Aqueous Corrosion and its Control
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Lecture – 13
Forms of corrosion: Preventative measures for uniform corrosion (Part-II)

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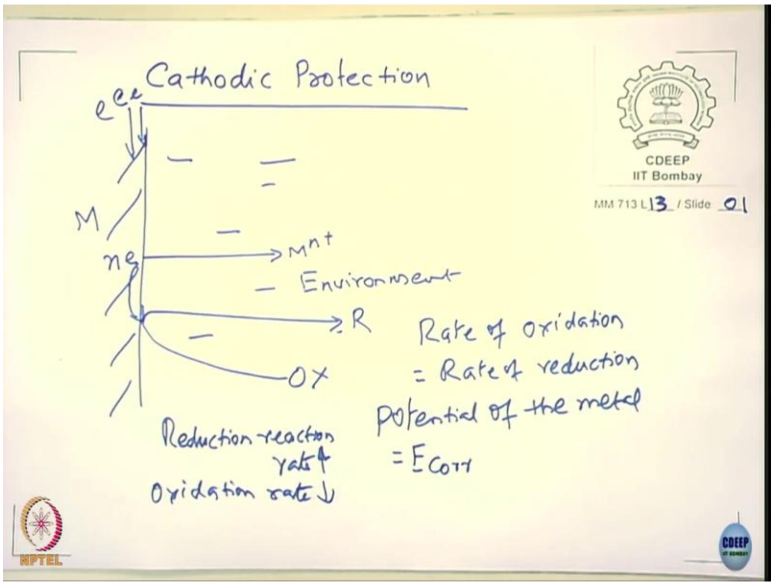

Cathodic Protection

Rate of oxidation = Rate of reduction

Potential of the metal = E_{corr}

Reduction reaction rate ↑

Oxidation rate ↓

We will continue to discuss the cathodic protection method for the control of corrosion. We saw earlier that in a corroding metal which are exposed to a the environment, suppose you have an environment, the metal is getting oxidized, the electron. This is the metal, and they release the electrons on the surface.

There is a cathodic reaction and which takes away these electrons, so these electrons will flow and there can be some species in oxidizing species which would accept these electrons they become reduced. So, in this case the rate of oxidation equals the rate of reduction. The potential exhibited by the metal is equal to what? The metal is equals to the E_{corr} or the corrosion potential.

Now, if you are going to supply electrons to this surface, if you are going to supply electrons to the surface, if you are going to supply electrons to the surface then what will happen? In that case the reduction reaction rate increases, right, the oxidation rate decreases. So, that is it is a simple Le Chatelier principle. And that is how the cathodic protection works.

Now, we need to understand this more in detail about what are the factors that control or that are required in cathodic protection of a given metal. This we can understand by looking at the Evans diagram, right. We know how the Evans diagram is you know can be constructed, right. So, let us construct the Evans diagram. I think all of you could do that, right.

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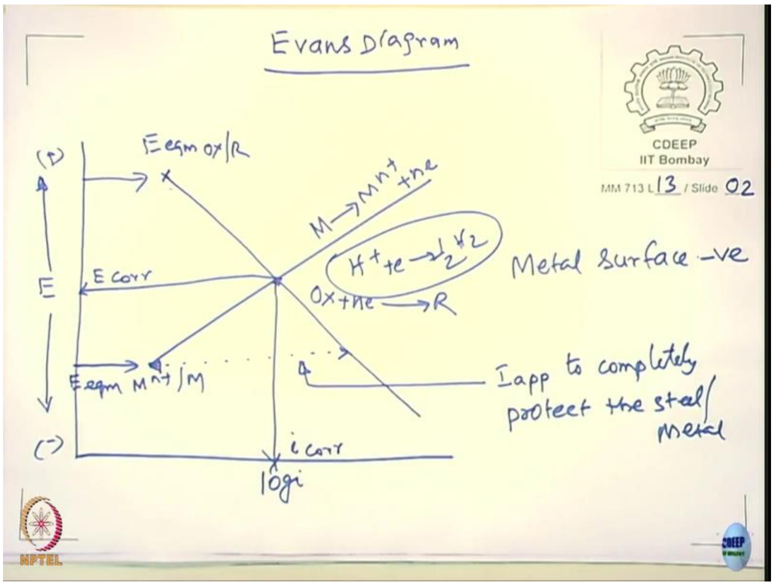

And you can do the, you can draw an Evans diagram. What is the Evans diagram here? You have, so log i versus the potential, right. And how we get E_{corr}? So, you represent the cathodic reaction, starting from its equilibrium potential somewhere here and reduction reaction and you also have somewhere your an oxidation reaction. So, this is a metal Mn plus plus n electrons, right.

$$M \rightarrow M^{n+} + ne$$

And this corresponds to what? This corresponds to oxidizing species accepting the electrons and getting reduced.

$$Ox + ne \rightarrow R$$

And what is E_{corr}? It is this intersection point you guys know and this is your corresponding i_{corr}. So, what you are doing actually? You are forcing electron onto the metal surface. How can you do that? By making the metal surface negative, right. So, you are going to make the metal surface is negative; that means, you are polarizing the metal negative to the corrosion potential. Am I right?

So, you are moving from down from here, you have to; you have to move down, right. So, you have to bring down the potential from this point to this point. What is this? This is we called as the equilibrium potential. For what? For the metal equilibrium. And this is the equilibrium potential for your oxidants and the reductant got it.

Now, I have to move, in order to reduce the current corrosion rate I need to move from here to this point by applying an external voltage, applying external voltage, I do this. Ideally, the metal stops corroding when if I reach this particular potentials. At this particular potential the metal becomes totally immune to corrosion. If you have to make it immune to corrosion I need to supply the current.

