

Aqueous Corrosion and its Control
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Lecture – 26

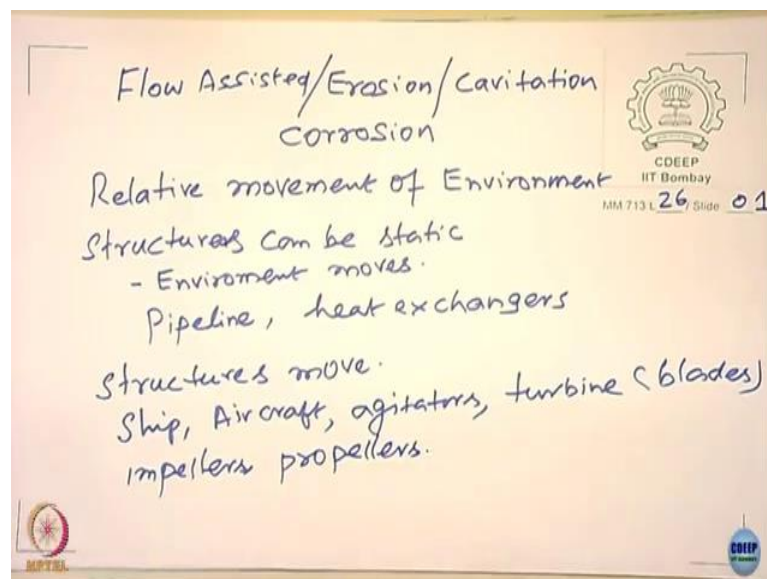
Forms of corrosion: Flow assisted corrosion and erosion corrosion (Part- I)

Today, we shall look at the effect of the flow of corrosive environment on the corrosion of metals. So, far what we discussed was related to the environment being very static. And in several cases at least in industry, the environment need not be static, the environment you know there is a flow. There are so many complex flow conditions that exist in the industrial scenario. The corrosion of metals are different if the environment flows in relation to the metallic structures. So, this topic so assumes very greater importance.

So, we will discuss in detail what are the kinds of flow that affect the metallic structures from the corrosion point of view. And what are the mechanisms involved the factors that control the flow assisted or velocity affected corrosion.

And then also we look at the control measures.

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So, here we would say that flow assisted, I am going to separate out like this and or erosion or cavitation corrosion. Now, as I told you there can be relative movement of

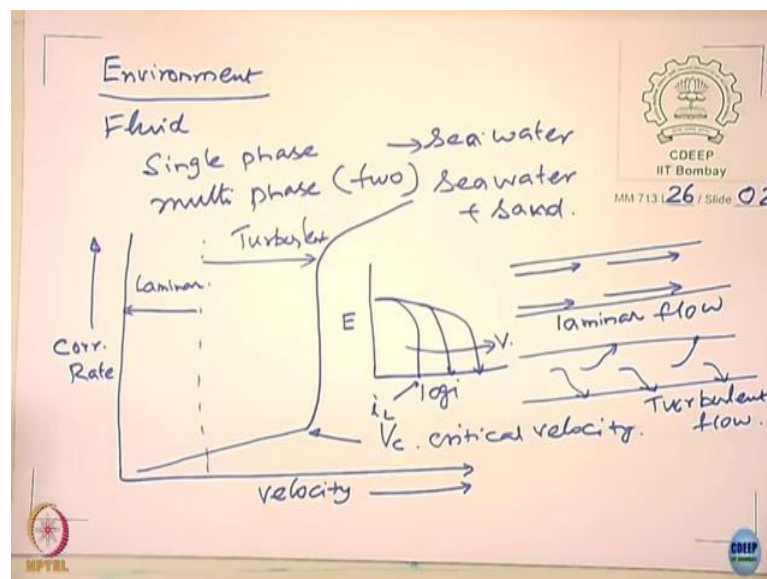
environment, please notice that when you say the environment, we talk about not the benign one, it is a corrosive environment.

Now, let us try to understand what do you mean by relative movement first of all. The structures can be static, what happens the environment moves I would say. See an example it is pipeline carrying water, carrying waste types of chemicals. And example could be heat exchangers. The structure is static, the environment moves maybe at different velocity, different pressure, temperature. The structure move. Give me an example, anybody?

Student: Ship.

You can say ship, velocity is not much, but ok, I mean talk about an aircraft also, spacecraft, so that aircraft moves at a very high speed. Other examples, industrially? Agitators in a turbine, the turbine the blades; it could be a gas turbine or it could be hydraulic turbine, a gas engine. Anything else? Impellers, they move – propellers they move. So, these are about the two types of structures I would like to say ok.

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Now, let us look at the environment. What is mean by the environment here? Of course, you talk about the fluids; at least one has to be fluid, I mean corrosion environment this is a fluid, it could be a single phase or it could be multiphase.

Generally, two phases can happen common right. It is a simply a water, a sea water, an example. This is sea water plus some sand can happen. In a thermal power plant, for example, you talk about a steam generators, you may have a gas, steam, may have water. In a gas turbine, there can be corrosive gases, there can be a particles.

So, when you say fluid, it is not necessarily a liquid ok; it can be a corrosive gases; it can be a liquid, but the solid is not necessarily a corrosive most cases you do not even consider them as corrosive. Their role is to give an impact. We will see this later how they can really affect the corrosion of structures. If you look at you know in the fluid conditions when the when the fluid moves, how the corrosion rate of the structure or metallic structure can change with respect to the velocity.

We have seen in you know somewhere right I think the role of velocity on corrosion, corrosion rate. We have seen before. Can anybody recollect?

Yeah.

Student: Concentration polarization.

Yeah, we are talk about a concentration polarization. When there is a concentration, polarization, when you increase a velocity the corrosion rate.

