Lec 28: Filtration

Hello everybody. Welcome to this massive open online course on solid-fluid operations. As we have already discussed about that particulate material separation in gaseous stream and how to separate those particulate matter from the gaseous streams. There are several mechanisms that we have discussed. Now we will start another module. It is called filtration.

This module also will include the mechanism of particulate material separation, but it will be the particulate material would be from the slurry. So if any slurry reached in suppose some unwanted materials or particulate materials or particles at a certain concentration, then those particles how it can be separated. So there may be that very micro particles, nanoparticles, even other different sizes particles also will be there or not only that particles may be some other chemical compounds as a very fine particles it will be present or maybe as ions in the liquid that will be present in the solution. Then how to separate all those things that will be discussed in this module.

So in the successive lecture, we will try to discuss the various mechanism or what are the governing equations to assess those that separation efficiency that we will also discuss in this module. So let us start with the lecture here first regarding that filtration. So common name is filtration here. We will first discuss about that what is basically that filtration, what are the different types of filtration and how that filtration works that we will also discuss in this lecture. So what is the definition of filtration? What do you understand by that filtration? So this is basically a process by which you can just separate that particles from a particle laden fluid either fluid or gas by a filter medium that allows the fluid to pass through it at a certain driving force and also separate the solid particles in it.

So this is the definition of the filtration. So what is that? This is basically that under a certain driving force, the particle laden fluid will be passed through a certain filter medium and that filter medium will allow to pass the fluid except that particles based on the characteristics of the filter media. So for that you need some driving force by which that fluid will be flowing through that filter media. So it is basically a method of separation of particles by a certain that filter media. So you will see that here in this slide it is shown that one mechanism of separation of particles from the feed where solid and liquid presence.

Here you will see that the one that barrier which will be porous that barrier it is called the filter or it is called filter media and this is basically a material that is made just by different materials or composition of the materials as a composite and that material will be that will have that certain degree of porosity and because of that porosity the fluid will be passed through this force of that material and this material is called filter media. So filter media will have certain force or that certain path through which that fluid will be passed through. Whereas during that flow of fluid which have that particles or other materials which is to be

separated that will be retained in one side of this filter media from which part of this filter media that particle laden solution will be allowed to pass in that side or that part that solid materials will be retained and the other side the clear liquid or the liquid with certain concentration of particles will be leaving from that filter media. Now, it depends on that characteristics of the filter media, whether all those particles will be retained in one side of this filter media or not that depends on the pore size of the filter media. So this filter media will allow that particles to retain on this one side of this filter media those particles will have more or higher pore size of that particle compared to the pore size.

That means the particles which have bigger than the pore size of the particles those particles will be retained in this part or one part of this filter media. Whereas those particles have the size smaller compared to that pore that will be passed through that filter media along with the filtrate. Now that filter media actually designed or procured or synthesized or made in such a way that your objective is to fulfill to separate all those materials by this filter media. That means there will be a certain degree of separation by this filter media. Now what is that degree of separation that depends on what will be the amount of particles will be retained in one side of this filter media whereas other side with that filtrate is there any particles will be passing through that also will effect on that efficiency or you can say that degree of separation of that particles by the filter media.

If suppose 100% particles will be or 100 all the particles will be retained in this side by this filter media then you can say that the efficiency of this filter media is 100% or you can say that a degree of separation will be 100% whereas if suppose 10% particles will be passing out through this filter media. Since then what will happen 90% particles also will be only retained in the other part of this filter media. So here 90% efficiency of that filter media will be considered. So in that case there will be certain terms whether that rejection how much rejection of that particles will be that. Rejection means what? That means how much particles will be retained by this filter media.

That means that will reject to pass through that filter media whereas the filtrate that will be allowed to pass through that filter media. So this is the filtration. So filtration is basically a process by which the particles are separated from a particle laden fluid that fluid maybe either liquid or gas by a filter medium. That filter medium allows the fluid to pass through it at a certain driving force and separate the solid particles in it. So this is the definition of filtration.

So here in this picture we have shown that this is a filtration process where feed will be passing through that filter media whereas particles would be retained those half size will be greater than the pore size of the filter media. Whereas other part the filtrate will be coming out along with some particles so those particle size will be less than that pore size of this filter medium. Here also we have seen such type of filter media. You will see that in our laboratory we can separate some precipitate by that filter in laboratory in a funnel that we are keeping that some filter paper and on this filter paper on this funnel we are allowing to

pass through that filter paper all those solution where that precipitate or some particulate materials will be retained by this filter paper whereas that clear liquid will be passing through that filter paper and that clear liquid will be poured down in a container or beaker. So here this is the one example of that filtration process.

