Heat Exchangers: Fundamentals and Design Analysis

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Lecture – 57
Fouling in Heat Exchangers

Welcome friends. Today, we are going to start a new topic related to heat exchanger. This is a very important topic and again, this topic could be very vast and there are many aspects. But, as this is a course on course covering almost all the important aspects of heat exchanger. So, we cannot be devote much time on a particular aspect or particular topic.

So, we will try to do with the available time. We will try to give you a brief overview and the person who are of course, students for them this information will be useful and those participants if I expect that there are professional also professional engineers also, for them this will be some sort of a baseline information. And they can take up this topic with this baseline in information and do further studies or can gather more advanced information.

So, the topic which I am going to cover is fouling in heat exchanger and many of the material of this particular topic that has been taken from a particular book that is the heat exchanger design by R K Shah and D P Sekulic. Earlier also, we have referred to this book and in our reference we have given this book as one of the book which one need to follow for this particular course or for that matter for knowing heat exchanger.

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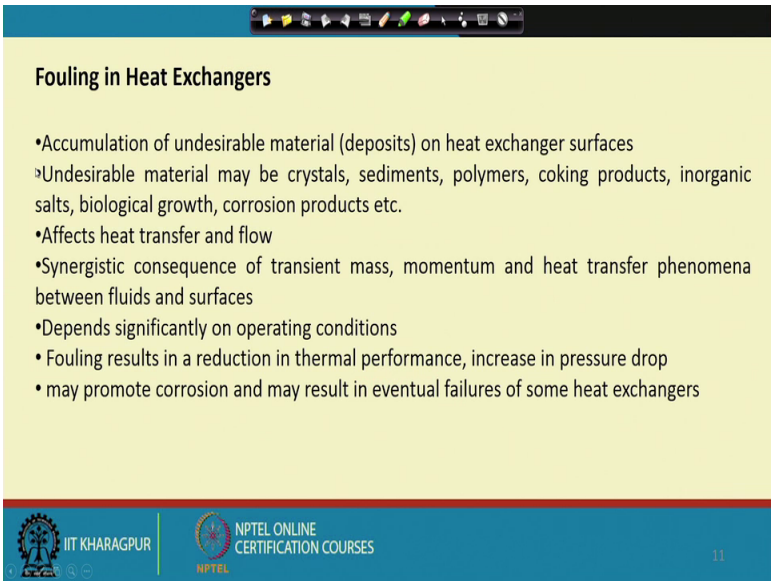

So, if we go to the next slide, this is fouling in heat exchanger. What is fouling? From the very beginning of this course, we have time to time referred to this particular term and you see whenever we have derived, the overall heat transfer coefficient we have accounted for fouling resistance. Probably, at that time, we have told that when a heat exchanger is being used for some time, then on the wall of or on the heat transfer surfaces there will be deposition and this deposition is known as fouling and that will give some sort of extra resistance.

And, unless we account for that resistance, then there will be error in our estimated capacity of the heat exchanger. So, we will look into more of it. So, fouling that is if we go to the slide, it is accumulation of undesirable material; accumulation of undesirable material deposits on heat exchanger surfaces. It could be inside, it could be on the internal surface, it could be on the external surface, it could be on the base surface, it could be on the finned passages.

So, it could be everywhere so, of course, if there are 2 fluids. So, some fluid will be or some one side of the heat exchanger maybe more prone to fouling while the other side is not. So, that is there.

The undesirable material maybe crystals, sediments, polymers, cooking products, inorganic salts, biological growth corrosion products etcetera so, you see due to the physical and chemical changes of the fluid due to the interaction between the fluid and

the heat transfer surface which will be again augmented by the presence of flow and heat transfer, there could be different kind of deposits. There could be crystals, there could be sediments polymers, cooking products, inorganic salts biological growth, then corrosion products.

So, when I am telling biological growth and correction products, at least for this 2 thing you can see that there could be some sort of reaction also and due to this reaction. So, not only physical change chemical changes are also important, that is what we have to recognize.

