Water Quality Management Practices

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Lecture-48

Bio-electrochemical Systems: Types and Definition

Hello everyone, welcome to this NPTEL online certification course on Water Quality Management Practices. My name is Gourav, Professor Gourav Bhowmick. I am from the Department of Agricultural and Food Engineering of Indian Institute of Technology Kharagpur. In continuation with my discussion on Advanced Aerobic and Aerobic treatment systems, today we will be discussing about a very innovative technologies like that technology that is now budding and people are researching on this particular topic in which we call it bio-autochemical system or bio-autochemical process all over the world. There is a specific research group now like you will see like people are working literally this research group, they are called this microbiological electro microbiological and electrochemical. It is a combination of these two technologies and we call it micro bio-electrochemical technologies or in some cases we call it bio-electrochemical systems or bio or bio exo-electrogenic systems or bio-electrochemical technologies.

So, it is named in different with the, but the primary objective is same is to discuss about the potential of living organisms, potential of living microorganisms to generate electricity out of only treating the waste that we normally feed out of I mean like from the sewage or the industrial waste. So, the concept is that this living organisms mostly they are called the exo-electrogens. This exo-electrogens they consume the waste, consume the nutrient present in the waste and then it converts into some form of energy. That energy if we can harvest we can actually utilize it for different other purposes.

So, that is the overall concept of this bio-electrochemical systems. So, there are different types of bio-electrochemical systems that we are going to discuss like in a later slide and

later discuss in lecture module as well. So, basically today we will be focusing on the microbial fuel cell. So, in this particular lecture we will be discussing about the introduction and the historical development of bio-electrochemical processes or the systems, microbial fuel cells, microbial culture and the materials used, economic considerations for implementations of MFCs, one case study with the copper-zinc catalyst, performance matrix with lab scale and the fuel scale MFCs, mediators and the membranes. To start with bio-electrochemical system as I was discussing our main motto in this advanced wastewater treatment system is to treat the waste that is our major target.

While treating the waste we are generating some valuable by-product. We can generate the valuable by-product in the in terms of chemical, in terms of energy as well as in terms of some biological living beings, ok. I mean like some living beings are actually they I mean like this con this nutrient is converted into some biomass, this exerotogenic biomass they keep on you know growing on the surface of different electrodes of this or different you know the accessories that is present in the fuel cell and that can be utilized for different other purposes. We will discuss about it. So, in general different the type of this bio-electrochemical process are employed for imitation of wastewater with the first concept demonstrated by M. C. Potter in 1911. So, and he was the first person actually even before that Louis Galvani you know the famous scientist Louis Galvani he also showcased that if you if you there is some electrical surge in our in our in a dead frog's body. So, what they did what he was doing he was trying to you know experiment with the frog and all. So, he anesthetizes and then he is trying to do some experiment he try figure it out that there is some electricity that is flowing inside its body and all. So, that was the first living electricity I mean like you know electricity from the living body that is being documented.

But later on it is it is it is like we also know that our brain and our heart it is completely living on the electricity and for that for this different kind of electricity and all what is happening we supplying it by means of different minerals that is present in our body and all. So, anyway so, we have this opportunities and all. So, what is happening in general the in any this next electrogens there is specific type of microbes what they do they consume the waste and they convert it into some like you know the viable form of electricity that can be easily harvested. So, microbial fuel cell is a concept where actually we implement this idea and we try to figure it out like you know how it can be used for generating electricity in the rural households as well as how those valuable byproducts from this nutrients can be utilized for further processing and all. What are the basic what is the major benefits of bioretochemical processes? Generation of additional revenue from this valuables recovered while treating the wastewater as well as the operating cost is also

can be partially recovered because and makes it economically beneficial then other traditional wastewater treatment processes like activator sludge process where we need enormous amount of waste, enormous amount of sorry enormous amount of energy in order to run those aerators in the activator sludge process you remember we designed it.