Now we have actually discussed about that the filtration will be processed based on certain driving force or filtration will be governed by a certain driving forces. What are those driving forces? The filtration may be happened based on the gravitational force, filtration may be happened based on the centrifugal force, filtration may be happened based on the application of pressure, filtration may be happened based on the electric force field or maybe the concentration gradient or concentration difference. So this gravitational force, centrifugal force, application of pressure, that electric force field and concentration difference are those called the driving force of filtration. In case of driving force of gravitational force in that case this gravitational force is used in large sand bed filters and in simple laboratory filtration like gravity filters like in the funnel that particles are retained whereas by gravity the liquid will be fall down through the filter paper. And then centrifugal force you will see that centrifuges that we were actually discussed in our earlier lecture also that particulate material separation by centrifuge where centrifugal force is applied and the solution in that centrifuge and due to that centrifugal force the particles will be driven to that tangential direction and it will be that pass through that membrane or you can say some separating medium or filter medium.

And in that case that in one side of that centrifuge that is inside that particulate materials will retain in one part and the other side that through the force that particles will be separated. So centrifuges with a porous filter medium in which that gravitational force is replaced by the centrifugal force many times greater than the gravity and based on which that filtration will happen. And applied pressure where it acts on the fluid above the filter or application of vacuum below the filter or by a combination of such forces. So here in this case some force will be applied and that force will give you basically the pressure force. So that pressure force will be applied on the fluid above a filter paper or you can along the flow of the fluid through which that filter medium will be placed in the vertical direction.

So under the action of pressure that fluid will be passing through that filter media or some vacuum can be created based on which that liquid will be sucked from the feed solution through that filter media. So this is also to be considered as a driving force. And electric force you will see that in case of electrodialysis there that electric force field will apply to drive or the movement of the ions or salt ions or some other ions which is to be segregated or separated based on this membrane or certain filter media. So different difference is also one driving force there. Here concentration driven membrane separation process it is called the dialysis also here based on that salt concentration differences in a medium you will see there will be a certain flow of that ions from concentrated solution to the diluted solution.

So in that case it will be called that driving force will be called as a concentration difference.

And then you have to know what are the different type of process for this filtration. The type of filtration process there. So based on that driving force as well as that some certain procedure to be followed so based on that membrane type this filtration process actually is categorized. Now you will see that some will be gravity filter process, some is called that plate and frame filter pressure, some is called that leaf filter, some process is called the rotary drum vacuum filter.

So all those process are based on that certain category of that driving forces. In the gravity filter you will see that gravity filtration that is basically the filtering the impurities from the solution by using gravity to pull liquid through a filter paper or a bed of solid with a minimum porosity. Whereas plate and frame filter pressure these are actually being used industrially in industrial scale for separation of the particulate materials from the slurry. So in this case you will see that some slurry that is a mixture of solid and liquid is actually allowed to pass or piped you can say under certain pressure to cloth and supporting plates. That means here slurry will be passed through a cloth or supporting plates under a certain pressure.

So in that case the filtrate as a clear liquid will be removed through the recessed channel in the plates. So these are called plate and frame filter pressure. Here is basically that cloth will be attached to a frame or plate and frame where that under a certain pressure the fluid will be passing through that cloth whereas that pressure will give you the press under a certain force so that the solid particles will be retained on the cloth whereas through the pores of the cloth the liquid will be passed through. So this is basically the process it is called plate and frame filter pressure and it will be acted based on the driving force of applied pressure. And then lip filter here also the slurry is generally pumped under a certain pressure into a vessel that is fitted with a stack of vertical lips certain lips that means here some filter cloth will be there as a leaf and that will be served as a filter element or filter medium.

