Corrosion Failures and Analysis
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Lecture - 35
Erosion Corrosion: Protection methods and cavitation corrosion

Let us start lecture 35 and the course is Corrosion Failures and Analysis. We have been discussing Erosion Corrosion and we talked about several aspects of erosion corrosion, in the sense that characteristics factors and let us talk about some of the protection methods one can employ to combat erosion corrosion.

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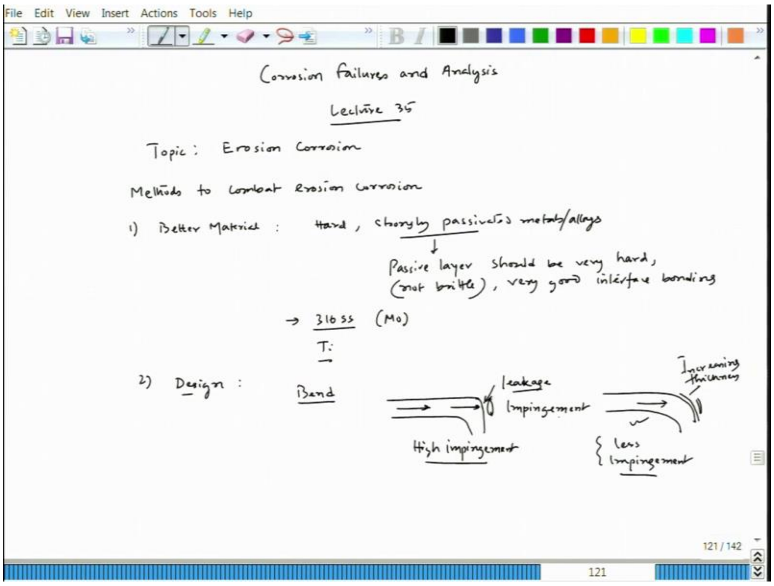

So, let the top, the course is corrosion failures and analysis, lecture 35 and topic Erosion corrosion and in fact, we will start with methods to combat erosion corrosion. Now, when we try to talk about methods, then 1st thing comes better material, hard as well as strongly passivated metals and alloys are good.

They are good and when we talk about strongly passivated, the passive layer should be very hard; not brittle, not excessively brittle, very good interface bonding. So, like that way what happens? Even if there is erosion factor then definitely that passive layer would not get knocked off from the any portion of that particular metal.

So, that way, we can protect it and for that better material means we can think of 316 ss which contains molybdenum. Actually molybdenum helps in preventing erosion corrosion. We can think of titanium, if you recall that with speed in with the velocity of water of sea water, even if the speed goes to around 27 feet per second, still the erosion corrosion rate of titanium as well as molybdenum are you know is very low.

In case of titanium, there is hardly any erosion corrosion even at that speed of 27 feet per second of sea water and in 316 also it is almost about negligible. So, that way better material can definitely prevent erosion corrosion to a great extent. But interestingly, in many instances, we do not use those costly materials. These are costly materials.

So, we have to think of using some carbon steel and there in order to prevent erosion corrosion, we have to think of some other means. The other means comes simply by design. So, design plays a big role. Without doing any costly changes in the system or costly changes in the material, we can get a very good resistance to erosion corrosion by simply changing the shape or size of components. For example, if we talk about a bend; bend.

So, that bend portion for example, a pipe is having a bend like this. In this course cases, the major and water let us say it is a slurry which is moving that slurry hits here ok. So, that is what at this portion, we have impingement. So, this impingement factor would erode that particular portion quickly, so there could be a possibility of leakage here.

So, in order to stop that leakage, one can think of reducing that impingement effect. How can it be reduced? Without changing any material, one can make it a much, this kind of bend which is a kind of a gradual change in direction ok. So, this is a sharp change in direction, here it is a gradual change in direction; still there will be impingement of course.

But that impingement would be much less in this sketch case less impingement and here, it is high impingement. Now, since we cannot think of reducing impingement completely, so there will be impingement and there will be erosion corrosion factor in this location. So, the one possibility is we can think of increasing the thickness here. So, increasing thickness. So, that it can last for longer period. This is one sort of design.

