Membrane Technology
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Lecture-35
Gas-liquid and liquid-liquid contactors, membrane reactors and bioreactors,

Good morning students this is lecture 35 under module 12 and under this lecture today we will discuss about gas liquid and liquid-liquid contactors. Basically the different type types of contactors that are available for a membrane separation applications then we will learn about membrane reactor and bioreactor and in a nutshell we will discuss about the PEM hydrogen fuel cell of a fuel cell where membrane plays a very vital role.

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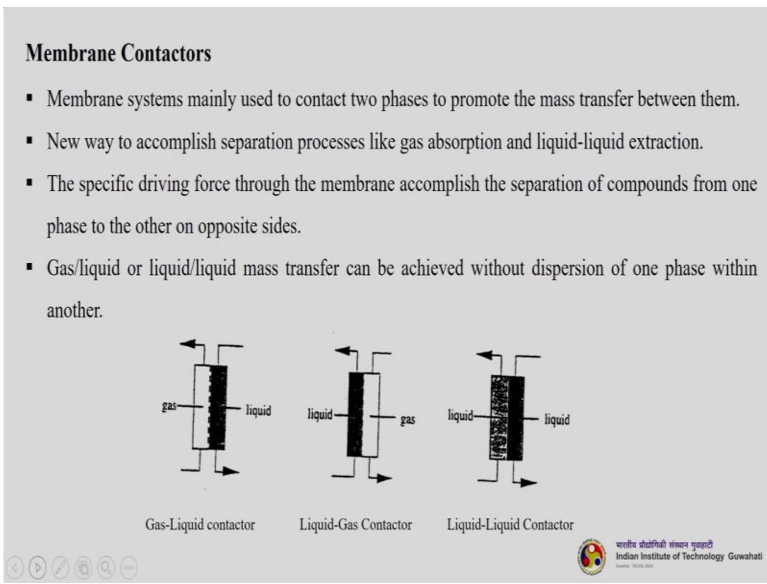

So if you talk about membrane contactors or the membrane systems mainly used to contact two phases to promote the mass transfer between them. So, it is a new way to accomplish separation like gas separation and liquid-liquid extraction. The specific driving force through the membrane accomplishes the separation of compound from one phase to the other opposite side. So, you have a gas liquid a liquid-liquid mass transport both can be achieved without dispersion of one phase within another phase.

So two phases are being separated by membrane you can see there is the three types of membrane contactors that is I have shown it here. The first is gas liquid contactor, so basically one phase is gas another phase is liquid and in between there is a membrane this is your membrane so that a second one is gas liquid contactor. So, here the liquid phase is in the upstream side and gas is the in the opposite side and this is just the reverse of the first one that will under two different phases have changed the sides.

And then we have a liquid-liquid contactor in which both the phases are liquid and being separated this one by a membrane.

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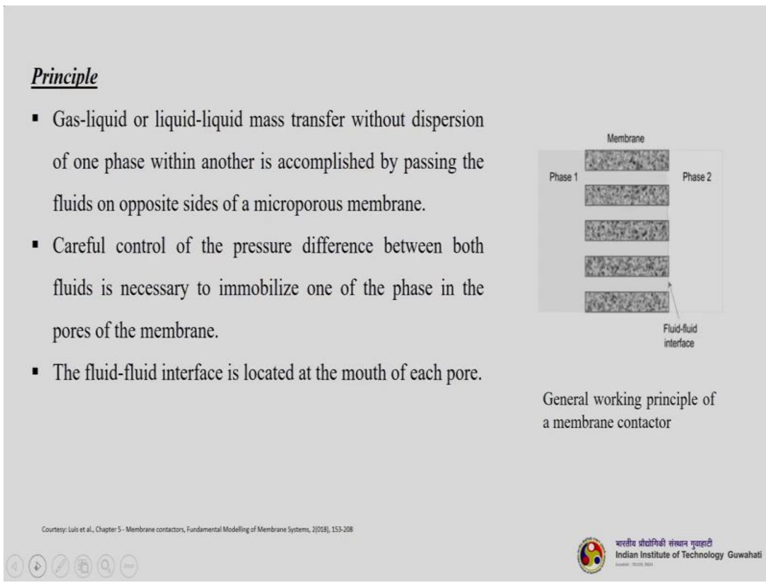

If you talk about the principle then gas liquid and liquid-liquid mass transfer without dispersion of one phase within another is usually accomplished by passing the fluids on opposite sides of a micro porous membrane. So, careful control of the pressure difference between both fluids is necessary to immobilize one of the phases in the pores of the membrane. The fluid-fluid interface is located at the mouth of each pore so basically this you can see the fluid-fluid interface.

So this is the pore mouth right the main role of the membrane is to act as a barrier and to increase the surface of mass transfer exchange between both the phases. So, the common feature in these processes is that the separation performance is determined by the distribution coefficient of a component in two phases which component basically or which solid you want to separate what is its distribution efficient in both the phases that place the big role in deciding how the solute will be transported apart from other governing factors.

So generally it is the large area per volume that makes the process more attractive rather than the and has to mass transfer.

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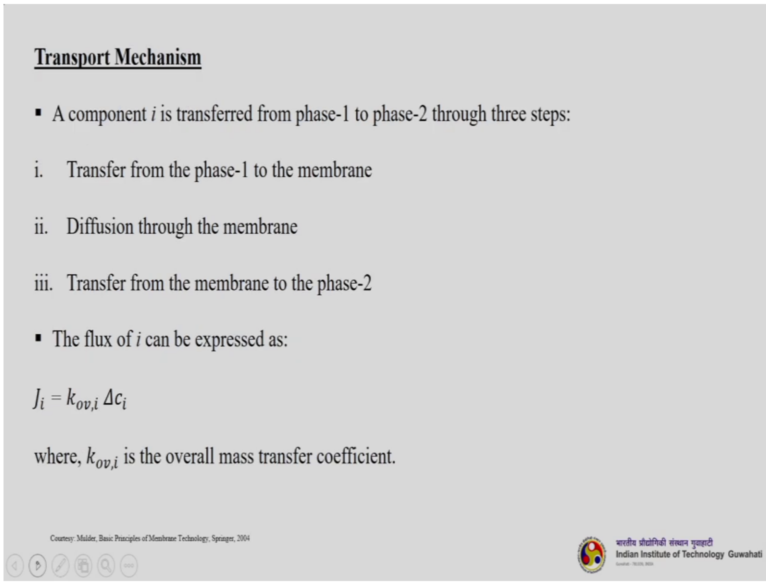

So the transport mechanism let us understand how this is happening. So, a component i is transport from phase 1 to phase 2 using three steps. So, first is of course the transfer from phase 1 to the membrane then diffusion through the membrane. So, I can just trying to draw say let us say this is the membrane ok. So, this is here let us say phase 1 this is your phase 2 so let us say this component which is present in the bulk is to be transported to the other side of the phase or the side of the membrane that is permeate side and this is your membrane right.

So what will happen so it will first move from the bulk and will come to the surface of the membrane. So, it will then sit on the surface membrane right then it will diffuse through the membrane. Once it diffuse through the membrane it reaches the permeate side then it dissociates itself from the membrane completely or detach itself and then comes to the permeate side. So, the flux of Pi can be re-expressed as Ji is equal to K ov, i into Delta Ci here K ov,i is the overall mass transfer coefficient.

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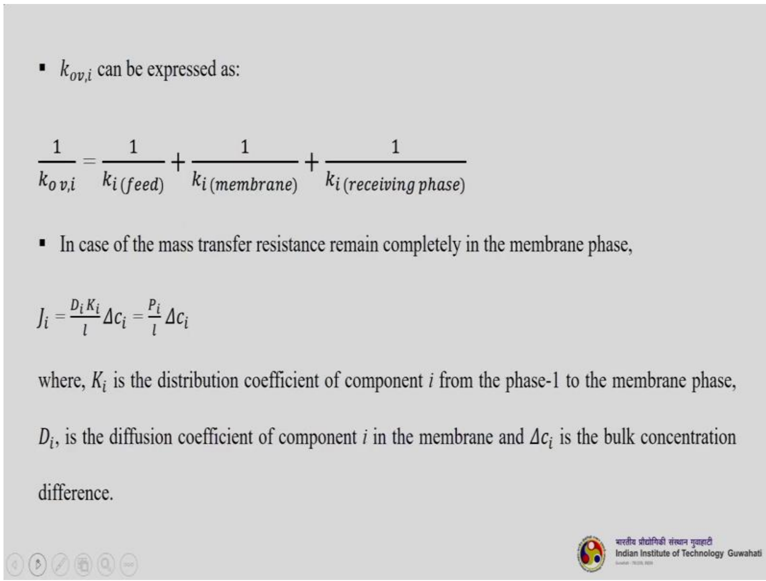

This also we have learned but just repeating once again for your first understanding that 1 over K ov,i which is the overall mass transfer coefficient can be expressed in such a form which is the combination of the mass transfer coefficient up three factors so k i feed, k of membrane and k of the receiving phase that is the permeate phase that say. So, in case of mass transfer resistance remain completely in the membrane phase.

So you can write that Ji equal to D i K i by l Delta C i or Pi by l Delta C i so where K i is the distribution coefficient of the component I from the phase 1 to the membrane phase and D i is the diffusion coefficient of the component i in the membrane and Delta C is the bulk concentration difference l be the thickness of the membrane.

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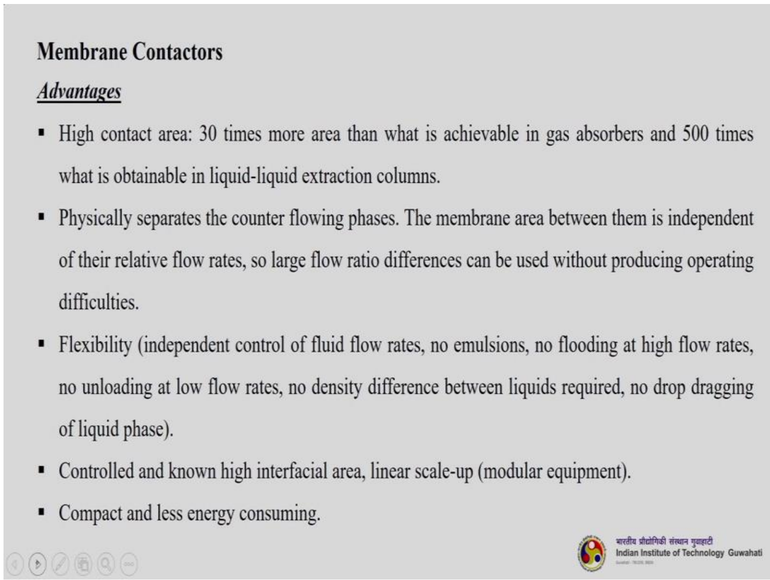

So advantages are so high contact area 30 times more area then what is what is achievable in gas absorbers and 500 times what is obtainable in liquid-liquid extraction columns. Physically separates the counter of flowing phases the membrane area between them is independent of their relative flow areas. So, large flow ratio differences can be used without producing operating difficulties.

Now flexibility that is means independent control of fluid flow rates so there is no emulsions and there is no question of any flooding at high flow rates which is actually a problem in fact column towers I mean distillation towers also no unloading at low flow rates there is no density difference between the liquids that needs to be considered not dropped dragging of liquid phases. So, you can say this is more a very easy to operate type of system and controlled and known high interfacial area linear scale up and compact and less energy consuming.

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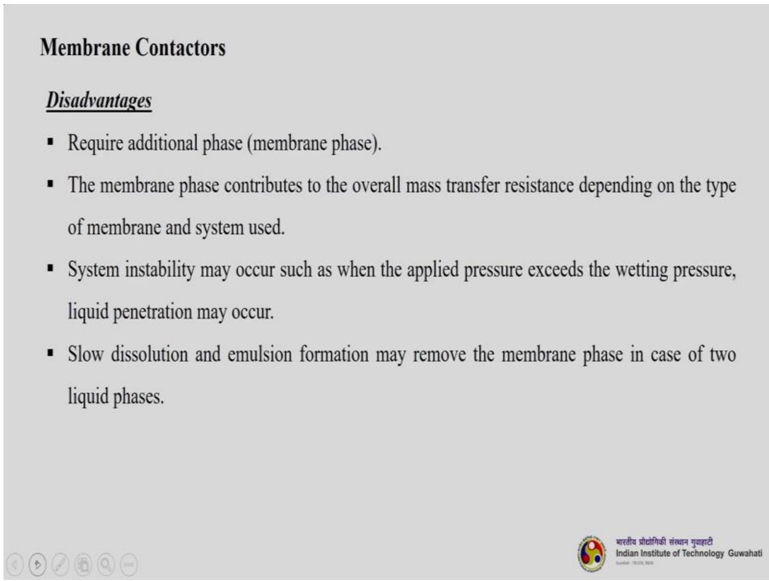

However it has certain disadvantages also it requires an additional phase which is here membrane and the membrane phase contributes to the overall master spur resistance depending on the type of the membrane and the system used. System instability may occur such as when you at the applied pressure exits the waiting pressure a liquid penetration may occur inside the pores so this is another problem.

So pressure has to be controlled very efficiently slow dissolution and emulsion formation may remove the membrane phase in case of two liquid phases when we are talking about two liquid phases if one is a gas phase another is a liquid phase then it is fine. But when there are two the liquid phases then if they are mixing and forming some emulsions then it may create another or an additional problem.

