Introduction to Process Modelling in Membrane Separation Process
Prof. Sirshendu De
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 02
Fundamentals of Separation Processes and Introduction of Membrane System (Contd.)

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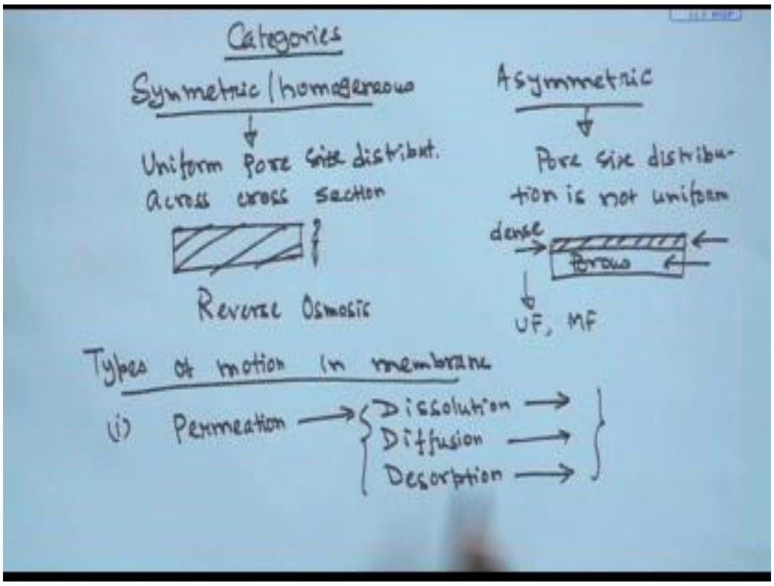

Welcome to the session of the course. So, in this class what we will be looking into will be categorising the various, so in the last class you have seen how a membrane is cast and what are the various controlling factors of to control the pore size distribution of the membrane. Now, in this class, you will be basically broadly doing the categorisation of the membrane which processes. First, we will divide the membrane based process into two broad categories one is the symmetric or homogeneous membranes and another is the asymmetric membranes. In symmetric membranes, throughout the whole cross section of the membrane the pore size distribution is more or less uniform. So, it is more or less uniform pore size distribution across the cross section. But in case of asymmetric membranes, there will be a distribution of pore size pore size distribution is not uniform across the cross section.

So, in case of asymmetric membrane, there is a thin skin followed by a porous substructure and typically this is a dense thin skin. And there is a porous substructure which will be following the thin skin and the controlling the selectivity of the membrane will be coming from this thin skin. And what is the objective of this porous support the porous support will be giving a kind of porous subtraction will be giving a kind of mechanical support to the thin skin. And typically these skins will be having a thickness between let say 10 to 50 micron and the porous sub structure will be rest among the total thickens of let say 150 or 200 micron. So, because the actual membrane is this thin skin the throughput of the process will be really very, very high compared to a homogeneous or symmetric membrane.

In case of symmetric membrane, the pore size distribution is more or less uniform throughout the membrane. So, therefore, the there are two disadvantages of this; one is thickness of the membrane is really very high it will be decreasing the throughput of the process, but if you have a dense in a polar structure the throughput will always less. So, for example, a symmetric or homogeneous membrane is a kind of reverse osmosis membrane. On the other hand, the typical other membrane is like all grids of ultra filtration micro filtration they are typically asymmetric membranes, and because of the smaller thickness of the skin the throughput of the process is more.

So, let us look into the various types of motions they will be occurring in the membranes; the first you know type of motion or transport mechanisms is permeation. Permeation is a process involving three steps dissolution, diffusion and desorption. So, first the solute will be dissolved into the polymer matrix then because of the concentration gradient, it will diffuse from the return feed stream or the feed stream to the permeate stream, and then it will be dissolved in the permeate stream. So, these stream mechanisms in one are called permeation.