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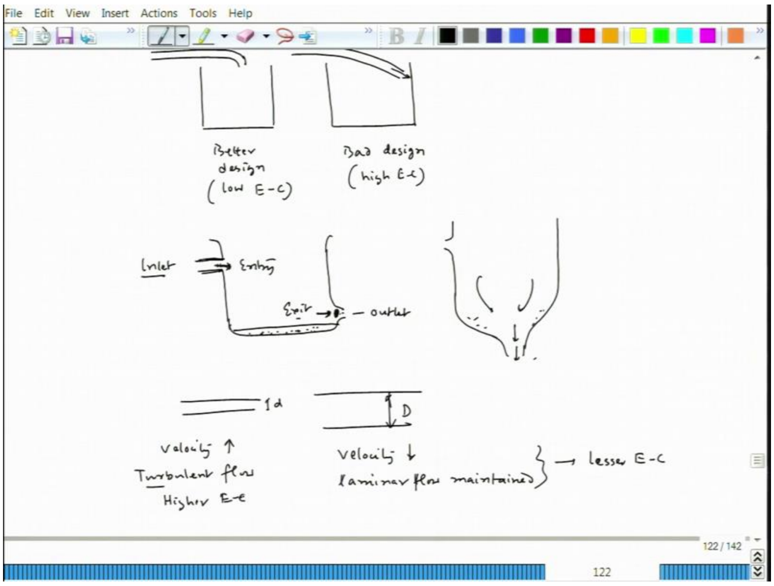

The another design for example, if you have a tank, let us say we have a tank. This is a tank and one way is a pipe is coming, pipe is directed to the center of the tank and in another case, pipe is actually coming and water is coming and hitting the wall of the tank.

So, now, in these two cases, this is better design and from the point of low erosion corrosion. You see you can say you know erosion corrosion. Now, here this is a bad design, high erosion corrosion. So, now, you could see that the problem comes when some water flow hits the metal object at a very high rate ok and that involves impingement and if we can reduce that impingement, the erosion corrosion can be reduced to a great extent.

So, this is another sort of design. Here you are not changing any materials or any stuff, only thing is changing the position of water flow, we can reduce erosion corrosion fine. Now, comes to other aspects like for example, if you have a tank and let us say this is a tank and this is the inlet pipe let us say. Now, this is let us say this is outlet pipe, this is inlet fine.

Of course, this design is not good. We have already seen before that if we have this if the water contains dust particles, they will get deposited at the bottom. Now, when we try to clean it up, it will be very difficult to remove the entire water because in the industrial tank could be very huge. So, that case little bit of water can be left out here. Now, the major problem is this dust particles. See dust particles can also clog this particular pipe.

Now, here inlet case, there is a possibility of clogging; but the clogging would be much less here compared to this. Because here depending on the flow rate, one can have a kind of deposit here. Here also can have deposit definitely. Now, that deposit can lead to a problem because once you reduce the thickness of the pipe, the speed increases and that speed leads to turbulence because also there is a blockage and that turbulence will create lot of erosion and corrosion ok.

Now, in this particular instance, if the pipe the entry point in this case and this is the entry point. This is you can say exit point and this is entry point exit point. So, in this cases we have to make sure that the deposit is not forming over there. Now, in this case, there is a still possibility of deposit; but if we have a design like this, design like this, at least in this case the bottom deposit of those dust particles would be much less because with the flow of water, those dust particle will go through the pipeline.

And here is a gravity effect and that gravity effect also allows rid, also allows less amount of clogging in this case ok; but here, the clogging would be more right. So, the clogging if we can stop, then definitely the flow would be laminar, there will be less turbulence and less erosion corrosion. So, this is another design aspect, one can think of. Now, if we let us say two pipe, this is one pipe and this is another pipe, where the diameter in this case let us say this is D, in this case it is d.

So, now with the increases increase in diameter, in this case velocity would be less laminar flow maintained ok. So, in this two situation would lead to lesser erosion corrosion; but in this case, speed would be high or velocity would be high, velocity would be high and in this case, there will be a possibility of non laminar flow or there could be even turbulence, turbulent flow smaller pipe ok. Now, why we are saying this comparison?