So, but in case of in system like this bio electro chemical processes what is happening we are harvesting some amount of electricity while treating the wastewater. So, that electricity can somehow you know surface the requirement energy requirement overall energy requirement of the system. So, the first technology that we are going to talk about is the microbial fuel cell. In general what is happening here we are treating the wastewater and with the simultaneously we are recovering the bio electricity. There are two separate chamber that is present there in the if you see the schematic of a microbial fuel cell.

In this figure the left one is the anodic chamber and the right one is the cathodic chamber. In the anodic chamber we are introducing the wastewater and whereas, we are providing some amiable temperature amiable condition for the microbes the exo-eutectic target microbes to grow on the surface of this anode and it will consume this nutrient present in the wastewater and it will reduce the pollutant load. And then by because of this process what happens the biogas will generate at the same time some this nutrient will be converted into biomass in the in the anaerobic biomass and all. So, we have to maintain the anaerobicity that is also quite important in case of anodic chamber and then there comes the cathodic chamber. We will discuss in details the functionality in that from the next slide onwards.

And then in the middle we provide the proton exchange membrane. The what is the main purpose of proton exchange membrane? To let the protons pass through the through this through this proton exchange membrane from anodic chamber to the cathodic chamber ok. This recovery of this bioticity it is attributed to the exo electro electro exo-eutectic residing on the anodic chamber and where they oxidize the organic matter and produce the electrons and the protons by and this electrons which reduce the anode and its pass and the protons which I mean like the protons also pass through the PEM to the cathodic chamber ok. So, if you see this picture, in this picture what we are doing we are having a in the left side we have an anodic chamber, in the right side we have a cathodic chamber. In this anodic chamber, so what is happening here? If you see this is the anodic chamber, in the anodic chamber we introduce some feed say like some acetate feed ok.

So, this feed is now converted into some by product and during this process it liberate some amount of some ions. So, the ions are the electrons as well as protons. This electrons it the protons and the electrons. This electrons it will pass through this external circuit to the cathodic chamber. And the protons it will pass through this proton exchange membrane to the cathodic chamber.

What is happening in the cathodic chamber? This excess amount of proton which is coming through the proton exchange membrane and excess amount of electron which is coming through this external circuit it will react with some terminal electron acceptor. So, in this particular case say like oxygen. It reacts with the oxygen and it will form the H_2O. So, that is how the process looks like that is how it happens. So, how actually the whole circuit will like you know will form and because of that only we can get some valuable by product.

So, what is happening? Once this electron is actually being utilized and the proton is utilized there will be again a divide of ions. So, that in order to fill it up what will happen from the anode the keep on the electrons will keep on coming to this cathodic chamber and the protons will also pass through this proton exchange membrane and will make the circuit like will compute the circuit here. So, here we have divided into see different colored circle where this elliptical structures we made like you know this green one, this red one, this blue anode. So, I will keep on focusing on one after another and I will tell you what is the basic function, what is the basic science of the chemistry that is going on in each of these compartments. To start with let us start from the substrate.

So, if we talk about the substrate what is happening? We know that we are providing some food right this nutrient is present in the waste water carbohydrate, protein and fat. We already know what is hydrolysis, what is acidogenesis, acidogenesis and methanogenesis right. So, what is happening during the process of hydrolysis? This carbohydrate protein fat is converted into sugar, amino acid and fatty acids respectively. Then this sugar, amino acid and fatty acid which is which is now converted into the due to the during the process of acidogenesis into some organic acid in the form of butyric acid, propionic acid etcetera, alcohol, H_2, carbon dioxide and ammonia. Then there comes the acidogenesis.

In the acidogenesis what is happening? All this acidogenesis by product will convert into acetic acid, H_2 and carbon dioxide. Then this carbon dioxide, H_2 and acetic acid it is converted by the methanogenic micro or consocia into methane, H_2 and carbon dioxide that is the biogas which maximum methane percentage is quite high. This is the whole process that is that normally occurs in the anaerobic treatment processes. However, there is one very basic difference between the anaerobic treatment processes, standard anaerobic conventional anaerobic treatment processes and microbial fuel cell.