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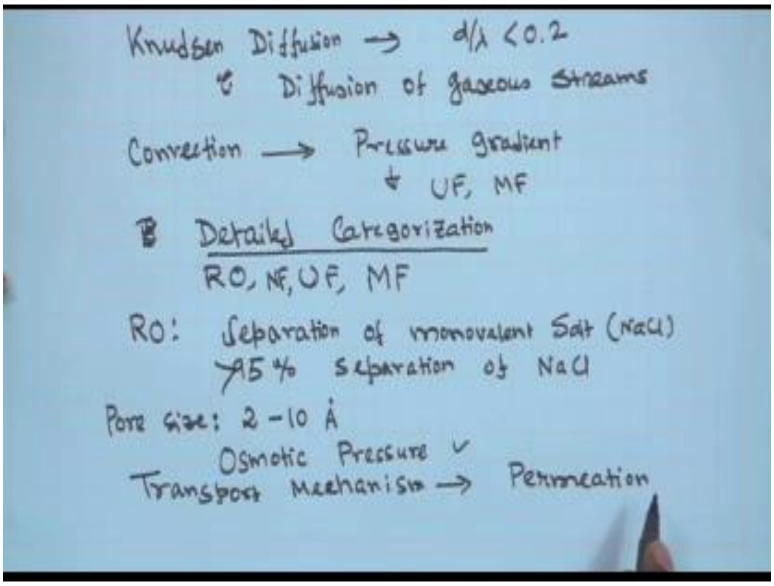

Then comes Knudsen diffusion if d by lambda; d is the pore diameter, lambda is the mean free path is less than 0.2 then the diffusion is called Knudsen diffusion. Typically, for the diffusion of gaseous streams Knudsen diffusion becomes very important. In case of reverse osmosis, the permeation is very, very important and then the third transport mechanism is convection. So, convection is basically occurred due to the pressure drop pressure gradient there can be a mixture of convection and diffusion as well. And these type of transport mechanisms is observed in ultra filtration, micro filtration and higher cut of membrane and more porous membrane.

Once we understand the different transport mechanisms, those are involved into the membrane based processes now let us categories this processes broadly. So detailed categorization, we do there are mainly four processes will be dealing with one is reverse osmosis, and other is ultra filtration reverse osmosis; then in between reserve osmosis ultra filtration, there is nano filtration, so reverse osmosis, nano filtration, ultra filtration and micro filtration.

So, let us go and see the characteristic of each of these processes in detail. In case of reverse osmosis typically we are talking about separation of monovalent salt, salt like Na Cl, so these this is widely used for the dissolution to produce the potable water from saline water or sea water. So, a good reverse osmosis membrane means we are definitely talking about 95 percent more than more than 95 percent separation or rejection of sodium chloride. And typically the pore size is varying from 2 to 10 angstrom that is a typical range of pore size in a reverse osmosis membrane.

Osmotic pressure plays a very, very important role in case of reverse osmosis will be coming to the concept of osmotic pressure definition and other quantifications probably later on in this class itself. And then we will be seeing very will be seeing why this osmotic pressure is important in case reverse osmosis. So, osmotic pressure plays very important role. And the transport mechanism is permeation, because we are talking of a very small pore sized membrane, it is a dense membrane something it is the reverse osmosis membrane is also called almost a nonporous membrane. So, therefore, the transport mechanism is dissolution, diffusion and desorption. And it is basically depending on the operating pressure range.

