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NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

Environmental Degradation of Materials

Module Lecture 08

Broad Subject: Erosion corrosion, Cavitation

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So we see that velocity as well as surface films that two are important parameters or factors in case of erosion corrosion and we have seen the example of lead pipe. The lead pipe will operate longer period while handling dilute H2SO4. But when the concentration of H2SO4 is increased the lead pipe fails in a very short time because when it is in contact with dilute H2SO4 it forms PBO and PBSO4 surface film and when it is exposed to concentrated H2SO4 the PBSO4 a PBO layer that is dissolved and that leads to a further attack and more severe corrosion that can happen in case of lead pipe. Now there is one more example let's say the example of copper, the copper and brass, copper and brass and that time they are handling if they're handling NaCl solution, seawater solution, that time the copper forms CuO –the copper forms CuCl2 layer which is black colored and yellow brown, yellow brown film of copper, copper chloride that forms whereas brass it forms dark gray film of CuO so the CuO because of this CuO formation it gives you the brass gives much better protection towards against erosion corrosion than copper because this can – this is a very – this is much stabler oxide layer or the surface film compared to this and so this can operate better to give better resistance against erosion corrosion.

Now this is another example. This is case one. One case studies. This is a case study why brass can give a better erosion corrosion resistance than copper while handling chloride solution. Now let us also see what happens in case of aluminum. In case of aluminum when it handles nitrate solution or nitric acid, when it is handling nitric acid this is – so this time if you see the corrosion rate as a function of this CR CR means corrosion rate as a function of velocity till it reaches around 4 meter – 4 feet per second up to that point corrosion rate is moderate and of course it is not that aggressive corrosion but once it crosses 4 feet per second then actually corrosion rate increases. So actually it happens like this. The corrosion rate increases. Now this is due to the fact that up to this limit aluminum forms nitric -- nitrate surface layer, aluminum nitrate as well as aluminum oxide. Now this aluminum nitrate and aluminum oxide until and unless it reaches 4 feet per second those surface layer or surface film stays with the substrate but once it reaches beyond 4 feet per second then the corrosion rate increases to a great extent because the oxide layer is removed due to the velocity -- due to the velocity of the effect or erosion effect. So this is another example.

So we are talking about the erosion corrosion. Now this is about velocity surface film. Then we can have the third parameter which is or the factor that is the turbulence. Turbulence, or sometime it can be impingement, impingement effective. Now in case of turbulence or impingement effect we have already seen that if you have a larger pipe and then suddenly if you would like to the system from a larger pipe your system will the water of or the solution flow will go into smaller dimension pipe that time this portion is more vulnerable and that portion the erosion corrosion would be maximum because when the water is flowing this way the solution that time it develops a laminar flow and once it reaches here because of this contraction in the cross section we have a lot of turbulence that is developed in this section. So because of this turbulence corrosion would be very rapid and after some time once it goes into the smaller cross section after some time water again develops laminar flow so these part is not the problem. The problem would be felt, the erosion corrosion problem will be felt more in this section because you have turbulence effect.

Now another example is let's say the water you have some bent in the pipeline. Now the water or the system solution is moving this way and suddenly it basically takes a sharp turn and this problem would be more severe in sharp turn so the water actually hitting this surface first and then it take it takes the sharp turn and at the same time it develops a turbulence here.

Now if the solution contains lot of dust particle then those dust particle will hit the surface so that means these surface is, this part is getting impingement effect. The water flow is basically impinging against this facing wall. So this section you have very severe erosion corrosion. So that means you have turbulence at the same time you have impingement. There could be a possibility of turbulence let's say the pipe design somehow there is a extra this part the dimension has increased and the system has become like this a pipe has a basically a dent, a large dent and if this is happening then then also then water can have a turbulence in this section. So this part will be having more corrosion and that is due to erosion corrosion. So this is basically effect of turbulence, effect of impingement and this is also one example of turbulence. So turbulence can increase the erosion corrosion rate.

Now fourth factor is basically the galvanic effect. The galvanic effect for example one case study that is let us say 316 stainless steel, 316 stainless steel and if this is connected to or galvanically coupled to lead with this 316 stainless steel while it handles high velocity H_2SO_4 there will be combined action of erosion as well as galvanic effect because 316 surface film is cathodic to the base material at the same time lead is also cathodic. So you have let's say you have surface film is formed like this. This is my surface film somehow due to the erosion effect you have this surface film is chipped away and then this the base metal is exposed to the solution or the corrosive solution and you also have a contact with lead so this one, this one both will act cathodic with respect to this section. So this section will be anodic there will be for the dissolution until and unless another surface film forms and stops the rapid dissolution. So the galvanic effect would be another serious parameter or factor that can control or that can govern the erosion corrosion rate.

