Aqueous Corrosion and its Control

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Lecture – 16
Forms of corrosion: Galvanic or dissimilar metal corrosion (Part-III)

Welcome to the 16th lecture on Aqueous Corrosion and its Control. Now we are discussing on the Galvanic Corrosion Part III, right. We are looking at the galvanic corrosion, correct.

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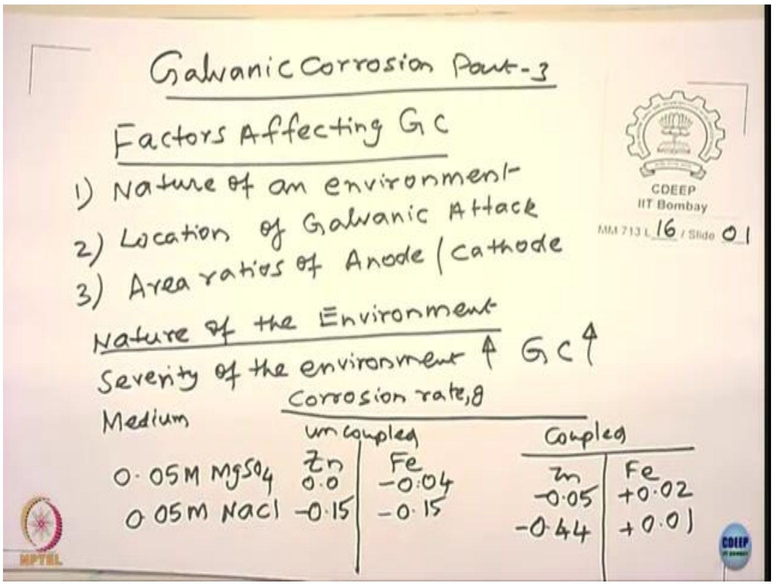

Galvanic Corrosion Part-3

Factors Affecting GC

1) Nature of an environment
2) Location of Galvanic Attack
3) Area ratios of Anode / cathode

Nature of the Environment

Severity of the environment ↑ GC ↑

Medium	Corrosion rate, g uncoupled Zn	 Fe	 Coupled Zn	 Fe
0.05M $MgSO_4$	0.0	−0.04	−0.05	+0.02
0.05M NaCl	−0.15	−0.15	−0.44	+0.01

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Now after looking at the electro chemical parameters that govern the galvanic corrosion, we need to look at overall factors, which can influence the galvanic corrosion of dissimilar metals, ok.

So, I term it as factors affecting galvanic corrosion. The more obvious one is the nature of the environment; the second is location of galvanic attack. The third we are using two different metals; two different structures having different chemistry, different electrochemical parameters and that area ratios are very relevant, very important ok; area ratios of anode and cathode.

So, we shall go in details and try to understand. If you understand the factors controlling galvanic corrosion, it will be much easier for you to devise; means of controlling the galvanic corrosion. So, that is what basic idea of analyzing the factors, those can influence the galvanic corrosion.

Let us start with the nature of the environment. We can say the severity of the environment if it increases, the galvanic corrosion also increases; the vice versa is also true, if the environment is quite mild, then the galvanic attack becomes relatively slower, ok.

Now, we can have just few illustrations to demonstrate; how the severity of the environment is going to be influencing. I give two examples; one is the corrosion in magnesium sulfate which is relatively a mild environment, and corrosion in sodium chloride solution which is relatively a severe environment and take the two metals which are steel and the zinc.

If you can look at the corrosion rate of these two metals in uncoupled conditions and galvanically coupled conditions; you will see how the corrosion of the zinc which is more active would change, significantly if the environment becomes very severe. This is a data taken from the Fontana's book, you can just have you know feel for it; lets take the case of 0.05 molar magnesium sulfate, zinc which really does not dissolve and corrode, steel corrodes.

When you galvanically coupled these two you notice that, zinc corrodes at a higher rate and steel in fact shows a marginal improvement in the weight; in fact weight gain. But you notice that the weight gain is not because of growth of steel, growth of iron; it primarily happens because when you make a metal cathode, you know the pH goes up and some deposition occurs.

So, if you clean them up, you would not see there is any significant improvement increase in the corrosion rate. So, this raise in the weight is not anyway related to the metal deposition here. As opposed to this you take molar NaCl solution over the steel and zinc corrode; see both corrode in fact the corrosion rate is almost the same, primarily because it may be diffusion controlled, right. The diffusion controlled it does not depend upon the corrosion tendency of a metal, right.

In the coupled conditions you will see that, zinc corrodes at much high rate and steel it does not corrode at all. So, the corrosion rate of the active metal here; I mean the relatively active metal here, it is a zinc is very much dependent upon the how severe the environment is and the environment here sodium chloride proves to be very aggressive in nature**.** There are also cases where the galvanic tendency of the metal changes if you change the temperature or concentration; it is possible at given temperature and pressure or a concentration, one metal act as a active, other one act as a noble. Slightly change the temperature, the metal which is active turns into a noble metal.

