Membrane Technologys
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Lecture – 19
Basic Principles of UF, Membranes and Modules, UF Configurations

Good morning students. Today is lecture 9 of module 7 and in today's lecture we are starting actually ultra-filtration. So we will learn the basic principles of ultra-filtration, the various advantages of ultra-filtration, the membranes and modules that is designed for ultra-filtration and different types of ultra-filtration, configurations.

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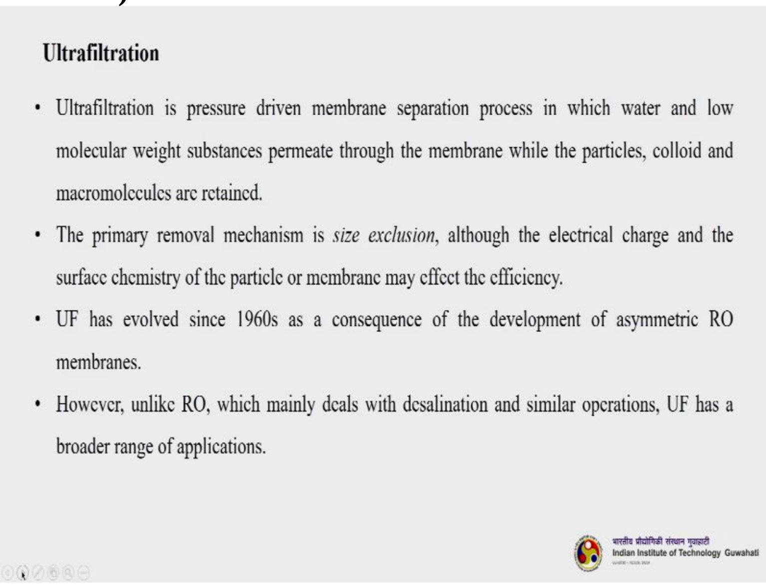

Means the different way how ultrafiltration can be carried away. So as you know, it is our pressure driven process in which water and low molecular weight solutes permeate through the membrane while the particles collide and other macromolecules are retained or rejected. So, the primary mechanism of ultrafiltration is size exclusion. That means basically it is size by separation, although electrical charge and surface chemistry of particle or membrane may effect the efficiency also.

So ultrafiltration has developed since 1960s as a consequence of the development of the asymmetric RO membrane. However, unlike RO, which is basically or mainly deals with desalination and similar allied operations, ultrafiltration has a wide range of applications, we will see in subsequent discussions in our lecture, what are the different types of ultra-filtration applications.

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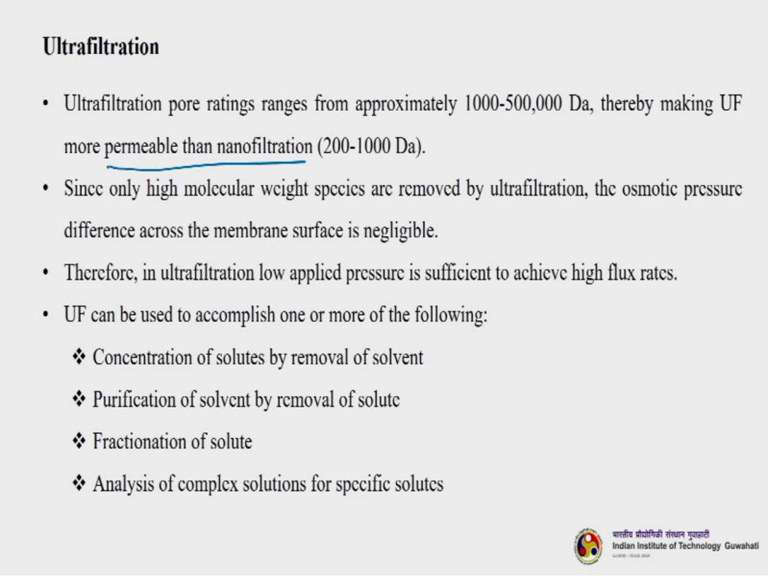

So, ultrafiltration pore ratings ranges from approximately 1000 to 500,000 delta thereby making ultrafiltration more permeable than Nano filtration. So, this is one of the most important thing since, only high molecular weight species are removed by ultrafiltration, the osmotic pressure difference across the membrane surface is negligible. So, we are not considering the osmotic pressure difference actually in ultrafiltration.

Because only high molecular weight species are getting removed, not in the case of RO, they are put in ultrafiltration the applied pressure is required is actually lower than RO to achieve high flux rates and multiplication can be used to complete one or more of the following objectives, so, either you can target a concentration of solutes thereby removing the solvent or you can have a purification of solvent by removal of solute and fractionation of solute. So, we have binary fractionation we have tertiary fractionation some analysis of complex solutions for specific solutes.

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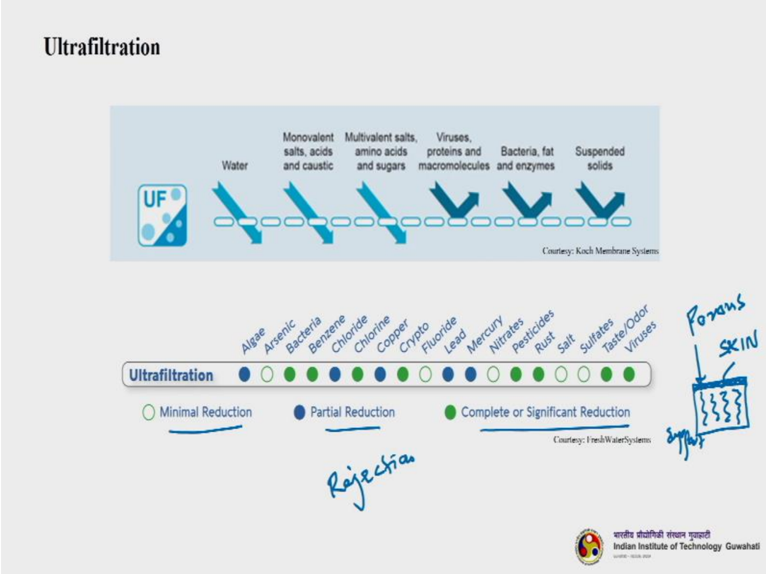

So, you can see this particular scheme is telling us about the first one. It is telling us about what the ultrafiltration membranes are doing basically, you can see water and monovalent salt acids caustic is all along with some of the amino acids and sugars, they are permeating through the membrane because they are this one cut off or they are the size is less than that of the pores. Please remember that ultrafiltration is a porous membrane, though it is asymmetry, but it has porous.

So, mostly our interpretation membrane surface skin membranes. So this you can consider as a support micro porous support and over that there is skin layer it is just like your RO asymmetric membranes but RO membranes are not actually porous, but here the skin layer. So, this is also porous. So, that is why you need to understand this due to the nature of the ultrafiltration membrane in spite of having it is a symmetric in nature.

It will permeate some of the solutes along with the solvent which is essentially water however, it will reject viruses, proteins and different macromolecules bacteria, fats and enzymes and suspended solids. So, most of the times ultrafiltration also used in water treatment to remove the TSS the total suspended solids. So, here you can see another example, where ultrafiltration what it is doing is been classified into 3 things first is this minimal reduction than partial reduction or complete or significant reduction.

So, this reduction means it is a rejection. So, you can see algae its partial rejection because there are algae there are micro algae and all these things. Arsenic one of the most this one talked about heavy metal because of its pollution that it creates in so many parts of the world.

So, it is reduction is also minimum whereas your bacteria benzene then pesticides then viruses they are completely rejected then some of other heavy metals like lead Mercury, copper chloride, all these things they are partially rejected.

So, this particular slide understand makes us understand that what can be achieved or what type of rejections can be achieved for what type of solutes, using ultra filtration membranes.

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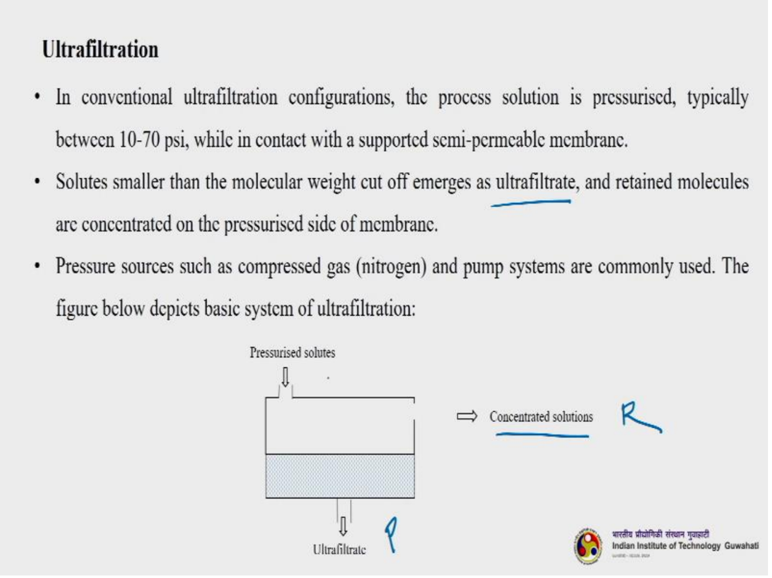

So, in conventional ultrafiltration configurations, the process solution is usually pressurized typically between 10 to 70 psi while in supported semi-permeable membrane. The solute smaller than the molecular weight cut off of the membrane they are they will emerge as the ultrafiltration retained molecules are concentrated on the pressurized side of the membrane. So, usual scheme of operation for any membrane is something like this.

