Membrane Technology
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Lecture-24
Models for MF transport, plugging and throughput, fouling in MF, MF applications

Good morning students and today is lecture 24 under module 8, as you know, we are discussing microfiltration. So today we will discuss the fouling mechanism in microfiltration and how to control fouling as well as we will also learn different models for microfiltration fouling, and few applications of microfiltration in general we will discuss, though several applications are there. As you know, fouling in any membrane process, whether it is microfiltration, ultrafiltration, reverse osmosis. So, fouling means actually it is the accumulation

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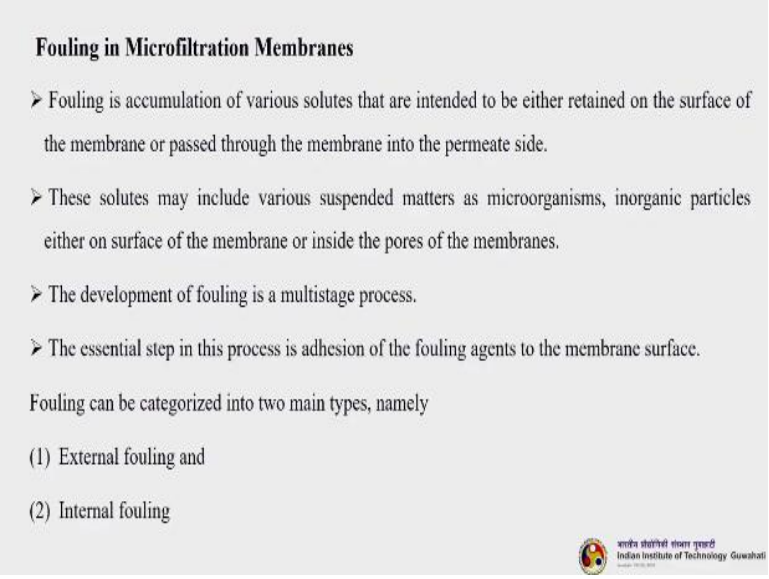

Of various solutes that are intended to be either retained on the surface of the membrane or passed through the membrane into the permeate side. So, now while passing some of these solutes will be retained inside the pores of the membrane. So due to different interactions like charge based interactions some affinity based interactions of the solutes along with the membrane pore wall.

Now this solute may include various suspended materials, there may be microorganisms like your bacteria viruses. So there may be inorganic particles either on the surface of the membrane or inside the pores of the membrane. So development of fouling is a consequence of a multi step process, or you can call as a multistage process. So the essential step in the fouling, the way how fouling begins actually with the adhesion of the fouling agent to the membrane surface.

So we can call it some form of adsorption also. So basically we can divide fouling into two categories one is external fouling and another is called internal fouling.

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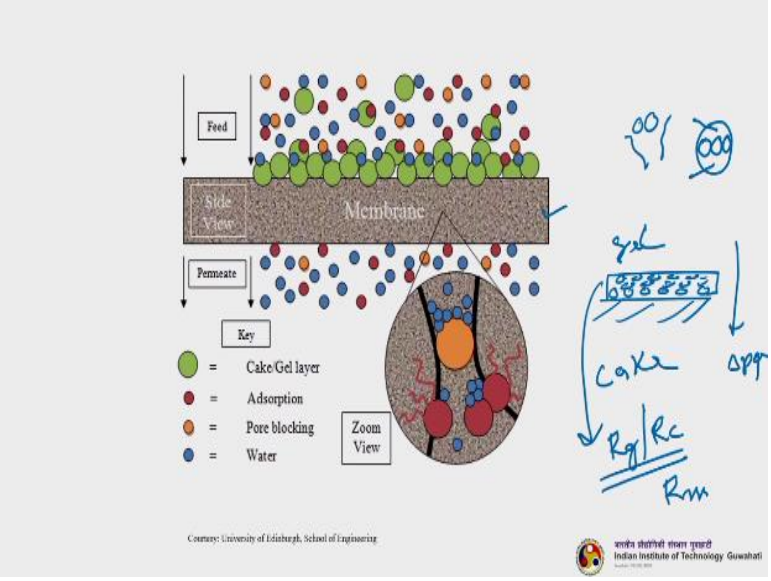

Now, let us have a close look at this particular picture this is proposed by the University of Edinburgh School of Engineering where they studied the harvesting of microalgae from the water, basically algae was removed using microfiltration after they are mature in the broth. So this is your membrane? And the green particles are the cake or gel layer deposition. So initially before the gel formation of cake formation takes place.

What happens is that so solutes start interacting with the membrane surface. By virtue of their charge based interaction, or hydrophilicity or hydrophobicity, whatever may be the case? And they will start depositing on a monolayer. So initially, there will be if this is a membrane surface. So there will be a monolayer deposition of the solutes. So slowly, slowly is here time progresses, you are increasing your delta p also.

So more and more of solute will get deposited now a time will come at a certain pressure what will happen, now this depositions will form a gel layer structure. So we can call it gel or many people call it cake it is fine so anything you can call does not matter? So it is very soft that is why it is called gel, so many books it is written cake so gel or cake whatever may be the case. So what it is formed then what will happen this layer is providing a huge resistance.

So we can call it a gel layer resistance or a cake layer resistance, so this resistance will be much more than the resistance which is afforded by the membrane which is the clean membrane basically the Rm. the resistance due to the membrane thickness. So now what will happen your permeation the flux declined profile? We will be very severe and a permeate flux whatever you wanted to achieve you will not achieve it?

So, you can see that in this particular figure adsorption pore blocking all these things are happening, so it depends upon what type of molecules you are processing or may be what are the components, that is present in the feed. Now you remember one thing that it may happen that a particular feed stream may contain so many different types of solutes. So out of that one solute may be your pair interest.

Let us say in this particular example, we want to harvest algae. That means we want to retain algae on the surface of the microfiltration membrane and apart from algae there are so many other components also now we have to choose a microfiltration membrane in such a way that it will retain the micro algae there passing and allowing the water and other low molecular weights compounds to the permeate side.

So this is how it will actually it happens, so during this process of lower molecular salts or even water the components, which are smaller in size than the pore, of the membrane will of definitely pass through the membrane pores so and they will try to get attach themselves inside the pores or even sometime. Last class as you understand that if you remember so we talked about the bridging mechanism.

So let us say this is a pore two particles are forming a bridge or three particles are forming a bridge, thereby blocking the pore mouth? so the entire, if you see the cross sections, it looks something like this, however this and this persons are still available for, solute transport now but there is reason that why we are discussing about this bridging or pore blocking mechanism is there.

So if we even if the entire pore not completely blocked, however, the pore size of the mouth of the pore has become reduced so obviously there will be more deposition on the surface of the membrane and the flux declining profile will be very steep.

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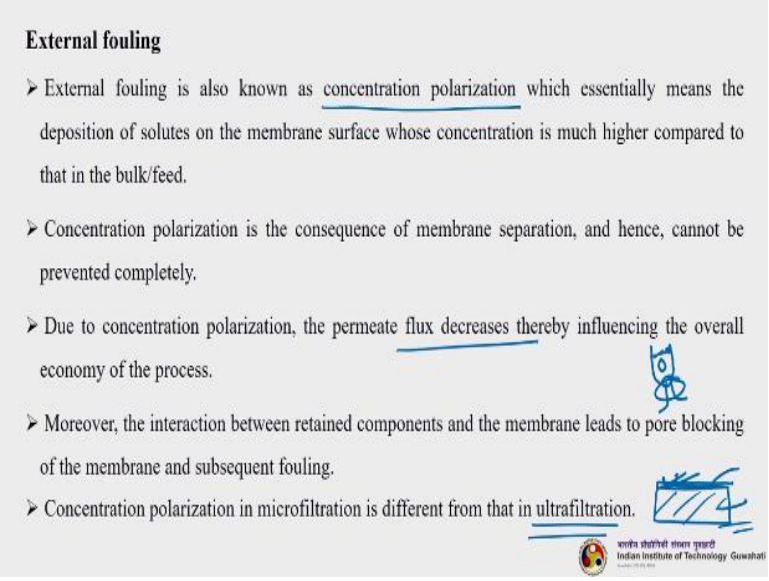

So let us now understand the external fouling. So external fouling is also known as concentration polarization. So which essentially means the deposition of the solute on the membrane surface whose concentration is much, much higher compared to that in the bulk feed. So the concentration polarization is the consequence of membrane separation and hence cannot be prevented completely.

