Modeling of Tundish Steelmaking Process in Continuous Casting
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Lecture – 12
Characterization of Flow

Welcome to the lecture on Characterization of Flow. So, we talked about the stimulus response techniques, in that we talked about the pulse input and step input. So, just having an overview of that. So, as we see that if you go for the step input then we get the F-curve.

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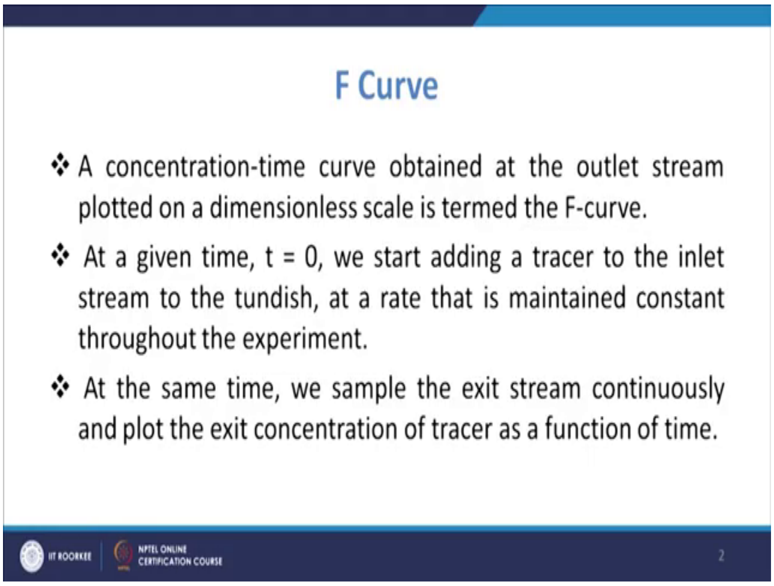

And the F-curve is nothing but the concentration time curve that is obtained at the outlet stream plotted on a dimensionless scale. So, then it is known as the F-curve. So, you have on the y axis you have dimensionless concentration and on the x-axis you have dimensionless time. So, in the case of F-curve what we, how we go with it is that at a given time t equal to 0 we are starting the adding or the tracer into the inlet stream, at a rate that is maintained constant throughout the experiment.

So, you have the tundish and you are giving that you know tracer into the tundish constantly at a constant you know rate. So, that way and its concentration at the outlet will be you know you know monitors. At the same time we sample the exit stream continuously and plot the exit concentration of tracer as a function of time.

So, we allow the tracer to go into it, it will go inside the tundish and it will flow as per the path which is available to it depending upon the you know configurations inside the vessel and then it will coming out. And then at there, we have the instrument by which we measure the concentration of the tracer at the outlet of the tundish. So, this way the curve which we get that is known as the F-curve.

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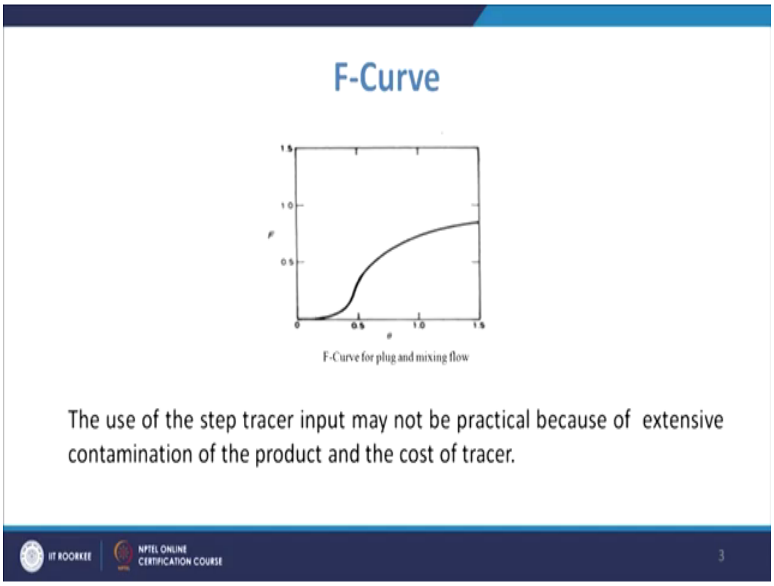

And a typical F-curve you know for the plug and mixing flow will be like this; so that we will talk about what is that plug and mixing flow. But then you can see that you are you know once you look at the F-curve; so this is where you know. From here the concentration starts appearing at the exit.