It affects the heat transfer and the flow. So, basically what will happen? 2 things will happen. The passage area heat transfer passage area that will change heat transfer surface condition; that means the roughness of the surface that will also change. So, obviously, both of them effects heat transfer and fluid flow. So, heat transfer and fluid flow will be affected. Now, thing is that a new heat exchanger when I am putting in the system or when I am putting it in the plant, so, there is no fouling.

So, one might have design the heat exchanger based on the assumption that all the surfaces are clean etcetera, passage area are known from the initial geometry of the heat exchanger and some sort of performance prediction could be there. Already, we have seen how to do it.

But then, when the heat exchanger is operated over sometime then the fouling has started taking place and the fouling is a progressive phenomena; that means, with time the fouling that increases or the deposit on the surface that increases. So, obviously, there will be some sort of a change good or bad, we will see later on of the performance of the heat exchanger. So, if we are unaware and if we do not provide this kind of some sort of a consideration for the fouling, then my heat exchanger our heat exchanger will not perform properly.

Now, it is synergistic consequence of transient mass momentum heat transfer phenomena between fluid and surface which I have explained, depend significantly one the operating condition. On the operating condition means flow rate, on the operating condition means, sometimes the cleanliness of the fluid which are, which we are using and obviously, pressure temperature etcetera in sometimes the environmental condition.

So, operating condition means let me explain certain thing. Let say, in a plant, there is a circulation loop and in that circulation loop somewhere we have got a filter. Now, the filter is not operating properly. So, then what will happen? I my operating condition has change and depending on my operating condition, I will have different kind of I mean different aspects of fouling present or let us say that in my plant for the fluid, there is some sort of a let us say water is there and we are suppose to get water with certain amount of dissolve solid.

So, somehow the supply condition of water that has changed, that has not changed the transport properties of water per say, let us say the dissolved solid that um ppm level of dissolved solid has changed. But, that will not change the viscosity or thermal conductivity or density of water.

So, from the heat transfer point of view, I will not find any difficulty. But, due to the change of the dissolved solid, what will be the deposition on the wall? That will change and obviously, that will have some effect on the performance and ultimately maybe on the serviceability or the life of the heat exchanger. So, this is very important. This is a topic of very I mean, much or substantial practical of substantial practical importance and one should not put an blind eye; put a blind eye to the issues of fouling. Fouling results in reduction of thermal performance increase the pressure drop.

So, this is more or less accepted fact that fouling will reduce the thermal performance; that means whatever heat exchanged between the fluids, I could have expected at the beginning or expected for the best design or initial design of the heat exchanger with time, I will find that that has reduced.

And the pressure drop that will increase so, this has got 2 effect and none of these 2 effects are good for the plant. Then, it may promote corrosion and may result in eventual failure of some heat exchanger. In case of some heat exchanger not in all heat exchanger, it may have eventual failure of the heat exchanger; failure means, it may not always mean the structural failure.

It may also mean failure to serve the purpose; that means, passages are so choked due to this deposition that almost no fluid is passing through it or the pump which is or the prime mover which is attached or which is there in the system for circulating the fluid. It

is unable to circulate the fluid due to very large resistance at the in the heat exchanger. So, this may happen.

This may even which has not been mentioned over here. This may even effect the performance of the downstream equipment. If there is some sort of a fouling or deposition in the heat exchanger. Now, this deposition or some of the deposited material can get disclosed and pass with the liquid to the downstream component. So, that way, it may effect and it may also affect because the downstream equipment may not get the fluid at the required temperature and at the required flow rate.

