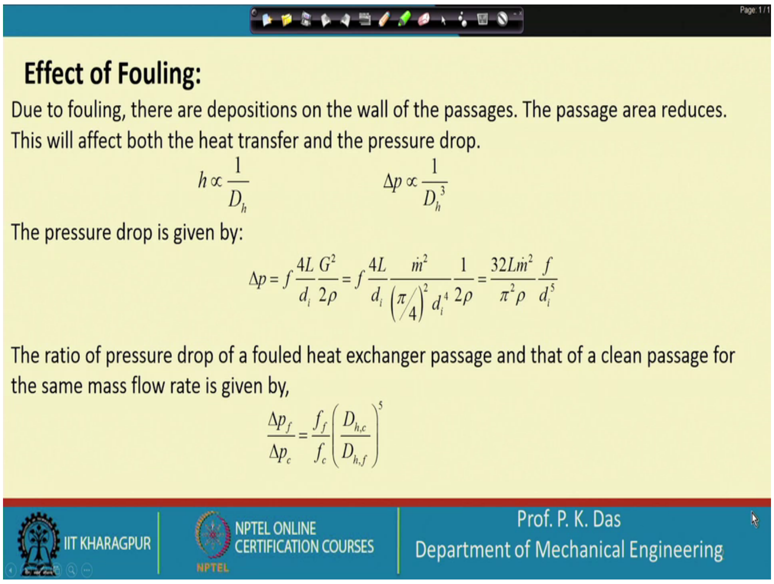
Heat Exchangers: Fundamentals and Design Analysis
Prof. Prasanta Kumar Das
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 58
Fouling in Heat Exchangers (Contd.)

Hello everyone. If you recall, we were discussing a very important practical aspect of heat exchangers, that is Fouling in Heat Exchangers and we have seen that how or we have discussed how fouling can deteriorate the heat transfer performance. It has got effect both on pressure drop and rate of heat transfer and how we have seen some snapshots, photographs taken from different sources that how fouling deposits are there on the passages of heat exchanger and how it changes the geometry.

(Refer Slide Time: 01:13)



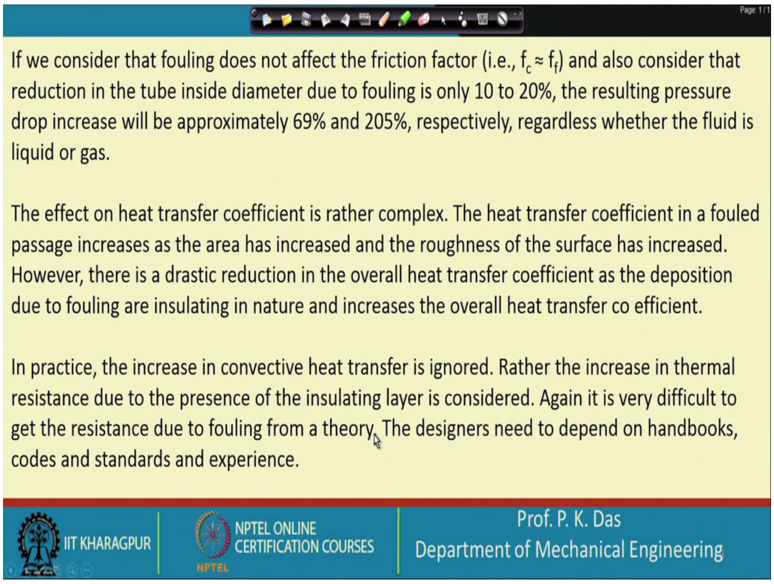
So, once we have the basic idea regarding fouling, let us proceed and let us see some details of it. So, next slide if we go, this probably this slide probably I am repeating. Due to fouling, there are the deposition on the wall of the passage.

So, the passage area not only the cross sectional area, but the surface condition that will also change; if we consider that only there is change in the passage area, that is only the hydraulic diameter is affected. Then, from the basic physics from the basic science, heat transfer coefficient that is that is inversely proportional with hydraulic diameter and delta p that is pressure drop that is inversely proportional with the cube root sorry with the third power of hydraulic diameter.