And finally we have fifth one of course the material as well as metallurgy. As we have talked about erosion corrosion, the surface film importance of surface film, the surface film the material which has highly adhesive stable and strong surface film that will behave now that will have much better erosion corrosion compared to the material which has a less stable and less adherence surface film. Now that is what the material would be another important issue and generally if let's say for example Nickel chromium compared to Nickel, this Nickel chromium would have much better erosion corrosion resistance compared to Nickel and it will act better compared to iron since Nickel if you choose Nickel it has better corrosion, inherent corrosion resistance compared to iron. So that's what the depending on the situation we can choose different materials. One such example and this is the material part and second thing is a metallurgy how we can change the property of the material by doing change in processing, composition or heat treatment so you can change the property, and finally we can change the micro-structure also. So all this thing to be put together. If we change the metallurgy of the materials in such a fashion the surface film becomes much more adherent. Let's say normal 18:8 stainless steels in that if we add molybdenum, molybdenum improves the adherence and stability of the surface film. So if we had molybdenum into it, it will act better, it will have a better erosion corrosion resistance.

Now another thing is this is metallurgy change. We can change metallurgy by simply changing the composition a little bit or addition of a different allowing element that improves the stability of the surface film. Even we can think of having a better hardness, surface hardness. Better surface hardness means that it has inherent better wear resistance. Higher hardness higher wear resistance and also it is supposed to give a better erosion corrosion resistance. So hardness is another important parameter. So the material or metallurgy of both are -- this both things are important issue if you would like to control the erosion corrosion property of the material. So now we have surface film, velocity. Then we have turbulence. Then we have galvanic effect and finally we have material and metallurgy.

So now once we have understood this different parameters or factors that can govern erosion corrosion property of a material then definitely we can think of some protection mechanism. Now for example first of all it comes the material we can choose thing which has inherent better erosion corrosion property. For example, we can have iron chromium alloy. So if you would like to have a protection against erosion corrosion protection or control erosion corrosion that time first is better material. Better material. Let's say we can choose iron chromium 80:20, Nickel chromium 80:20 these alloys have a very good erosion corrosion resistance. And sometime we can even choose a modified stainless steel after addition of molybdenum which also helps in giving a very good erosion corrosion resistance. So better material is one issue.

Then second thing is better design. Better design by simply changing the design we can avoid erosion corrosion effect to a great extent. For example if we would like to come to this part that means if we have a sharp turn or if we have a bend like this if we have a dent like this then we have the tendency of erosion corrosion. So in order to avoid that what we can do instead of having a sharp turn we can put a bent with a gradual change in angle and so we are making a bend with a smooth angle instead of sharp angle change. So if we make it smooth so the turbulence effect or the impingement effect will be avoided to a great extent.

Now another design criteria would be and also if we have a dent like this try to avoid that dent try to make it flat so the turbulence, the local turbulence part is avoided. Now always we are saying that the this part of the section let us say this is my pipe thickness, if this is my pipe thickness then we see that this part is not that much affected due to erosion effect or impingement effect compared to this part. So one thing is making it very smooth change in angle. Another process would be since this part is always having some impingement effect let us make it thicker at this end. If we make it thicker at this end only this part so what happens we can have though the erosion effect would be there gradually this part is removing small, small part would be removing but since it has a much higher cross-section that's what this pipeline or the bend section will operate for a longer duration compared to the smooth section thickness of the pipe thickness. So making it thicker would help. This is simply the design part. We are not changing any material or something or any material or we are not changing any velocity, velocity remains same, the materials remain same and also the angle remains same but simply by putting extra thick -- extra material at that part where impingement effect is maximum so we can improve erosion corrosion resistance.

So we can talk about this design factor later when we come to the protection mechanism on the basis of design but with respect to the erosion corrosion this is one example.

Now third is environment alteration. Environment alteration means we have the velocity we have a solution which is moving at a very high speed in the pipeline system let's say this okay. So somehow if the solution contains small small dirt particles or emulsion the effect of impingement would be much higher compared to the situation where these dirt particle is not present. So that's what if we have some sort of filter so that we can filter out all those dust particle then we can avoid impingement effect to a great extent. Now this is filtering. Now second case we can add inhibitor into the system. We will talk later inhibitor in a greater depth but inhibitor there are many types of inhibitor. These are basically chemicals. So these chemicals are added sometime it is added to improve the fill forming ability. So what happens if we add a fill forming inhibitor let us say this particular section is one particular film is broken, let's say this part is broken, now somehow if we add some sort of inhibitor it will enhance the film forming ability. So the more rapidly the film will form and it will avoid the erosion corrosion effect. And of course, we all know that if we have oxygen, dissolved oxygen into the system that will act positively towards erosion corrosion that means if we have more oxygen it will enhance the erosion corrosion rate. So somehow if we can get rid of this oxygen or deaeration if we can perform. So we are basically changing the environment.