So this is also work based on applied pressure. The rotary drum vacuum filter here in this case again that in a drum in the periphery of this drum a filter cloth will be attached and that vacuum will be created so that the drum whenever that filter cloth that attached in the drum periphery you will see it will be some part of this drum will be submerged in a slurry and whenever it will be rotating and the vacuum will be created you will see that the liquid will be sucked through that filter cloth whereas the solid particles will be retained on that surface of the cloth and it will be formed as a cake and then it will be taking out as a cake and then dried then it will be separated. So in this way that solid particles will be separated from the mixture of solid and liquid by this rotary drum vacuum filter. So it is basically what that cylindrical drum with internal some divisions, pores and valves for application of the vacuum and removal of the filter with a filter media usually a woven wire, a screen or cloth generally being used and partially it will be submerged in the slurry which is to be filtered. And then what are the basic components of the filtration that also you have to know.

Here you will see for the basic components if you are talking about that you will have that for a filter processing there will be a certain filter medium that may be called as a membrane or cloth or some woven wire or some other sheave also you can say and then will be compressor, some will be support, some will be wrapper to just take out that deposited particles on the membrane or filter media. So filter medium is one component, compressor is one component, support, wrapper and other accessories will be there. So these are the basic components. So as a filter medium generally filter cloth, filter screen, common laboratory filter paper, thick and mass barriers such as sand beds, coke beds, porous ceramics, porous materials like this. These are the things are being used as a filter medium.

Compressor what does it do basically it push the particle laden fluid to the filter medium whereas a mechanical device that holds the filter medium which will be called as a support that is rectangular or square plate or frame and or cylindrical or drum surface like this and wrapper which is basically a knife type devices which will just take it out that cake which is deposited on the cloth or filter media and then it will be washing that particulate material from the cloth. So as a wrapper you can say it is basically a washer. Then coming to that component membrane this is called filter media. What is that membrane? We will see that this is one of the important components in the filtration process. So without this membrane you cannot do anything for your separation.

So a membrane is a basically thin layer or you can say it is regarded as the interface of semi permeable material that means to which some materials will be passed through whereas other materials will be retained in one side of this membrane. So it is a semi permeable material through which pure solvent can pass while molecules ions or other small particles are retained and separated. So this is called membrane. Here in this picture it is shown that here C membrane how it is there it will have some pores it is shown in the picture and the degree of separation is largely depend on the membrane charge and porosity and pore size. So degree of separation depends on the membrane characteristics like pore size whether this membrane will be charged or not what will be the size of the pore and also strength of the membrane.

So these are the things that is required to know for the degree of separation assessment. Now what are the different types of membranes are basically available or how can you classify that membrane. So there are you will see that two types of membranes available one is called solid membrane another is called liquid membrane. In the solid membrane you will see that it is synthesized, it is procured, it is made you can say in different way. So based on that procurement procedure and based on the material the solid membrane also can be classified.

The solid membrane can be classified into two types one is called isotropic another is called anisotropic. Isotropic means here you can say that to be symmetrical in shape that

means all the pore size will be uniform in size or uniform diameter you can say and also it will be porous, non-porous and electrically charged. So here the solid membrane is one is called isotropic membrane or it is called symmetric membrane. So this symmetric membranes may be porous, may be non-porous, may be electrically charged or not charged. But here isotropic means here or it is called symmetric.

Symmetric means the all pore size of the membranes will be almost same in size. Whereas other type of solid membrane it is called anisotropic. In that case different type of structure of this membrane to be formed. That is why it is called asymmetric. That means this pore size in this filtered media or membrane will not be same in size.

Some maybe will be longitudinal, some maybe that spherical, some maybe valid shape. So all the membrane pores will not be same in size. So that is why it is called asymmetric. Also this anisotropic membrane will be of different type, some will be structure, different type of different structure of materials and also it will be composite in nature. There are different type of materials will be used to make this or procure or synthesize this solid membrane.

And then liquid membrane, this is also some will be supported, some will be unsupported membrane. There itself you will see that one liquid itself will be acting as a membrane media or you can say the filter media. That means some components will pass through that liquid, pool of liquid whereas some components will not pass through that pool of liquid. So that liquid media itself will be acting as a filter media.

So that is called liquid membrane. So here the supported membrane, some liquid will be supported that keep that stack so that it will be supported whereas some will be unsupported there. That means here some drop or you can say that some internal phases, those who are not mixed to each other, they will be forming a droplet or some distributed phases will be formed there and through which that materials will be transported. So it is called unsupported whereas supported membrane that will give you the simple shape as a single shape that will not be changed its droplet or other shape of this liquid. So this is the classification of membranes that you can classify the membranes in this way. And also this you will see membrane can be classified based on the pore size.

