Heat Exchangers: Fundamentals and Design Analysis
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Lecture – 59
Fouling in Heat Exchangers (Contd.)

Welcome friends, we were discussing Fouling in Heat Exchangers. So, in our course heat exchanger fundamentals and design analysis, fouling in heat exchanger and as it is there in all the title slides, most of the material I have taken from the very comprehensive book on Heat Exchanger by Shah and Sekulic. There are other information, but this book has collected information from many other source books. So, I have taken from this book and but only a small portion what is there in this book has been presented in this lecture.

So, this reference I have given it has got 2 purpose. First thing is that, first thing is that I like to acknowledge, and second thing I like to give this reference to persons who are interested in digging some more information regarding fouling. So, they can straight forward go to the books of Shah and Sekulic. Get some more information further they can get the reference is given in that book. So, further information will be available in those references. Well, now so far we have seen different aspects of fouling, what fouling can do, how fouling can take place, what are the different types of fouling, little bit of mechanism of fouling.

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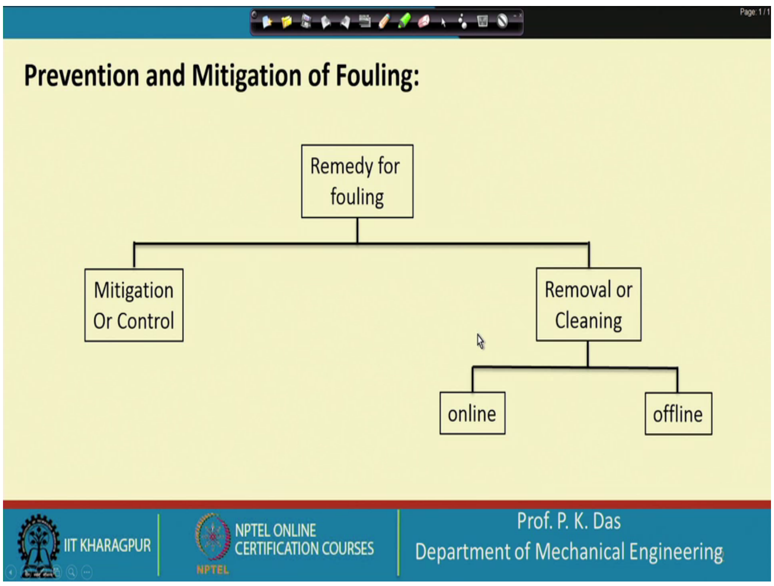

So, all these how fouling proceeds, now we know by this time we know that fouling is not good. And fouling is to be avoided controlled, removed whatever you may say. So, remedy for fouling mitigation or control removal or cleaning and cleaning could be online, offline. Let me spend some time mitigation no control; that means, we and it is this is a very good strategy for many of the cases. That if we can prevent fouling, in many cases for health if we can prevent I mean if we become healthy and if we a food not falling sick that is the best way, but when you cannot avoid sickness you are not well, in spite of your good care of health then you have to take medicine. Then you have to take different kind of strategies maybe sometimes one has to undergo an operation. So, it is like this.

So, initially we have to do certain things so, that fouling can be minimised or avoided. How it can be done? It can be done by selecting typical design of heat exchanger. It can be done by of course, it is within the design, but it can be done by changing the material. So, material is also a part of the design, but when first I have talk talked about design it is the configuration of the heat exchanger shape, size etcetera.

And next is the heat exchanger material. It can be done by changing the operating condition of the heat exchanger. It can be done by some other thing, let us say in some system I install certain filter. So, certain particulates so, when there is a circulating fluid stream certain particulates are getting caught in the filter. Or let us say that I have got some HBSE system, air conditioning system. I have to take outside air and outside air there could be dust particle dirt etcetera so, I have got a filter. So, obviously, I take care of certain amount of fouling at the upstream itself, and fouling will be less on the heat exchanger surfaces the position will be less.