So, you need to pressurize the module. So, you can do it by many ways. So, either you can have a pump or you can have a compressed gases for example nitrogen. So, your feed is coming here, entering and then you get your concentrated solution R. At enter permeate you are getting the ultrafiltrate.

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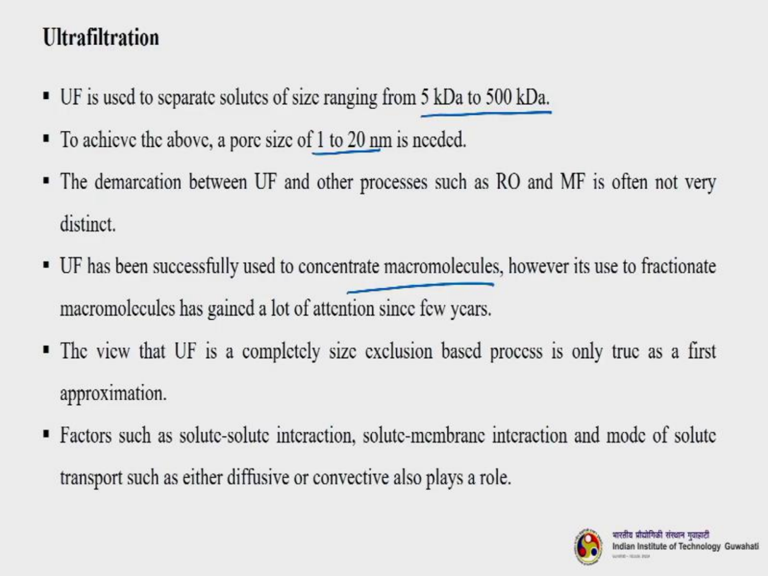

So, ultrafiltrate is used to separate solutes ranging from 5 kilo Dalton to 500 kilo Dalton. So, this is the solute size that can be separated using or you can say the receptor using the ultrafiltration membranes. So, to achieve this, perhaps would be the pore diameter or pore sizes of multiple systems. So, it is almost 1 to 20 Nano meters that is required to have a ultrafiltration membrane to reject 5 kilo Dalton to 500 kilo Dalton solutes.

So, please note that the demarcation of ultrafiltration and other processes, membrane processes such as a reverse osmosis and micro filtration is not often very distinct, but it is also the size of solutes that they are separating and of course, the type of membrane as well as the presence that is required to do the separation. So, ultrafiltration are one of the most successful use is to concentrate macromolecules.

So, however it is also used to fractionate macromolecules that has gained a lot of attention since last few years. Initially it was when ultrafiltration came into picture so, the initial applications of Protein concentration. Later on the fractionation of macromolecules also have been achieved using ultrafiltration. So, the view that ultra-filtration is a completely size exclusion process is only first approximation as you know that there are many other factors that play a role in the separation of anything any membrane separation.

So, they are solute membrane and interaction solute-solute interaction mode of solute transport, especially in ultrafiltration the mode of solute transport can be either diffusive or convective or can be a combination of both.

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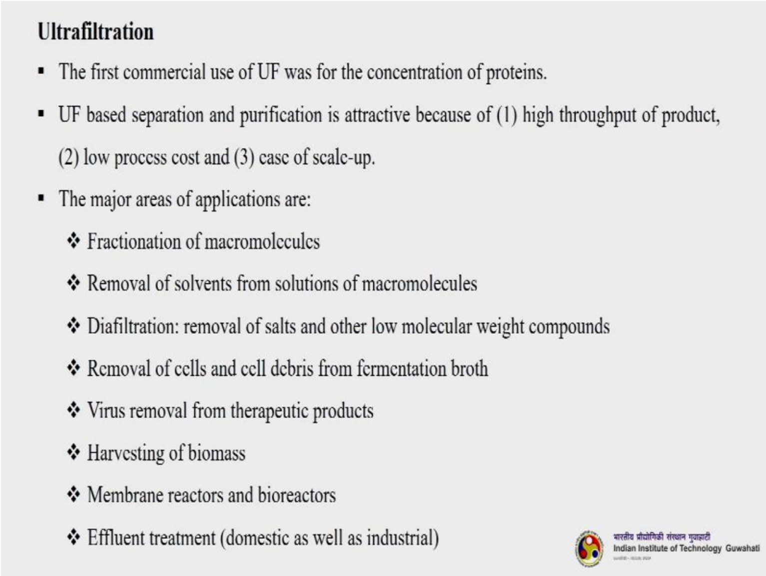

The first commercial use of ultrafiltration was for this was what I told you just for the concentration of proteins. So ultrafiltration based separation and purification is attractive because that the throughput of the product is very high. The process cost is actually low and the scale-up is very easy. So, the major areas of applications are listed here. So, they are fractionation of macromolecules removal of solvent from solutions of macromolecules dia filtration.

So, the diafiltration is a classic example, or a mode of operation of ultrafiltration, I will show you the scheme later on. And so, here what is happening, the removal of the salts are actually carried out and other low molecular weight compounds then, the removal of cells and cell debris from the fermentation broth virus removal from therapeutic products, harvesting of bio biomass that was basically cells, muscle cells, membrane reactors and bioreactors and effluent treatment both for domestic as well as industrial.

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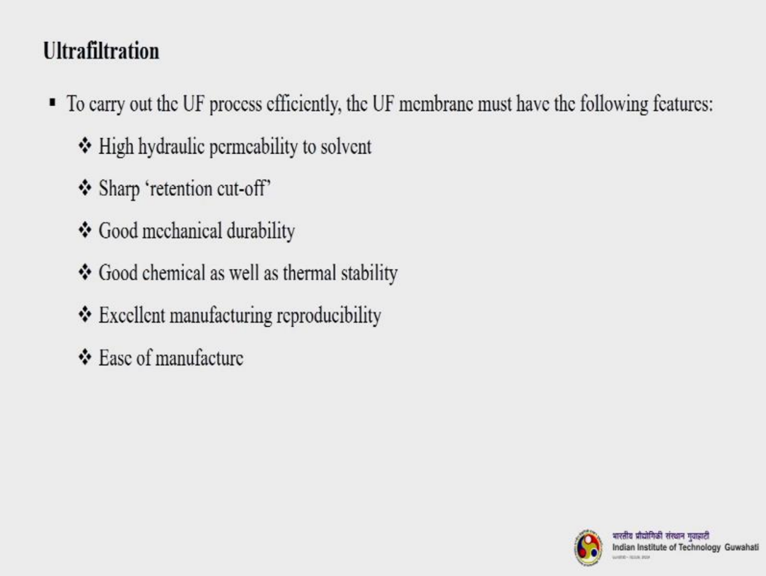

What should be ideal ultrafiltration membrane look like. So, what type of features this should have. So, ultrafiltration membranes should possess high hydraulic permeability to solvent they should have a sharp retention cut-off. We have already discussed what is this return some cut-offs are and diffusive it would have a good mechanical durability their mechanical strengths would be good, good chemical as well as thermal stability for various types of applications.

Excellent manufacturing reproducibility as well as the ease of manufacture. Reproducibility is one of the most important factors when you talk about commercial membrane manufacture.

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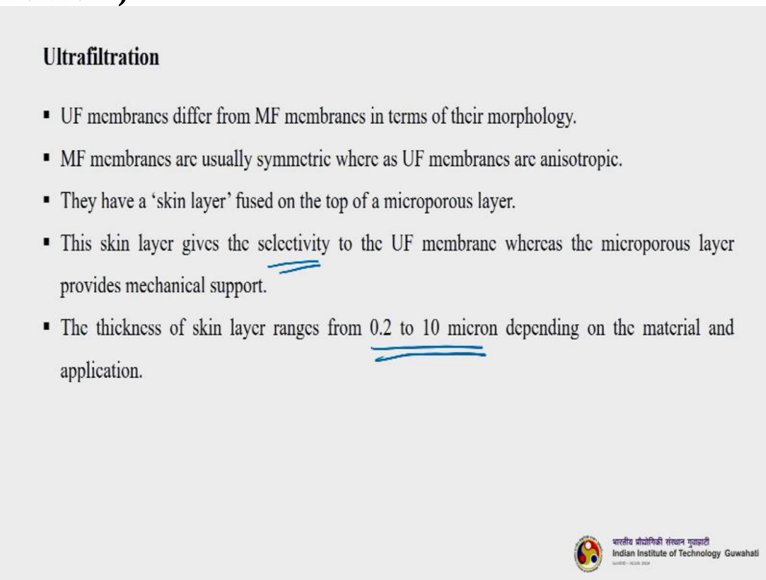

So, UF membranes easily differ from the micro filtration membrane in terms of their morphology. So, micro filtration membranes are symmetric membranes pores separate size may be different however, ultrafiltration are estimated I just draw you and show you how there is a skin layer. So, microfiltration membranes do not have a skin layer. So, however ultrafiltration layer do possess a skin layer but it is a porous skin layer.