Now, pressure drop the I have given the entire formula how the pressure drop is to be calculated and if we consider that though there is a change in the passage area, but the mass flow rate of the fluid that we have kept constant. Then, we can find that delta p that is proportional to d to the inversely proportional to d to the power 5. The ratio of pressure drop if we take the ratio of pressure drops of a clean heat exchanger or other a foul heat exchanger and decline heat exchanger.

That means, delta p f divided by delta p c f is the fouling condition and c is the clean condition, then this friction factors are coming into picture and then diameter, I mean it is inversely proportional to the fifth power of the diameter.

(Refer Slide Time: 03:02)



Now, if we consider that fouling does not affect the friction factor a very a very crude simplification that f c is equal to f f and also consider that the reduction in tube inside diameter due to fouling is only 10 to 20 percent, then the resulting pressure drop increased will be approximately 70 percent to 205 percent. So, you see a 10 percent sorry a 20 percent reduction in the diameter will give us 205 percent increase in pressure drop assuming that friction factor has not changed. And also, we are we have assumed that we are maintaining the same mass flow rate.

We are assuming that well the geometrical shape has not change much so, all these things. So, crudely it gives some idea that how pressure drop is effective. So, what we find? This is a very important observation. What we find that, we have to have heat exchanger should that should be free from fouling as far as practicable. And if there is fouling, we have to take some strategy to mitigate it. Now, as we will proceed, we will see that fouling is a continuous phenomenon, it is a transient phenomenon, but it continuously happens, it takes place continuously.

So, if there is any kind of control technology, control strategy, if there is any, let us say quote unquote cleaning strategy, that we will keep the heat transfer passages clean. So, that cannot be only once, that cannot be only twice. So, at regular interval we have to have some sort of heat exchanger cleaning of these passages. Quote unquote cleaning how we will do this things? Some something we will tell there are it is again a I mean detailed technology how cleaning of heat exchanger surfaces can be done.

So, basically then, what we can find that just like other equipment heat exchanger also need some sort of maintenance, regular maintenance to get the performance out of this heat exchanger and this is very crucial. Because, if we put or if we offer a blind eye to this aspect, there could be large deterioration of the heat exchanger performance and that will have it, say on the overall plant performance.

The effect on heat transfer coefficient rather complex. So, this we have seen only effect on pressure drop. What is the pumping power that we can determine from the pressure drop. So, the effect on heat transfer is rather interesting, what we can see the fouling deposition will reduce the passage. If it reduces the passage and if we keep the mass transfer or other mass flow rate constant, passage is reduced mass flow rate is kept constant which amounts to that we have increase the velocity.

If we increase the velocity, so obviously, the convective heat coefficient of convective heat transfer that we increase that is one part. And second part is we have seen the photographs that the deposition of foulance that makes the surface irregular. And generally, this irregularity gives an increase in heat transfer coefficient in general. So, heat transfer coefficient will increase by these 2 effects, which heat transfer coefficient. It is the convective heat transfer coefficient which will increase, but is that then a some sort of a boon that fouling has taken place and heat transfer coefficient has increased not at all.

Because, the foulant which will deposit on the surface, they are highly insulating. Generally, in most of the cases or many of the cases not most of the cases; in many of the cases, we neglect the resistance to heat transfer from one fluid to another fluid the part of the resistance which comes due to the solid wall that we neglect. Because the solid material has got high conductivity and it is very thin the solid metallic wall etcetera are very thin in many cases.

But, when is there is deposition of foulant. The foulants are insulating material their conductivities are low and the thickness can increase to a greater to some to some finite extend. So, we cannot neglect the deterioration in overall heat transfer due to the appearance of a new resistance, convective heat transfer coefficient probably is increasing, but there is appearance of a new resistance due to the deposition of the foulant and that we cannot neglect.