Do I need to supply current? See at this point at E_{corr}, I do not supply any current, agree. But when I move here the rate of reduction reaction is higher than the rate of oxidation reaction; that means, the remaining current has to come from an external source, agreed.

Student: Yes.

So, this is the current that is to be applied. So, this is the current, this is I applied to completely protect the steel or metal, I can put any of them actually, structures. So, this is the difference in current, right, the cathodic current minus anodic current gives you the net current I have to apply externally to bring the potential from this point to this point. That is the principle of cathodic protection. How do I apply the current? I apply the current. What should be then the case?

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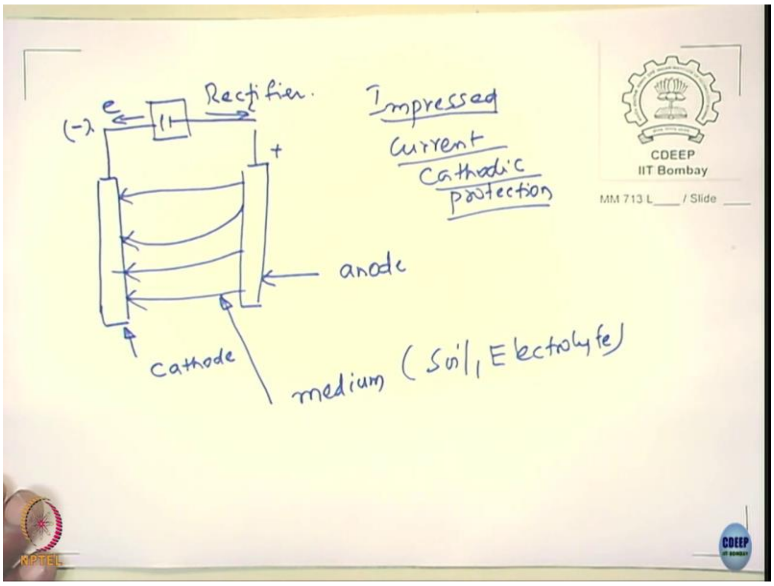

If you have a metal, if you want to bring down its potentials, right and I need to have anode and this is going to be your cathode. What kind of current I apply? Is it AC current or DC current?

Student: DC current.

DC current, ok. So, apply DC current, ok. So, this is a on the negative terminal, this is the positive terminal. And this is what? This is a can be rectifier. It can be rectifier if you want. You can call it as a rectifier.

What happening now? What is the direction of the flow of current? The direction of the flow current is opposite to the direction of the flow of electrons. Now, this anode now current flows like that systems, agreed. So, rectifier now provides the current to the anode and the anode, sends the current to what? To the medium. The medium could be a soil or any electrolyte in general, may be sea water.

So, the purpose of the anode here is to send current in the electrolyte which corrodes the metal structure and the role of rectifier is to provide the current, to provide the voltage. Now, what should be the voltage in this case? The voltage in this case as per the theory is equal to the equilibrium potential of the structures. We will see that whether that is should be you should do it or not we will see later.

So, this is one form of catholic protection. So, this is called as the impressed current cathodic protection because you are using an external source rectifier and the role of anode is only to supply current to the soil and from the soil or from the electrolyte the current enters the cathode or the steel and renders this metal into a cathode.

So, what it does, ok. So, that means, electrons start flowing like that, right, electrons flow here, the current starts flowing in this direction, agreed. So, this is called as impressed current and or a impressed current cathodic protection system.

You can also have you know the galvanic series, right, we have seen it before. Are you seen, I have given you a table before that is a series or you have a EMF series. If you look at that series, the corrosion potential of the metals and alloys are given in some order that is in the table you will see that the potential the corrosion potential decreases from the top to the bottom. Top most is platinum and bottom most given there is a magnesium there.

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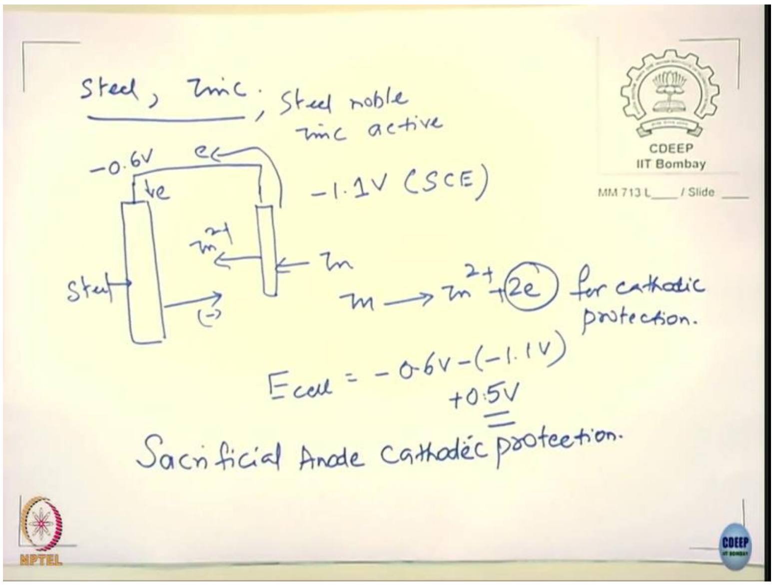

Suppose, you take the case of steel and just take the case of let us say a zinc, you take this case right which is relatively noble? Steel, a steel is noble and zinc is active, right. If I can short steel and connect it and zinc, I short them up here.

The potential of the galvanic potential of zinc is normally considered as minus 1.1 volt and the corrosion potential of steel in sea water is considered as something like minus 0.6 volts with respect to saturated calomel electrode. This is a relatively noble and this is relatively active.