So, do not confuse with the RO membrane which is also asymmetric membrane. So, this key layer gives the selectivity to the ultrafiltration membrane, whereas the micro porous layer is providing the support, mechanical support basically. The thickness of the skin layer usually ranges from 0.2 to 10 microns depending upon the material and also the intended application. But again you remember just like even RO also here also the thickness of the top layer that is the skin layer must be as thin as possible.

So, because if it is more thick than it will provide an extra membrane resistance to the overall resistance of the flow of the solvent or solute so, which is not good.

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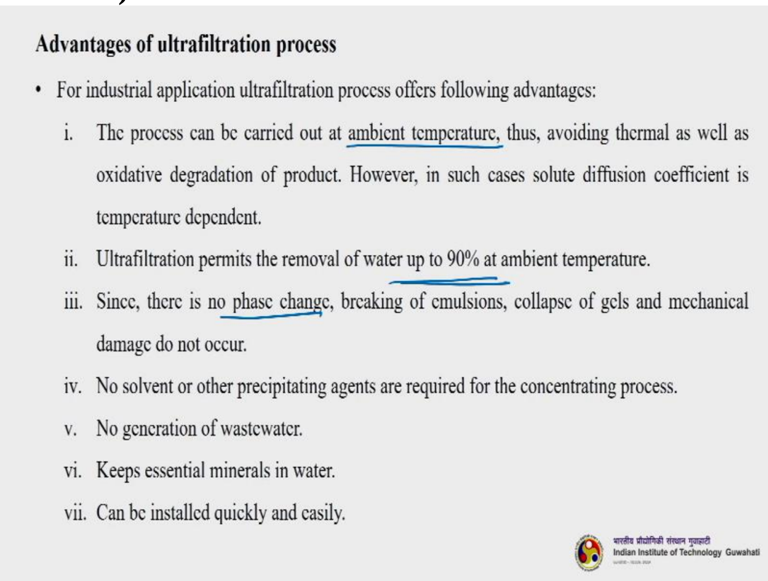

So, let us understand the different advantages of the ultrafiltration processes. So, for industrial application ultrafiltration processes offers the following advantages. The first one is that the process can be carried out at ambient temperature. So, thus avoiding thermal as well as oxidative degradation of products. So, no thermal requirement is there here. However, in such cases solid diffusion coefficient is temperature dependent.

So, second thing is that ultrafiltration permits the removal of water up to 90% at ambient temperature. Since there is no phase change there is no phase change occurring. So, breaking up emulsions collapse of gels and mechanical damage do not occur. No solvent or other precipitating agents are required for the concentrating process. No generation of wastewater please this is one of the things which you can compare with RO reverse osmosis there is RO reject. So, here there is no generation of wastewater, so, keeps essential minerals in water unlike your RO and can be installed quickly and fitted easily.

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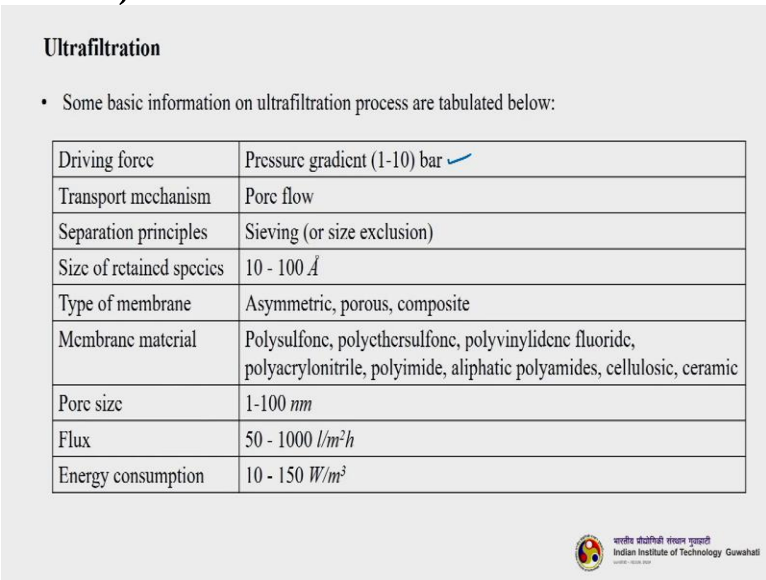

Ultrafiltration

- Some basic information on ultrafiltration process are tabulated below:

Driving force	Pressure gradient (1-10) bar
Transport mechanism	Pore flow
Separation principles	Sieving (or size exclusion)
Size of retained species	10 - 100 $\mathring{A}$
Type of membrane	Asymmetric, porous, composite
Membrane material	Polysulfone, polyethersulfone, polyvinylidene fluoride, polyacrylonitrile, polyimide, aliphatic polyamides, cellulosic, ceramic
Pore size	1-100 nm
Flux	50 - 1000 l/m^2h
Energy consumption	10 - 150 W/m^3

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So, these are some of the basic information of ultrafiltration processes. So, the driving force is of course, the pressure gradient usually 1 to 10 bar, the transport mechanism is pore flow, the seperation principle is actually sieving or you can call it size exclusion. The size of the retained species or the rejected species lies between 10 to 100 angstrom. Membrane type can be asymmetric, porous or composite membrane material can be polysulfone, polyethersulfone polyvinylidene fluoride, polyacrylonitrile.

Polyamide, aliphatic polyamides, Cellulosic, as well as ceramic also. Ceramic ultrafiltration membranes mostly tubular type is becoming very popular nowadays for most of the commercial applications, Pore size is usually 1 to 100 Nano meter. Flux is 50 to 1000 litre per meter square hour. Energy consumption is 10 to 150 watt per meter cube.

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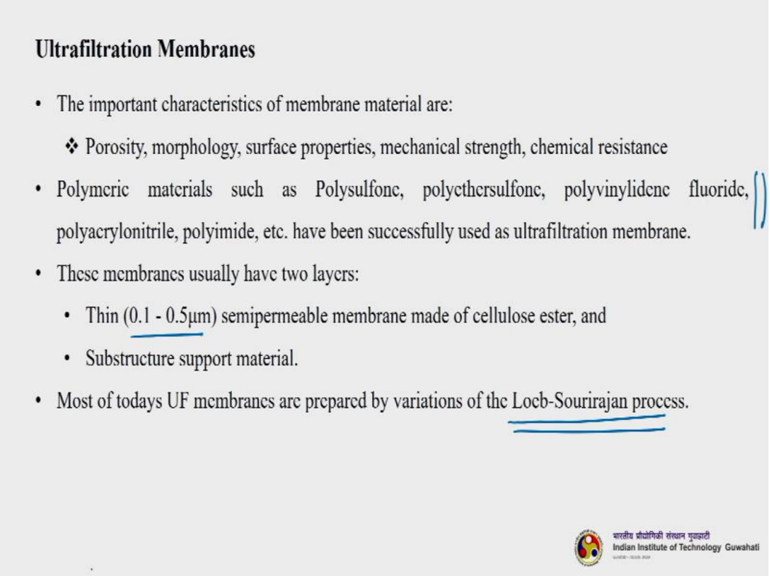

So, the important characteristics of the membrane material are porosity morphology surface properties mechanical strength as well as chemical resistance. So, this we have just seen what are the different types of materials, membrane materials that can be used to prepare ultrafiltration membrane. These membranes usually have 2 layers a thin layer which is 0.1 to 0.5 micron layer made up of cellulose ester and as substructure support material the more micro porous one. So, most of the todays membranes are prepared by a slight variations of the Locb-Sourirajan process.

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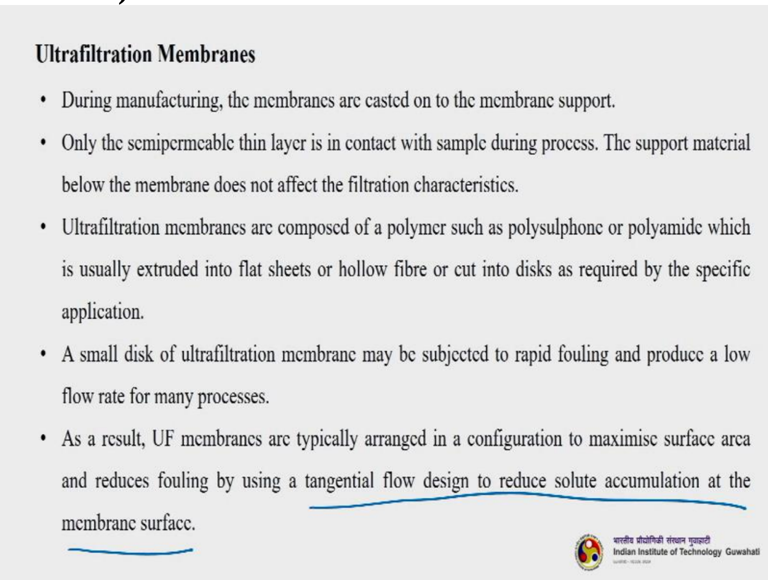

During manufacturing of ultrafiltration membranes, they are a membrane, so casting onto the membrane support. So, only the semipermeable thin layer is in contact with the sample during the process. So, the support material below the membrane does not affect any filtration characteristics. Ultrafiltration membranes are composed of a polymer such as polysulphone or polyamide which is usually extruded into plastics or hollow fiber or cut into disk as required by the specific applications.