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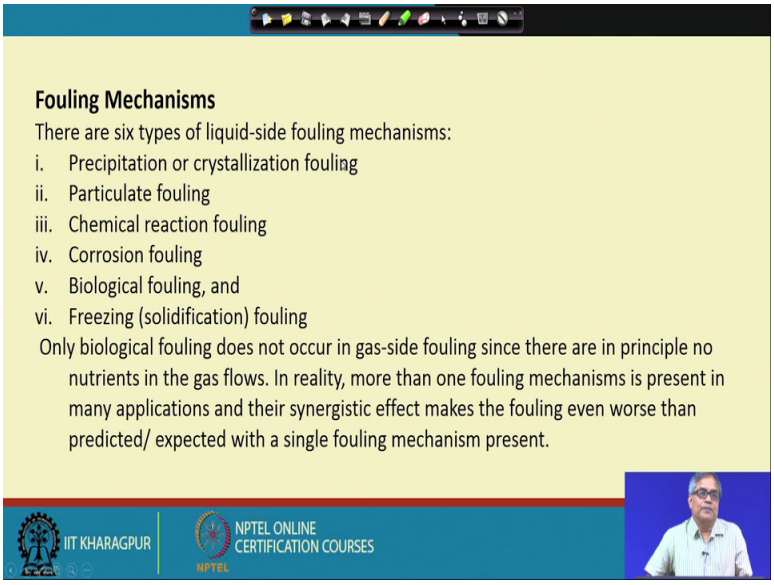

So, fouling is important. Fouling mechanism there are 6 type of liquid side fouling mechanism; precipitation or crystallization fouling. I do not need to explain it it will happen with this one some sort of chemical nature of the fluid depending on the temperature, there will be precipitation and fouling crystallization.

Precipitation, it can happen that the fluid picks up solid particles and that gets deposited through the crooked passages of the heat exchanger then, particulate fouling. Of course, there will be particle the deposition etcetera or even there could be some sort of vibration when the fluid stream is carrying particles.

Chemical reaction fouling this I have explained that there could be some sort of a chemical reaction between the fluid and the wall of the heat exchanger. Then, corrosion

fouling; corrosion fouling that if the corrosion is produced and then some material will get separated from the heat transfer surface and that may create some other difficulty.

Then, biological fouling there could be biological growth particularly when there is liquid and when there is I mean there are situation like that, it is exposed to open atmosphere or it has got some sort of oxygen supply. So, then there would be biological fouling. Then, freezing or solidification fouling; so, freezing is also one thing that if the temperature goes below. So, sometime freezing occurs. So, obviously, ice crystals will form and choke the passage, show this is also one kind of fouling.

Now, these are the fouling mechanism one can elaborate on all those mechanism and the book which I have mentioned, you can go through that book to if you want to get some details of each of the fouling mechanism. In other books also information is available, but if we are not bothered about the details of this one we from the name we have some idea that what could be a typical kind of fouling.

So, let us consider in case of gas side. What it will be in gas side? So, biological fouling is very uncommon because the nutrient is lacking in the gas flow. So, gas side is not very conducive for biological growth.

In reality, more than one fouling mechanism is present in many application. As we have told one need not think that fouling will be there in a typical case only for a particular reason, it is not that there could be several reasons and several type of fouling taking place simultaneously. There are many application and their synergistic effect makes the fouling even worse than the predicted or expected with a single fouling mechanism present.

That means, that when there are multiple mechanism of fouling or multiple types of fouling present, then it becomes the situation becomes bad and sometimes one fouling promotes the other fouling may promote corrosion and corrosion may give rise due to the, due to corrosion the surface will become rough and that may promote further founding. So, this could be some sort of a (Refer Time: 15:27) circle kind of a thing. With these, let us go to the next slide.