So, what will happen now? Zinc will dissolve as zinc ions, the electrons will start flowing and enter this steel like this. Of course, this go like this only, ok, the current will start, I mean the current moves in directions, the negative ion starts moving in this direction. So, to put it in this way, zinc dissolves as zinc 2 plus plus 2 electrons and these electrons are available for cathodic protection.

$$Zn \rightarrow Zn^{2+} + 2e$$

What is the driving force for that? The driving force for this is you can consider E_{cell} is the driving force. Is equal to what? It is equal to minus 0.6 volts minus of minus 1.1 volt. So, what is the value?

Student: (Refer Time: 16:38).

The 0.5 volt approximately, ok. So, you have that much driving voltage for the system to sustain. So, zinc is able to provide you a driving force, so that the steel can become cathode is made as a cathode and this process is called as, ok. So, you have two types of cathodic protection system, one is called impressed current cathodic protection, the other case is sacrificial anode cathodic protection system.

Let us look at this cathodic protection a little bit more in depth and try to understand this. Let us go back to this diagram. When we do a cathodic protection of these structure, no doubt there is a reduction in the corrosion rate. But what is happening to the cathodic reaction rate? It increases, right. The cathodic protection the cathodic reduction reaction rate is increasing. Assume that this cathodic reaction is let us say H plus plus electron gives you hydrogen, right.

$$2H^{+} + 2e \rightarrow H_2$$

Assume that the cathodic reaction is this one. So, what will happen now? Lots of hydrogen gas will evolve on the metal surface and it can lead to hydrogen embrittlement. We will see later. Right now we are not talking about it. If you apply a coating the coating will get damaged because of the gas evolution.

So, it is not a right thing to do that you can apply as much of voltage as possible. You apply a very high voltage from here to this, the chances of hydrogen evolution rate is very high. So, in practice we do not normally keep this the cathodic protection potential at or is equivalent to the equilibrium potentials.

So, it is kept in a way that it is more practical and more appropriate from engineering perspective of this actually, so that becomes a criteria for cathodic protection understood. So, from otherwise ideally speaking you can make the metal immune to corrosion by bringing the or potential from E_{corr} down to equilibrium potentials.

The disadvantage is that the hydrogen evolution will takes place and the metal may become embrittled if you have coating the coating also get disbonded. So, in practice you do not do that. So, what you do in actual is as follows.

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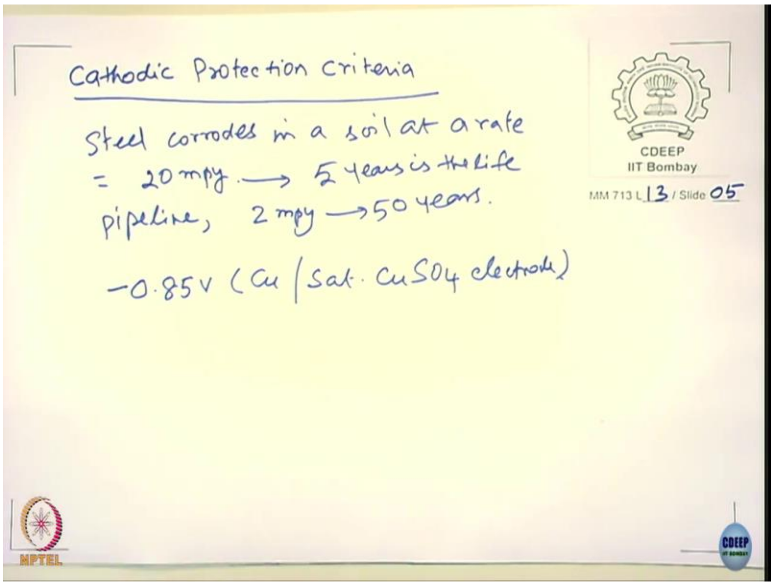

Cathodic Protection Criteria

Steel corrodes in a soil at a rate = 20 mpy → 5 years is the life pipeline, 2 mpy → 50 years.

−0.85 V (Cu | Sat. $CuSO_4$ electrode)

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So, you come up with a criteria which is called as cathodic protection criteria. The idea here is that if I can reduce the corrosion rate by 10 times, the life of the structure increases by 10 times, right.

Assume that without a cathodic protection the steel corrodes steel corrodes in a soil at a let us say at a rate equals to let us say about 20 mpy, right. So, you can design the structure, right. Suppose, I want a pipeline, for example, I have a pipeline I can design the thickness based on the pressure and all right.

If you can bring down the corrosion rate to 2 mpy, assume that with this I have about 5 years is the life, if I can bring down the corrosion rate from 20 to 2 mpy it becomes 50 years. So, I am not completely stopping corrosion, but it is from the point of view of engineering applications.

So, the criteria of corrosion or the criteria of cathodic protection is based on that particular concept. So, the following criteria is generally used. It is actually called minus 0.85 volts with respect to copper saturated copper sulfate electrode. Very widely used criteria. It has some limitations, we will not discuss now actually, ok. But let us just take it as a normally used criteria for the cathodic protection.

That means, when after applying cathodic protection I should get a potential which is equal to minus 0.85 volt with respect to copper saturated copper sulfate electrode**.** This is a reference electrode that is understood as is adequate protection to serve the required life of the particular pipeline.

And here you minimize the hydrogen evolution, you minimize the hydrogen damage, all is done. In fact, if people are going to use high strength steels you know in the case of a ship and all, in fact, they do not even go this much they slightly make it a little more anodic because in the sea water if you make it more negative the hydrogen evolution occurs, then there will be cracking taking place. So, there are some variations within these defined a criteria based on the applications, but most of the pipeline application this criteria is followed.