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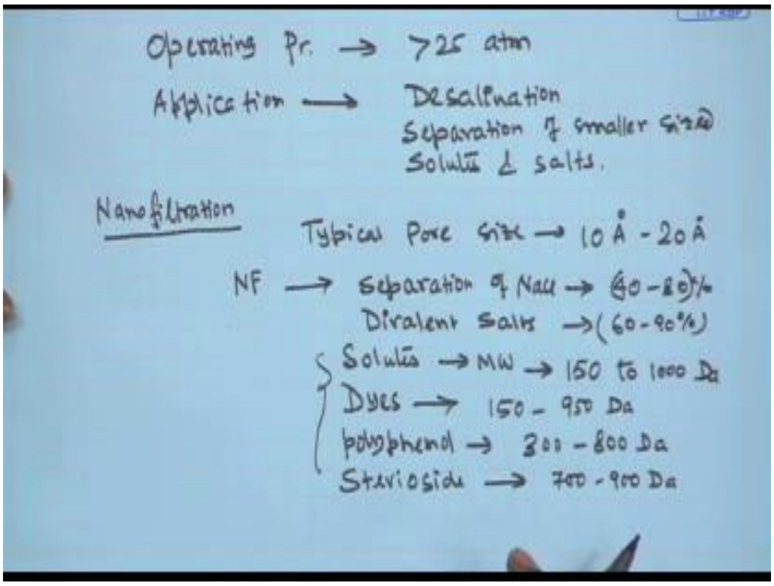

What is the throughput of the process will be depending on the operating pressure range. Typical operating pressure range will be above 25 atmospheres. So, in most of the plants dissolution plants the operate around 50 atmosphere, 60 atmosphere, because one has to over comes the osmotic pressure of the solution in order to get the first drop of water out of the reverse osmosis membrane. More be the operating pressure more gradient will be created and one will be maintaining and effective driving force that is the operating pressure minus the osmotic pressure to that will be more if that will be more the throughput of this process will be more and it will be commercially you have it will be more viable commercially.

So, what are the various applications of reverse osmosis? First application as I told for the desalination purpose and it have been it has been used quite widely in Middle East in other countries as well to produce the potable water of form saline water. Then other purpose is for example, separation of smaller sized solutes, and salts from any process streams. What is nano filtration, nano filtration is basically a process in between reverse osmosis and ultra filtration. Typical pore size of the nano filtration membrane lying in between 10 angstrom to 20 angstrom, and we are talking of a very good nano filtration membrane leads to separation of monovalent salt between 40 to 80 percent; and divalent salts quite high 60 to 90 percent or even higher. Then all the molecular weights that will be all the solutes having the molecular weights in the range of 150 to 1000 Dalton, they can be separated by the nano filtration membrane. In fact, there will be grades of nano filtration there are various cut offs of nano filtration membranes are available can be fabricated which will be separating various solutes which will be having the different molecular weights.

Now, all the dyes, therefore, we are encountering for textile industry and other purposes, industrial purposes, we have the molecular weight in the range of 150 to 950 Dalton. All the polyphenols from plant extract. They will be having a molecular weight between 300 to 800 Dalton. Steriosides like there are various speciality like phytochemicals obtained from the plant, for example, sterioiside rubusoside they will be having molecularity in the range of 700 to 900 Dalton. So, all these solutes can be separated or can be concentrated for the nano filtering. In fact, if you remembered that membrane based processes can be used either for purification, concentration, separation and even fractionation if you select a proper membrane and if you fix your objective what type of you know operation you would like to carry out.

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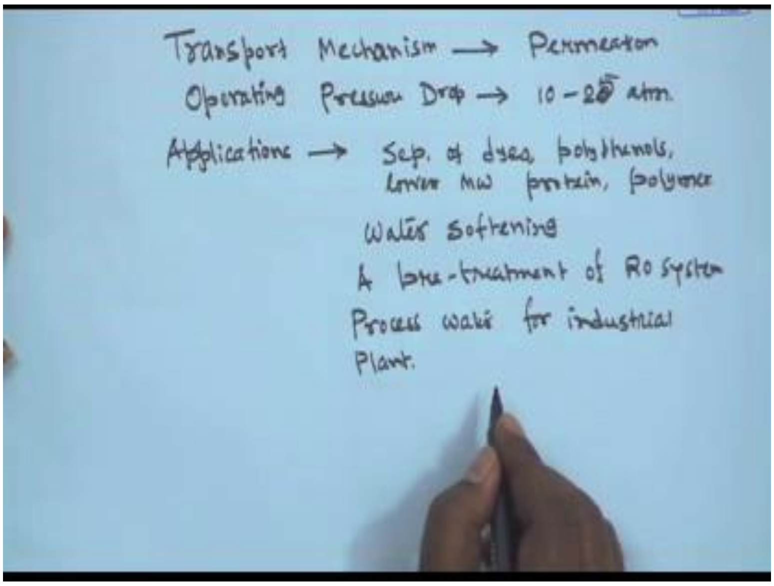