So in no case you can get rid of concentration polarization. The reason is that when the separation is happening there are solutes which are getting either transmitted to the permeate site or the solids that are getting retain on the surface of the membrane. So in any case whether a

membrane is hydrophilic or hydrophobic or whatever the environment feed properties or the solute properties.

There will be some deposition of the solute on the surface of the membrane. You cannot get rid of it, what is our intention is we need to minimize it. So due to concentration polarization the permeate flux decreases thereby influencing the overall economy of the process. In industrial parlance, we always wish that we should achieve a higher permeate flux so that you get a proper rejection or retention.

So the interaction between the retain components and the membrane leads to pore blocking of the membrane and subsequent fouling. Initially when this pore blocking is happening it may block the mouth of the pore slowly they may get inside smaller, smaller particles inside the pore and as I told you earlier in one of the class about the constrictions of pore separation. Suppose this is a pore there may be a constitution Again it might open to the other side.

However the particle which is smaller than the pore diameter, this is pore diameter and it will pass through it? Let us say it comes inside the pore. However due to this particular constriction, it gets deposited on this surface of the constriction or the mouth of the constitution. So this is some sort of pore blocking mechanism. We can call it an internal pore blocking mechanism. So concentration polarization microfiltration is different from that of the ultrafiltration.

Because you remember ultrafiltration is an asymmetric membrane. So there are basically two membranes. one support membrane and then there is a very thin top layers. So obviously the pore size of this membrane and pore size of this membrane are different. So once and it is quite clear we know that the pore size is here of the skin layer is obviously very, very small, much smaller than the porous support. So the mechanism is different.

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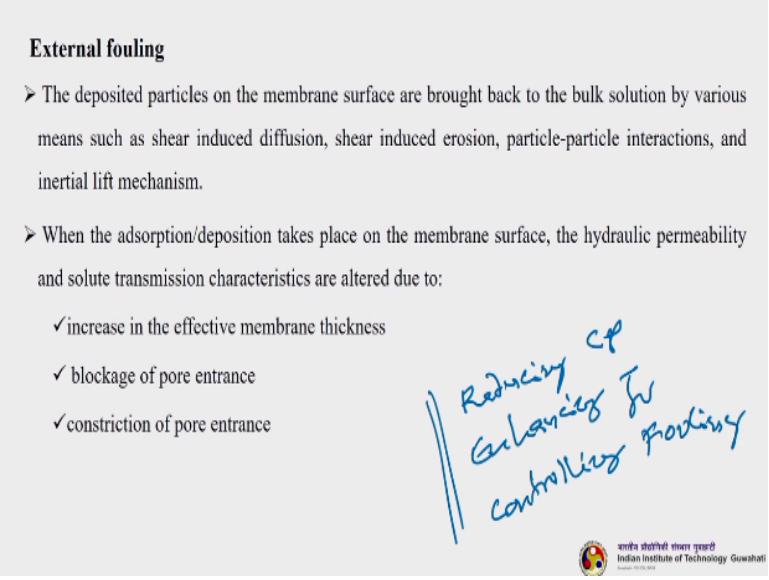

The depositor particles on the membrane surface are brought back to the bulk solution by various means. Now, this is one of the, we have already discussed in ultrafiltration, how do you reduce concentration Polarization of subsequent blocks or then interrelated? So one thing, how to reduce Cp or concentration polarization and enhancing permeate flux Jv or controlling or minimizing your fouling.

So all these are related so all these are related so when you trying to reduce concentration polarization, you are obviously addressing the enhancement of the permeate flux also and thereby minimizing or controlling fouling. So when there are various techniques, we have discussed here in this diffusion erosion, particle interactions, in a cell lift mechanism. There are other techniques also.

So when adsorption and deposition takes place on the membrane surface the hydraulic permeability and solute transmission characteristics are altered due to; increase in the effective membrane thickness, blockage of pore entrance and constriction of pore entrance. So now let us understand.

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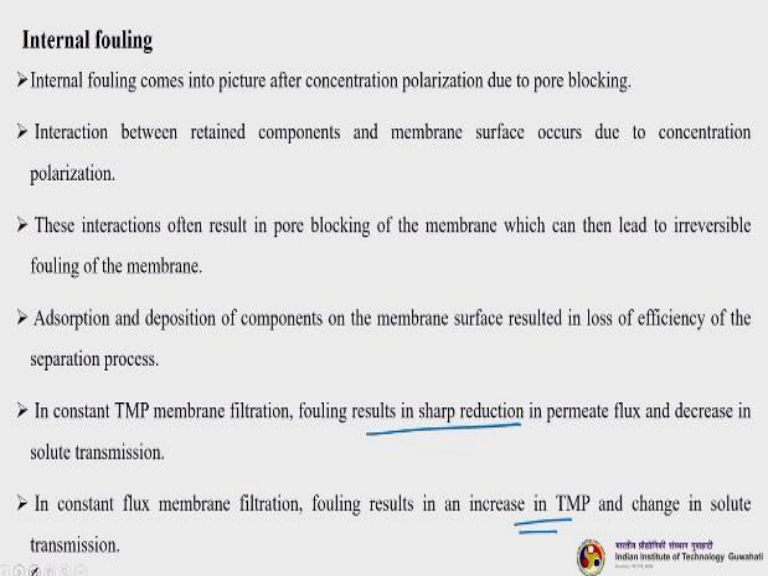

Internal fouling; internal fouling comes into picture after the concentration polarization layer is devoloped due to the pore blocking mechanism. Because I already told you that due to bridging the pore is getting blocked or due to a large size of the particles are sitting on the mouth of the small size pore so the pore mouth is getting blocked. And some of the pore mouths are not completely blocked, some small lower or smaller lower molecular weight components will try to pass through that particular space inside the pores.

Now and they due to constitution they will get retente, so interaction between the retente components and membrane surface occurs due to concentration polarization. Now these interactions often result in pore blocking of the membrane which can then lead to irreversible fouling of the membrane. Now fouling is of two types. So we can also classify the exterior interior that is what we are discussing. We can also tell them reversible and irreversible fouling.

Reversible fouling is one in which we can reverse the fouling that means we can control completely remove the fouling by some mechanism by backflushing, by some acid or alkaline treatment and irreversible fouling is very strong bounding of the solute molecules most probably due to the charged based interaction and so that even if you use acid alkali treatment some buffer solution backwashing with the higher cross flow velocity.

Then also you are not completely getting out of the membrane pores so that is irreversible fouling. So in constant TMP filtration fouling results in sharp reductions. So when we are going for a constant trans membrane pressure filtration so the permeate flux decline is very sharp and in constant flux filtration where you are mentoring the flux at the same level so fouling results in increasing TMP and change in solute transmission is to maintain the constant flux.

You have to increase the trans membrane pressure. So in that since you are increasing the trans membrane pressure the change in solute transmission is also occurring.