Student: Increases.

Increases, it is simply a diffusion control process actually there. If there is no different control process, the velocity does not play any significant role. You can go back and see where the first part of the course on thermodynamics and kinetics of electrochemical corrosion.

If you plot this something like that, the corrosion rate initially increases gradually like that, a steep increase in corrosion, then again slope stop like this. There is, you see here there is a velocity called a critical velocity, above which the rate of corrosion steeply increases with velocity.

When you visualize, let say so a pipeline suppose visualize it, and if the fluid moves, travels in the pipeline, if the movement of the fluid is parallel to the surface, what you

call that? We call a laminar flow. The flow rate is increased, what happens now, it is no more parallel to surface, it is going to hit the surface. What do you call this?

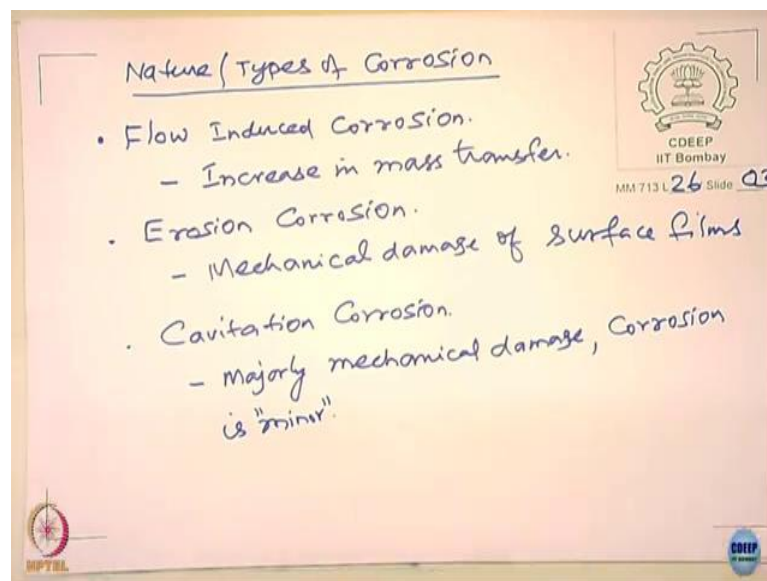
Student: Turbulent.

Now, the laminar flow, turbulent flow, they all depends this described by Reynolds number and there are equations, we will not get into that kind of discussion here. But is it is enough to understand that the velocity or I put other way around the nature of flow decides the kind of corrosion it can happen.

The laminar flow or a turbulent flow that depends on velocity, density, the dimensions of the pipeline so many factors. So, the rate of corrosion over here the nature of corrosion over here is different that of over here can happen.

So, you can say that in this case we can divide this something like this is going to be a turbulent, and it is going to be laminar. And major part of the laminar flow, I mean we can say that can be now the corrosion rate can be controlled by the diffusion processes if it is essentially a corrosion is a diffusion control. Some of you would have the study effect if you can recollect that should recollect, if it is a cathodic reaction, so diffusion control, this is called i_L . And the velocity increases we talked about this in the first part of the class. So, it is a diffusion control process and the corrosion can assist, and the mass transport is important. You see later how the corrosion can get affected.

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Now, depending upon the kind of flow conditions exist in a pipeline, the types of corrosion can be broadly classified into three types. Nature, I call as types of corrosion which are induced by the flow. One is called as flow induced corrosion; this is essentially related to increase in mass transfer; mass transfer of what? The mass transfer of the corrosion product, how quickly it can get removed from the surface. Earlier we talked about the diffusion control process of what, in that case what is what is diffusion control there?

If you remember, when we said here, what does the mass transfer control here? It is the cathodic species that is mass transfer controlled. You will see here in this case, it is not necessarily the cathodic species reduction species mass transfer controlled, it is anodic species which are mass transfer control. I will just talk about soon.

Next is an erosion corrosion. Here it is mechanical damage, mostly of surface films. So, there in an impact, there is there is really erosion taking place in the sense of mechanical factor. The other one is a cavitation corrosion; it is majorly mechanical corrosion, if you can say is minor I put within quotes, is minor.

Now, we have classified the corrosion occurring on a metal into three different categories, primarily because the mechanism of corrosion in all these cases are different. When the mechanisms are different, the solutions are going to differently.

So, we are not going to apply the same solution all the case of course, I mean, there can be an overlap of properties and the protective measures, but distinctly they are different. You can see that.

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The slide is a handwritten note on a light-colored background. At the top left, the title 'Flow Induced Corrosion' is underlined. Below it, the text reads 'Flow assist the solubility of Corrosion products. Reduce film formation.' This is followed by a list: '- Enhance corrosion.' and '- Single / two phase flow.' To the right of the list, there is a note: 'Thermal power plants 1997, 63 plants.' Below the list, a diagram shows a vertical pipe with arrows pointing outwards from its surface, labeled 'Fe²⁺' and 'Fe³⁺'. A layer on the pipe surface is labeled 'Fe₃O₄' and 'film formation'. To the right of the diagram, there is a note: 'Solubility of Fe²⁺ / Fe³⁺ is less than the conc of ions'. Below this, it says 'high flow rate' and 'low conc of Fe²⁺ / Fe³⁺'. In the top right corner, there is a logo for 'CDEEP IIT Bombay' and the text 'MM 713 26 / Slide 03 04'. In the bottom right corner, there is a small 'CDEEP' logo.

So, now let us look at the first type of thing, I mean that is the flow assisted corrosion, flow induced or flow assisted we can we can called either way actually. What is this flow induced corrosion or flow assisted corrosion? What is this? What does it do? What it does is that, the flow that happens in the system mostly in the pipelines. They assist the solubility of corrosion products, then reduce film formation, and so you can enhance corrosion. It can happen in single or two phase conditions, two phase yeah two phase flow I would say.