So, this is what we can do. So, these are strategies at the design stage. And then by doing all this thing also we cannot totally avoid fouling. So, there should be removal or cleaning methods. How removal and cleaning could be done, that depends on many many things; that how critical is the heat exchanger. So, then depending on that I have to take my cleaning strategy whether, it is a liquid liquid heat exchanger, gas to gas heat exchanger or gas to liquid heat exchanger; so, those kind of things.

What kind of heat exchanger design it is. So, if it is a shell and tube heat exchanger, then; obviously, we have got some sort of a cleaning strategy. Let us say that one strategy could be that we open the entire heat exchanger take out the tube bundle, clean the cell side, clean the tube surfaces etcetera and put it back. That could be; for inside the tube we can have some water jet or abrasive water jet or kind of a brush kind of a thing. So, those kinds of things could be done and obviously, the way I have explained it is a time consuming thing.

But let us say we have got a plate and frame heat exchanger of gasketed plate heat exchanger; there the opening is very easy, we have to open it, clean each of the plates then put them put the gasket at the required space; tighten the frame and again my heat exchanger is ready. In many dairy industries food and beverage industries, the gasketed plate heat exchangers are used. And sometimes everyday these heat exchangers are cleaned. Because the product we have to get it is some sort of a edible product, and the cleanliness is very important. Not only that the growth of foulant is very at a very high rate in this kind of heat exchanger, as we are dealing with some sort of a food material or biological fluids etcetera.

So, it depends on many things. Suppose, there is a big heat exchanger, how should I clean it that will depend on the on the size of the heat exchanger, but let us say I have got a micro heat exchanger, simply it can be put in a furnace and temperature can be controlled at high temperature. Of course, but the temperature can be controlled which is called baking, and we can get rid of most of the foulants which are deposited on the surface. So, but a large heat exchanger in that way we cannot put it in a furnace.

So, there are different strategies and different ways of cleaning the heat exchanger. Now they are divided into 2 parts; like online and offline. Online offline the demarcation is again a little bit fuzzy. One make all online when you are not removing heat exchanger from the total circuit and keeping the heat exchanger in c 2 you are doing the cleaning, but let us say for the time being when you are cleaning the heat exchanger, you are your heat exchanger is not a part of the active part of the plant. So, some sort of bypass mechanism is there and you are cleaning the heat exchanger.

So, some people call this also as online cleaning of heat exchanger. And some people are very stringent in defining it; that online cleaning means it will not affect the performance of the plant, the plant will run as it is and the heat exchanger is to be cleaned. So, very few heat exchanger will give you that opportunity. And, offline in most of the cases you have to take the heat exchanger out of it is place, maybe in the same plant you can clean it, maybe you have to take it somewhere to clean it and there are elaborate procedures for cleaning the heat exchanger.

Now cleaning there could be different strategies, I think I will not have opportunity to discuss all such strategies. But there are different strategies of cleaning, that by brush as I have told, chemical cleaning is there mechanical cleaning is there. So, different strategies of cleaning is there. Let us go to the next slide.

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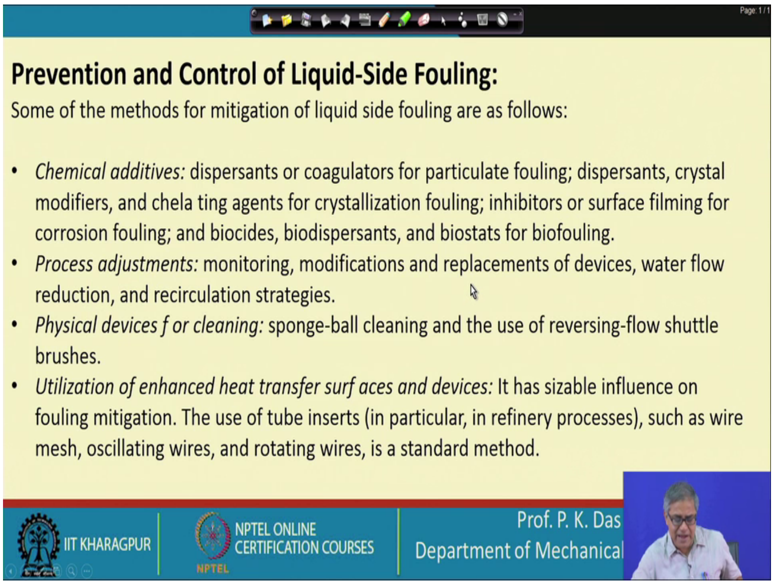