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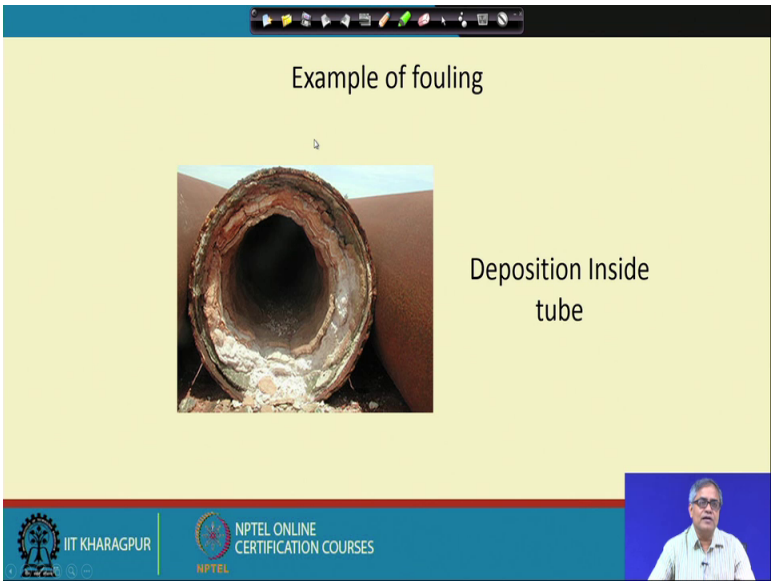

So now, I have I wanted to show some sort of fouled components of heat exchanger. So, this is a tube of a heat exchanger typical tube of a heat exchanger and you can see inside there is deposition, there is fouling and how the diameter of the tube has reduced. So, obviously, one can think that the liquid is very much fouling prone not only that proper servicing probably has not been done time to time.

So, that is why, the tube diameter has reduced to a very large extent to the position inside the tube. So, inside the tube it may happen. So, then the question is will it happen only inside the tube; outside the tube it will not happen. No, that is not true. Even outside the tube it will happen. So, in a shell and tube heat exchanger fouling may occur or fouling will occur inside the tubes and fouling will occur also outside the tube let us see.

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So, here I have shown the shell and tube heat exchanger; one is end view. So, this could be the tube seat in which the tubes are tubes are hold or fixed. So, you can see that in many cases, we cannot see the tube, we cannot see the area in between the tube it is so much fouled. So, obviously, here the fouling has taken place outside the tube also and here the tube bundle has been taken out of the shell.

So, here clearly one can see that fouling has taken place probably here corrosion has also taken place the rusting kind of a thing one can see. And so, when fouling is taking place, it is not only on the tube surface, on the baffles also the fouling has taken place. So, let us go to the next slide.

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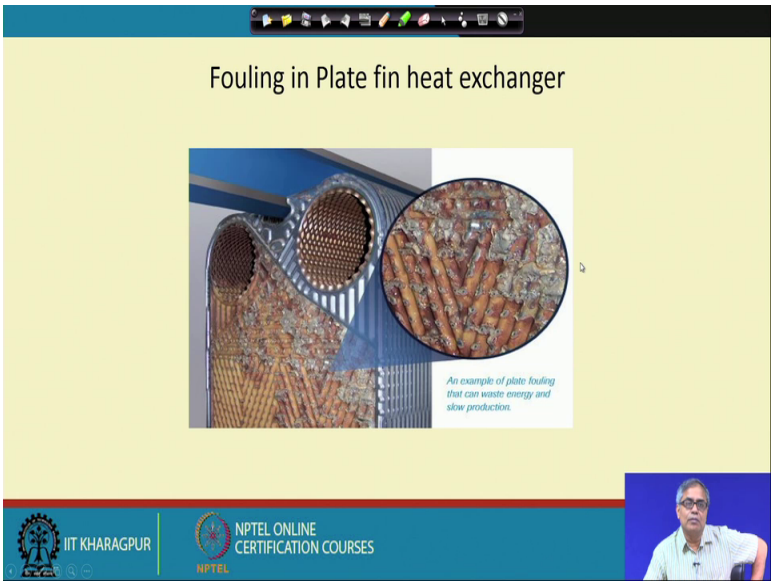

This is fouling in a plate fin heat exchanger. So, plate fin heat exchangers again plate fin; sorry, it is not a plate fin heat exchanger it is gasketed plate type heat exchanger, it is a plate heat exchanger sorry for slip of tongue. So, in the plate heat exchanger, there are small passages and plate heat exchanger should use very clean fluid because the passages are very narrow.