Then of course if we can think of some better coating, better coating material which will withstand this erosion effect and finally we can employ cathodic protection. So that means we can make the system cathode and avoid the dissolution of metal into the solution in the form of ions. So these are basically the protection or control mechanism in case of control processes or control ways to control erosion corrosion.

So this is about erosion corrosion. Now let us get into one more form of corrosion that is also falling under erosion effect. That is called cavitation damage and the cavitation if you are seeing this erosion effect is basically there is a combined action of corrosion at this at the same time there is a combined action of force. The cavitation also is basically the combined action of pressure and corrosion. So will see the cavitation effect. Cavitation damage. Cavitation damage happens due to formation of bubble, let's say on a free surface you have the bubble formation and the rest of the system is basically solution and the bubble forms and after some time due to this bubble forms due to the lowering of pressure and after some time if the pressure at this zone is increased the bubble collapse or the bubble burst and due to the bubble burst there would be corrosion. So this corrosion is happening for example if we have a surface film let's say we have a surface film now the bubble is forming and after that it is collapsing due to increase in pressure so that time this locally the surface film is destroyed. This is my surface film. If the locally the surface film is destroyed so this base material is exposed to the corrosive solution and there will be a dissolution at this part. Now once we have dissolution there then gradually there would be a formation of another passive film. So this passive film again form. Now since we have a crack or line sort of thing so there again another bubble will form so because actually it's a forming a notch there so around that notch a bubble can nucleate while it is the system is going under low pressure position and when it is again coming back to the high pressure section the bubble will again collapse. So due to this formation and collapse of the gas bubble the damage is happening in the material and that is basically the cavitation damage, and this type of damage we always come across in the form of pits but the nature of appearance of those pits are a little different compared to the pitting corrosion. Here the pits for example if you have a turbine -- if we have a propeller blade and there let's say this part is low-pressure zone. This is experiencing low-pressure zone, and then here you have bubble formation and then when it goes to the high pressure section so the bubble will collapse and then there would be formation of pits like this and this surface would look very rough, very rough appearance of those pits. So that is basically a significance of cavitation damage. Pitting type -- pits there will be a large pit formation at the same time the section would be very very rough and this happens in case of propeller, ship propeller, then impeller, pump impeller. We can – where actually the system, this kind of situation it handles high velocity fluid and this accompanies pressure change. So the situation where we have very very high velocity fluid at the same time the pressure is changing alternatively that case we can come across this cavitation damage or that case during low pressure zone bubble will form or the – this cavitation will form and then the bubble will burst and giving rise to pressure on the base material and that lead to corrosion.

Now and this is the system where we can see cavitation damage and it is becoming very rough and there are a lot of pit formation. Now let us get into the fundamental of cavitation damage. If we would like to understand the fundamental of cavitation damage let us see what is basically the theory behind it. Why bubble forms and why bubble burst. Now if we see that let's say this is my surface and the material is a passivating material that means we have passive film formation. As we have said that the passive film on the surface there could be little bit of scratch and on those portions when it goes through low pressure zone there we have bubble formation and second stage the bubble will burst. So this is my surface fill. So bubble is bursting and due to that a lot of pressure is exerted on the material and due to this high pressure and that pressure can reach up to 60,000 PSI pound per square inch. So add that amount of pressure what it comes on this passive film there could be localized passive film breaking. Now this material is exposed to the solution, corrosion happens and until and unless a fresh passive film forms.