Some membranes will be called as microfiltration membrane. Name of the process it is called microfiltration. There itself the size, separation size will be 10 to 0.1 micrometer. And some membrane will be called ultra fine membrane or you can say ultrafiltration membrane.

So it is basically the separation size will be here based on that less than 0.1 micrometer to 5 nanometer in size. So it will be regarded as ultrafiltration. Whereas some membrane will give you the separation of particles almost near about 1 nanometer and that type of membrane will be called as nanofiltration membrane. And also some membranes which will be acting in such a way that it will separate the less than 1 nanometer particles and it will

be called as reverse osmosis membrane or it is called hyperfiltration membrane.

And also you will see that some membranes that will be regarded as electrodialysis membrane, there the particle size which will be less than 5 nanometers will be separated whereas dialysis is also the same that 5 nanometer size particles will be separated. But those have that suppose electrodialysis and dialysis that separates the contaminates size less than 5 nanometer or ion size less than 5 nanometer or less than 5 nanometer for dialysis and electrodialysis. Both the cases the same size will be separated but their driving force will be different. In the dialysis case the driving force is concentration gradient whereas the electric field gradient will be the driving force for the electrodialysis. So based on the pore size of the membrane or filter media it is divided or classified accordingly and the process will be classified also based on this pore size.

So it will be called as microfiltration, ultrafiltration, nanofiltration, reverse osmosis, electrodialysis and dialysis. So, the microfiltration case it is generally used for the particles smaller than 0.1 micrometer generally within a range of 10 to 0.1 micrometer. Large colloids particles, microbial cells that are separated by this microfiltration whereas ultrafiltration will separate the emulsions, colloids, micromolecules, macromolecules, proteins like that.

Even we will see that nanofiltration that will separate some dissolved salts, organics like that and reverse osmosis will separate dissolved salts, small organics in our you know that domestic use we are using that reverse osmosis to separate that dissolved salt from the water that we are doing. And then electrodialysis generally separate the dissolved salts, dialysis also that is used for treatment of renal failure where that some dissolved salts to be separated. Then regarding that membrane of course you have to know what are the basic materials that are being used for synthesis of membrane. To make that membrane there are different materials that is available and also nowadays different types of materials also are being synthesized to have that increase in increment of the capacity of the membrane or efficiency of the membrane accordingly. So nowadays most of the membranes are made from synthetic polymers and other materials also are used commercially that will include that PVDF that is called polyvinyl dinifluoride and also polyvinyl nitrile and also polypropylene it is being used for this membrane preparation.

For ultrafiltration and microfiltration applications membranes are generally procured from polysulfonates and also recent times it is seen that interest in the use of ceramic materials that is increased for ultrafiltration and microfiltration. For reverse osmosis membranes generally often made from polyamide compound and nanofiltration membranes are constructed from a variety of polymers including polysulfon and polyamide and ceramic materials. So these are the basic materials by which you can prepare membrane. The basic membrane separation process that we have already discussed that based on the driving forces you will see that sometimes this membrane separation process is being classified and you will see that some membrane process will be based on that driving force of

pressure applied pressure. So in that case some will be low driven pressure membrane separation process some will be high driven pressure membrane separation process.

So low driven pressure membrane separation process includes microfiltration where it is characterized by a membrane pore size between 0.05 nanometer and 500 nanometer and it is operating under a pressure below 2 bar. Whereas ultrafiltration that is characterized by membrane pore size between 2 nanometer and 50 nanometer and operating pressures between 1 and 10 bar. So this microfiltration and ultrafiltration are basically a low driven pressure membrane separation process. Whereas high driven pressure membrane separation process is basically nanofiltration process reverse osmosis or hyperfiltration it is said.

Where nanofiltration is characterized by a membrane pore size between 0.5 and 2 nanometer and operating pressures between 5 and 35 bar. Whereas reverse osmosis it is also a high driven pressure membrane separation process it is characterized by a membrane pore size less than 1 nanometer and operating pressure is ranges from 10 to 70 bar. And also you will see that some will be electric field driven membrane separation process it is basically electro dialysis and some will be concentration driven membrane separation process is called dialysis and some will be thermally driven membrane process like you know that membrane distillation process is a process where the water is a main component of the feed solution and only water vapor can pass through a some hydrophobic membrane pores where that some components from the water will be separated based on that heat driven or you can say thermally driven membrane process. Also you will see that some will be called pervaporation process it is basically membrane separation process for separating liquid mixtures where in the upstream of heat is in contact with the feed liquids and downstream that means from which part that filtrate will be coming out downstream is kept at vacuum state or applied to the sweeping gas or heat.