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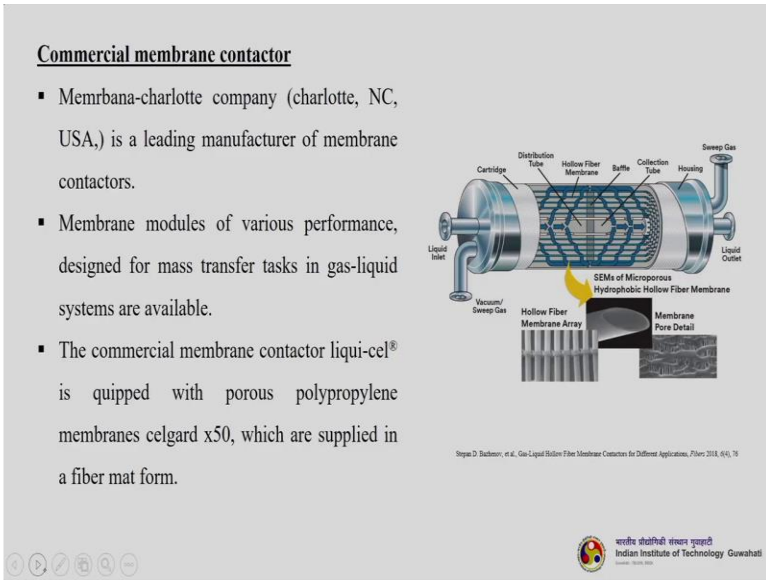

So commercial membrane contactors are this one basically they are manufactured by so many different companies just listed one or two here. So, a membranous added company in United States is a leading manufacturer of membrane contactors. So, membrane modules are various performance design for mass transfer tasks in gas liquid systems are available. The commercial membrane contacted liquicell is equipped with porous polypropylene membranes Elger x 50 which are supplied in a fiber mat format.

You can see how this is this looks like actually but this so this is a gas liquid hollow fiber membrane contactor for different applications. You can see this liquid will go here and liquid it out here and so your vacuum gas or sweep gas will come here or it will be out here right so this is you can see how the distribution two stiffs inside. And these whatever you are seeing these lines here so they are actually hollow fiber membranes right.

There are baffles inside to help in and distribution of the liquid inside that and there is a collection tube in between which you are seeing in which your liquid will be collected. So, this is how the assembly looks like actually on a hallow fiber assembly this is a single hollow fiber membrane and this is how a membrane pores are in detail this is an SEM image. So, you just get an idea basically about how these things happened.

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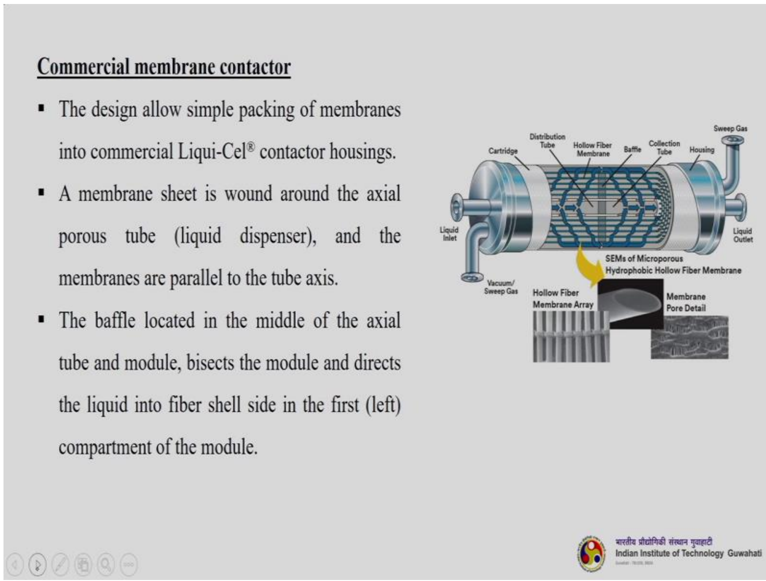

So the design allows simple packing of membranes into commercial liquicell contactor housings a membrane sheet wound around the axial porous tube and the membranes are parallel to the tube axis. Anyway these things we have discussed during our membrane modules and all but just quickly going through it will read this one so that you can recollect the things quickly. So, the baffle located in the middle of the axial tube and module bisects the module and directs the liquid into fiber cell in the first compartment of the module.

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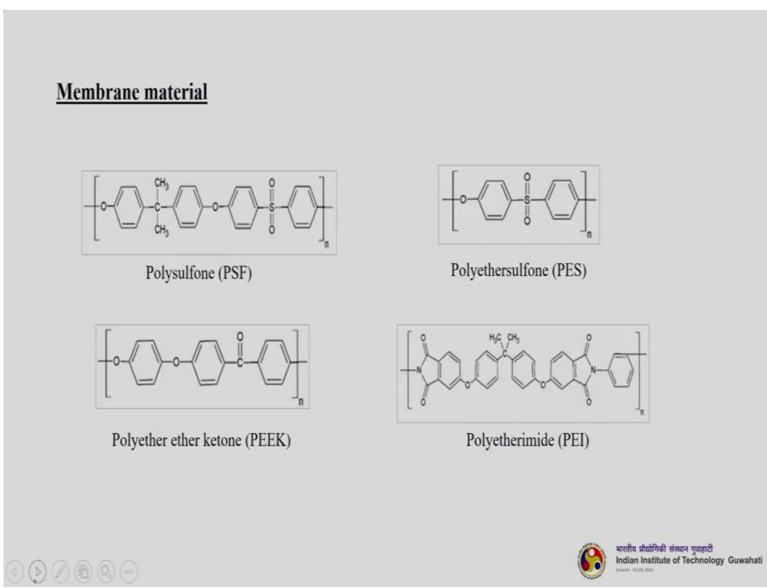

Just let us quickly go through the different types of materials that is being used for the membrane though we have discussed it in detail polysulfone, polyethersulfone polyethyletherketone then polyetheramide Pi.

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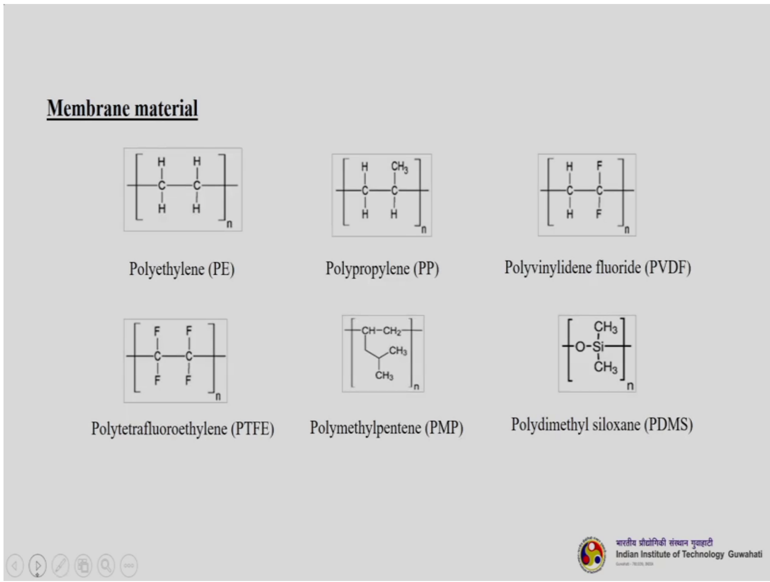

It is gaining a lot of interest nowadays in this particular membrane otherwise mostly commercial membranes you will see that that polysulfone or polyethersulfone or PVDF or PTFE. So, then polyethylene, polypropylene PVDF PTFE polytetrafluoroethylene PMP then PDMS, so, these are some of the materials that are being used for the preparation of that membranes.

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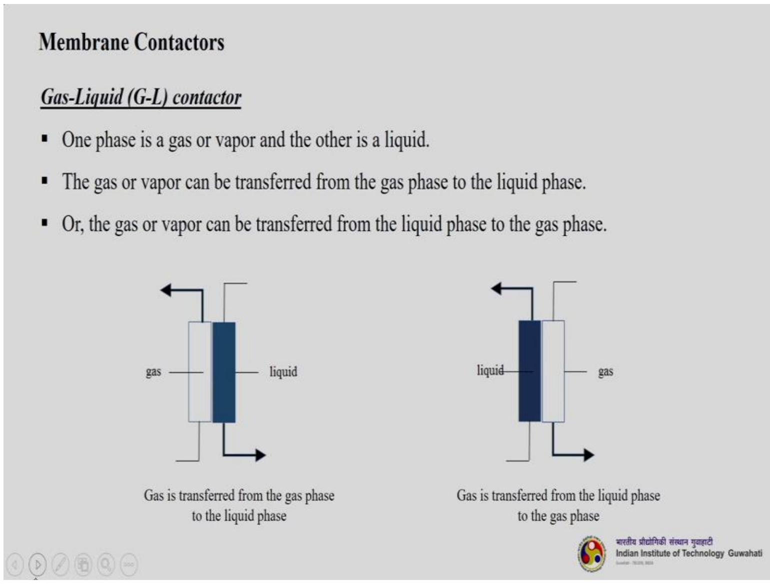

So, let us now I will discuss little more detail about the contactors. So, let us first understand about the gas liquid contactor. So, here one phase is a gas or vapour and the other phase is a liquid. So, the gas or vapour can be transferred from the gas phase to the liquid phase or the gas or vapour can be transferred from the liquid to the gas phase either way you can operate it. So, if you do it like this that the gas is transferred from the gas phase to the liquid phase so this is how it happens actually. And here it is just the reverse of that the gas is transferred from the liquid phase to the gas phase.

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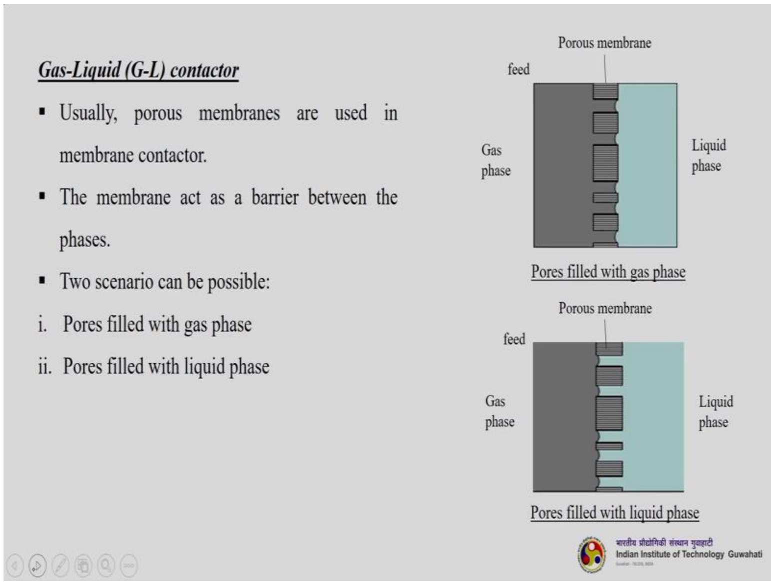

So, usually porous membranes are used in this; such type of contactors the membrane act as a barrier between the two phases two scenario can be possible. The first pore filled with the gas phase second pores filled with the liquid phase. So, this is the schematic is showing about how it happens, so here you can say the pores are these are the pores so these are filled with the gas phase. Here you can see the same pores these are filled with the liquid phase.

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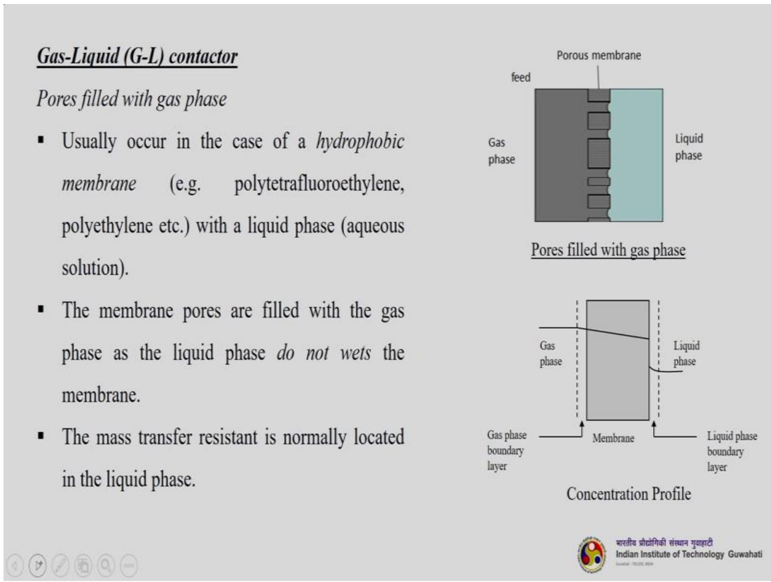

So pores filled with the gas phase usually occur in case of a hydrophobic membrane to achieve that the first case where the pores are filled with gas which we need a hydrophobic membrane. So, as for example polytetrafluoroethylene, polyethylene etcetera with a liquid phase which is basically our eco solution, the membrane pores are filled with gas phase as the liquid phase do not wets the membrane.

So, you have to choose the membrane material in such a way that is why hydrophobic material. The mass transfer resistance is normally located in the liquid phase. So, this is the concentration profile how it happens this is your membrane the gas phase then liquid phase and this is the gas phase boundary layer this is the liquid phase boundary layer this is up stream side this is downstream side.

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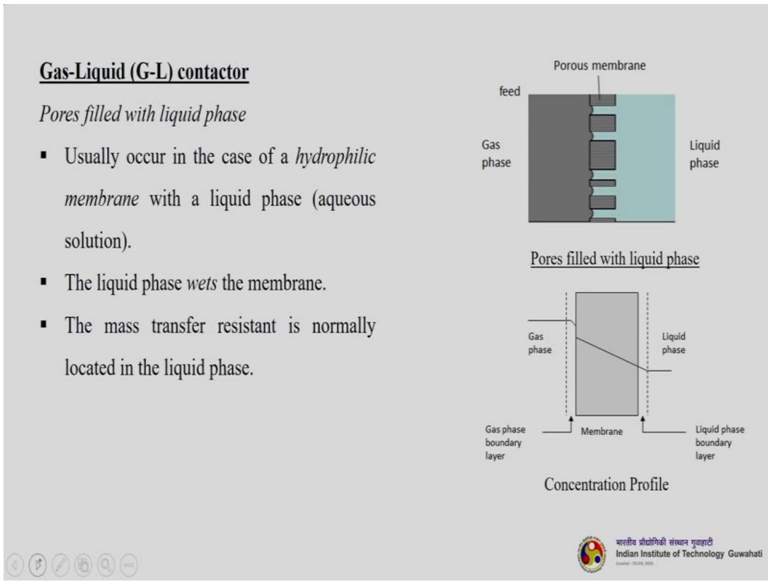

So, in the second case which are pores filled with liquid membrane start to achieve that we need a hydrophilic membrane that is the reverse of the hydrophobic one with a liquid phase obviously that is a aqueous solution. So, the liquid phase here wets the membrane yeah in the earlier case the liquid phase is not wetting the membrane. So, the mass transfer resistance is again normally located in the liquid phase.