For example, if this pipe is carrying some fluid and flow rate of that fluid, let us say at one bucket that fluid is accumulating. Let us say in each hour, we have to accumulate 100 kg of that fluid then definitely the speed at which the fluid should go through the smaller pipe diameter would be much higher. So, that would lead to a higher E-c or higher erosion corrosion fine.

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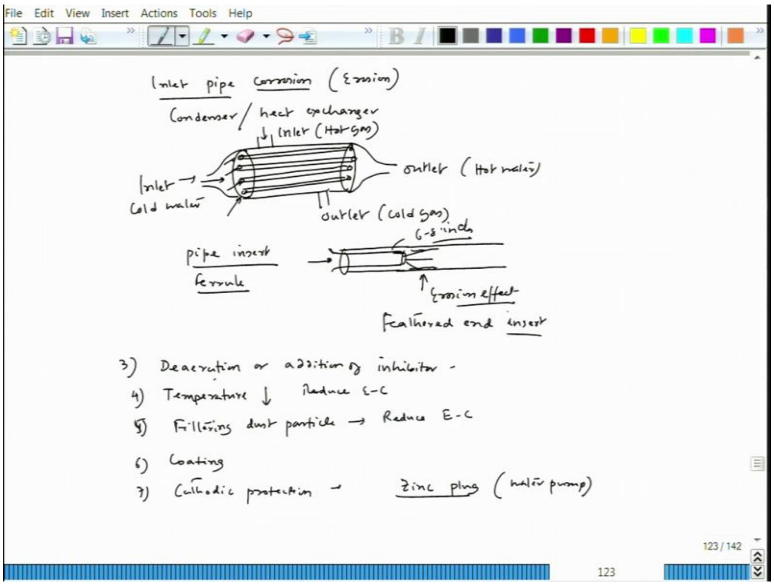

So, these are the design factor. But I would like to consider one small incident that is we call it inlet pipe corrosion. In fact, this corrosion is involving erosion, fine. Now, in that happens in case of condenser or heat exchanger. So, what it is basically? So, now, we have this is a design, we have condenser or heat exchanger. So, this is circular tube fine.

Now, in one end, so this is other end fine. So, now, there are small small pipe, multiple number of pipe; so, this pipes are there and this would be this would be the inlet, this is outlet; this is inlet, this is outlet. Let us say in this case hot gas, this is cold gas, this is let us say cold water, this is hot water. That way we are recovering temp heat from the hot gas in the form of heating water ok.

So, now, when the water goes-in in the inlet, then from the larger diameter it is going through a small diameter pipe. So, that means, in the pipe entry part, that pipe entry part will have a greater degree of erosion effect because there will be lot of turbulence. So, that turbulence would lead to a huge degree of erosion corrosion in the inlet section ok. So, that is what in order to stop that and that is what it is called inlet pipe corrosion ok. So, in order to stop that people use ferrule, ok. It is basically a pipe insert.

So, the pipe insert looks like this fine. So, now, this insert is actually taken into the heat exchanger pipe, it is inserted quite a deep inside this around close to 25 to 30 inches ok. So, that is the distance one tries to take the. So, this is not that much it is around 6 inches; sorry 6 to 8 inches. So, that is the level of insert distance or insert length.

So, this insert is actually now inlet water is entering through that insert into the main heat exchanger pipe. So, now, in this portion at least, there is no effect of the turbulence. Of course, when this water goes out from this particular part, close to that exit part of that insert, we can have little bit of erosion effect. So, here erosion effect would be there ok. So, that is what people use feathered end insert.

So, that makes the water flow when the water comes through the insert into the main heat exchanger pipe, the flow would be not very sharp flow; it will be a smooth flow ok. Impingement factor would be much less. So, now, so this is the pipe insert or we call it ferrule. So, this particular design aspect one can think of.

So, what is advantage? Advantage is of course, the main tube end which is the main tube end means this is tube, one end is here, another end is here. So, the main tube end, if you consider the inlet end will not get any erosion corrosion, the effect would be very very low and in fact, almost negligible.