So, therefore, the in case of nano filtration, the operating pressure drop will be less and the transport mechanisms is same as permeation like reverse osmosis, because it is pore size is slightly larger than the reverse osmosis. The transport mechanism is permeation and operating pressure drop will be slightly less than reverse osmosis and typically it will be in the range of 10 to 25 atmospheres. And what is the applications as has been discussed the applications will be separation of dyes, polyphenols, lower molecular weight protein, polymer; it has a wide application in the pharmaceutical industries.

So, nano filtration can be used for the fractionation even for the concentration even for the fractionation. So that goes for the nano filtration then it can be used for the water softening because the divalent salts calcium, magnesium, iron can be removed by the nano filtration operation. And nano filtration is also used as a pre treatment, sometimes to pre treatment as a pre treatment of reverse osmosis system, so that some amount of salt is removed by the nano filtration unload on reverse osmosis is reduced. It is also used to produce the process water for an industrial plant, because in any plant if you use saline water for as an utility stream then there will that will cause the corrosion of the pipes lines. So, one can use a nano filtration for softening to remove the salts and calcium, magnesium so that the deposition killing of the pipelines can be reduced. So nano filtration has quite you know different applications.

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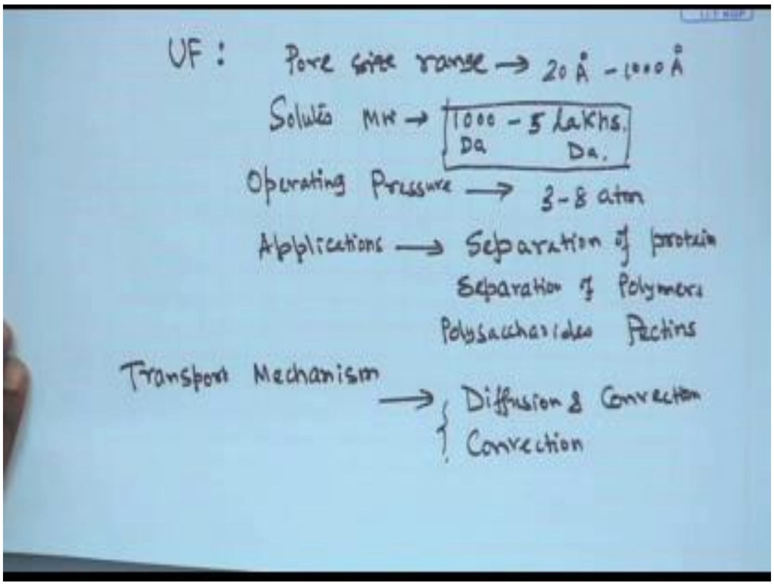

Then we will come to the categorization of ultrafiltration. The ultrafiltration has the versatile capacity membrane. So, it has a pore size distribution pore size range in the range of let say 20 angstrom to 1000 angstrom. And it has the solutes that can be separated as a molecular weight in the range of 1000 to even several lakhs, may be 5 lakhs 1000 Dalton to 5 lakhs Dalton. So, bigger size particles can be separated by the ultra filtration membrane. And the operating pressure requirement is less, and it will be in the range of 3 to 8 atmosphere.

And typical applications and it has huge applications because these take care of solutes separation of solutes of a wide range of applications. So, separations of proteins, separation of polymers, polysaccharides like pectins in clarification of fruit juice their various applications of ultrafiltration. And the mechanisms of transport it is a mixture of diffusion and convection for lower cut of membranes where we will separating the solutes which will be having low molecular weight. For open membrane open ultrafiltration membranes mainly the convection is a governing mechanism, so that goes for the ultrafiltration.