So there would be little extra dissolution and the fresh passive film is forming. So this is the passive film again forming. Now second – after this another bubble and this bursting is happening this is low-pressure zone and this is high-pressure. Now again it will go to low-pressure zone because of this high velocity fluid and the pressure change it will again come to the low pressure section. So then again this zone, this zone there would be another bubble formation and then this is again low pressure. So when it comes to high pressure this will crack again. This will again burst so further little more extra damage. So the damaged part would become like this till it forms passive layer. So gradually the damaged part would go on increasing. So that means this will go low pressure, bubble will form, high pressure bubble will collapse or burst and then again it will go to low pressure zone and since we have already a notch here so here bubble will form and then when it comes to the high pressure zone the bubble will again collapse and there would be further little more extra corrosion because when the bubble collapse that time little more of this passive film also breaks. So like that way it will go on. So bubble formation, bubble collapse, passive film, breaking down of passive film, dissolution, further passive film formation. Again when it goes to low pressure zone bubble will again form and then again it will burst when it comes to high pressure zone. So gradually that time also the passive film will break and there will be extra resolution till the passive film forms. This is with respect to the passive film forming material but it can also happen in case of active -- non passive film formation forming material and that time the material if it is non passive forming material and when this bubble is bursting that time they do the exertion of pressure there could be local slip band formation and due to this local slip band formation there could be a dent also and due to this there will be zone with no pressure, no slip band and there will be zone with slip band. This is with slip band. So this part would be vulnerable for corrosion and this part will dissolve at have much rapid speed and then again this entire cycle will continue.

So in case of non-passive film forming material that time the cavitation damage happens due to the formation of slip band where the bubble burst. When the bubble burst it exerts pressure on the material and that pressure can be so high that there will localized deformation and the localized deformed part which contains a larger amount of dislocation and that becomes very active and so dissolution starts from there and the rest of the material there will be very little dissolution. So wherever you have bubble bursting phenomena on non-passive film forming material so this section let's say we have bubble bursting phenomena so there would be localized deformation at the same time there would be extra corrosion from that part because this part has a much higher energy due to a much higher dislocation content because this has deformed locally.

So this is because this is for the material where it is non-film forming material. This is non-film forming material. So how the cavitation damage happens in case of non-film forming material.

Now let us check why there is a formation of bubble when it goes through low-pressure zone and why there is a bursting of or imposing of or this is formation of bubble and this is the bursting of bubble or the collapse of the bubble. Why there is the formation of bubble and why there is collapse of bubble when it is at low pressure zone, the formation happens and high pressure zone collapse happens.

Now for that let's say if the system is handling water or let's say end suction centrifugal pump in case of end suction that case we have the pump is basically nothing but like this. So you have this is the pump part so here we have a small section which is called eye of the pump and this is basically the facing the pump. Now actually if you see the cross section then it looks like this. So actually it will look like this. So you have eye portion here and the impellers are inside. So impellers are basically like this. These are basically the impellers. These are the impellers. So the impellers are rotating like this and the water is basically sucked through this eye portion and due to this centrifugal action due to the movement of this impeller the water goes to this part. Now we will always see that the bubble formation would be in this zone. The back of the impeller pump, impeller blades. So if we have the impeller like this, this is let's say the impeller part and if it is moving this way so the bubble would be always forming on the back-end of the blades. This is observation okay and this is the suction zone and this is discharge zone. Now why the bubble is forming on the back of this impeller blade? For that we need to take help of phase diagram, water phase diagram. Now if you see the water phase diagram, the water phase diagram shows like this and this is temperature, this is pressure and here we have the triple point and the triple point. This is let's say atmosphere and the triple point water pressure is of the order of 0.006 atmosphere and the temperature is 0.01 degree Celsius and that triple point is the point where liquid vapor and solid all three phases coexist. Now if you see the phase diagram it looks like this. This is liquid. This is vapor. Then you have vapor and if you see this, this part it is like this. So this section we have solid. So here we have a liquid phase and this is H20 or water phase diagram and this axis is pressure and this axis is temperature.

Now these lines indicate the equilibrium between two phases; liquid and vapor at different temperature and pressure. Similarly this line indicates equilibrium between solid and liquid and this line is basically the equilibrium between solid and vapor, and from the definition of melting point of water as well as boiling point of water we know that we have to see the temperature corresponding to one atmosphere. So this is my 0 degree Celsius and this is my 100 degree Celsius which corresponds to one atmosphere pressure.

Now if the transformation is like this that is solid to liquid we call it melting and if it is liquid to melting -- liquid to solid then it is freezing. Similarly if liquid to vapor we call it vaporization and if it is vapor to liquid that time it is called condensation.

Now similarly this part if it goes from solid to vapor that time it is called sublimation and if the vapor goes from solid that time it is called deposition, and let's say if we are at this point that time vapor phase would exist and if the solid is taken from this to this then all the solid would become vapor. So here sublimation would happen. Similarly if we take a paper and take it to this level we can make it solid.

Similarly if I am here and if I take the vapor to this level without changing the temperature here I am without changing the pressure I am just changing the temperature I can make the vapor to solid or I can make the solid to vapor. Similarly I can make vapor to solid by changing the pressure without changing the temperature. So I can have this sort of phase transformation if I know those position of those lines and if I know the pressure temperature information for water system.