So, that is why, the effect of fouling in all the cases, almost all the cases that will deteriorate the performance as a heat exchange device in practice the increase in convective heat transfer is ignored. Rather, the increase in thermal resistance due to presence of insulating layer is considered again. It is very difficult to get the resistance due to fouling from a theory what will be the thickness of the fouling layer, what could be the composition and that is how what could be the thermal conductivity. All these things, it is not easy almost impossible to determine.

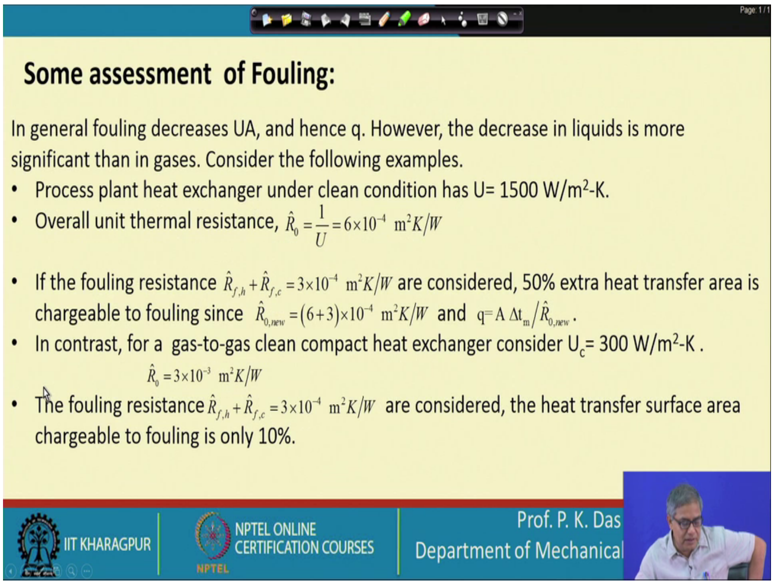
So, if that is so, the designer need to depend on handbooks codes and standards sometimes and many times on experience that how one can 2 things are there, how one can rate the performance of a heat exchanger in the presence of fouling. And how much extra area or extra surface or extra capacity of the heat exchanger is to be allowed in the design stage at all to allow for the deterioration of fouling. There is another aspect also that, what should be the cleaning schedule, up to how much time we can allow the foulant to deposit on the surface so that my deterioration of the heat transfer performance is within the level of my expectation.

And then I have to definitely clean the heat exchanger so that it again performs in a better way. So, there are many aspects of fouling. First thing at the design stage, I have to take some sort of a precaution so that fouling does not take place in a rampant way; precaution so, that my design is slightly oversized or to some extent oversized.

So, that even with fouling also, I am capable of having the plant performance what I have aimed for and then, I have to also decide regarding the cleaning strategy or cleaning cycle, cleaning schedule. So, all these things should come from some sort of simple calculation where though the phenomenon is very complex. So, some sort of simple calculation because many simplifying assumptions has to be taken and we have to depend largely on handbooks codes and standards.

So, how to take care of fouling are the extra resistance due to fouling that has been discussed earlier when we had the design of heat exchangers simple heat exchangers. So, that part I will not discuss here. Rather, other aspects of fouling that we will discuss. It has to be kept in mind that all the standards of heat exchanger all the data book of heat exchanger will have information regarding the fouling resistance and we have to select the appropriate fouling resistance from those handbook. Obviously, the engineers experience regarding this goes a long way in selection of the proper fouling factor or fouling resistance. We go to the next slide.

(Refer Slide Time: 12:19)



So, some assessment of fouling in general fouling decreases U A. So, U is the U A is the overall heat transfer coefficient. There is a decrease in overall heat transfer coefficient because a new resistance element is coming into picture, probably 2 new resistance elements will come into picture. Because, 2 fluids are flowing; 2 fluids are flowing separated by a solid surface and on both the sides of this solid wall, there will be deposition of fouling. So, there will be 2 fouling resistances, these things you know.