So you can see the same thing here guess with this is liquid phase this is membrane this is gas phase boundary layer this is liquid phase boundary layer.

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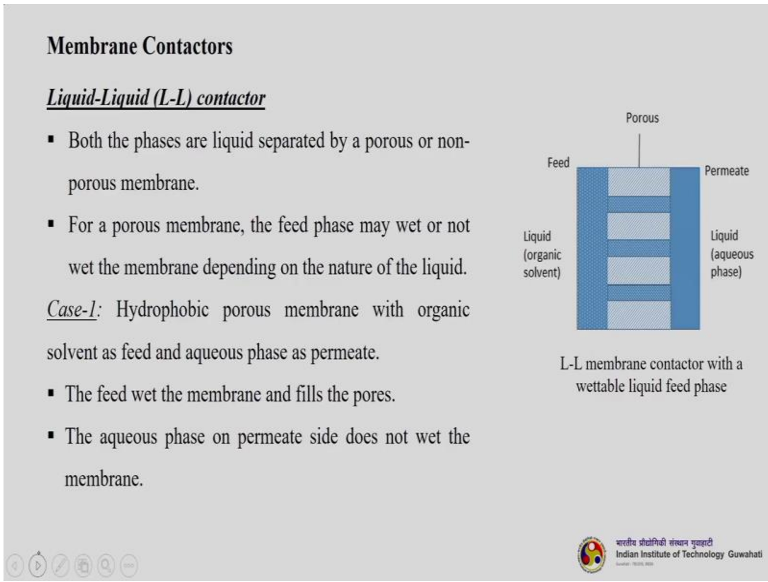

Then the next one is liquid-liquid contactor so here both the phases are liquid separated by a porous or non porous membrane. Now for a porous membrane the feed phase may wet or not wet the membrane depending upon the nature of the liquid. So, let us understand different cases let us take the first case which is hydrophobic porous membrane with organic solvent as feed and aqueous as the permeate.

So you can see how it looks like this schematic diagram here you had liquid or phase here another liquid phase here so let us say phase one phase two. So, this is feed side this is permeate side this is the porous membrane here the membrane contactor with a wet table liquid feed phase actually the membrane. And the liquid phase which is in the feed side it is wetting the membrane basically so the feed where the membrane and fills the pores.

So feed side or liquid is being filled here you can see that dotted here so all the pores are filled with the feed phase liquid because that liquid is wetting the membrane then the aqueous phase on the permeate side does not wet the membrane.

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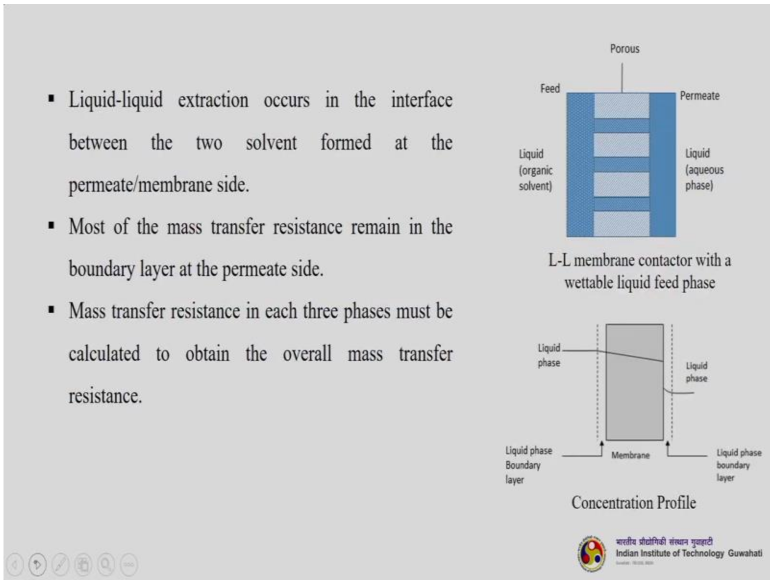

So, liquid-liquid extraction occurs in the interface between the two solvent formed at the permeate membrane side. So, most of the mass transfer resistance remain in the boundary layer and the permeate side so here only most of the mass transfer resistance is calculated and mass transfer resistance in each three phases must be calculated to obtain the overall mass transfer resistance and of course to found out that which is dominating.

So it has been seen that the mass transfer resistance in the boundary layer of the permeate side that means this one is the dominant one.

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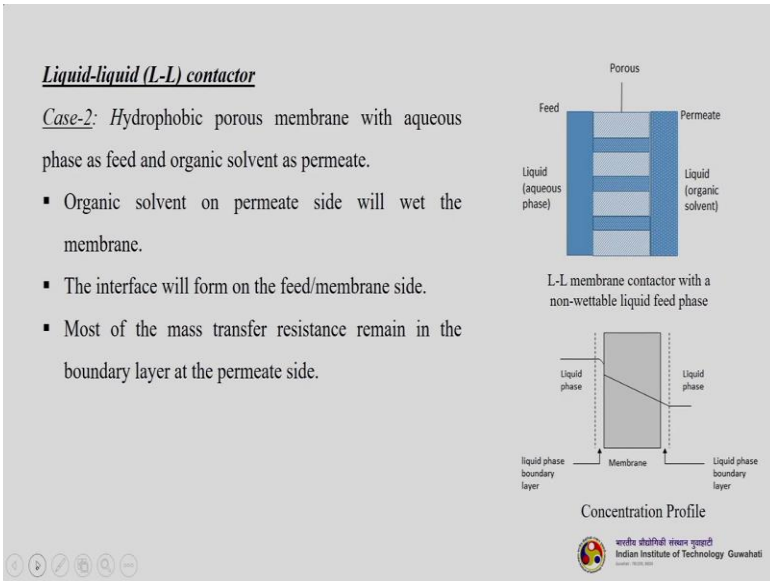

Then the case two here hydrophobic porous membrane with aqueous phase is a feed and organic solvent as a permeate right. So, here you can see the feed phase is a eco phase liquid again its liquid-liquid basically but in the permeate side it is organic solvent instead of a aqueous solvent. So, organic solvent or permeate side will wait the membrane. So, organic this thi one will wet the membrane. So, you can see now the pores are filled from the permeate side liquid and the interface will form a feed the interface will come here.

Here it will be basically that is the feed and membrane side most of the mass transfer resistance remain in the boundary layer at the permeate side. So, again the mass transfer resistance will be here.

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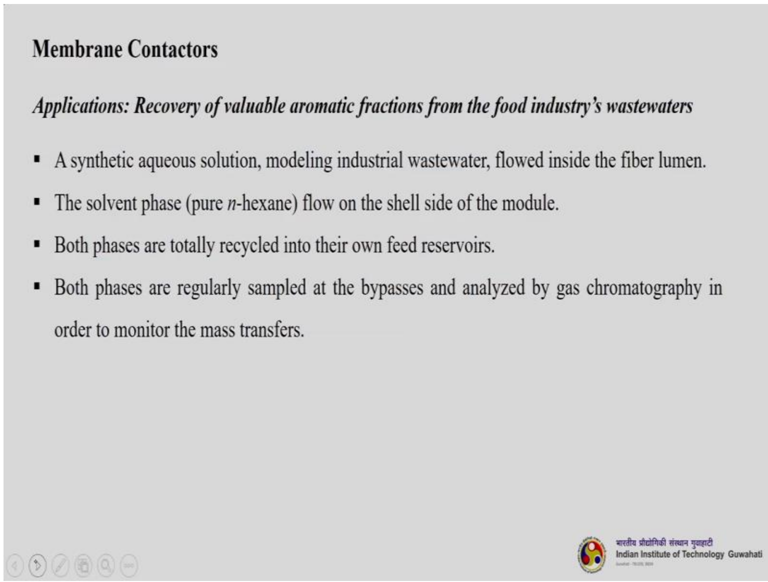

So just quickly we will go through certain applications the recovery of valuable aromatics fractions from the food industry's waste waters. So, a synthetic let us say synthetic aqueous solution which was used as a model which in distill wastewater flow inside to a fiber lumen. Hollow fiber alumina the solvent pure phase that is being used is n hexane a flow on the shell side of the module.

So, tube side and cell side let us say this is the tube side then we have a shell side like this right, so you can just extend it little more here to understand, so something is here and something is here. So, this is we can say that n-hexane, so this is your feed. So, both the phases are totally recycled into their own feed reservoirs, so both edges are regularly sampled at the by process and analyzed by gas chromatography in order to monitor the mass transfer.

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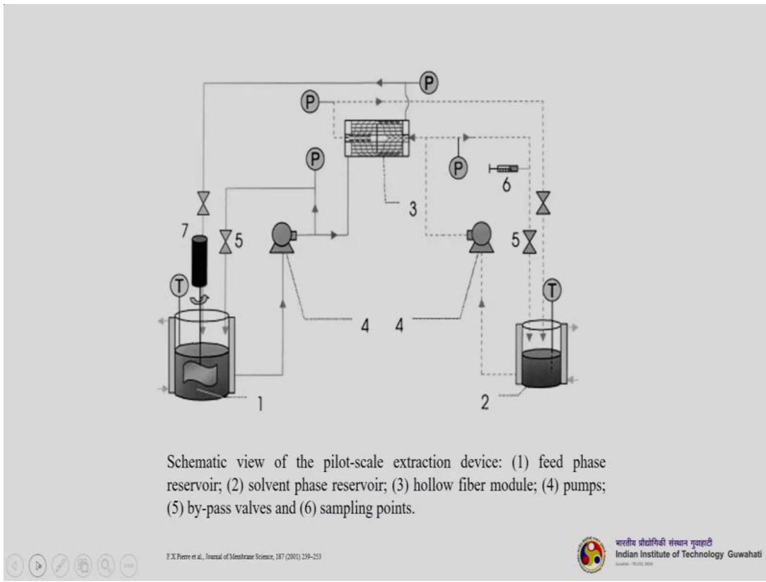

So, this is a most better complete schematic diagram so you can see that this is a pilot scale extraction device here the feed phase reservoir this is feed reservoir where this is your solvent reservoir which is n hexane, this is your hollow fiber module and then there are different pumps bypass valves and sampling points. Since; I told just in the earlier slide that both the feet as well as your solvent which is being used passing through the membrane are totally recycled but so this system operates in a total recycle mode.

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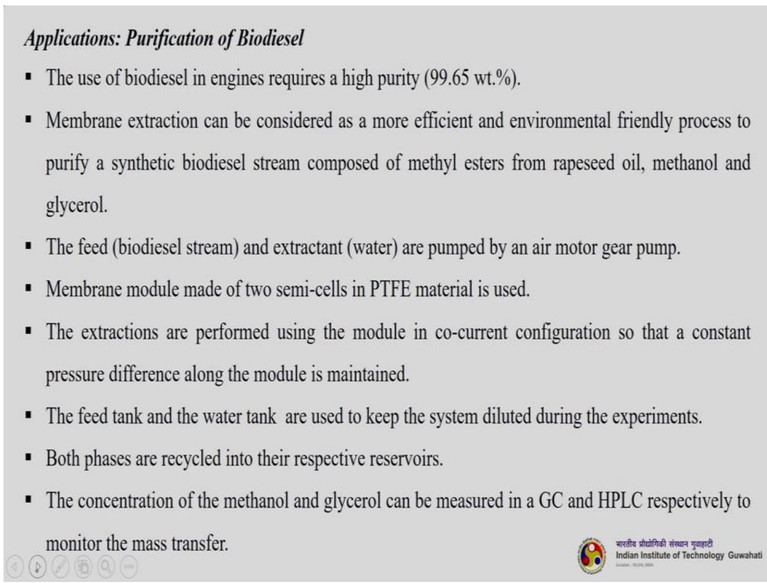

So another application is purification of biodiesel. So, that use of biodiesel in engine requires a high purity almost 99.65% so membrane extraction can be considered as a more efficient and environmentally friendly process to purify a synthetic biodiesel stream composed of methyl esters from rapeseed oil methanol and glycerol. So, the feed biodiesel stream and extract and water are pumped by an air motor gear pump membrane module made up of two semi cells in PTFE material is used.

The extractions are performed using a module in a co-current configuration so that constant pressure difference across the maintenance module is maintained. The feed tank and the water tank are used to keep the system diluted during the experiments both phases are recycled into their respective reservoirs the concentration of the methanol and glycerol can be measured in a GC and HPLC respectively to monitor the mass transfer.