So, somehow if the fouling take place so, this passages will get choked and here we can see very extensively fouled plate of a plate heat exchanger, gasketed plate heat exchanger and this fouling can give rise to corrosion loss of plate in number of places. So, all this kind of complications may arise due to the fouling, mind that the fouling so far I have given the examples inside tube, outside tube, in a plate of a plate and frame heat exchanger or gasketed plate heat exchanger. So, these are basically liquid side fouling. There is no reason to think that fouling will be in the liquid side there could be on the gas side also.

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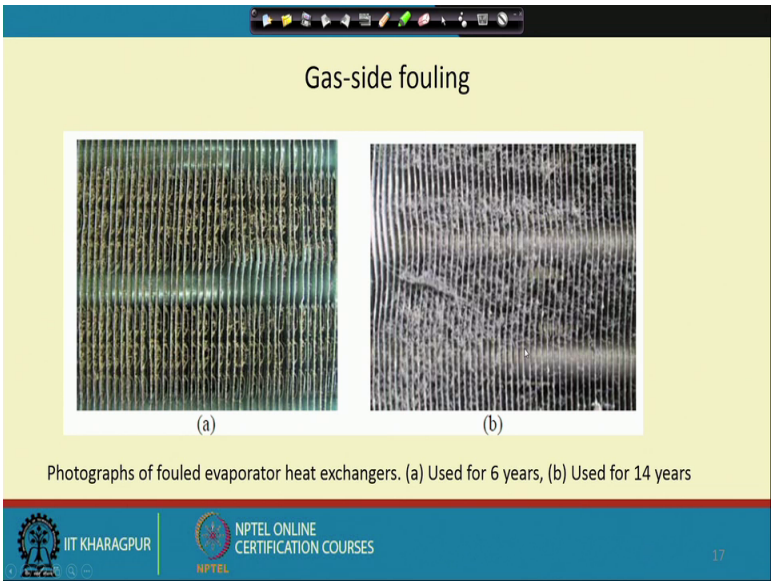

This is a gas side fouling. So, photograph of fouled evaporated heat exchanger. So, evaporated heat exchanger we can see that is it is a fin tube type heat exchanger. The tubes are visible and then there are closed spaced fins and in the fin side there will be; in the fin side there will be fouling. So, rather in this kind of heat exchanger if it if a clean refrigerant is used and there is a filter in the circulation circuit.

So, tube side fouling will be less rather we will have more fouling on the fin side because most of the cases we take ambient air or let us say in some HBSE application, we are taking the ambient air and ambient air will have dust and dirt and if it is not filtered properly. So, this kind of fouling will take place and then you see with time the fouling will increase. Of course, the rate of increase need not be the same or uniform throughout the whole duration. But with time, there will be increase in fouling.

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So, basically, these are deposition kind of fouling what one can see. If we go to the next slide here air side or gas side, let us say air side fouling for different reason. So, these are again fin tube, but not as has been shown. So, here what could be fouled on this kind of fin surfaces? Let us say, if the combustion product is there. So, particulate will be there that will deposit on it. On the combustion product there could be in some sort of volatile gas and which will condense while the non-condensable part will go away, but those kind of oil and char. So, those kind of things we will deposit.

If there is some sort of a insulation and the insulation has gone away due to or got deteriorated due to high temperature that can, make some sort of a fouling. So, similarly there could be different kind of fouling and you can see the bad condition of the heat exchanger one may think and he will not be very wrong that with this kind of heat exchanger how heat transfer is possible.

Not only how heat transfer is possible. It is also one can think that passages are almost choked how flow of a gas will be there because, flow of gas takes place between the passage between the through the passage generated by 2 adjacent heat transfer surface and those kind of passages are almost absent here.

So, in a nutshell, what we have got that liquid side? Fouling is there. Obviously, and gas side fouling's are also present and in gas side fouling of course, certain kind of things certain kind of mechanisms are more prominent in liquid side fouling. The certain other

kind of mechanisms are more prominent like crystallization etcetera are more common in case of liquid side fouling whereas, deposition particulate deposition etcetera are more common in gas side fouling.