So, in this case this pervaporation process is basically operated based on that vacuum system that is vacuum pervaporation some will be sweeping of action of the gas it is called sweep gas pervaporation and some will be thermally driven it is called thermo pervaporation. And also you will see that there will be certain configuration of the membrane. So, what are those configuration whether this membrane whatever made for that ultra filtration, micro filtration, nano filtration or electro dialysis or dialysis or reverse osmosis in that case there will be certain configurations certain shape of that membrane to be configured or made. So, in that case some micro filtration it will generally made in a tubular shape spiral round shape hollow fiber plate and frame type ultra filtration it will be sometimes you will say tubular shape spiral round hollow fiber plate and frame system also. Nano filtration it is also tubular shape spiral round shape hollow fiber shape and reverse osmosis tubular spiral round hollow fiber all these things and electro dialysis it is tubular homo dialyzer whereas dialysis it is tubular homo dialyzer.

So, these are the configurations that is available in the market or you can make

commercially based on your material and also application of your specific case. And then you can say that what type of what are the shape of the tubular size of membrane here in this picture it is shown that what is the tubular shape of membrane it is seen that in the membrane you will see that it is called as a module membrane module also. So, in the membrane field you will see that the turn module is also used to describe a complete unit that will be composed of membranes the pressure support structure the feed inlet the outlet permeate even retentate streams and an overall support structure the principal types of membrane modules are generally some tubular spiral round and also other shape. So, what is the tubular shape in this case you will see that membrane are placed inside a support porous tubes and these tubes are placed together in a cylindrical shell to form the unit module and this tubular devices are used in micro and ultra filtration applications because of their ability to handle process streams with high solids and high viscosity properties as well as for their relative ease of cleaning. And another type of configuration it is called hollow fiber membrane as shown in the you know slide the picture it is shown in this case it consists generally bundle of hundreds of or thousands of hollow fibers you can say the entire assembly is inserted into a pressure vessel and the feed can be applied to the inside of the fiber that is it is called inside outflow or the outside of the fiber it is called outside inflow.

So, either way you can allow the feed to pass through this filter media or this called membrane. So, it is basically a bundle of hundreds to thousands of hollow fibers and through which that feed is allowed to pass either that is inside outflow or outside inflow. Then you will see that plate and frame filter configuration or module in this case you will see that it consists of a series of flat membrane sheets and along with that support plates here as shown in the picture. The water to be treated here passes between the membranes of two adjacent membrane assemblies and the plate supports the membranes and provides a channel for the permeate to flow out of the unit module. So, here you will see that here membrane and plate and frame will be there in the frame that membranes will be attached in such a way that whenever feed will be passed through that membrane that liquid will be passing across this filter media and it will be separating here as the flow direction is shown in this picture how that you know retentate that means that the solid materials or that which will not be passing through that membrane it will be retained whereas the other that permeate that will be separated after this that you know separation by this filter cloth.

So, this filter cloth is basically that attached in a frame with a support plates and through which that the feed materials to be allowed to pass under a certain pressure. Here the driving force is pressure and in that case that membrane will retain that you know particulate materials where that clean liquid will be passed through that force of that cloth. So, this is the mechanism of this plate and frame. So, it is widely used in industry to segregate or separate that slurry like suppose that Ganga river water or Mombaputra river water there it is muddy water to separate that particulate materials dispersed to that filter plate and frame filter fresh and continuously and then separating those particulate materials to get that clear water. After that further process is being done for the perusing

to that drinking water stage or other uses.

Another module it is called ceramic and polymeric flat sheet membranes. This is also the same type of that plate and frame filter fresh. Here also flat sheet membranes are made in such a way that here instead of that pressure here some vacuum will be created. So it is called vacuum driven filtration system which consists of stack of modules is with several sheets here. So filtration mode is outside in where the water passes through the membrane and is collected in permeate channels here as shown in the picture.

And cleaning can be performed by aeration or backwash here. Whereas spiral wound as shown in the picture here how that spiral wound membrane modules are procured. In this case it is also the similar to that flat sheet types except that the whole assembly is wrapped up rather like a Swiss roll. So in this case the feed flows down the retentate channels while permeate flows radially through the membrane and spiraling into a central permeate duct. So this is the one configuration of spiral wound of membrane. And also you will see that what we are talking about the different modules of this membrane you will see that there will be certain operational modes for that membrane processes.

