Aqueous Corrosion and its Control
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Lecture - 01
Introduction to the course and corrosion implications

Welcome to IIT Bombay and welcome to this course on Aqueous Corrosion and Control. Here the courses are most likely to be more interactive an object oriented courses right. You are not going to have a too much of you know routine and textual informations so, rather than we focus on the fundamentals of this subject. And this course all of you know is an aqueous corrosion and its control.

It is a postgraduate course mainly taken for mm 4 we call it corrosion science and engineering, but the students from other disciplines within the department, outside the department they do take this course.

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To briefly introduce myself I work in the area of corrosion science and engineering, I give quite a bit of focus on electrochemistry and corrosion. You will see later how important it is to understand electrochemistry and corrosion there is quite a bit of interrelation between these two.

Then I also look at corrosion mechanisms at the atomic level, microscopic levels related to materials of course. I have wide range of interest in materials mostly metals and alloys and you do some work (Refer Time: 02:08) coating off late we have been focusing quite a bit on stress corrosion cracking. You will see later that stress corrosion cracking is a very important subject for any materials integrity yeah.

So, this course today lecture is basically to introduce you to subject of corrosion and to give an outline about what we are going to cover in this particular course. We are also going to discuss an outline, what are the evaluation method that we do for grading the students. So, that you get a clear idea about how to proceed how to prepare for the course.

However, I would like to say that do not prepare for the course for the sake of grades, I think that is not going to help you in the long run what is going to help you in the long run is what you have understood. So, that you can apply them in the field and for that you need to understand the science and you need to understand the technology, you need to understand the relation between the science and technology.

And how many of you have seen corrosion problems or failures how many of you have seen? 1, 2 I thought everybody raise the hands you know you have not seen at least you see in the newspaper that the bridges collapse and the so, and probably it attributed to corrosion they may not and rusting is quite common right. I think rusting is quite common you might have seen steels being used for various purposes right.

It is a very very extensively used material for various applications might be defence, be it a reactor pressure vessels or be it a transportation sector pipelines steel is very common and steel of course, all of you know that it rusts ok. But then if you rub it off and you see that yeah everything looks fine you know its not really a problem, but it is not really that problem it is much more, the corrosion is just not confined only to steels it is confined to all kind of materials which are made by human being we will see that shortly.

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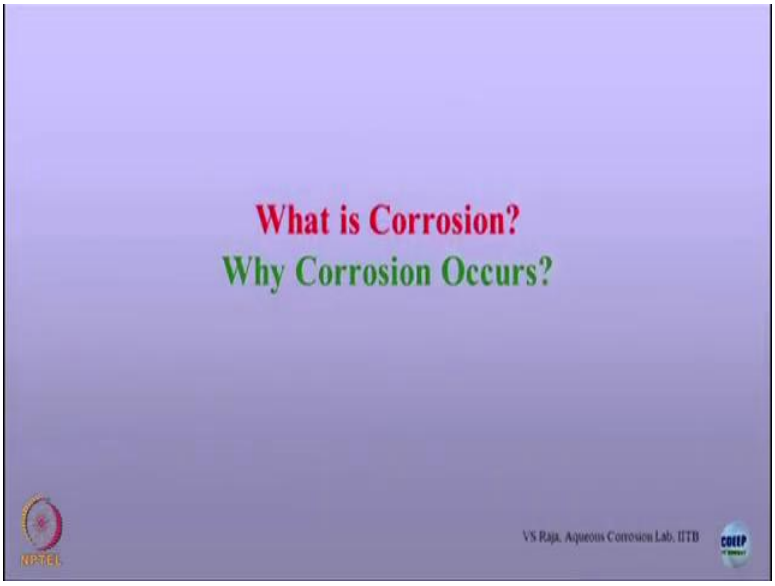

So, before we start discussing about the corrosion probably you should know what is corrosion and why does the corrosion occur. These are the primary question that haunts everyone's mind and you like to know the answer for that and just not the answer, a clarity is required actually. So, what exactly mean by corrosion? What is the clarity in that? Ok.

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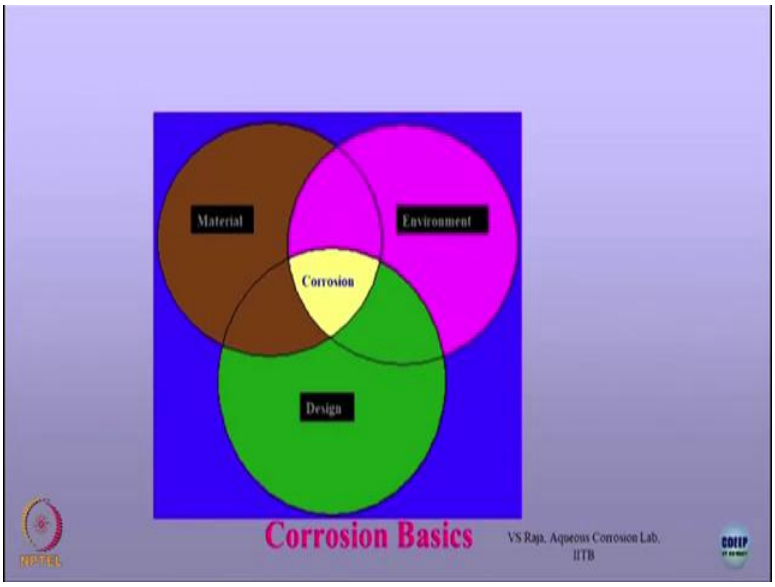

Now, corrosion why it becomes important because, you have seen wherever there is a material that you have materials without material there is no civilization right it is used

for you to take a mobile, you take a laptop or you go to anywhere I think material of construction is important one for human civilization.

So, these materials are used for various engineering applications, when they come in contact with that we call environment here and they start interacting with each other leading to what is called as a corrosion process. But these materials are just not freely hanging you know it is not like I have beaker, I put sodium chloride in that, I have hang a sample its not, these materials are for structural applications right.

They may carry a load could be a tensile could be fatigue whatever or it might be a container to store a sulfuric acid for example, still it is applying certain pressure. So, the materials are designed for certain function that the very design itself alter the course of corrosion. So, there is a change the way the corrosion occurs that is why we always worry about design and try to relate the corrosion of a reactor or a system with material with the design in the environment.

It is actually it is a failure it is just fails it does not find functions. Can you then say whatever component that you see is failed for example; can you say it is due to corrosion? What are the failures that you are aware of can you tell me? I am talked about the structural failures, right. What are the failures?

Student: (Refer Time: 08:05).

Yeah.

Student: tensile failure.

Yeah, it could be a simple a overload failure you know I simply apply a load beyond the ultimate tensile strength, the metal deforms and it fails not necessarily corrosion right not necessarily or you heat the material beyond the melting point or whatever it fails or you have simply wear and tear it fails. So, not all the failures are related to corrosion no its not. So, it is not correct to conclude that corrosion is the only the mode of failure.

Corrosion is one of the modes of failures, but of course, it is a predominant failure that happens in various industrial components that we will see that. Now, then how do I really define that?

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The way to define here I made it very simple, you can have your own way of defining things as I told you need to rewrite the way you think. So, this definition is the I have written my way in way of writing it actually.

So, when I say corrosion, you need to have a material and you should have a chemical environment coming in contact with this. Only when the metal fails we call them a corrosion failure. I can have a plastic failure taking place because of gamma radiation right that is not a corrosion failure a physical failure. So, I need to have a chemical environment that is the primary requirement to call the failure as corrosion.

So, that is a very important you will understand. Why does it important? Because the failure leads to loss of materials there are several definitions the loss of materials, if it fails there could be casualties can happen. Primarily if you look at from operational point of view, there is a loss in the function of the component.

When I say the function of the component it is very important to realize that. It is not necessarily it leads to leak, it is not necessarily it should have a crack still there can be a loss of function, I give two examples anybody from mechanical engineering back ground here?

Student: Yes sir.

You know about the heat exchanger right. So, heat exchanger it exchanges heat between two fluids, it could be a gas or it could be a liquid and you have a shell side the one liquid and tube sides another liquid and you transfer the heat? Assume that there is a corrosion very small amount of corrosion leads to scale formation. Scale is a thermal insulator. Structurally it takes all the load no problem, but the exchanger is not functioning because of corrosion leading to loss in the thermal conductivity of the component.