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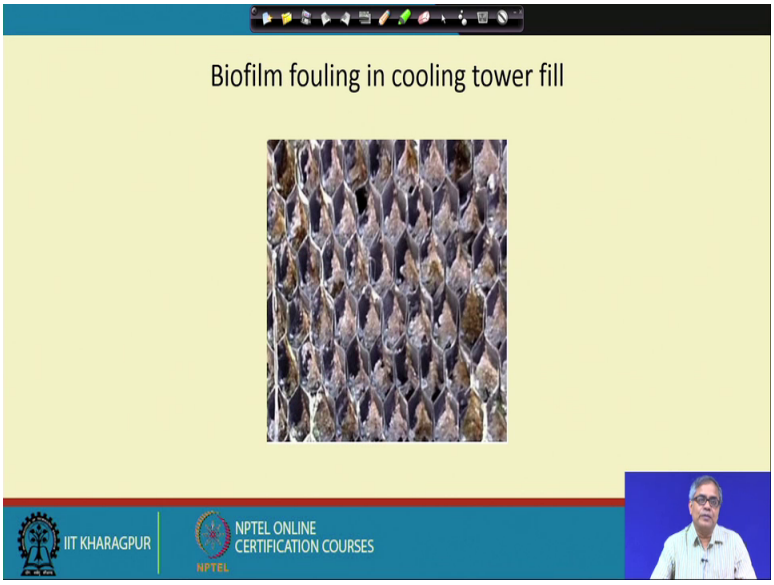

This is biofilm fouling in cooling tower fill. So, cooling tower, I mean as we know that cooling tower, there is heat transfer direct, contact heat transfer between hot water from the plant and the cold ambient air. So, this is in open atmosphere and water is there and there are field or heat transfer surfaces which supports water film where the velocity is relatively low. So, that is very good for biological growth and we can have biofilm formation and biological route of fouling in this case of course, other kind of fouling's like precipitation like crystallization.

So, those kind of fouling's are also present. So, this is one thing that one typical kind of fouling and fouling of cooling tower fill is very common and unless we keep this film fills heat transfer surfaces clean time to time, the performance of the heat exchanger that falls; sorry performance of the cooling tower that falls drastically.

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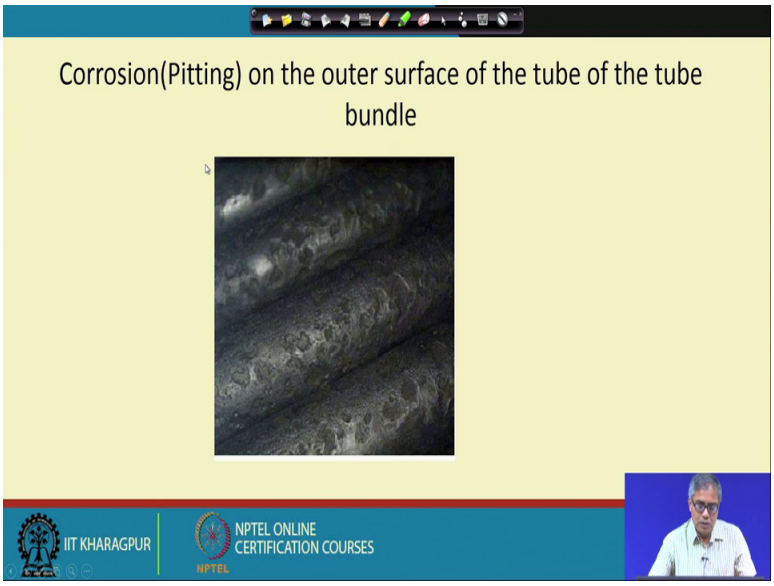

Then, here I have shown corrosion pitting on the outer surface of the tube bundle there is a tube bundle and fouling took place from fouling corrosion took place and due to corrosion there will be pitting. So, some of the material from the surface that will be taken away or that will fallen from the surface. So, there will be pitting this is called pitting there could be different reasons of pitting, but corrosion is also one kind of I mean one reason of fitting and the source of corrosion or inception of corrosion that could be from the from the fouling itself. So, this is another example.