Prevention and control of liquid side fouling: Some of the methods for mitigation of liquid side fouling are as follows. Chemical additives: dispersants or coagulators for particulate fouling; dispersants crystal modifier and chela ting agents for crystallization fouling; inhibitor or a surface filming for corrosion fouling, biocides, dispersants biostats for biofouling. So, different type of fouling and what can be used.

Now, you see sometimes the situation is very tricky. I have already mentioned in one of the earlier lecture, that cooling towers cooling towers are very pone to biological fouling. And cooling tower what does it do in a plant or let us say, in a big refrigeration plant, what is the purpose of a cooling tower. So, in the condenser the refrigerant is to be cooled, and the refrigerant when it is getting cool let us say it is a big water cooled refrigeration system. So, the water is getting heated, and that hot water will be taken in the cooling tower, to cool it coming in contact or bringing it in contact with the atmospheric air.

So, the water circuit there are two heat exchangers. One is a condenser and another is a cooling tower. So, in the cooling tower there will be biological fouling. And in the condenser there will be different kind of other conventional fouling like deposition etcetera. And if there could be some chemical corrosion or (Refer Time: 11:55). Now to prevent biological fouling what can what one can give some sort of chlorine dosing etcetera; one can give some sort of a chemical, what one can give that will prevent the biological fouling in the cooling tower.

But, most of the cases that will have a detrimental effect on the tubes of the condenser; so, you see one has to strike a balance, and mitigation of fouling or control of fouling is not that not that easy job. Because, many cases there are different mechanisms of fouling if you want to suppress one mechanism another mechanism gets assisted by your method. So, one has to be judicial, one has to take proper precaution and in some cases some sort of optimisation is to be done some sort of optimum strategy is to be taken.

Process adjustment; monitoring modification and replacement of devices, water flow reduction and recirculation strategies are good, these are process adjustment. Physical devices for cleaning like single sponge ball cleaning, the use of reversing the flow shuttle brushes etcetera. So, this is what I have told that you have got brush let us say nylon brush, and in the circulation system this brushes are also moving from one part, one into another end and while they are moving they are not allowing any deposition on the surface, ok.

Then utilisation of enhanced heat transfer surfaces and devices, it has sizable influence on fouling mitigation. The use of tube inserts in particular in refinery process; such as wire mesh, oscillating wire, rotating wire are standard method. So, using of this heat transfer of maintain augmentation devices; which will make the rate of heat transfer, at the same time when they are moving components. So, they will give some sort of delay in filing deposition.

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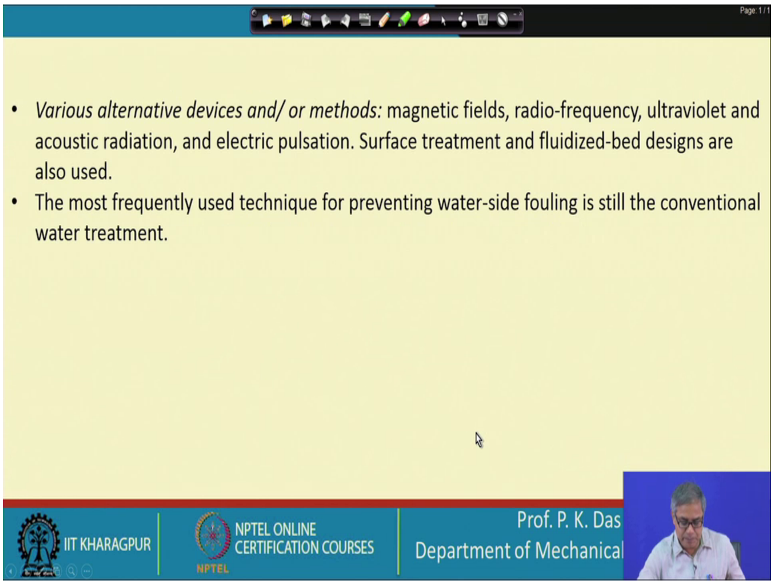