Let me try to explain what we mean by this all this factors here. The flow assisted corrosion was first a problem, or found in thermal power plants. Here found in a thermal power plants and they made a survey in 1997 of 63 power plants, 63 plants utilities. In all these cases, they have found quite an extensive plants suffered the flow assisted or flow induced corrosion. Now, you know in power plants, what we use I mean to I mean you generate steam, and steam is used to run the turbine, so that means, you are going to use water, it is essentially a pure water. So, we are not discussing that probably in the next course on industrial corrosion control, we will talk about corrosion of boilers and all the steps.

The generation of steam means you use pure water, there are certain specifications depending upon the pressure of the boilers. They maintain the pH; they maintain the purity levels, conductivity and so on so forth. They normally use steels. How does the

corrosion resistance of the steel occur there? Primarily because by controlling the pH, you can do that.

When you do that, they form a film on the surface. See, otherwise you can imagine that steel in typical boiler, the temperature can be about 250°C to 280°C, and in economizer maybe 130°C, 140°C, the temperature of the steel tubes are in this range, and use water and you know it will undergo corrosion. You know very well and you have a lot of steel structures here when rain comes you see a flash first, just couple of hours you see or turn turning it is brown.

How is it possible for the steel to resist corrosion here? By controlling the environment, that means, you change into alkaline pH, and the film formation becomes a dominant mechanism of corrosion prevention of steel. So, that means, these oxides are generally a magnetic oxide, this is what is magnetic oxide Fe_3O_4 is a magnetic oxide formed. And this oxide prevents the corrosion of steel structures.

You please look at you have this formation. When does it form? This will form only when the solubility of Fe^{2+} and Fe^{3+} . This constitute Fe^{2+} and Fe^{3+} . Am I right? The solubility of this one is less than the concentration of ions. So, here what happens? You have Fe^{2+} and Fe^{3+} ions are coming, there are dissolving. If the concentration exceed certain limit, they form the precipitate they form a protective oxide please understand this. So, that is how generally these metals are prevented.

Now, if I have a flow, what happens? They swiped away these ions from the surface. These ions are not going to get enriched and so the film formation becomes very low. So, high velocity, high flow rate means low concentration of Fe^{2+} and Fe^{3+} taking place, that means, the metal start dissolving more and more as you increase the velocities.

So, here that is what it means. So, here the velocity increases, the dissolution process by sweeping away the corrosion products that means, the film formation becomes very low in in that cases. So, that is the primary mechanism of corrosion of a steel by flow induced corrosion process.

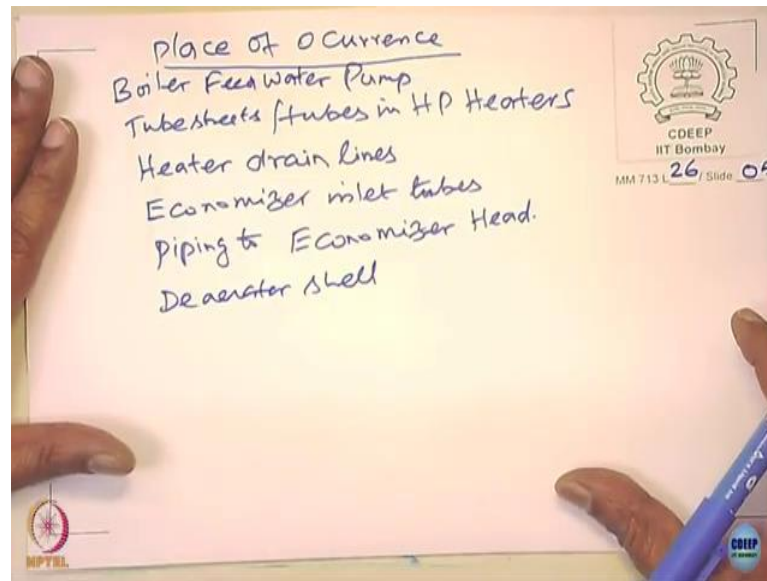
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How do they appear? How do they appear? This is the photographs taken on steel pipeline I mean you know superheated heated water. You see the left side has got a single phase flow here the two phase flow. You can see that the surface is quite rough. Because of the dissolution process the surface become rough, see they are all they are dissolved in water. Here, it is we call as they call as this tiger stripes it looks like a appearance like a tiger stripes. So, they named as tiger stripes.

Please understand that this these are not a very high magnification they are lower magnification they are not microstructures. So, this is kind of appearance of the surface you are affected by flow assisted or flow induced to the corrosion process.

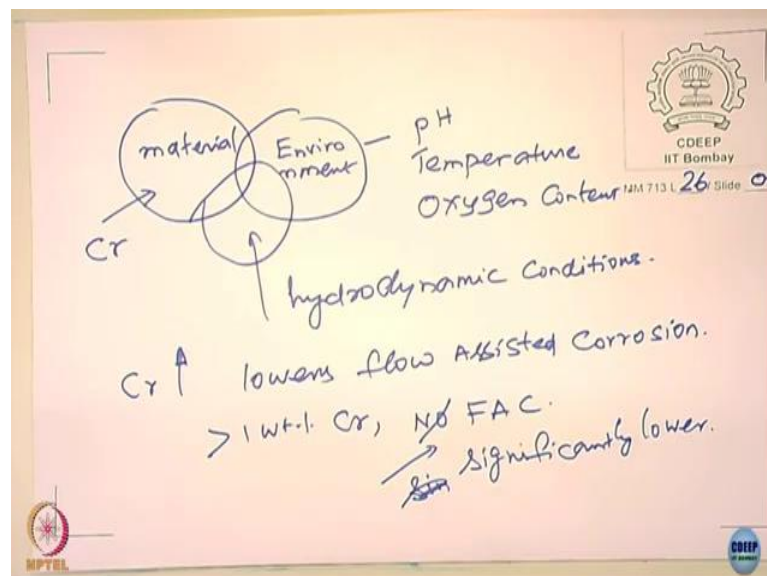
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Now, these are very important. It occurs in the power plants in several places boiler feed water pump, place of occurrence, feed water pump, tube sheets, tubes in HP heaters, heater drain lines, economizer inlet tubings, piping to economizer heads, deaerated shell.