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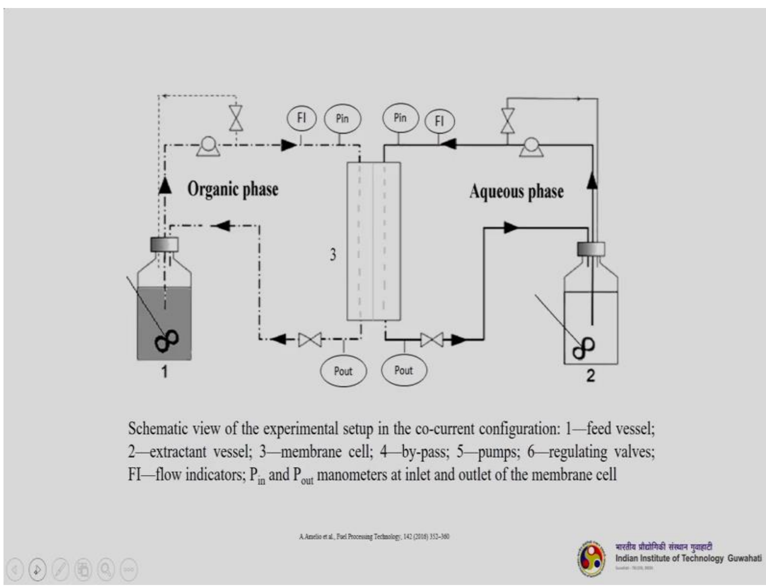

Schematic view of the experimental setup in the co-current configuration: 1—feed vessel; 2—extractant vessel; 3—membrane cell; 4—by-pass; 5—pumps; 6—regulating valves; FI—flow indicators; P_{in} and P_{out} manometers at inlet and outlet of the membrane cell

So, let us see the schematic diagram here, so this is the experimental setup in a co-current configuration so this is your feed vessel and this is your extraction vessel this is this is your membrane. Then there are different types of bypass valves pumps regulating valves flow indicators so an manometers in the inlet and outlet of the membrane cells.

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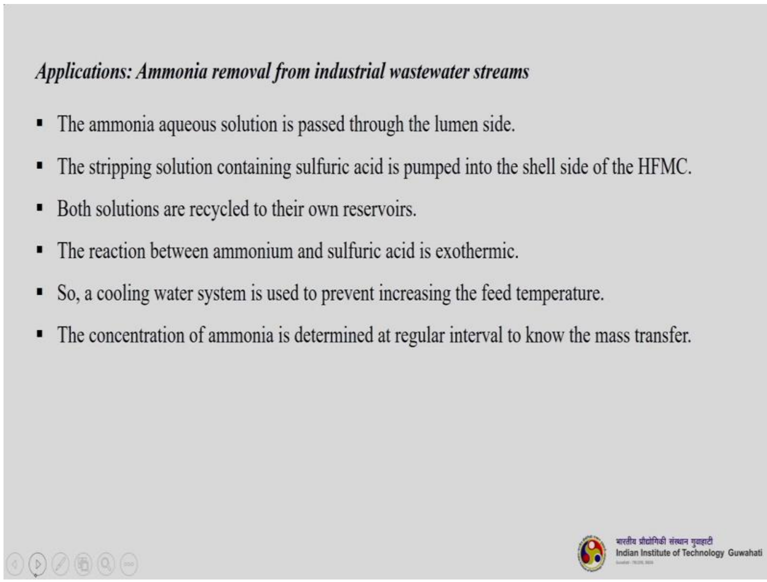

So, another application is ammonia removal from industrial wastewater streams so the ammonia aqeuous solution is passed through the lumen side and the stripping solution containing sulfuric acid is pumped into the cell side of the HPLC see hollow fiber membrane contactor. And both solutions are recycled to their own reserves the reaction between ammonia and ammonium and sulfuric acid is very exothermic.

So a cooling water system is used to prevent in to prevent increasing the feed temperature. The concentration of ammonia is determined at regular interval to know that mass transfer.

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So, it is a very simple schematic of this separation actually for ammonia stripping. So, here you can see the feed resolution so that the cooling is provided because it is exothermic reaction happens so you pump it and the hollow fiber membrane system HFMC so then the stripping said this is the stripping solution whatever is coming out here after passing through it is mostly returned again being recycled to the feed tank.

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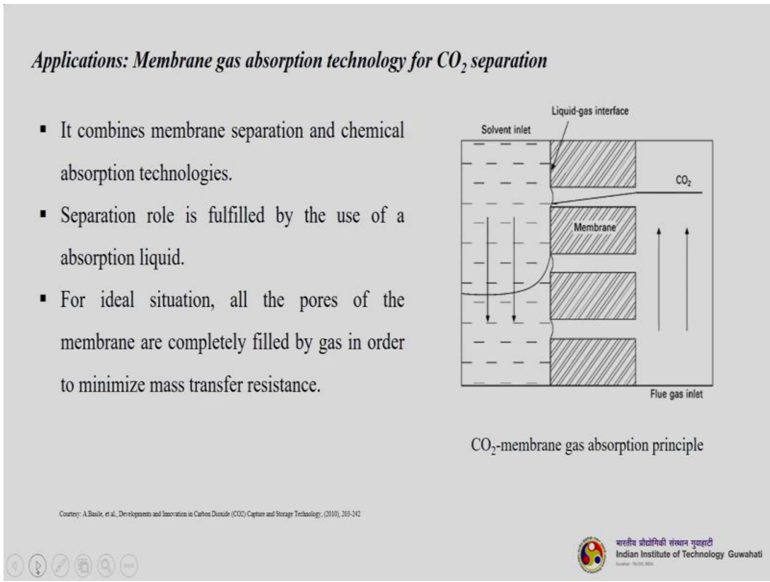

So another application is membrane gas absorption technology for carbon dioxide separation. So, you know it combines membrane separation and chemical absorption technologies. Separation role is fulfilled by the use of a absorption liquid for ideal solution all the pores of a membrane are completely filled by gas in order to minimize mass transfer resistance. So, this is a carbon dioxide membrane gas absorption principle what is happening you say this is solvent here this is flue gas inlet which is having carbon dioxide.

So you can see that the this is the how the carbon dioxide is going like this is your liquid gas interface here you have the liquid gas interface the carbon dioxide is passing through the membrane pores and then getting absorbed in that solvent or absorption liquid which is present on the upstream side.

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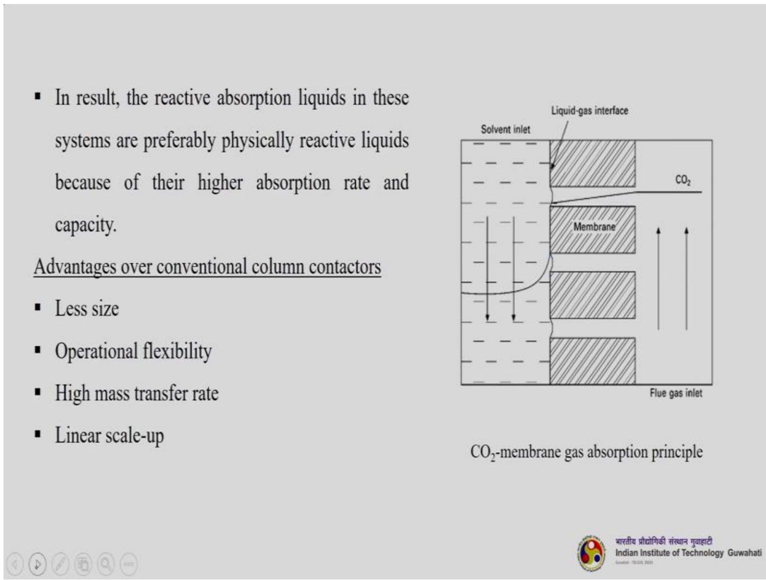

So in a result the reactive absorption liquids in these systems are preferably physically reactive liquids because of their higher absorption rate and capacity. So, the advantages are so it requires less size then the conventional absorption towers operational flexibility is they are easy to maintain basically and easy to operate. The rate of mass transfer is very high and as you know the scale up is linear.

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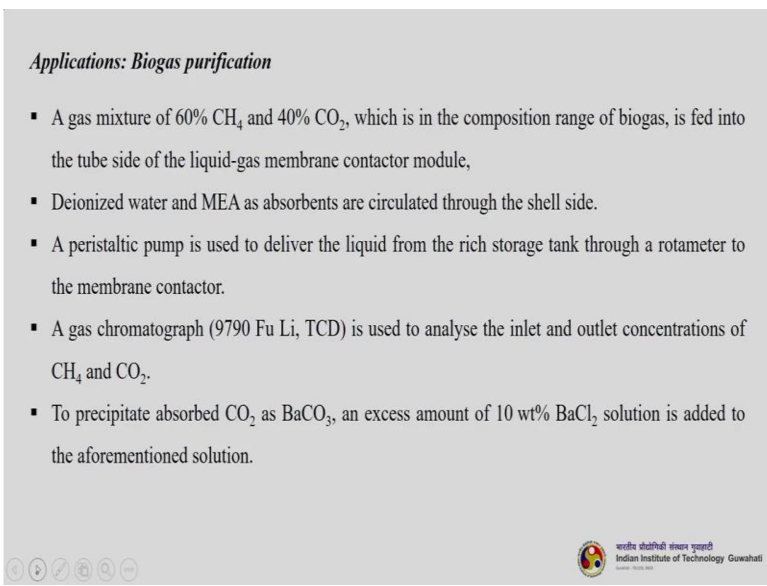

So another application is by gas purification so biogas or you can call a gobber gas, so a gas mixture of 60% methane and 40% carbon dioxide so which is in which is in the composition register biogas is fed into the tube set of a liquid cast membrane contactor module. So, what about being reported here actually so this is this is simulated by gases basically so de-ionized water and MEA absorbance are circulated through the shell-side.

A peristaltic pump is used to deliver the liquid from the rich storage tank through a rotameter to the membrane contactor. A gas chromatograph was used to analyze the inlet outlet concentrations of methane and carbon decide to precipitate absorb carbon dioxide as barium carbonate excess amount of 10 weight percent of barium chloride solution is added to the aforementioned solution.

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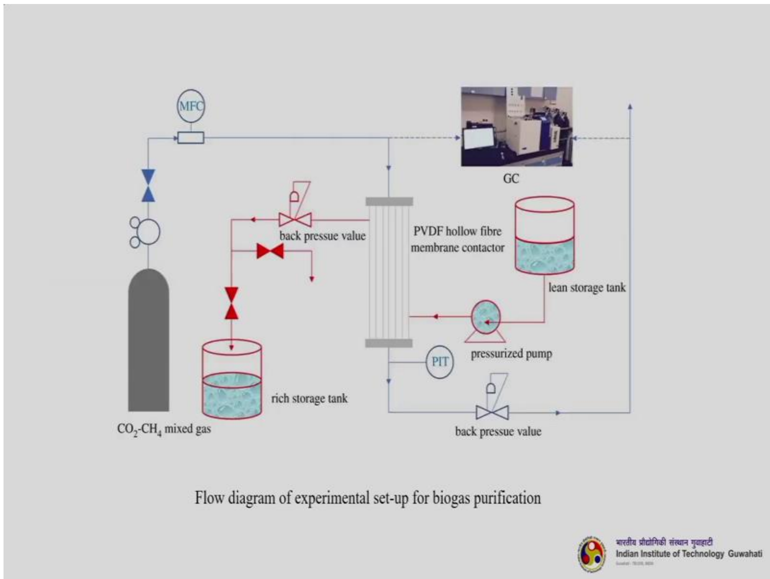

And this is the schematic representation so you see the carbon dioxide methane mixed gas is being fed to the membrane system which is fitted with PVDF hollow fiber membranes. Then you can see this lean storage tank the feed is coming here and then whatever it is coming out in the permeate side is being collected here and some of the pressure this one gas after removing it is going through this one then you can collect here.

And you can measure of course through the GC or HPLC system to find out the concentrations of both carbon dioxide and methane the very simple operation actually.

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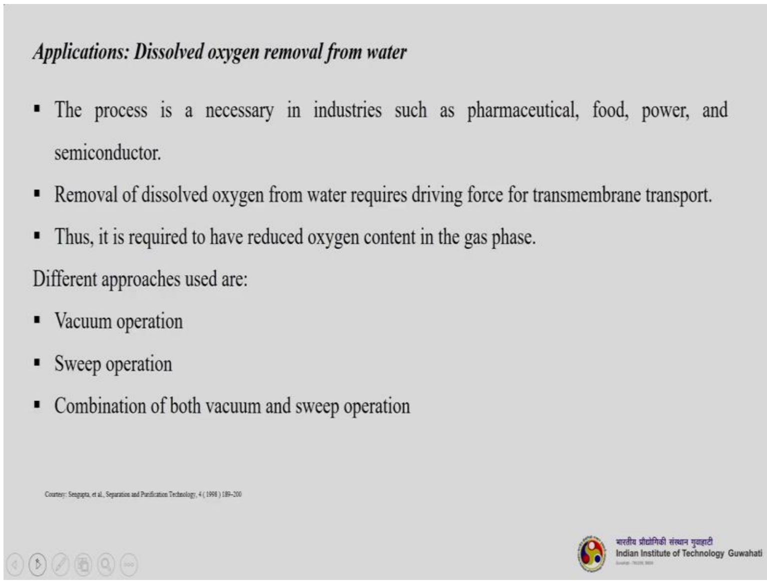

Another application is dissolved oxygen removal from water. So, this is a very important application in industry. Industry such as pharmaceutical, food, power and semiconductor so you need to remove the dissolved oxygen from water, removal of oxygen dissolved oxygen from water requires driving force for trans membrane transport thus it is required to have a reduced oxygen content in the gas phase so different approaches are used.

So you can have a vacuumiser operation so you can use a sweep case or you which is called the sweep case based operation or you can use both vacuum and sweep together.