Next line slide if we see various alternative devices and methods; like magnetic field, radiofrequency, ultra-ultra violet and acoustic radiation, electric pulses and surface treatment fluidized bed design; these are all different methods. The most frequently used technique for preventing water side fouling is still the conventional water treatment. So, we had water treatment, we give treated water sometimes deionised water.

Sometimes water with some chemical additive to the circuit so, that we reduce the water side fouling. As water is in many cases, one of the main constituent of the liquid stream so, that is why the discussion is to some extent bias towards water. It does not mean that there cannot be other kind of liquids there are other kind of liquids, but water is very common industrial fluid, and that is why it has been told. And water treatment is a very common practice in large industries. So, that fouling can be kept to the minimum.

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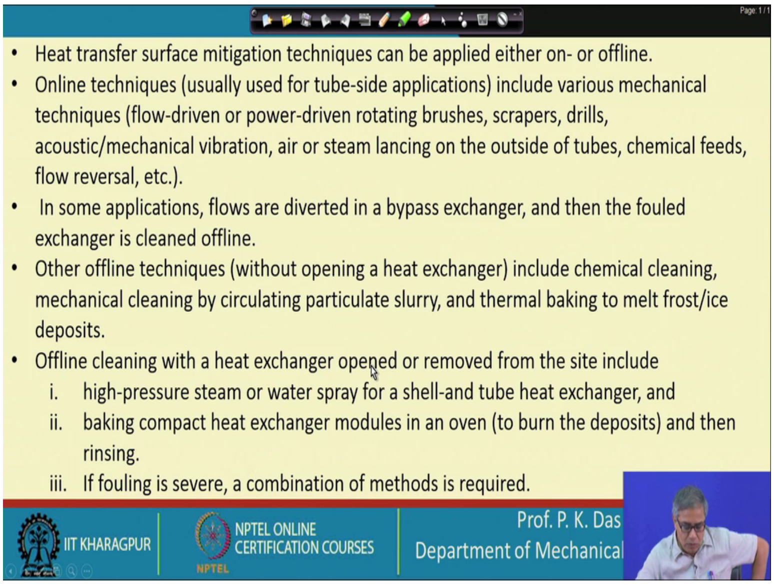

Well, heat transfer mitigation techniques can be applied either on or offline. Online techniques usually used for tube side application include various mechanical techniques flow driven or power driven rotating brushes, scrappers, drills, acoustic, mechanical vibration, air or steam lancing on the outside of the tube, chemical feeds, flow reversal etcetera. So, these are the different method by which we try to rejuvenate the heat transfer surfaces. We try to get the deposition dislodged, we try to clean the surfaces so, that the heat transfer again become good.

In some application flows are diverted in a bypass exchanger. Then the fouled heat exchanger is cleaned offline; that is what I have told. That fouled heat exchanger is to be taken out and to be cleaned. Other offline techniques without opening the heat exchanger include chemical cleaning mechanical cleaning by circulating particulate slurry thermal baking to melt frost ice deposit. So, this is also thermal breaking is also done. Sometimes what happened that frosting is very common evaporator of a of an air conditioning system. And in that there should be heater inserts, and with this inserted heater time to time heating will be there and that can melt the ice and give the good performance.