Try to understand. In this methanogenesis process it is a electron scavenging process. What does that mean? Electron scavenging process that means, during the process of formation of methane from carbon dioxide or H_2 this hydrogenotropic or the this acidotropic methanogens what they does? What they do? They consume the excess amount of electrons present in the nearby vicinity. So, what will happen if this system methanogenesis is also occurring in the microbial fuel cell? It will lead to the decrement, it will lead to the reduced I mean like almost 0 generation of this bio electricity. Because whatever the ion that will generate, whatever the electron that will generate it will consume this electron to form the methane right. So, whatever is happening like because in the anodic chamber we are introducing the waste water.

So, this if the whole process will finish then there will be no excess ion, excess negative ion, excess electron that will be prevailing in the system. We need to stop this system stop this particular step to occur. In order to stop this particular step to occur why we what we need? See we normally provide some kind of methanogenesis, methanogenesis suppression techniques. We somehow do not let the methanogenics to grow on the microbial fuel cell on the anodic chamber of microbial fuel cell. So, we can treat it with the lauric acid, we can treat it with the 2 bromoethan sulfonate, we can treat it with the heat, we can go ahead with the ultrasonic treatment.

There are thousands there are like tens of different techniques which are available in the literature you can go through it and you can see that those literature mention that if you introduce this methane suppression technique then only there is a chance you will get maximum volumetric power density or your coulombic efficiency will be much higher ok. So, you know what is power density here like the power that you will generate by utilizing per meter cube of waste water by treating the per meter cube of waste water that the that

much of power that you can generate. And what is the coulombic efficiency? Coulombic efficiency means suppose you have in your waste water does have a certain amount of coulomb. What is coulomb? Coulomb is a charge of electron that means, whatever the charge theoretical maximum charge that is present in your waste water and the practically whatever the amount of charge you can actually harvest out of those charge that is prevailing there. So, in the denominator there will a total charge available with your waste water the total amount of theoretical possible extraction of the electricity that you can do whereas, in case of numerator it will be like the actual scenario how much you can actually recover ok.

So, this is called the coulombic efficiency ok. How much coulombs are recovered from the actual amount of coulomb present in your target waste water? This is called the coulombic efficiency ok. So, what is happening here? We are targeting in this microbial fuel cell we are targeting the methanol analysis to not to occur that is our first target ok. And for that before even introducing the enochulum to your anodic chamber you need to do the analysis you need to do the methanol you need to go ahead with the methanol separation technique. So, now, we have introduced the first thing that we have introduced is the enochulum.

Try to understand there is one difference when you start your fuel cell first you will introduce some enochulum that means, some you will collect the collect some sludge from the existing conventional existing treatment systems anaerobic treatment systems. So, that it will be reach with those microbes anyway now, but you know that that is they will also be reach with methanogens. So, what you are going to do? You collect it from the existing say like anaerobic digester or USB and all you collect it from there the sludge from the bottom from the sludge bed somehow you collect it or as easy as that you can just go to the any hydrant and you can collect it from the bottom if the water table is quite high on the bottom there will be anaerobicity present there that can also be used or you can take some soil from the pond bottom if the pond has more than 1 1.5 meter of height. So, from the bottom you can pond bottom pond sediment also can be used because they will be reach with this anaerobic anaerobic microorganisms.

So, out of this anaerobic microorganisms the methanogens will also be present there. So, your first target is to kill those methanogens. So, whenever you will collect the enochulum or sludge you will first get it through the through some methanogenesis suppression technique. After the suppression is done then you introduce it to your in your system in

your I mean like in your anodic chamber ok. So, now, it is done now you keep on introducing the new amount new I mean like now you keep on supplying the waste water now.

So, once you supply the waste water there now this waste water is target waste water now you are you are expecting that waste water will be converted into some by product and it will liberate some amount of electricity some amount of ions that is the procedure first enochulum second waste water. Now, let us see what is happening with the anodic biophil. So, this is the there are certain mechanism that is happening at the same if you if you see what is happening if you see the cellular level if the cellular level what is happening this is the inner membrane this is the outer membrane we have the cytoplasm in the in the periplasm region. So, what is happening in the cytoplasm region it is nicotinum adenine type phosphate you know this NADH and all. So, what is happening it is hydrogenated or it is plus.