I give an example other one which you are more familiar with right. You have seen lot of electronic gadgets right you have pins connectors you have and if there is a small rust and you put the connector what will happen? The current will not pass through so, easily there will be resistance its ok, but it lost its function. So, corrosion when you talk about is not necessarily a structural failure.

Any loss in the function, efficiency of the unit that we talk about that is the concern for us, but that problem should be as a result of corrosion, the corrosion is coming because of what? Because of the material interacting with the environment. So, the definition of the corrosion should be should encompass all these whatever way you write it or whatever way you want to convey it ok.

The chemical environment is the key, materials are the key and the loss of function is another important key the definition of what corrosion means is.

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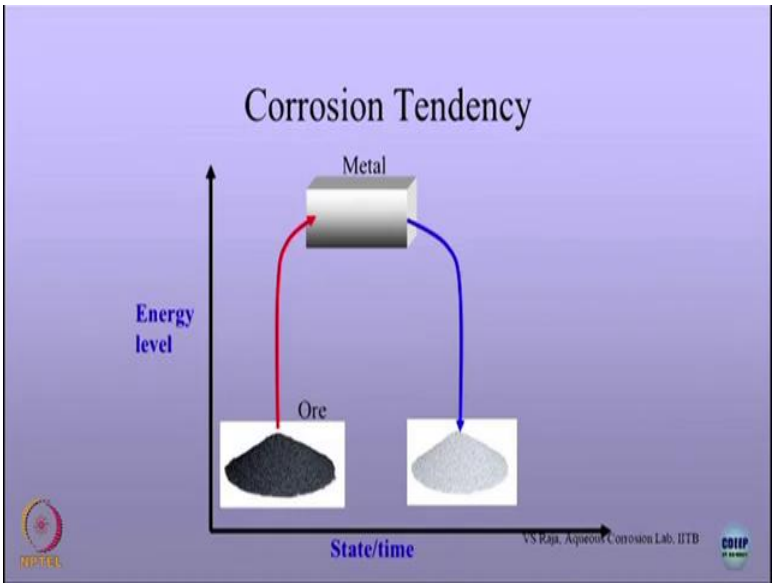

Now, why would the metal corrode? This question that happens to us most of us. It is not in equilibrium with the nature. It is a very very nice question nice answer I would say it is not equilibrium with nature. Now most of the metals and alloys that you deal with you know can you tell me example of what are the alloys used for structural applications

Student: (Refer Time: 13:10)

Yeah?

Student: (Refer Time: 13:11).

Be little louder.

Student: Steel (Refer Time: 13:14).

Steel is one.

Student: Steel is.

Aluminium is the other one, magnesium, titanium what is common to all these material? The common because it is the man who made them or who makes them from the ore into metal right. You take platinum gold what is common there? It is naturally available. So, how do you make this material how do you make these metals is, the origin is the ore that you have here talk about the ore is in the earth crust you have and the ore is nothing, but oxides, chlorides, sulfates all these compounds.

You convert this into metal how do you convert it? You convert by providing energy right you provide energy, reduce this, the energy of this is increased because of the conversion form of things ok. So, the energy of the metal is higher than the energy of the ore what is natural is that what goes up as to fall down that is natures law the physics says that. So, when it interacts with the environment what happens?

It goes back to its original state here. So, what drives the corrosion? The free energy change that drives corrosion. So, engineering materials that we deal with more specifically the metals I would say, if they do not corrode you may get surprised ok. It is not surprised that the most of them will undergo corrosion process corrosion is a very very common thing. Now, what is that corrosion means ok?

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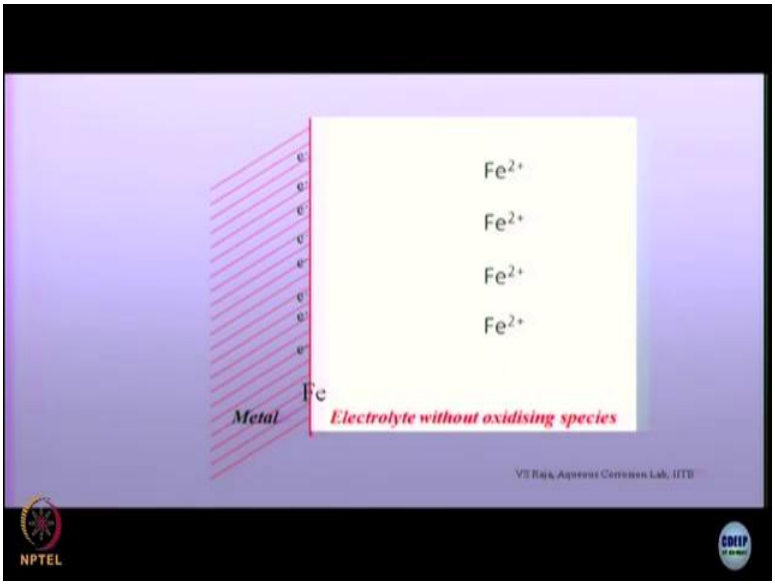

What is this corrosion means? The corrosion means when you have metal it comes in contact with environment. Now what is happening now? See there is an oxidation process I have given an example as iron here, in the process the electrons are deposited on the metal surface the iron goes in the solution. Now look at this the reaction is not going to continue right does not continue at all why does not continue? Why the iron cannot continue to oxidize? See its stops here why does not why does it stop?

Student: (Refer Time: 15:48).

Yes, because the surface is enriched with the electrons, negative charges it loses its neutrality the reaction does not continue. So, if corrosion to occur what happens? You need to remove these electrons from the surface how do you remove that? You remove it by environment you see now here what happens. It releases two electrons is accepted by the species in the solution here the example I given is H plus.

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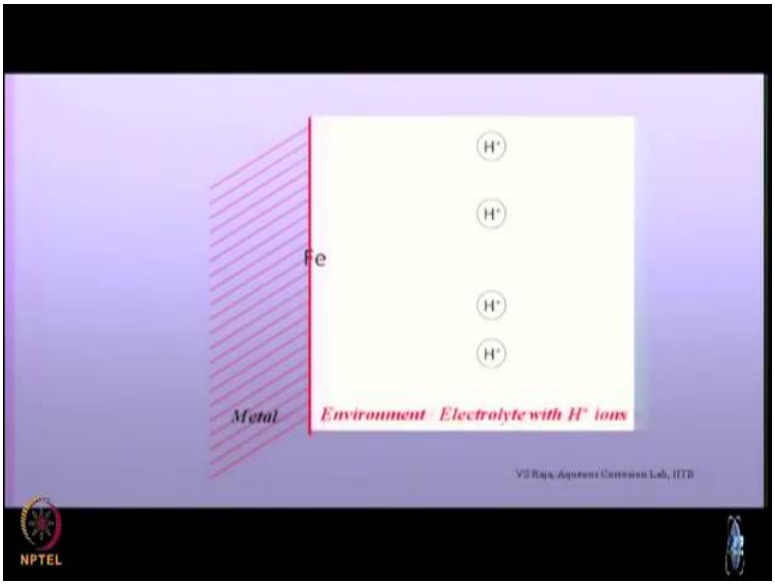

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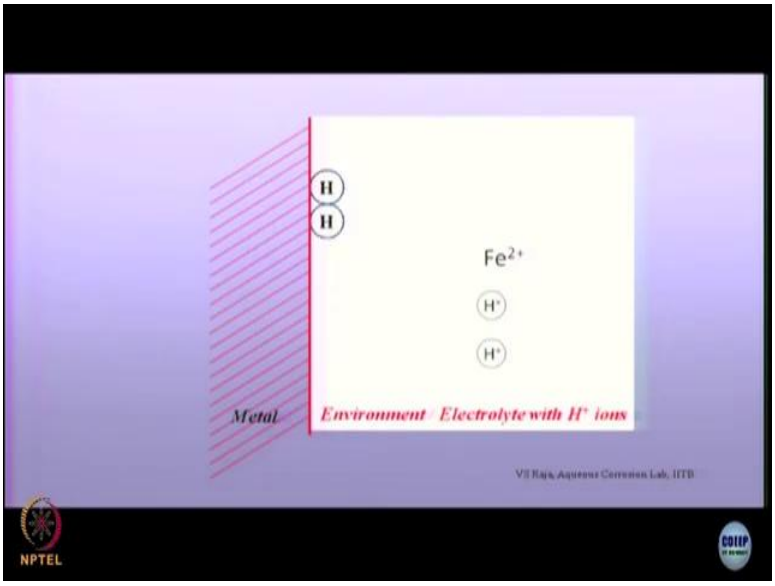