Generally two operational modes for membranes are used. These are like one is called dead end filtration another is called cross flow filtration as shown in the picture here. You will see that whenever the pressure applied along the feed flow to that membrane you will see that solid particles will be retained on the membrane whereas the flow of the fluid will be there in the cross direction of the applied pressure. So it is called cross flow filtration whereas you will see some particles will be retained on the membrane whereas that membrane will be retaining that particles and the liquid will be passed through in the direction of the pressure. So it is called that dead end filtration. So here you will see that where all the feed applied to the membrane passes through it obtaining a permeate since there is no concentrate streams all the particles are retained in the membrane.

Raw feed water is sometimes used to flush that accumulated material from the membrane surface and cross flow filtration where the feed water is pumped with a cross flow tangential to the membrane and this model implies that for a flow of feed water across the membrane only a fraction is converted to a permeate product as recovery. So in the case of cross flow you will see that only a fraction of materials to be you know retained on the membrane whereas dead end filtration most of the particles will be retained on the membrane. So what are the key elements of that any membrane process? So the key elements of any membrane process relate to the influence of the parameters on the overall permeate flux that are membrane permeability, the operational driving force per unit membrane area and membrane pressure you can say and the fouling and also subsequent cleaning of the membrane surface. So these are the key elements that you have to remember. Then what are the general governing equation to express that membrane process or you can say what is the actually material balance based on which that you can assess that you know membrane process.

So the general form of equation for pressure driven membrane separation can be written by this equation here where you will see that J will be is equal to delta P minus delta pi divided by mu into Rm plus Rc.

Here the Equation

$$J = \frac{\Delta P - \Delta \Pi}{\mu (R_m + R_c)}$$

What are those here? J is basically the membrane flux which is expressed as volumetric rate per unit area. It is called flux that means what is the feed rate per unit cross sectional area that means what the amount of feed is passing through the surface of the membrane per unit time. Also you can say that per unit time what are the feed is flowing per unit cross sectional area.

So that is called flux. So this flux and delta P is called the pressure difference applied across the membrane. This is the driving force minus delta phi here. Delta phi is basically the difference in osmotic pressure across the membrane. You will see that any solution has a certain tendency to have some pressure based on which you will see that some components will be driven from its lower concentration to the higher concentration or solvent will be passing from that lower concentration to the higher concentration or higher concentration to the lower concentration. So in that case that natural tendency of flowing of that components from one position to the another position of that solvent molecules that will be driven by a certain pressure.

It is called osmotic pressure. So that delta phi here is basically a difference in osmotic pressure across the membrane. And Rm is what? Rm is the resistance of the membrane. Due to that some membrane material there will be certain resistance. So that resistance will give you of that separation process by that material. And Rc is the resistance of the layer deposited on the membrane called the filter cake and gel fowlants.

Sometimes you will see that whenever particles will be separated by that membrane particles will be depositing on one side of that membrane and depositing the particles as a layer that layer it will be called as a cake layer. So this cake layer itself will give you some resistance to flow of the fluid further. So this resistance will be considered as a Rc and mu is the viscosity of the solution. Then if suppose membrane is only exposed to a pure solvent, there is no other component, say water, then equation will be converted to 2 here, equation number 2.

Here the Equation

$$J = \frac{\Delta P - \Delta \Pi}{\mu (R_m + R_c)}$$

This equation here, that means here delta phi will be equals to what is that? 0 and their cake deposition will be negligible compared to the membrane material resistance.

So that is why you can write this equation J will be equal to delta P divided by mu Rm.

Here the Equation

$$J = \frac{\Delta P}{\mu R_m}$$

And the overall pressure drop at any time, if we consider that certain slurry, it will be passed through that membrane. So in that case what will be the overall pressure drop at any time? That will be actually a sum of pressure drop over medium and cake. So the pressure drop contribution will come from medium as well as cake what is deposited on the medium, that is filter medium. If suppose your case here Pa is the inlet pressure and Pb is the outlet pressure of this membrane here.