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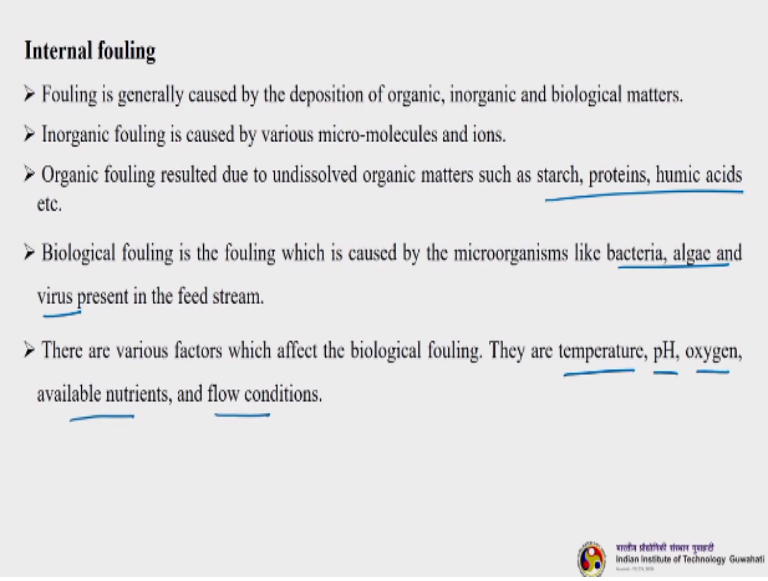

So fouling is generally caused by deposition of organic, inorganic and biological matters. Inorganic fouling is caused by various micro molecules and ions. Organic fouling resulted due to un dissolved organic matters such as starch, proteins, humic acids etc. A biological fouling is the fouling which is caused by microorganisms like bacteria, algae and virus present in the feed stream. So, microfiltration has the huge application in biotechnological and biopharmaceutical industry varying.

They remove these microorganisms like bacteria, viruses, moles, algae all these things from the process water so as to make it, sterilized. So there are various factors which affect the biological fouling so that temperature, pH, oxygen content available nutrients and different flow conditions.

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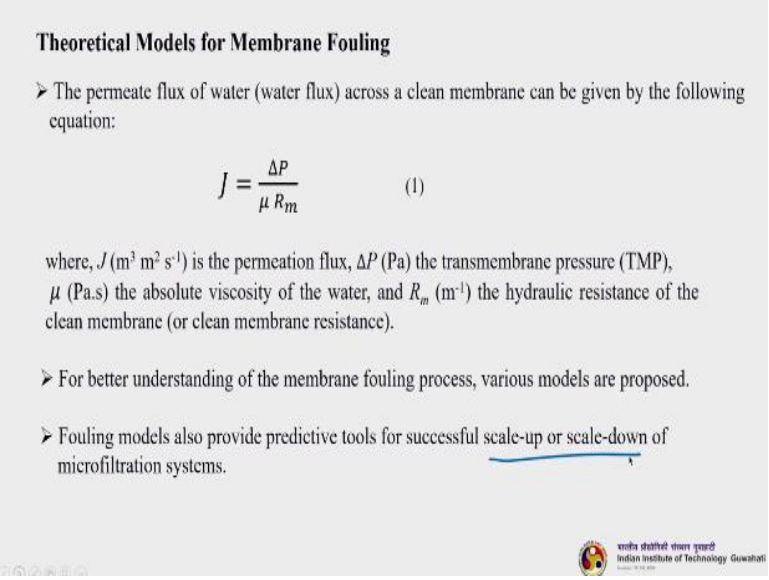

So let us now understand the theoretical models on the membrane fouling so all the models are based on actually resistances. So the permeate flux of water or water flux across a clean membrane can be given by this following equation, which is J equals to delta p by mu Rm, so either you are write Jv, Jw So it is permeate flux basically J is the permeate flux, delta p is the trans membrane of pressure mu is the absolute viscosity of water.

And Rm is the hydraulic resistance of the clean membrane or clean membrane resistance we can call. So for better understanding of membrane fouling process, various models are proposed. So, fouling models also provide predictive tools for successful scale-up or scale-down of microfiltration system.

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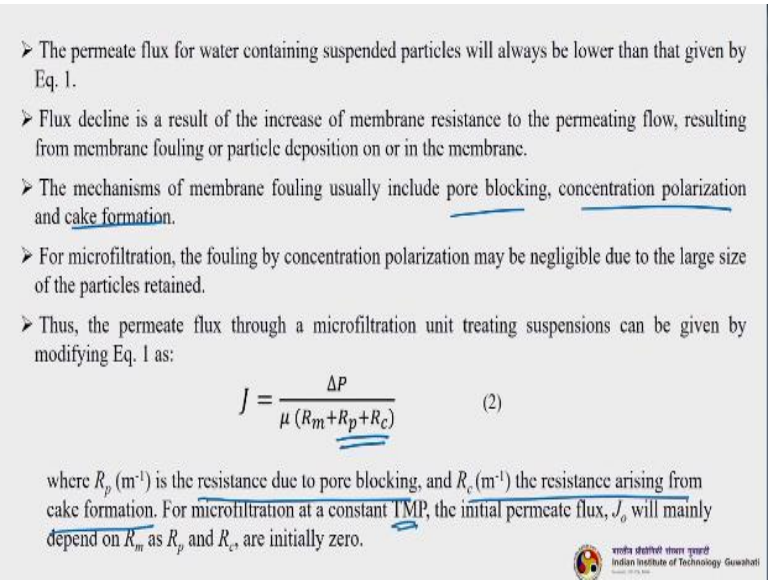

So the permeate flux for water containing suspended solids will always be lower than that given by equation 1 that means the clean water flux will always be high because there are nothing no solutes present in there, when there are solutes in present in suspended form or dissolved form, Then the flux will decrease or the amount of the flux whatever you will get will be obviously less than that of the clean water flux or clean membrane flux.

Flux decline is a result of the increase of membrane resistance to the permeating flow resulting from membrane fouling or particle deposition on or in the membrane. So the mechanism of membrane fouling usually include the pore blocking concentration polarization and cake formation, so these are happening simultaneously once you are increasing pressure so initially there will be deposition on the surface.

Slowly, slowly it deposition amount becomes more then its gel or cake layer forms than gel layer forms, so and then gradually subsequently they lead to fouling. So for microfiltration fouling by concentration polarization may be negligible. Due to the large size of the particles retained. Thus permeate flux to the microfiltration unit treating suspensions can be given by modified earlier equations.

So you can write instead of Rm we are adding two more resistances? So you know, resistance are always added in series so Rm is the thin membrane resistance, so + R p + R c so what is Rp? Rp

is the resistance due to the pore blocking and r c is the resistance that is arising from the cake formation. So for microfiltration at a constant TMP, initial permeate flux will mainly depend on Rm as Rp and Rc are initially zero. So when it is j0 so that means initial flux so it will be only delta p and mu Rm.