Now, let us look at the difference between the impressed current cathodic protection system, the sacrificial anode cathodic protection system. What are the; what are the advantages and disadvantages of each of the systems? And I think we can look at it. Two systems.

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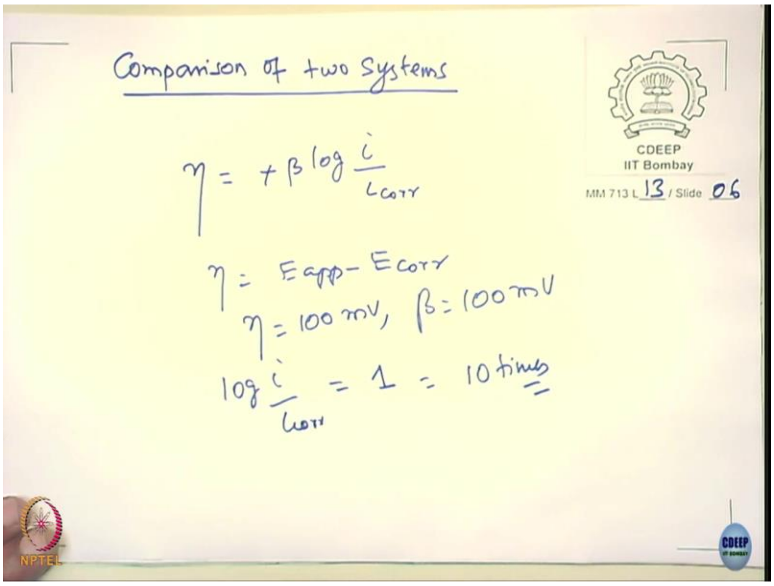

Comparison of two Systems

$$\eta = +\beta \log \frac{i}{i_{corr}}$$

$$\eta = E_{app} - E_{corr}$$

$$\eta = 100\ mV, \quad \beta = 100\ mV$$

$$\log \frac{i}{i_{corr}} = 1 = 10 \text{ times}$$

Student: (Refer Time: 24:32), so minus 0.85 volt (Refer Time: 24:35). So, even if the soil is changing whether it is aerobic anaerobic, the criteria remains same between the generalize statement (Refer Time: 24:48).

Whether soil is aerobic or anaerobic the criteria is almost the same. The only difference that happens is that if the soil has got a microbial corrosion, then you add another 100 millivolts, you becomes minus 950 millivolts. And where the problem is uncertain for example, see what happens since you have started that I can clarify in some cases the corrosion potential itself is equal to minus 0.85, you measure with respect to the copper sulfate, ok.

So, then the people use a criteria called as 100 millivolt criteria. Now, what we do is when I apply a cathodic protection the potential drops you know, assume that it is minus 0.85 it may go to minus 0.95 volts, right. You turn it off you know, and when you turn it off then there is a shift from the protected potentials to the unprotected potentials, ok. And that if it is 100 millivolt difference then we consider that the pipeline is or tank is well protected.

Now, the criteria is very simple you know the Tafel equation, right. What does the Tafel equation say? All of us know that eta is equal to what? Eta is equal to let us say in the case of a anodic thing, beta log i upon.

Student: (Refer Time: 26:36) i^o.

i^o or you can say i_{corr} whatever you being called, ok. You can call i_{corr} here. What is eta here? The eta is equal to E applied minus E_{corr}. Now, if you substitute here 100 millivolts, is not it; if substitute here 100 millivolts assume that the Tafel slope is about 100 millivolts, ok. Then, what happens? This ratio becomes one, you can see here now.

Assume that the beta is a 100 millivolt and the shift is 100 millivolt, right, is not it. The eta is equal to shift is 100 millivolt, right. So, if shift is eta is equal to 100 millivolts and beta is assumed as 100 millivolts. What happens? Then you find log i upon i_{corr} is equal to 1; that means, from this you have moved, ok. How much you moved? You moved about 10 times, ok. Am I right or not?

So, that is how you can able to; you can able to see that 100 millivolt criteria means it is about 10 times you are lowering the corrosion rate of the metal. If you make it let us say 300 millivolt it will be 1000 times you are reducing the corrosion rate provided the Tafel slope is equal to 100 millivolt. Of course, that is the assumption that you are making it actually, ok.

So, there are other criteria people use it. And we are not discussing right now. We will you know you should take the other course advances in design and control of corrosion there will be detailed discussion on the cathodic protection engineering. You will see the merit and demerits of various criteria.

It is not that this criteria is ideal criteria for that. For simplicity it is to understand that minus 0.85 volt with respect to copper sulfate is normally used across the various you know structures and soils and so on, ok. But yes, there are issues which I think should be taken care of, ok.

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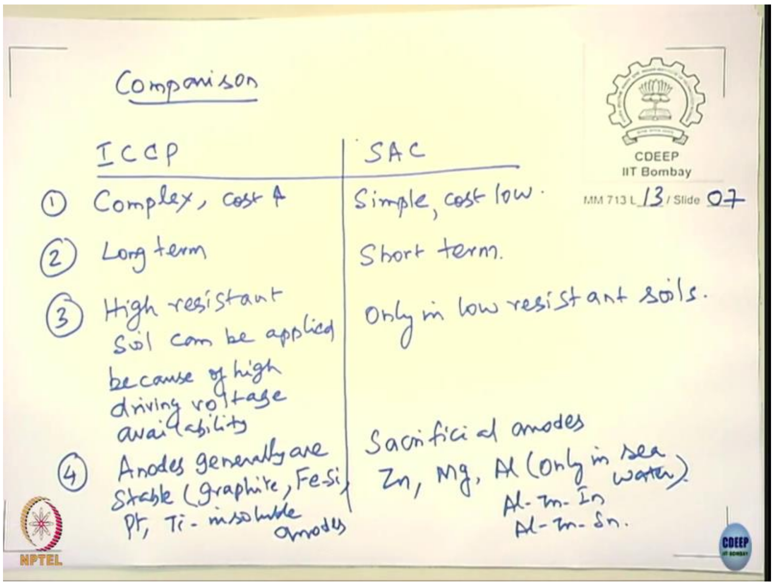