Now, there are several places, I think I just give some illustration that they are important for thermal power plant, of course, can happen for newly power plant as well. So, you have seen now the mechanism of flow assisted corrosion, we have seen the importance of the flow assisted corrosion.

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Now, let us look at what are the factors that affect the flow assisted corrosion; obviously, always have a material component. You have the environment conditions, then you have what is called as hydrodynamic conditions. So, people have modeled this actually in fact this is one of serious problems in nuclear power plants. They have modeled this flow assisted corrosion. The factors that involve are material have seen the environment and the hydrodynamic conditions existing in a flowing system.

Now, in the materials mostly people talk about the chromium content will see later. The environment we have the pH, temperature, the oxygen content, and the hydrodynamic condition means it is all related to mass transfer coefficient. How the mass is being shifted from the surface the solution, so there are going to be a complex parameters.

So, if you look at this, it is very interesting now in a pipeline, the hydrodynamic conditions might change depending upon what? Depending upon the diameter, the velocity, the shape, for example, it is a U-bend or maybe it is an elbow.

So, these locations are affected by severely by this flow assisted corrosion. But these are straightforward pH, temperature and oxygen content. And increase in chromium content is supposed to be better from the resistance point of view, chromium increases, increasing chromium lowers flow assisted corrosion.

And it say that if it is a more than 1 wt.% chromium, there will be no flow assisted corrosion at all. I do not say no and you say I would say I think significantly lower.

Student: Occur in stainless steel?

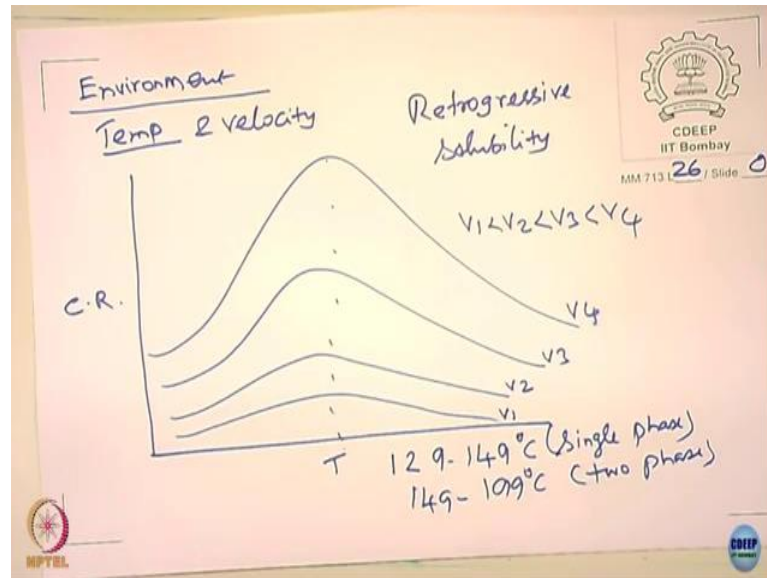
It does not occur in stainless steel. And stainless steels are not used very extensively, because it is an expensive process, materials. So, in economizers many of the units we discussed here, they are not made up of stainless steels, they are earlier they made up of simply carbon steel.

Now people go for chrome steels, 1 chromium or even two, two quarter chromium kind of, but 1 chromium is quite common materials now people use in order to prevent the flow assisted corrosion of metals.

Student: How 1 wt.% chromium?

Yeah, it is a good question. You just give me just some time we will discuss now, you will see how this 1 wt.% chromium is sufficiently enough to form a stable oxide on the surface.

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Let us look at the environment now. First the temperature and the velocity, these two are very critical. So, plot temperature versus the corrosion rate, you will find like this. And very interestingly the temperature in these range these are different velocities v_1 , v_2 , v_3 and v_4 ; and $v_1 < v_2 < v_3 < v_4$.

When the velocity increases, the flow assisted corrosion increases. But notice here it increases a steeply at this temperature; with temperature rises and again there is a drop in the corrosion rate. So, it is a very unusual thing that you notice for any corrosion process.

And it is not same as we discussed earlier you remember earlier we discussed that effect of temperature on the corrosion rate of water, remember I think some of you I said that when you raise the temperature above 85°C or so, the corrosion rate of water drops because the oxygen escapes from the surface from the filmed water, boiler that does not happen. Oxygen cannot escape from that nor the oxygen is present in this water at all.

So, what happens is that essentially if you rise a temperature, what will happen to solubility, in some cases solubility increases, in some cases the solubility decreases. What you call the solubility called?

Have you heard of this, retrogressive solubility? So, the metal starts precipitating after certain, certain temperatures. So, when raise a temperature the ability of the system to precipitate to form protective film increases.

So, the rise in temperature increases the kinetics of dissolution. Assume that there is no film on the surface. The rise in temperature will only lead to increase in the corrosion rate. Am I right? Assume that no film is formed. And if you rise only the temperature, the corrosion rate only will increase with temperature.

But so there are two factors the rise in temperature increases the corrosion rate, but the rise in temperature also increases the scale forming tendency, so the corrosion rate starts falling like this. So, you have an optimum value here wherein the corrosion rate is highest, and then it starts falling.

