Aqueous Corrosion and its Control

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Lecture - 27
Forms of Corrosion: Erosion corrosion (Part-II)

The flow assisted corrosion in details; we looked at the Erosion corrosion of metals. We shall continue that erosion corrosion now and then you go on to the cavitation corrosion. In the erosion corrosion we looked at the importance of erosion corrosion. We also saw how erosion corrosion can be different from the flow assisted corrosion. In the flow assisted corrosion it is the diffusion of the corrosion product that is the rate determining step.

If it diffuses faster, then the flow assisted corrosion rate increases. And so, the formation of the film is essentially governed by the dissolution of the metal ions. In the case of iron it is Fe^{2+} majorly and certain amount of Fe^{3+} and then the reform as, in a magnetic oxide.

And the role of flow is to retard the formation of this magnetic oxide. And as the flow is higher, the film becomes thinner and the film also becomes rough we can say to some extent.

We saw that the factors that affect the flow assisted corrosion or material. In the case of steel you add chromium when it becomes strongly oxide forming chromium in the flow assisted corrosion decreases. And the environment you know what are that. The ph is one factor, the other factor is a velocity, other one is temperature, ok that we look at these the oxygen content, ok.

More importantly that the, the flow assisted corrosion goes to the maximum and the maximum temperature depend upon with single phase or the two phase flow; irrespective of the velocity that happens. Velocity increase of course, the erosion I mean not I am sorry, this is flow assisted corrosion increases.

So, that and so that is its a interesting thing that high temperature, they do not really happened boilers, they do not happen at all. The increase in oxygen content also lowers the flow assisted corrosion because it facilitates the oxide formation on the surface. So, that leads to the, what I called as a new water treatment called as the oxygenated water treatment in some other boilers. The oxygenated treatment may have some problem that we are not going to discuss now here. The other effect is a is mechanical effect and flow and related to that actually ok; and that depends upon the factor like the velocity, the pressure and the turbulence that are going to be there.

So, they are all going to contribute to the flow assisted corrosion and turbulence means design also plays an important role. Then comes erosion corrosion, we say the damage is really that is impact and leading to film damage, and there is a film damage and of course, corrosion production falls. Over year to increase in turbulence would increase the erosion corrosion. The erosion corrosion would get accelerated when you have solid particle suspensions actually. And, so that is a key issue in the erosion corrosion of metals.

We saw the various factors that affect, we list a rather; the various factors affecting the erosion corrosion and they are film formation, the film stability. Other is the velocity and the next was on the materials. We saw the film formation, you in film instability in the arms of film characteristics, right. What are the characteristics we talking about?

We talked about the hardness, resilience, porosity and you know loss of porosity, other I think options of porosity, density, ok. And, the ability of the film to reform that probably we did not discuss, ok; if the foreign film gets damaged how quickly the film can reform on the surface.

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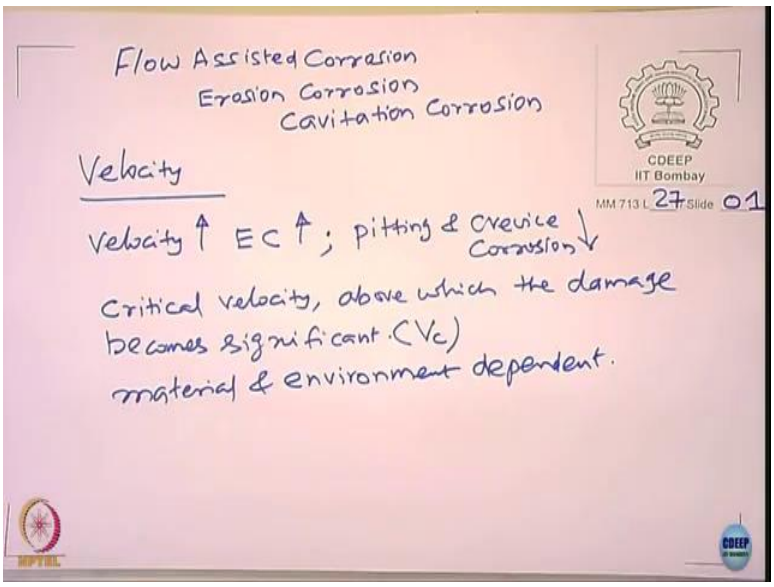

The next aspect that we would be discussing now is on the velocity. One thing that you might look at is we can generally say that, that when the velocity increases erosion corrosion increases. But, we also know that there are other forms of corrosion, like pitting corrosion and crevice corrosion. They are all drop when you have velocities, right we have seen when you discuss the pitting corrosion and crevice corrosion topics.

It is also necessary to understand that there is a critical velocity, above which the damage is becomes significant, right. And this critical velocity that we talk about, it is material dependent, material and of course, the environment dependent.

Now, if you want to just have a feel of it, ok; I just give some data here, ok how the corrosion rate, the erosion corrosion rate will change depending upon the, on the other materials ok.

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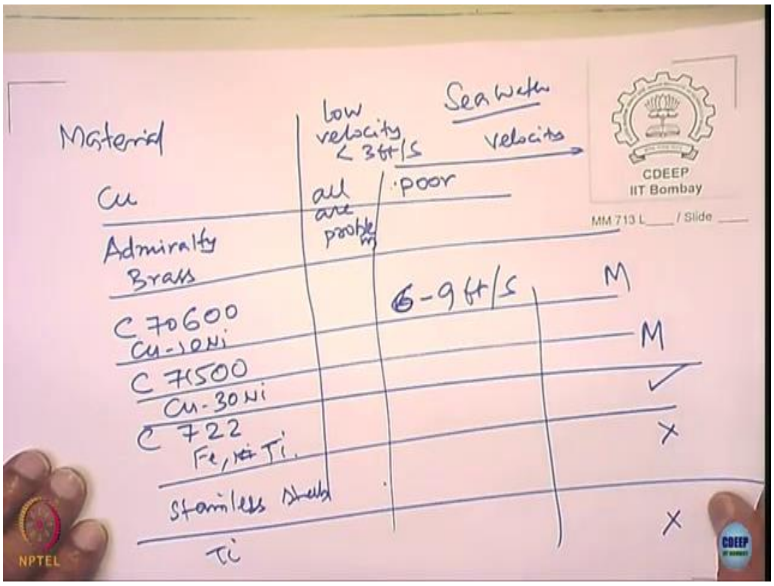

Suppose, you take a say material, let us take copper and admiralty brass and you can take, the say C 706 and this is copper nickel, right; this is copper 10 nickel right and you also have C 715of course, we need to put some 00 here ok.

This is a copper, I think 30 nickel. We also have C 722 and this consist of some alloying elements like, you may have some iron maybe some nick, no not nickel, iron some titanium and things like that.

If you look at copper. In fact, its very interesting, low velocity right; if it is going to be less than 3 feet per second, all are problem. You know why you take a pipeline, you taken heat exchanger with the flow velocity is low and they are not the right material to use. Any idea about it? What do you think?