So, when you are making ultrafiltration on polymeric membranes, it is very easy to do that. So, you can make into various cells whether you can make into hollow fibers, you can make into plate sheet membranes, you can make spiral-wound membranes but when you talk about test ceramic capacitors and membranes, you cannot have different types of separate sizes though there are plate-and-frame ceramic membranes are available, and most of those are actually tubular.

So, plate-and-frame has a lot of problem but as you know that ceramic membranes are usually they are brittle and since the sizes will be and they are very heavy. So, carrying and transportation is a big problem, if there is a big plate type of membrane, the fixing it has to be done in a very carefully little pressure on that will actually damage the membrane and then that plate membrane can become can break.

So, this is why most of the ceramic membranes ultrafiltration membranes are actually tubular. So, a small disk of ultrafiltration membrane may be subjected to rapid fouling and produce a low flow rate for many processes. As a result UF membranes are typically arranged in a configuration to maximize surface area and reduce fouling by using a tangential flow design to reduce solute accumulation at the membrane surface.

That means, most of the times the ultrafiltration membranes, does not matter what type of module it is, it is fixed in a cascading systems or in series will do today we will see how we go actually carryout multistage operations.

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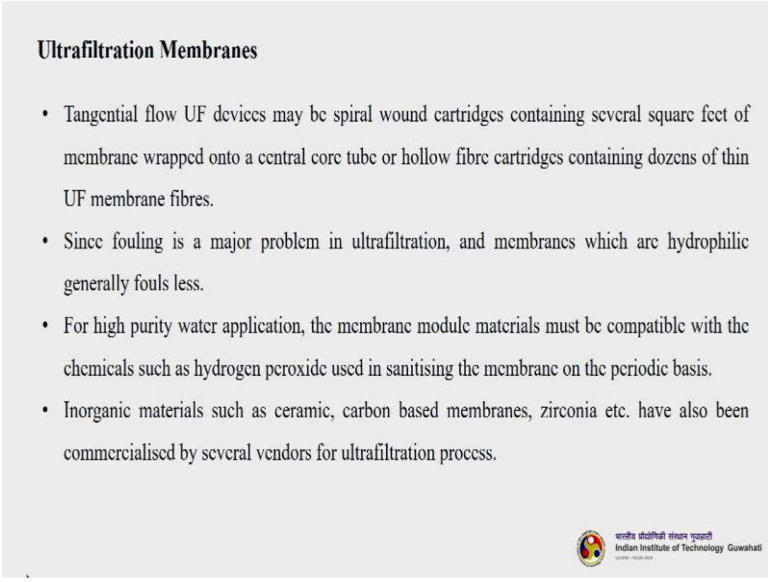

So a tangential flow ultrafiltration devices may be spiral-wound cartridges containing several square feet of membrane wrapped into a central core tube or a hollow fiber cartridges containing dozens of thin film UF membrane fibers. Now, since fouling is a major problem in ultrafiltration membranes which are hydrophilic are usually used because they are foul less. So for high purity water application membrane module materials must be compatible with the chemicals such as hydrogen peroxide used in sanitizing the membrane on the periodic basis.

Inorganic membrane materials such as ceramic carbon based membranes, Zirconia etc, have also been commercialized by several vendors for ultrafiltration applications, but we just discussed that what the disadvantages of having ceramic membranes are, but there are plenty of advantages also.

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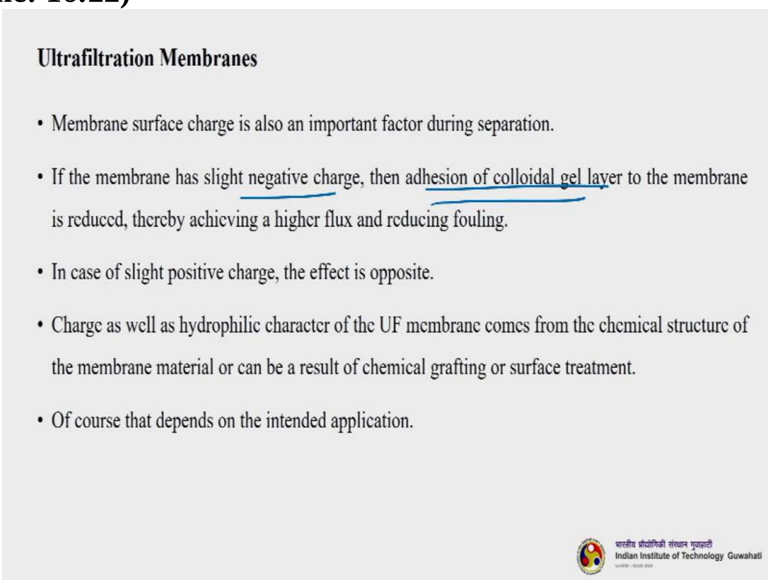

Membrane surface charge also plays a very important role during the separation if the membrane has slight negative charge, then addition of colloidal gel layer to the membrane is reduced thereby achieving a higher flux and reducing fouling subsequent fouling. But in case of slight positive charge the effect is reversed. That means that concentration polarization buildup will be faster.

And since it is a pressure driven process, some of these solutes will try to squeeze themselves inside the pores of the ultrafiltration membrane and there by fouling the pores as well as the membrane. Charge as well as hydrophilic character of the ultrafiltration membrane comes from the chemical structure of the membrane material and can be a result of chemical grafting or surface treatment.

Of course, that depends on the intended application and what is your intended application or targeted application. What do you want to achieve? Are you willing a separation are you going for a concentration you are going for purification, you are going fractionation. There are so many things can be done in ultrafiltration system. So depending upon that intended application, you can teller make a particular ultrafiltration membrane as well as module.

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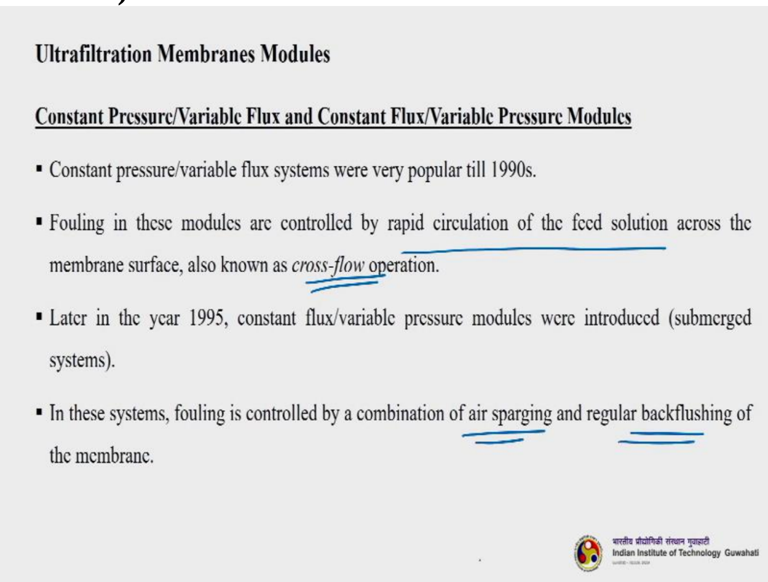

Now, let us understand the different types of modules, we have been discussing membrane modules in general then we have discussed the membrane modules in detail in the RO systems here we will just in a brief we will discuss because most of the modules configurations are same. However, their operating features are different. So, instead of understanding at the module and their operation today we will try to understand what the operating systems are or operating parameters.

For these particular modules what can be done what cannot be done with respect to ultrafiltration. So, usually 2 types of modules exist for ultrafiltration systems. The first one is constant pressure but a variable flux systems and the second one is constant flux and a variable pressure systems. Now, what are those that constant pressure variable flux systems are very popular till 1990s later on what happened actually the constant flux and variable pressure systems as come into picture in 1995?

They are mostly popular for the submerged system. So submerged membrane reactor submerged membrane bioreactor, you might have heard sometimes we will see what are those. So, in case of constant pressure variable flux systems fouling are controlled by the rapid circulation of the feed solution across the membrane surface. So, these are cross flow present. So, constant pressure and variable flux modules operate in a cross flow system. So, in constant flux and variable pressure systems fouling are controlled by continuous air sparging, as well as regular backflushing. They are mostly actually submerged systems.