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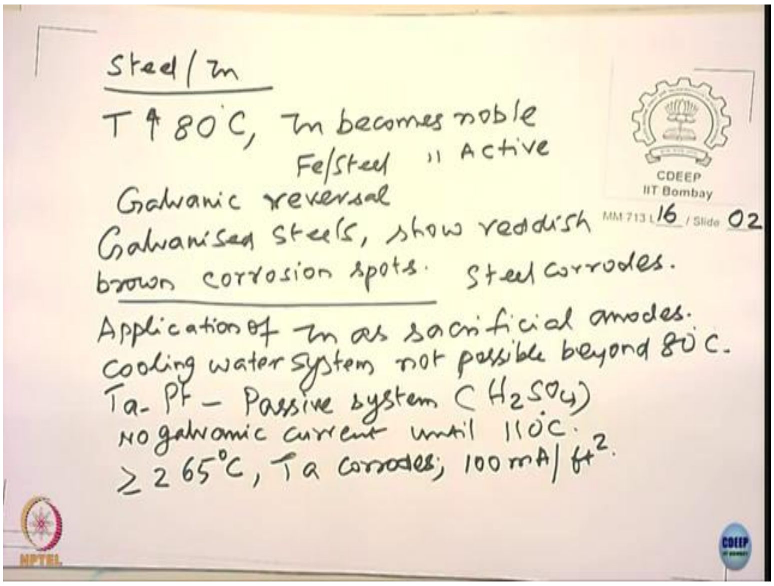

Steel / Zn

$T \uparrow 80^\circ C$, Zn becomes noble
Fe/Steel " Active
Galvanic reversal
Galvanised steels, show reddish brown corrosion spots. Steel corrodes.

Application of Zn as sacrificial anodes.
Cooling water system not possible beyond 80°C.
Ta- Pt – Passive system (H_2SO_4)
No galvanic current until 110°C.
$\geq 265^\circ C$, Ta corrodes; 100 mA/ft^2.

These things are having practical relevance importance. We give some examples; let us take the case of steel versus the zinc here. And all of us know that galvanized steels and the zinc coated zinc you know it sacrifices and then steel is getting protected, right.

But if the temperature of the coating is increased, if the temperature goes beyond 80 degree Celsius; zinc becomes noble and iron becomes iron or steel becomes active and this is called as galvanic reversal. Such a phenomena has a practical problems; one is you have seen that you know, the galvanic corrosion of steel; you know if the steel is a galvanized steels, what does it mean? Here steel corrodes.

One more example which is relevant we will discuss it little later actually, is application of zinc as sacrificial anodes in a cooling water system not possible beyond 80 degrees. Why? The zinc starts passivating, it loses its protective nature; in which case you may have to use magnesium or anyway zinc is not going to work.

There are few more examples which is important, in fact very interesting; you take tantalum and platinum, this is a passive system this is sulfuric acid right. And you will see no galvanic, no galvanic current ok, until 110 degree Celsius. Temperature of the sulfuric acid; we have no problem, you can have platinum and tantalum coupled together, you do not give any galvanic corrosion rate at all.

But if you raise it above or equal to 265 degree Celsius and tantalum corrodes, and you will see galvanic current of about 100 milli amperes per square feet. The tantalum turns into a active metal, the galvanic corrosion was not operating at all. There is one more practical example is you know, the thin coated steel containers for storing the food right, it is a beverage cans, ok.

If the food, I mean the if someone say juice for example, orange juice or apple juice, it decomposes and give rise to organic acid, it attacks tin tin complexes, the tin becomes active; otherwise tin is a noble metal right compared to steel, ok. That is not going to work; now steel, I mean your tin starts corroding because of the complexing of this actually.

So, such kind of galvanic reversals are of importance in industries and should be taken care of or should be studied very well before you select the system. Let us look at the location of the galvanic attack, take an example.

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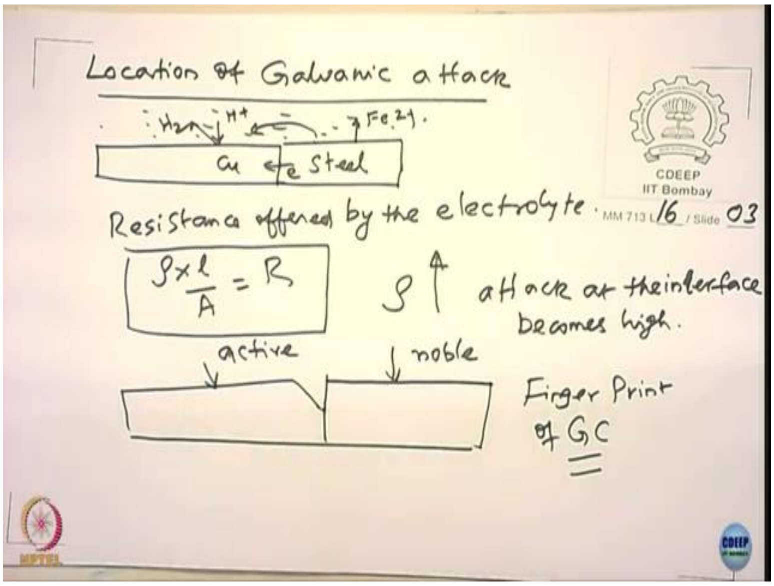

Location of Galvanic attack

Resistance offered by the electrolyte.

$$\boxed{\frac{\rho \times l}{A} = R}$$

$\rho \uparrow$ attack at the interface becomes high.

Finger Print of GC

Student: (Refer Time: 13:46) these is the reversal in galvanic content.

In which case see.

Student: Why is this reversal occurring increase in temperature?

In the case of tin you are, in the case of zinc you are talking about.

Student: Yeah.

Yeah. See you take in the case of zinc ok; you raise the temperature, a zinc forms a nice adherent zinc hydroxide, zinc carbonate which are somewhat similar to passivation. And you know that when the metal is passivation, the corrosion potential moves up, the corrosion rate drops; whereas in high temperature, steel does not get protected, it does not form a protective oxide film.

So, the corrosion potential of zinc becomes higher compared to the corrosion potential of steel, because steel does not form any passive films. Please understand the galvanic corrosion depends primarily on E_{corr}, it does not depend on corrosion rate at all.