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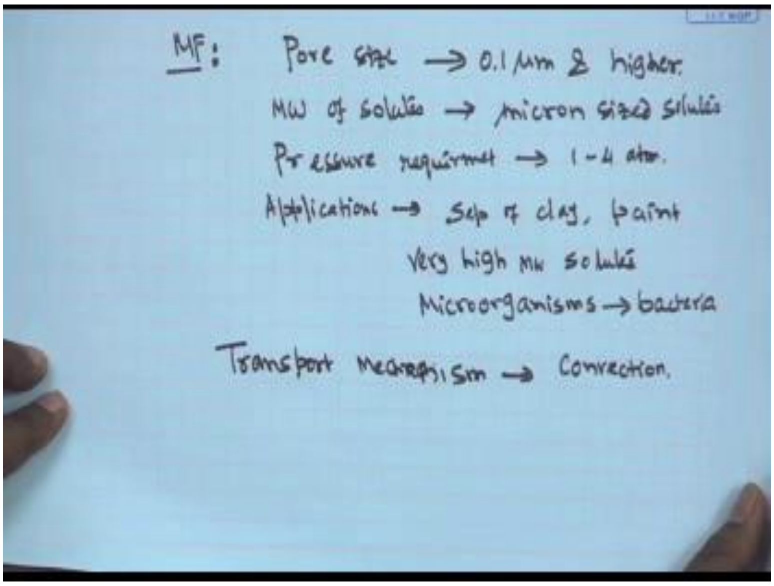

The final membrane based process is micro filtration that we will be talking about in case of micro filtration we are really talking about a porous membrane, which will be having a size more than pore size in the range of microns 0.1 micron to an higher. And molecular weight of solutes that needs to be separated will be high may be more you know larger size molecules micron sized solutes are separated by micro filtration. And the pressure requirement will be less 1 to 4 atmosphere.

And what are the various applications; applications are separation of clay, paint, very high molecular weight solutes. And then micro organisms they following in under the category micro organisms like bacteria. Typically, all the water born bacteria can be separated by the micro filtration processes, but the virus they will be having a lower size one has to go for a for an ultra filtration membrane to remove the virus from the aqua solution. So, what is the transport mechanism transport mechanism is mainly convection. So, these are the four major categories membrane based separation processes.

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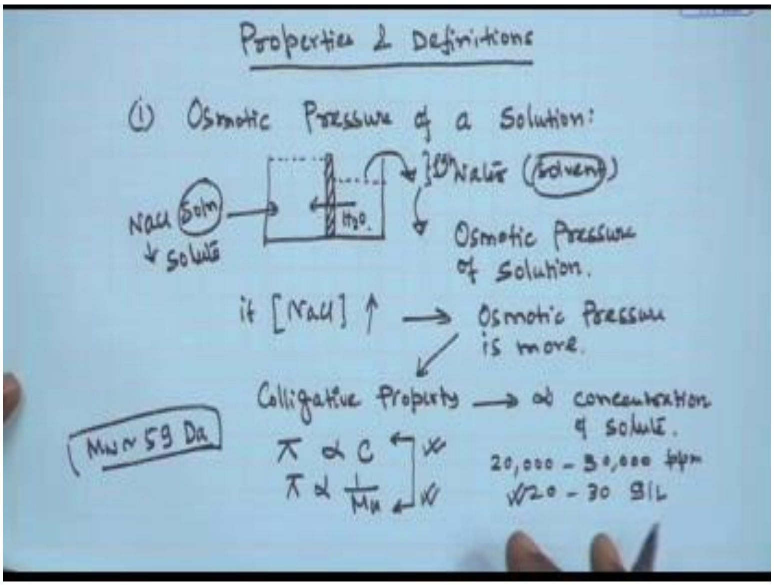

Now, we will be looking into the various properties and definitions, which will be coming across quite often in this course, in order the model and modelling and simulation of the process. So, will be the first property that will be looking into the osmotic pressure of a solution. What is the osmotic pressure of a solution? Every osmotic pressure of a solution indicated the thirst of water. So, a solution more osmotic pressure means if the solution is more thirsty for a water.