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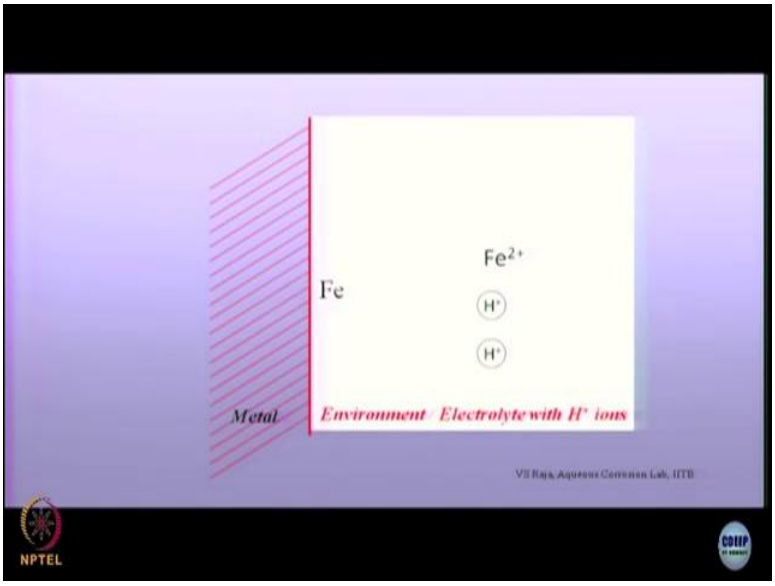

The H plus take the electrons and the reaction continues.

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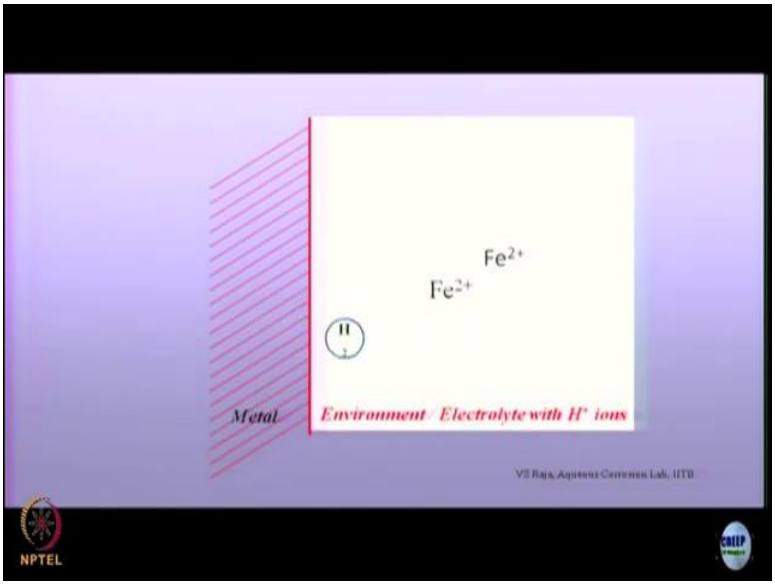

So, it is a chemical reaction occurring on the metallic surface there are two sub reactions two partial reactions you want to call it one is an oxidation, the other is reduction process. Both of them have to occur if only one occurs the corrosion will not proceed it might happen first two steps, three steps, but corrosion does not continue to occur.

It is a very important thing to understand, this becomes a key to understand not only to understand corrosion, to control corrosion also right. Suppose you are not an engineer

you are a common man sitting on there is somebody he gives a lecture now, he tells please tell me from this how do I control corrosion. Can you tell me how to control corrosion? I have to use steel, but I need to control corrosion; how to do that? How do I do this do this?

Student: (Refer Time: 17:36).

That of course, but of course, I can give a coating and all, but I cannot I have for example, pipelines carrying water how do I do that?

Student: In (Refer Time: 17:45) electrons (Refer Time: 17:46).

In (Refer Time: 17:47) electron so in fact, the answer come from that you have given one of the examples give a coating.

Student: Electro chemical (Refer Time: 17:53).

You put electrons to that you said actually the one person will say what will say please remove H plus from the electrolyte. In a boiler can you give a coating? If you give a coating what happens? Thermal conductivity is a problem

Student: hm

You cannot do a cathodic protection what you do there? You simply remove the H plus how do you remove H plus? By turning the solution into a alkaline solution to pH (Refer Time: 18:21) water is increased. So, you do that.

So, what I am trying to say if you know the principle, it is easy for you to devise new methods you do not have to read what I am saying, do not have read what Fontana says you can devise your own methods, the basic is very important in advancing the technology I think you should really do that. One way you have seen again in the day to day life right you have seen how do you people store sodium.

Student: (Refer Time: 18:53).

Kerosene right we put in kerosene right how does the corrosion is stopped?

Student: (Refer Time: 19:00).

Yeah, in kerosene why no corrosion occurs?

Student: (Refer Time: 19:09).

There is no interaction the air is gone secondly, there is no free H plus in water in this particular environment no corrosion very simple ok. So, it is for us to understand what the corrosion how it need to be tackled at all actually. Now, to summarize what you have seen so, far you have metal, it comes in contact with environment here, you have an oxidation of the metal taking place right.

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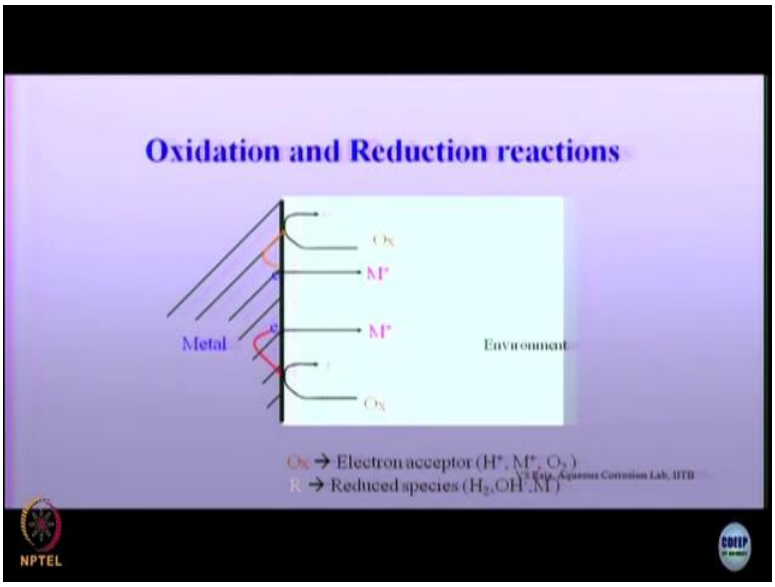

Releasing electrons on the surface and from the environment you have a species, it comes and accept the electron here and gets reduced and these species can be H plus metal ions oxygen and so, on. If you do not understand what are these electron acceptor, reduced species you do not worry that the course is meant for that to make you understand I am trying to only trying to tell you how the course is going to evolve what we are going to address in understanding the corrosion process.

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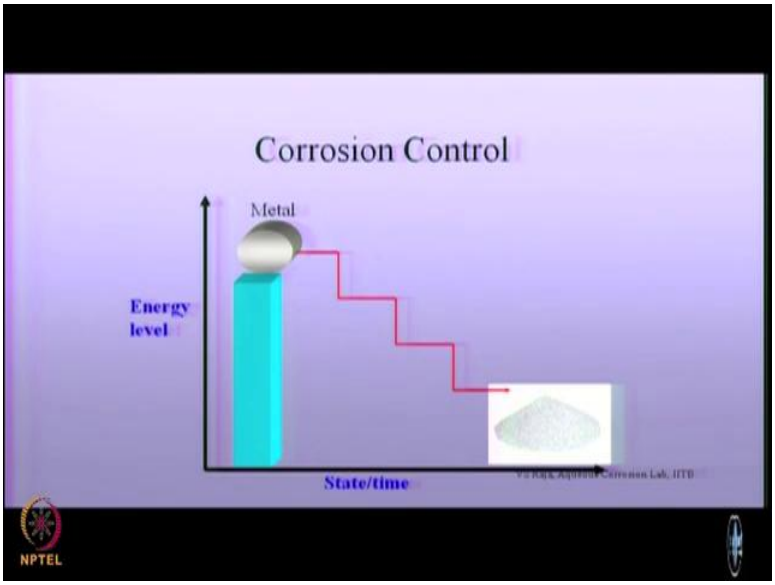

Now, as you have seen before thermodynamically, most of the engineering alloys the structural materials are bound to corrode right. Why? Because the energy of the metal is higher and any time it can form it can corrode. Can you ever completely stop from corrosion? You cannot forever you cannot forever cannot stop it what we can do is, we can slow down the corrosion process right.