So, what is happening? So, here you do with the some with some during the anaerobic digestion process when it is occurring it liberate some amount of excess electrons. What is happening this excess electrons will keep on move through this pathway different pathway that is happening in the periplasm region as well it will go to the outer membrane from outer membrane it will reach to the its appendages. Why it will reach and accumulate on the top of this appendages can you tell me? If you know whenever we want to target we want to catch the in any building in a high rise building if you see on the top of this high rise building there is like some pointer we normally place like this kind of pointer with the sharp edges on the top. What is the reason behind then it is connected to the earthing line to the to the ground what is the reason behind it? Because normally maximum number of charge accumulates in the max in the least amount least possible area and because of that what will happen during the lightning and all. So, lightning targeted the area which is having a very minimum amount of surface area that is available.

So, it will target will catch the on the surface on the top of this lightning collector and all and then it will be easily transferred this excess this charge can be easily transferred to the grounding system it will be grounded on the on the bottom of those buildings and all. So, the same way if you collect if you see the Van de Graaff generators also if you see when we touch it all any thing we will see the our hair will grow like you know go straight and on top of it in like if you see this on the top of the hair in the if you check the ion concentration ion concentration you will see on the top of the hair on the extreme edge the

maximum amount of ion will be accumulated. This is the this is the static electricity concept you can I think everyone knows about it. So, that is the same thing that is happening. So, in case of this exo-illutogens the ions this excess amount of electrons they keep on accumulating on the surface of this appendages.

So, what are the appendages that they have? They have filae like they have filae they have fimbri they have this like different kind of you know this locomotive organs that they have at the on the edge of this locomotive organs normally this kind of ions normally they accumulate. So, our target is somehow collect those accumulated electrons right. So, this is why it is called the bioelectricity we are collecting the electricity from the living being. So, we are targeting this bioelectricity by simply having it suppose in with a different way first of all we can have it by the process directly direct transfer is possible. If you see in this case there is a direct transfer that means, we let the electrons to attach to the surface of the anode this is the anode surface.

So, what will happen whatever the ion that is whatever the excess amount of electron that is accumulating on the surface on the appendages of this bacteria of this microbes it will be directly transferred to the anode surface because anode we know it is a positive electrode right. So, it will be reduced it will collect the it will get the electrons. Next another way is the electron transfer by through biofilm with the conductive pili. Pili is the locomotive organ it is like quite I mean like which this microbes are having. So, they will be entangle with each other and because of that this excess ion will easily pass through this is like it will it will act like a electrical wire it is a biological wire.

So, biological wire the electron will be passing through this living beings to the anode chamber in the anodic body anode body. And then another way is mediated one mediated means you can apply some additional mediator excess I mean like some chemicals which will act as a which will shuffle the electrons from the body of the microbes to the anode. So, it will it will get reduced on the when it will reach to the surface of this bacteria and then it will then the anode will reduce by consuming the like you know consuming like you know taking the electrons from those mediators and all. So, this is how the process will keep on keep on going and this additional excess amount of this additional mediators are also quite famous in early stage of development of microbial fuel cell where they use this chemicals to actually enhance the electron transfer from the bacterial body to the anode surface. Then there are electron transfers through the anode biofilm where the shuffle is localized in the inside biofilm that is also procedure that there are some shuffling shuffle

means the mediator which will carry the electrons suppose there are some gap in between the anode surface and the biofilm body.

So, that those additional electrons will not be able to pass through it. So, if this mediators will help it to pass through it and actually reach to the I mean like the to the surface of the anode. So, there this mediators are majorly conductive in nature. So, they will help conducting the electrons passing the electron from the anodic from the biofilm to the anodic anodic surface of the anodic. There are some more research going on with the concept called quorum sensing.