The first and foremost condition is the potential difference; a Tafel slope, exchange current density all of them are important. But, if the potential difference between these two metals do not exist, then there will be no galvanic corrosion or the one which exhibits relatively active corrosion potential will act as a as an anode, ok. So, the potential what happens?

So, surface changes would bring in this kind of effect. Tantalum is the similar situation; raise the temperature sulfuric acid the passivation is no more stable, it just goes away. A tantalum is one of the reactive materials right; how does the corrosion resistance for tantalum affected? Somewhat similar to stainless steel or titanium alloys; in fact better than titanium alloys, the oxide film is very stable, ok.

And that is why a tantalums used in most aggressive environment, although it is very expensive. But, oxidized films are kinetic resistance right, if you raise the temperature, the film breaks, the film dissolves and so the galvanic reversal occurs this case, right? Ok. Thank you for the question.

Now, look at the location of the galvanic attack, it is very important relevance for us actually, ok. Let us take an example of let us say a copper, you have a steel and it is exposed to the environment. And you know that this is the anode right and electrons move like this and that is going to be maybe H plus or oxygen whatever the comes and hydrogen is getting liberated, agreed? This is what happens. Now you tell me where will the galvanic attack be severe in this case, the most severe? Yeah.

Student: Interface.

At the interface right; the galvanic corrosion will be more severe at the interface. Why it is more severe at the interface?

Student: (Refer Time: 17:38).

The answer is correct; why it is more severe you consider? The potential difference between these point and this point remain the same that is going to be almost independent of that, ok. What more is coming to picture here? If the resistance offered by the electrolyte right, the resistance offered by electrolyte. So, the current flows like this what; electrons flow this way and current flows in the electrolyte.

So, if the current has to flow from this end to the other end, foremost end, the resistance increases that the quantum of current that reaches this place will be less compared to the quantum of current that reaches to the interface, because the resistance it depends on what? Resistance depends upon the

Student: (Refer Time: 18:37).

Rho into l upon A gives you the resistance.

$$\frac{\rho \times l}{A} = R$$

The resistivity of the electrolyte, the length over which the current is going to flow; of course area of which the current is going to flow, cross section over which the current is going to flow related to resistance.

So, as this the resistance increases, the quantum of current it is going to flow reduce. So, the amount of current corrosion is going to be decreasing from this point to this point. So, that means if the resistivity of the electrolyte is increasing, what is going to happen?

Assume that there are two electrolytes; one with a higher resistivity, the other with the lower resistivity and you will see the attack and what kind of attack difference you will find? The same copper and steel; one with a higher resistivity, other one with lower resistivity; what kind of differences do you see by just observing them**?** That is true, but between the two.

Student: The one.

Student: If the resistance is via in the electrolyte in that case it will be high.

Yeah. So, when the resistivity is more, the localized attack is more and the attack is confined to the interface right; more than the attack at the interface face becomes high. In fact this is one of the characteristics of galvanic corrosion, ok. If you want to diagnose a problem, if you see in the industry that there are two different you know set of metals which are electrically shorted.

And you want to show that there is a galvanic corrosion; the first criteria is that what? The interface should have a deeper attack; in fact attack will be something like that. This is your active metal, your relatively noble metal right. All the on the other hand assume that I have pipeline, and pipeline I got you know the two different metals in the pipeline, ok.

And I have a pipe. So, one side is a little bit active, other side is little bit noble; the fluid is going inside and it is corroding. If the corrosion is away from the interface and is severe, would you call it as a galvanic corrosion? And it happen in the active metal, right. Would you call it is a would you call it as a galvanic corrosion? Do you get my question? So, pipeline carrying of corrosive fluid, the pipeline has got you know two parts; part 1 is active metal, part 2 is noble metal and they are electrically shorted as interface. Pipeline leaks, you found that the leak has occurred at the anodic member of pipeline.

But you also notice that the leak is not at the interface, it is about say about 10 centimetre away from that or 5 centimetre away from this; would you call that as a galvanic corrosion? You have to give an answer.

Student: (Refer Time: 23:02) films.

Why do you call a galvanic corrosion then?

Student: Copper by the electrolyte.

Yeah.

Student: So, (Refer Time: 23:13).

If the resistance is offered, then you should be confined more towards; when you say resistance means what, higher resistance, then you should be more confined to interface.

Student: If the (Refer Time: 23:26).

Student: If there is a resistance, but still the corrosion is occurring.

Student: So.

Student: Sir liquid is moving.

Yeah liquid is moving; that is what the problem we get in the industry, right. Now what do you think; if the corrosion has to occur by galvanic mechanism, there is no other way, but the interface has to corrode at higher rate. Is there any other way you can do that?

When the resistance of the electrolyte is you know of the electrolyte it increases from the cathode to the anode has to move away from it. The current will not flow more, we expect current to flow more at higher distance and less current at the interface, the physics does not permit. It has corroded no doubt; but it is not due to galvanic corrosion at all, it is not going to happening, you need to diagnose what the problem is.

There may be other form of corrosion that is happened; but yes certainly it is not a galvanic corrosion, ok. So, it is very important that you need to know the fingerprints; you need to know the characteristics of the corrosion failure.

The characteristic of corrosion failure is; it happens in the active metal, it happens more at the interface. If it happens for example, at the noble metal; you would not call a galvanic corrosion, maybe something maybe a erosion has taken place, metal may be noble, but is softer it happen, maybe there are some microbial corrosion taking place.