So, this is a typical, you find in thermal power plants, they are they are operating for the utility essentially. And this temperature is in the range of 129°C to 149°C for single phase flow, and it is in the range of 149°C to 199°C for two phase flow.

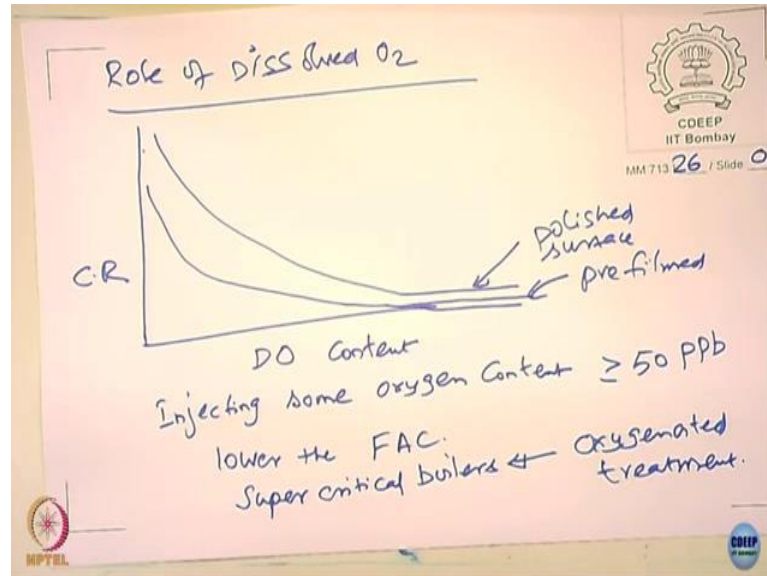
So, what are the factors that then can control flow assisted corrosion, velocity, the temperature, the pH, now all of them should be seen in the in the light of the ability to form an oxide film or to damage the oxide film, please look at it. So, those factors which assists the formation of the film will lower the flow assisted corrosion, and those factors which dissolves the film will increase the flow assisted corrosion.

So, you do not need chromium to form a passive film in steel. How was the film is form? The film is formed by maintaining the pH is a primary thing for that. So, the role of chromium is just to assist the film formation. So, it is not going to be a pure chromium rich passive film that you see in stainless steels. Here the same the film will be here having rich in iron oxide is Fe_3O_4 , but the chromium assist the formation of a stable Fe_3O_4 . So, the kind of film formed here is not same as the kind of film formed in stainless steels. The chromium is only assisting it.

If, the pH is not properly maintained, I do not think that chromium will be sufficient to form any film at all actually. So, that is from you are seen from only from that point of view and so the 1 wt.% of chromium is good, of course, you increase the chromium content it is even more better, but of course, it cause increases. In industry every penny is

important. You do not want to keep increasing the MOC, better materials because that is going to cost more.

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Now, what else can improve the film formation interestingly is the role of dissolved oxygen. So, whatever you discussed is, supported by this, dissolved oxygen content DO content versus the corrosion rate.

So, it is this is called as polished surface; this is pre-filmed. Please notice that generally the boilers all passivated it is called a treatment called passivation treatment, people do they are called alkali treatment in order to form the film ok. If you have a film here, it is even better.

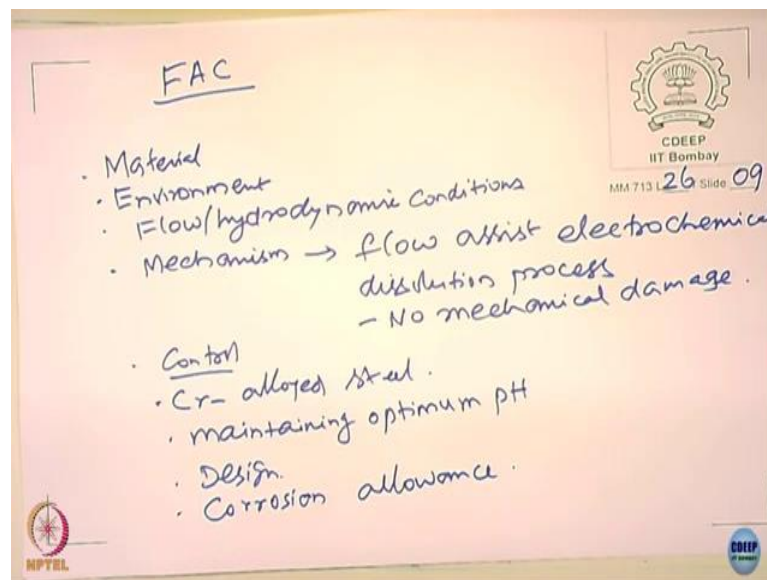
So, please notice that the oxygen content helps to decrease corrosion rate because the oxygen will, what are the oxygen do? It, stabilizes the, it increases the corrosion rate no doubt. But if it increases the corrosion rate beyond certain level, it will enrich the metallic ions on the surface and forms a film. It is very similar to critical current density right. When reach critical current density, at that point of time, you have more metallic ions then the passive film starts forming.

So, you need a critical amount of metal ion concentration on the surface in order to form the protective oxide film. So, the oxygen content it does help to do this. This means it is a very interesting here.

The corrosion control in this case is done by injecting some oxygen content in the boilers, and they its about it is about 50 ppb. Please look ions it is not ppm level, this is 50 ppb levels. So, they lower the flow assisted corrosion. So, we will not get into discussion of the mechanism of that. There are lots of papers available those who are interested you can read.

Please notice this water treatment is not common for all the boilers. The normal boilers we talk about they do not use this. But now we use boiler such as hope you people might have aware of this supercritical boilers, they give this statement, they give the this is called as oxygenated treatment in order to reduce the flow assisted corrosion. So, I just summarized now what we have seen so far, so that you have some clarity.