I take long time I take more time for to corrosion here take long time right. So, we have a steel pipeline, the pipeline can last for let us say 25 years, engineering it has served purpose for us actually. So, how do you how do you study this? What is this science called? What is this science called? This science is called the kinetics the first one we talked about the thermodynamics, the free energy change now this is called the kinetics.

So, this course will devote time in understanding the kinetics. In fact, the kinetics are the most important thing in controlling corrosion because thermodynamics says I am helpless you are using materials which are supposed to be corroding ok. So, this kinetics we are going to spend for a quite large amount of time so, that we can understand the mechanisms that give us the way to control corrosion of metals.

One of the ways to control corrosion we are talked about a coating the metallurgists do right. How do I control corrosion of a steel from metallurgy point of view?

Student: (Refer Time: 22:16).

Yeah.

Student: Chromium oxide.

It forms chromium oxide ok. I form a film in the surface you have seen metals there outside you have set of (Refer Time: 22:24) there right steel how they prevent corrosion? You apply a paint coating, it is a barrier coating the metal can develop its own barrier oxide coating right and how does it happen?

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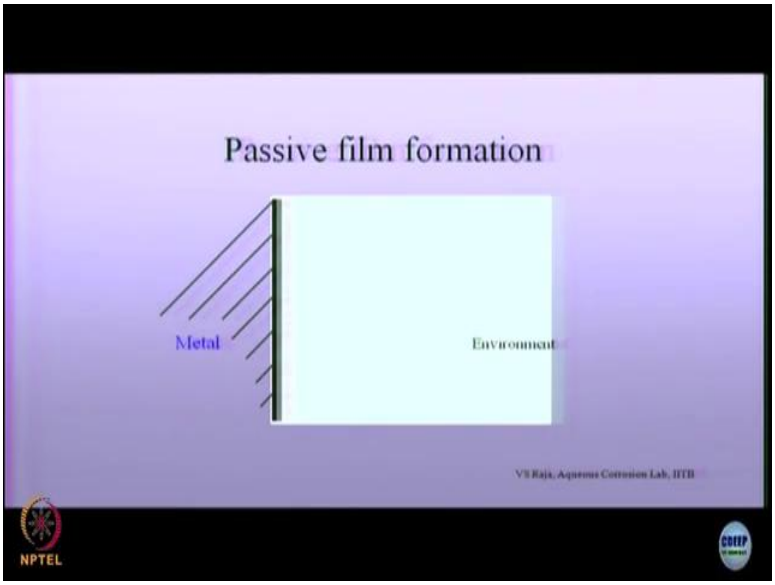

You have metal here; it comes in contact with environment here what it has to do? It forms a film on the surface and this film is a barrier for the environment to come in contact with. This is corrosion stainless steel all of us know. Can you give another example of a reactive material having high corrosion resistance? Yeah?

Student: (Refer Time: 23:10).

Aluminium to certain extent other one anybody? Anybody can give an answer? Have you heard of titanium? An example of that titanium is very reactive ok. So, it gives you in fact, titanium is more reactive than aluminium, but it gives you better corrosion resistance it forms oxidative films. So, you can develop your alloys based on that. So, all these we talk about the kinetics ok.

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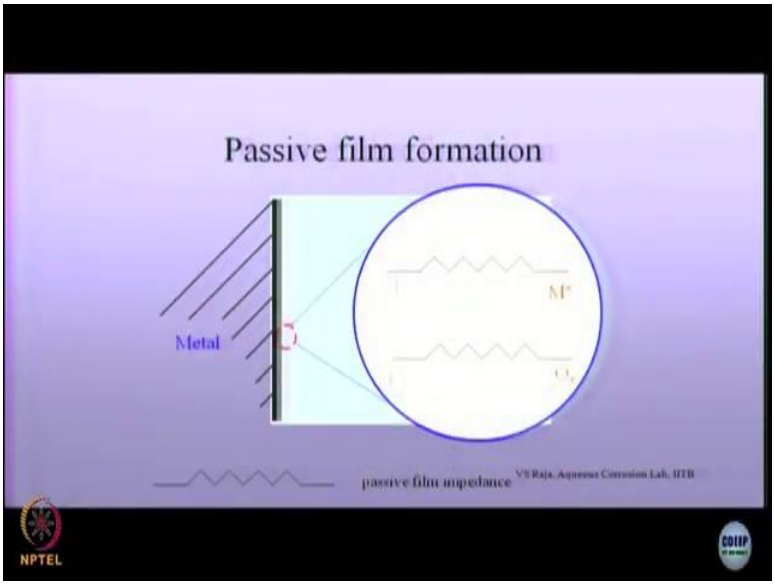

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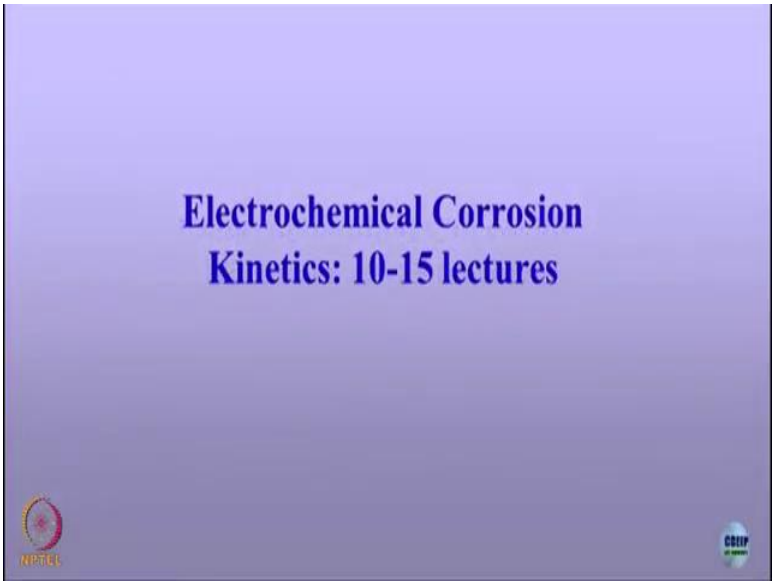

So, the course we will spend about 10 to 15 lectures on the electrochemical corrosion, thermodynamics and kinetics about 10 to 15 lectures we will review this ok. We will see some examples and there will be some problems to solve so, that you can understand how the kinetics are happening at the metal solution interface. Please see all are happening at the metal solution interface, we do not talk about what happens in the electrolyte it is on the interface ok.

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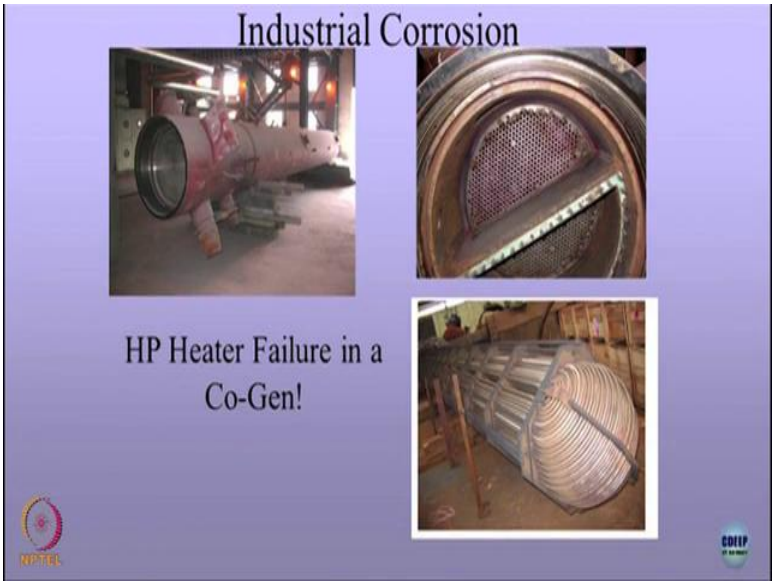

So, we talk about that actually things are not that simple alright if we have to simply talk about electron transfer you so, simple to corrosion control, you do not need a big subject, you do not need lot of consultants, you do not need you do not need a specialized you know engineers to tackle the problems.