Quorum sensing it is more like you know some way of communication in a I mean like in how to say in normal in layman's language I can say it is a it is like a way of communication in a micro in the micro world. So, in the quorum sensing mechanism if one microbes go there and release the electrons they will also release and they will also their system will also keep on running. So, they will actually let the other microbes know that come here and you can release the electrons and you can be you know free from all the electrons. So, this is how this works. So, they go there and they actually release I mean like this is just for you to understand in gross there are intense chemical fundamentals that is going on here.

Then let us discuss about how the protons are moving. So, we know that the electrons are moving through the external circuit to the cathodic side. Now, how protons are moving there are two existing models first of first one is called the Grotthaus mechanism where there is a bound water present there. Bound water means when the water what is the difference between bound water and free water suppose you let a soil wait and then and then make a hole. So, hole suppose you have a small bottle in the bottle you make a lot of hole in from the bottom and then you put some soil on the top of it tiny hole just only.

So, the soil will not pass through it, but the water will definitely pass through it. So, you will put the soil there and then you fill the water from the top. So, the moment you will fill the water from the top what will happen it will it will like make the whole soil moist and then you will see drop wise manner the water will come out of the systems. So, whatever the water that is come out of the systems after say like couple of hour. So, this

is called the free water which is like not bound it will be easily removed from the soil system.

Then there comes when the then the rest of the soil will be still moist then you put it in the oven and it will take some time to you know make it like all sun right or you can put it at the oven at certain degree temperature. So, that the water this water some amount of bound water will release from the system. So, this additional amount of this additional work that you need to do additional energy that you need to supply to get rid of this water this is the bound water. Then there comes the you know like you know then there comes this adsorbed waters and all ok. Some adsorbed portions of the water is it is it is like this is also bound only, but those are very difficult ok.

Bound water can be also loosely bound or say like you know tightly bound loosely bound one you can still get rid of it, but the tightly bound one it is it is it is it is very difficult for you to actually you know get rid of it from the surface of this soil system or any say like here because majorly water is it is a polar liquid right it is a polar molecules polar water molecules. So, this is very difficult because of it is polarization phenomena right it it actually get attached to the surface of this particles this like you know in a very tighter way. So, this bound water the moment you have a bound water in your system. So, in that case you will see the difference you will see certain difference in the way the protons will behave proton will exchange. So, in the first program that is first model which is called the Grotthaus mechanism or on the given to the like you know within lame the scientist itself Grotthaus.

So, what is happening here? Here the excess amount of ions the protons when it attached to the surface of the water body any water molecule it will become the hydronium ion H_3O positive. So, this additional H plus that is present there it will give it to some say thus the molecules that is present in the on the wall of the this proton exchange membrane. And then it will be delivered like you know it is like you know it will give the proton to one water molecule to another water molecule then it will give it to the other it will give it to the other. So, it is like a conduction process it is like a conduction process you remember conduction process of heat transfer it is giving each one another. So, and then at the end it will release from the last molecules last water molecules that is bound water that is present in your system.

Then there comes another system which we call the vehicular mechanism. Vehicular mechanism means you will carry the one water molecule will carry the H plus it will become hydronium ion and it itself will go till the extreme end if it is possible it will go further and it will carry it by himself not using any you know you know any other molecules it will not exchange with any other molecules and it will not it will carry it by himself to the maximum way possible and share it with other water molecules and this way it will carry till the end. So, here we are actually exchange it with some other foreign molecules as well, but in case of vehicular mechanism it goes by itself till the end. If possible it may go the molecules itself can go till the end. So, that is why it is it looks like more of a convection process like it you know the convection way of heat transfer that it will move from one place to another.

In the conduction it is not moving it is just sharing its additional amount of energy to others it is same as like same as that. So, it also additional sharing the excess amount of protons with the others. So, this is how the proton transfer takes place in the in this kind of you know microbial fuel cell bio-autochemical processes. Then here comes the let us try to understand what is happening in the cathodic side once it receives the protons and the electrons. So, we need some amount of see there will be some how to say terminal electron acceptor right.