Low velocity is also a problem. See most of the process fluids might have some kind of, some kind of particles you know, second particles you know dispersed particles. Sometimes in heat exchangers if you see water, may be some (Refer Time: 10:52), and the velocity is very low then what happens? They start depositing on the surfaces. Its not erosion corrosion problem, it is another kind of problem there you are going to get ok. And so, you normally have a problems in these cases.

So, you can if you want to rank it in terms of the properties. I, I say this is, this is, this is poor. I mean in terms of the erosion corrosion resistance I would say this is, copper is, no its going to be here ok. And of course, you can also go for stainless steels and titanium alloys ok.

So, maybe in sea water, see if you increase the velocity ok; you would find that stainless steels are good, titanium are good ok. And, this could be, I would say; I would say moderate levels, ok and they could be moderate levels and it could be moderate levels ok.

This, is can be even it could be ok. So, these all you know, all these copper based alloys, the velocity is maybe around about, see proud about you know we can go up to maybe yeah about 6 to 9 feet per second velocity. That you can go for it this is higher ok.

So, beyond that the copper based alloys would have a problem. So, higher velocity means stainless steels and titanium alloys. These of the ways that you can use it, but titanium alloys cannot be used, I mean titanium alloys can be used, but the stainless steels of all categories cannot be used in seawater application, right.

These are some problem. What is the problem there? We use a stainless steel in seawater application, what is the problem? Yeah, it could be pitting corrosion crevice corrosion. So, you can only use a highly alloy stainless steels like super duplex or hyper duplex in the stainless steels, or go for super austenitic grade stainless steels.

Now, if you look at the copper based alloys compared to the stainless steel; stainless steel is much harder. When copper based alloys are reasonably softer, using before. So, the utility of these materials are, you know restricted based on the flow rate applications. The flow rate is increasing, I think the choices are going to be much limited, ok; you go for stainless steel or titanium base based alloys.

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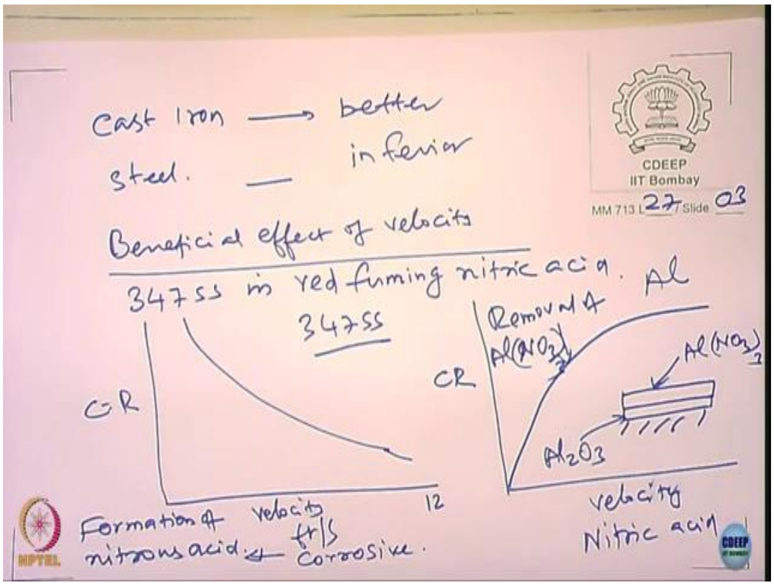

But the same logic if you look at; if you look at a cast iron and steel, so which one do you think will be better from the erosion corrosion point of view? Okay, so this is better. This is inferior compared to that. Sometimes the velocity can have beneficial effect, right.

This they were reported for 347 stainless steels in red fuming nitric acid. They found corrosion rate, it drops like this. May be within about; let us say 12 feet per second a drops like this.

In the case of; in the case of aluminum alloys slightly different, corrosion rate versus velocity, something like this. The reason being, in aluminum alloy what happens is, so aluminum alloy that you have, it forms two kinds of films.

Aluminum nitrate and the other film is Al_2O_3 film, they are also nitric acid. Now, aluminum nitrate is, is a salt film and if we increase the velocity the salt film just gets disturbed and goes away.

Aluminum oxide is quite intact. So the, so initially the corrosion rate increases because of the removal of aluminum nitrate salt product. After this what happens? The aluminum oxide remains on the surface and subsequent velocity it does not disturb Al_2O_3 stable. So, the corrosion rate does not change after this. So here, so this means here removal of $AlNO_3$ salt.

The mechanism here is different, the mechanism here stated mechanism is that the corrosion of steel in nitric acid leads to the formation of nitrous acid, and the nitrous acid is corrosive ok; is corrosive.

Now, what happens? The flow, when there is a flow, what happens now? The nitrous acid is removed from the surface. So, subsequent corrosion by nitrous acid is avoided. So, increase in velocity decreases the corrosion rate, because the accumulation of nitrous acid does not occur because of the flow of the velocity.

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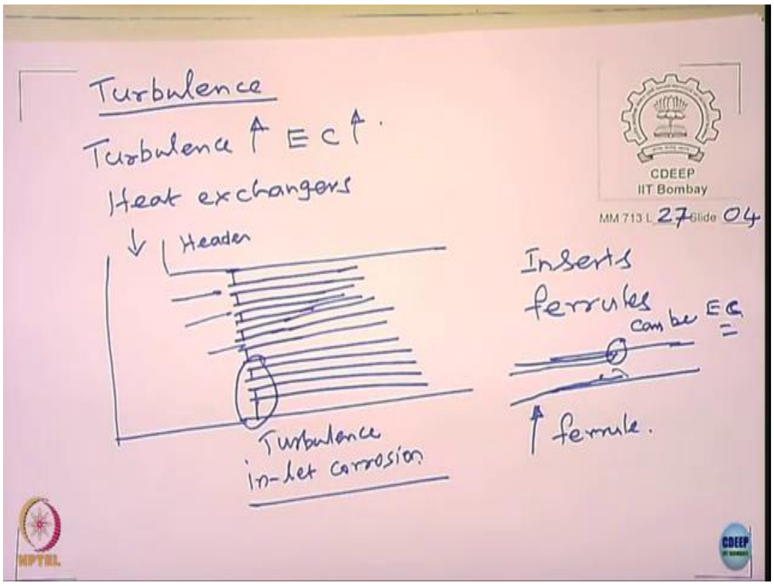

The next thing that we talk about is the turbulence. Now, the turbulence can happen if the surface is not smooth, if there is a change of direction or if there is reduction in the diameter of the pipeline, can happen. So, higher the turbulence, higher is the erosion corrosion.

This is very predominant in the heat exchangers. We have seen the heat exchanger in overall, when you discussed I think galvanic corrosion. Some of you might, might recollect right. What is that? If you recollect, so you will have lots of tubes right I think.

So, the liquid you know enters through the header, right; this side and there is almost a 90 degree turn and it enters. The maximum turbulence, they occur at the inlet right, and as a travel towards inside, the degree of turbulence decreases.

Student: Decreases.

So, the maximum damage in the heat exchanger, it occurs are the inlet right. So, that is why it is called as inlet corrosion. Now, how do you really avoid this?

