon the two concepts that the depends upon the two things. The first is the application where parameters such as pressure, pressure drop, type of membrane available. All these things are important, as well as the economics of so.

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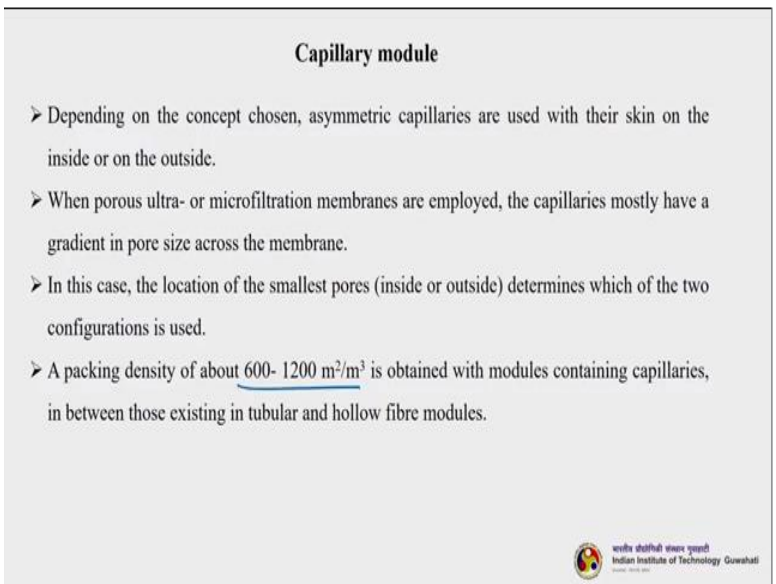

So depending on the concept choosen, asymmetric capillaries are used with their skin on the inside, or on the outside. And when porous ultra-or microfiltrations membranes are employed, the capillaries mostly have a gradient in pores across the membrane. So in this case, the location of the smallest pores inside or outside determines which type of configuration is used. So, usually the packing density is about 600 1200 meters square per meter cube is obtained with modules containing capillaries.

In between those existing tubular and hollow fiber so basically in systems packing density is higher than other ones because since they are self supporting. They do not need any support has we can pegg more and more capillaries inside a particular tube or a module, so that we will get many more packing density as well as what is the overall membrane area increases.

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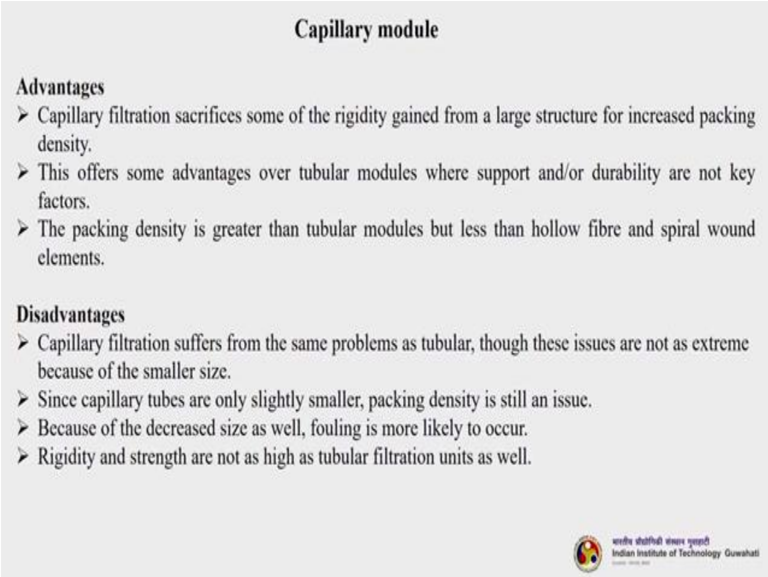

So the advantages are capillary filtration sacrifices some of the rigidity gained from large structure for increased packing density. Okay, so you do not have to go for a very large structure or very large system to achieve a more packing density. However, since they are self supporting so in a smaller space, we can have more number of capillaries fused together, to have a better packing density.

So this supports. Some of the advantages of a tubular modules where support and durability are not key factors. Right. And the packing density greater than any other module. However, they also suffer from certain disadvantages. So the problems are which are regular actually in tubular membrane also. They are the same in case of capillary modules, because the sizes are also very small year since capillary tubes are only slightly smaller packing density still an issue.

Because of the decrease sized as well fouling is more likely to occur and rigidity and strength are not as high as tubular filteration units because since their self supporting and they do not have any external support, hence strength is a mechanical strength is basically is an issue.

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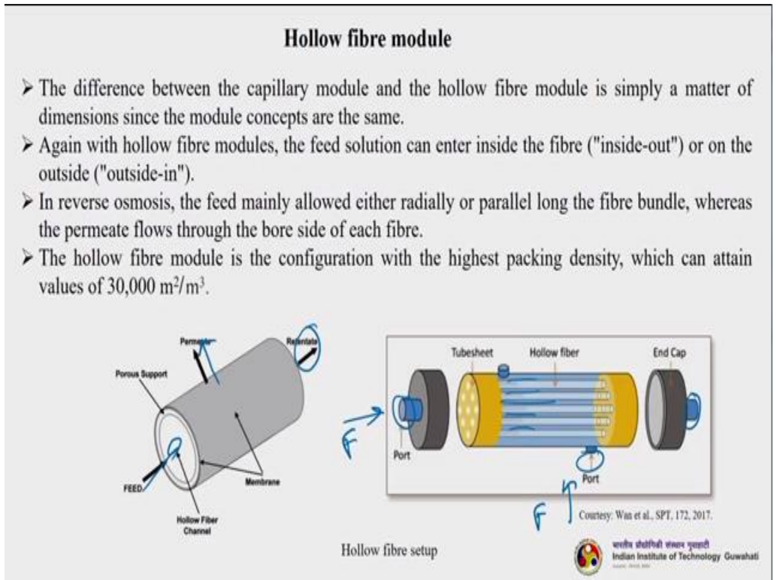

So students, the next one is hollow fiber module. So, this is one of the most important development in the membrane technology. Here the difference between the capillary module and the hollow fiber module is simply the matter of diamensions, okay since the module concepts are mostly the same. So, the hollow fiber modules the feed solution can enter the, can enter inside the fiber, either inside out, or outside, outside in, so we can have two different configurations possible here.