Those terminal electron acceptors it will consume it will try to it will reduce by consuming the electrons additional amount of electrons that is coming from this external circuit and all. At the same time it will also consume the you utilize the excess amount of protons that is passing through this proton conduction membrane and it will react with each other and then it form the water. Though it sounds very easy that oxygen it reacts with electron and proton and converts into water it sounds very easy, but there are very there are some scientific there are some chemistry going on there as well and which is obviously, but and obviously, very it is very fascinating for you for you if you understand the process. So, in order to break the oxygen in order to form the H_2 first that oxygen molecule has to be broken down right. This oxygen molecule is broken down into individual associated atoms.

So, this is called the bond dissociation energy. So, in order to form H_2O from oxygen single oxygen molecule the bond dissociation energy that energy that it requires is around 498 kilo joule per mole. So, we it goes through some dissociative and associative

organization process and at the end. So, we come out with the with the process of this bond dissociation energy we supply this amount of energy and that is the major reason why it is important for us to have a cathode catalyst. In the cathode this oxygen reduction reaction it is a sluggish in nature it is quite sluggish like it takes time it is very difficult for you to provide that energy in some cases. So, in that case the product the production of the way you want the way you want your fuel cell to perform it will not be able to perform in its best.

So, because of that we introduce some amount of some type of cathode catalyst some type of catalyst which will accelerate this oxygen reduction reaction and because of that this amount of oxygen that will be reduced will be increased that percentage will increase ok. So, this is how this is the reason why we provide the catalyst. When we provide the catalyst we it will reduce the bond dissociation energy and because of that it will make it much easier for the for the oxygen molecule to convert into H_2O while accepting the electrons and the protons coming from the anodic chamber. You see this in this case the cathode we have a platinum surface where in the bond bond dissociation energy goes down to 399 kilo joule per mole. And because of that also it actually helps and provide some additional surface also which will lead which will which will provide this I mean like this additional surface this catalyst it also helps to increase the reduction rate also isn't it.

Not I mean a reaction yield total yield final yield because of the additional specific surface area this react this kind of cathode catalyst can provide on the surface of the cathode ok. So, I hope you understand the reason why we need to have cathode catalyst specially when the cathode is concerned that the oxygen reduction reaction is constant concerned. There are different type of losses that may occur. The first one is the activated over activation over potential activation over potential is majorly due to the solution resistance. So, what does that mean activation over potential it is more like you know the amount of resistance that your what do you mean by the resistance it is like you know we are providing certain barrier to the electron to flow through certain system right.

So, ion to flow through it. So, this barrier is called a resistance right. So, this resistance how we going to find out how you going to find out this activation over potential it is because of the because of the amount of say like the from the generation of the electricity on the cell surface to come to come and reach to the to the extreme end of the biofilm. So, and this is like say that we call it activation over potential in a sense. Then ohmic over potential it is majorly comprised of all the additional wire or additional connections and

all and there also it it experiences some it experiences some resistance this is like say ohmic over potential. Then we have the concentration over potential because of the say like from ion from the electron to pass through the concentration through the anolite or the catholite it also needs some amount of it also provide some additional amount of resistance.

So, this is also can be this is also can be considered as a cathodic concentration over potential anon. So, actually if you see this different actual voltage that is obtained by the MFC you know MFC it is much less than the thermodynamically voltage that it can experience. So, there are theoretically if you suppose have a sucrose feed anon. So, there are theoretical consideration they say that you can go up to 1.1 volt for like you know for normal sucrose fed or acetate fed and feed anon. So, but actual you see actual what is happening there will be activation over potential ohmic over potential and the concentration over potential losses in cathode as well as the same in anode as well. And because of that this losses should have to be reduced this resistance this losses should have to be compromised and then we will get the final voltage actual voltage which is much less than that. Then this actual amelite is thermodynamically possible voltage generation. Let us go to the catholite what is happening in the catholite we know that the catholite how this oxygen reduction reaction is happening you see this equation. This is the oxygen reduction reaction process oxygen consumes the like you know it reduced by consuming to 4 amount of electron and 4 amount of proton it becomes H_2O.