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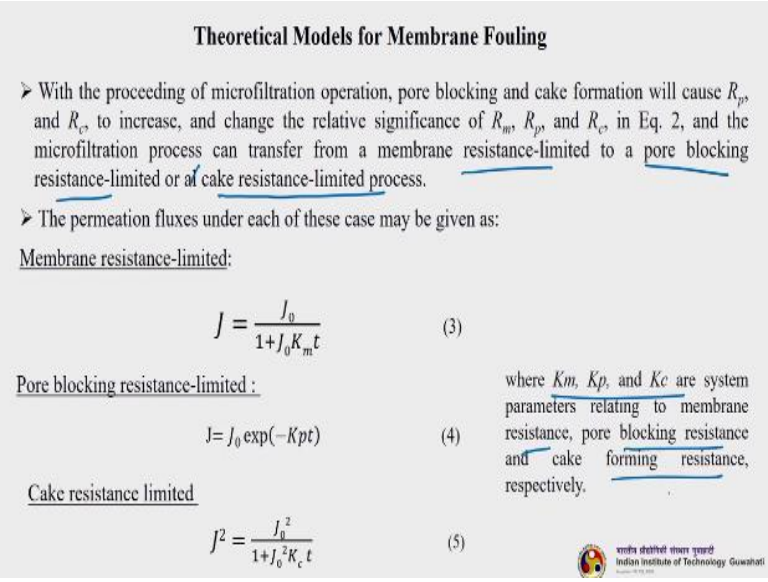

So with the proceeding of micro filtration operation, pore blocking and cake formation will cause Rp and Rc to increase. So once you start the process slowly the solute will be build up on the surface of the membrane. So the resistance due to the pore blocking as well as resistance due to the cake will increase or the contribution will increase basically. And change the relative significance of Rm of Rp and Rc in equation 2.

And the microfiltration process can transfer from a membrane resistance-limited to a pore blocking resistance-limited or a cake resistance limited process. I hope you understand that when if you look at this earlier equation, so initially when for the clean water flux, so initially we are starting so rm will be predominant. Slowly Rp and Rc will come into picture. So when Rm is actually predominant here.

Then it is a membrane resistance controlled process that is in the initial because the initial membrane will be clean. Then when the solute deposition starts slowly pore blocking and RC, so these two will have more impact on overall process dynamics? So then your membrane process

will no more be, membrane resistance the limited it may become either pore blocking resistance-limited or it can be cake resistance-limited.

Depending upon whether Rp is contributing more or Rc is contributing more. So anyway the permeation flux under this can be written like this if it is a membrane resistance limited so it is j0 + 1 + j0 kmt pore blocking. So it is j0 into exponential of - kpt and cake resistance, so j square equal to j0 square divided by 1 + j0 square kct, now under km, kp, kc that km, kc are system parameters in relating to membrane resistance pore blocking resistance and cake forming resistance respectively, so now this equations you can always express.

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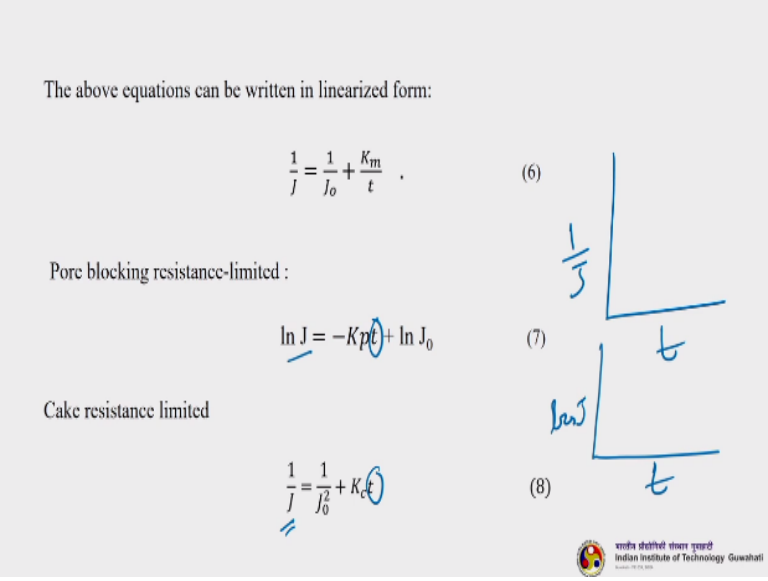

In a linearized form so you can write 1 over j by 1 over j0 + km by t you can always plot it, so you plot 1 over j versus 1 over t. So you will get the slope is k and 1 over j0 is the intercept, so similarly you can plot lnj versus t here so you get kp and j0 from that similarly one by j versus t, so, Another you plot 1 by j versus t so here we can plot Lnj versus t.

So this is just the linearized form that will help us to plot the data easily and find out what is the value of km and j0.

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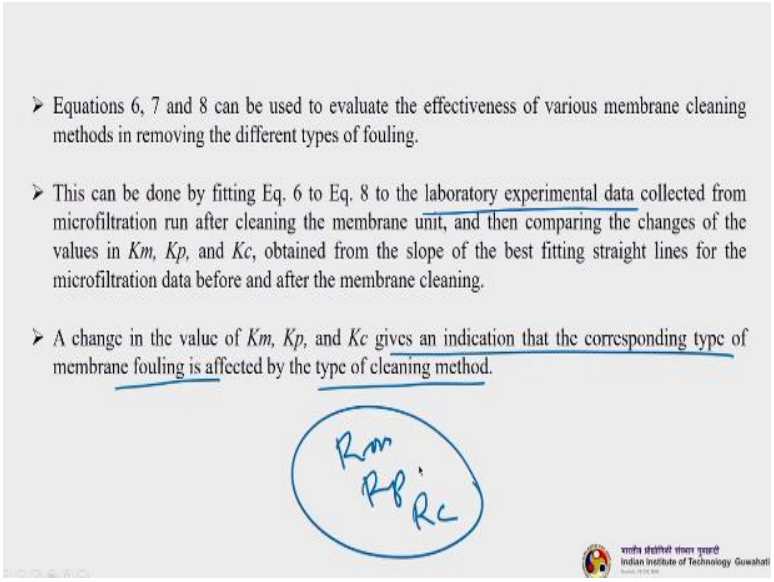

So this earlier equations can be used to evaluate the effectiveness of various membrane cleaning methods in removing the different types of fouling. This can be done by fitting these equations to the laboratory experimental data, what about the experimental data we are getting in the laboratory will be fitted to this linearized form, after cleaning the membrane and then comparing the changes in the value of km, kp and kc what you do basically is that.

First you get the clean data then you get one set of experimental data with certain pressure then clean the membrane again use it for one set of experiment again clean it again use it, so you get so many different types of data from the laboratory scale experiment then you fit it and then from this fitting you will get different values of km, kp and kc. So then you can understand what is the effect of km, what is the effect of kc, what is the effect of kp on the system diagrams.

On the membrane efficiency also directly, so a change in the value of km, kp, kc gives an indication of the corresponding type of membrane fouling whether Rm is dominating whether Rp is dominating or whether Rc is dominating, now, this can be find out from the value of km, kp and kc.

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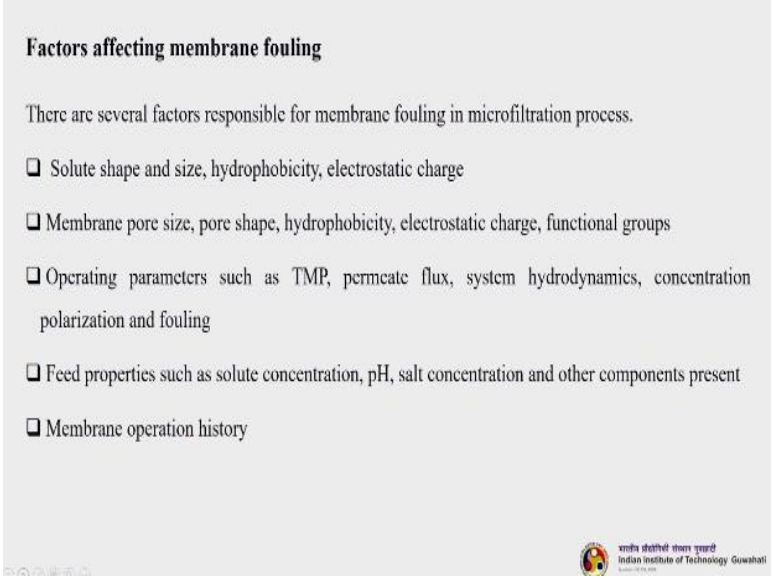

Now there are different factors that affect fouling, this we have discussed during ultrafiltration also but let us just quickly go through again, so the solutes shape and size hydrophobicity and electrostatic tests are very important roles. Similarly the membranes pore size, membranes pore shape its hydrophobicity and its electrostatic charges and its functional groups if at all or reactive groups that present on the membrane sometimes also plays a big role.