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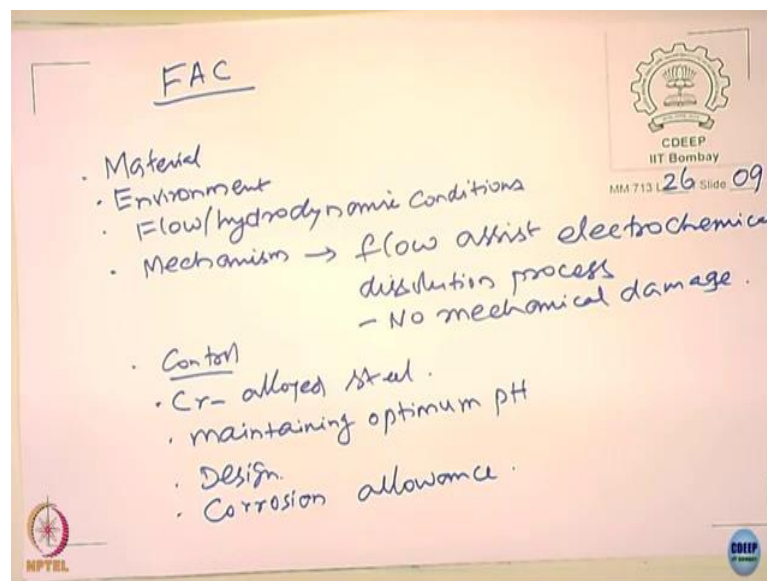
You have flow assisted corrosion. What are the factors that affect flow assisted corrosion? It is a material, the environment involved, and of course, the flow conditions or hydrodynamic conditions. The mechanism here is what the flow assist what? Simply the electrochemical dissolution process. Notice, no mechanical damage, it is simply that the flow conditions help to sweep away the corrosion products and so the corrosion is increasing. They do not allow the film formation or lowers the film formation on the surface.

How do you control this? Control measures, chromium alloyed steel used, maintaining the optimum pH. Very important thing the design, why you say design? The hydrodynamic conditions existing on the surface depend upon flow conditions.

So, you could change. If you are going to have a sharp bends, you are going to have more flow assisted corrosion. If you avoid that it may reduce. If reduce velocity, then also the flow assisted corrosion would decrease. So, the design of the system also is equally important.

You know of course, the corrosion allowance, you do not want that as the primary way of preventing it, but that still is because we are not going to totally eliminate flow assisted corrosion, but incorporate the flow assisted corrosion rates in the design. Especially in a unit some places inlets for example or maybe the bends, elbows, you should incorporate that you know the corrosion allowance to lower the flow assisted corrosion.

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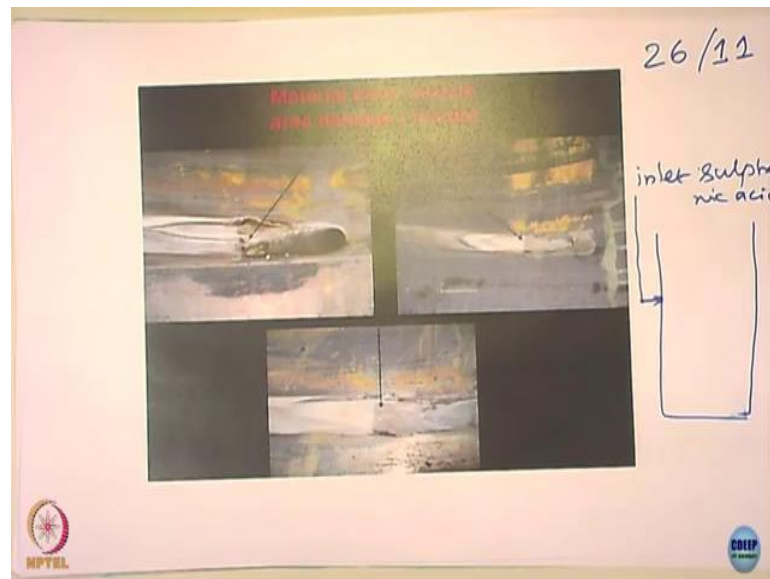


Move on next topic which is erosion corrosion. Let us straightaway bring out the difference between erosion corrosion and the flow assisted corrosion. Here no mechanical damage. The erosion corrosion mechanical damage is predominant; it happens very widely across several industries. The flow assisted corrosion mainly I would say related to the power plants whether it is a nuclear or fossil fired boiler I mean power plants.

So, you see this, I now in almost the pipelines the locations I would say, the locations or where you see them the erosion corrosion are see pipelines, especially on the bends and elbows see this, you can see that them in the heat exchanges, especially the inlets. You see them the reaction vessels.

You will see the agitators, grinders, for example, see in the mining industry that grinding is very common. And sometime even this the ore is transported as a slurry along the pipelines. So, you see huge amount of erosion corrosion taking place in the pipelines. Again you will see that you know impellers and gas turbines and hydraulic turbines, nozzles, they are all quite common examples of erosion corrosion taking place.

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It is an example of the erosion corrosion, please do not use the term flow assisted corrosion here. It is now erosion corrosion. What you see is, this is a reactor vessel, it is a wall, actually it was there is a reactor, there is an inlet here. See the inlet for this is actually the sulphonic acid. So, reaction vessel here it is a kind of autoclave, you want to call it reactor you call it.

Through this the sulfuric acid is pumped. This is the surface of the reactor, the sulfuric acid travels like this. You can see the mark, you can see the marking here; severe corrosion here taking place. Next to that there is not much of corrosion; for two reasons of course, one is the velocity you see here. The second is then the sulfuric acid get

diluted I mean sulfuric acid diluted the corrosion rate of the sulfuric acid also comes down, sulphonic acid here.