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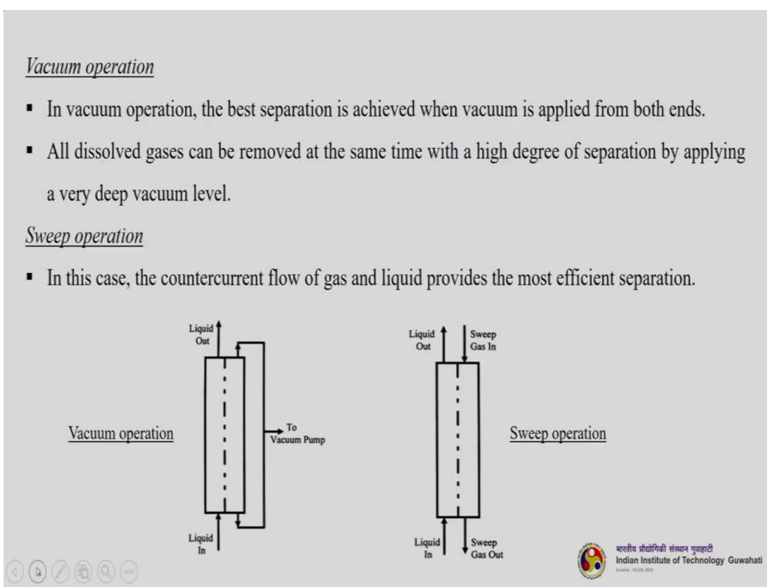

So in the vacuum only operation the best separation is achieved when vacuum is applied from both ends. So, all dissolved gases can be removed at the same time with a high degree of separation by applying a very deep vacuum level. So, you can see how it is happening actually so this is the vacuum operation the membrane liquid is containing here liquid is out here and now you are vacuum eyes the entire system here something very similar to pervaporation type of operation. Sweep gas again here liquid in liquid out and we have sweep gas in and sweep gas out.

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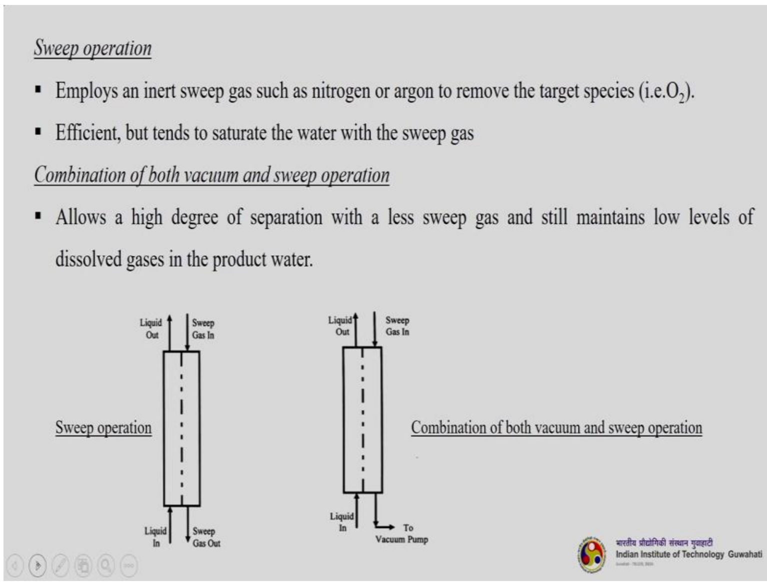

So, during the sweep gas operation employed it employs the inert so it gets such as nitrogen and argon to remove the target species here the target species is our oxygen. So, it is a efficient process but tends to saturate the water with sweep gas. And then combination of both vacuum and sweep operation you can see here and this is how it is happening here. So it is a combination of both the cumin soup so liquid in liquid out sweep gas in and it goes to that's what ever sweep case is being out it is vacuumiser right.

So here and allows a high degree of separation with a less sweep gas and still maintains low levels of dissolved gases in that product water.

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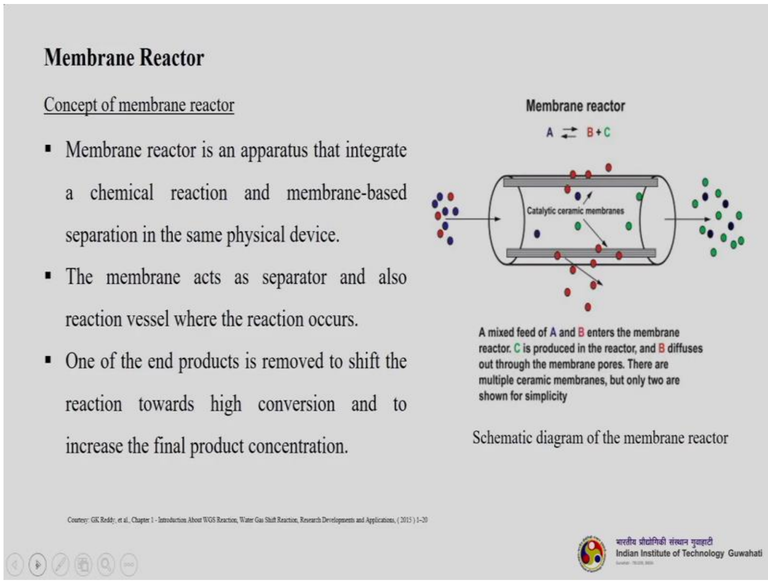

So now let us discuss little about membrane reactors then we will of course talk about membrane bioreactors also. So, that what is concept of membrane reactor is that so it is an apparatus that integrates a chemical reaction and a membrane base separation basically in single-unit the chemical reaction is happening and as well as within the presence of membrane that separation is happening. So, you see how it happens in the schematic diagram.

So the membrane acts as the separator and also the reaction vessel where the reaction occurs one of the end product is removed to shift the reaction towards high conversion and of course to increase the final product concentration. So, let us say a is giving B + C so this is a schematic diagram of a membrane reactor where a mixed feed of A and B enters the membrane then C is produced in the reactor and B diffuses out through the membrane pores.

So there are multiple ceramic membranes these are ceramic membrane systems but only two are shown here for the simplicity purposes and you can see that B is diffusing out through the membrane pores right and then you get C is the product.

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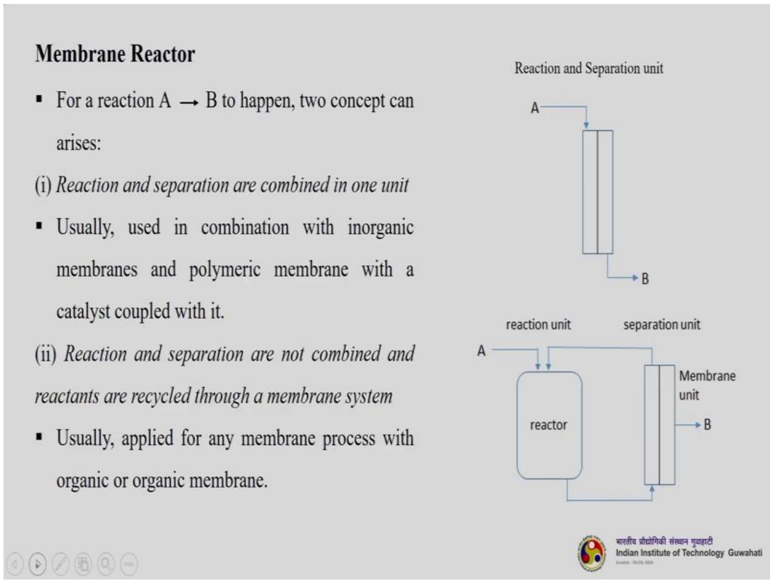

So, for that reaction and A and B to happen to concept can be arises. So, either reaction and separation can be combined in this one unit so where it is used usually used in combination with inorganic membranes and polymeric membrane with a catalyst coupled with it and otherwise you can have a reaction and separation are not combined and the reactants are recycled through a membrane system. So, here it is usually applied for any membrane process with organic or inorganic membrane.

So here you can see how it happens so if we are talking about a single unit so this is something like this simplest one right. So, here the reaction separation is happening in the single unit here in this case that you have a separate reaction unit which is reactor where the reaction is happening then the product stream goes here, so here is a membrane unit here we are getting our let us say the product B and what about unreacted A is there, left out so here it is again a recycled back to the reactor, a reaction and separation are happening in the different units.

A membrane and catalyst configuration since we talked about catalyst catalyst are equal product rate and hence the rate of reaction so we can have different types of arrangements.

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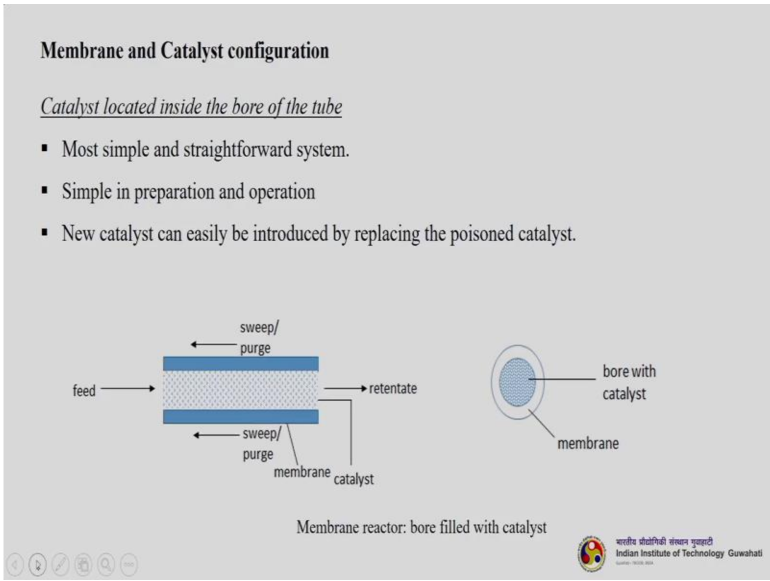

So, the first arrangement is that catalyst located inside the bore of that tube, the bore of the tube is that the membrane tube. So, most simple and straightforward system you can see how it happens here actually so the feed so if you see the bore this is how it looks actually so bore with that these are catalyst, bore with the catalyst and this is your membrane. This is your membrane phase right and inside that hollow fiber you can see; inside of the string so let us say this is a single hollow fiber.

So this total area this is filled with your catalyst in a packed bed type of system something like that you can just assume. So, it is a very most; it is a very simple and straightforward system so it is very simple to prepare and operates a new catalyst can be easily introduced by replacing the poison catalyst. So, you can just remove the poisoned catalyst because it is just packed inside this one no permanent attachment.

So your feed is entering and directly coming in contact with the catalyst whatever the reaction is happening and if you are having a partnership case outside the lumen of the membrane so that helps us in the rate of enhance set of past as well. So, your product-oriented is coming here and other things can come out like this.

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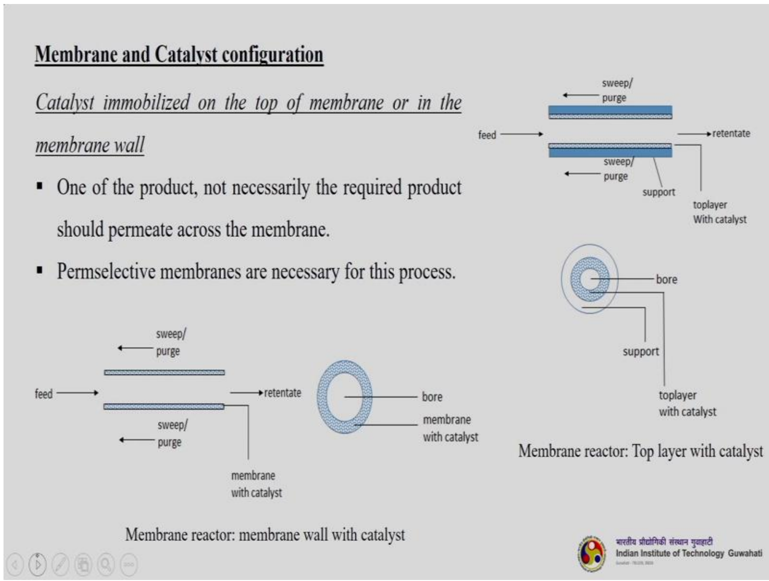

So, another thing is that catalyst can be immobilized on the top of the membrane or in the membrane wall. So, here the membrane wall is mobilized it catalyst so this is bore, bore is now completely empty the membrane itself is the membrane area what about the membrane so that is impregnated with the catalyst. So, one of the product not necessarily the required product should permeate across the membrane.

So that you decide actually by virtue of the nature of the reaction what type of the external happen so one will diffuses out something like this through the membrane. So, this is another one where the top layer is loaded with the catalyst so you can see how it is happening here. So, the not the entire membrane but the top layer on the top portion of the membrane itself is only loaded with this one and the bore is remained.

So the area which is inside the bore basically so that is being you can see the schematic how it looks like, so the feed is entering here and the retentate is getting here so you can get some product from here through the membrane so, of course you use perm selective membranes.

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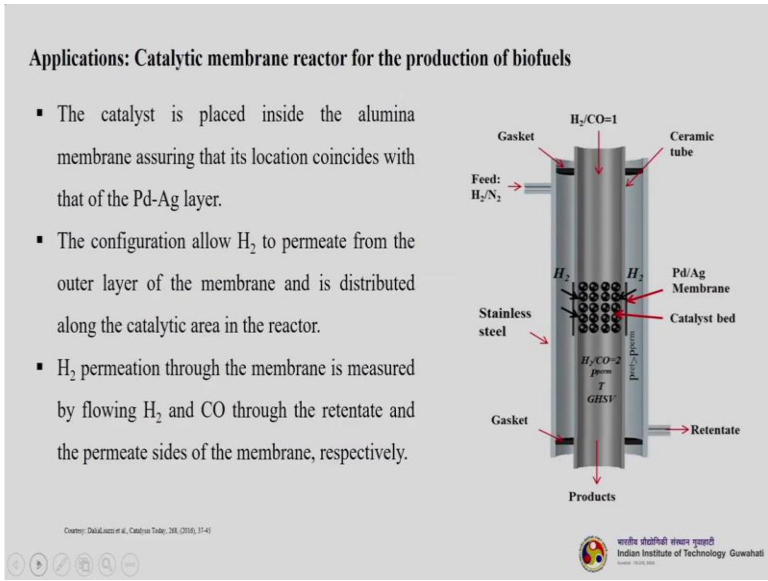

Let us understand fewer applications quickly so catalytic membrane reactor for the production of bio-fuels. So, the catalyst is pressed inside the aluminum membrane assuring that its location coincides with that of the Palladium and silver layer. So, in this case particularly confirm this particular actually reference. So, you can see that the configuration and is done in such a way that hydrogen will permeate through the outer layer of the membrane and is distributed among the catalytic area in the reactor.