Apart from that operating parameters such as transmembrane pressure, permeate flux, system hydrodynamics of the module basically the length of the channel the diameter and all these things how many tubes are inside or how many seats are inside all these things then concentration polarization apart from that feed property such as solute concentration, ph, salt concentration and other components also play an important role.

Then most importantly membrane operation history, So all industries uses membranes that always keep an economy of the membrane operation history.

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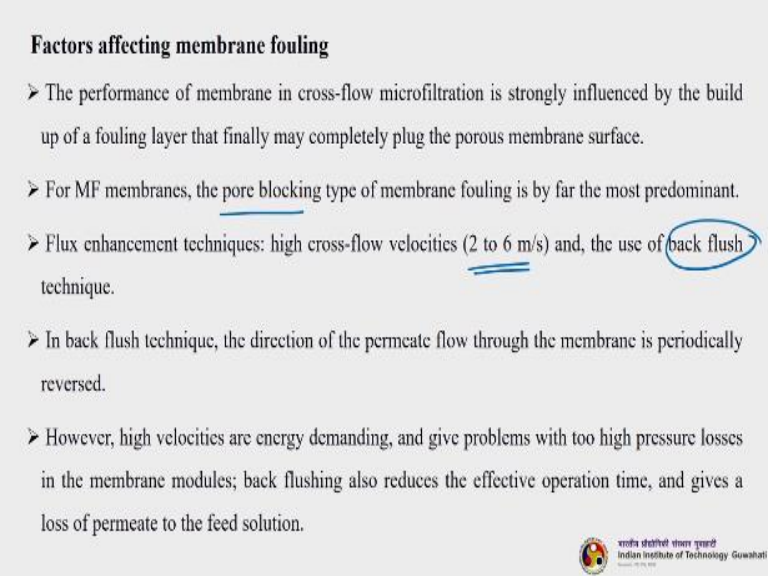

The performance of the membrane in cross flow microfiltration is strongly influenced by the build up of a fouling layer that finally may completely block the porous membrane surface. Especially this is more effective when we are removing proteins or retaining proteins. So for microfiltration membranes. The pore blocking type of membrane fouling is by far the most predominant.

In most of the solutes it has been seen that pore looking is the most predominant. So flux enhancement techniques so you can have either higher cross flow velocity about two 6 meter per second or you can go far back flushing. This also we have discussed in ultrafiltration. So in back flush technique the direction of the permeate flow the member is periodically reversed. First we have seen how back flushing is done from the feed side?

Then again you close the permeate truck and from the back side again, you back flush, so by doing that the entire area of the membrane will be back flush. So however higher velocities are energy demanding and give problems with two high pressure losses in the membrane modules. Back flushing also reduces the effective operation time and gives a loss of permeate to the feed solution.

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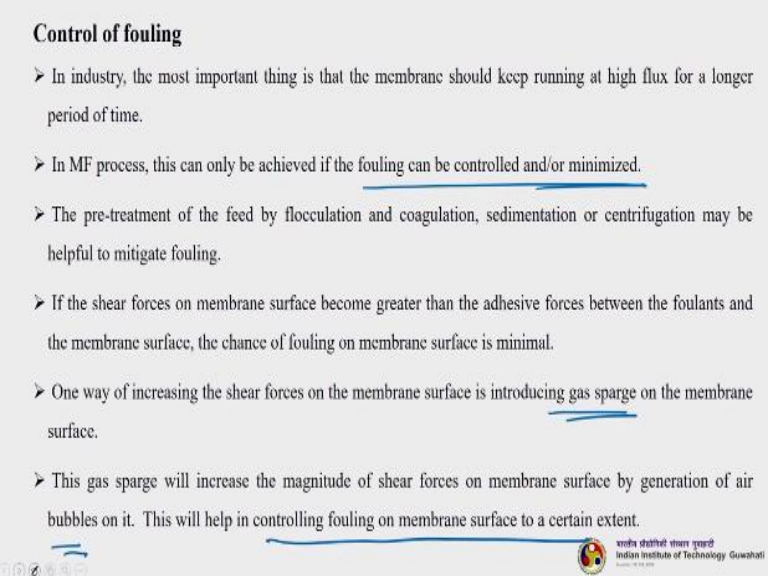

So let us understand the control of fouling thus this also we have discussed in our ultrafiltration. But let us just quickly go through, so in industry the most important thing is that the membrane should keep running at high flux for a longer period of time, so its should be more technically sustainable as well as economically also sustainable. So the microfiltration process this can only be achieved.

If the fouling can be controlled or minimized to a greater extent. the pre treatment of the feed by flocculation and coagulation sedimentation and centrifugation may be helpful to mitigate fouling. Now pleases remember as I told you in the beginning of the class the fouling mechanism, the buildup of concentration polarization all these things are little different in ultrafiltration and microfiltration. The reason that there pore size are different, microfiltration pore sizes are bigger.

In general ultrafiltration, the pore sizes are much much smaller than the microfiltration. Then ultrafiltration is a asymmetric membrane and microfiltration pores are more defined, well defined. Last class we have seen how the pores, we have discussed about the skin filtration, there filters. So if the shear forces on the membrane surface becomes greater then the adhesive forces between the foulants and the membrane surface the chance of fouling on the surface membrane becomes minimum.

One way of increasing the Shear process is by introducing gas sparge, this also we have discussed how gas sparging can be done basically you sparge gas nitrogen in air, depending upon what is the solute inside the feed is there and this sparging will help gets bubbles so you are basically creating a different types of multiphase flow inside the module. It is two faceflow basically.

So this gas sparge will increase the magnitude of shear process on the membrane surface by generation of air bubbles, so this will help in controlling fouling on the membrane surface to certain extent.

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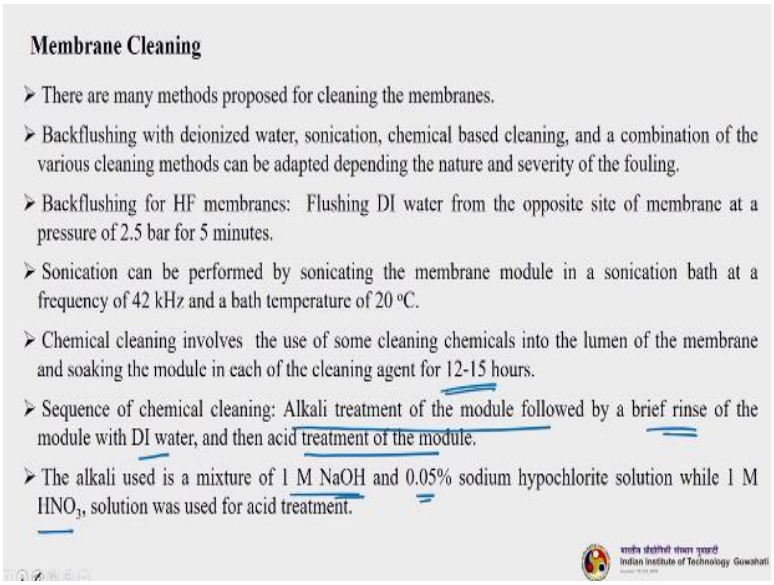

So how do you clean membranes? So there are many methods proposed in cleaning the membrane. Back flushing with deionized water, sonication, chemical based cleaning and a combination of various cleaning methods can be adapted depending on the nature and the severity of the fouling. Now back flushing for hollow fiber membranes. So it is recommended that flushing with deionized water from the opposite side of the membrane at a pressure of 2.5 bar for 5 minutes.