So, this pathway it can be either we can call it 2 types of pathway we normally differentiate path A and path B. But one is the direct pathway where it involves the 4 amount of electron directly see this is the this is the final actual what is happening there. This is the oxygen with this double bond it involves 1 amount of electron it becomes superoxide ion that involves another amount of electron and plus $2H_2$ 2H plus it becomes hydrogen peroxide H_2O_2. If we stop the reaction here if we stop this reaction here which normally happens in a lot of cases what will happen there will be generation of H_2O_2 in the system plus it will also that means it is a 2 electron pathway because it takes only 2 number of electron. However if we keep on if we continue further it will further consume another amount of electron and then another one and it will become hydroxyl radical then it will become the water.

If we complete this whole procedure it will be 4 electron pathway the reduction process will be called 4 electron pathway 1, 2, 3, 4. So, because of this 4 electron pathway finally, the oxygen it will convert converted into H_2O understand. So, this whole procedure our

target is to go through the whole procedure in majority of the cases. In some specific cases you can go ahead with 2 electron pathway also what is the benefit of a 2 electron pathway in this case there are benefit there are disadvantages as well pros and cons both are there. What is the pros part that hydrogen peroxide it can also further reduce the what the pathogen load reduce the it can act as a disinfecting unit because it is quite reactive in nature and because of that what will happen it will I mean like it will reduce the pathogen load or the disinfection load it can be act as a disinfecting agent in the cathodic chamber.

So, from the anodic chamber that wastewater effluent can go to the cathodic chamber for further disinfection and then it will go like you can it can reduce the pathogen load. However, what is the negative part this hydrogen peroxide can also start like you know etching the cathode surface because of this etching that cathode surface will also be problematic it will also be an issue it will face some issue also it will also rust on the surface of the depending upon the type of proton exchange membrane that we will use it can also affect there as well. So, our target is in general to go ahead with the 4 electron transfer and then at the end we will get the H_2O and the finally, as as water. So, this is the whole procedure as you can see. So, but it is not necessary that you always need the oxygen for terminal electron acceptor.

You can also have potassium ferricyanide, permanganate, sodium hypochlorite, par sulphate. So, this can also be used as a electron acceptor, terminal electron acceptor in your cathodic chamber, ok. But oxygen we normally use because it is readily available you can make the cathode air cathode. So, oxygen is anyway there in the air it can act on it or you can make it aqueous cathode and in the aqueous cathode you in the cathode and you can have some you can sparge it with the diffuser or aerator.

So, it will keep on providing the enough amount of oxygen. So, in the dissolved oxygen for your reactor oxygen reduction reaction to take place, ok. So, this is the functionality of the microbial fuel cell. I hope you understood that at the end we get the final output in the load or the resistance because we you know that we need the resistance right to get the get it to to some viable means of like you know operation like you know this electricity this electrical energy we convert in this load cell to some other form of energy which where we can use it you can have the resistance with the fan you can have the resistance with the light. So, these are nothing, but it will it converted into some viable form of I mean like you know uses for us. So, we understood very like you know in in in details about the concept of microbial fuel cell.

We understood that the plain carbon as electron electron material for oxygenation can be used, but it is sluggish in nature which restrict the power generation of the MFC. So, that is why we sometimes use this like cathode catalyst and all or the anode catalyst. Exo-electrogenic microorganisms which present in the anodic chamber it is efficient in transferring the electrons from the exo-electrogens to the I mean like the anode and also governs the power generation of the MFC. We understood that the low cost cathode catalyst it is very much essential and as well as the cathode anode catalyst as well. What is the necessity of cathode catalyst? To overcome to help the oxygen reduction reaction to take place.

And what is the necessity of the anode catalyst? To facilitate this proficient conduction of electron from the exo-electrogen to the anode. It is like a mediator that you remember we talked about it. In the membrane material we understand that in the membrane material we can use it we can normally use it for conducting the transferring the protons from the anodic chamber to the cathodic chamber. There are very famous polymeric membranes which are available I mean like which has a very superior proton conductivity, but it is extremely high cost.