One way people avoid is they go for inserts, they called as ferrules right. So, this is a tube for example, this is the ferrule ok, and it will not necessary do not protrude they just go inside, you know these things, ok. I just shown it for convenience.

Now, this ferrule that model this ferrule is that, the ferrule can undergo erosion corrosion. When it gets damaged you can replace it and put another ferrule. So, life of the heat exchanger significantly increases ok, but there is similar problem. What is the problem? When the fluid or liquid enters here there is going to a small step this is small step. So, there can be erosion corrosion here.

So, we need to smoothen out, you need to make it like a feathery kind of you know tapering off has to be done in order to reduce this erosion corrosion ok, but use of ferrules are, are being done. So, its industrially its accepted practice to minimize the inlet corrosion of heat exchangers. Impingement is there ok.

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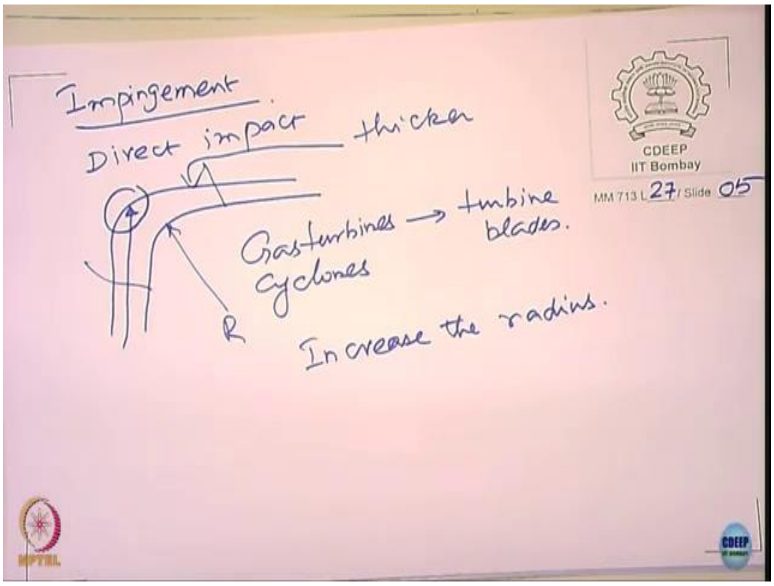

Impingement is at a direct impact. So, the impact can be high here. So, more erosion corrosion can take, this is impingement attack where impact takes place. And if you are going to have soil particles then the extent of impingement attack becomes quite significant.

And these are common, it can happen in gas turbines ok. It can happen in cyclones, it can happen actually right. So, some of the units they, really feel you know in gas turbines where do it happen? It can happen in the turbine blade right. It can happen in aircrafts external part it you know, it moves at a very high velocity. It can happen.

Some cases we can change the design and we can improve upon, but there are cases where you cannot change the design everywhere right, but where the that is possible we can change the design. For example, here you do not make, you know you increase the one way to do is that increase this radius. When you increase the radius what happens now?

You will have less impact, less turbulence you can occur. The other way of course, to visualize this is that you take this part little heavier right. You make it as thicker, where you know for sure that you are going to have impingement taking place.

See, it can happen in a heat exchangers you know, the you know you in heat exchangers you have baffles, you know sometimes they hit right. So, its possible that that you can increase the thickness of that you know, more for that life of the overall component can be increased significantly.

So, when you look at this, one thing becomes clear that the design plays a very important role in minimizing the erosion corrosion right. When I say design, all that reduces the impact impingement, all that reduces the turbulence can increase the erosion corrosion resistance of a system. So, its a design parameter as much as material parameter as well as the environmental conditions that are operating in a given system. Let us go to materials. What should be the material property you think that would give you a better erosion corrosion resistance?

Student: Should be hard (Refer Time: 29:16).

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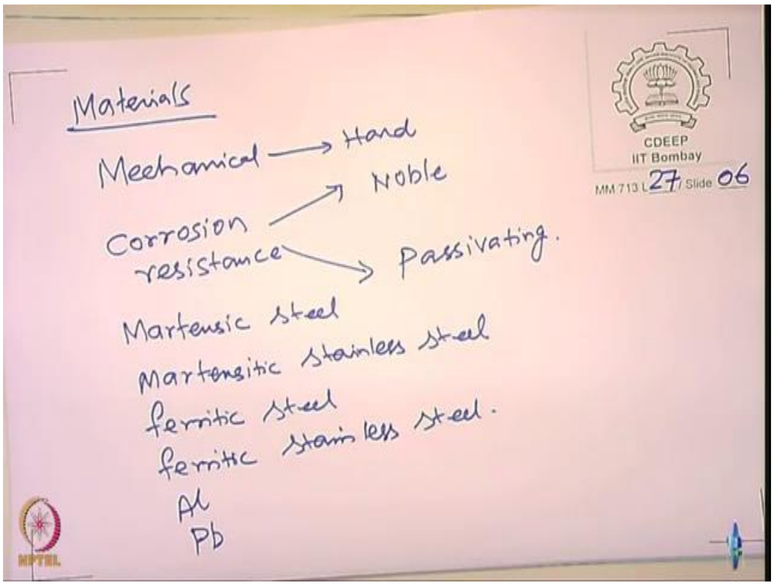

Should be hard. So, it you should be a mechanic from mechanical properties, point of view it has to be hard. Yeah its sufficient to have only hard thing, what else?

Student:(Refer Time: 29:35).

Yeah, abrasion resistance comes from hardness, I mean you increase the hardness generally your resistance do that. Is a sufficient to be just hard?

Student: (Refer Time: 29:44).

Yeah.

Student: (Refer Time: 29:46).

So, you should be also having corrosion resistance.

Student: (Refer Time: 29:56).

Of course, this that is involved in the corrosion resistance package, right. So, in corrosion resistance, how can you; how can you improve the corrosion resistance?

Either the material can be noble, material or it can be passivating material. These are the criteria right. Let me give an example, martensic steel. I given some, 4 examples here, I can give I, if you want I can give you even aluminum, I can give you even lead if you want.

Now, let us take for simplicity only the stainless steels steel family. Can you just compare and what will be your view about just erosion damage resistance, and erosion corrosion resistance damage?

Please you know, listen to my question. You have 4 different type of steel, you can have 2 types of damage mechanism; one is erosion, other is a erosion corrosion. So, what will be in your view? Suppose, I take for example, simply erosion right. How do you rank this one? Ok; nobody. Yeah, you are right then.

Student: Sir I do not think (Refer Time: 32:22).

So when it comes to erosion of course, assuming that the hardness is same. I mean I am not really going to way too many things right. Assume that the hardness of martensic steel and stainless steel are going to be same ok.

So, if you look at erosion both martensic steel and martensic stainless steel be almost the same. When it comes to erosion corrosion, martensicstainless steel will be better compared to martensic steel. In fact, it might so happen, the ferritic stainless steel may be better than even martensic steel, depending upon the corrosive nature of the environment.