So this is for the hollow fiber members not true all members so sonication can be performed by sonicating the membrane module in a sonication bath and a frequency of 42 kilohertz and a bath temperature of 20 degree centigrade. So this particular parameters those are fixed you are seeing

this has been recommended by various researchers after using various types of solutes, chemical cleaning involves the use of some cleaning chemicals into the lumen of the membrane and soaking the module for almost 12 to 15 hours.

So the sequence of chemical cleaning is that first alkali treatment, followed by a brief rinse of the module with deionized water then acid treatment. So this is the treatment proposed and adapted by most of the industries the alkali used is 1 molar of sodium hydroxide and 0.05% sodium hypochlorite solution while 1M nitric acid was used for the acid treatment.

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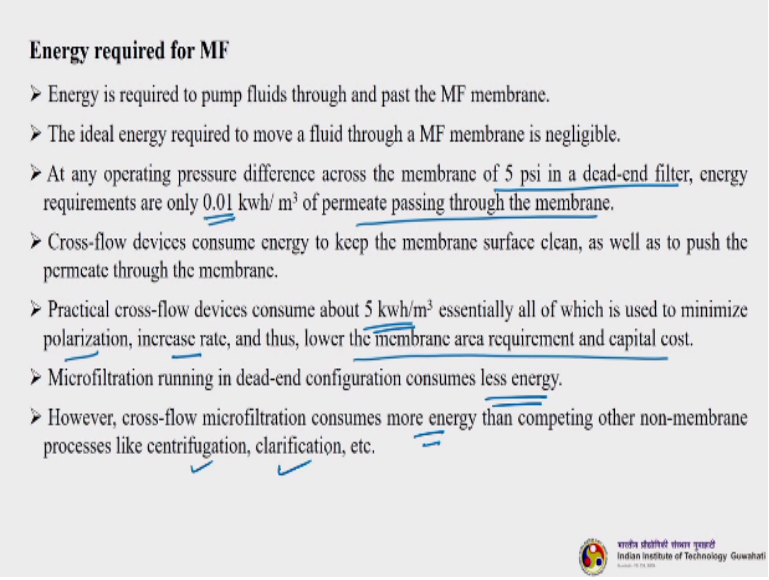

So the energy required for microfiltration is basically the energy that is required to pump fluids through and as well as pass the membrane. So the ideal energy required to move a fluid through, microfiltration membrane is usually very negligible. Because the pore sizes are bigger, so you do not need much pressure to pressurize or to achieve the retention. So at any operating pressure difference across the membrane of 5 psi in a dead end filter.

And usually five psi for a dead end filtration system. So energy requirement is only 0.01 kilowatt hour per meter cube permeate passing through the membrane, so a small pressure so cross flow devices usually consumes little higher energy because there is an additional cross flow of pump is required for the recirculation. Practical cross flow devices consume about 5 kilowatt hour per meter cube essentially all of which is used to minimize polarization.

Increase rate and thus lower the membrane area requirement and capital cost. So microfiltration running in dead end configuration consumes less energy however cross flow consumes more energy than competing when we are comparing with other non membrane processes like centrifugation, clarification etc.

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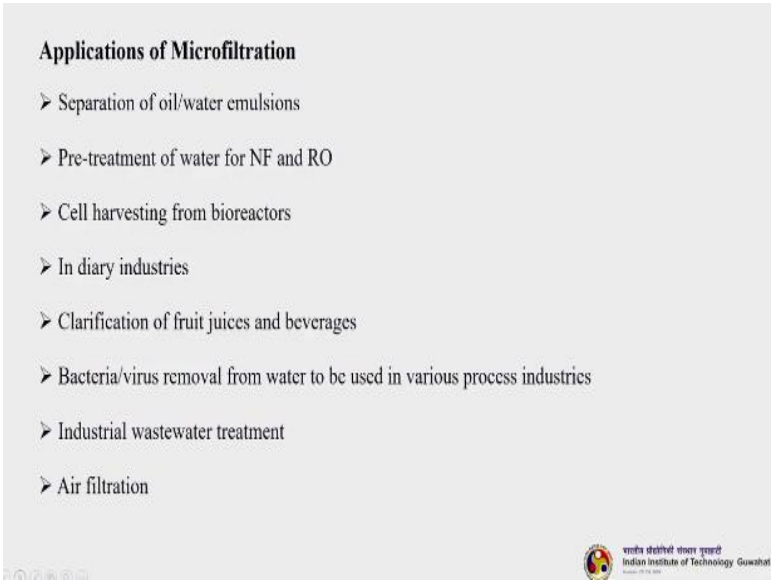

So let us quickly discussed some of the applications of microfiltration. There are many applications just listed some of the most relevant applications industrial wise. So a separation of oil water emulsions, pre treatment of water for NF and RO, this is one of the most important applications and then cell harvesting from bioreactors in dairy industries, we discussed last class also in ultrafiltration also that memory technologies have huge application in dairy industries.

So clarification of food uses and beverages. Bacteria virus removal from water to be used in various process industries, industrial wastewater treatment and air filtration. We will see the diary one.

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So in the dairy industry milk protein fractionation and separation. So whey and casein protein separation are newer and important processes used in, dairy industry in nowadays because the last course in the microfiltration membranes whey protein to pass through the membrane and casein to the fractionation before the use of ultrafiltration to further concentrate and purify each protein product.

So that it can go further this cheese production. So that this technical protein fractionation allows for more options to manufacture unique protein products.

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Then fat and microbial removal, so microfiltration membranes can be used in the final fat and microbial removal stage in the production of milk in order to produce high quality WPC's whey protein concentrate and WPI is whey protein isolates. So, with larger portions range microfiltration is commonly used to extend the shelf life of milk and produce high quality milk products. It is especially applicable for use of bacteria spore removal.

When treatment options involving high temperature conditions are not suitable. Now this process can be used as a pretreatment step to pasteurization to ensure that the vegetative spores are completely removed.

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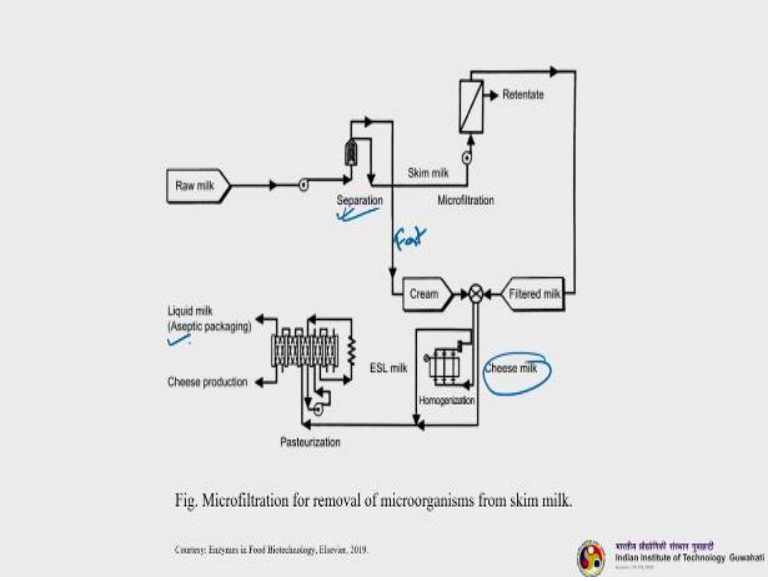

Fig. Microfiltration for removal of microorganisms from skim milk.