So, it is very important that you need to understand the fundamental and then try to relate to the failure; it cannot be having a conflict with the basics, ok. So, it is not really a galvanic corrosion, in which case it may be different; then you need to diagnose and find out the root cause, why the corrosion has taken place there. Now this is in fact is a fingerprint of galvanic corrosion; the environment is less severe the (Refer Time: 25:52) attack become less only; but you cannot say that corrosion occurs far away and so there is, it is a galvanic corrosion.

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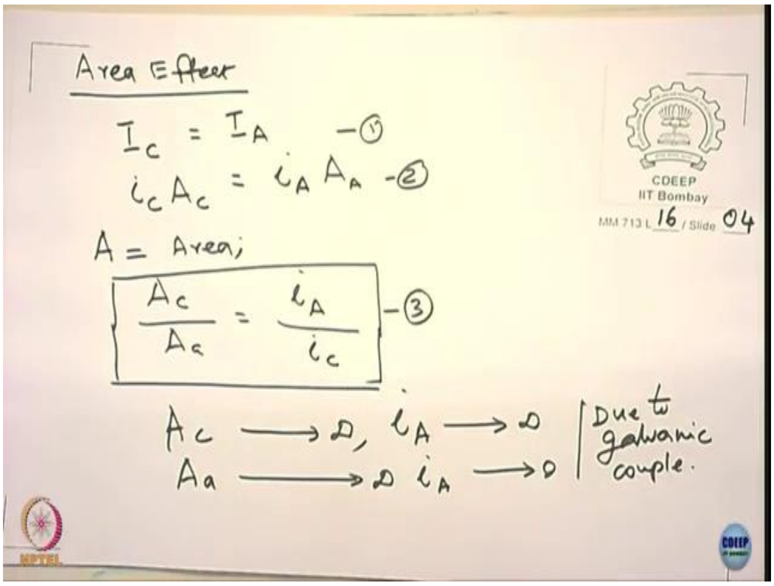

Area Effect

$$I_c = I_A \quad -①$$

$$i_c A_c = i_A A_A \quad -②$$

A = Area;

$$\boxed{\frac{A_c}{A_a} = \frac{i_A}{i_c}} \quad -③$$

$A_c \longrightarrow \infty$, $i_A \longrightarrow \infty$

$A_a \longrightarrow \infty$ $i_A \longrightarrow 0$ | Due to galvanic couple.

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Let us go into the next important aspect of it, the area effect. It is very easy to understand and it is a very impacting in designing structures to avoid galvanic corrosion. Let us look at the mixed potential theory and see whether it helps us. You know that total cathodic current is equal to the total anodic current right, it cannot really change. Now what is this is equal to what? This is equal to current density

Student: (Refer Time: 26:52).

Multiplied by the area of the cathode; it is equal to right; current density at the anode and area of the anode, agreed.

You know what it is right; A represents what? A represents area and other variables that you are aware of it, right. Let us rearrange this equation 1, equation 2, 3; what do you understand from this equation? Yeah.

Student: (Refer Time: 27:47).

If the area, if the cathode area of the cathode is becomes very high; the corrosion current density on the anode is going to be.

Student: High.

High, so that means, you can say that if a cathode tends to become infinity, i_A is going to tend to become infinity; when I say i_A here, I mean the increase in the corrosion rate because of galvanic action. On the other hand Aa tends to become infinity i_A tends to become 0 due to galvanic couple, understood.

So, what does really mean in practice? If you are an engineer you want to construct certain component; what should be the design criteria? Yes, you should take care that, that the component you are thinking about you are choosing a material you have to choose two metals, you have no choice, but to do that.

Should always ensure that the anode is larger and the cathode is smaller; the vice versa could be a real problem, ok. And this can be also seen by the mixed potential theory as well, ok. Let us look at the mixed potential theory, see whether it is correct or not.

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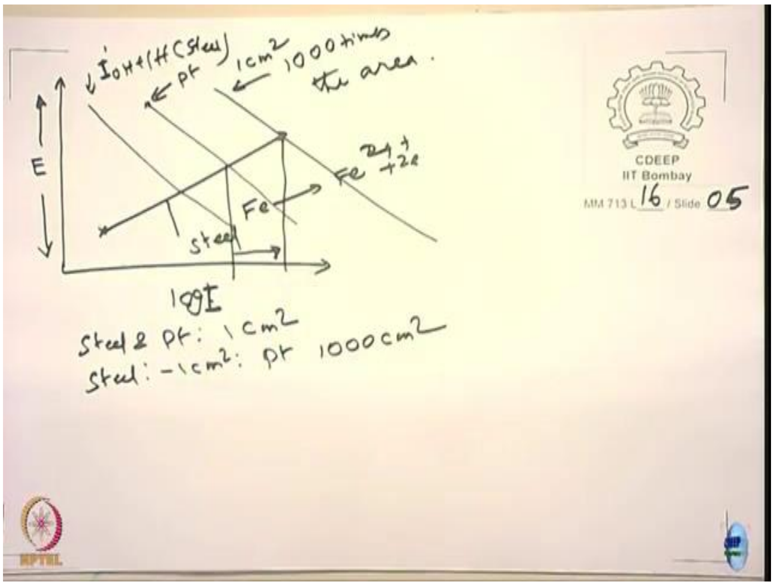

I am putting log capital I here, I am not using here small i; capital I means what current right, ok. And assume that this is steel, steel and so it is iron going as F e 2 plus; in acid right. And I have the area ratio of iron and platinum are equal to 1; I am not showing the cathodic curve corresponding to steel, because the hydrogen evolution on steel is lower compared to hydrogen evolution or you can show it here, it is ok, $i^o_{H^+/H}$ on steel, a then you can use platinum, platinum right.