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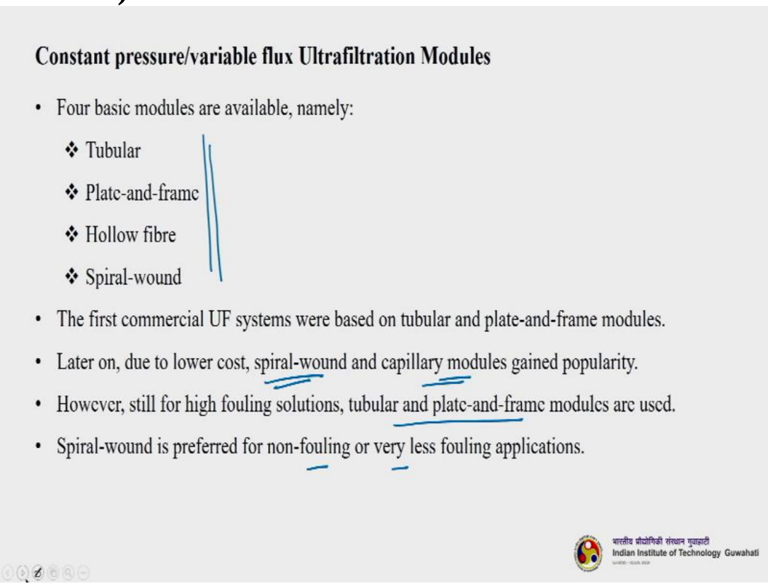

So, let us now understand the constant pressure and variable flux ultrafiltration membranes or we can call them cross flow ultrafiltration membrane systems. So, 4 basic modules that are available tubular, plate-and-frame hollow fiber and spiral-wound. So, now, I am not going to discuss in detail about all these things as we have been discussed. We have discussed this earlier also there are typical configurations.

Now, but we will try to understand with respect to ultrafiltration and how they actually how they are. So, the first commercial ultrafiltration systems were based on tubular and plate-and-frame modules. Later on due to lower costs spiral -wound actually as well as hollow fiber, capillary hollow fiber modules gain popularity, however still for high fouling solutions tubular and plate-and-frame modules are used spiral -wound is usually preferred for a less per non fouling or a very less fouling applications.

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Yes, these are hollow fibers, this is a hollow fiber module ultrafiltration module. This is your tubular ultrafiltration module, this is plate-and-frame ultrafiltration modules.

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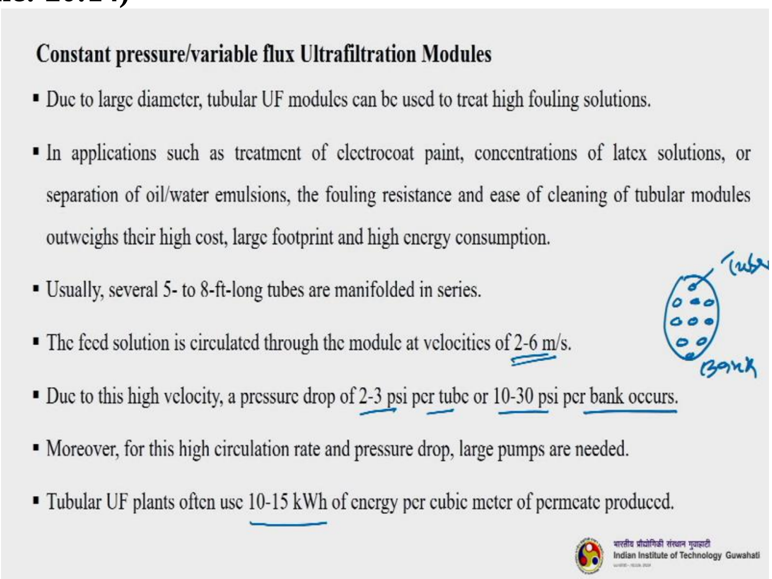

So, due to large diameter, our tubular ultrafiltration modules can be used to treat high fouling solutions in application such as treatment of electrocoat paint, concentrations of latex solutions or separation of oil water emulsions, the fouling resistance and ease of cleaning up tubular modules outweighs their cost, large footprint and high energy consumption. So, basically there will be cost and there will be thoughts coming into mind that what type of module what type of membrane has to be used.

As I told you earlier many times I am again repeating that the intended application will tell us what type of membrane as well as module will we are going to use let us say for one example, I have to remove virus from therapeutic products for the pharmaceutical industries in the biopharmaceutical industry. So, that is for human consumption. So, you can understand that all the viruses or any such new sense which is present in the initial feed solutions needs to be removed.

So, in that when we are designing such a system to designing a membrane system, may it be ultrafiltration or anything, then for the therapeutic applications, then please note that we do not think about cost that much of course cost is a factor in the way it is for the therapeutic applications needs to be removed. Now let us say we are talking about a wastewater application where we are removing the different components of the wastewater stream.

And we want almost a water in which the pollutants it should be free from pollutants as well as microorganisms. So, here we can little do compromise depending upon the heart is the intended application of the water which is coming from the membrane system. Are you going to use the potable water if it is a potable water then maybe RO is fine? It may need a little demineralization but that is a different issue.

And if it is not so then ultrafiltration also give us ultrapure water, may not be directly used for the drinking water purposes but can be used for other purposes. So you can have micro filtration membrane processes. So, cost is we have to see actually what is the intended application then you decide what type of membrane as well as module has to be constant. So, in case of tubular ultrafiltration membranes usually several 5 to 8 feet long tubes are manifolded in series.

So, the feed solution is circulated through the module at velocities of 2 to 6 meter per second you can see that the cross flow velocity is very high actually 2 to 6 meter per second. So, due to this high velocity the pressure drop of 2 to 3 psi per tube or 10 to 30 psi per bank occurs.

Bank is something which is also you can I am just trying to draw one you can see I can call this is a 2 bank.

So, this is a bank and this is a single tube. So, due to the high flow rate of the cross flow rate. So, the pressure drop is almost 10 to 30 psi per bank. Moreover, for this high circulation rate and pressure drop, large pump certainly needed. So that means you are adding more cost of the energy tubular UF plants often use 10 to 15 kilowatt per hour energy per cubic meter of permeat that is produced.

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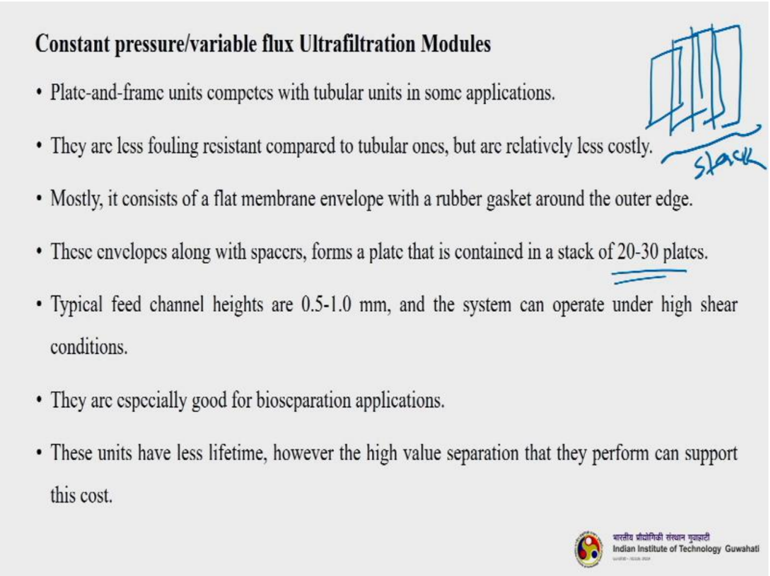

So the next is Plate-and-Frame units so they compete with tubular units with some applications they are less fouling registered compared to tubular ones, but a relatively less costly. So when that is what I was telling him if we are going through the application which are not therapeutic product application, you can always go Plate-and-Frame process system or some other membrane applications, mostly it consists of a plate membrane envelope with a rubber gasket around it center outer edge.

Now these envelopes along with special sponsor plate that is content in a stack up 20 to 30 plates. So one single plate I am trying to something like this. So it is a single plate. So you can have so many different types of plates. So and thereby making it stack of plates. So you can have a stack. So usually a stack contains 20 to 30 plates. So, typical feed channel heights are 0.5 to 1 mm then the system can operate under high shear conditions. So they are especially good for bioseparation applications.

Bio separation usually means that separations of proteins and antibodies. So, these units have less lifetime however the high value separation that they perform as per example the bio separation they can support this cost.

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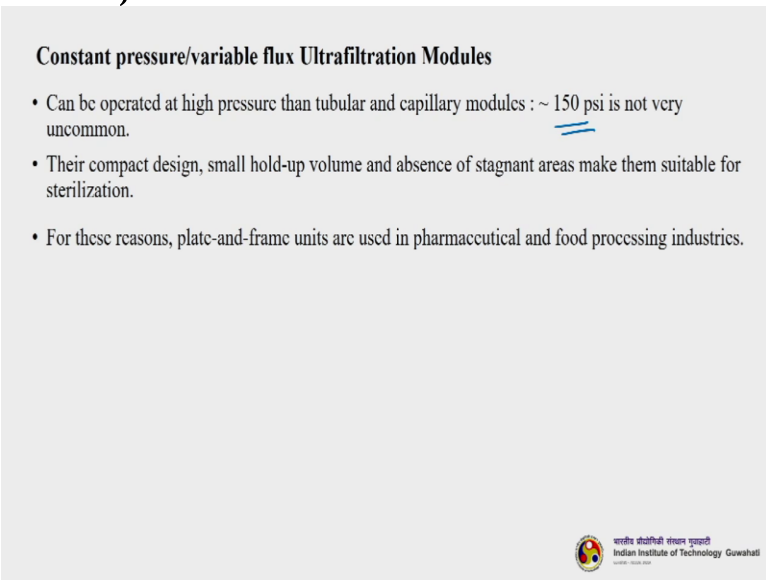

They can be operated at high pressure then tubular and capillary modules usually 150 psi is not very uncommon. They are compact design and then small hold-up volume and absence of stagnant ideas make them suitable for sterilization. So, when you are doing separation applications, that means we are purifying say, or concentrating as proteins. Then sterilization of the module centralized membranes is a must, so they are sterilizable. This is one of the beauty of this Plate-and-Frame systems. For these regions Plate-and-Frame units are used in pharmaceutical and food processing industries.