This is the membrane over and on this surface of this membrane some cake is deposited during that operation of the filtration. And so here it will be membrane medium or you can say membrane material. So in this case, the pressure difference Pa minus Pb delta P that will be contributed by this what will be the pressure drop because of this cake and what will be the pressure drop because of the membrane material because of that. So in that case, you will see that if we consider that there is a pressure difference Pa and Pb, then delta P will be considered as a overall pressure drop and the pressure difference over this cake formation, it will be regarded as delta Pc, it is called pressure drop over cake and pressure drop over this membrane material, it will be called as that pressure drop over medium, it is denoted by delta Pm. So we can write here equation number 4 as delta P is equal to Pa minus Pb and we can write here Pa minus P dash here P dash is here at the interface that pressure drop and also P dash minus Pb that will be equal to what delta Pc plus delta Pm.

Here the Equation

$$\Delta P = P_a - P_b = (P_a - P') + (P' - P_b) = \Delta P_c + \Delta P_m$$

Delta Pc is the pressure drop over cake and delta Pm pressure drop over filter medium. And then you have to know what will be the pressure drop over that cake formation. Since that cake formation is basically a what is that packing material like a packed bed operation. that porous media cake itself is a porous media. So here we can say that packing material, packing material will be considered as a cake here.

So, it is a packed bed through which that that feed will be passing through. So in this case, we can apply some other equation, well-known equation. Already we have discussed in our earlier lecture that different type of equation for flow through porous media like Kozeny-Carman equation, Darcy's law equation, even you know Ergun equation. Those

equations we can apply here for that pressure drop calculation over the cake. So, if your flow is very laminar, generally it happens that laminar flow at this high pressure through this stack cake medium since the pore size is very small. So, in that case the high pressure is required and in that case flow of the fluid will be very laminar.

So, in that case we can apply Kozeny-Carman equation. So, to calculate the pressure drop over that cake, we can apply this Kozeny-Carman equation here.

Here the Equation

$$\frac{dP_c}{dL} = \frac{4.17\mu u(1-\varepsilon)^2 (s_p / v_p)^2}{\varepsilon^3}$$

Or

$$\frac{dP_c}{dL} = \frac{150\mu u(1-\varepsilon)^2}{(\Phi_s d_p)^2 \varepsilon^3}$$

Already we have discussed in our earlier lecture what is that Kozeny-Carman equation and this Kozeny-Carman equation that is given here in equation number 5 or you can represent this equation number 5 by equation number 6, either what will be the surface area of the particle and the specific volume of the particle there. So, based on which we can have equation number 6, so we can apply the pressure drop to calculate for this cake deposition that can be calculated by this Kozeny-Carman equation. In this case, some other points that you have to remember that the tangential or cross flow velocity is a key parameter in all membrane processes. In that case, this parameter is simply the average velocity of the solution or suspension as it flows tangentially to the membrane and also if you consider that the feed flow rate is Q meter cube per second and the membrane module contains n number of tubular individual membranes of diameter Dt, then the cross flow velocity U can be represented by this equation number 7 here that U will be equal to Q by n divided by 5 Dt square by 4.

Here the Equation

$$u = \frac{Q / N}{\pi d_t^2 / 4}$$

And then in this way, you will be able to calculate what will be the cake resistance there. So, here by this equation number 5, you will be able to calculate what will be the frictional resistance due to that cake and also other assessment of that filter media. Let us do an example here as per this theory. Suppose a tubular membrane is used to clean suspended particle from the cloudy Brahmaputra river water to produce 50 litre of clear filtrate in 30 minutes at a certain operating pressure.

The membrane module contains 100 individual tubular membranes of diameter 0.006 meter, the viscosity of the filtrate to be 0.001 Newton second per meter square and assume that the membrane resistance is negligible. Consider the particle of diameter 100 micrometer in the suspension are spherical, the void fraction is 0.45 in the cake formed during filtration. So, in this case, you have to find out what will be the operating pressure per unit length of that membrane.