This is area ratio is it is let us say is 1 centimetre square you know, steel platinum 1 centimetre square, steel 1 centimetre square; I make platinum it is about 1000 centimetre square. When I make it 1000 centimetre square, you can please make a I think see it is a small change here, you cannot make it i^o here should be capital I ok, because we are talking about the area; we are not talking about the normalizer, we are talking about actual current, right.

So, if you are going to have multiply the area of that, it going to be like this ok; this is 1000 times the area, ok. So, the corrosion rate would increase because of the galvanic action. And this has some practical implications and I just repeat the illustration given in Fontana's book; it is not too concentrated, but it is you know it is in reasonably concentrated sulfuric acid.

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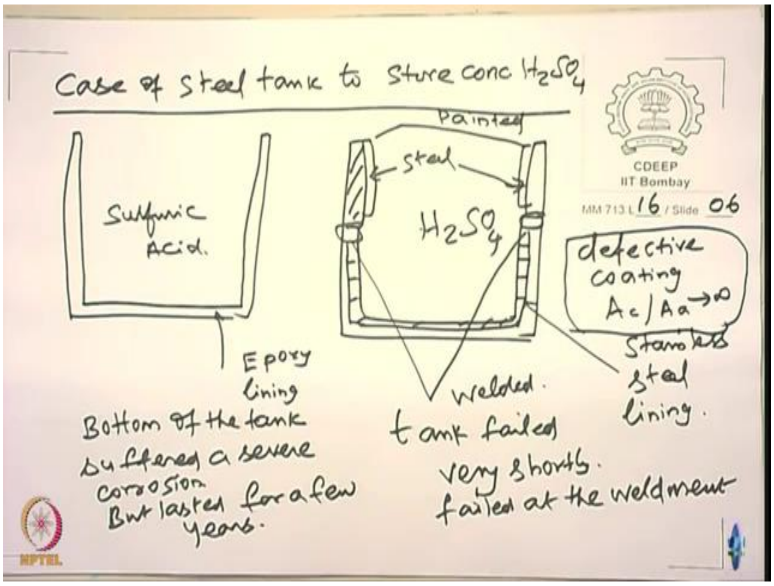
Case of steel tank to store conc H_2SO_4

Bottom of the tank suffered a severe corrosion But lasted for a few years.

tank failed very shortly. failed at the weldment

defective coating $A_c/A_a \to \infty$

See if it is very highly concentrated sulfuric acid ok, you do not need anything, the steel is it offers very high resistance to corrosion; but moderate concentration and dilute concentration you know you know dilute acids, a steel corrodes heavily in in sulfuric acid.

So, how do how does the how does this steel becomes resistance to corrosion? You apply a coating; you called a lining actually right, you give a epoxy lining. The difference between a lining and a coating is the following; the coating is normally given in order to prevent the corrosion of the metal, but lining is given not only to prevent the corrosion of the metal, but also to see the product does not contaminate, right.

So, you know I mean, you may allow metal to corrode because you can replace it; but if the sulfuric acid has got too much of iron corrosion products there is no use. So, the lining is generally meant to you know prevent corrosion to the extent that, the corrosion products they do not contaminate whatever process fluid that you are talking about.

Now, initially a tank was, steel tank was used and they had this was the epoxy lining, this is sulfuric acid; it working well ok, it gave us too few years of service ok, there is no problem. But what happens know, there is always a mechanical damage; you know people you want to clean the tank and. So, when you start cleaning the tank and the bottom of the tank more often suffered the corrosion, severe corrosion.

But lasted for a few years; 7, 8 years it lasted and they found that the corrosion is more often on the bottom, is more due to mechanical damage due to corrosion damage. They thought that they can line this tank with stainless steel; stainless steel is harder and mechanically it is quite sound and you know you do not have to worry about mechanical damage. When they want to do a lining of stainless steel, then you thought that let them let us not line it completely the tank; because this cost more, see many other tanks are very very big, right.

It you know you can save money by reducing the you know the lining and it is happening anyway only at the bottom of it; so they started giving a lining in this manner, they gave a lining to this. And the top portion, the steel and it was a steel, the tank and it is coated; it is not really well drawn anyway, it is a paint, this is painted.

How do you line it? And this is a place you weld right, weld it and you can see you can make it little more neat; this is stainless steel lining, stainless steel lining is done. Interestingly this is sulfuric acid, now tank failed very shortly. And it failed where? Failed at the weldment.

Now, you see here, you spend on the stainless steel very high expensive lining; despite that the life is very short, very interestingly the guy diagnosed saying that the painting is bad and so the tank failed. Because the painting occur, I mean the corrosion occur at the paint and this place is welded here right and you weld it and painting is always difficult at the at the painted location, right.

Normally you grind very nicely and then you paint; so the person said that oh the failures happened because of the improper painting, come back. And then we went on to say that you should we should redo the painting; but some wisdom prevailed and try to look at why it is failed? Why it failed? Before I go into that answer, can you anybody guess?

Student: There is a.

Or find out why does happen?

Student: There is a small prevailed paint thus area of the anode will be very small as compared to that large area of the.

Fantastic ok, the paint can never be impervious, always porous; when the paint is not impervious, it is porous now what happens? They are very fine finite place, small locations you have an anode; not only that, you have a lining which is stainless steel lining which is a cathode, that cathode is of infinite area compared to very finite anode below the coating defects.

So, very highly accelerated corrosion taken place, right. So, the reason is simple, this is what is the reason. The reason is ok, defective coating; then what happens? You have Ac upon Aa tend to becomes infinity. Why it failed? So, there are several such cases, why coatings you know ought to be given only on cathode if you cannot coat both, right.