The reason is very simple the metals are fabricated into different design you know, one of the slides I told you have a material, you have the environment design come into pictures illustration here right.

What is this? This is a heat exchanger right a heat exchanger for a power plant we call a co-generation done in one of the petrochemical industries, you do not want to waste the heat, you extract the heat and convert into steam then use for various purposes. It is heat exchangers right if the shell we call it what you call this? Call the tubes right. Now, look at this, this is tube and tube sheets.

These tubes are welded to the sheet here we have welded now; that means, now you will start welding. What is welding? Joining right of course, how do you people join tig weld? What happens during a tig welding? Now, metal is melted join together metallurgically there are changes. The location where you have joined it has a different electrochemical properties compared to surroundings corrosion there same thing electron transfer will takes place all.

But the solution there is different ok. I am not saying that electron transfer does not takes place corrosion does not takes place, but the engineering solution to the problem is different the mechanism of corrosion different and so, you have to look at corrosion from a different perspective of what we call as a different forms of corrosion, you will see later.

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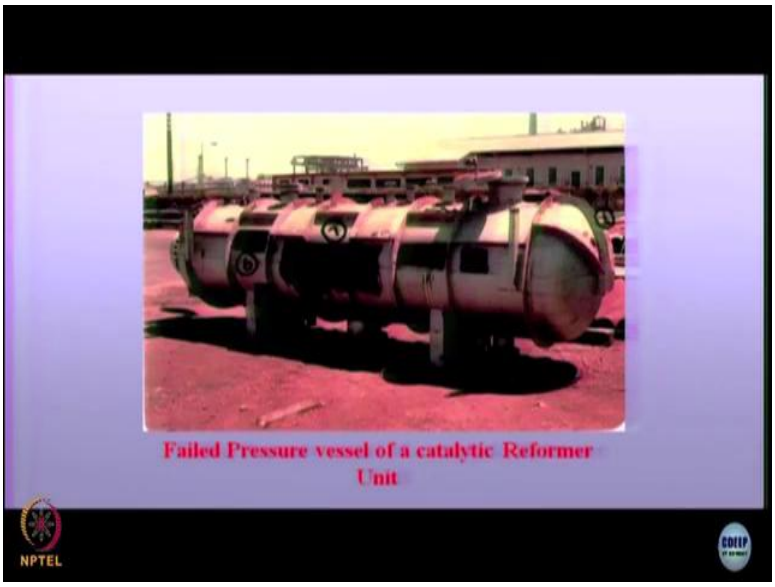

The similar thing we have seen right this is a reformer unit right one of the refineries you served of course, about 14 to 20 I think about 14 years is served and they have found that there are some bulging slide is not so, clearly visible.

So, there is a bulging they sectioned this and they saw you see that how looks like? A sectioned plate you see looks like a fish mouth and its a different type of failure and this failure we call them as hydrogen damage hydrogen blistering we call it.

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What does it happen? When you when you take a steel and put it in a environment hydrogen evolves its a corrosion, but one more thing happens the hydrogen enters the steel and gets into the material it affects it, in this case the hydrogen got accumulated. Now you see, now we have getting into a different dimension of the problem, the primary cause is corrosion, the secondary cause is a real reason for failure.

If the hydrogen has not gone into this, the corrosion was in minor have the hydrogen has not gone into it minor. Now, this is a different kind of problems how do you solve it? So, this is called different mechanism we called hydrogen damage in a broader sense of that.

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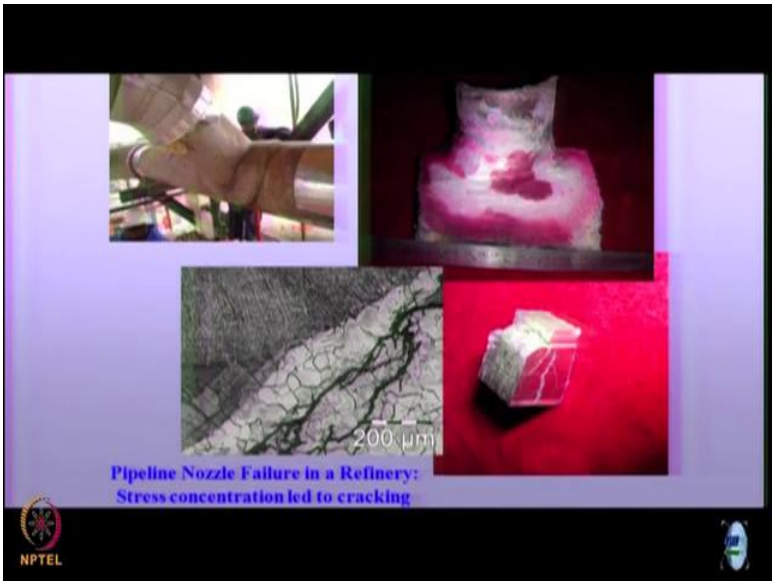

You can see law of you know this is a kind of a kind of you know pipeline you see here in a refinery there are insulated by with a lot of insulators. It carries lot of lot of steam inside actually high temperatures very nearby here only this refinery was located and its a nozzle there is a nozzle here, the nozzle is a crack you cannot see this so, clearly these things is cracked what was the material? Material was stainless steel material was stainless steel and see how the crack was? The crack start to like this start branching, they thought stainless steel is a better one unfortunately it is not actually ok.

And the cracking took place on you see this is a weldment if you are a metallurgist you know this different micro structure here, different micro structure here, there is a cracking taking place from the so, called heat affected zones it takes place you know what the solution for that was? We are not using better material (in double quotes) solution was using a steel not a stainless steel.

How do I come to the conclusion? Need to understand the mechanisms. It is in your use stainless steel is better compared to carbon steel is not correct always. If you want to illustrate this further tell me how do I store how I store chlorine gas? You may think I gone to swimming pool and use it for bleaching right what kind of cylinders they use? They use simple carbon steel cylinders what if I use a titanium?

Student: Titanium is (Refer Time: 29:54).

Isn't it? So, titanium is prone to cracking, but the same chlorine gas add small amount of water in that, I make it wet chlorine your carbon steel cylinder will not work the titanium works there actually.

The reason being in water the titanium forms nice oxide film that is a reason why I said you need to understand the science otherwise you simply cannot go by intuition what really happens on to the materials at all. So, that is what I think you will see in this course.

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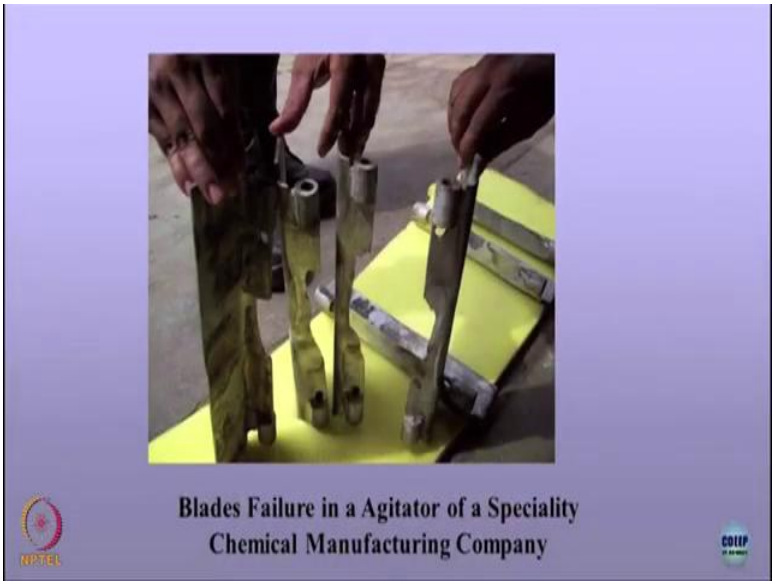

So, different kind of failure we have seen one of the chemical manufacturing company is in Agitator arms, you see this here because of the jet here impingement the corrosion occur its velocity is one factor.