Just like our capillary systems, and in reverse osmosis, the feed maily allowed either radialy or parallel long the fiber bundle, whereas the permeate flows to the board side of each fiber. The module configuration with the highest packing density can be achievable it is almost 30,000 meter square per meter cube very high packing density. So you can see here in this particular figure.

Okay, so the feed is entering here, right, there's a single module that is being shown here, right hollow fiber Channel. This is actually the membrane and permeate is coming out side of the membrane. Okay, and the retentate is coming through the membrane that means from inside the membrane retentate is getting collected. So this is actually, inside out system. So a more clear understanding picture you can see here.

You can see how so many different types of hollow fibers are fused together. Okay. And there is a tube here, that is being shown as port. Okay. And there is a port here. So, either we can flow feed from here. Okay, or we can flow feed from here also, it depends upon whether you want to pour inside out, or outside in.

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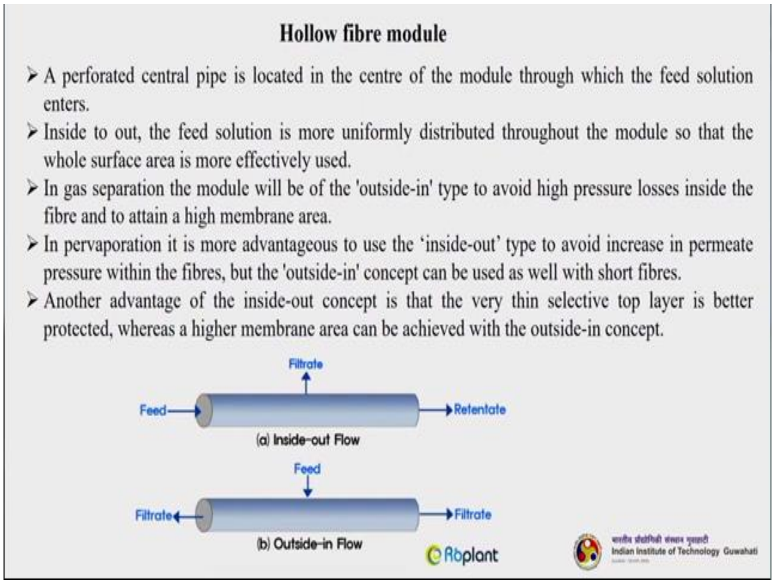

Right. So, a perforated central pipe is located in the center of the module through which the feed solution actually enters. So inside to, incase of inside to out the feed solution are more uniformly distributed throughout the module, so that the whole surface area is more effectively used, and in gas separation, the module will be always outside in, why because it has been done to avoid the high pressure drop, across the membrane.

Okay, and to achive a higher membrane area. In pervaporation, it is more advantageous to use inside out. Let, the feed flows through the membrane and the permeate will come, will be collected outside the membrane okay because you need to, many times in pervaporation system to achive pervaporation, you need to vacumize the system so as to generate low vapor pressure. So we will discuss in pervaporation, detail in one of our subsequent lectures.

So that time it will be more clear that what is pervaporation, actually. So, just for your understanding I am telling that we need to vacumize the permeate stream in case of pervaporation, Okay, so to achieve our targeted separation so in case we are having out to in system that time it is very difficult to achieve vacumized. So that is why feed flows through the lumen of the tubes, and we get permeate outside.

And another advantage of the inside out concept is that where it seems elective top layer is protected, whereas in hand membrane area can be achieved with the outside in concept. So if you go for it inside out, concept. And if you have a composite membranes, where the surface area is actually very surface layer is very thin, and it should be protected. Otherwise there will be wear and tear.

Okay, so then inside out is better. And if you want to achieve a higher area than outside in actually better, so there is no asses thumb rule, what you are going to recommend it all depends upon many factors. Okay. We have already discussed the factors.

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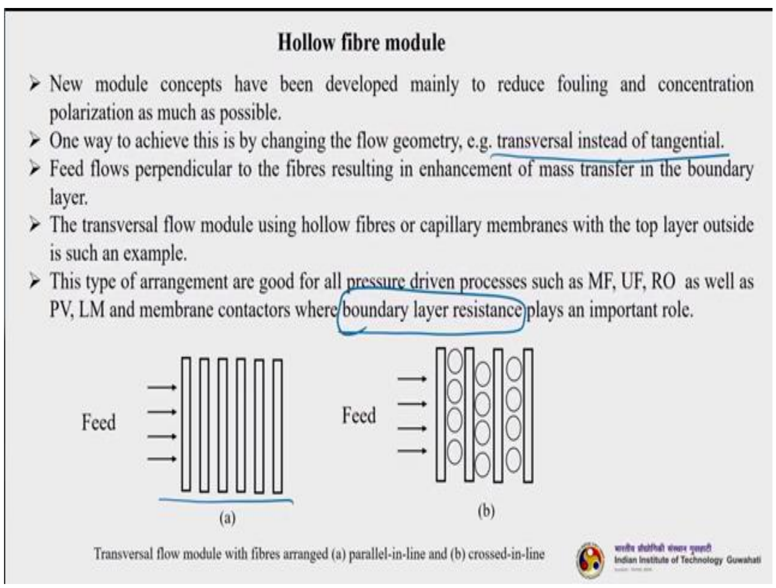

Then and now it is new module concepts concepts have been developed, mainly to reduce fouling and concentration polarization as much as possible, because that is the most important problem in separations, membrane separation is the concentration polarization, subsequent fouling. So to reduce concentration polarization as well as minimize fouling, so many new developments are coming every day now some membrane scientists are working.