However, the decrease in liquid is more significant than in gas. Suppose, there are 2 fluids streams we considered liquid fluid stream sorry liquid stream and gas stream. So, liquid side there will be high fouling, more fouling compared to the gas side, it is in general but there could be some exception also, process plant heat exchanger under clean condition has U is equal to 1500 watt per metre square Kelvin. Let us take an examples overall unit thermal resistance that is R o is 1 by U, that is 6 into 10 to the power minus watt minus 4-watt sorry minus 4 metre square Kelvin per watt.

So, we have got the overall resistance for this particular application fouling resistance. Let us say hot side and cold side combined together is 3 into 10 to the power minus 4 watt sorry metre square Kelvin per watt is considered. So, here it is 6 and here it is 3.

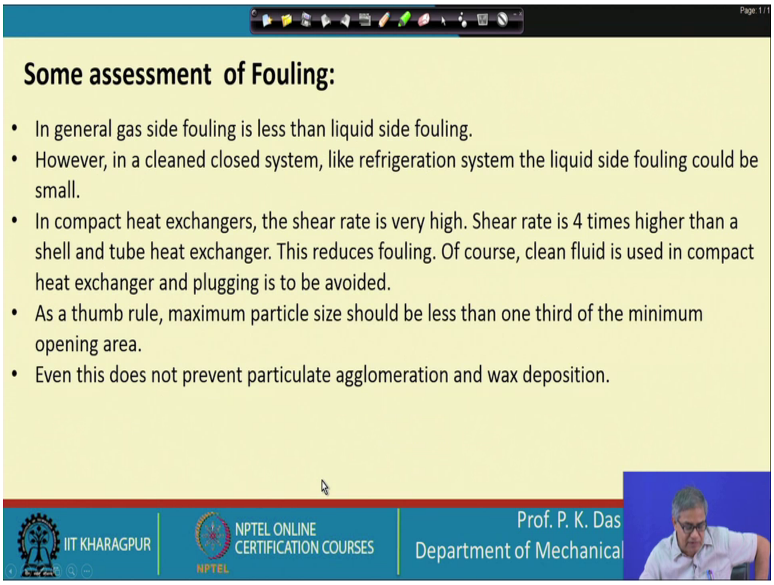
So, you see 50 percent extra heat transfer area is chargeable to fouling. Because, the fouling resistance is 50 percent of the resistance of the clean heat exchanger; in contrast let us take a case typical case of gas side gas to gas clean compact heat exchanger. Consider U c is equal to 300 watt per metre square Kelvin the overall heat transfer coefficient of a gas to gas heat exchanger is much lower compared to a liquid heat exchanger.

So, R o is of this order and the in fouling resistance is 3 into 10 to the power minus 4 which is equal to that what we have considered in case of liquid heat exchanger. So, fouling resistance is equal to that, but the fouling resistance is now only 10 percent of the overall resistance. So, you see that absolute value of fouling resistance that is not very I mean that is important, but that is not the only thing to be considered how much deterioration of heat transfer will take place that depends not only on the absolute value of fouling resistance. This example shows us very clearly.

So, generally in dirty condition, what could be very detrimental fouling in a clean condition or other vice versa in a clean condition what could be a very detrimental fouling, the a dirty condition that may not be that much serious problem.

So, there are examples and some such examples people when what is on the practical field they will get familiar with these kind of examples. Now, a thing is that in this course, we are trying to give a first step overview of the heat exchanger out of which fouling is very important. So many cases we will not be able to go into much detail. Some basic idea regarding fouling different kind of fouling, their effect strategy to mitigate them those will be the concerned for the present course. So, let us go to the next slide.

(Refer Slide Time: 16:45)



Again, we are assessing fouling; in general gas side fouling is less than the liquid side fouling this is what we have shown by calculation also however, in cleaned closed clean, very clean closed system like refrigeration system and the refrigeration. Refrigerator is circulating through some sort of a closed systems and there are filters etcetera. So, the liquid side of a fouling could be small.