Or you coat completely suppose had the guy has coated completely both the anode and cathode, then what happens? There are defects, the paint coating; the cathode also very small in number right, small in area no problem. So, this leads to the understanding that if you have dissimilar metals, you coat both the anode and cathode; if you cannot coat, then what happens? They coat only the.

Student: Cathode.

Cathode. So, if you can coat only the cathode, then what happens; then you will have a very very finite area of the cathode, the galvanic corrosion becomes very minimal and you would not have any problem at all. So, coat both anode and cathode; or if not possible, coat only the cathode and not the anode.

So, such kind of surprising you know conclusions that will come out of understanding of the parameters affecting the corrosion, ok.

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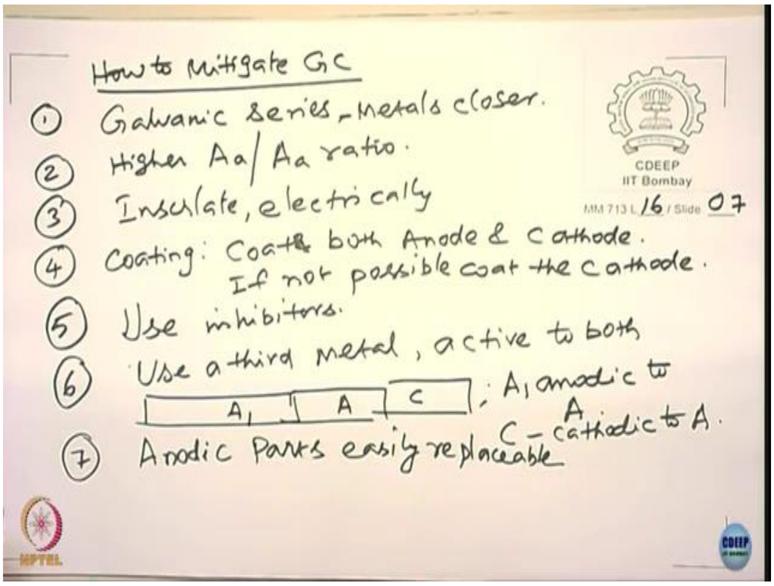

How to Mitigate GC

① Galvanic series – metals closer.

② Higher A_a / A_a ratio.

③ Insulate, electrically

④ Coating: Coat both Anode & Cathode.
If not possible coat the cathode.

⑤ Use inhibitors.

⑥ Use a third metal, active to both

A_1 | A | C ; A_1 anodic to A
C – cathodic to A.

⑦ Anodic Parts easily replaceable

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So, we have seen now the factors affecting corrosion then I think you should able to now find out or able to propose; how to prevent or mitigate galvanic corrosion? Yeah I want a very quick answer, quickly you should move forward. How I mitigate galvanic corrosion?

Student: As far as the we would avoid use of.

Avoid use of dissimilar metal that is simply not possible ok; in many cases you have seen in the case of heat exchanger not possible. If I have to use, then I have to use I use what the first criteria; what do I see look for first?

Student: Larger anodic area (Refer Time: 43:47).

I look for anodic area I look at it, but I if I can choose metals.

Student: As close as (Refer Time: 43:52).

Student: Important.

Yeah.

So, I look at the galvanic series right, look at the galvanic series ok; metals closer in the galvanic series. What more I do that? I can also look at higher anodic and ratios ok; where is it is it is possible, if you look for higher anodic to cathodic area ratio. Then what happens? I can isolate electrically right; I can insulate, insulate electrically. Please look at it where possible you know, it may not be possible everywhere, ok. What else I can do? Coating right, it is coating; it is an important lesson here, right. What is the lesson here? Coat.

Student: Both coat.

Yeah both coat, coat both anode and cathode; if not possible, coat the cathode. So, we also had one more lesson in terms of effect of environment on galvanic corrosion; what is that? More severe is environment, more severe will be the galvanic attack. So, how do I reduce the corrosivity of the environment?

Student: Inhibitors.

Yeah, what is that? Inhibitors right, use inhibitors they are done, in cooling water systems, people add inhibitors. What more you can do?

Student: (Refer Time: 46:43).

Yeah you can use the third one, use the third metal active to both ok, this is used much in industry.

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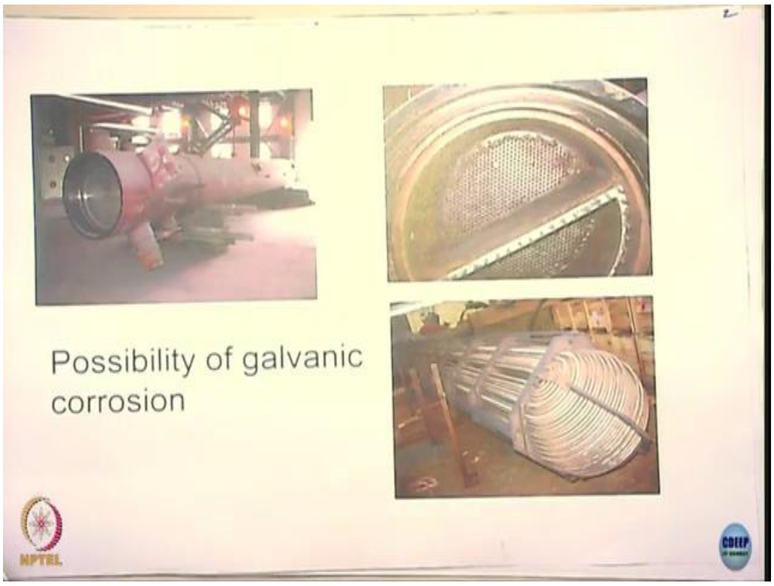

Possibility of galvanic corrosion

This is done mostly in industries I just given, this figure you seen before right and it is an heat exchanger, this is the this is called as header or water wall boxes header it is; these tubes generally are stainless steels, that the galvanic corrosion here. How do I control galvanic corrosions?