So, let us conduct an experiment, suppose we will be having two chamber systems separate by a semi permeable membrane. Semi permeable membrane means it will be opened to particular species and it does not allow to transport any other species. For example, if you have a salt and aqueous solution of salt that means there are two species in this system, one is the salt another is the water. So, water being smaller in size these perfectly semi permeable membrane will allow water to permeate through it, it does not allow salt to permeate through it. So, therefore, let us keep one chamber to be filled up by water there is a solvent; and we fill the other chamber by let say Na Cl solution, so Na Cl is a solute.

Now, these membranes allow water to permit through from the solvent side to the solution side, so it is basically the solution side, and these are solvent side. So, as time progress the water concentration or activity of water is less in the solution side, so since this membrane is a perfectly semi permeable membrane, it allows only water to permeate through it from the solvent to the solution side. Therefore, the water being transported from this side to this side and these will be kept on going unless equilibrium will be reached and they are typically that equilibrium will be reached then around it will take around 24 to 36 hours. So, at the equilibrium what happens? The level of water comes down in the solvent side and in the same type the level of water in the solution side goes up. So, therefore, it will be creating a hydro static pressure of rho g h, where h is the final height difference of the level of solution in both the chambers. So, this rho g h or the static pressure that will be created by this system is known as the osmotic pressure osmotic pressure of solution. Now, this osmotic pressure will be very, very important.

So, if we now let us look into another system, where we have a higher concentration of salt in the solution side. If we have a higher concentration of salt in the solution side the water activity will be will be very, very less in the solution side and therefore, more water will be coming from the solvent side to the solution side in order to attain the equilibrium. So, therefore, the after equilibrium, the height of the solution side will be more compared to the height of the water solvents of water in the solvent side. So, the height difference will be more in this case and the osmotic pressure will be more.

So, if the conclusion is if Na Cl concentration goes up the osmotic pressure development will be more. Therefore, osmotic pressure is known as a colligative property. And it is directly proportional to concentration of solute. So, osmotic pressure is typically denoted by a symbol pi and pi is proportional to C. Another property of osmotic pressure is that osmotic pressure is inversely proportional to the molecular weight. So, if we are talking about the molecular of smaller solutes which will be having a molecular. In fact, size of the solute is directly proportional to the molecular weight. So, if we have a smaller solute that which will be having a smaller molecular weight, it is osmotic pressure is high.

So, therefore, one can have high osmotic pressure under which situation if you have a smaller molecular solute and larger concentration of the solute. Typically, in sea water, the osmotic the concentration of salt is around 20,000 to 30,000 ppm that is 20 to 30 grams per litre or kg per meter cube. And what is the molecular weight of salt, it will be having very less in molecular weight is around 59 Dalton 58.5 to be precise, so it will be having the salt. So, therefore, at this concentration of salt - sodium chloride at with a molecular weight around 58.5 Dalton is osmotic pressure is very, very high. If you really calculate the osmotic pressure Trans out to be around 20 to 22 atmosphere. So, therefore, in order to get in order to get the reasonable throughput through the process or system one as to have an operating pressure which will be higher than the osmotic pressure which will overcome this osmotic pressure. So, therefore, 25 atmosphere and more is prescribed as the operating pressure of the reverse osmosis system.