Comparison

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	ICCP	SAC
①	Complex, cost ↑	Simple, cost low.
②	Long term	Short term.
③	High resistant soil can be applied because of high driving voltage availability	Only in low resistant soils.
④	Anodes generally are stable (graphite, Fe-Si, Pt, Ti - insoluble anodes	Sacrificial anodes Zn, Mg, Al (only in sea water) Al-Zn-In Al-Zn-Sn.

Let us go into the comparison. Look at ICCP, Impressed Current Cathodic Protection system. You also have sacrificial anode cathodic protection system. It is, first of all it is a complex system. You need a rectifier and a system like monitoring them, in practice it is very very complicated feedback systems are there. It is very complex and it is cost high. This is simple cost low. I am talking in relation to that each other, right.

This is for long term. If you want to apply a long term cathodic protection like say 20 years, 25 years like that the people go for ICCP. This is for short term applications.

The third is a very important criteria. If you talk about a pipeline a lying in a very highly resistant soil, right soil has got resistance, if the soil has got high resistance I need a driving force has to be a higher in order to pass the current from the anode into a soil and then on to the pipeline, right. So, it requires higher driving voltage. If the soil is low resistance I have less problems.

So, high resistant soil, I can use this soil, ok, can be applied. Rectifier can give you 50 volts, I have 20 volts, I mean there is no restriction as it is in terms of capacity, right because of high driving force driving voltage availability, ok. Can be used only in the low resistant soils not possible always.

4, anodes generally are stable, are stable. They are like they are like let us say graphite, iron silicon, platinum, titanium insoluble anodes. These anodes are sacrificial anode. They are like zinc, magnesium and these alloys you have aluminum, aluminum only in sea water applications. Aluminum forms a passive film, right, so it cannot be used everywhere, ok. Aluminum and aluminum alloys people use, actually aluminum people use aluminum, zinc indium system, aluminum zinc tin systems, these are the alloys they use for sacrificial anodes.

There are more differences, we will not be discussing about for example, there is something called interference current, stray current corrosion, all they are in ICCP, but they are not there in the, they are not there in the sacrificial anode cathodic protection system. But I think we will not discuss those into details of that.

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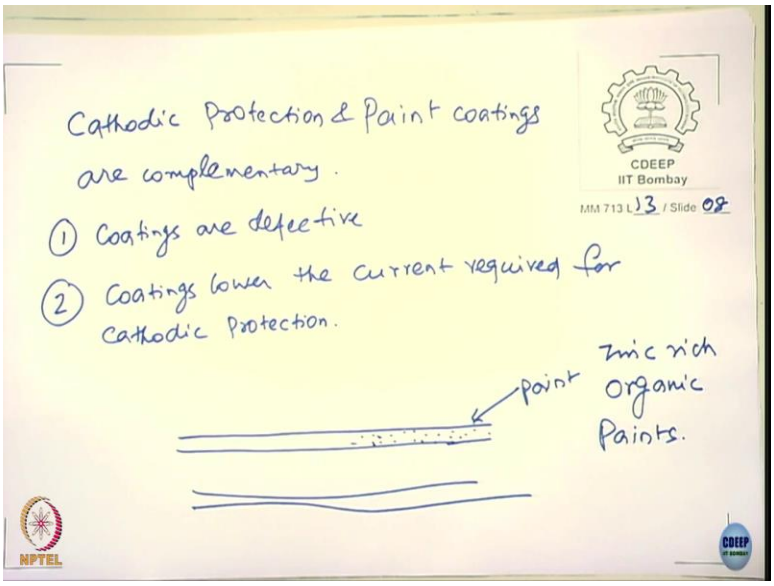

Cathodic Protection & Paint coatings are complementary.

① Coatings are defective

② Coatings lower the current required for cathodic protection.

Zinc rich organic Paints.

One thing I just want to say here because it is not out of place to talk about is that cathodic protection and coatings and.

Student: (Refer Time: 35:08).

Paint coatings, I put it more specifically paint coatings are complementary. They help each other, right. You apply coating for what? To reduce corrosion you apply. You apply cathodic protection to reduce corrosion. Why you should have coating as well as cathodic protection?

Student: (Refer Time: 35:44) all of the time coating can be of mechanical damage chemical damage of coating or something can be (Refer Time: 35:49) let (Refer Time: 35:50) that time this cathodic protection can, so some (Refer Time: 35:54) try both of them together. So, that (Refer Time: 35:57) system.

Ok.

Student: Over there is any (Refer Time: 36:01) when we are applying the both with the paint some pores or some something which has been left out holes are there that time also (Refer Time: 36:12).

The second one is more correct. You do not find any paint coatings which is 100 percent impervious to water. You know there are certain defects in the system. So, coatings they do protect, but they are not going to protect completely first of all. First reason that, so it is going to aid the coating in preventing corrosion to a large extent, ok. So, the reason is the coatings are generally or defective.

The second important point. The current requirement for cathodic protection is significantly brought down, you would not believe, you know from amperes you can bring down to milliampere about 1000 times, even more you can bring down the current requirement. So, coatings lower the current required for cathodic protection.