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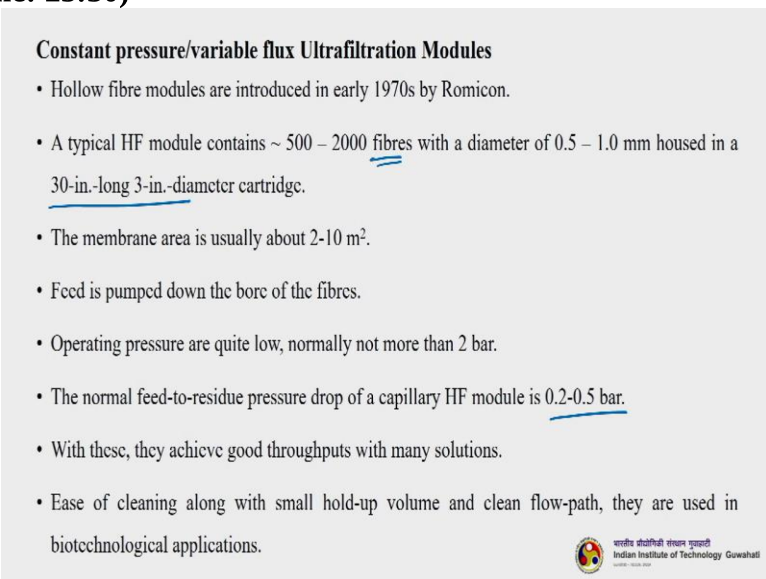

So, the next category is hollow fiber modules. So, they are introduced in 1970s by Romicon. So, typical hollow fiber module contents usually 500 to 2000 fibers single fibers with a diameter of 0.5 to 1 mm housed in a 30 inch long and 3 inch diameter cartridge. Now, please understand that this is not something sacrosanct so, this is usual it can be as smaller than the size or it can be larger than this size also.

So, the membrane area is usually about 2 to 10 meters square. So, feed is pumped down the pore of the fibers and operating pressure is quite low. Normally not more than 2 bar the normal feed-to-residue pressure drop per capillary hollow fiber module is 0.2 to 0.5 bar. Now with these they achieve good throughputs with many solutions ease of cleaning along with small hold-up volume and clean flow-path. They are used in biotechnological applications.

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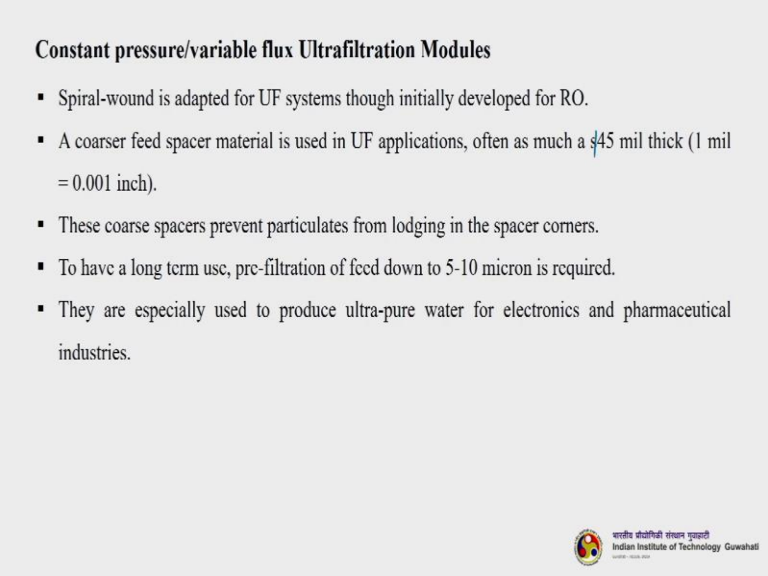

So, the next one is spiral-wound modules. So, spiral-wound is adapted for a UF system. Though initially developed, they are developed for the reverse osmosis systems. So, unlike RO here in case of UF the spiral-wound modules, they have coarser feed spacer material upon as much as 45 mil thick, so, 1 mil is equal to point 001 inch, so this unit is usually used when you are talking about this spacer materials.

So these course spacers prevent particulates from lodging in the spacer coordinates to have a long term use pre-filtration of feed down to 5 to 10 microns is usually required so that the clogging will be less and they are especially used to produce ultra-pure water for electronics and pharmaceutical industries.

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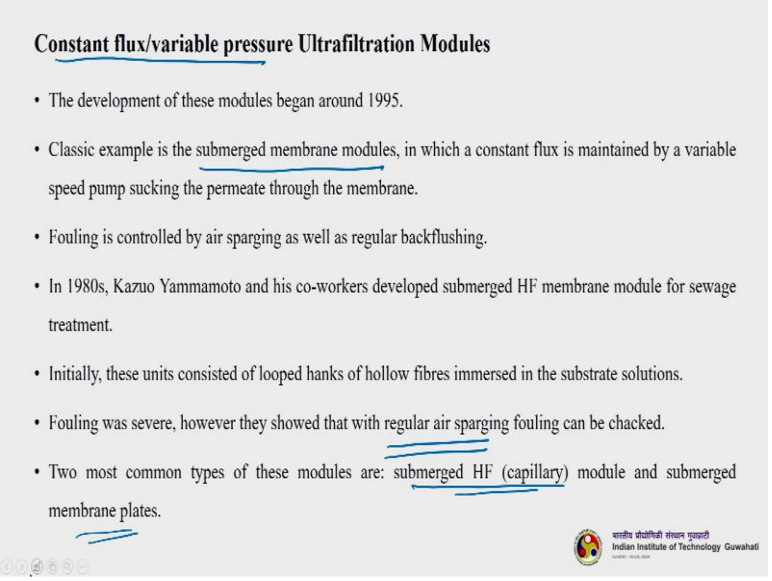

The development of these modules actually began at around 1995. So we are talking about a constant flux. So we discussed about constant pressure and variable flux models. Now we are discussing constant flux and variable pressure systems. Now, the classic example is the submerged membrane modules in which a constant flux is maintained by a variable speed pumps sucking the permeate through the membrane.

The fouling is controlled by either air sparging as well as regular backflushing. So, in 1980s, kazoo Yamamoto and his co-workers developed submerged hollow fiber membrane modules for sewage treatment. Now, initially these units consist of a looped, hangs up hollow fibers immersed in a substrate solutions. Now fouling is very severe. However, they have sought that regular air sparging with regular air sparging can be checked or it can be minimized. 2 most common types of these modules are submerged modules that is capillary modules are so most membrane plates.

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So in the next one I am showing you the diagram actually so these are submerged hollow fiber UF membrane modules and this is plates. So, you can see here how actually the hollow fiber the plate system looks like you can see this air and water both are flowing in this direction and we are getting air aeration is done inside this, this is the membrane This is another membrane. So, this aeration is done here in between the space between this membrane and this is this yellowish color you can see this is the supporting panel.

So, you are getting the permeated water from here from the opposite side. And you will see the sludge deposition on the surface of the membranes, and eventually they will be taken out and this is a 2 membrane system this particular image is showing. However, you can see here there are so many membrane plates are stacked together maybe more than 50.

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Now, let us try and understand one of the most important thing that is the common modes of ultrafiltration operation. So, there are various modes. So, most commonly these are the modes of operation, total recycle operation, batch operation, diafiltration, single pass operation feed and bleed operation and multistage operation.

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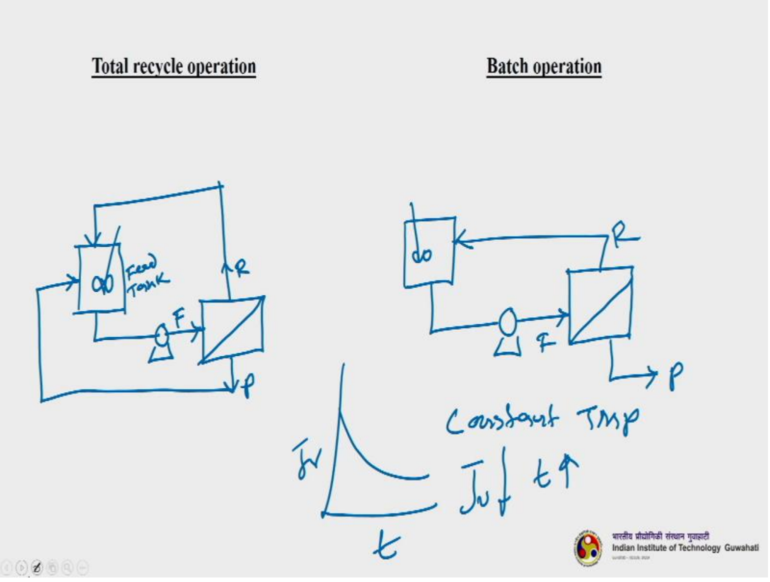

So, I try to draw the images or the sketches. So, let us see how the total recycle operation actually looks like. So, initially you will have a feed tank. Of course, you will have a feed tank everywhere then feed is pumped. So, pumped with membrane So, I am showing the cross flow operation we are talking about cross flow operation. Then since we are talking about the total recycle more. So, this is your feed. This is your retained.