You heard about the naphion NAFIO. This naphion it is a type of the polymer membrane which is very costly, but it is very like quite perfect proton conducting membrane. So, this extremely because of its extreme high cost and we are targeting on focusing on some ceramic based membrane nowadays. In India in IIT Kharagpur we are working on this kind of systems we even in outside also we have some collaboration with other institute all over the world where we are focusing on the ceramic based membrane for which will actually like you know nullified the use of the polymeric costly polymeric membranes. And also in field scale also polymeric membrane does not make any sense.

So, because those are very fragile and also very not very does not have much of a strength. Whereas, the ceramic membrane it does it can give you some structural strength as well to the system. That is why ceramic membranes are now I mean nowadays it is been quite like you know famously used in different a different verticals and all. Base electrode metal we normally use the carbon felt, graphite felt, carbon cloth, graphite rod, graphite sheet all these things as a electrode metal is as a anode and cathode ok. So, our target is what? First it has to be cost effective, second superior catalytic effect activity, conductivity has to be

high and the specific surface area should be high. So, it is taken from one of my paper only in the specific surface area mean high means that if it has a high specific surface area though so that the biofilm can attach to its surface in a with the maximum space.

The maximum biofilm that can attach the maximum amount of electron that will be delivered you know. What is the drawback? This base materials has to be coated with the active catalyst to improve the performance and the cost of this materials also govern the economic sustainability of this field scale application of MFC that is also permanent. One case study low cost cathode catalyst like copper-jink can be used for you know in case of in as a cathode catalyst which actually comes out as a 300 times cheaper than the platinum based catalyst. However, it exhibits 38 percent as higher COD removal efficiency and then the then the then the in actual COH then the in control and a compared to the control one and without any cathode catalyst. So that means, it has the efficiency that it has the capacity to be con to be used for you know like you know alternate to the platinum based catalyst in the cathode as a in the in the cathode on the top of the cathode layer. Performance of MFCs in the in general the lab scale MFC it can demonstrate 70 to 90 percent of COD removal efficiency. The removal efficiency it depends on the tie analyte it is a bacterial culture and the exo and the electro catalyst anode or cathode catalyst that we use. Field scale efficiency though it cannot go that high the removal efficiency is slightly less 60 to 70 percent, but quite quite comparable to the conventional aerobic anaerobic treatment systems because when the MFC are scaled up electrochemical losses are adding up. So, it they reduces the performance.

Anode catalyst or mediators are normally employed in this kind of cases. So, to you know mediate the excess amount of electrons generated by the exo to the surface of the air and this mediator reduce the loss of electrons in parasitic site reactions while increasing the power generation in the MFCs. Tungsten or trioxide and like this kind of different mediators are used electro anode catalyst are used and it is shown that it can increase the coulombic efficiency like anything. Polymer based membranes are used MFC because of its, but I mean like nowadays it is as I mentioned like it is we are trying to focus on low cost clay wire ceramic membranes which will reduce the cost and also it will be helpful for application in the field scale scenario. So, in conclusion we understood different understood about the biotechnical processes. We have a very good idea about how microbial fuel cell works and we also understand the historical evolution from the M.C. Potter's 1911s demonstration to the development of microbial fuel cell what we can see now. If you see the literature, if you see the videos in YouTube or if you read some paper even I have some paper on it and you can go through it and you can understand the system

more in details and it will it is really fascinating. It is like you know you are generating energy out of waste. It is like you know waste to wealth I mean like proper waste to wealth concept can be you know followed. There are some problems with the scalability issues with the MFCs that is now being taken care of by people like researchers from all over the world in specially one of the pioneering institute IIT Kharagpur is also one of the pioneering institute in MFC research and so, there are lot of work going on to make it to the field scale and it is more make it more feasible for people to actually use it in real life scenarios and all.

This is the references please go through these references and that is it. So, thank you so much. See you on the next video where I will be discussing we will continue with the discussion on the microbial fuel cell and how the hybrid microbial fuel cell hybrid biotechnical systems can be developed and how those MFC can be added can be used as a polishing treatment systems or can sometimes be used as a pretreatment systems for existing waste water treatment plants and all that will also be discussed in details. Till then thank you so much.