I think we can keep discussing more and more, I think because in engineering you know it is you know what we saw is only the science of it, right. The engineering is complex. If you want to install a cathodic protection then you have to define how much current is required, how many anodes are required, how to distribute them what are the, what is the rate capacity of the rectifier, several issues are there. So, that is we call a engineering. That is not discussed now, ok. And those who are interested you can look at the book.

Student: Can we conjugate the cathodic protection by sacrificial anode into the paints.

See, I mean that is not called as a cathodic protection, ok. In the paints also, you add a zinc as a pigment, zinc powders, zinc flakes are add as a pigments and there is a zinc you know when they sit on the steel surface it can cathodically protect the structure you know that is what, right. It is a good question. Now, for example, suppose I have a pipeline and I apply a paint on this sorry, this is the paint and in the paint if I am going to add you know zinc particles sufficient quantities, ok. Now, what happens now?

The paint is we saw in the morning that it is a barrier, right. It does not allow the water to permeate just like that, it is a barrier, ok. But nevertheless the water will permeate, the corrosive species like chloride, sulfate may permeate, over a time period the water will ingress here. The second level of defense, the first level of defense against corrosion here is the barrier by the paint, the physical barrier.

The second level of defense is that, if the water comes over here the zinc now will act as a sacrificial thing. So, it is a mini cathodic protection system, right, is not it, at a micro level they are operating. So, the life of the paint coating is increased significantly because of the presence of zinc in the paint. And they called as, these paints are called as zinc rich organic paints.

Now, the issue is you should have enough zinc powder, so that all the zinc powder should be touching each other, right, otherwise if the zinc powder is not sufficient and then the cathodic protection may not be operating. So, there are critical amount of zinc powder like 80 percent is added, so that this zinc is effective cathodic protection.

Here we do not call a cathodic protection in true sense of it, ok, but the principle of cathodic protection is very much applied here. And of course, it is a conjugate with the physical barrier offered by the paint system. It is this is what it does work. So, it use the same concept to develop a new paint, ok.

Any questions? Any of you, ok? Let us go into the next aspect of the controlling the uniform corrosion of metal through electrochemical means. And this is we call as anodic protection.

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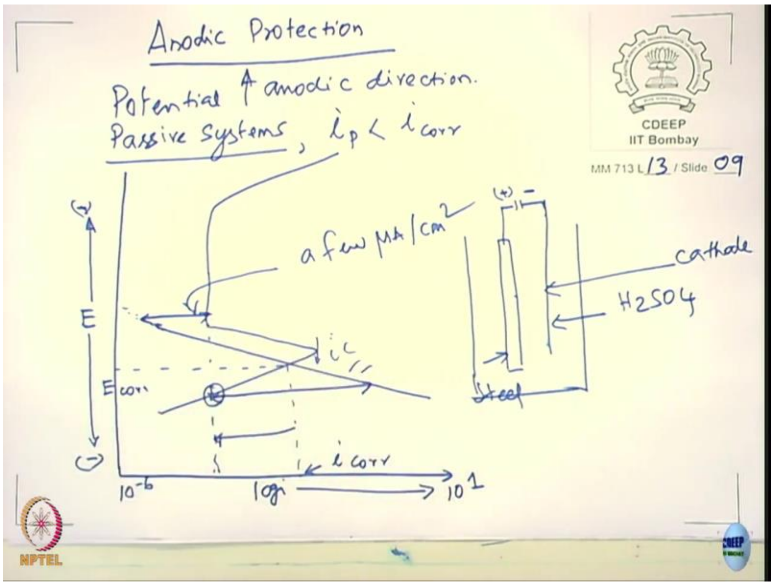

Anodic Protection

Potential ↑ anodic direction.

Passive systems, $i_p < i_{corr}$

It is not very difficult to understand how and when anodic protection can work. What is anodic protection? You are rising the potential towards the anodic direction, right. So, potential is increased towards the anodic direction. If you increase the over voltage, is not it, right, this is what you do. What you expect to happen in a normal metal? The corrosion will.

Student: Increase.

Increase, right. But if the metal is passivating, if you rise the potential to the passive region, right. So, what will happen to the corrosion rate? It decrease. In which case what will be i corr? i_{corr} equals to.

Student: i p.

i p, right. So, by rising the potential to the passive region and you are moving the i_{corr} which is going to be equal to i passivation. So, this is a simple principle, right. So, that means, the system has to be passive, ok. So, it is for the passive system. Only passive systems you can able to do this.

The secondly, i passivation has to be lower than i_{corr} otherwise no use. If i_{corr} is going to be smaller than i_p it is not going to help you at all, right. Let us look at the Evans diagram. Let us look at the Evans diagram for a passive system and see how the anodic protection system works, right.

So, let us draw the Evans diagram. I suppose you can draw yourself and see how it can be done, is not it. The system is not passivating, right. What happens? You have a cathodic curve and you get the i_{corr}. I can do it provided I raise the potential, right, this.

So, if I can raise this potential to this level, assume that I am going to have I take it to this level now, ok. If I hold the metal at this particular potential, the corresponding cathodic reaction and the corresponding anodic reaction rate, right you at this particular potential suppose I have a metal, right metal is immersed in a let us say in sulphuric acid somewhere, right, say in sulphuric acid.

And from E_{corr} I am going to rise it by applying a positive potential and negative potential over this, right. This is let us say a steel maybe. If I rise it to this look at this the E_{corr} has moved up, but what happened to the i_{corr}? Just come down to this value. So, corrosion current density has significantly reduced by rising the potential from E_{corr} up to the passive region. So, many interesting things are happening here, right.

Look at this now if I were to bring down the same corrosion rate as I do for passive system for example here. If I have to do it by cathodic protection, suppose I have do with the cathodic protection, right, I can bring down the corrosion rate either by making it is anodic passive or I can bring down the potential and make it cathodic, right. Both the cases I can bring down the corrosion rate, but what is the difference there?