The corrosion occurring in a tank is different from corrosion occurring in a pipeline or nozzle or maybe an impeller things are different ok.

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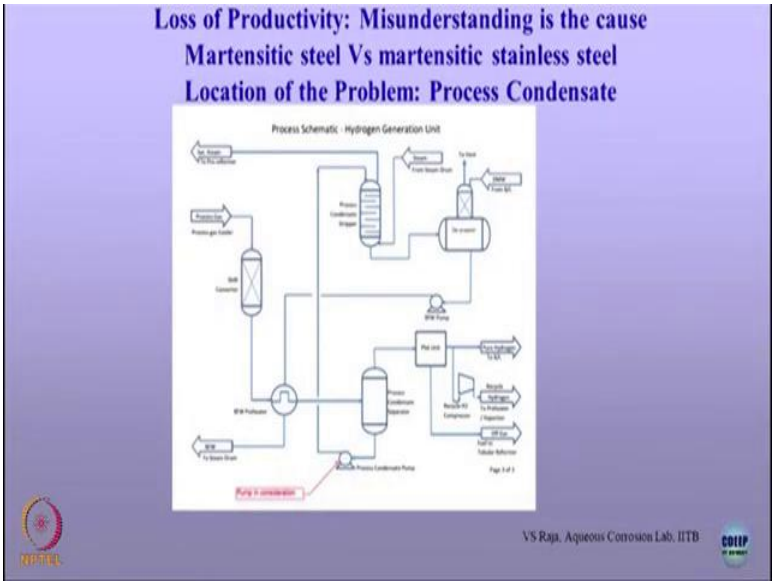

Sometimes people misunderstand the issues. Its an example of how people do not read the fine prints. What is the difference between a martensitic steel and the martensitic stainless steel are both the same or different?

Student: Composition.

Composition wise right. The martensitic what is the difference between a martensitic steel and the stainless steel what is the difference?

Student: (Refer Time: 31:36).

Heat treatment what are the property you get in a martensitic steel? High hardness good erosion resistance right all these will happen. Martensitic steel will give you good wear and tear erosion all these, but you have an environment corrosive environment the martensitic steel is no good at all because that is going to corrode very high. So, people use for farm applications martensitic stainless steel not martensitic steel.

Here is the case it was somewhere in Siberia it happened one of the company which is a French company located in India who went for the overall plant and over here, they used in the pump a martensitic steel instead of martensitic stainless steel, they did not notice oh this really a problem why? You know here what is the liquid here is simply it is not really a acid you know very interesting.

Yeah, actually it is called a condensate you know in a hydrocarbon what you do suppose you get a LPG gas right it may have water what happen you are separate the water and then take the gas out that is called as condensate right.

You condense and remove the water from the process liquid and that water is being pumped here you know very interesting thing, that water is more corrosive than the water you have in the pipelines, it is a pure water ok. You will see why later and they got worry you know what they did? They start using two pumps alternatively one of the other, right.

Oh, I said why need you use alternatively because any time it will go if I order a new pump with a martensitic stainless steel; it may take not less than 6 months. Now, without this pump if the whole unit cannot run what is the cost of this pump? So, small compared to shunting the whole plant for about 6 months they thought ok. There is erosion corrosion let me work alternatively.

I said it could be the some lot of work and to find out what happens and all, but at the first instance I told do not use two pumps alternatively why? If you shut one pump down there is a water inside keep corroding all the time shutting pump does not mean that you do not have water inside.

So, please do not do this at least keep the dry you have a problem to start running after 1 month then you shut the other one dry it and start running it because you know what really happens and all.

So, we did of course, some calculations about the pH all these and then found yes I think you run a pump for 3 months continuously one case and another case run for 3 months another case, I think you can sustain the production for 6 months by the time you can buy a new one. So, sometimes you have money, but you cannot do anything at all a loss of productivity takes place is one of the issues.

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Very similar issue, this is refinery is again close to us, a simple condenser tube in a refinery they were using seawater. Seawater you cannot use carbon steel you know because of high velocity it is a problem you cannot use stainless steels, they start using copper nickel alloy it is called cupro nickel alloy right alloy.

And they found the inlet portion, there is a erosion corrosion taking place very low velocities. I am not going to give answer for this please look for answers when I am teaching this course; that means, you understood it is a better I am just rising the questions now ok.

Now, this is the velocity see its called inlet corrosion taking place real problem in fact, every you know fortnightly they used to pull the tube out and then plug it and keep doing actually shutting out and then it used to cost 10 million rupees per day because you cannot do anything at all one day finish one day means 1 crore rupees gone for that. So, cost of the tube is less, but the consequence productivity is quite the huge amount of loss you will see.

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Now, whereas this is not the structural thing, it is not just function that is one more ok. I do see a car right if I am talking about a car like this, oh structurally its very good I can drive no problem who will buy the car if it is rusted it looks. So, bad nobody buy the car is not it. Now the gm or some of these companies you know they give guarantee of 12 years of rust free coatings the technology has developed over a time period.

So, aesthetics are important. Why do you coat nickel on some of this you know steel plates? Because you want to have good appearance you go to washroom you see collar some of these you know fittings are extremely good looking actually right because appearance is also of an equally important and that can get damaged if you have corrosion problems you have corrosion is a real problems is ok.

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This is another aspect of why corrosion should be controlled and again if you see very interestingly you know you need to look at it. You see what is this? What is this? Why does the red colour appear here? If chipping actually a stone hit and coating paint coating broke and you have rusting here so, that is colour.

You see here also you know there are some blisters taking place there are blister taking place this is called blisters ok. And the blisters occurring because of the cathodic reaction or I would say a reduction reaction we are not told about what the cathodic is, I think is probably very appropriate for me to say a reduction reaction.

Because there is alkalization reduction reaction here, the corrosion takes place. Corrosion problem not only associated with the oxidation sometime the corrosion problem structural failure can occur if some cathodic reaction occurs reduction reaction occurs on the surface, this is also be a problem is taking place this is another thing that really happens.

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I given this example, pipeline I think some of you would have seen it, here this is internal this is external corrosion entirely different. The internal corrosion depends on what? Depends upon the water chemistry water it is going to use.

In this case the corrosion occurred because of microbes you call microbial corrosion taking place with here, but here the in the outside they exposed to soil; the soil chemistry is little different entirely different solutions are different from that ok. So, corrosion can be very complex in a single structure it can be different depending upon how the environment is really exposed to.

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There is so many reasons why corrosion should be seen and I have been shown this here if it is happened within India it has got larger impact in terms of you could you know off in terms of problems that you face.

The two accidents happened here right the right side you see here. See gas pipeline happened about a few years back and it got the fire why did the leak occur? The primary reason was corrosion on the pipeline and you know a lot of casualties you know you see 18 people were reportedly killed and 40 injured. See this is kind of problems that you can have actually.

So, there are cases where we call pennywise pound foolish. We do not really do things thinking that you can save the money the money is not really saved in fact, the money is spent more they destroy the environment. They not only destroy the environment, it is also a matter of sustainability right you have a steel or how long the ore is going to last? How long the natural gas is going to last or if you are going to pollute this environment how long this is going to happen?

The question of sustainability; depleting resources actually. Sometimes as a metallurgist, I will develop a better alloys; as a mechanical engineer, I design a very nice structures, but corrosion does not allow it. I say oh I want to use magnesium because it is one of the lightest engineering metal right; people still use it right I think, but then magnesium is really highly corrosive is not it? In auto wheels or transportation sector people use

magnesium, but if you know of any of the chemical industries magnesium is also used as a sacrificial anode you corrodes and use that.

How can you reconcile both that is the critical thing that we talk about. The technology sometimes cannot be advanced unless you take care of the corrosion control that is the important thing. And of course, the process becomes less efficient loss of profit, cant have a production, the profitable levels.

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Now, as you have been talking about industrial things are very complicated, materials are subjected to fabrication. On the process side, they are subjected to temperatures and pressures. They are all contribute to various different forms of corrosion a complex forms of corrosion.

Now example here this is one which I went I have done a consultancy work for one of the industry right. See this is all fabrication all, I have done it right. You just cut open this and see this is one weldment here, another weldment here. This is called a seam weld seam weld is getting corroded, the stainless steels here, the seam place that suffered corrosion.