So, up to this much of time there is no tracer concentration being appeared at the you know turn this outlet. So, the tracer which has gone inside the tundish, it has come all through without you know going to the outlet. And then after that the part has started appearing at the outlet. So, it will start appearing and then slowly it will go on increasing.

So, you have a plug component, we have a mixed component, so the mixing taking place and then this curve is you know. So, this is your dimensionless concentration. And basically if you look at so this is 1. So, if you go for larger values it will go and touch nearly 1, so that will be you know that will be the F-curve. Now, use of the step tracer input may not be practical because of extensive contamination of the product and the cost of tracer.

So, its not very much you know in practice except you know we can certainly go for the numerical analysis of these processes, where we do not require these expensive tracers and its use. But you know you do not prefer that because, if the tracer you know is going continuously into the molten steel you know so that may even contaminate the steel.

So, you may like to have the concentration analysis at the exit, but then you have a you know that will certainly contaminate the whole steel. So, that is one issue. Another issue is that since you are continuously supplying, so it also adds to the cost factor. So, the cost of tracer will be another burden. So, because of that you tried not to use it practically, you better go for the other kind of analysis like C-curve or pulse input. So, we have already studied that in the C-curve your injection of tracer is made as a short pulse.

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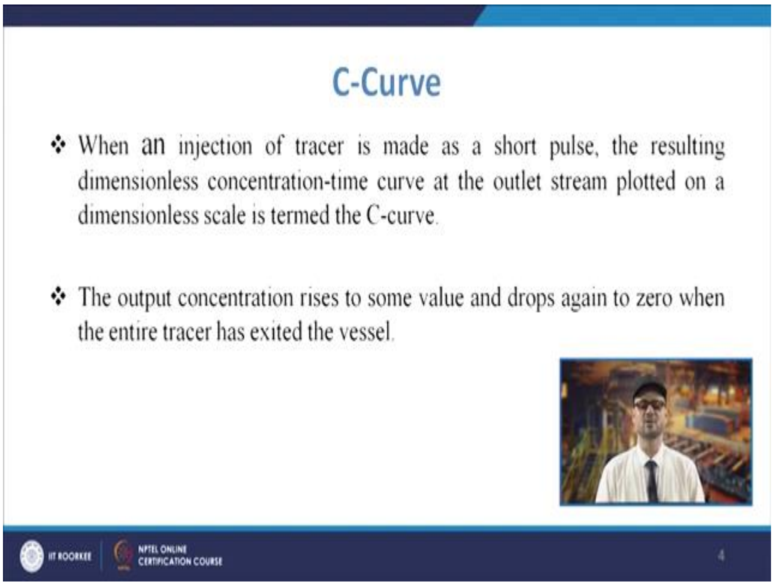

And the resulting dimensionless, so that results into dimensionless concentration. And time curve at the outlet stream and the curve which you plot for the dimensionless concentration and the dimensionless time that is C-curve and it will rise to some value and then drop again to 0 when the entire extra cell has exited the vessel.

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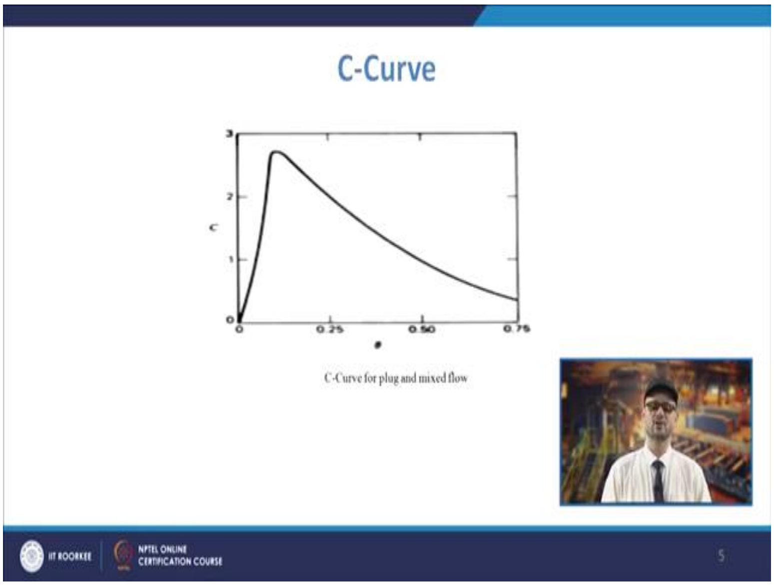

So, we already had discussed about it. Now this is how the C-curve looks like for the plug and missed flow. So, know what happens that this is you know it starts appearing from here and then it has reached to a peak value and then further it has started decreasing.