You can see these are the catalyst area inside the reactor through which hydrogen is coming here then hydrogen and carbon monoxide, so you will get the your products here and basically the outer one is made up of stainless steel there are gas gets to hold it and this is inside this is the this one basically so this is your palladium silver membrane. So, a hydrogen permeation through this membrane is measured by flowing hydrogen and carbon monoxide to the retentate and permeate sides of the membrane respectively.

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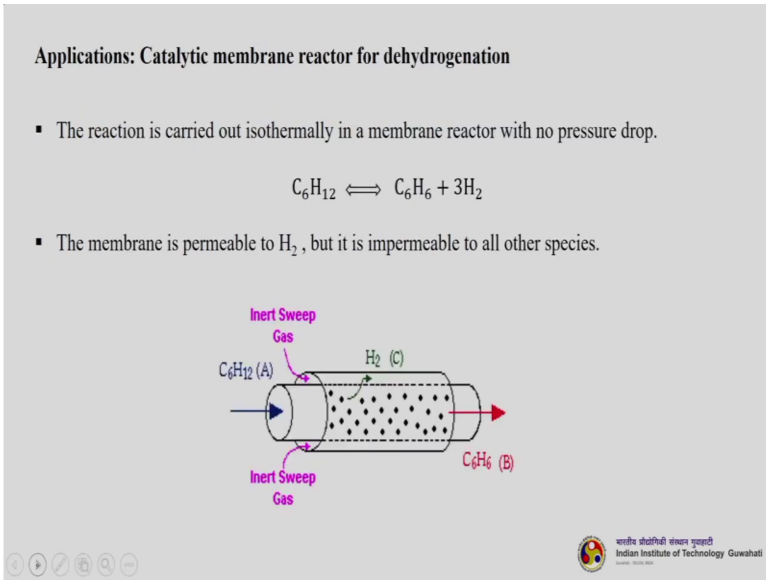

So, another application is catalytic membrane reactor for dehydrogenation. So, the reaction is carried out isothermally in a membrane reactor with no pressure drop. You can see reaction and how C6 H12 is getting converted to C6 H6 +3 hydrogen. So, since the membrane is chosen in such a way that is permeable to hydrogen so hydrogen diffuses through the membrane and you get yet pure C6 H6 here. Of course there is a sweep gas you can see here that is flowing that helps in enhancing the rate of mass transfer also.

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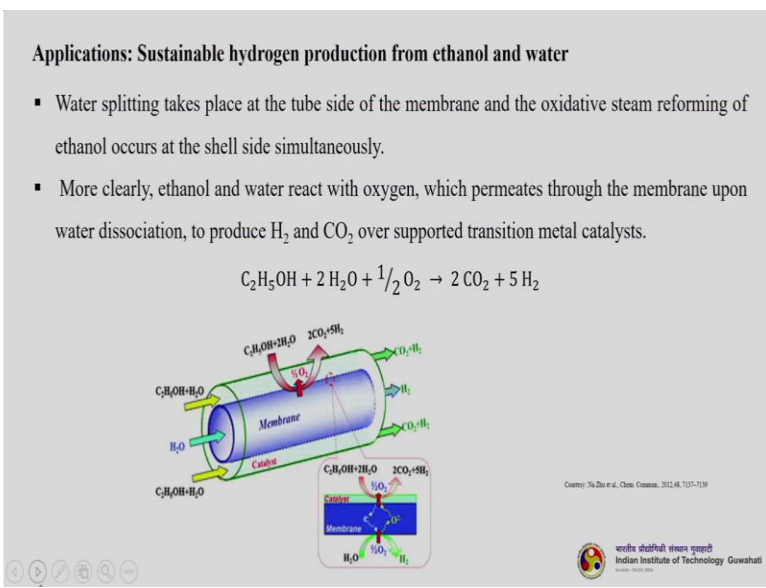

So, a sustainable hydrogen production from ethane and water, so water splitting reaction that takes place at the tube side of the membrane and the oxidative steam reforming of the ethanol occurs on the cell set simultaneously 2 reaction are happening one is this water splitting another was here ethanol steam reforming reaction. So, you see the ethanol + 2 water + 1/2 oxygen is giving us 2 carbon dioxide + 5 hydrogen so more clearly ethanol and water react with oxygen which permeates to the membrane upon water dissociation to produce hydrogen and carbon dioxide over supported transition metal catalysts.

So you can see how it is happening this is your membrane and this is your cell side right. So, in the cell side we are passing methanol plus water sorry ethanol plus water, so water is only being passed through your lumen side and that is the water splitting reaction is happening where do you get hydrogen here and we get carbon dioxide and hydrogen here.

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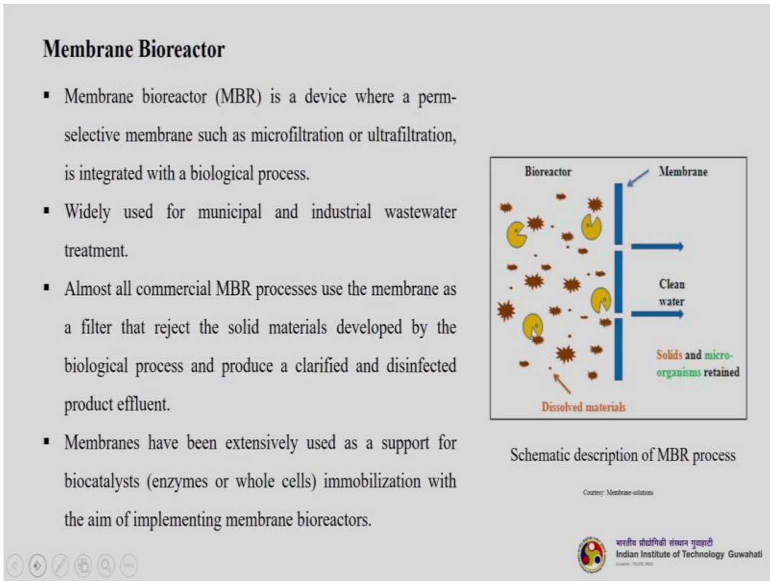

Now let us discuss little about membrane bioreactor, so you know membrane bioreactor is a device where a perm selective membrane is used such as microfiltration and ultrafiltration that is integrated with a biological process. So, in a membrane reactor it is their chemical reaction that is happening and separation that is happening inside the membrane module and here the reactor by director it is coupled with the membrane contactor is basically coupled with biological processes.

So widely used for municipal and industrial wastewater treatment almost all commercial membrane bioreactor processes use the membrane as a filter that rejects the solid materials developed by the biological processes and produces a clarified and disinfected product effluent.

Some membranes have been extensively used as a support for bio catalyst so that is those are enzymes or whole cells immobilization with the aim of implementing membrane bioreactor.

So this is a schematic representation of the membrane MBR process you can see the by reactor here the cells are there, there may be extra cellular enzymes other by catalyst also so the membrane is helping to retain them everything on the on this side where the biological reaction is happening. And whatever it is unwanted it will pass through the membrane. So, you will get basically solids and microorganisms there is a return and clean water is coming to the permeate side.

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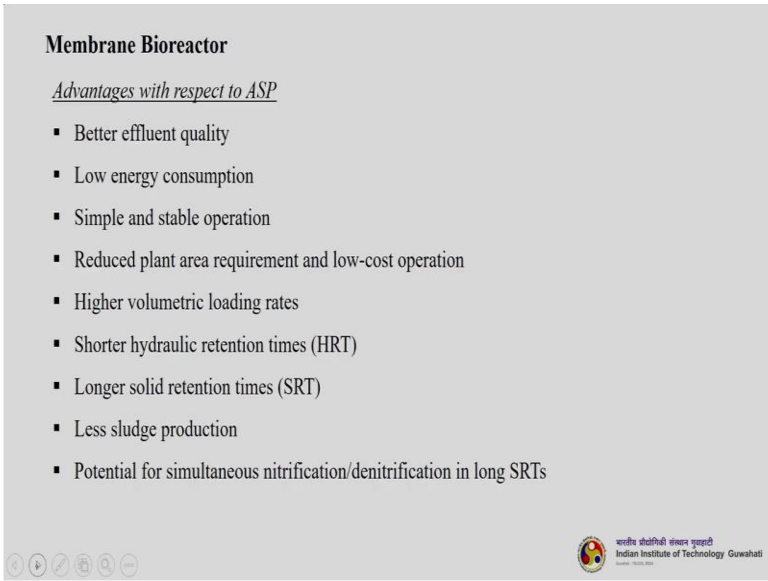

If you compare its membrane bioreactor advantage to the traditional ASP the activated sludge systems ok ponds. So, the quality of effluent is far far better in superior and the consumption of energy requirement is very low because you are dealing with the membrane system you know membrane system consumes very low energy, it is simple and stable because of the membrane integration and since you are integrating membrane in between so you do not know very huge pond size.

So, the plant area requirement becomes less of course with a reduced operational cost higher volumetric loading rates and the best two things are these that sort of hydraulic retention time. HRT is very small and longer solid retention time, SAT is very high this is what actually we need in biological systems less sledge production then that of the activated sludge process and it is potential for simultaneous nitrification de-nitrification in case of long SRT's. However it has some disadvantages advantage is the membrane fouling.

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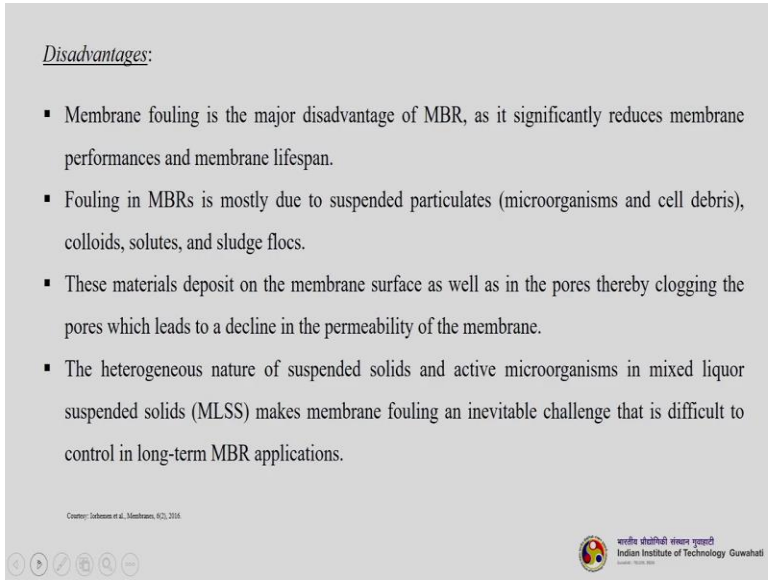

So, yeah the fouling of the membrane significantly reduces the membrane performance and membrane lifespan. Fouling is mostly due to the suspended particulates which are microorganisms and cell, debris, colloid ,solutes and sludge flux. So, these materials deposit on the membrane surface as well as in the pores thereby clogging pores which leads to a decline in the permeability of the membrane.

The heterogeneous nature of suspended solids and active microorganisms in mixed liquor suspended solid that is MLSS max membrane fouling an inevitable challenge that is difficult to control in long term MBR applications.

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Now we will just see how this is helping this fouling business actually. So, this is the mechanism of membrane fouling in membrane bioreactors. You can see this is the new membrane no fouling. So, you will get the cleanest of water the flux will be very good just the operation started continuing you see that a pore narrowing started that means the particles started getting deposit inside the pores and the solids had started depositing on the membrane surface and thereby in the form of flux.

Then pore clogging is coming here you see that the flux coming and sitting on that mouth of the pore so this is called pore clogging. Then you can see the cake formation or gel formation or gel formation whatever you can say. Now this is complete fouling mechanism in a very nice picture it has been depicted how fouling actually happening in case of membrane bioreactors.

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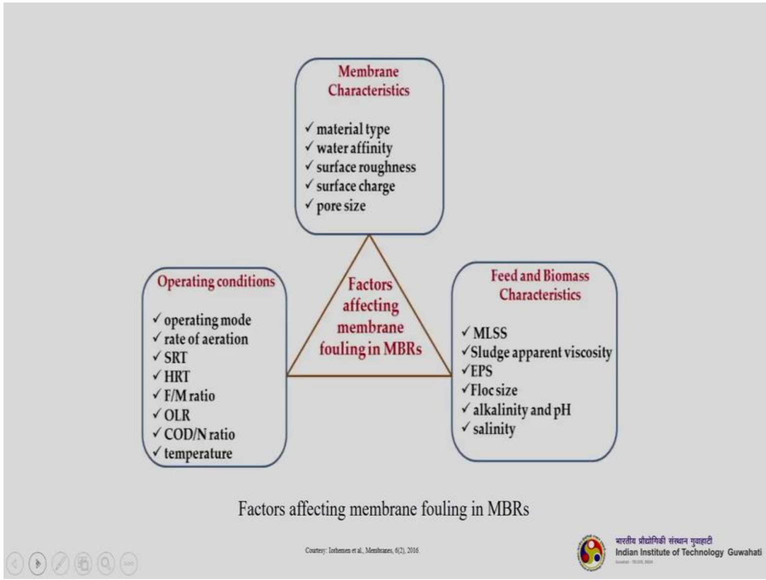

So, these are the factors that affect the membrane fouling in membrane bioreactors membrane characteristics. So, as a material type what is the water affinity what is their water affinity of course; surface roughness surface charge and pore size. Then operating condition such as operating mode, rate of aeration SRT, HRT F by M ratio, OLR COD by N nitrogen ratio temperature if at all is there, then feed and biomass characteristics.