The environment is very corrosive; it is possible that the erosion corrosion resistance of a ferritic stainless steel could be better than erosion corrosion resistance of a martensic steel.

Why? Because martensic steel generally are more prone to corrosion compared to ferritic steel here, but the most vulnerable among all these; among all these from the erosion point of view, which is the most vulnerable here? 1234?

Student: Ferritic.

Ferritic would be a more, right next better would be ferritic stainless steel. Now, of course, martensic steel and martensic stainless steel would be almost similar. So, I wanted to understand ok, the concept of our development how its been done.

Aluminum and lead of course, if they are low velocities and we have less problems, when the velocity is increased then its a problem. See this is very interesting thing. It is not necessary that you can extrapolate at all velocity.

At a normal velocity it is possible that the lead in, let you know lead for example, in sulfuric acid in the dilute sulphuric acid at static conditions at a very low flow conditions lead may be good, ok; whereas, with a high velocity the lead is softer. So, that is fellow will not even withstand that actually.

So, it is not possible to extrapolate you know, I had given velocities to because, are higher velocity is the mechanism of damage may be different. Is more mechanical damage dominated corrosion problems than the corrosion dominated problems.

At low velocities, what is the dominating mechanism? Low velocities is corrosion, at higher velocities the dominating mechanism will be mechanical factor actually. So, it is not possible to just make extrapolations the way you want it actually, ok. I would like to give an example, of how these things really happen in practice. Is one of the industries in India was making, what is called as hydrogen generation unit.

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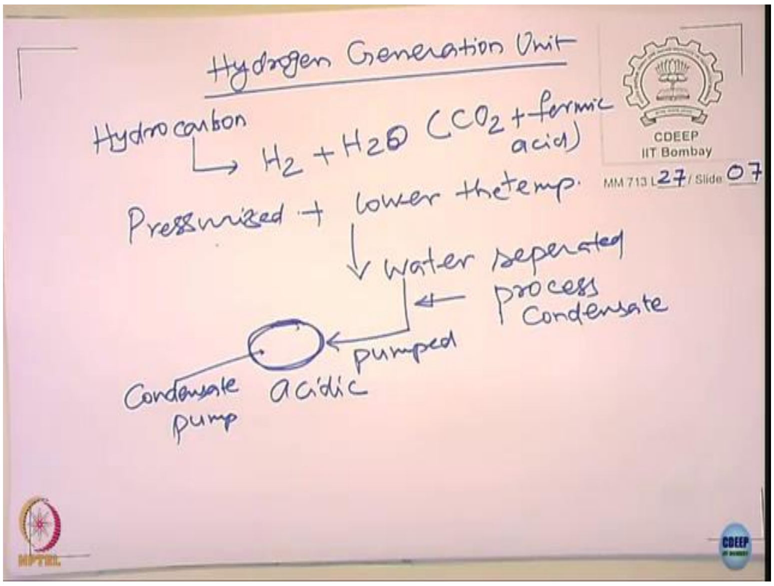

It was, it was you know, they had license it is able to have a engineering you know capacity, this unit was I think you know commissions somewhere in the eastern Europe. The hydrogen was generated from hydrocarbon. When it generated from the hydrocarbon it consisted of hydrogen plus water.

Of course, there will be some amount of some amount of carbon dioxide, some amount of formic acid or kind of stuffs, but these are very low quantities. If I want to give hydrogen to the user, what I should do? I should strip the hydrogen from water a carbon dioxide and formic acid. The carbon dioxide and formic acid they dissolved water. So, when you remove water, automatically this go away. Right; how do I remove water from, from the gas? Yeah.

Student: (Refer Time: 37:05).

You hit it, we think gas will remain there, how do you do that?

Student: (Refer Time: 37:15).

You are talking about industry unit, they are want to produce a few tons of you know hydrogen, right. You cannot use chemicals and all kind of stuff. Any other method you can do? No? Simple.

Student: (Refer Time: 37:29).

Yeah, first of all pressurize. Not sufficient, lower the temperatures. You pressurize and lower the temperature, what happens to water? Water will condense, right. The water condenses and the air will be free from, a gas to be free from water. So, the work done people do in the industries.

Now, when you pressurize it, you low the temperature. The water is getting separated is a good water. So, this is now pumped and they call this as process condensate in the industry. Its so nice water, no chlorides and all, but what does it have; what does it have?

It, it has carbon dioxide has got a formic acid, its a pure water is almost like distilled water. So, what do you think is property? What would be its pH you think? It will be alkaline, neutral and what do you think? Yeah?

Student: Formic acid is just (Refer time: 39:12) Acidic.

So, it should be slightly acidic right. Now, whole line is under a higher pressure right. So, you compress it, you pump and then. So, there is a pump here. So, pump; so there is a compressor here ok. So, this is called as a pump ok; say condensate pump. And this water is pumped to, you can pump it to a water treatment unit and then to boiler, you can do that ok. Now, the interest comes over here, this is the pump. In the pump, the fluid goes at a very high velocity right. So, what are the process parameters?

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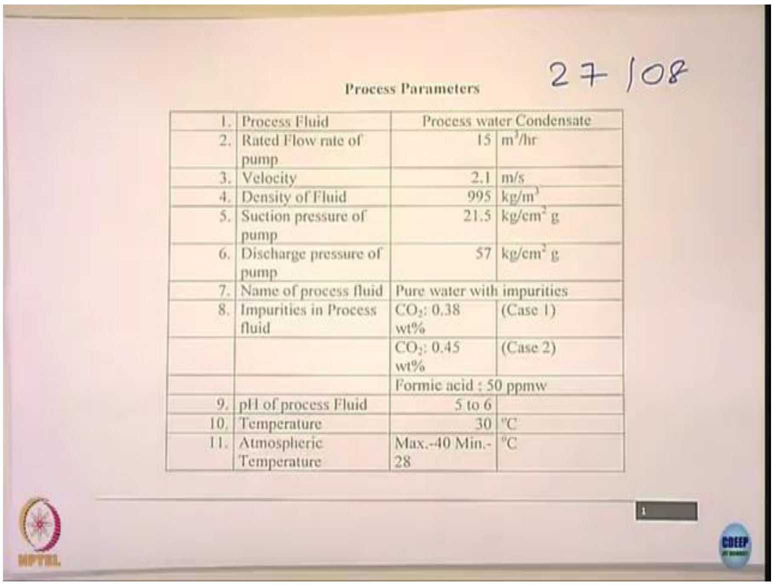

Process Parameters

1.	Process Fluid	Process water Condensate	
2.	Rated Flow rate of pump	15	m^3/hr
3.	Velocity	2.1	m/s
4.	Density of Fluid	995	kg/m^3
5.	Suction pressure of pump	21.5	kg/cm^2 g
6.	Discharge pressure of pump	57	kg/cm^2 g
7.	Name of process fluid	Pure water with impurities	
8.	Impurities in Process fluid	CO_2: 0.38 wt%	(Case 1)
		CO_2: 0.45 wt%	(Case 2)
		Formic acid : 50 ppmw	
9.	pH of process Fluid	5 to 6	
10.	Temperature	30	°C
11.	Atmospheric Temperature	Max.-40 Min.-28	°C

These are some of the process parameters right. You can see that the flow rate is 15 meter cube per hour and linear velocity is what matters for us its about 2.1 meters per second. That is the velocity water goes, and other parameters like you know suction pressure and discharge pressure are given. From the point of your corrosion these are interesting. Now, impurities of carbon dioxide you know formic acid all stuffs. So, the pH is between 5 to 6.