Now since in case of corrosion cavitation damage we are handling water, water-based solution now there let's say I am here and so let's say I am at this point on this line at this point which is one atmosphere pressure and the temperature let's say it's 50 degree Celsius so my common observation would be at one atmosphere pressure if my temperature is 50 degree I will not have any vaporization since I am in the liquid zone. Now somehow if we can reduce the pressure, so I can take it to this level. Once I reach to this line and this line indicates the equilibrium between vapor and liquid I will start forming bubbles at this point. If I reduce the pressure at the same temperature which is 50 degree I can achieve to this point and then where I can form vapor and once paper forms that will form bubbles in the system, and actually you are reducing the boiling point to a much lower temperature by reducing the pressure. So we have if we have a system like this where I have liquid and let us say the pressure is one atmosphere, so that time the liquid and if the temperature is 50 degree I will not have any bubbling but if I change the pressure to this level let's say this level is around depending on this phase diagram if this pressure is P dash if I reach this pressure to P dash which is much lower pressure compared to one atmosphere I will see that there is bubble formation. Fine.

So that means I will have boiling at much lower temperature and that is inherent with respect to H20 system since it follows phase diagram with respect to pressure and temperature. So I will see boiling at much lower temperature if I it lower down -- if I decrease the pressure. This boiling of course we can also achieve if I increase the temperature at one atmosphere pressure. So this case without changing this pressure if I take the temperature to 100 degree Celsius I will see that again the bubble is forming. So keeping pressure same, increasing temperature I can form bubble or keeping temperature same if I decrease the pressure I can form bubble and decrease in pressure and forming bubble at the operational temperature that is basically the culprit for this cavitation damage. Actually we decrease the boiling temperature by reducing the pressure and that's why bubble forms.

Now let's say the situation becomes like this if the situation becomes like this let's say this is my system and this is my piston. This is my piston. Now here the pressure is one atmosphere, temperature is 50 degree Celsius and during – and this is liquid H20 I will not have any bubble formation but if I start decreasing the pressure I will start seeing the bubble formation, and this will also try to go out. So this position will change. So from this position it will go to this position because I am reducing the pressure so we have this bubble will go up and it will be stored here and this is basically vapor and this is liquid, and in the liquid we have all the bubble and the pressure has gone down to P dash which is less than one atmosphere and this P dash corresponds to this point.

Now if we start increasing the pressure so from P dash if I start going back to one atmosphere pressure then what would happen, this pressure since I have increase in the pressure when I pull it out I decrease the pressure in case of piston arrangement and if I increase the pressure by pushing the pressure in the piston inside that time again I will come from this position to this point. So this section will go off, there will be no this section since initially you have started with this part only which is the piston lower part is touching the liquid surface. So that point if I go back to one atmosphere at 50 degree I will reach to this level and when I reach to this level what is the system, that system is the phase is simply liquid without vapor. Now that time since I am increasing the pressure what would happen to those bubbles? Let us say those bubbles are also sticking to the walls. What would happen to those bubbles? Those bubble will try to collapse. So there would be bubble collapse due to increase in pressure and this is happening due to this phase diagram concept. So when I decrease pressure at a particular operation temperature bubble will form. If the condition satisfies that means if the condition with respect to this phase diagram satisfies now again at that temperature where the operation is going on so that point if the pressure again increases those bubble will collapse and when the bubble colas there would be huge pressure exerted on the surface.

Now why that happens? Let's say I have a balloon. I have a balloon like this and this balloon is resting on the flat surface. Now if I start putting some weight here let's say this is w1 this will be compressed so this will become like this. This will become like this. So if I start increasing the weight let's say I put another w1 load so actually the total load becomes w1 plus w2 so that time there is a possibility of bursting of that balloon and if the balloon bursts what would happen to those loads? Those loads suddenly will fall on the surface and there will be certain pressure on the surface. Same thing happens let's see if we have a bubble like this and then the water is around the bubble and this bubble will collapse the water column will suddenly fall on those metal surface and there would be huge shock wave creation on this metal surface when this bubble collapse. So water column is coming and hitting this surface and this there would be creation of shock wave and that shock wave could be so severe there could be local deformation and that deformation can lead to cracking of passive film or it can lead to local deformation and increase in dislocation density and increase in corrosion dissolution rate. So this is a sort of relation between phase diagram, bubble formation, bubble cracking and introduction of shock wave and which led to the cavitation damage.

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