Which is completely recycle and whatever it is permeate also completely recycle. So, this is your feed tank. Now, you know how why this is actually required. So, in this total recycle mode operation, because most of the times when you are trying to develop a membrane and you want to characterize it studies properties and its performance, initially we will study the membrane using this total recycle mode.

However, they are not very popular in commercial and industrial applications. In the lab skills they are carried out. The second one is that classical batch operation. Many times you will see many books they are writing that batch concentration they are the same? So, you have a feed tank then your feed is getting pumped to a cross flow membrane. So, you will get your permeate here and you are returned to it you will be taking and back to the membrane to the feed tank.

So, there is a pump. Pump is of course required to feed this one feed solution to the membrane. Now, batch concentration is carried out under a constant trans membrane pressure TMP. So, however your flux will decline as the time increases, so you have flux declined profile will be like this. So it is a J v by time. So, you will see the instant flux decline profile.

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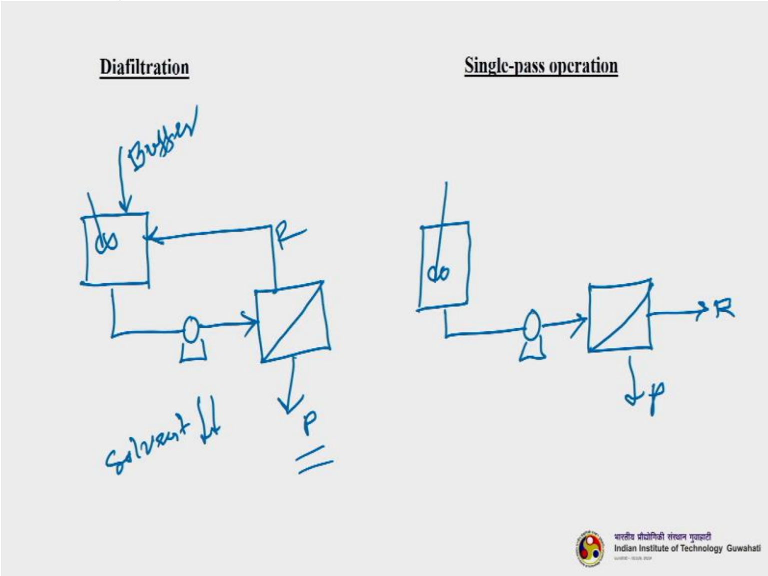

So, let us understand the next one. So, next is diafiltration. So, as I told you previously So, the diafiltration is actually carried out to remove salts as well as low molecular weight solutes. So, let us see how this looks like, again the feed tank there is a pump that is feeding to the cross flow membrane system. So, in the diafiltration the retained is getting circulated and we get the permeate here. So, what is happening actually, we can separate solutes also here 2 solutes.

However, what is happening in diafiltration is that the solvent is getting reduced. So solvent is getting reduced here. So we need to add buffer. So we add actually buffer here. So it is called diafiltration buffer usually it is nothing but a solvent only. So, separation of 2 solutes is usually carried out using the application or to remove or reject low molecular weight compounds.

So, since the solvent is getting lost, so solvent needs to be replenished. So using a buffer, now, single pass operation, now single pass operations there also same thing as a feed tank. So, there is a pump, which is getting to the cross flow system. So, it is retentive and you get a permeate. Now, this is a typical single-pass system. Now what is happening in this now try to understand that in a single pass system we cannot achieve the targeted separation and they are not common also in industrial application, because they request very high peak flow rates.

So, single pass cannot achieve the desired separation that is why there are other things have come into picture.

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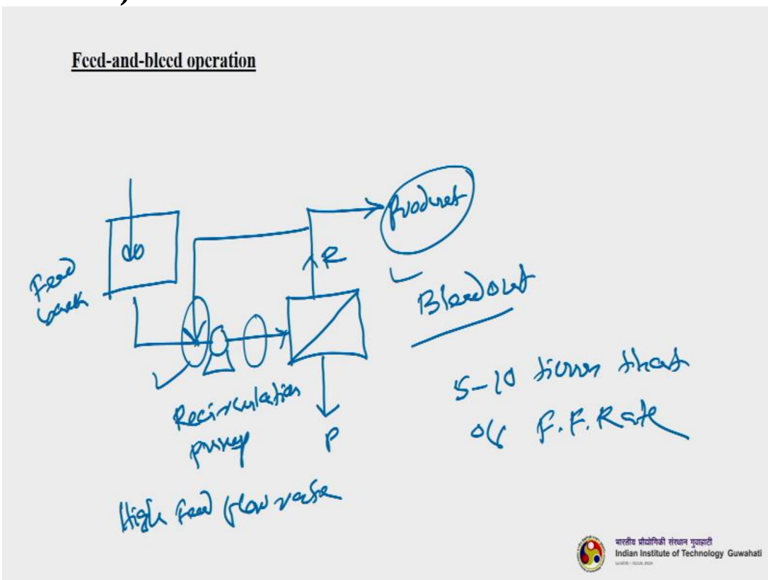

For example, feed-and-bleed operation. So, let us now understand what is feed-and-bleed operation, so, I will draw a single feed-and-bleed system. So, there is a difference of pump, this pump is called a recirculation pump, in case of feed-and-bleed operation, this is called a recirculation pump. So, you are seeing what this is the retentate. So, this is called recirculation pump.

So what is happening here actually high feed circulation velocity we can maintain high feed flow rate basically the part of the retentate is being fed back to the loop just before the recirculation pump. So, that means what is the major thing it is happening here volume of product that some taking out. So, that is this much and the volume of the retentate that is being again recirculated here are the same, it is actually called bleed out that is why feeding and bleeding continuously taking.

So, feeding continuously is happening here and bleeding continuously is happening. So, this is a continuous of process so, product of recirculation loop is almost this loop is almost 5 to 10 times that have feed flow rate. Now we can have multiple feed-and-bleed units that are joined in series or in caskets.

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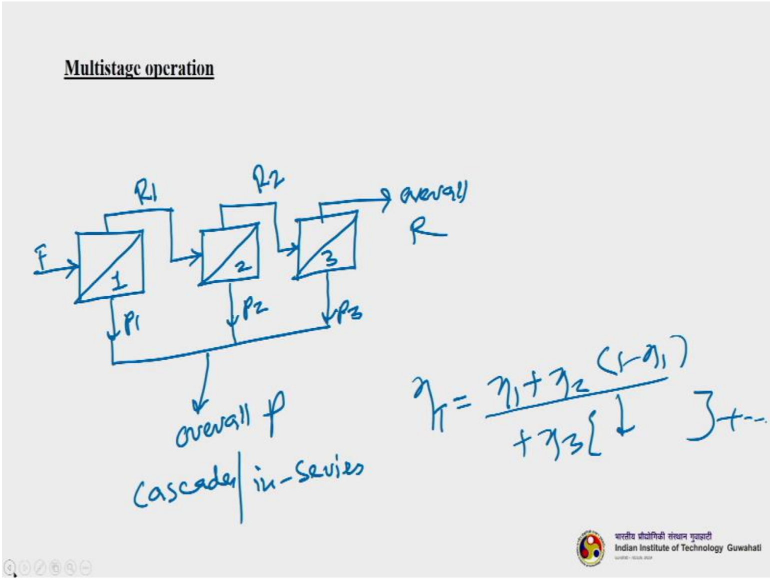

So, now, let us try to understand some multistage operation. Now, multistage operation has come into picture because you know in a single emitter operation system any process whether it is adsorption, absorption, distillation anything in a single step system the efficiency is usually very less restricted to 70 to 80% not more than 80% in any case, because there are so many different types of problems that are associated.

So, many factors that actually governs the separation and let us assume that we want a pure product or we want to separate or get rid of everything all virus not a single virus will be there in a therapeutic products. I want a 99.99% pure product. So, in that case what you can do so, in biopharmaceutical industries, were we talking about bio separation proteins separation antibodies and all these things you usually after the batch concentration, we feed them to the chromatographic columns to achieve 99.99% purity.