To have a better module and design. So one way to achieve this is by changing the flow geometry. So, we can go for a transversal flow, instead of a tangential flow. Okay, so the feed flows perpendicular to the fibers, resulting in enhancement of the mass transfer in the boundary layer. So feed is flowing perpendicular to the fiber, you can see how the feed is flowing here. Okay.

And this is called, these are actually called transversal flow systems in which a hollow fibers or capillary membranes with top layer outside is a classic example. Right. This type of arrangements are good for all pressure driven processes, whether it is microfiltration, ultrafiltration or RO process, as well as as pervaporation and in liquid membranes also, and especially membrane contactors, where boundary layer resistance plays an important role. Okay.

In many membrane systems, the boundary layer resistance plays an important role, wherever it is anticipated to play a greater role because then it will provide a more registers to flow a resistance will be drastically reduced. Then in such systems, we can go for this type of transversional flow, instead of the tangential flow.

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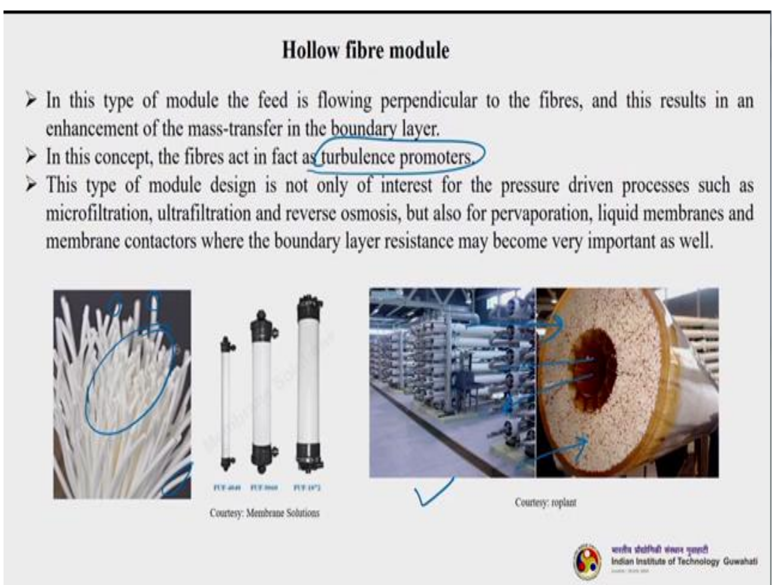

So, in this type of module the feed is flowing perpendicular to the fibers. So this results in an enhancement of the mass transfer in the boundary layer and fibers act in fact turbulence promoters as earlier also we have discussed that in one of the plate-and frame type. So, we are providing a feed spacer. So that is actually creating turbulence. So, here also the fibers themselves act as turbulence promoters.

So this type of module design is not only of intrest for the pressure driven processes, such as microfiltration, ultrafiltration or RO, but also for any other system like pervaporation and in liquid membranes and membrane. Okay, so you can see how these are these are single single hollow fibers, you can see, this is one single hollow fiber. This is one. There are so many fibers, so they are joined together and form a module and the modules looks like this.

So, there are different types of system company makes it actually membrane solutions. And this here you can see. Okay, so this is the plant. Okay, so the in this plant you can see, this is one such tube here, you can see how so many lakhs and lakhs of fiber, hollow fibers are fused together, heat will flow here like this. Okay. And permeate can be collected here. Otherwise, it can also possible.

That feed can be flow here to the this one and permeate will be collected. Okay, overall from here. Any, sets possibilities there in out or out it.

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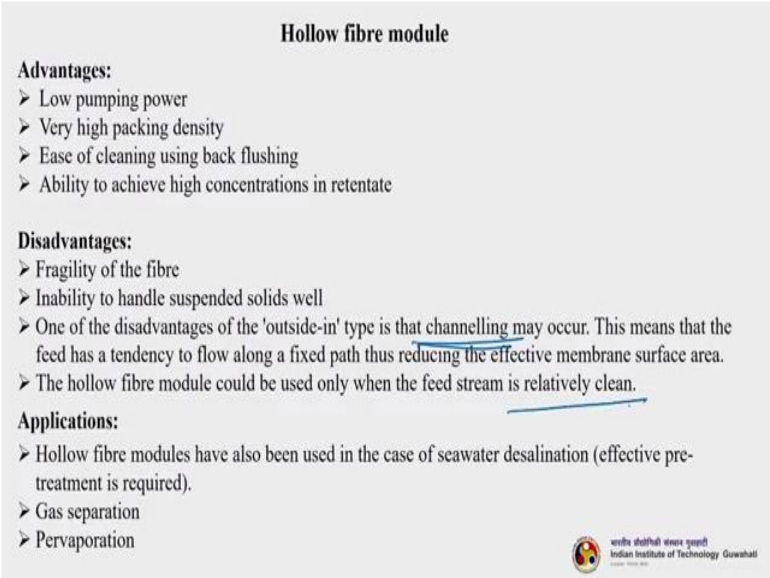

So the advantages is that low pumping power that is one of the sets, it saves actually energy and cost and very high packing density. So, we could have seen how just we saw that in a industrial establishment, how lakhs and lakhs of hollow fibers are fused together in a single module that means you can understand that in a very small plot space, we can have so much a membrane area.