You can in these places, you can use zinc anodes, zinc anodes, zinc anodes ok; when I weld these places with the zinc anodes, what happens now? The steel though active to stainless steel, it is rendered noble with respect to the zinc.

So, zinc corrodes. So, you know couple of years no problem and you can replace the zinc anodes periodically and it is done in industries ok; it is not uncommon, it is done widely practiced in order to reduce the corrosion of corrosion of the active metals, it is done.

So, use a third metal, that means you have ok; this is your cathode, so anode. What happened? You are going to use A1 and A1 is anodic to A. And C is what? C is a cathodic. So, you can have you can replace this A1 all the time, I am you know whenever you find this anode is dissolved. So, it is a sacrificial one, ok.

You can also do one thing, you can also you know 7 make this anodic parts easily replaceable. You can design that right, you please notice we have given some 7, 8 like this right 6, 7; not necessarily that all of them will work, it depending upon the particular application, you might use combination of one or two or one or more. The idea is that the cost bring down and there is a reliability is safety in the system, ok. So, that is an engineering aspect of ok; what kind of technique can be used to avoid the galvanic corrosion of metals.

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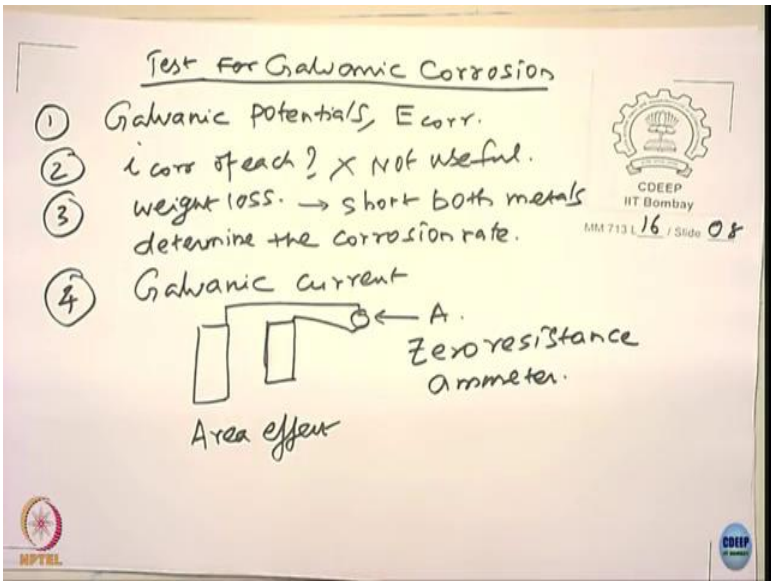

Test For Galvanic Corrosion

① Galvanic potentials, E_{corr}.

② i_{corr} of each ? × Not useful.

③ weight loss. → short both metals determine the corrosion rate.

④ Galvanic current

← A. Zero resistance ammeter.

Area effect

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So, we are talked about a mitigation, let us go to the last important one that is how do you test for galvanic corrosion. So, what are the testing that you would like to do? The most simple test.

Student: (Refer Time: 50:27).

What would be that? I just give two metals, I want to know if they are compatible or not or I give three metals, you find out which is which are the two are most compatible? I want to do a very quick test, ok. What test will be useful?

You studied all of them, all parameters now; three metals are given to you or I will given you, let us say half a dozen metals are given to you, you do not have much time I just want to choose two of them. Otherwise all six of them are all satisfy the requirements like whatever requirements I want to choose.

Student: (Refer Time: 51:13).

Yeah.

Student: Potential difference.

First of all you can determine the galvanic potentials, right. It is like I called as E_{corr} actually ok, E_{corr} at a given environment you just measure it, right. You choose those two metals which lie close in E_{corr} values, right. So, E_{corr} is one important parameter; but it does not give you the corrosion rates right, it does not give the corrosion rates.

So, in order to determine the corrosion rate in the galvanic systems; what parameter do you use? Will i_{corr} of each of them will work? It will work, I give you i_{corr} of metal A, i_{corr} of metal B; will that be useful you think, can use that? Whether be useful, not useful; if useful how it is useful, if it not useful tell why it is not useful?

Student: Does we need to know that the corrosion (Refer Time: 52:31).

Yeah.

Student: (Refer Time: 52:33).

Yeah. So, i_{corr} by itself is not useful, it cannot give you a direction which of the two will undergo corrosion first of all; it does not even tell you which of the two will be anodic in nature or cathodic in nature. So, not useful, ok. I can do a weight loss method, right. I can do a weight loss method. What I can do? I can short both of them right and I can determine the corrosion rate right; I can just short, short both the metals, determine the corrosion rate. This is a time consuming, it takes more time, right. What I can do?

If I want to use a Faraday’s law and I just given a clue right and I want to find out you know what kind of corrosion rate. You know I just give half an hour, assume that system is stable; in half an hour times I want to find out the galvanic corrosion rate. What parameter do you measure? Assuming that the system becomes stable of course; what do you want to measure? I can measure galvanic current or not? I can measure the galvanic current, can I?

Just have metal one, metal two, only problem here is I should use a zero-resistance ammeter; otherwise what will happen? The ammeter itself will offer a resistance, the current flow will be reduced, right. So, use a zero resistance ammeter you can do that. So, it is a quick method, it may not take as much time as it will happen in the case of weight loss.