Offline cleaning with a heat exchanger opened or removed from this site include high pressure stream or water spray for a shell and tube heat exchanger. And baking compact heat exchanger module in an woven to burn the deposits and then rinsing. If fouling in severe a combination of methods are used. So, sometimes the depositions are so heavy that real mechanical impacts are to be given, ok. Chemical cleaning is also not sufficient, real mechanical hammering kind of impact is to be given, and then of course, chemical cleaning. So, there are combinations of methods to be used. And a golden rule is that, the cleaning schedule should be such that deposit layer are not so heavy or so tight so that the separation or removal of the deposit layers becomes a very profitable job.

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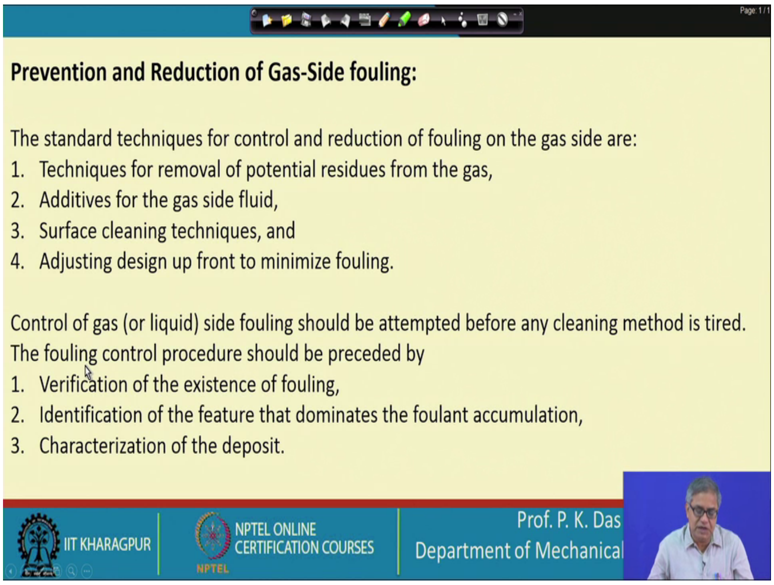

Prevention or reduction of gas side fouling; the standard technique for control and reduction of fouling on the gas side are, technique for removal of potential residues from the gas. So, that is what I have told that, just putting a filter, we will prevent many of the problems. If you put a filter so that will provide that will give a good solution. That is one thing, another that additive for the gas side fluid. Surface cleaning technique; obviously, surface cleaning technique ultimately you have to have, then adjusting design of front to minimise fouling.

So, that is always a good practice. Control of gas or liquid side fouling should be attempted, before any cleaning method is tried. The fouling control procedure should be preceded by verification of the existing fouling. So, what kind of fouling is taking place that has to be assistant, then only some sort of fouling control procedure is to be adopted.

Identification of the feature that dominates the foulant of accumulation; So, first think what kind of foulants are generated? First point, second point is that how this foulant points accumulate or gets deposited, then characterization of the deposit. So, you see whatever we have discussed, if really one has to take care of it the chemistry department of the plant that has to be very careful. And that has to do a good kind of analysis that what is the chemical composition, physically what is happening; so, then only one can have a good strategy of fouling control.

And same heat exchanger can be used for different applications. So, a gas to gas heat exchanger can be used for different purposes. In one case, it is using the flue gas; in another case it is using some sort of a hot gas. Or flue gas it is using from 2 different sources so, fouling will be different, and the cleaning strategy that will also be mitigation or cleaning strategy that will also be different. So, this part one has to be very careful.