Now, entire erosion corrosion would be taken by the ferrule. Now, if there is you could see that there is a huge erosion corrosion effect of that ferrule and it is trying to affect the main pipe, so we can take out the ferrule and replace with another fresh ferrule. So, now 6 inch or 8 inch ferrule removal would be much easier; but this pipe, the main heat exchanger pipe would be around close to 62 for 25 to 20 to 30 to 40 meter feet in length ok.

So, that case, if we find some problem erosion corrosion problem of the inlet of the main pipe, the entire piping should be removed and that will be very costly of here and it will stop the plant operation. So, it is a better to use ferrule so that 6 inch ferrule can be removed quickly and then immediately, the heat exchange process can be restarted.

So, that is what this is one such instant of design, where erosion corrosion can be avoided to a great exchange using inlet pipe, in using pipe insert or ferrule ok. So, this is another particular instance one can think of ok. So, now, there could be possibility of this is a design part, there could be possibility of a deaeration or addition of inhibitor fine because of the high speed the inhibitor can be taken to every place and then corrosion protection can be obtained ok.

So, then temperature; so, temperature can be reduced so that erosion corrosion effect can be controlled to a great extent. 4, 5th is of course, if we consider this particular design what we have thought of, clogging happens if we have lot of dust particles in the water flow.

Now, somehow if we have a filter plant, before the water enters into the main operation that filtering process can reduce erosion corrosion effect to a great extent because it actually filter out all those dust and dirt particles. So, cleaning or filtering, dust particle can reduce erosion corrosion ok. So, dust particle, so it will reduce erosion corrosion.

Temperature reduce erosion corrosion. This is also addition of inhibitor or deaeration can also. But this is not a very convenient process in deaeration ok. People can think of coating; hard coating, adherent hard coating can reduce erosion corrosion effect. Now, 7th is people can think of cathodic protection ok. So, in this case, but it is not a very common practice in order to reduce erosion corrosion effect; but still people use zinc plug in case of water pump.

So, zinc plug actually gives sacrificial protection methods to the pump material fine. So, these are some of the examples, where one examples which can prevent or combat erosion corrosion. But if you could see that mostly we are thinking of design part ok. So, design makes a huge difference in case of erosion corrosion fine. So, now, let us take up one particular mode of special mode of erosion corrosion that is cavitation ok.

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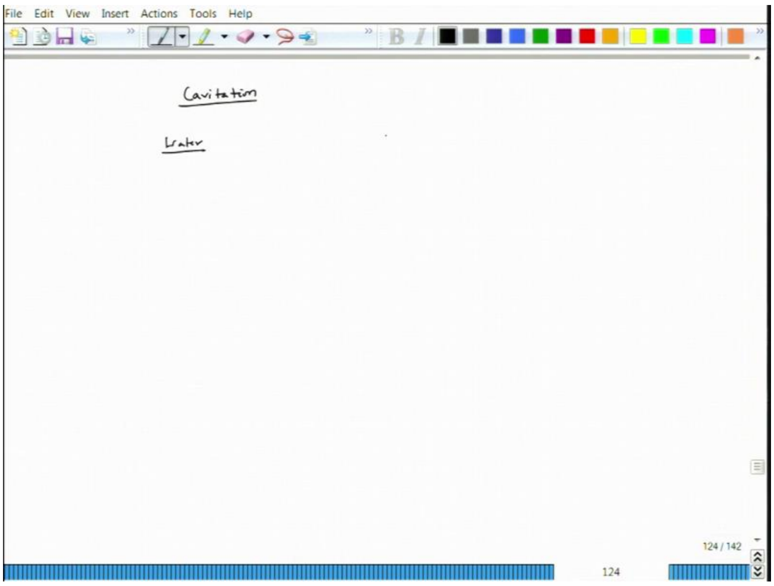

So, let us talk about cavitation ok. Now, in order to know cavitation, we have to just think about the effect of pressure on boiling ok, boiling of water or boiling of any fluid liquid ok. Now, if we see a water phase diagram ok, let us consider water. Now, water if we see the phase diagram, just let me look at the phase diagram, I have just taken it from internet.