Then, there are other things due to fouling, what happens this fouling gives rise to corrosion and in a big heat exchanger. When there is fluid flow, there could be there could be vibration, due to vibration also material may fall apart material has already become weak due to corrosion and that that may the surface may use material. And then again, I as I have told that it is kind of a cell promoting thing that initially smooth surface was there fouling was bit difficult deposition of material was bit difficult.

Now, fouling took place due to fouling, corrosion took place due to corrosion the surface has become rough and it promotes fouling or deposition of the deposition of different kind of material. So, fouling increases so, this is one thing one has to be very careful that it may go on increasing in a cyclic order.

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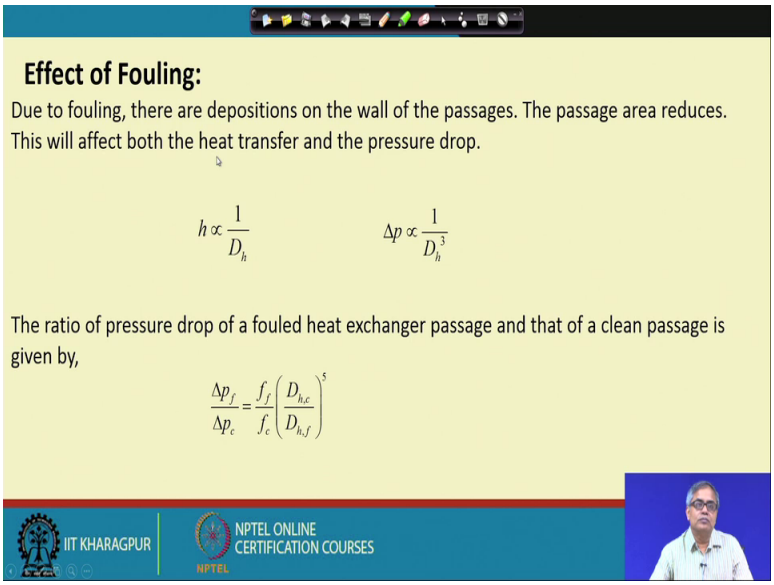

Now, the effect of fouling; due to fouling there are deposition on the wall of the passage there will be deposition on the wall of the passages; the passages are the passage area will reduce which we have seen very quickly if we go for our earlier the first diagram. So, here due to fouling the passage area initially, this was the diameter of the tube. Now, the diameter of the tube has reduced. Of course, the tube surface has become very rough and jagged and irregular that is one thing, but the area available for fluid flow that has reduced drastically.

So, let us go back. So, sorry so, due to fouling there are depositions on the wall of the passages the passage area reduces. This will affect both the heat transfer and pressure drop. So, it has been shown h is proportional to 1 by D h; that means, hydraulic diameter and delta p is proportional to 1 by D h cube this is some sort of a rough estimate, the ratio of and again the surface area is changing. So, here only we have considered the diameter effect or flow area affect. So, if the surface sorry the surface roughness is changing. So, if the surface condition changes, then for heat transfer coefficient. There will be some change and the friction factor that will also change.

So now, in if we take a ratio of pressure drop, then the fouled heat exchanger passage and that of the clean passage is given by this particular formula. So, you see this friction factor is coming and diameter is coming. So, what we can see in a nutshell that both the heat transfer and the delta P will change and by a simple analysis, it can be shown and

that is what we have done. I will not proceed further this is just an initiation how pressure drop and heat transfer can be affected by fouling. I will take it from this point and in our next lecture I will try to explain what will be the effect of fouling on heat transfer and fluid flow.

Thank you for your attention.