So, that is the only way you can get so, high purity, but you know chromatography columns are very costly. So, due to this actually the downstream processing cost is becoming very high and the product cost becomes very high to get rid of all these things, the membrane systems or membrane scientists have suggested that we can have cascade systems instead of having to do let us say we are doing the best concentration of 60 initially 6 to 7% purity to 60 to 70% purity, then we are taking it to this one chromatographic separation ultimately.

it has to pass through a chromatography separation because no other separation will give you 99.99% purity, they are extremely selective. So, if we can have a series of gaskets of membranes, membrane ultra-filtration system then we can actually concentrate it to a higher range than that doing it in more number of chromatography columns. So you can operate multistage operations in different way.

I am just trying to show on one such thing. So let us see how it happens. So this is our feed. So this is unit 1 this is unit 2 this is unit 3. Let me draw then I will explain. See this is feed, so we get permeate 1 we will get here permeate 2 will get here permeate 3. So we collect them all and we get overall permeate here and here what is happening. Retentate from unit 1 is being fed as feed to the unit 2 again the retentate from unit 2 is the feed to the unit 3.

So, what we get here, we get overall retentate here R here. So, this is called in caskets or they are called in-series. So, those who have read chemical reaction engineering, they must have read tanking series model where the equation of overall performance is usually given by eta T equals to eta 1 + eta 2 into 1 – eta 1 + eta 3 into this total here plus it goes on. So, that was all about this one multistage operations. Now, we can have this multistage operation in a different way also.

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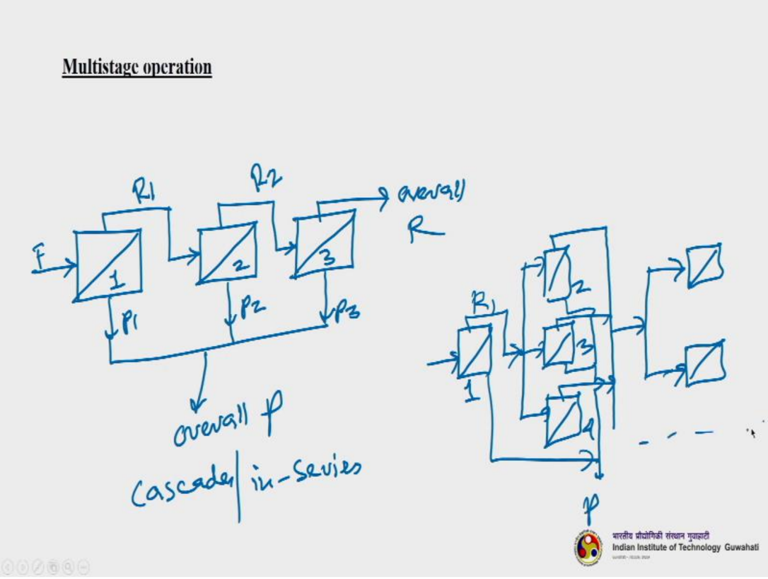

So, like I am just trying to just it is this then we can just try to draw also some other small system here. So let us say this is here, so actually they are the same, but here let us say this is this gets divided here what is the difference between this system and this system here you see, initially if we did then the entire it entire retentate from unit one goes is the p 2 unit 2 here it is not so. So, here the feed that retentate R 1 is divided and feed to 3 different units.

Now there retentate will be collected and again will be feed to across flow systems. So, this is how it happens then the permeate will be collected. So, this is the permeate and this actually goes on.

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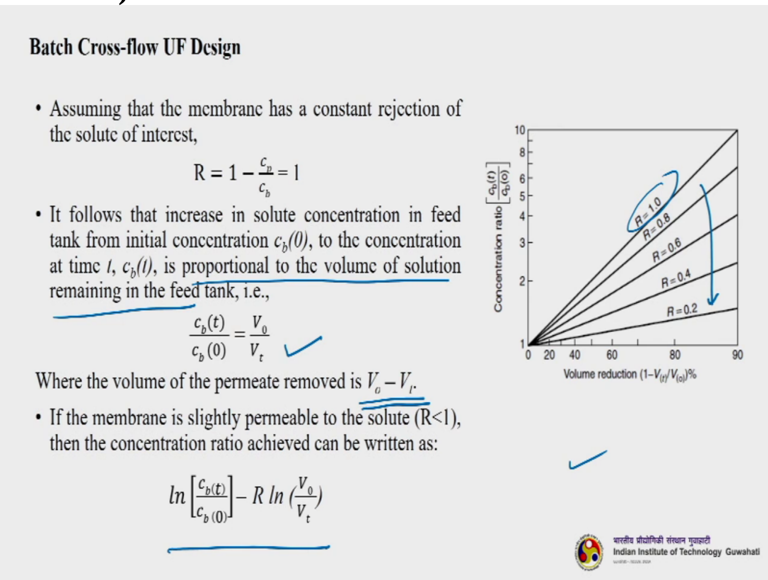

Now, let us understand the design of a cross flow system. So, let us assume that membrane has a constant rejection of the solute of interest. So, that means R equals to 1 – C p / C b, so, that is equals to 1. So, C p is your concentration of the solute in the permeate C b is the concentration of the solute in the bulk or feed you can see. So, it follows that increasing solute concentration in feed tank from initial concentration C b 0 to the concentration at time t that is C b t is proportional to the volume of solution remaining in the feed tank.

So, this is a question so C b t by C b not equals to V 0 by V t. So, we notice the initial volume of the tank feed tank and V t is the volume of the feed tank at any time t. So, the volume of permeate that is removed is nothing but V 0 – V t. So, if the membrane is slightly permeable that means, r is < 1, then the concentration ratio that can be achieved can be written in this equation. So, let us log of C b t / C b 0 equals to R ln V 0 / V t.

So, you can see this particular diagram or the figure in which the concentration ratio C b t by simply not is plotted against volume reduction that is 1 – V t / V 0 in percentage. You can see where R = 1 that means the constant rejection or the complete rejection. You can see the volume that is reduced is the highest right and when membrane becomes semi-permeable little your rejection reduces point 8.6 you can see. So the volume that is reduced actually getting less. So with this, we will wind up today's lecture.

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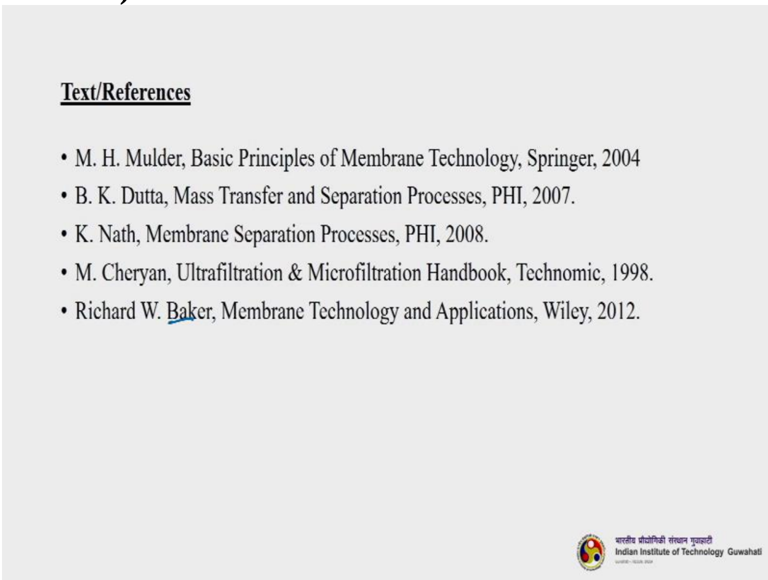

So, most of these lectures are taken from various books and this one some from Baker some from this one Mulder. So, please refer to these books and read in case you have any doubt, please feel free to ask me or write to me at kmohanty@itg.ac.in.

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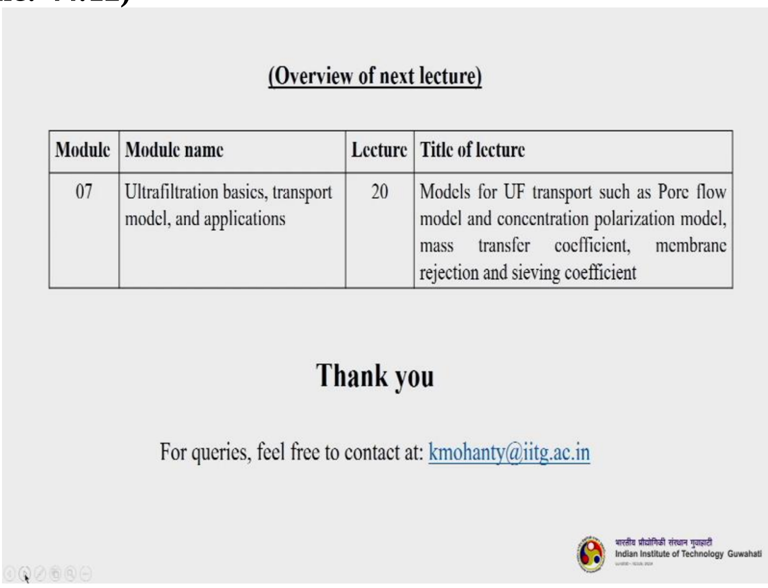

And in the next class we will discuss about the models of multiple tests and transport such as Pore flow model and concentration polarization model mass transfer coefficient, membrane rejection sieving coefficient. So, thank you very much.