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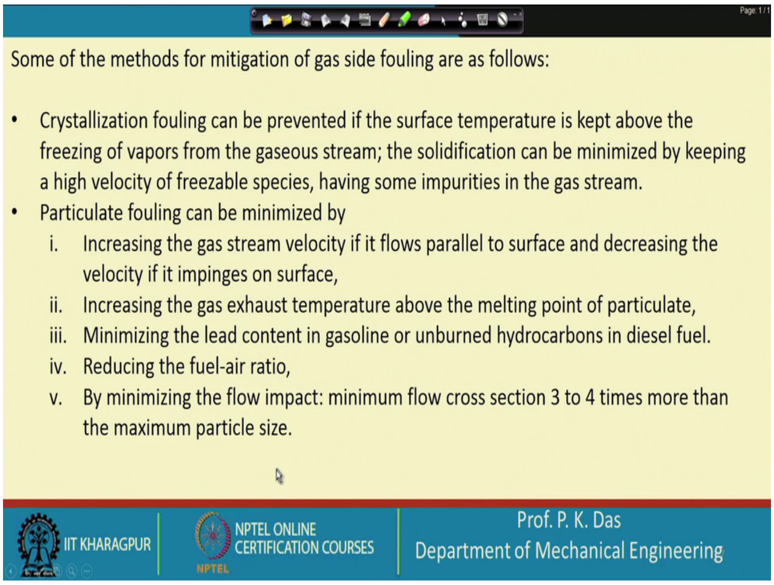

Some of the methods of mitigation of that side fouling are as follows. Crystallization fouling can be prevented if the surface temperature is kept above the freezing of the vapour from the gaseous stream; the solidification can be minimised by keeping a high velocity of the freezable spaces having some impurities in the gas stream.

So, if there are impurities in the gas stream, sometimes the freezing is getting freezing gets delayed. Particulate fouling can be minimised in gas side particulate fouling is also very common. And increasing the gas stream velocity if it flows parallel to the surface, and decreasing the velocity if it impinges on the surface so, please see. Increasing the gas stream velocity, when it flows parallel to the surface so that, this will prevent deposition.

And generally impact that gives the position, if you increase the velocity of an impacting gas stream that will decrease the deposition, particle deposition.

Increasing the gas exhaust temperature above the melting point of the particulates; so, sometimes what happens that there are certain constituents of the gas product of combustion, mostly product of combustion, sometimes it could be reaction products from other reaction product. So, when it passes through the heat exchanger, the temperature of the gas stream that reduces and that can go below certain temperature where some of the constituent are I mean they liquefy or even the sublimation process could be there. And they get deposited on the heat exchanger surface.

So, this can be prevented if the temperature is such that such kinds of phase change are not possible, then we can avoid the situation. Minimising the lead content in gasoline or unburned hydrocarbon in diesel fuel; so, you can understand why this has been told. Reducing the fuel air ratio ok, then by minimising the flow impact minimum flow cross section 3 to 4 times more than the maximum particle size; this is just a thumb rule.

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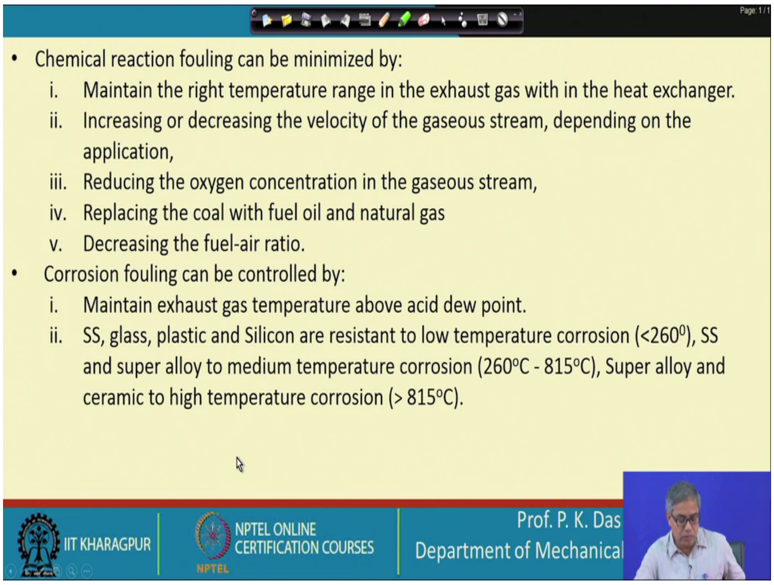

Chemical reaction fouling can be minimised by maintaining the right temperature in the exhaust gas with the exhaust gas within the heat exchanger. Increasing or decreasing the velocity of the gaseous stream depending on the application. So, sometimes we have to by increasing the velocity of stream it is convenient. Sometimes the reverse is good. Reducing the oxygen concentration in the gaseous; so many times this oxygen and particularly at high temperature, that gives some sort of reaction, and reaction maybe in the gas stream maybe on the solid surface it cell and that gives deposition fouling deposition even corrosion which we will discuss.