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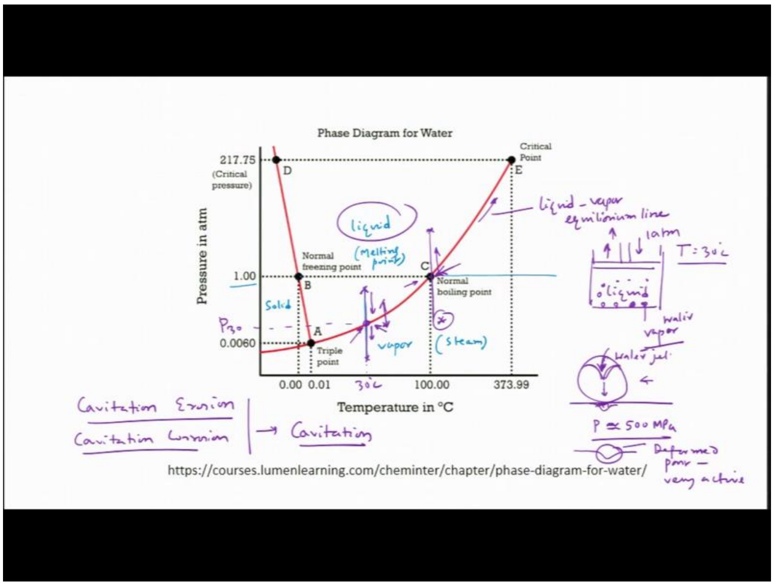

This is only for teaching purpose ok. So, this is one particular phase diagram, we have taken. I thought that with the just by remembering, it is better to project it; in fact, I can draw it anytime. So, this is a diagram. So, this is solid part. It is not given here, but let me put it those marker ok.

So, this is solid, this is liquid, this is vapor or we can say steam fine. Now, if we try to look at the triple point which is the influx which is the invariant point that point as per thermodynamics principle, this particular point cannot be achieved at a particular fixed pressure and temperature.

Now, if we try to look at our normal freezing point, we have to look at 1 atmosphere pressure. So, this is 1 atmosphere pressure and at that 1 atmosphere pressure, you just draw a parallel line to the temperature. So, this line has been drawn, this parallel line has been drawn and the equilibrium line between solid and liquid wherever it cuts that is basically the normal freezing point or we can say melting point.

Remember this is thermodynamic melting point ok and thermodynamic melting point and freezing point, they would differ little bit when we try to practically see those kind of situation. For example, during freezing, it does not freeze at that particular thermodynamic melting point because when it freezes, we need to create interface and because the solid is forming that interface needs extra energy.

So, by cooling and that cooling gives you the under cooling effect that is del t and that del t gives you the free energy, volume free energy that is available for doing work and that work is done to create interfacial those interfaces because interface always carries positive energy, we call it interfacial energy right. So, that is what the freezing point would be, the practical freezing point would be little less than the actual thermodynamic melting point.

But this is a thermodynamic melting point. This is actually thermodynamic boiling point fine. Now, at a fixed pressure at two different temperatures, we have boiling and freezing and generally at for example, in Kanpur or normal 1 atmosphere pressure, it evaporates at 100 degree Celsius ok. Now, question is if we look at across this line ok, now if we look at across this line and across this line, the situation will be very clear.

Now, across this line, if we increase pressure, if we start from this point and if we increase pressure, at this particular location it will start forming liquid ok. And then, if we cross the pressure, then everything would be liquid. All the vapor will convert into liquid.

Now, similarly if we start from here and then, if we reduce the pressure without changing the temperature at this location, it will start forming small small bubbles and then, once we get to this, it will be completely bubble. So, at this point, we will not be able to tell what is the amount of bubble and what was the amount of liquid and that bubble does not contain air, that bubble contains steam ok.

Now, similar thing happens here. So, because this line is basically liquid steam or liquid vapor equilibrium line right. Now, at this pressure, everything will be liquid because this is within this liquid zone. Now, as we decrease the pressure at the same temperature, let us say this temperature is close to 30 degree Celsius.