So, ease of cleaning using a backflushing so cleaning is easy here, we can use backflushing to clean the membrane and, as well as the module also an ability to achieve high concentrate in the retentate, so you can have very, high concentration in the retentate. So disadvantage is the fragility of the fiber, since they are not actually self support, they are not actually supported. Okay. They are self supported more or less.

So in this case here the fragility of the fiber is an issue. So inability to handle suspended solids is another problem, because they are very thin, there is very small structures actually very thin. So that is why they cannot handle suspended solids. And one of the disadvantages. If you use for outside, is that channeling may occur. Okay, so channeling is something which is very much inherent to the pegged type of reactors.

The same the same thing may happen here. If we are using it outside to in system. Okay, so this means that the feed has a tendency to flow along a fixed path thus reducing the effective membrane surface area. So, if we want that the entire surface of the membrane surface whatever it is available inside the module is being utilized, then it is better to take the feed and flow it through the membrane.

Okay, the hollow fiber module could be used only when the feed stream was relatively clean. That means it is clearly understood that it cannot handle suspended solids. So applications is there. In case of seawater desalination which is a practice, but still there is some effective pre-tratment is also required, gas separation and as well as pervaporation.

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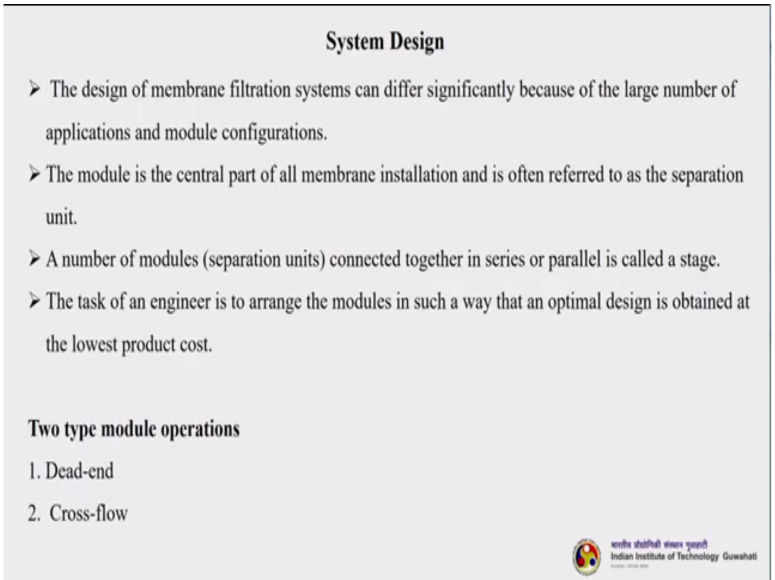

So now let us talk about the system design. Okay. The design of membrane filtration system can differ significantly because of the large number of applications and module configurations, so there is no thumb rule. So everything depends upon what is there. What is your requirement. And what are the things that is available with you. So the module is the central part of all membrane instllation.

And is often refer to as the separation unit and number of modules connected together in series are called or parallel are called a stage, we can have 2,3,4 or 6 modules together and they are connected in such a way that I can call it a stage, so we can have more than one stage two stage three stage. So, this is basically in series or we can call them cascade also, so the task of an engineer is to analyze the module.

In such a way that an optimal design is obtained with the lowest product costs because anyway you have to take care of the economics and two type module operations are possible one is dead-end and cross-flow. And we have discussed what is a dead end flow and cross flow in one of our previous class,

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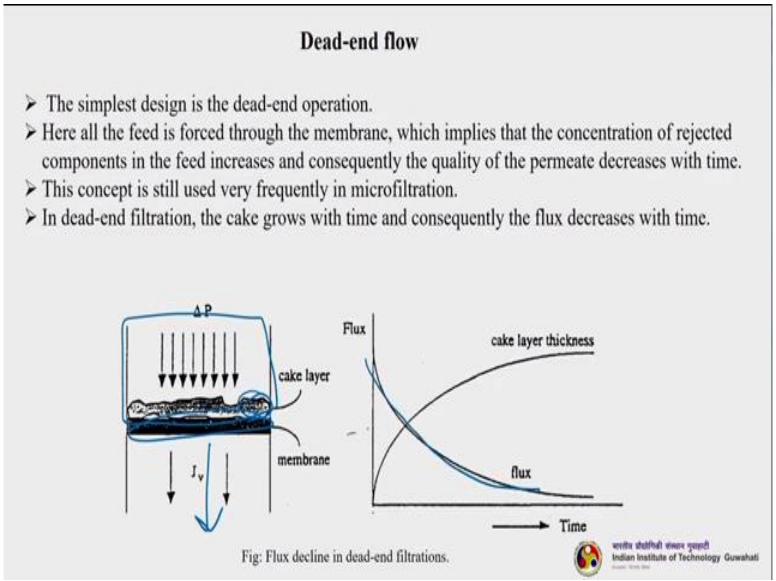

Let us again quickly go through what is cross flow and trust flow with reference to module. Okay. The simplicity, the dedenne proper reason he had the PDS post to the membrane, which implies that the concentration of rejecter components in the previous getting enhanced or increased as the time progresses. Okay, and consequently the quality of the permeate decreases with time, so usually bedtime.

You can see how the flow is occurring here. Okay. So, if this is a module. Okay. Right, which is holding this membrane. So the feed is transferred to the module and it is the module is closed, then we are applying pressure from the top side. So the palm is it is coming here. However, the detected is getting written on the surface of the membrane. Okay, so in the identification the cake grows with time.

Okay, So the position of the clear capillaries is nothing but, neoconservatism place earlier. Okay, he's very faster. Okay, and surplus decline is also replaster, so you can see how the flux is declining here. Okay. And with respect to time, as well as the thickness of the club that is, and what is happening simultaneously at a very faster rate.