So, that is what we have to do. Replacing the coal with fuel oil and natural gas; so, coal combustion is gives more pollution or more pollution that is one thing, but it gives more fouling tendency of fouling is much more in case of coal combustion. Because, there are particulates there and unburned carbon particle; the way the combustion of a of fuel air is efficient, the same way the combustion may not be that efficient. And of course, natural gas combustion that is also very efficient combustion there is no particulate etcetera.

Decreasing the fuel air ration once again; the corrosion fouling can be controlled by maintaining the exhaust gas temperature above the dew point. So, above the acid dew point if we maintain the temperature then there will not be any kind of formation of acidic deposits. And then material selection is very important; SS that means, stainless steel glass plastic and silicon are resistant to low temperature corrosion. So, if we have low temperature, application we have to select this kind of material.

So, that is less than 260 degree Celsius, 260 degree to 850 degree Celsiussuper alloy to super alloy, and stainless steel can be used in this range. And super alloy and ceramic can be used for high temperature applications where the temperature is higher than 815 degree Celsius. So, these are some sort of a strategy by which we can avoid corrosion.

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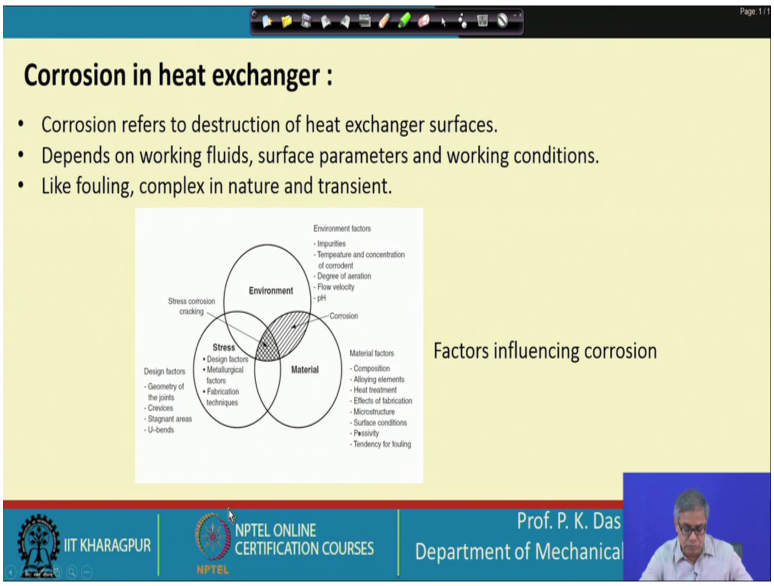

Now, sorry, avoid fouling. Now with that we are going to corrosion in heat exchanger. Corrosion refers to destruction of heat exchanger surface. Fouling is deposition on the heat exchanger surface. Corrosion is destruction of the heat exchanger surface. Now they these 2 are very closely related. Sometime fouling can give rise to corrosion, and sometimes corrosion can give rise to fouling. Because the due to corrosion some materials from the heat exchanger surface is coming out, that can get deposited and create fouling. Sometimes both of them exist side by side. Depending on working fluid surface temperature and working condition the corrosion will occur; like, fouling it is complex in nature and also in transient.