So, you can also see some kind of flow patterns. Are you able to see this here? I hope you are able to see this flow pattern here. So, these are all having specific features to show that there is certain amount of uniqueness in the way the metal gets damaged the it is called fingerprints. This reactor did not even last for about 6 months, within 6 months the reactor starts leaking, yes.

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This is a the earlier one was a stainless steel, what you seen here it is not a carbon steel, it is a stainless steel. This one is a cupro-nickel alloy. It is copper- 10% nickel. And this is a tube for a heat exchanger. In the tube the sea water was flowing.

Look at this the velocity was hardly about 1 m s^{-1} was the velocity. The external, I mean on the shell side the process fluid it essentially is hydrocarbon, you do not see any corrosion on the shell side. I hope you can see the marks here, you see the marks here the marks, and I hope you can able to see some mark here also.

This is an inlet – the inlet of heat exchanger. It is a very interesting and there are several tubes in the heat changer within about few months of commissioning, some tubes started leaking, few months. It was in a refinery located in Mumbai. So, they change the tubes,

within another 1 month, the heat exchanger started leaking again, and they again change the loop change the tubes. Almost every month they had to shut down the plant.

See when you shut down the plant, because this is a critical heat exchanger if this exchanger does not operate, then the whole refinery has to shut down, if you shut down the refinery for a day, it just runs in the crores of rupees this is not just lakhs, it is a crores of rupees.

The material is not very expensive compared to the production lost, you see this. They were using sea water. And sea water stainless steel will have some problem, because they may have pitting corrosion or you may have crevice corrosion. And cupro-nickel alloy supposed to be good, because they do not pit and alright. And cupro-nickel is suddenly better from the point of view of what we called as De-alloying as compared to brass we seen it you seen yesterday. Little bit of discoloration you can see this little bit of green colored that is happened because of the nickel dissolution process.

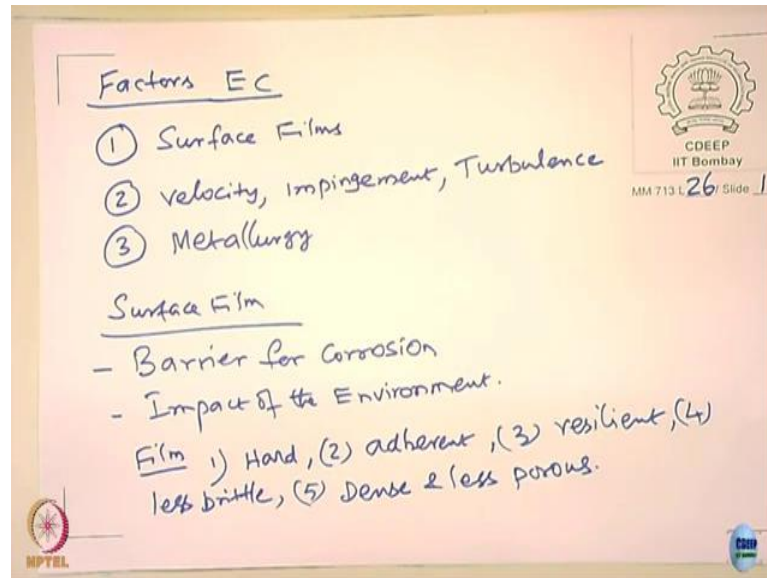
But nevertheless 1 m s^{-1} is hardly a velocity and is fading so frequently, so that was on the problem. We will probably see what could be the problem in subsequent discussion when we start analyzing the erosion corrosion, then we come back to this problem, and see what was the real reason for the erosion corrosion of this particular heat exchanger.

Now, what I was trying to say was the inlet of the heat exchangers generally undergo the erosion corrosion, in fact, that is termed as inlet corrosion. So, when there is a turbulent, it mechanical damages you see it removes mechanically. But what is the difference between the erosion and erosion corrosion? So, I give an example. Suppose, there is a pipeline and you are passing let say nitrogen gas in a pipeline maybe there are certain solid particles and the tube gets damaged. So, it is a purely erosion damage. You put a bit of moisture in a system, and you say that gas is no more dry, the solid particles are no more dry you just have some water, now it becomes erosion corrosion. Why? Because you have a corrosion component coming over here.

So, erosion corrosion it is a conjoint action of the mechanical erosion factor and assisted by the corrosion factor. So, when you talk about erosion corrosion, then we look at the mechanical property of the material as well as the corrosion property of materials, so that makes a difference.

In the flow assisted corrosion we never talked about mechanical property of materials, we are talked about the film formation film stability that is why I said the mechanism are different and so the way you prevent corrosion also going to be different here.

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So, what are the factors affecting erosion corrosion? Here also we talk about the surface films; they are important. Talk about velocity, impingement, turbulence, etc. They are related to the physical state of the environment velocity, impingement, turbulence.

They are not talking about chemical set of it. We are not talking about the pH of that, corrosiveness of that, it is a physical state of environment. Metallurgy of this, the metallurgy of the alloy will also decide these surface films, it is not necessarily they are independent. But metallurgy here we generally mean in terms of the other mechanical properties such as hardness, toughness all kind of stuffs.

So, let us look at the surface films. Let us take the first one. Please notice the film offers a barrier for corrosion, it also takes the impact of the environment. So, what should be the property of the film or properties of the film which can provide a better erosion corrosion resistance? What are the properties? It should be the film, should be 1; it should be hard, is not it? Then what happens?