The MLSS you know then sledge apparent viscosity, EPS, what is the flux size, alkalinity and pH and salinity all of this so you can understand there has so many different parameters that affect that membrane fouling in case of MBR’s.

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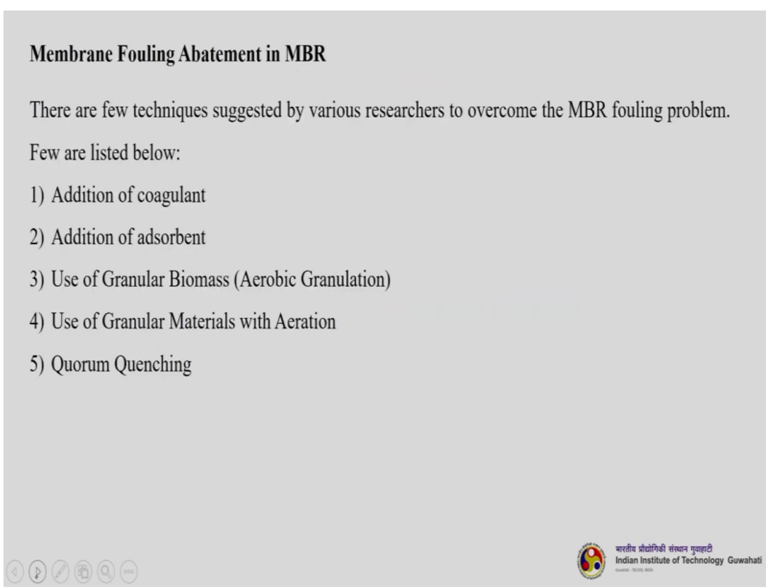

So how do you abate it how do you reduce it basically though you cannot do away with you can reduce it minimize it, so there are few techniques suggested by various researchers to overcome them where fouling problem. The first is addition of coagulant which is very popular the another one is addition of adsorbent mostly the similar procedure but the two different method the one is coagulant and then one is adsorbent.

And then you have use of granular biomass basically that aerobic granulation and then you can have granular material with aeration and Quarantine just we will just quickly go through one or two of the things.

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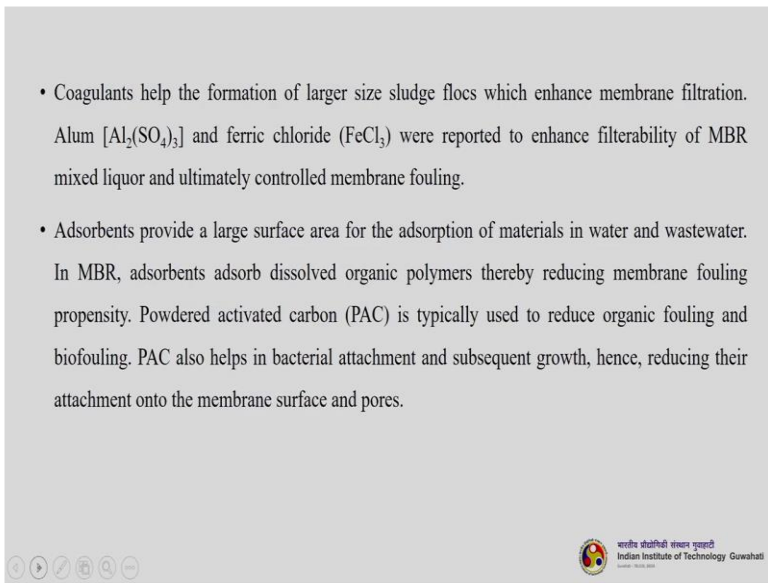

So, what the coagulants who is doing so coagulants helped the formation of large size sledge flocks why want to do it because if the sizes are small they will try to penetrate through the membrane pores, so we do not want that right. So, if the more bigger the particle sizes the flux edges become very big they will just sit on the membrane surface they will not push themselves to the membrane pores.

So alum and ferric chloride are very good coagulants they are imported to enhance the filter ability of MBR mix clicker and ultimately control the membrane fouling. So, and then you can add adsorbents also you know adsorbents ad. So, they have a very large surface area but the adsorbent of materials in water in wastewater, what they are adsorbing basically depending upon the charge based interaction of the component that wants to be adsorbed on the surface of the adsorbent.

So that basically are their adsorbing dissolved organic polymers thereby reducing membrane fouling propensity is a powdered activated carbon can be used because their surface area is far higher than that of the granular activated carbon. To reduce organic fouling and bio fouling but the problem with powdered activated carbon is to get rid of it or filter it basically take it out is a problem. So, that many times you use granular activated carbon which is known as GAC.

So PSA helps in bacterial attachment and subsequent growth once they do it then the sizes of sizes of the PSA's becomes bigger so that it is easy to retain on the surface of that membrane right.

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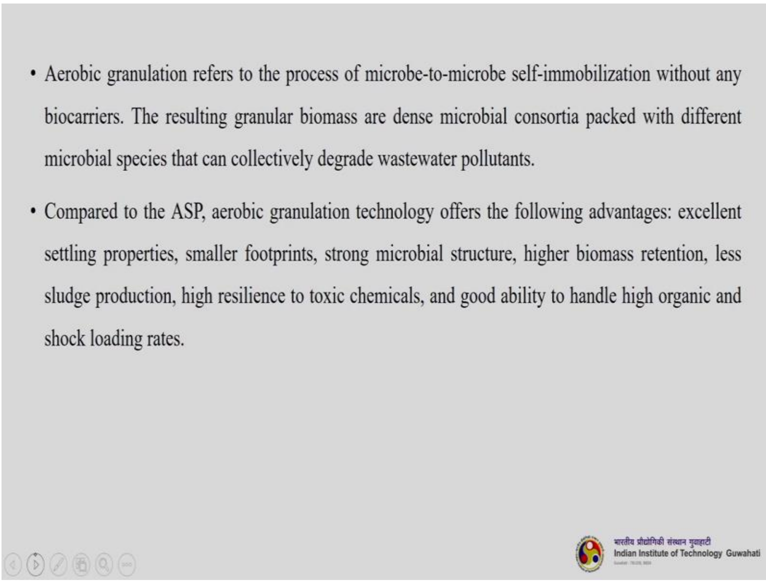

So, what is a aerobic granulation? Aerobic granulation refers to the process of microbe to microbe self immobilization without any barriers there are no bio carriers here. So, the resulting granular biomass a dense microbial consortia packed with different microbial species that can collectively degrade waste water pollutants. So, compared to the ASP aerobic granulation technology of first the following advantages.

It has excellent settling properties, smaller footprint, a strong microbial structure, higher biomass retention, less sledge production high resilience to toxic chemicals and good ability to handle high organic and shock loading rates, so this is all about how you can reduce the MBR fouling basically fouling in the membrane bioreactors. So, the applications there are many applications the most and for most important application is of course wastewater treatment.

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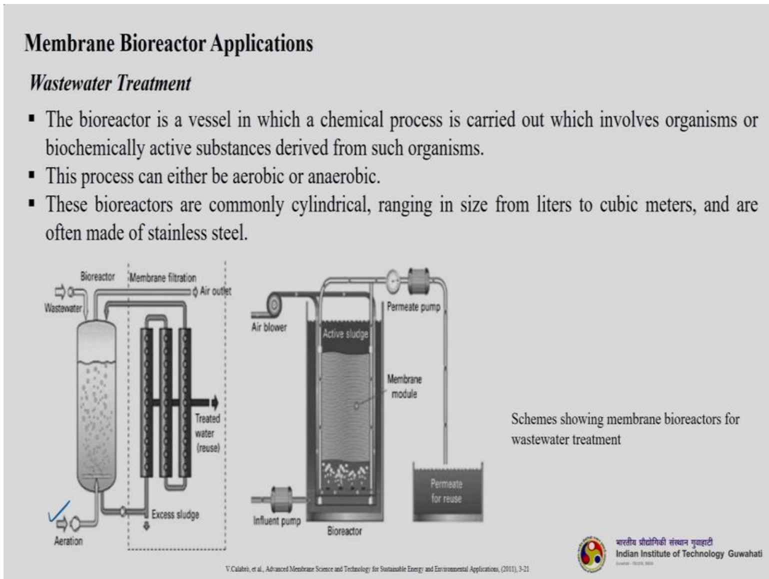

So the bioreactor is a vessel in which the chemical process is carried out which involves organisms or biochemical active substances derived from such organisms. So, this is an aeration system filtration system you can see here. So, and membrane filtration you in terms of tubular systems you can have or you can different a different types of membrane contactors can be used see can be used plate and frame type also can be used.

So the process can be aerobic and anaerobic and does not matter both can be fine for the membrane bioreactors so they are commonly cylindrical ranging in size from liters to cubic meters and are often made up of stainless steel. So, you can use either this type of hollow fiber H these are HFMC systems membrane conductors. So, you can otherwise use plate and frame type modules something like this they are hanged in your activators sledge ponds. So this is also possible it is easy to do you can take out one was it again put it back right.

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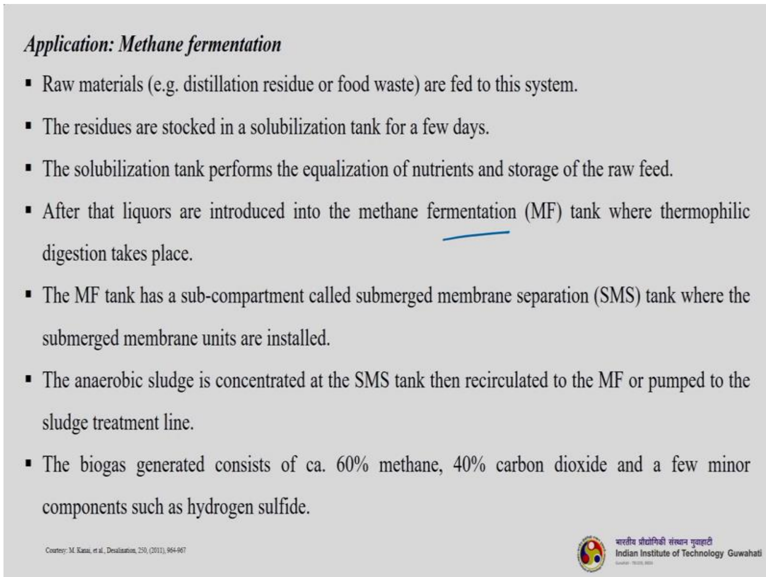

Then another application is methane fermentation. So, here raw materials basically distillation residue or food waste are fed into the system the residues are stocked in a solubilization tank for a few days. So, let them solubilize basically stabilized so the solubilization tank performs the equalization of nutrients and storage of their own field. So, after that after few days so that liquors are introduced into the methane fermentation tank where thermophilic digestion takes place.

Now the MF tank has a sub compartment called submersed membranes specific separation tank the SMS tank where the submerged number and units are installed. The anaerobic sludge is concentrated at the SMS tank then recirculated to the MF or pumped to the sledge treatment line the Magnus generator consists of 60% methane 40% carbon dioxide and a few minor components such as hydrogen sulfide.

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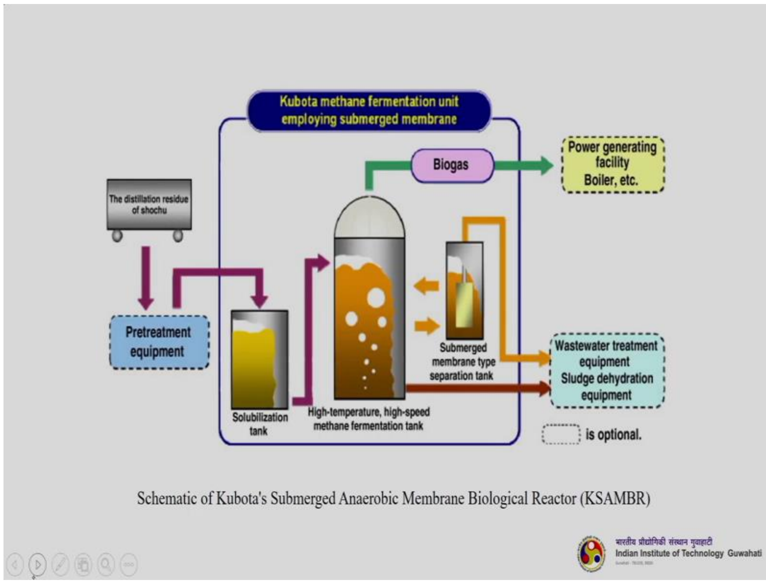

Schematic of Kubota's Submerged Anaerobic Membrane Biological Reactor (KSAMBR)

This is the schematic this is Kubota is a company which makes this famous anaerobic this one membrane and biological reactors known as KSAMBR. So, you can see the pretreatment equipment here that is lessened addition and getting equalized here in a soluble adjacent tank after that it fed to a high temperature high speed methane fermentation tank where the methane is getting formed right.

Then it goes to the submerged membrane type of system here, so it is a tank in which the membrane module is being submerged in a whose system or form. So, then you get the wastewater treatment equipment it goes to the whatever it is coming from the membrane system goes to the waste water treatment equipment alright and from the sludge also comes whatever from the methane fermentation tank, sledge dehydration equipment right.

Then the biogas which is forming here is go over power generation facility boiler etc. So, this is an excellent system it is in place in many installations around the globe and is found to be one of the best or efficient systems.