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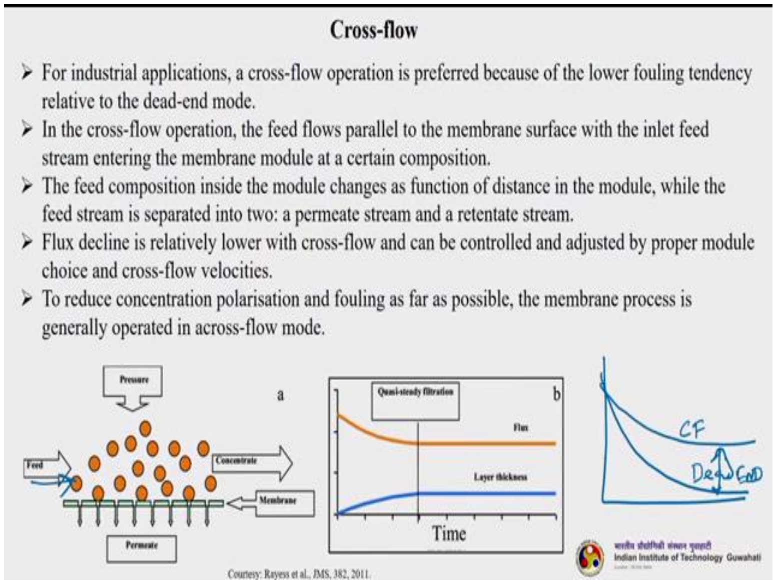

So the next is cross flow for in industrial application cross play operation is proper because of the lower falling tendency related to the dead and more seems the ploy is happening about the surface of the membrane. So that is why you can see here how the page is playing here. Okay. And this is a membrane. Right, so loops are getting deposited on the surface of the membrane harbor says the Pro is continuous.

So, the piece itself. Okay, is not allowing the deposition of the solids particularly about the surface of the membrane. So lift the positional happened the concentration buildup. However, the rate at which they are depositing on the surface of the membrane will be much slower with comparison to the dead in prison systems. So the feed competition inside the module tennis is a function of distance in the module was the feedch team is separated into the mainstream and their attendance to the flux decline is relatively low.

So we can just compare the plugs dignan profile. Okay, let us say this is the dead and filter some flux decline. Okay, so this is dead end. Okay. And in case of the cross below the plug stick like this. Okay, so this is cross blow. Okay, so you can understand that there is a huge gap up plucks decline, and the dead end and cross blood system which is why the cross for systems is usually prefer. Okay,

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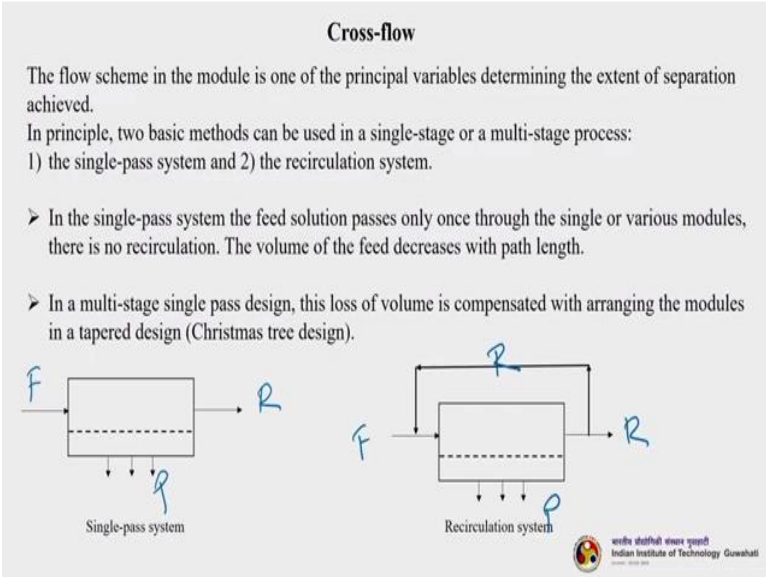

So, the pro scheming the podium, is one of the principal variables, determining the extent of separation, in principle, two basic systems are actually used one is called single pass system,

and another is the resell cluesive system. So every single pass we are feeding. Feed from here. Okay, and we get attended here, and we get familiar. And in the circosta System, part of the feed we're recirculating actually represented here.

It is circulating to the PDL. Okay. So, in a multistage single pass design, the loss of volume is compensated with everything the module Sigma Kappa design, which is also called a Christmas tree design. Okay,

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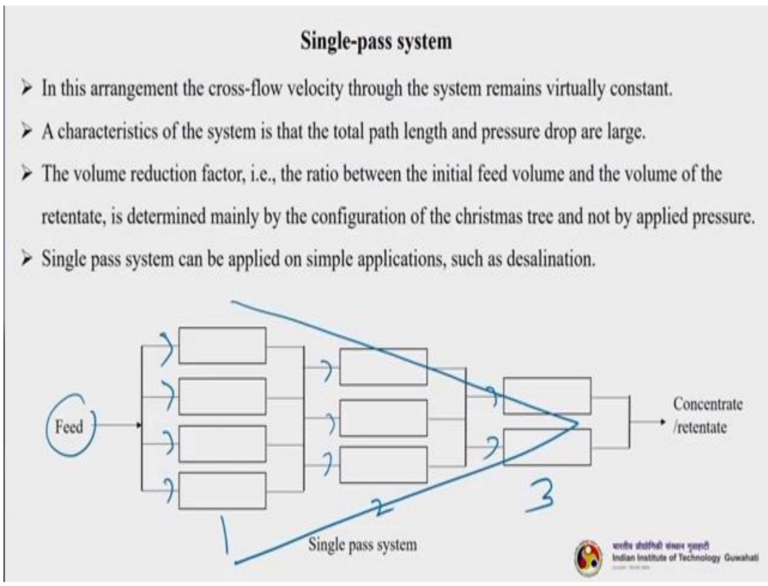

So in single pass I was but system the crossbar velocity to the system and immense but surely constant characteristic of this system is that total path linnaean presser drop at last, the Bollywood index and character. Now that is the ratio between the initial period volume and the volume of the attented is determined, mainly by the configuration of the Christmas tree and not by the applied pressure.