The temperature is between 30 degree celsius and maximum of course, we can go to 40 degree celsius atmospheric temperatures. So, if they initially thought that in the design, they thought that the pump should be made up of martensic grade stainless steel. They were planning to have martensic grade stainless steel, but somewhere something happen.

Finally, when they just about to start the unit a found as a typo problem instead of martensic stainless steel they went for martensic steel ok. So, they realized just one day before that this is the problem. Now, the whole unit hydrocarbon unit is the part of the refinery system. You cannot stop this, you stop it everything will be stopped. And they start running the system now.

The good point was they were having standby pump, because to know these are the you know, units that can go bad and so they do not want the system to be, you know shutdown, unplanned shutdown. So, they had a standby pump.

Then they thought they probably knew that martensic steel is not same as martensic stainless steel. Then it started, they started operating one pump for about 3 hours, then move to another one for another 3 hours. They keep on shuttling between these two things actually happening at all. So, they were little worried.

Why they worried was that if you want to order the another one, if they got 9 months, is just not possible, its not just off the shelf. It takes about 9 months to get the; to get the new one actually. Is ok? This about 27 its slide is 9, right.

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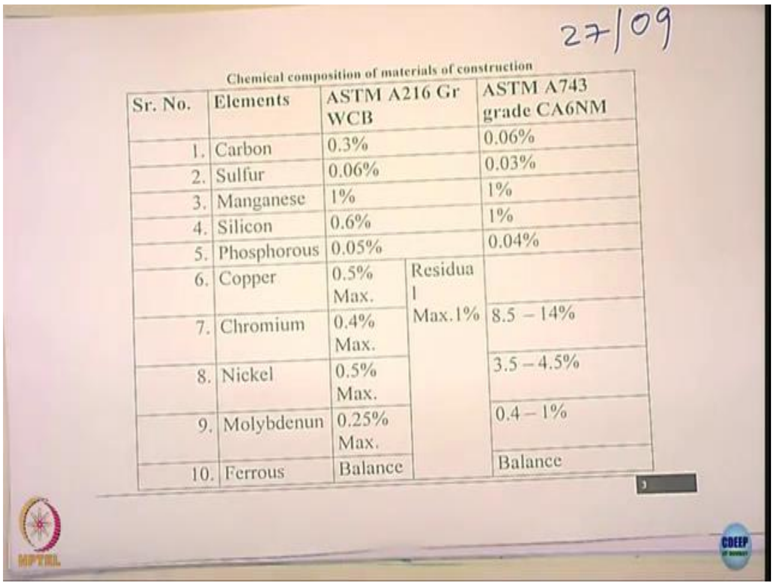

Chemical composition of materials of construction

Sr. No.	Elements	ASTM A216 Gr WCB		ASTM A743 grade CA6NM
1.	Carbon	0.3%		0.06%
2.	Sulfur	0.06%		0.03%
3.	Manganese	1%		1%
4.	Silicon	0.6%		1%
5.	Phosphorous	0.05%		0.04%
6.	Copper	0.5% Max.	Residual Max.1%	
7.	Chromium	0.4% Max.		8.5 – 14%
8.	Nickel	0.5% Max.		3.5 – 4.5%
9.	Molybdenun	0.25% Max.		0.4 – 1%
10.	Ferrous	Balance		Balance

So, look at these comparison of this materials now. Between the martensic grade ASTMA216 grade is a martensic steel and ASTM A743, it is martensic grade I think stainless steels. The chromium is between 8.5 and 14 percent. Nickel is about 3.5 to 4.5 percent ok. molybdenum is in this ranged now, now they are worried because martensic steel is really you know corrosive and compared to carbon steels actually ok.

So, what will happen? So, they started working alternatively and then they start called one day and they said was is a problem. It was indeed a problem. The issue here was different, suppose you have pump 1 and pump 2, 1 pump operates other pump is standby. When you keep a standby, if this environment the pH about 5 is there stored, the corrosion are not going to stop. Only erosion corrosion of course, is reduced because there is no flow, but corrosion will not be stopping, right.

So, its not prudent to keep the corrosive liquid getting stored. They might think that there is no erosion corrosion, but there is a corrosion at all right. So, one thing, one of the thing that they can at least look at is monitor the thickness of the pump. And see what happens, one thing you can do that, right; other thing that you can do is that I do not start alternatively, at least start one for 1 week and keep other one dry. So, that the fellow does not corrode at all right. Other is what happens, you are simply corroding both of them and you are not really happening.

So, what was done was they are advised that, ok; at least do not start alternatively it is keep for about a week time and keep other one dry, happen. So, then what happens, and subsequently what we do is, then we can make a calculations actually ok; you can make a calculation because you know what is the normal pH and all.

Of course, its very difficult to make exact calculation, we can make some kind of comparison. For this particular pH, what is expected to happen at all? It so happened there is, I mean the pump was safe for 6 months by the time they can get a another unit. The point I want to emphasize here is that it looks simple between the martensic steel and martensic stainless steel, but a small error can land into a problem and can lead to unexpected failure can happen at all.

So, that is something you do see happening in this is not very old this probably about 2 years. Yeah, about 2 years back this incident happened and it was the one multinational company, its not that its some spurious company dealing with this system at all. So, the point that we need to be looking at is, look at the corrosion plus the mechanical the hardness properties are both are important.

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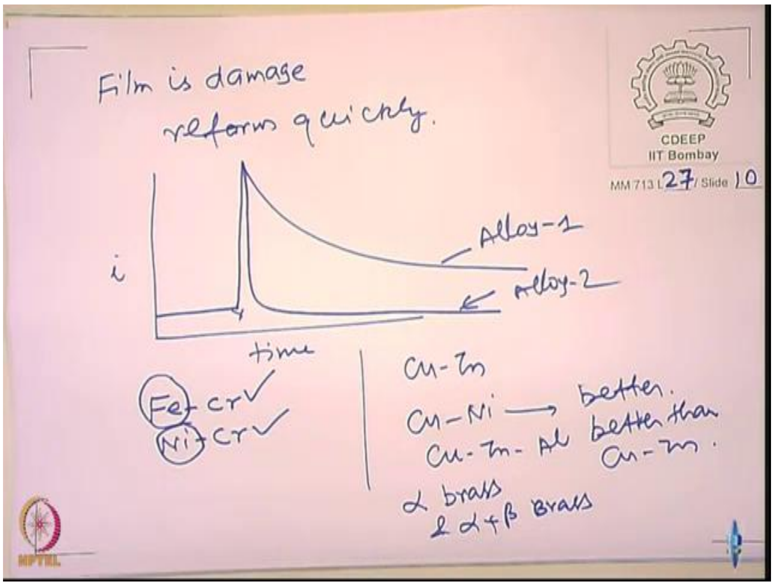

This is the passive current, if I damage here, current will rise, it can go like that or it can go like this alloy one, this is going to be your alloy two, which is better, alloy two is better. So, the alloy development program will take care of both the electrochemical and the metallurgical aspect of corrosion.