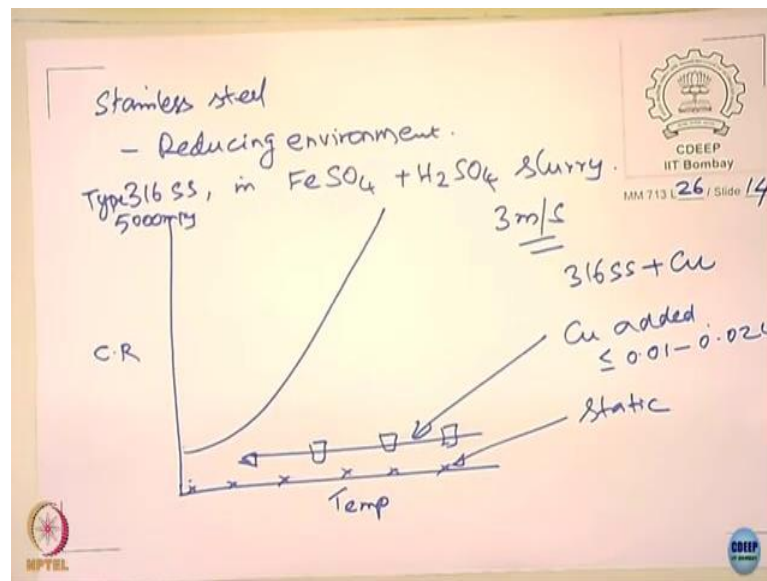
It should be adherent – 2; 3, what happens, it should be? Resilient. And if you want to do more explicitly.

Less brittle. What more? It should be dense and less porous. So, those alloying elements that added to the alloy that can promote all these properties will ensure that the alloy has a better resistance against erosion corrosion problems. So, these are the important thing that is the guiding factor for alloy development also.

So, please notice it is not necessarily very thick film, sometimes thick films can be a problem, is not it? A thick film is generally the oxide films are brittle compared to the metal. When the film becomes thicker and thicker, what happens to the resilience?

It becomes very bad. If the film is thin is more resilient against any kind of elastic deformation. And in erosion corrosion you are not going to get into too high impact, cavitation it does happen. So, you are talking about resilient within the elastic limit, most of the deformation would occur in erosion corrosion.

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Let us look at some examples of the surface film formation happen. The surface film formation will also depend upon the nature of environment. It is not just only metal also ok. Suppose, I take a stainless steel, I have a reducing environment.

What happens to the film forming tendency of a stainless steel? Decreases, because you need oxidizing conditions, so that could be seen very well in the case of let say type 316 stainless steels, corrosion in ferrous sulphate plus sulfuric acid slurry. Please notice

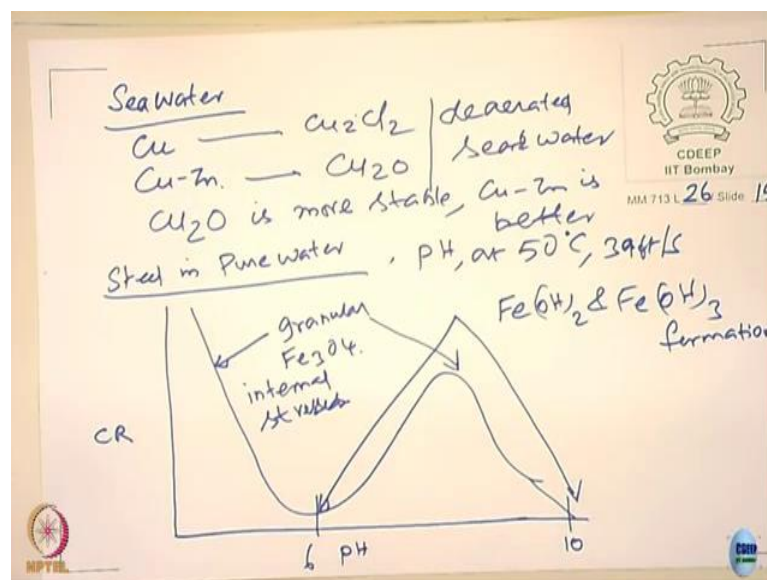
ferrous sulphate is reducing condition, it is not oxidizing condition; ferric sulphate is oxidizing condition.

If use 316 stainless steels and if you can look at the corrosion rate, and again with respect to temperatures, the corrosion rate of that somewhere about 5000 mpy something like that. In the static conditions, ferrous sulphate plus sulfuric acid slurry in the static condition, it is not flow condition.

But if you increase the velocity or something like that. So, I think it is about some I do not about 3 m s^{-1} rate is going. So, it is going very high corrosion rate steeply also changes with respect to temperatures, but you add 316 stainless steel and add some copper to that, the corrosion rate you know.

Copper added. So, when add a copper to a stainless steel, the film forming tendency becomes very high. In fact, if you look at the material selection for sulfuric acid applications, the stainless steels have copper in it. So, copper helps to form stable passive film. So, this is a significant drop a significant drop in the corrosion rate. And these copper additions are all what, they are all in terms of what 0.01 to 0.02 wt.%. It is not a very large amount of copper content, it can happen.

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Similarly, and what people have seen sea water, a copper brass. The copper forms cuprous chloride, and it forms cuprous oxide in deaerated seawater. And cuprous oxide is

more stable. So, what happens? So copper zinc is better. So, what we trying to say is that the maximum of the film that forms on the material besides the largely the erosion corrosion resistance of the material.

The other example is a steel in pure water. It is ok, where they studied the pH at 50°C, and the velocity is about 39 feet per second. Corrosion rate, and this around about 6, it is about 10 pH.

Now, the reduction in the corrosion rate, both the places are largely related to ferrous hydroxide and ferric hydroxide formation. Here form granular Fe_3O_4 oxide formation. Again, there are lot of internal stresses. So, the point that we need to emphasize here is that, the nature of oxide forming on the metal surface bears a significant influence on the erosion corrosion of metals.