So single pass system can be applied and simple application. So just be silliness. So you can see how the single pass system. So this is the world period periods is being feed to four modules here. Then, whatever the written word is coming. Okay, so they are being feed to the sensor if this is one this is two. This is stage three. Okay, then there again Feed here. And whatever that is coming out here is again pettier okay.

So gradually, the membrane of modules in this particular stay see is decreasing. That is why, this looks like a Christmas tree, we can see something like this.

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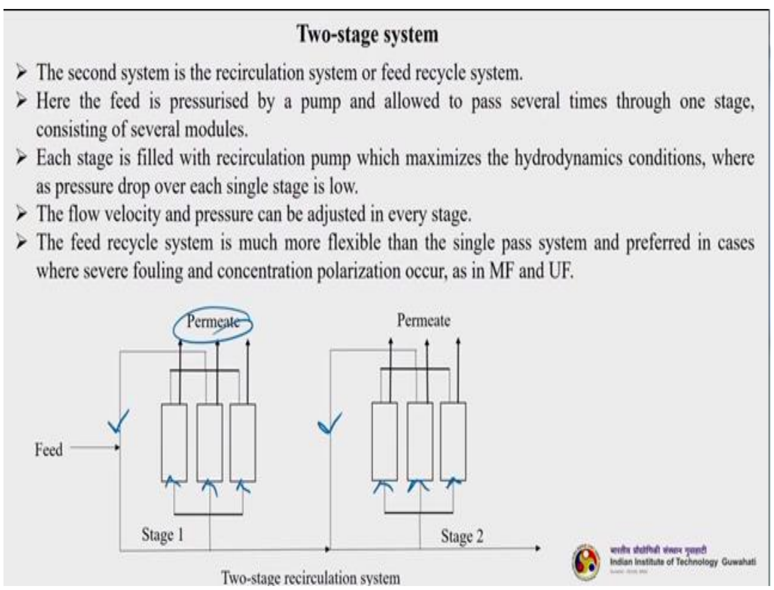

So, let us say to stay system. So the second system is this reset to a subsystem of the payday recycle system here the feed is pressurized by a pump and allowed to pass several times through one stays consisting of several modules. Okay, that is recent missile is happening actually here. So, each stage is filled with recirculation pump which maximizes the hydrodynamic conditions, and we're pressing up our each single stage is slow.

The flow velocity and pressure drop can be adjusted in every state, the PD cycle system is much more flexible than the single payer system and preferred in cases where severe fouling and concept assimilation occur in the case of micropolitan Ultra Feedrson. So you can see here there's two stages here stage one and stage two. Okay, the predetermined pad here. Okay. And whatever the retentive is coming. Okay, the attendees is again recycle back to the feedch tip. Right?

And we get a world permeate here, again, part of this period, and the tented is against circulated to the second stage where it is being played here. Okay. And whatever we are getting the retentive partly again recirculated to the feedch the feedch of the second stage, and this process goes on. So you can either gradually we can have a reducing membrane of modules, or we can have sales membrane of modules and depending upon actually what is your requirement how many stages you require to achieve a targeted separation.

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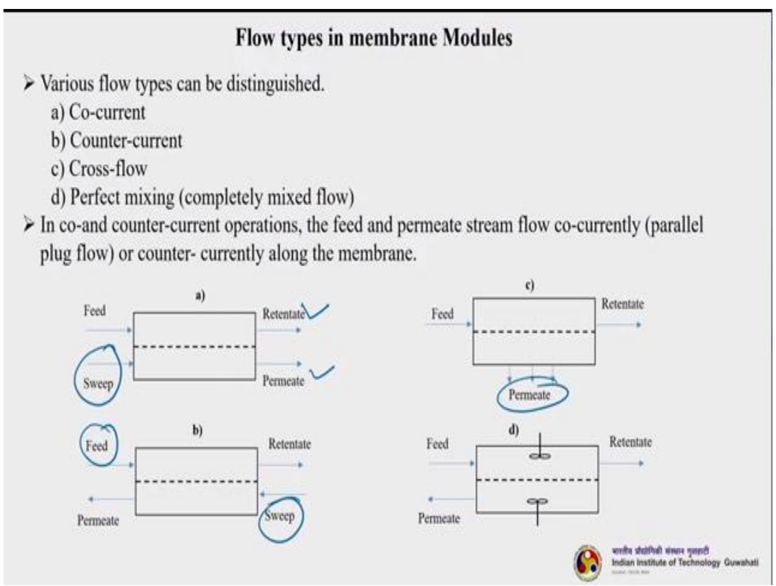

So, now let us discuss the different types of prototypes in membrane modules. So, classical here for different types of things. This one prototype that is possible, apart from the dead end here. petition mode, so they didn't am not seeing because we've already discussed that, and it is not used in commercial or large scale also. So, last killer presents and prototypes are mistakenly restricted to co current counter current grace flow.

And perfect mixing type so perfect person is completely mixed protein. So in CO and counter current operations the freedom permeates Tim pro quo currently, which is called parallel flow pro or counter currently lm the membrane. So the first case is coconut flow. See, Feed. Okay, is being prone. Entering from one direction only we get detected and permeate in the same cell, and we can have a strip sweep is optional sweep is not mandatory.