So, the corrosion is complex. So, between different types of mechanisms that we have and failures are different; some examples of mechanism are given and not all of them.

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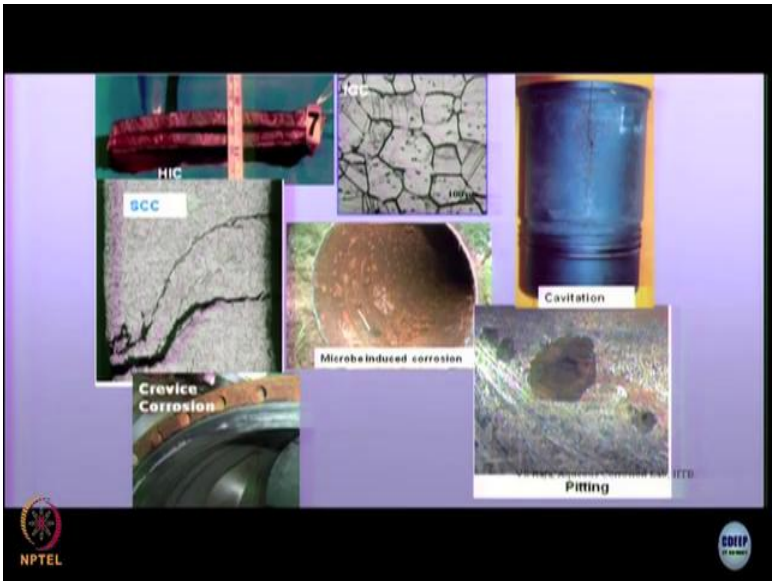

We have seen this before. this is called hydrogen induced cracking, hydrogen gets into the material and then builds pressure and cracks. This is called stress corrosion cracking when you apply a stress and you have environment it cracks, you know when it cracks its brittle what is the ductility of a typical 316 alloy stainless steel. Anybody here can tell? Ductility is could be 60 percent ductility; it spread that is why metals are used.

In a environment, the ductility in terms of percentage elongation can draw from 60 percent to 10 percent, 5 percent mostly acts like a ceramic now. So, it become brittle. They are brittle failures. You have what is called as a crevice corrosion right; you have mechanical joints, a flange joints, you have rivets right. It undergoes a different form of corrosion.

We call them as a crevice corrosion, another mechanism that you have ok. You weld it the grain boundaries of the stainless steels become very reactive, we call them as sensitization, but another form of corrosion called intergranular corrosion mechanism.

Just now you have seen it you have microbes induced corrosion here, There are microbes a different forms of corrosion mechanism and it is called a cavitation damage. It is a its actually what? It is a engine block actually for a ship and because of constant vibrations you know and bubbles form and then the impact leading to failure is called as a cavitation damage. You can have a pitting look at this here a pitting corrosion taking place only localized on corrosions.

So, we started with a simple concept of corrosion, what is that? Metal exposed to the environment leads to two kind of reactions; one in oxidation where the metal releases electrons and the environment picks up that electron here is called reduction process in all corrosion process is taking place. But the way this reaction occurs can be very complex the solution to these problems are different.

So, we have different forms of corrosion in Fontana book it calls it calls as 8 forms of corrosion, you may not agree with it, I also may not agree with it you may call 9 forms and 10 forms and 12 forms of corrosion. When we say mechanism why you call a mechanism? I said mechanism that tells me how do I counter it, is not it? If I know the mechanism I put a obstacle for the movement of the process.

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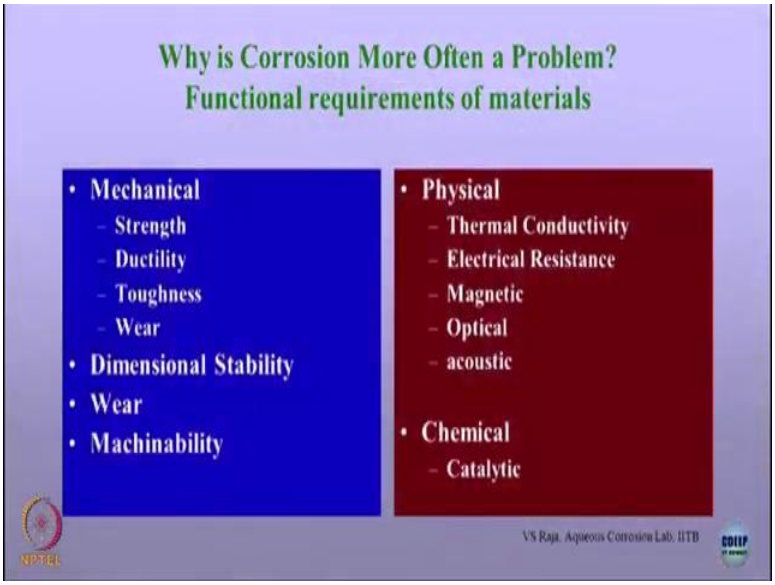

So, the mechanism is different and the solutions are different. So, that is what is to be seen. It should be seen in the light of the fact. Material selection when you talk about for any industries where you talk about aerospace or talk about a car or to pipeline or a pressure vessels, you go to a mechanical engineer or design engineer; what does he first thinks?

He first things about he or she will think about, what thinks about oh what is the strength? What is the toughness? Ductility, is it wear resistance? Is it dimensionally stable? And machinability all these; if you are going to be another kind of guys who are

making devices like that oh what is thermal conductivity? What are magnetic properties, optical properties? Corrosion does not figure in material selection more often industries.

Oh I have a very nice glass borosil glass, it does not corrode. Can you use it? Can I go and tell a mechanical engineer that oh it is a oh crazy guy, he will say oh I want to use magnesium carnivals.

Can you provide a solution for that? So corrosion engineer, you provide solution where the metal is or metals are expected to corrode. So, how do you prevent the corrosion? So, that is the science of engineering of corrosion look at there actually ok. So, that is what I think you do that.

So, this course is to show that the corroding metals can be safely used a definite time without corrosion failures.

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So, is it that trivial problem (Refer Time: 48:28) this some electron some welding and what is so, big about? Is this is really a problem? What is impact? You ask your question counter way, can you tell me an industry system where you will not find corrosion? Can you just tell me can you just point out one industry where oh there will be no corrosion?

Student: Glass industry.

Glass industry. If you want how do you know how do make glasses? Glasses are melted right. Is melted in what? Melted in.

Student: (Refer Time: 49:05).

Various steel retorts, it corrodes. In fact, one of the this thing you know I was giving one of the consultancy service to the company making glass for the cars you know for car and you have that nice glass and coverage right. You start melting and it is just you know deteriorates over a time period that corrosion of course, is called high temperature corrosion ok.

Glass of course, it does not have. But the glass it is not eternal right if somebody is going to use hydrofluoric acid for his own purposes can he the use a glass? No people stepped wrong. In fact, those industries which deals with hf you know what they use they use Monel(Refer Time: 49:50)? It consists of copper and nickel the glass may not going to work.

So, it is only safe to say that those industries which are not using materials metals will not have corrosion problem, but can you find industry which is not using a materials and metals, no it is not likely to happen. Where does the corrosion problem occurs? It occurs almost all industries talk about all industries using metals and materials or bound to have corrosion problems.

The extent of corrosion changes a chemical process industry a petrochemical industries a fertilizer industries for example, may have different, aerospace industry maybe somewhat different, how the transportation industry may be different, a nuclear industry may be different, but I do not see that there are any industry would not have any corrosion problem at all so, long as they used metals and alloys I mean engineering metals and the engineering alloys.