Now, if we reduce the temperature, when it crosses the equilibrium point between solid liquid and vapor, there first vapor would start forming. We do not know the amount how much amount or vapor; but if we still decrease the pressure, if we reach to this point, everything will be vapor. Now, that means, at a constant temperature, if we reduce the vapor; let us say constant temperature is 30 degree, if you reduce the vapor below this point; that means, this is the let us say P 30.

So, this is the vapor pressure at that point and remember this vapor pressure is also nothing but the equilibrium vapor pressure at 30 degree, where vapor and liquid coexist. Now, below this, it will be all vapor. So, now, if we have a liquid, if we have a liquid and if we have a piston fine and let us say this is a temperature constant temperature bath, this is a constant temperature bath.

Now, this piston if you push it and initially, let us say it is 1 atmosphere. This is isothermal bath. If you push this particular piston and if we contain vapor here fine, now as you push that particular piston at a constant temperature at some point of time, it will cross this particular pressure point at that temperature. Let us say temperature is 30 degree Celsius.

So, things will convert to liquid. But if we start with the liquid and the vapor, the liquid, now we are releasing the pressure ok. So, that means, at a constant temperature, we are releasing vapor. At certain point of time when this particular point is reached, there will be small small bubble that will be created ok.

So, this bubble contains vapor steam, water vapor. It is as if the boiling is taking place because this is the boiling point; that means, when liquid forms steam, this is also a boiling point at 30 degree Celsius, where liquid forms steam. So, this is the boiling temperature 30 degree and the steam is forming.

So, now, when the vapor forms so that vapor is forming and gradually, if you keep decreasing this vapor, lot of vapor will form and then vapor will be released and now, these vapor when you now again press it, let us say again cycle this reverse operation you do, that time those vapor will again start collapsing ok. So, that means, vapor is forming because reduction of pressure and vapor is collapsing because of increase in pressure.

It is basically nothing but we are playing up and down over the red line, which is basically the equilibrium line between liquid and vapor fine. Now, situation comes let us say the vapor pressure reduces or the pressure reduces and vapor forms. Now, when pressure increases, this vapor will collapse and let us see if this is the vapor, it does not collapse like this. It collapse like this.

It become like this and then, there is a water jet. This is a flat surface, where the vapor has formed and it is collapsing like this kind of nature it collapse and then, water jet will hit this surface, this surface. When everything collapses, then this water jet will hit the surface and this water jet pressure what it exerts on that particular surface because of the bursting of one particular vapor bubble.

So, that pressure could reach up to around 500 MPa. You can think of the kind of pressure, it exerts on the metal surface because of this collapse of bubble and that bubble contains nothing but steam or vapor, water vapor. So, now, if that happens let us say this surface is a soft metal, let us say mild steel.

The mild steel, the strength would be around 200 to 250 MPa yield point. So, that means, if this much of pressure it exerts; that means, it will yield because the pressure this particular stress is more than the yield stress of the mild steel. So, then it will definitely yield. So, there will be deformation ok. So, the material would get like this. So, the small deformation would start.

Now, we know that the deformed part is very active. So, if it becomes very active, so that means, there the corrosion would start higher degree of corrosion would start. So, now in the beginning of that particular vapor process, vapor formation, we need a low pressure.

And then, if we increase the pressure, those vapor bubble will collapse and that collapse happens in this fashion that it constricts and then breaks open and when breaks open happens that time this water jet will come sharply over that metal surface and it will deform and after deformation that deformed part will become very active site for corrosion. So, that particular site will corrode at a high degree ok. So, there corrosion happens.

Now, the next stage, again another vapor bubble form because of the lowering of pressure and second cycle that if pressure increases, that bubble will collapse again. So, like that by the repeated bubble formation and collapse leading to deformation of that particular surface and leading to extra corrosion of that deformed zone.

So, that way, this happens, this particular degradation happens. Now, this bubble formation, bubble collapse is basically and that damage, the lateral colateral damage of that particular material is basically termed as cavitation, cavitation erosion ok or cavitation corrosion and in fact, in many cases, it is simply called cavitation. So, we will talk about this cavitation in greater detail in our next lecture. So, till then, thank you.