So that we do not have erosion corrosion problems. So, let us give an example now, now you have iron chromium, nickel chromium alloy. Let us take an example here, assuming that the hardness properties are same, which of the two will have better erosion corrosion resistance? You got my question?

I am not giving other elements present here, I am just giving the base alloy is iron based, its a nickel based. I have chromium here and chromium here assuming that the hardness is same. Which of these two will have better erosion corrosion resistance and why? What do you think? Suddenly one would be better than other one. Do not you think so? So, what do you think?

Student: Chromium.

Yeah.

Student: (Refer Time: 48:40).

Nickel chromium, you, maybe you guessed it right or.

Student: (Refer Time: 48:42).

You or you figured out the science of it, ok. So, let us look at the science of it. Why do you think nickel chromium is better than iron chromium?

Student: (Refer Time: 48:54).

Yeah.

Student: (Refer Time: 48:58).

So, relatively nickel is more noble compared to iron is as simple as that ok. So, you have, you find that this is certainly its is better. So, those cast irons which are having more nickel ok; or will be better than the one with nickel free cast irons. So, broadly that you can say, the same is true in this case also right; you take copper zinc and copper nickel right, this will be better. Now, if you are going to add let us say, copper zinc and aluminum. Suppose add to this. So, this is better than copper zinc.

Now if you take, let us take the case of alpha brass and alpha plus beta brass. Which one do you think will be better in terms of erosion corrosion damage? Yeah.

Student: Alpha plus beta brass.

Alpha, beta will be better?

Student: Alpha will be better.

So, this is where do you have look at. So, I mean alpha beta brass as you metallurgy guys should know, right; its a 2 phase 1, right. The 2 phase will have a better toughness better hardness compared to that actually right. So, if you look at here, its very interesting thing that can happen.

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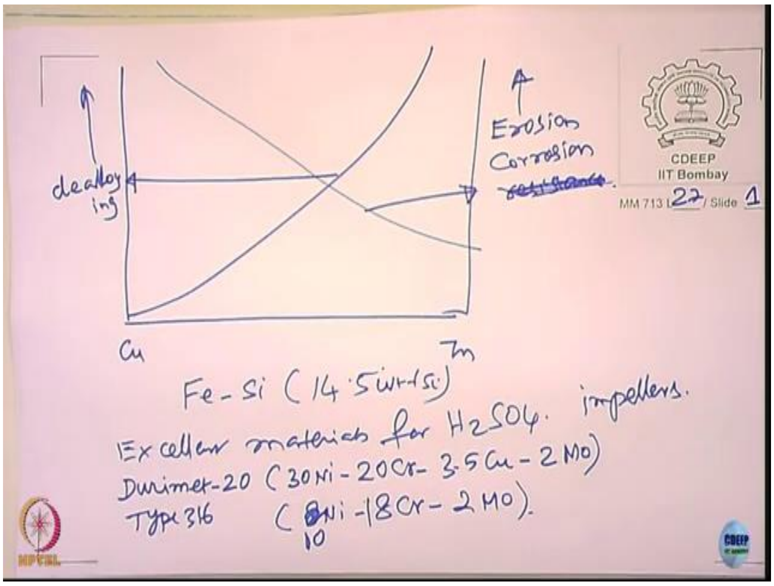

The limited extent, de alloying erosion corrosion resistance. No, I do not all resistance here, I say erosion corrosion both scales are going same manner, ok. Can you plot how this will happen?

Student: (Refer Time: 51:46).

So, there is a de alloying is concerned, this guy will go like that corresponds to this right. So, what will happened for erosion corrosion?

Student: (Refer Time: 52:01).

Something I will go, right; now depending upon which is the dominant mechanism right. If there is no flow very low velocities probably you choose alloys of this here right, but high velocities, you choose, try to choose alloys somewhere here. Otherwise instead of de alloying, they will fail by erosion corrosion damage.

The other example is iron silicon. Actually you are going to have14. 5 weight percent silicon. Is excellent material for handling sulfuric acid. Its very used for impellers. You cannot use for a pipeline there right, can you use our pipeline and silicon alloy of this one? Can you make a pipe out of this? You cannot. Its only a cast product you know, its so brittle you cannot make. So, its for the impeller pump, you can do that, no problem, pump also again no problem Ok.

So, the silicon forms a very hard silicon dioxide, protective oxide, hard oxide. So, its certainly better. You can also give an example, let us say durimet, its an alloy. Durimet20, its made only for the sulfuric acid applications actually, consist of 30 nickel, 20 chromium, 3.5 copper and 2 molly. Take this versus a stainless steel like I say, Type 316 stainless steel.

This is 8 nickel, 18 chromium, actually its not 8nickel, its 10 nickel. Actually 10 nickel and you have about 2 molly Durimet is far better from the erosion corrosion resistance point of view. it is nitric acid, it gives in sea water applications or want to be there actually. So, its a combination of the hardness plus this is what required.

In order to have better erosion corrosion resistance, that is a point we try to drive home in the discussion ok. So, we have almost come to the end of the discussion related to erosion corrosion and having understood the mechanism understood the factors affecting the erosion corrosion. You should able to tell how we can prevent or you can control erosion corrosion?

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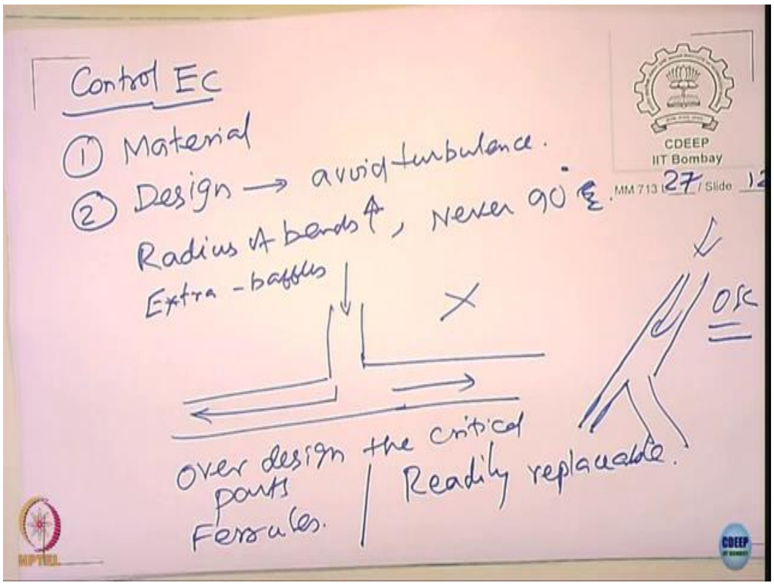

Yeah, can you just, what is the; what are the ways that you can do that?