So, here there is a very interesting figure, you can see that what are the different factors influencing corrosion. Environmental factors are there, material factors are there and stress factors are there. Stress is very important in case of fouling, sorry in case of corrosion. And you see these 3 factors this is the zone of corrosion. So, this is the zone where environment and material are interacting, there is no stress factor. This is the zone where 3 factors are responsible. So, environmental factors are there, material factors are there and stress factors are there.

I am not explaining this figure each and every item. So, you can go through it and you can understand what has been told. And what are the, this is almost self-explanatory. That material includes, material factors includes composition, alloying elements, heat treatment, effect of fabrication, microstructure, surface condition, passivity tendency for falling so, all this things. And similarly there are design factor and there are environmental factors. Now, if we go to the next slide.

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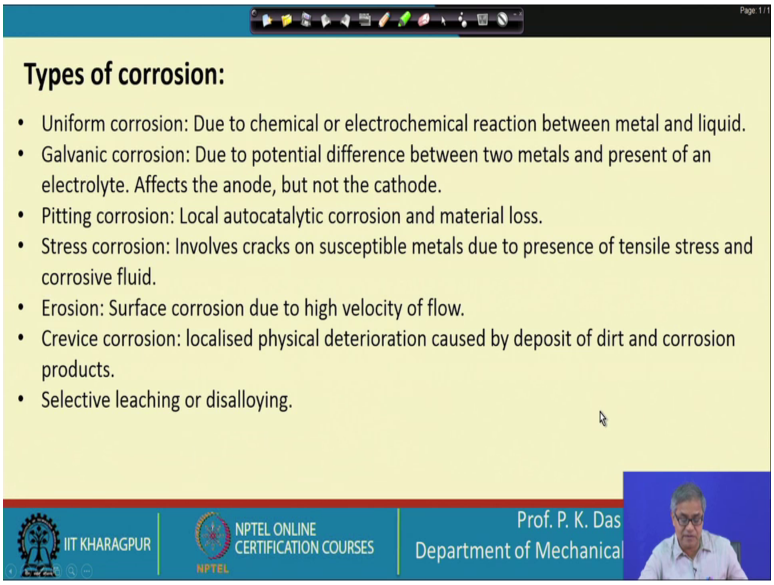

So, types of corrosion. So, there could be uniform corrosion, everywhere of the heat exchanger surface same kind of material loss is there, due to chemical and electrochemical reaction. There could be galvanic corrosion like 2 different metals are there, they do have different potential and in between there is an electrolyte. So, this forms some sort of a cell, electrolytic cell and then there is corrosion.

Then pitting corrosion, local autocatalytic and there will be material loss. So, you can see the surfaces become very uneven. Uniform corrosion, theoretically at least there will be uniform loss of material from everywhere. Pitting corrosion there will be selected places where the corrosion has taken place. So, we can pits or small holes or things like that, then stress corrosion. Corrosion is very much related to stress; it involves cracks on susceptible metal due to presence of tensile stress and corrosive fluid. So, when there is a materially stretch highly stretch so, corrosion takes place.

Then erosion, erosion you can understand that some material is getting loaded. It could be physical action could be in chemical action. Crevice follows corrosion, localised physical deterioration caused by deposit of dirt and corrosion products etcetera. Then selective leaching and. There are alloys so; alloys will have number of components and then only one component or some selective component is getting dissolved. Only one component is reacting chemically and getting removed from this place.

So, then we will have material with different composition. Material with different composition means, it maybe that initially what composition was there and finally, after the corrosion we will have different kind of composition. Or place to place we can have different kind of composition. And it will weaken this structure it is; obviously, this is not good.

So, with this I come to an end that very quickly I have told you regarding fouling, and then I have told certain things regarding corrosion; which is also one kind of detrimental effect which we can see in heat exchanger, and we have to avoid this thing. Some of the strategies I have told particularly regarding fouling I have told some of the strategies. For corrosion also there are certain strategies what one can adopt. So, I have given the reference please go through the reference. You will have some idea how corrosion can also be tackled; that book will have cross references if somebody is more interested then they we can go through the cross references. Thank you.

Thank you for your attention.