Student: i_{corr}.

Yeah.

Student: (Refer Time: 48:05) i_{corr}.

i_{corr} is the same both cases.

Student: (Refer Time: 48:09).

The current required for cathodic protection is lesser more than anodic protection. The effective amount of current I need to supply to make it anodically protected, which is more?

Student: (Refer Time: 48:30).

Cathode is more, anode is more?

Student: Cathode is.

Now, this current is going in this direction, right. They are in log scale. Please see this. Assume that this is let us say 10 power minus 6, assume that it is going to be 10 power 1, ok. Now, you tell me where you apply more current?

Student: Cathode.

Cathode, right.

Student: (Refer Time: 48:55).

So, you need only a few micro amperes. Here is generally you need only a few micro ampere per centimeter square. Here we need few milliamperes, is not it. You see you have to move in the log scale then you will understand that, right. This is higher value. So, cathodic protection generally requires higher current compared to the anodic protection, right. It is the one difference, right. So, one difference is that is let us look at the difference between these two systems. Comparison, right.

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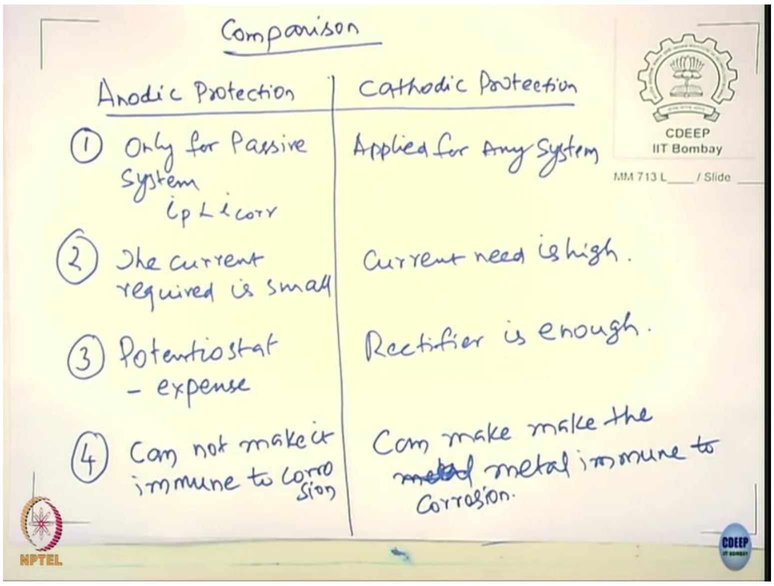

Comparison

Anodic Protection	Cathodic Protection
① Only for Passive System $i_p < i_{corr}$	Applied for Any System
② The current required is small	Current need is high.
③ Potentiostat - expense	Rectifier is enough.
④ Can not make it immune to corrosion	Can make make the ~~metal~~ metal immune to Corrosion.

Let us go to the anodic protection.

Student: Sir, I was asking about $i_{critical}$ to reach the $i_{passivation}$, do we have to surpass $i_{critical}$ in anodic protection? How do we do it?

That is a good question, ok. That is a good question. And I just come here, this is a very good question actually. Let us look at this process. You need to reach this place. How do I reach it? By making this as a cathode, right. So, you need a cathode, this is the cathode. In cathodic protection the counter electrode is a anode, in the anodic protection the counter electrode is a cathode, right.

So, how much current do I pass here? How much current do I pass here before I reach here? I need to pass a current which should be higher than the critical current density, then only I can able to reach this. This cathode should supply enough current so that I reach here. But once I reach here what happens?

Student: The maintaining.

The maintaining that becomes easier. So, it is a good question. So, the capacity of the DC source, but I do not call it DC source, we call this as a potential stat. We will come to this later. This has to have the capacity to cross the critical current density, otherwise you will not able to achieve the anodic protection at all. But after reaching that place then I think there is no problem, ok. You need less amount of current, that is something we should be you should understand that.

So, when you talk about anodic protection and cathodic protection, the one of the; one of the first and foremost is the anodic protection is applicable only when the system is.

Student: Passivating.

Passivating. But cathodic protection is applicable to almost all systems, we have no issue at all actually, ok. So, only for passive systems I want to go one step further and say that i p has to be lower than i_{corr} that is not sufficient it has to be other criteria for that. It can be, applied for any system.

The other important thing is generally the current required is small, current need is high. Let us look at this a bit more, closely this diagram. I have say suppose I am holding the potential of the cathode somewhere here, I start moving little bit up and down. What happens? The metal will not corrode more if in this case.

If I do not hold the potential properly then I will end up corroding at a very high rate than the than the i_{corr} values, right. So, the equipment required for that is called a potentiostat, ok. You need a potentiostat, ok. Here you need a potentiostat. And it is normally expensive. A rectifier is sufficient.

Now, the 4th point is you cannot make it immune, cannot make it immune to corrosion. Can make it, right. Can make the metal immune to corrosion. That is because cathodic protection is a thermodynamically stable system. But anodic protection passivation is a kinetically hindrance, so you cannot completely make the metal immune to corrosion, but that is not really required in actual service applications.

Now, the question now is anodic protection been used at all. It is now used actually, and because it took you know when you talk about a potentiostat, the potentiostat was first constructed by a person called (Refer Time: 56:56), ok. It came much later as compared to rectifier and other constant current sources. So, anodic protection is a relatively a new engineering concept that happened as compared to the cathodic protection system, ok.