So, here see basically that filter media resistance is negligible it is said. It is also said that what is the number of individual tubular membranes are used how many number that is 100. It is said what will be the flow rate of the water that is passed through that membrane, what is the viscosity and also what is the particle size, everything is known to you, what is the void fraction is known to you and also since the filter media resistance is negligible, we have to consider only cake resistance. So, to calculate that cake resistance, it will be based on that what will be the operating pressure because of that filter, cake. So in this case, first of all, you have to calculate what will be the u that means operating velocity. So operating velocity, you can calculate from that equation number 7 here, it is u is equal to q by n divided by pi t is pi dt square by 4.
Here the Equation

$$u = \frac{Q/N}{\pi d_t^2/4}$$

So after substitution of respective value, you can get its value as 0.0098 meter per second and then you have to calculate what will be the operating pressure per unit length. This is basically dpc by dl since only cake will be contributing that pressure drop. So it is basically based on that equation number 6, we can have this equation, this dpc by dl that will be the 150 mu u into 1 minus epsilon whole square by phi s dp square into epsilon cube. Here mu is given to you, u is already calculated, epsilon this void fraction is given to you, it is 0.45 and also phi s, this sphericity, it is 1 because the particles are considered as a spherical and dp particle size it is given, I think 100 micrometer.

So accordingly, after substitution of those values, you can get the value as 489.197 kilopascal. And in this case, then operating pressure will be is equal to delta p by l that will be the delta pc by l plus delta pm by l. Since here delta pc by l is the contributed by cake, whereas the filter media contribution is 0, it is negligible. So we are having that operating pressure will be basically that, that is contributed by filter cake, this is 489.197 kilopascal. Then other thing that you have to know also that membrane fouling, there will be certain that resistance that will be created whenever that operation of membrane because of , blocking of pores of membranes and also formation of cake or gel in inside the membrane pores and also formation of chemical precipitate in the membranes that will be as a scale.

Sometimes you will see that colonization of the membrane or bio fouling that will be takes

place when microorganism grow on the membrane surface. So all those , some unwanted parameters will be created on that membrane operation. So that will be called as a fouling. So it is related to the increased deposition of solid material onto the membrane surface. And then another important parameter that you have to know that solute and particle rejection of the membrane.

So in this case, one term it is called rejection, which is quantified the parameter known as the rejection coefficient, which is very important for , assessing that membrane. It is defined by sigma into 1 minus Cp by C,

Here the Equation

$$\sigma = 1 - \frac{C_p}{C}$$

where Cp is called the solute concentration in the permeate that means which is passed through that , membrane and C is its concentration in the retained state that means in the feed side. Thus the complete rejection implies that sigma will be is equal to 1 and if a membrane presents no barrier to solute then sigma will be is equal to 0. So here complete rejection implies sigma will be is equal to 1 that means here Cp will be is equal to 0 that means we can say that in the permeate side, that there will be no solute concentration.

Another term it is called permeability. It is also one of the important component to , assess that membrane. So this permeability basically defined by the equation 9 here, this is k is denoted and it is generally F by delta P,

Here the Equation

$$k = \frac{F}{\Delta P}$$

what is F? F is called flux that is the amount of fluid per unit time per unit cross sectional area passed through that membrane under a pressure of delta P and then k will be defined by this that is called permeability, where F is defined by this Qp by A.

Here the Equation

$$F = \frac{Q_p}{A}$$

Let us do an example here also based on this a membrane of cross sectional area 0.0015 meter square is operated at an applied pressure of 2.

5 into 10 to the power 5 Pascal to separate the particulate matter from a slurry. The permeate flow rate is maintained at the same pressure is found to be 0.15 meter a milliliter

per second and the density of the permeate is 1002 kg per meter cube find the permeability of the membrane. So in this case Qp is given to you cross sectional area also is given to you. So what will be the F value you can easily calculate and then k value that is F by delta P, F is already calculated.

So delta P is what delta P is given to you it is 2.5 into 10 to the power 5 Pascal. So after substitution and calculation you can get this permeability value is 4.0 into 10 to the power minus 7 your kg per meter square second Pascal. So I think you understood this a membrane operation filtration process, what are the different types of filtration, what is the basic components of the filtration, how that filtration process can be classified, what are the main important components of the filtration process that is called membrane, how that membrane is classified, how that membrane can be procured, what are the basic materials to be taken to make this membrane. Also what are the different modes of membrane operation, what are the different modules of membrane or configuration, how that membrane can be classified based on the pore size, where that membranes can be applicable, what are the different types of membrane process based on the pore size that also discussed in this lecture and also what are the important terms to assess that membrane, what is the rejection, what is the permeability and how to calculate that overall pressure of the membrane. So I think you understood this lecture, if you have any doubt you can consult with this email address and also we will discuss more about this filtration process in the next lecture.

It will be about that continuous filtration by dead and die filter and it is actually called as plate and frame filtration process, so it will be discussed in the next lecture. So thank you for keeping your kind attention and have a nice day. Thank you.