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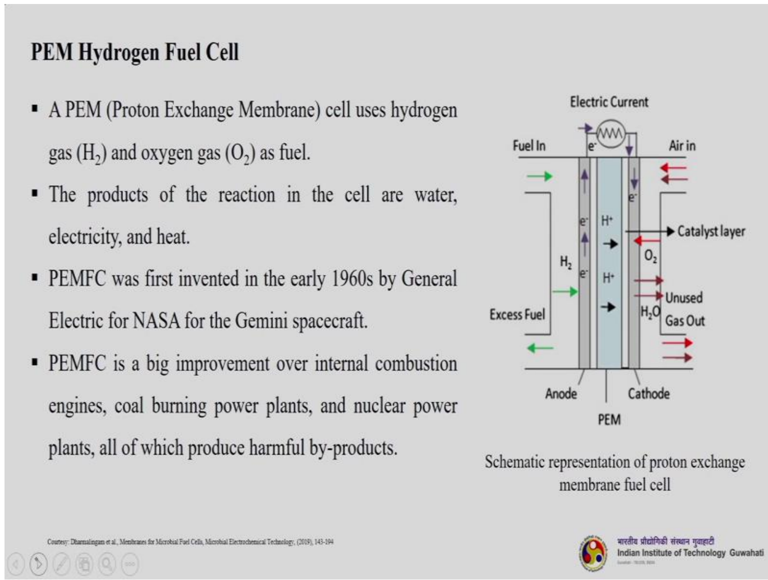

So, the next or the last which we are going to discuss in today's class is about PEM hydrogen fuel cell you know a fuel cells are gaining a lot of importance since few decades. Almost it was a first fuel cell was actually a PEMFC was actually designed by General Electric for one of the NASA's spacecraft known as Germini in 1960 long back. So, a PEM means proton exchange membranes cell uses hydrogen and oxygen as well.

So the products of reaction in the cell are water electricity and heat. So, PMFC is a big improvement of our internal combustion engines, coal burning power plants and nuclear power plants all of which produce harmful byproducts. The only but unlike in PMFC that we can do not have a very large size PMFC that can be fabricated and can be designed, so this is very small units you can up to a decent size you can make but you cannot have other you cannot just like that the scale cannot be compared with that of the power generation due to by a scene IC engines or thermal power plants or hydro power something like that.

You can see how it looks like actually so the fuel in here right the excess fuel that goes out here basically hydrogen then permeates through the knot. So, it comes in contact with the inert and it is yes they elect electrons then it passes so this is this is here PEM, proton exchange membrane right it is exchanging only the protons. It is a semipermeable membrane it exchange only protons nothing else right.

So the proton gets resistor diffuses through the membrane and then reaches to the catheter site where it gets converted to water and by virtue of the electron transfer electricity is getting generated here right and you can harvest it that.

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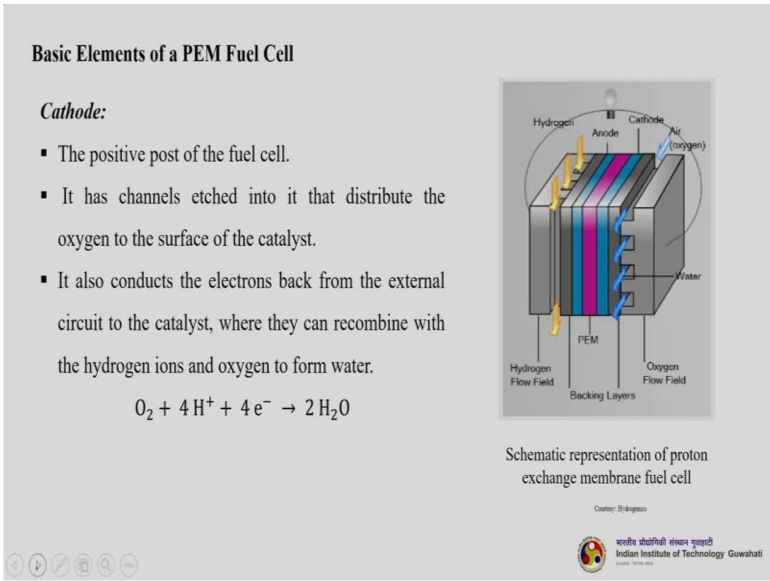

So, just let us quickly go through the different types of a different come owners of this one the first one is of course cathode. So, cathode this is the cathode you can see this, this is the cathode so this is the positive part of the fuel cell or post of the fuel cell it has channels s etched into it they distribute the oxygen to the surface of the catalyst. So, it also conducts the electrons back from the external circuit to the catalyst when they can recombine with the hydrogen and oxygen to form water.

See this is the reaction that happens in the cathode oxygen +4 proton and poor electron gives 2 of water.

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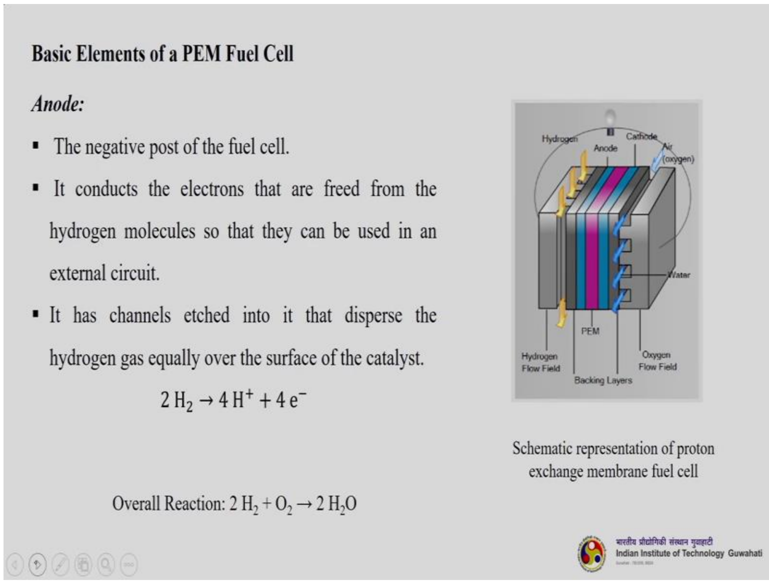

So in the next one is anode, so this is your anode here right so it is the negative post of the fuel cell it conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. So, it has channel etched into it that disperse the hydrogen gas equally over the surface of the catalyst the reaction that happens at anode is 2 hydrogen is gives proton + 2, 4 electrons so the overall reaction is 2 hydrogen + oxygen gives 2 water.

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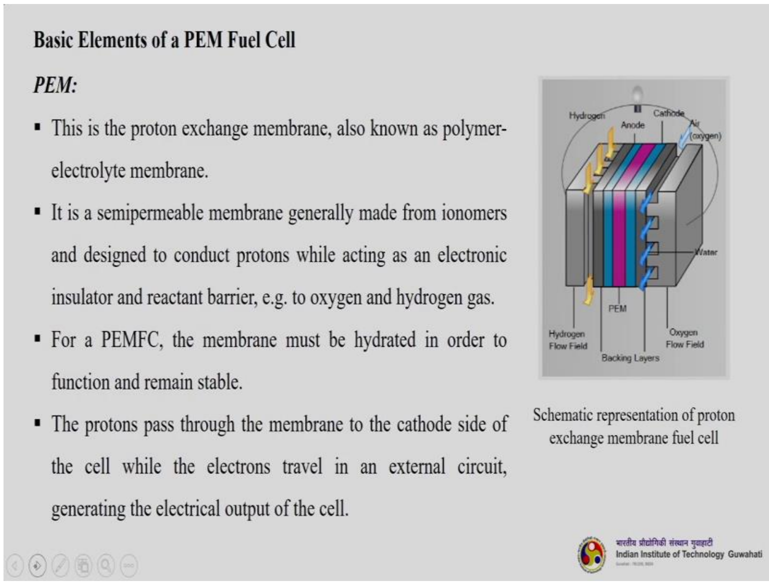

The next one is PEM the membrane itself so this is the proton exchange membrane also known as polymer electrolyte membrane. So, it is many times people call it electrolyte so it is a semipermeable membrane generally made from ionomers and designed to conduct protons while acting as an electronic insulator and electron barrier as for example to oxygen hydrogen gas. So, for a PEMFC the membrane must be hydrated in order to function and remain stable. So, the protons pass through the membrane to the cathode side of the cell while the electrons travel in an electrical circuit generating the electrical output of the cell.

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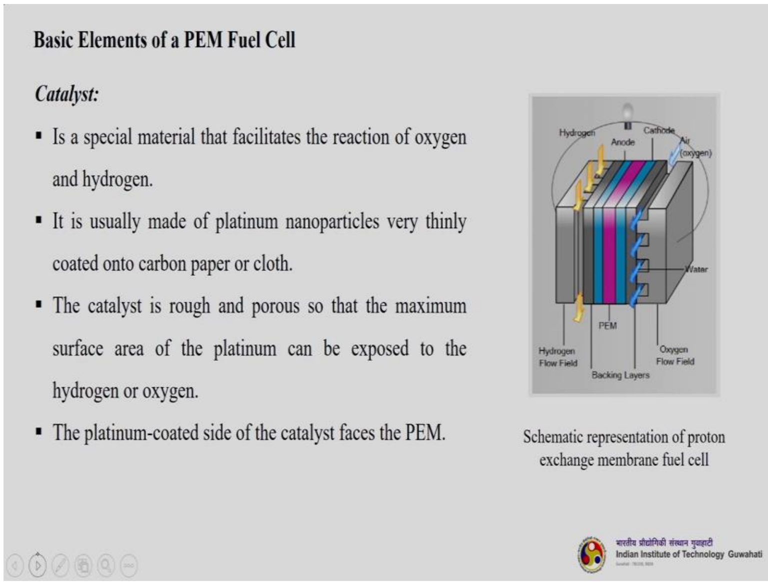

So it is seem very simple operation and another one thing that catalyst unit catalyst. So, it is a special material that facilitates the reaction of oxygen and hydrogen it is usually made up of platinum nanoparticles very thinly coated into the carbon paper or cloth. The catalyst is tough rough and porous so that the maximum surface area for platinum can be expressed to the hydrogen and oxygen.

The platinum coated side of the catalyst presses the PEM. So, you can we have just we have seen how this operates actually this is schematic representation. So, there is a node here there is a cathode here and the pink color is the membrane PEM membrane so hydrogen is coming here and added oxygen is flowing here. So, oxygen flow field you can see here.

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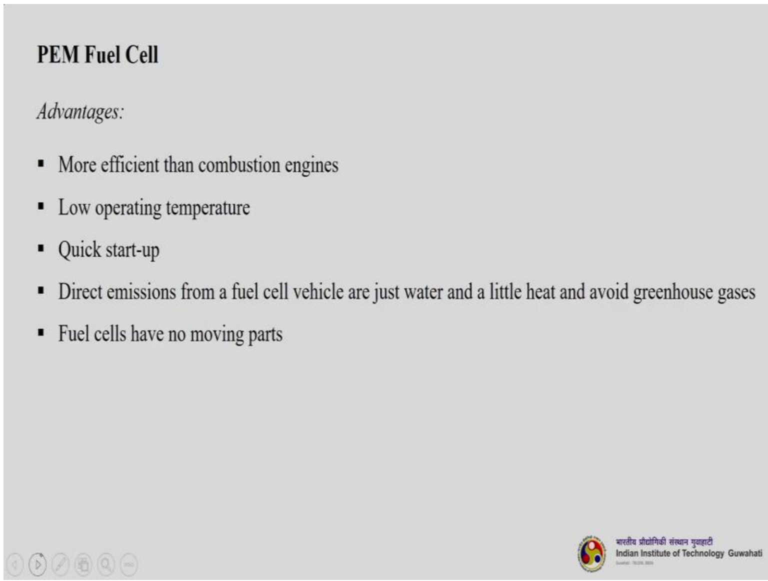

So, this is all about your p.m. fuel cell so just quickly go through the advantages the more represent than combustion no doubt about it but in a bulk or large scale it is difficult to do. So, low operating temperature quick startup, direct emissions from a fuel cell vehicle are just water and a little heat and avoid greenhouse gases. Fuel cells have no moving parts so that is another advantage in during operation.

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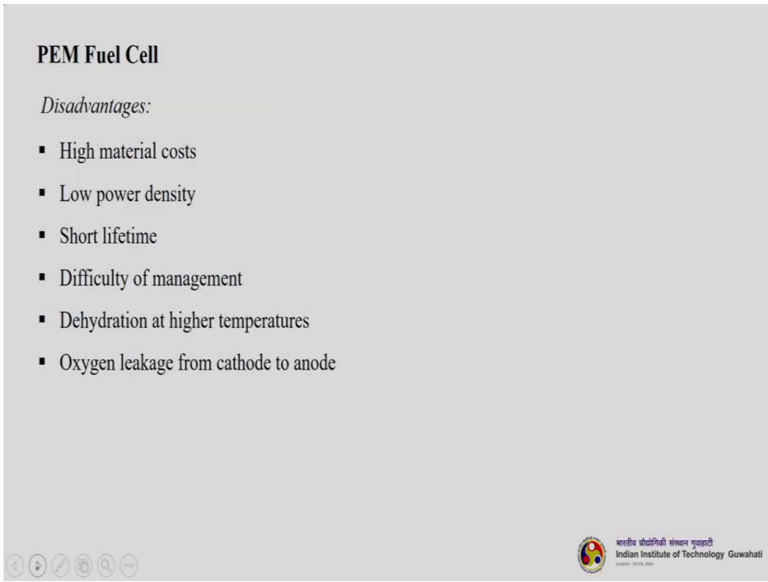

However it has certain disadvantages also the cost of petrol is very high the membrane itself is a huge cost and low the density of the power that will be generated is very low so you cannot just compare it with our other membrane separation sorry other this one power generation systems and lifetime is very short, difficulty in management, dehydration at high temperature and oxygen liquid from cathode to anode in that case the reaction will have a lot of problems.

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So with this we conclude today's lecture so mostly it is taken from different books actually so partly from Mulder and BK Dutta like this ok. So, please go through the lecture see in case you have any query do feel free to write to me so thank you very much you can write to me at kmohabty@iitg.ac.in. The next class which is going to be the last lecture of this membranes course that will be lecture 36 module 21 will discuss about path traction membrane chromatography and controlled drug delivery, thank you very much.