Courtesy: Enzymes in Food Biotechnology, Elsevier, 2019.

So this is a schematic of the microfiltration for removal of microorganisms for skim milk, you can see the raw milk anything that is suspended is usually removed here. Then some fat is also removed and, you are seeing this is basically you are removing fat here. So fat free milk or skim milk is going to a microfiltration, where you remove any other bacteria's or any other things are present then again, it is coming back to the filter milk.

Here cream is also coming. These all are going to become cheese milk basically homogenization then it is going for pasteurization, cheese product or liquid milk packaging.

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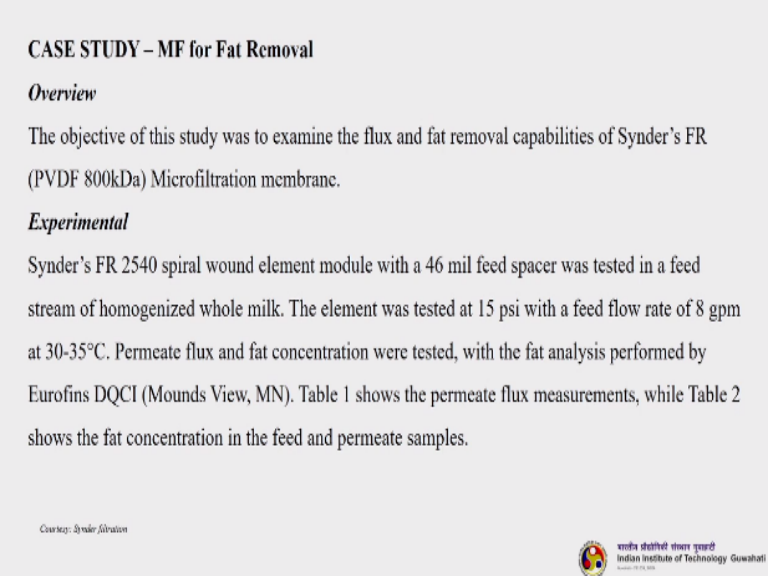

So let us discuss a case study that is proposed this is given in the Synder's filtration company. So this is microfiltration for fat removal. So the objective of this study was to examine the flux and fat removal capabilities of Synder's FR, microfiltration membrane, which is a PVDF 800 kilo Dalton membrane. So how the experiment is carried out? So Synder's FR 2540 spiral wound element module with a 46 mil feed spacer was tested in a steam of homogenized whole milk.

Now this element was tested and 15 psi with the feed flow rate of 8gpm and 32-35 degree centigrade. Permeate flux and fat concentration are tested, with the fat analysis perform by Eurofins DQCI, this is actually an analytical method so table 1 shows the permeate flux measurement while table 2 shows the fat concentration in the feed and permeate samples.

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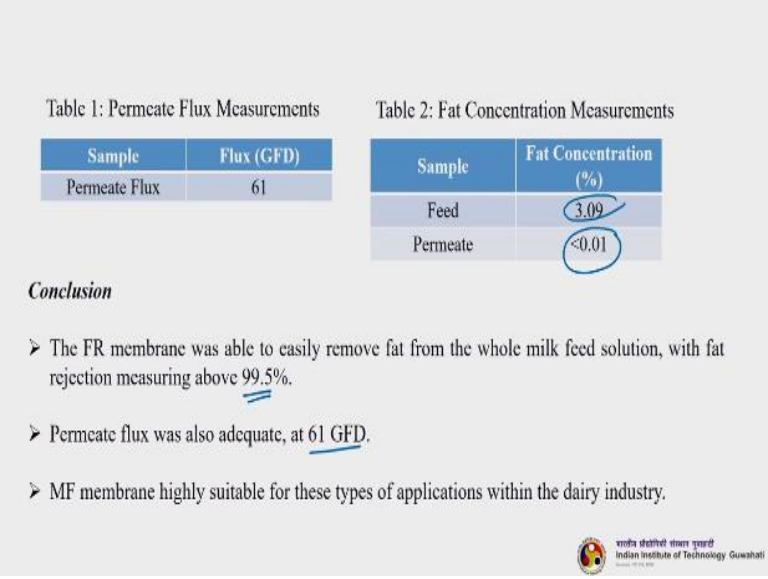

So you can see the flux is 61 GFD. The fat concentration in the feed, it is 3.09 it has been reduced to less than.01 ok so almost nil. So the conclusion is that the FR membrane was able to easily remove the fat from the whole milk feed solution, with fat rejection measuring above99.5%. So permeate flux was also adequate at a sixty one GFD microfiltration membrane highly suitable for this type of application with in the dairy industries.

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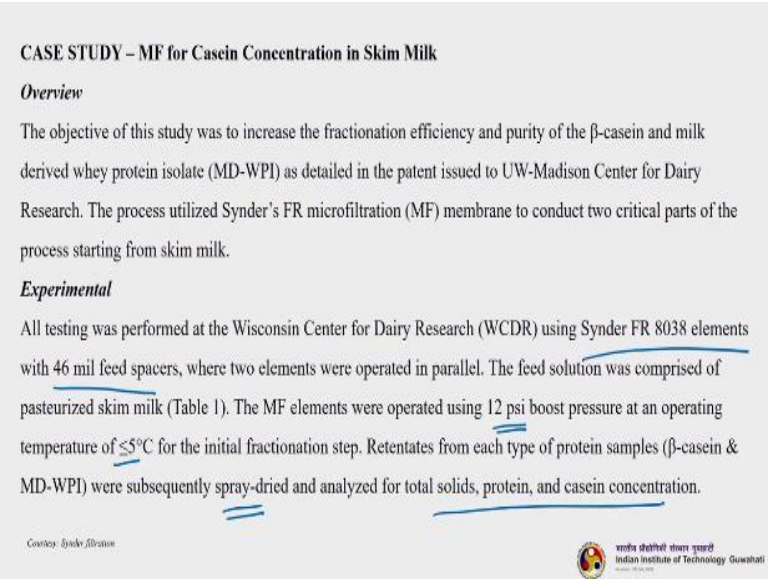

So the next is another case study so microfiltration for casein concentration in the skimmed milk. So what is the objective? The objective of the study was to increase the fractionation efficiency of the beta casein and milk derives whey protein isolate. As detailed in the patent issued to the UW-Madison center for Dairy Research by this Synder filtration, the process utilized Synder's

FR, microfiltration membrane to conduct two critical parts of the process starting from skim milk.

So the experiment goes something like this all testing was performed at the Wisconsin Center for Dairy Research using a Synder FR 8038 elements with 46 mil feed spacers, but 2 elements were operated in parallel, so there are 2 elements there on modules, so the feed solution has comprised the pasteurized skimmed milk. The microfiltration elements are operated using 12psi boost pressure at an operating temperature of less than 5 degree centigrade for the initial fractionation step.

Retentates from each type of protein samples, which is beta casein as well as the MD-WPI. MD-WPI is the milk derived whey protein isolate but subsequently spray-dried and analyzed for total solids, protein and casein concentration.