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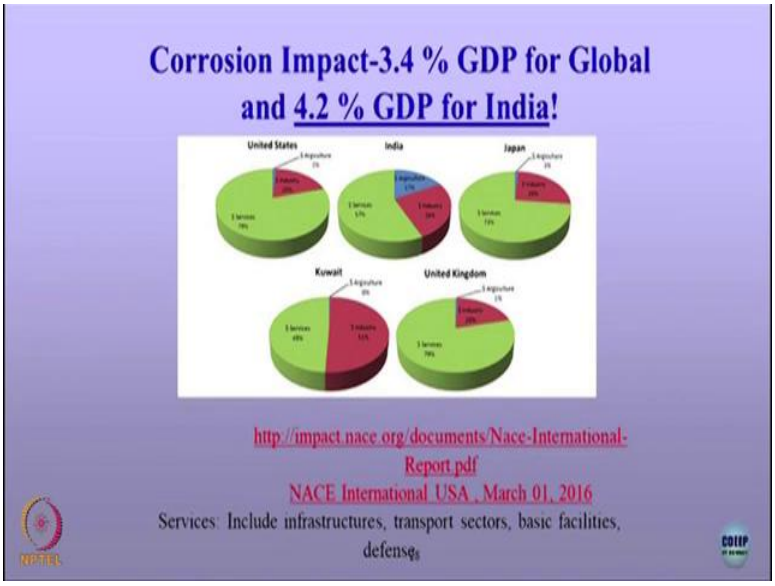

It has a great impact I have shown this here I have taken this from this you know this document called you know impact studies done by NACE international very recent 2016, they done it. They shown that the loss to nation is about 3.4 percent of the GDP.

Now, if you look at the western countries like you know you maybe France or UK or even Japan what is the growth rate of these countries? Many of them less than 1 percent; it is hard to get that actually.

So, there is a significant impact in terms of corrosion it happens at all because the cost that you can you know you can have to nation is quite significant, it contributes and of course, India we have about 4.2 percent that the if you see that.

So, corrosion is not trivial is this not confined to only one industries, it is just not see replacing materials oh I use a glass, I use a titanium, I use this you cannot find the solution at all. So, there is a science there is a engineering very important in order to fix the problem and it is even more important and the technology evolves actually ok.

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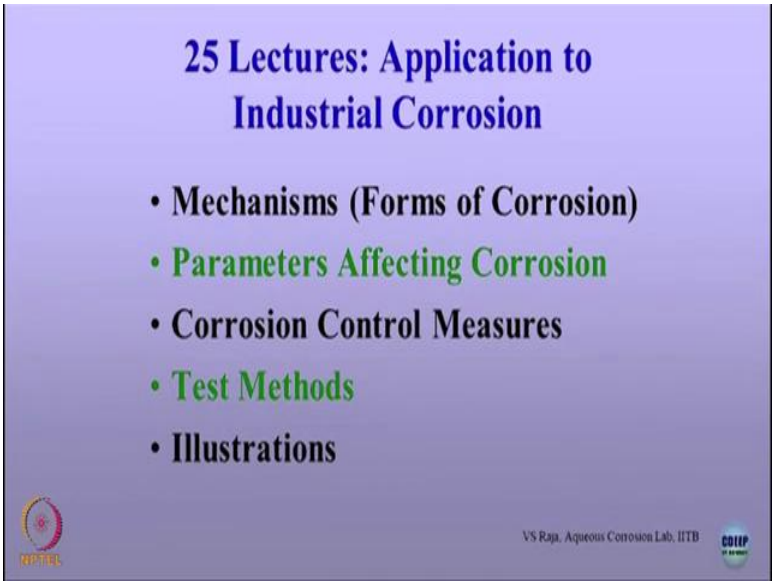

The technology evolves what does it mean? You know India about few years back the thermal power plants were all subcritical thermal power plant because subcritical boilers the mechanical engineers would know about it right the pressure of these boilers less than 25 mega Pascals. Now you want to rise the pressure more they called supercritical boilers.

Now, they have gone into ultra supercritical boilers why are we doing this? The efficiency of these thermal power plants will increase significantly not only that the carbon footprint the emission control this can significantly reduced if we increase this boiler temperatures and pressures because the efficiency of heat transfer becomes very high.

Student: Yes sir.

You cannot raise a temperature you cannot use a same steel. The corrosion problems faced by these industries are different from the boilers, the way you do water treatment is different. So, as a technology evolves with time the same methods of corrosion control may not work, the same understanding of corrosion of materials may not work it changes.

So, corrosion control is evolving because the technologies are being grown. You know the Apple phone iPhone, they use on the cover you know this is what used it this is what?

The magnesium right; it have been use magnesium. How do you think the magnesium can be used? Because you know, how to have good coatings to that.

So, as you develop new technologies you are under threshold; we cannot afford to allow corrosion. Yesterday I was went to one of the industry here. I do not want to mention the industries. It is supercritical. Within 3 months started failing. The heat exchanger in about 5 months they had 3,000 tubes in heat exchange tubes 1400 tubes are plugged because (Refer Time: 54:36) each of them started cracking.

They were very happy earlier, now they are not very happy because the technology has changed, you cannot use same way of corrosion control taking place. So, there is a need to change. How to do that? We need to understand the mechanisms; the mechanisms are going to be there.

So, the next part of my course, you have about 25 lectures. We deal with the mechanisms of various forms of corrosions. When you know the mechanisms it is for you, can figure out what are the parameters that affect corrosion under each cases right.

If you know the parameters affecting corrosion, you can device the control measures yourself; do that you, do not have to read the book. If you know the basics you can devise a test method yourself; you do not have to again go to the book; you can devise a test method ok. Of course, you also give illustrations to show how these failures occurred in industries, these illustrations.

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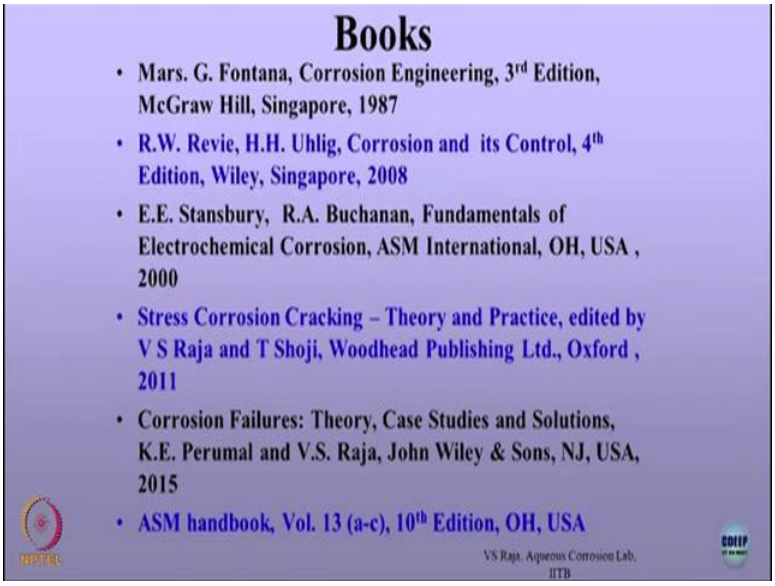

So, this will be the second part of this course. We can do that and I have these books here. I can share this slides with you, you can you do not have to take this notes of this.

As I told you in the beginning of the course, I will use Fontana as the main line you know of in the lectures ok. It is it has got a lot of industrial component here I also refer these books actually and Uhlig book, it is a good book, it spends quite a bit of the chapters on mechanisms; the fundamental understanding. The Fontana book is not really that one actually is not happening at all ok.

And if this is a Stansbury and Buchanan if you are going to be interested too much on electrochemistry, thermodynamics and kinetics and all these stuffs. This is a excellent book actually, you can refer this book or you are going to do a project later more involving electrochemical experimentations that is a good book to refer to ok.

And if you want to go again stray into more and more deeper we can also look at book on stress corrosion cracking. Here in practices lot about it is some 20, 22 chapters by very experts across the globe industrial problems also.

You want to go into more realistic problems and all, I would recommend the book corrosion failures theory, case studies and solutions of course, you do not want to go anywhere I am not be little lazy. I think you can look this ASM handbook, it is huge

collection of. Also, you have fundamentals volume a, volume b on materials and volume c is on what on industrial problems of course, each of them maybe a 1500 pages ok.

So, all put together probably about close to about 5000 pages will be there I think something like that. It is a nice book and you know any time that you can refer it and lots I do not know more than 600 authors or may be more have contributed to this particular book actually volumes, I would say ok; it is good.

So, these are the things I think you can daily do in addition to that and you are interested in some research, there are journals available you know corrosion is one general, corrosion science is another general, corrosion engineering science and technology is another general if we are all getting these journals in our library.

There are journals related to purely materials acta and all you know acta materialia, where you have corrosion and available people can treat it. You have very nice collection of books and journals in the in our library that should help you a lot actually and I think, we have now come to end of today's lectures.