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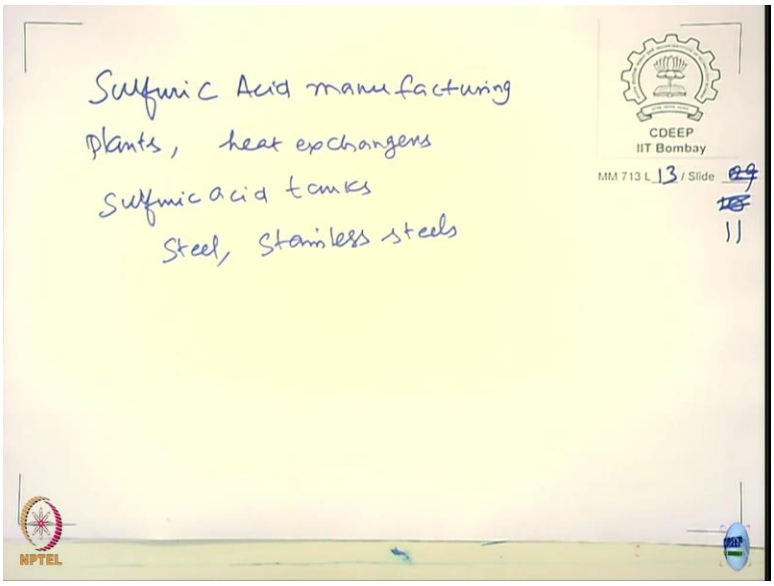

Sulfuric Acid manufacturing
plants, heat exchangers
Sulfuric acid tanks
Steel, Stainless steels

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IIT Bombay
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But nevertheless it is used, in fact it is used in sulfuric acid manufacturing plants. You use it for heat exchangers. It can be used for sulfuric acid tanks. It is used for steel, used for stainless steels. It is used for steel and stainless steels, but very limited applications compared to the cathodic protection systems, but indeed used, ok.

So, this brings us to the end of discussion or you know lectures on uniform corrosion. And if you have many questions any clarifications, we can we can have we can discuss.

Student: How much area can be covered by the ICCP and sacrificial anode method? What is the number and size of the anode is required in both the cases?

Actually, as I have been telling you cathodic protection is a engineering. Now, when you talk about ICCP, generally if you compare the structures be it a pipeline or a tank or a ship hull, the anode is a point source you can say it is infinite cathode, a very very finite anode size.

Now, that is where the location of the anode it matters. The current emanates from the point source and goes into the soil like a wave, right, like radially it goes and enters the pipeline. And if we compare to sacrificial anodes, the number of anodes required for ICCP is less, but in the sacrificial you need more anodes because the driving voltage required or offered by the sacrificial anodes are very small, ok.

But there are cases where the anodes can run parallel to the pipelines**.** There are very very isolated cases. For example, your pipeline going through a rocky terrain, right and the current cannot go through the rocks. So, what people do is they use what is called as the horizontal anodes buried in a very thin anodes, buried parallel to the pipelines, ok.

Because you keep it outside the current cannot penetrate to the rock actually, there are certain segments people do it. Otherwise, the number of anodes for ICCP are very very few and the size also very very small actually. No questions, ok.

So, then let us close the discussion today, and we shall continue the class that we can see when you can do that.

Student: Can an inhibitor be added as alloying element?

Inhibitors added as a.

Student: Like alloying element.

No, inhibitors are added to the electrolyte, added to the corrosive environment, right. But when you say alloy, I do not know we are using alloys general term anything you mix together you call as alloy, right. Are you talked about a mixed inhibitors?

Student: (Refer Time: 62:00).

Inhibitors can be added as a mixed. See, we discussed in the morning that it can be anodic inhibitor, can be cathodic inhibitor. You are going to design a inhibitor which is having a mixed function of anodic and cathodic or you can add an two inhibitors, one is having a anodic character, other is a cathodic character you can do that, ok. So, that is done in many many you know systems.

In cooling water systems, people add a combination of anodic inhibitor and a cathodic inhibitors, and you know that they are they are very common. In fact, that becomes more effective in this case. You see zinc, for example, people add zinc which is the cathodic inhibitor, you know zinc compounds and the molybdate is an anodic inhibitor, right. A system people add you know zinc phosphates and you have a molybdate you can add it to that actually, ok.

So, combination **of are** quite common do that actually they. In fact, very effective. And when you choose again inhibitors dependent upon the temperatures sometimes the temperature of the system can be quite large, in cooling water systems the temperature of the system can go to 50 to 60 degree Celsius. The stability of the inhibitors are also very important. In boilers it becomes even more higher, ok. There are so many variations in tailoring the inhibitors, ok, I mean you are, right we can have such variations.

Student: How does the functionality and mechanism of the inhibitors vary with the working conditions?

See, the electrolyte would have a bearing on any of this, ok. Now, basically the inhibitor they we have see in the morning, right either they form an absorbed layer on the surface. And how do they get absorbed? Either you will have a positive charge on the you know on the molecule you know or you can have a negative charge.

Here these charges are all what they are I would say polar groups or you know kind of things. So, they get attached to the you know to the metallic sides, you know you can attach to a cathodic site if for example the molecule is relatively having a positive character, right and you have negative character it may get into in anodic site. So, both are possible to do that.

And in fact, there are certain models you know people you know they look at the density function theory and all these they have use it to first of all understand. Second of all you want to tailor a new molecule you do that, ok.

And there are also people talk about adsorption isotherms like a langmuir isotherm, temkin isotherm you might be knowing where they look at the activation energies for absorption. More is activation energy for absorption; I mean more is the free energy change for absorption and they absorb far better.

So, these calculations that people make in order to characterize this inhibitors when they tailor the new inhibitors for various systems. They depend on the metal, they also depend upon the electrolyte significantly, that. Anything, ok?

Thank you.