In compact, heat exchanger the shear rate is very high. So, when the shear rate is 4 times higher compare to shell and tube heat exchanger in a typical compact heat exchanger. So, this reduces fouling. So, if the shear rate is very high we will read regarding some mechanism of fouling or we will discuss. So, you will see that when the shear rate is very high, then the foulant that will not be very easily depositing on the surface and that gives us some sort of advantage.

Of course, compact heat exchangers are design for clean condition. they cannot be design for I mean; they cannot be used for very dirty condition. But, as such here tendency of fouling will be less in case of compact heat exchanger, the way they are operated and fouling should be also not encouraged in compact heat exchanger because, if there is any plugging obviously, one can understand the consequence for a compact passage. As a thumb rule maximum particle size should be less than one-third of the minimum opening area.

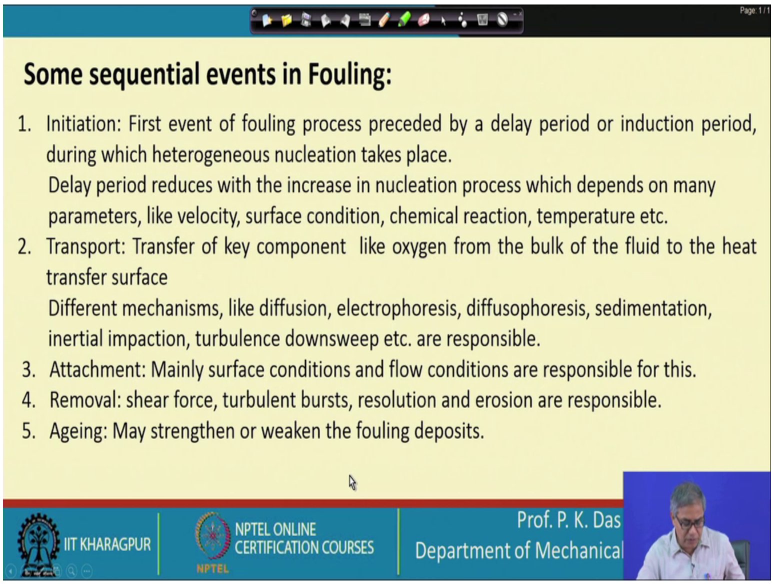
So, suppose there is a fluid and there could be some sort of a suspended particle, now suspended particle generate due to different reasons in a circulating system. So, that suspended particle diameter should be much less and the minimum passage area should be at least 3 times more than this suspended particle.

What does it mean? It means of course, at the system design level, we have to take care we have to also take care in selecting proper filter in a circulating system. There should be filter that what should be the efficiency of the filter, that we have to decide. So, based on this kind of consideration, but what happens? Many cases, we think of only the particle which can be there in the circulating liquid, but this particles sometimes agglomerate.

So, we have considered only the base size of the particle, but due to during circulation and with time they can be agglomeration, there can be wax deposition etcetera. So, there are different reason that even taking care of all these things taking care, I mean taking even after taking all the precautions, there could be some sort of a fouling in case of in case of compact heat exchanger.

So, the cleaning strategy, ultimately the cleaning strategy is very important. So, there should be some sort of a regular cleaning strategy. The cleaning strategy may not be similar for all the heat exchanger. But anyhow, there should be a cleaning strategy for the heat exchanger. Let us go to the next slide.

(Refer Slide Time: 20:36)



Some sequential events in fouling; initiation, the first event of fouling process preceded by a delay period or induction period during which heterogeneous nucleation takes place this is very important. So, fouling means, a new species is coming that was not there in the original liquid or original fluid or that was thoroughly mixed homogeneously mixed in the fluid stream. So, that is getting separated out and that is getting deposited on the surface heat transfer surface that is fouling.

So, fouling again, let me tell you that generation of new species or separation of a pieces from the circulating fluid stream and getting in deposited on the heat transfer surface that is fouling. So, for that thing many cases, what is needed? The first event of fouling is heterogeneous nucleation, heterogeneous nucleation because it will not take place everywhere. It has to take place for the fouling to be more rather the fouling to be effective, effectively there could be fouling if these nucleation take place on the solid surface, on the solid surface when the nucleation is taking place. This is called a heterogeneous nucleation.