Student: Material selection.

One is a material; select a better material that has good erosion corrosion resistant. That, that you know how it comes out, it comes out from the hardness plus the corrosion resistance properties, ok. Then what are the important thing?

Student: Structure and the turns the design.

Design is second most important thing. You can have a design to avoid turbulence. You may not avoid completely, but you can minimize it actually ok. You know all this involves, like you know you talked about radius ok, radius of bends to be increased and never 90 degrees will give you big impact. In fact, people talk about 20 to 30 degree is what is radius. I mean is the angle between the between the turn, you can talk about. What does we can look at?

Student: Filters maybe we can use.

Yes, you can use some filters even in the design also you can talk about using. What you can use? You can use; you can use extra like baffles, you can use to see that is not going to impact directly, right.

Again, how do see? This is not ok, right. So, you see that you know the fluid you know. So, the branching the way how we want make the branches there are I mean there are there are only examples they are not exhaustive by itself. Look at over design you know, plays over design where the critical parts. We talked about the Ferrules, heat exchangers see wherever the other way of looking at is this it is going to damage impinge, you should be readily replaceable. You can able replace it right quickly. So, that is also is acceptable. Yeah , you are talking about something, yeah; what is other alternative thing.

Student: Use of filters to remove solids.

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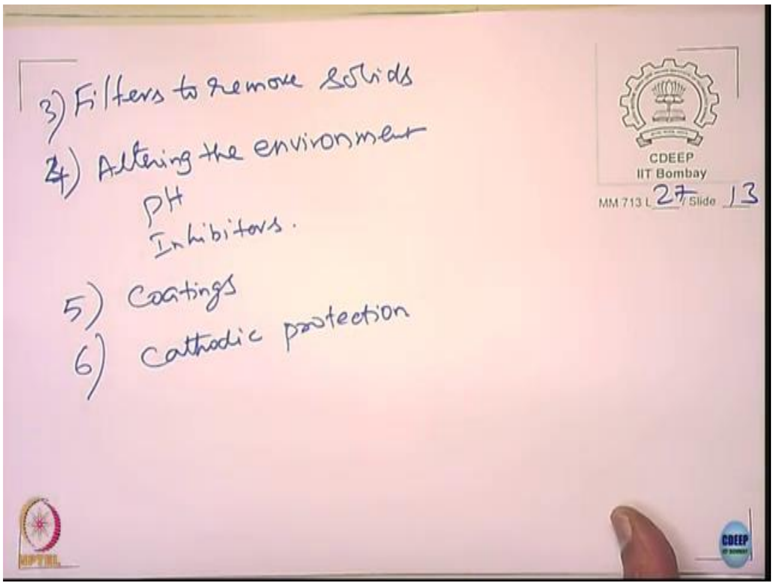

Yes, use the filters to remove solids. You can also talk about altering the environment right. pH control inhibitors, all these stuffs you can do that. You can talk about hard coatings. You can look at the time tested one, what is called cathodic protection where possible. But not of course, everywhere you can apply all these methods and where possible. But what is the bottom line? The bottom line is the bring down the cost right and the bottom line is safety where safety is involved right. So, a so, these are the few available methods to control the erosion corrosion, if you want you can discuss more on and this later.

Let me just finish off this cavitation damage, and I know its we are already spent about close to 1hour20 minutes right.

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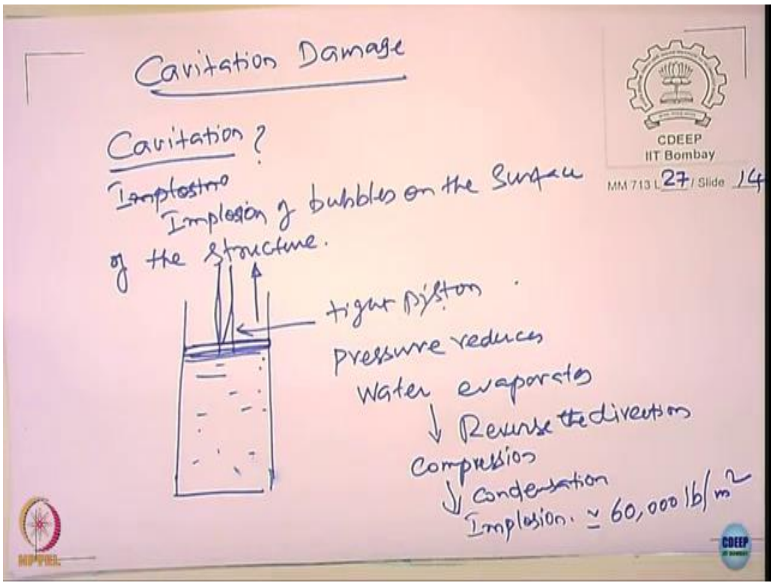

I think let us cover this topic of cavitation damage. Now you know what a cavitation is. What is this? Several persons with the mechanical engineering background, you should say quickly. What is cavitation damage?

Student: Sir, what happens? Sir in cavitation the pressure is different at different stages and this causes bubbles as pressure changes, these bubbles can implode when they implode. It can damage the surface layers of the turbine or the blades and other equipments.

Its very correct, ok. So, the cavitation damage essentially happens because of implosion, say (Refer Time: 62:49) right; implosion of bubbles on the surface of structure and this transfers huge amount of energy on to the structures.

This happens as you said in impellers, in propellers, in turbines, turbines also you compress right; you compress it ok, it happens. So, understand how these things can happen in an impeller ok. We can consider a situation, I just giving brief account given in the Fontana book; I will not go much details actually ok.

You can consider a cylinder having water, right; sorry ok. So, it is in contact with a tight piston right. So, you have water and I have tight piston. When you move this piston up what happens?

Student: (Refer Time: 64:39).

The pressure reduces, right. Now, we know that the water can be boiled even ambient temperature by lowering the pressures.

Student: Pressures.

So, it is possible that you can, we can boil the water ambient temperature if you are going to lower the pressure. So, as you lower the if you as you rise it up it lower the pressure here, then what happens now?

Student: (Refer Time: 65:14).

Water evaporates. When again you reverse this direction then there is going to be compression, then lead to condensation. The bubbles will start shrinking, but beyond certain level you cannot shrink, then what happens? Then is going to be?

Student: (Refer Time: 65:51).

Implosion. It implodes; it implodes then its a shock right. It exerts a pressure as much as 60, 000 pound where is, let us 60 psi, something like that we can say.