It surely sleep helps in reducing concentration polarized and also. So the second was in counter current here, feed. Again, and the sweep, they are actually entering in opposite directions, again, so we get feed in the preset and attended in the other side. Then in cross flow system. So, Feed is flowing across the membrane surface and we are getting permeate here. Okay. And in the perfectly mix flow, so he can have the system.

Mixed by using some sort of educators, either mechanical or it can be magnetically magnetically driven, so that the PDS get also continuously agitated as well as the permeate.

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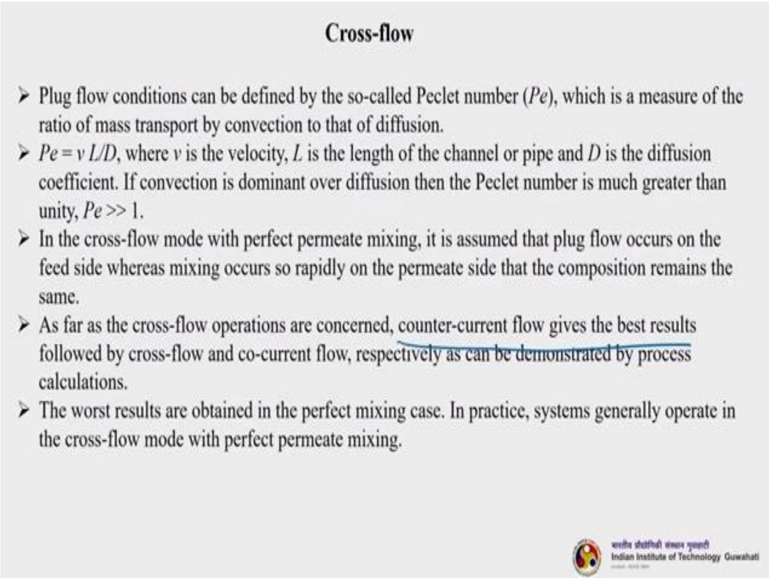

So, the block properly some can be defined by so called Padlet membrane, which is a dimensionless membrane or group. So the packet membrane is defined as the Masters but by conviction to that of the defuser, so it is v L by D where v is the velocity, L is the length of the chairman, or the pipe and DB D is the diffusion coefficient. Okay, so if context and its dominant about diffusion. The percolate membrane is much much greater than unity.

So it is much more than one, and in cross flow what with perfect permeate mixing it is a Jew that blood flow occurs on the pizza, where, whereas mixing of course for a period the permeate said that competition demon system. Since we have mixing both the feed and arroway let us say we are visiting with the president of permeate. Okay, so the concentration or the composition of the permeate, mostly remains the same.

And as far as cross flow presents are concerned, counter current flow, always gives the best results. Okay, so, followed by the cross flow and kokura. How would the worst results are given by perfect mixing. However, in general perfect mixing is done using a permeate resampler so that is why it is called pot with a perfect permeate mixing circuit the permeate is getting mixed continuously.

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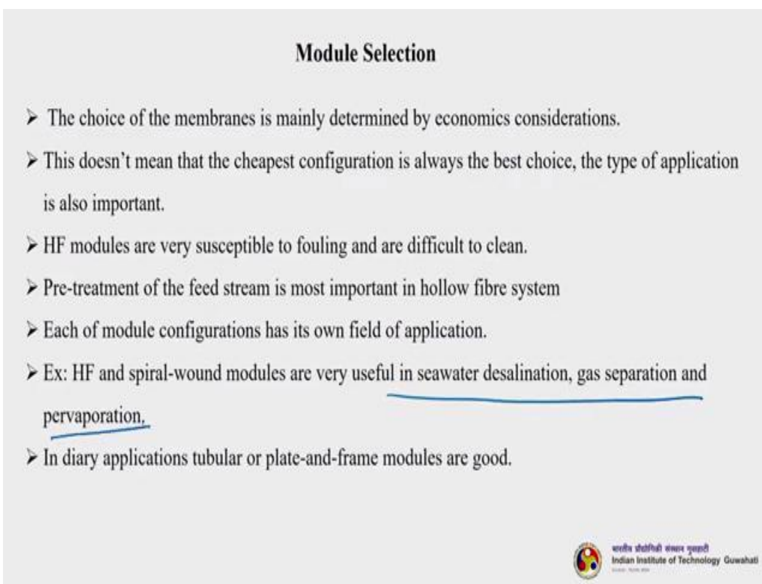

So now let us understand what is modal selection and how we are going to select a particular module. So we have discussed and understand the different types of modules that is possible, whether it is a store sell module, whether it is a tangential system that is plugged in from system, whether it is a capillary one, whether it is a tubular one or hollow fiber we have discussed so many things. Okay.

Now, which one you choose. Okay, so the choice of the membranes is mainly determine the economic condition consideration. Okay. This does not mean that cheapest configuration is always the best choice that type of application is also important. Okay. It is not always true that whatever is the cheaply available on which module cost and membrane and cost achieved that only you will use it is not so that what is your targeted separation that is most important.

So hello paper modules are very susceptible to falling and are difficult to claim. Okay. Pretty part of the system is most important in all of our systems. So, each module configurations has its own period of application. This is very true. Okay so that is why he after his module we have discussed that, there are advantages and disadvantages and upgrades that can be applied. So, for example, hollow fiber.

And spiral load modules are very useful in seawater desalination guests a person as well as property, sir. All right, hold up evidence by the loop but I cannot use other modules here entirely applications we can go for political modules. They are also very good in such food and beverage industry applications.