So, heterogeneous nucleation is in many cases, that is the inception of the fouling that does not take place immediately. You start operating the brand new heat exchanger and it take certain time. So, that is the delay time; after that there is transport. So, transport is the transfer of the key component like oxygen from the bulk fluid to the heat transfer surface. So, this is transport. So, there should be some sort of a transport.

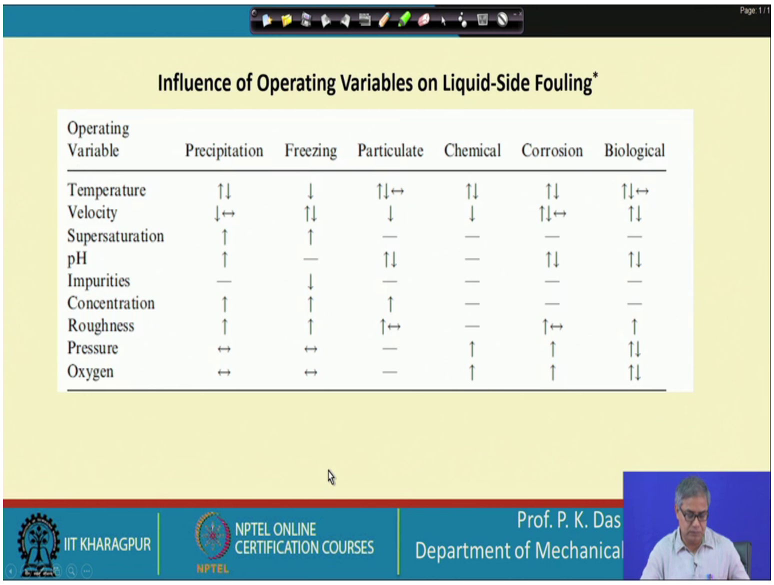
Different mechanisms like diffusion, there will be diffusion because of a concentration gradient electrophoresis, if there is some sort of electric field it need not be imposed electric field. It may be due to the potential difference of different components and an electrolyte is present. So, electrophoresis; diffusophoresis sometimes some material diffuse and then condense over the solid surface.

So, this motion is diffusophoresis; sedimentation it need not be explain what is sedimentation. Then, inertial impaction suppose, small particles are there, then there is some sort of inertial impaction and the particle gets deposited on the solid surface. So, turbulence down sweep due to turbulence, some particle goes in the down flow direction etcetera are responsible.

So, then first there could be some sort of a nucleation, then there could be some sort of a transport, then these things should get attached mainly surface condition and flow conditions are responsible for this then attach. Attaching does not give the, I mean it is not the final stage of fouling. So, what is getting attach that may get removed also due to shear force, turbulence bulks, resolution. Again, it is getting solved getting dissolved in the dissolved in the fluid stream and then erosion. So, what is what is depositing that may permanently not stay on the surface because there could be removal.

And this process is a dynamic process there is deposition, there is removal, etcetera and then ultimately the deposited layer should get aged. They should consolidate on the solid surface on the heat transfer surface. So, they may strengthen that is most of the cases or may weaken the fouling deposits. So, then some sort of a permanently we get certain amount of foulant deposition on the surface and we call it fouling, we call it fouling.

(Refer Slide Time: 25:26)