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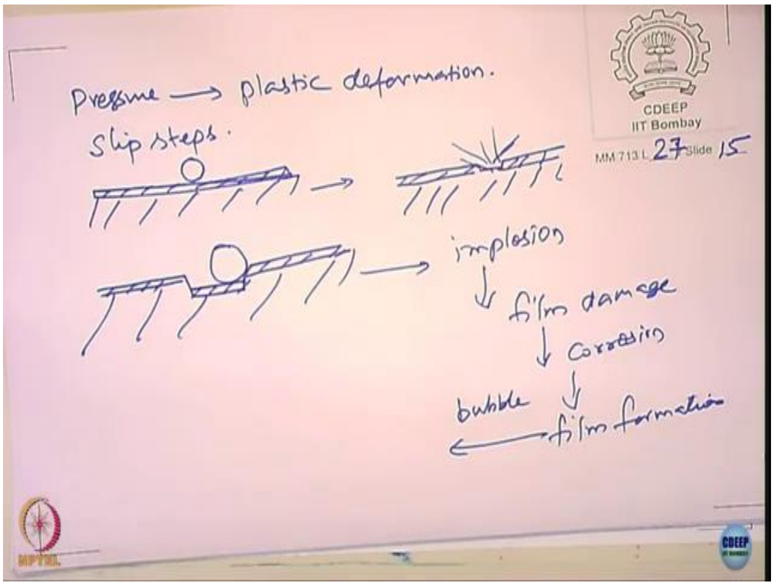

And this pressure exerted can lead to plastic deformation. How can you verify there is a plastic deformation or not? Yeah shape, fine.

Student: (Refer Time: 66:53).

But, see the small bubble you know, it would not change the shape so much.

Student: Dent (Refer Time: 67:02).

It could be a dent, yeah it could happen, but dent can happen and you know you know you could simply corrosion also can have a you know a dip if it is a plastic deformation, how can you do it metallurgist should tell, what do you see? You see a slip step. If you are going to look at this in the microscope and you see nice deformed layers, right; you see slip steps. Its indication of the plastic deformation of a metal.

To summarize that to cavitation to occur it must have a region of low pressure where the liquid will evaporate and then the evaporated you know, the vapor will be subjected to a higher pressure. The pressure is sufficient enough to condense and lead to implosion and that leads to the plastic deformation of the material.

If you look at the mechanistic point of view, you want to draw some kind of schematic diagram of what happens. In the material, all the metals are covered with some oxides, right; like this it form a bubble here. When you increase the pressure what happens?

Bubble implodes, this gets damaged. When the area is dead in damage then it gets corroded again, right. Now, what happens is very interesting now the formation of the bubble where here is much easier, right; because it gives you additional surface. So, the bubble can go and rest on this. Then what happens?

Then again implosion, film damage and what happens? Then there is going to be again corrosion, film formation the again starts, right; again bubble will come and form in surfaces starts continuing process.

So, the picked grows primarily because the surface becomes rougher, it becomes easier for the bubble to sit on surface. Please notice that they very implosion by itself is not a problem; if it happens within the liquid I have no problem. It happens only in the surface, it causes the damage.

So, the cavitation damage that is occurring here more of a mechanical damage and corrosion is a consequence of removal of the film exposure of the bare metal to that and again the further damage comes by a mechanical process, implosion of the bubbles. Of course, corrosion occurs, why? Because the environment interacts and then it forms the film and so on so forth.

Now, this is also you know, there are of course several examples, it can happen is this also depends on the design.

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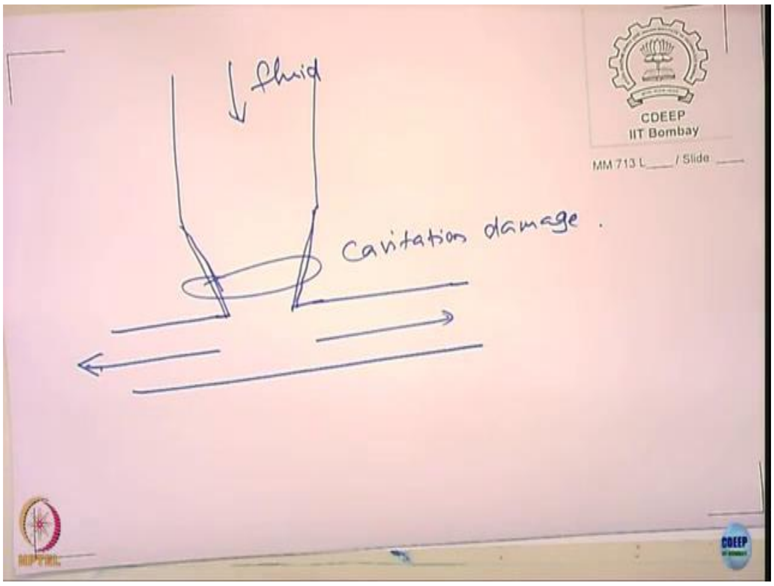

Suppose, I have a pipeline like this, they were to join onto this pipe actually. They reduced like this. Now, look at this design here is a pipe, the larger diameter, smaller diameter, you welder like this.

Where do you think the cavitation damage will occur? Yeah, just at the reduction area. This is a reduction area right, because the pressure is increasing. So such kind of design you know mistakes, it should be avoiding the impeller you cannot do anything, right. The, the impeller works on that principle only, there is a suction there is other pressure is increasing you cannot do anything, but these designs are it can be avoiding it actually.

Student: (Refer time: 73:05).

I talk to this many people do this, but surely this is the place where you have problems, for sure.

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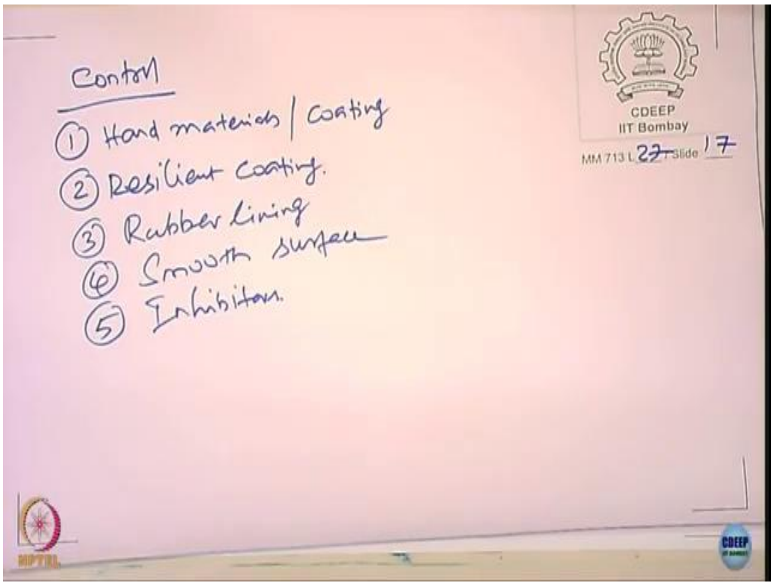

So, how do I control the, control of this? One of course, is hard materials, coatings know, you know stellate coating, cobalt containing coatings you can do that. You can also have resilient coating. See, the resilient coating what does it do? It just does not lead to plastic deformation, alright and you can also have it also means like rubber lining. For example, can do that, it can have smooth surface. What is the advantage of smooth surface? It does not allow the bubble to pit.

Student: (Refer Time: 74:20).

Thick on surface and use inhibitors. The fact that inhibitor is reduce cavitation damage means there is a corrosion taking place, simply not a mechanical damage per say, ok. So, that should come to the end of discussion.