But these two techniques suffer one problem; what is the problem? The galvanic corrosion it depends on what? It depends only on two different metals and difference anything, anything more? Yeah of course, that is taking care of here right; anything more that will affect the corrosion rate of the active metal? Environment is known, is that is given to you use environment only yeah; tell me what is that?

Student: Area.

Area is going to change right; if you are going to change the area, then the rate of attack of the anode is going to be different, right. So, there is going to be one more effect which is the area effect. So, which means when you do a test, you want to ask the question what is the area ratio in the actual field; I need to choose that area ratio, otherwise the corrosion rate so measured will not reflect the corrosion rate of a given metal in a given component, right.

So, area effect is a very important one. So, you may have to do several tests to find out what happens to the corrosion rate in the area if it is changed, ok. So, that can be circumvented by a simple technique which is called as the electrochemical technique.

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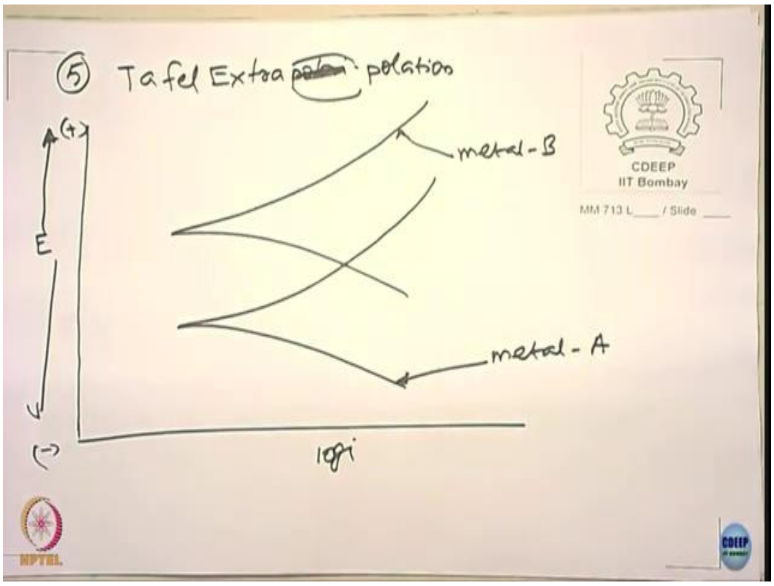

And use Tafel extrapolation; I hope you understood what I am, what I am trying to say. How do I, how do I determine? I say that I carry out only one test for the anode and one test for the cathode, so called cathode and I use the data for all variations in the area, right.

Can I? I give you only one data for anode, an so called anode, both cathodic curve or anodic curve and I gave one anodic curve and one cathodic curve for the noble metal.

Now, I say hey please use it for different area ratios, possible? Not possible. So, I carry out electrochemical experiment right; I just carry out an electrochemical experiment, is scanned from one potential to another potentials, I get this, ok. And so, this is the data I get; current density versus see this, this is the data I give it to you. From this can you determine the galvanic corrosion rate, if the area ratios are changed? Assume that the cathode is becoming hundred times more in terms of area; what happens?

Student: (Refer Time: 59:20).

So, you would, ok. So, what do you do in that case? So, you multiply this by hundred times, right. So, you do not plot I, small i, plot current here log current versus this. And so, these you multiplied by 100 times, it moves over here or is the anode is I mean sorry this is metal A; metal A in this case is this anode here, but if the sorry, see this is the cathode in this case right ok, it is a cathode here, is a anode here, right.

So, you multiply this by hundred times, it moves here; if the anode is hundred times you know larger in size, then you multiply this current by hundred times, then you start moving up here. The same curve can be used to determine the galvanic corrosion rate of metal under different area ratios; all you need to do is, you need to get only one polarization curve for the different metals and then you can find out the galvanic corrosion rate of the metals, ok.

So, it is much easy. So, what I mean is that; this where you understand how the Evans diagrams, how the electrochemical kinetics will help you in many ways in ok, even testing also, we can make it a very effective testing, ok. And you have any questions? So, with this we complete our discussion on the galvanic corrosion rate of metals. We saw in the beginning that, the galvanic corrosion primarily occurs because of the galvanic potential difference between the two different metals there in service.

The galvanic corrosion does not depend upon the equilibrium potentials of course. And we also looked at the cases like active metal and noble metal and two different active metals and the passive systems. And we say the electrochemical parameters such as exchange current density, Tafel slopes, the equilibrium potentials or the factors that control the galvanic potential, the galvanic corrosion current density, ok.

The extent of corrosion depends upon the nature of environment like, how corrosive it is. So, when the environment is changing its properties, you rise a temperature and all these issues; then that can be change in the galvanic behavior a one metal can turn into, a the metal which was behaving earlier as a noble metal can turn into active metal. And the other important thing is the fingerprint, the signature of the galvanic corrosion is very clear.

It occurs at the anode cathodic interface and the occurs at the anodic side, in fact is a groove, it is not even a straight one; occurs straight one I mean something like that, then there is something more than that actually, ok. Assume that I have you know metal one, metal two; it occurs at the anodic side, but occurs fully as a groove, is not like a you know, it is not like a V groove, then it is not really in my view it is not going to be a truly a galvanic corrosion, there may be some segregation of something happening at the interface.

So, the fingerprints of galvanic corrosion need to be understood. The other important area which you need to going look at is that, if you have a component where you are fabricating with two different metals; the anode area has to be always larger and the cathode area has to be always smaller. And we also seen how the Evans diagrams can be used to determine the galvanic corrosion rate of metals with a simple experimentation. And with this we will end our discussion on the galvanic corrosion of metals. In the next class I think we will go on discussing about the crevice corrosion, ok.

So, thank you very much.