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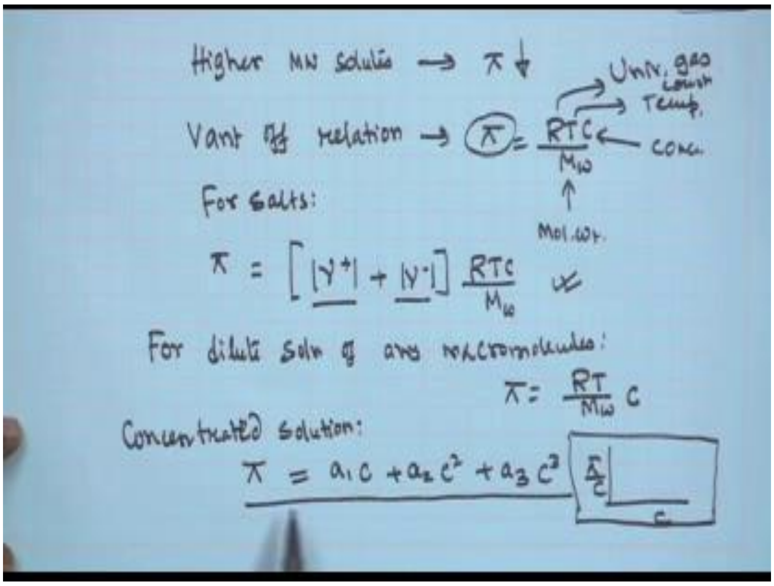

Now, you must have understood that osmotic pressure, if you go for higher molecular solutes the osmotic pressure will be less, because it is inversely proportional to the molecular weight of the solutes. Therefore, for higher molecular solutes the osmotic pressure is less. So, therefore, the operating pressure requirement will be less so that is why if you have observed when you have defined the various categories of membrane weight processes as the pore size of the membrane increases the pressure requirement decreases. So, this is the reason as the pressure requirement is decrease as the pore size of the membrane increasing, we are really talking about separation of solutes which will be having the higher sized or which will be having the higher molecular weights. So, their osmotic pressure is less so the operating pressure requirement for having a realisable throughput or which will be a which will be of significance that will be requirement of the pressure is less.

So, for the micro filtration membrane where we are talking about separation of very large particle the osmotic pressure is negligible and one can have very low pressure in the range of 1 to 2 atmospheres in order to get a realisable flux which will be commercially viable, the Vant. relation is generally used to quantify the osmotic pressure of a solution RTC by M. R is the absolute, R is the universal gas constant; T is the temperature in absolute scale, C is the solute concentration, M w is the molecular weight.

Now, these is generally used for salts; for salts this is slightly modified this there will be a factor that will be multiplied in front of this expression, v will be the valency of the strong electrolytes. If you are talking about sodium chloride this will be Na plus and Cl minus, so this factor will be 1 plus absolute of minus 1. So, it will be 2 RTC by M w. So, therefore, if you are talking about salts, this relationship, the linear relationship holds. And for dilute solution of any macro molecules, which is not salt, one can typically use the Vandoff of relation which will be linear in nature; for example, dye and other material.

Well if it is your talking about a concentrated solution of macro molecule one will be using a polynomial of concentration. How this relationship is generated this relationship is generated by conducting you know by measuring the osmotic pressure of different concentration of solutes in an instrument call osmometer. If you use an osmometer and prepare different concentration of the solutes, one can measure the osmotic pressure and then one as to plot pi by C verses concentration. In fact, this is very important how this relation or this correlation of osmotic pressure is generated, because we have to assume that the concentration for a pure solvent the osmotic pressure is less or osmotic pressure is 0.

So, if you talk about a concentration or if you talk about a pure solvent c is zero and osmotic pressure is 0. Therefore, whenever you are talking about the measurement of concentration, measurement of osmotic pressure of any solution, we measure pi as a function of C in an osmotic pressure then prepare a table pi by c verses c. And typically this curve will be a polynomial through origin and then this correlation will be fitted. And therefore, since there will be an intercept here. So, therefore, there will be an intercept in this case. So, therefore, one has you express pi as a function of concentration it will be going through the origin. So, therefore, one will be getting a relation confirm the relationship that for pure solvent when the concentration is zero solute concentration is 0, pi will be equal to 0.

We stop here in this class; in the next class, we will be looking into the others properties and definitions which will be very, very important throughout our course.

Thank you very much.