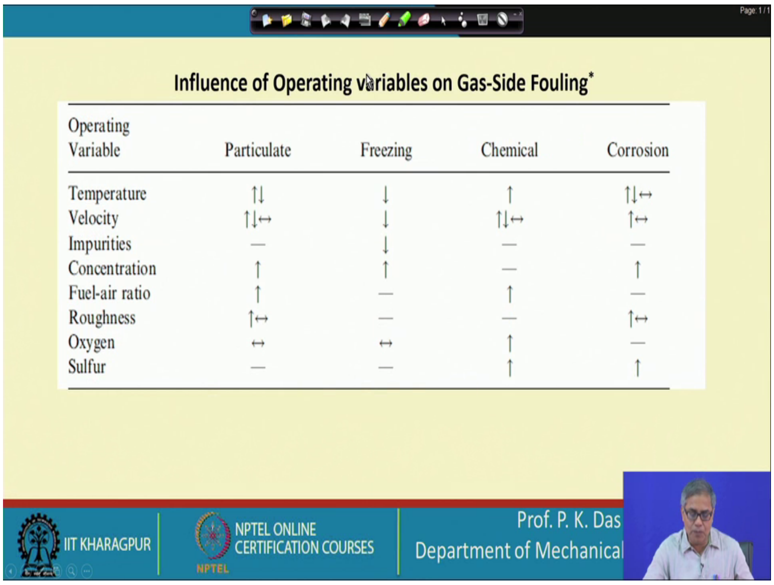
Operating Variable	Precipitation	Freezing	Particulate	Chemical	Corrosion	Biological
Temperature	↑↓	↓	↑↓↔	↑↓	↑↓	↑↓↔
Velocity	↓↔	↑↓	↓	↓	↑↓↔	↑↓
Supersaturation	↑	↑	—	—	—	—
pH	↑	—	↑↓	—	↑↓	↑↓
Impurities	—	↓	—	—	—	—
Concentration	↑	↑	↑	—	—	—
Roughness	↑	↑	↑↔	—	↑↔	↑
Pressure	↔	↔	—	↑	↑	↑↓
Oxygen	↔	↔	—	↑	↑	↑↓

So, this is what we get during fouling, influence of operating variable on liquid side fouling. So, there we have used some symbols the arrow head is upward direction; that means, it increases arrowhead is in the downward direction; that means, it decreases a arrowhead in both the direction. That means, so, it may increase, it may decrease not very it can happen like this depending on other condition and when there is no arrowhead that not much information is available, we do not know what will happen.

So, temperature on the precipitation it may increase it may decrease; temperature that decreases high temperature that decreases freezing. Obviously, particulate that may increase or decrease concrete proofs of increase, decrease and both way that has been observe. So, I am not going on explaining each and everything. So, these are available to you these are information and from this information let us take another example, pressure; pressure in case of chemical deposition. So, it will increase, but biological fouling, it has shown increasing trend in some cases, it is shown decreasing trend in some other cases.

Similarly, roughness concentration impurities p H etcetera so, this is just for information. So, please go through it is informative, but nothing much to be explained here from your common sense, you can correlate that why a particular factor is increasing a particular type of fouling. So, that you can give reason out yourself influence of operating variable on gas side fouling.

(Refer Slide Time: 27:25)



Operating Variable	Particulate	Freezing	Chemical	Corrosion
Temperature	↑↓	↓	↑	↑↓↔
Velocity	↑↓↔	↓	↑↓↔	↑↔
Impurities	—	↓	—	—
Concentration	↑	↑	—	↑
Fuel-air ratio	↑	—	↑	—
Roughness	↑↔	—	—	↑↔
Oxygen	↔	↔	↑	—
Sulfur	—	—	↑	↑

So, similar situations have been shown here, fuel air ratio is a new this thing new parameter which has come for gas side fouling. Particularly, when the flue gas is passing through a passage, we have to know what kind of fouling it gives; fuel gas when it is passing through the passage there are (Refer Time: 27:54) devices which are heat exchangers.

And obviously, fouling is a very important consideration over there in wasted recovery. One has to be very much concerned that what is the effect of fouling because, we deal with combustion product, there are different compositions the gases at high temperature and even there un-burnt fuel particle etcetera which can get deposited. So, different type of fouling can take place it is not a clean gas stream.

So, we have to be careful and what happens in case of fuel air? I mean, what is the effect of fuel air ratio that has been discussed here. So, I think with these, we have got some idea regarding fouling. Though our discussion has not ended, we will continue for at least one more lecture with fouling. So far I thank you for your attention and we look forward to know some more thing regarding fouling in the coming lecture.

Thank you.