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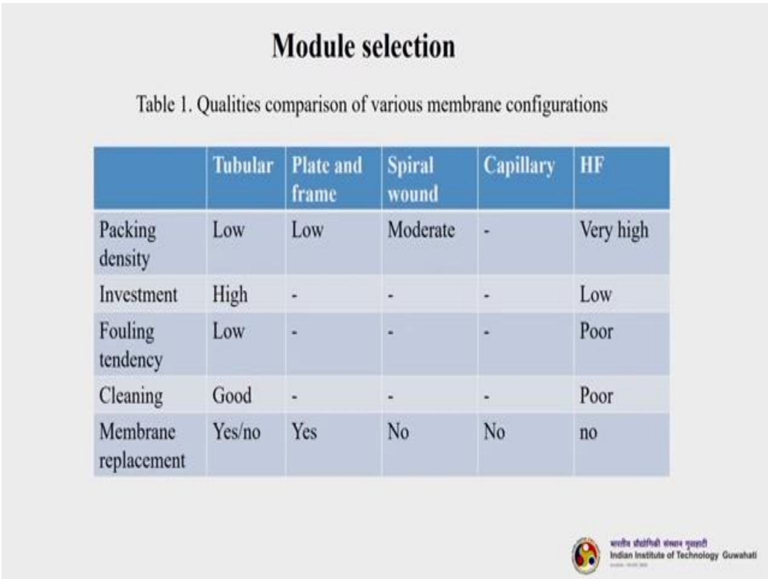

	Tubular	Plate and frame	Spiral wound	Capillary	HF
Packing density	Low	Low	Moderate	-	Very high
Investment	High	-	-	-	Low
Fouling tendency	Low	-	-	-	Poor
Cleaning	Good	-	-	-	Poor
Membrane replacement	Yes/no	Yes	No	No	no

So if you can compare the qualities of various configurations, you can understand that these are different parameters on which the competition is based. Okay, so we have compared to blood system platen print systems by the load calculation Hello paper. So these are the criteria of Hearthstone is breaking density, then the investment investment means the initial cafeedal investment, then Powell intendancy cleaning membrane and replacement.

Okay, based on this is a comparison table you can see, and Western this you can understand that, which modules to be chosen for a particular target so persona replicase.

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Table 2. Module designs most commonly used in the major membrane separation

Application	Module type
Reverse osmosis: seawater	Spiral-wound modules dominate. Only one hollow fibre producer remains.
Reverse osmosis: industrial and brackish water	Spiral-wound modules used almost exclusively; fine fibres too susceptible to scaling and fouling.
Ultrafiltration	Tubular, capillary, and spiral-wound modules all used.
Gas separation	Hollow fibres for high volume applications with low flux, low selectively membranes in which concentration polarization is easily controlled. Spiral-wound when fluxes are higher, feed gases more contaminated, and concentration polarization a problem.
Pervaporation	Most pervaporation systems are small, so plate and frame systems were used in the first systems. Spiral-wound and capillary modules being introduced.

So module designs most commonly used and measured membrane suppressant this couple will give you an understanding that what type of portals are being used for different application for example you can see in our reverse osmosis are open, actually see what traditionally Mr. We usually use balloon motors. Okay, hollow fiber modules are also possible. Hi BUT THE REAL JESUS sticker.

So similarly, industrial and brackish water desalination music arrow. Again, we use spiral and modules. Okay. Pine fibers are too susceptible to scaling and power. Okay, so put our interpreters and applications, either we can use tibula capillary or spider root membrane. So for guests a person, application usually hollow fibers for high volume application was Roblox is used. Okay, because the low selectivity membranes in which concept assimilation is easily controlled.

So you'll use by the load for guests per person, per processor, very high. Similarly per per person usually per operation systems are very small, they are small units. Okay, so plitt and Prem systems are very good for the spiral capillary and also being introduced. Recently, okay. So, today with this.

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We came to conclusion of today's lecture. So you can report the digital text and abraxas mostly it is taken from Moodle, which is the basic principles of mobile technology, or our. The basic textbook which I am reporting for this course, apart from other references.

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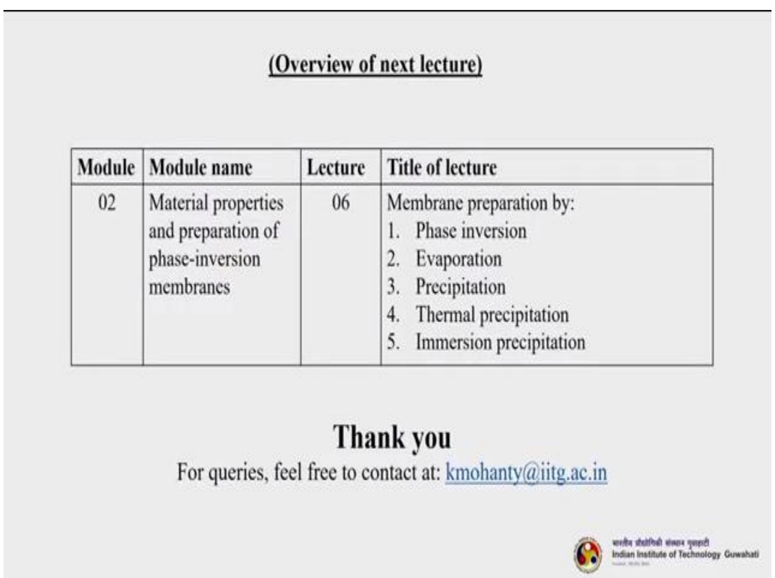

So the next class, which is module two and lecture six. We'll stirredt discussing what are the different types, or what are the different ways, or techniques to prepare a particular membrane. Okay, so basically you will learn membrane preparation techniques. so next class will discuss about hygiene verson evaporation precifeedation thermal precifeedation and immersive precifeedation techniques okay. So if you have any query you can write to me at kmohanty@itg.ac.in. And thank you very much.