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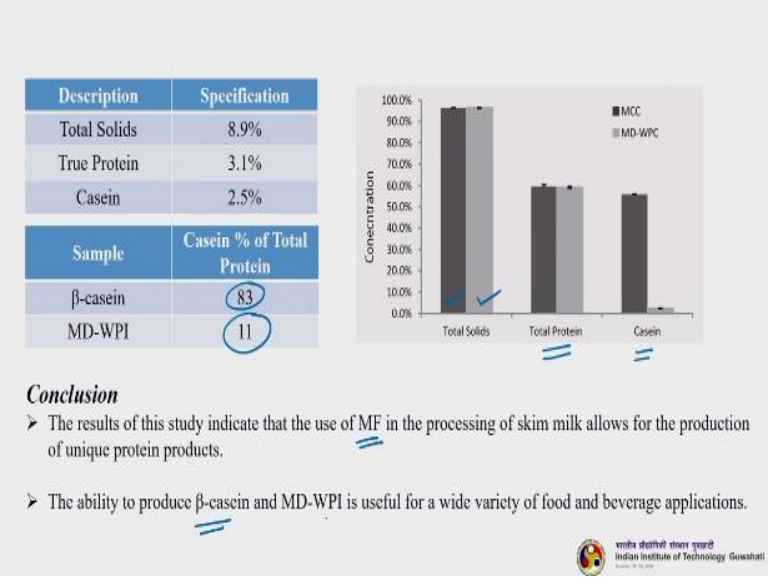

So you can see the total solid is 8.9%, true protein is 3.1%, casein is 2.5 percent. How they are getting concentrated? The beta casein is 83% and WPI is whey protein isolate is 11%, so you can see the total solids here in MCC, this is MCC, and this is your WPC and this is total protein and this is casein. So we can conclude that the results of this study indicate that the use of microfiltration in the processing of skim milk allows for unique protein products.

The ability to produce beta casein, whey protein isolate in wide variety of food and beverages applications. So these are very new developments in dairy industries.

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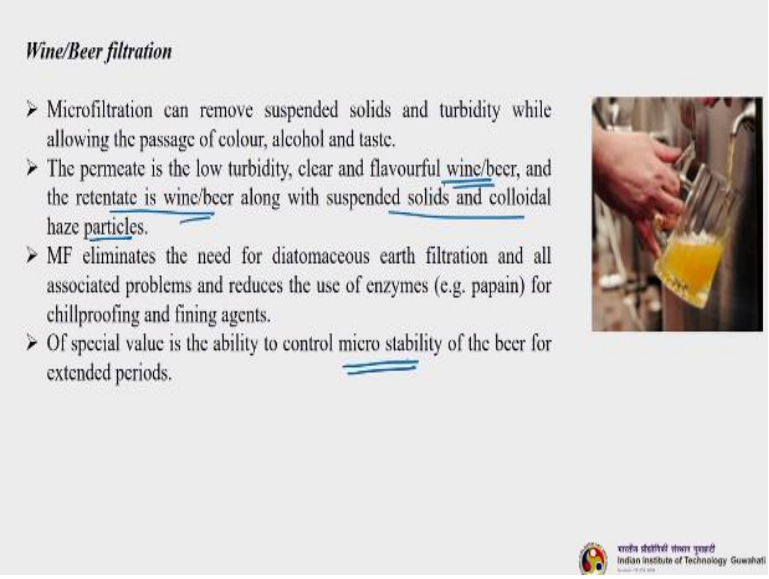

The next application is wine and beer filtration; so once we have discussed this long back, so microfiltration can remove suspended solids and turbidity while allowing the passage of color alcohol and taste. The permeate is the low turbidity, clear and flavorful wind and beer and the retanted is wine and beer along with suspended solids and colloidal haze particles. Microfiltration eliminates the need for diatomaceous earth filtration and all associated problems.

And reduces the use of enzymes for chillproofing and fining agents. Of special value is the ability to control micro stability of the beer for extended period. Since it is removing most of the components which were create a problem of stability, so then the stability is enhanced, if you are going for a microfiltration of the wine and beer.

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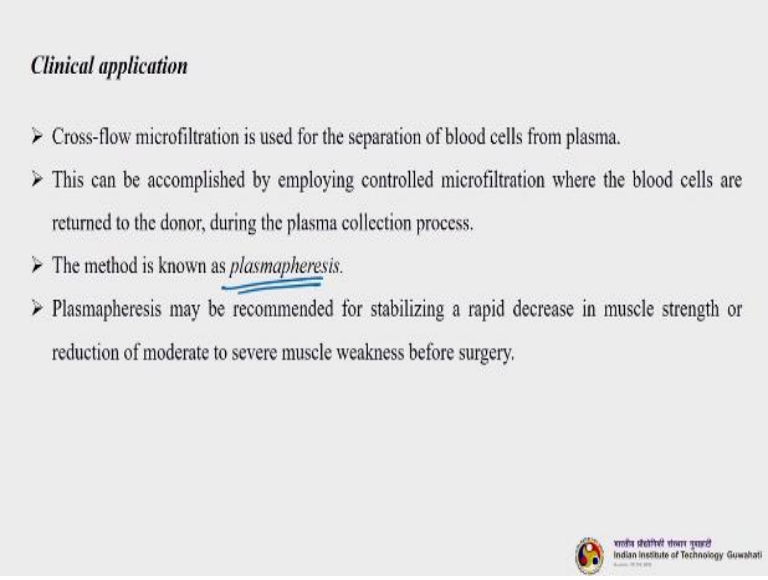

So then there are clinical applications also so cross flow microfiltration is used for the separation of blood cells from plasma, now this can be accomplished by employing control microfiltration where the blood cells are returned to the donor during the plasma collection process. And the plasma is getting collected. So this method is called plasmapheresis. So, plasmapheresis may be recommended for stabilizing a rapid decrease in muscle strength or reduction of moderate to severe muscle weakness before surgery.

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So the next most important application of microfiltration is of course industrial wastewater treatment, even domestic or municipal wastewater treatment is also it is being used. So microfiltration removes all suspended solids and insoluble metal hydroxide solids from

wastewater. So it is useful in the treatment of wastewater from the pulp and paper industry, textile wastewater, tanning and leather industry and so on. There are other industries also, so these are just a few of them.

So you can see a photograph of the JWC environmental wastewater treatment plants here, as I told you earlier also wastewater treatment is the most important application of microfiltration as well as ultrafiltration.

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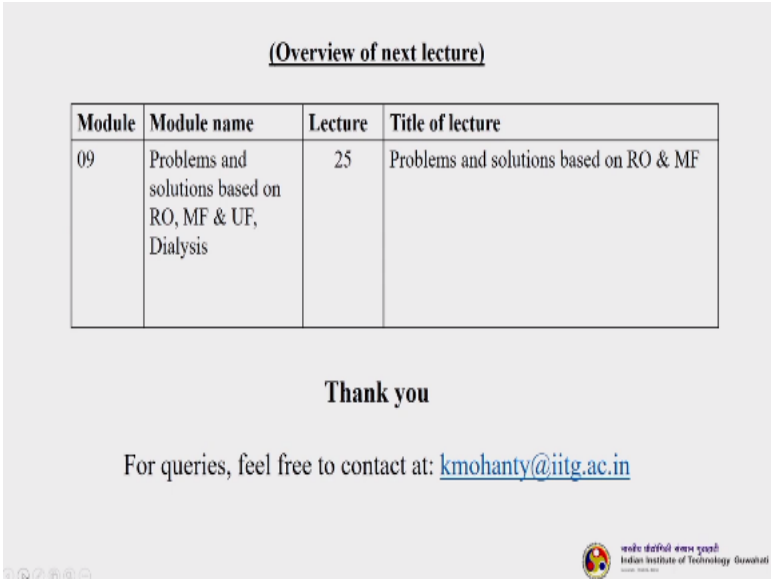

So with this with this today I conclude most of the materials are taken from Prof. Nath book, so you can refer to it so the next lecture will start a new module, Module 9 under which we will solve some of the Problems on reverse osmosis and microfiltration. Thank you very much in case if you have any queries please feel free to write to me at kmohanty@iitg.ac.in, Thank you.