And if you increase this dimensionless time you have access to larger value. Slowly it will be coming towards approaching towards 0. So, this is basically the C-curve. Now you know that we had already seen in our lecture. Now, the thing is that when we talk about these flow systems.

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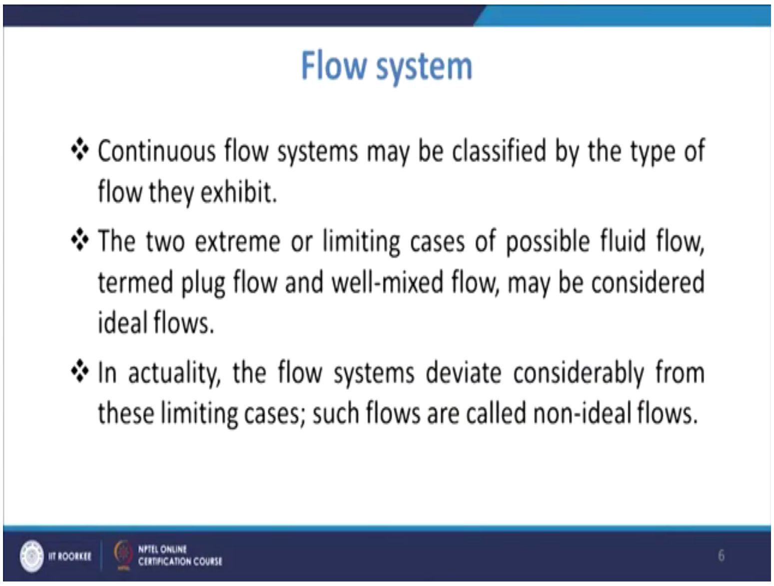

So, if you talk about the continuous flow systems they can be classified by the type of flow they are exhibiting. So, you have two extreme cases of possible fluid flow. And these two extreme cases are like you have plug flow and you have well mixed flow. So, they are normally considered as the ideal flow.

So, you know in actual case you will have certainly variation from these limiting or ideal cases. And though there will be non ideal cases, because in actual this a plug flow that is your ideal plug flow or ideal mixed flow that does not exist. But so, you will have the non ideal flows they are normally you know present which is practically seen inside the tundish. Now, coming to the discussion about the plug flow.

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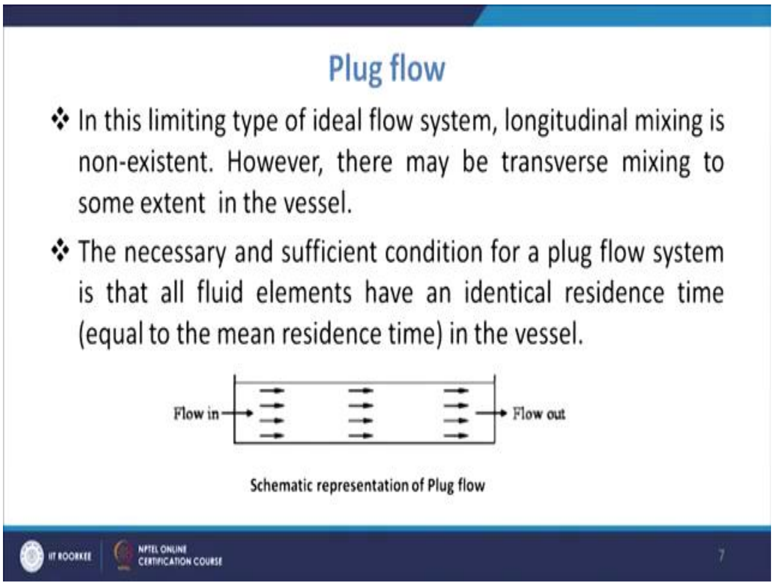

So, plug flow is; so in this type of limiting type of ideal flow system, the longitudinal missing is non-existent. So, what you see that normally you know we define as the metal which is the tracer which has gone. So, the plug flow means, the longitudinal mixing will be non-existent. So, the mixing in the longitudinal direction that is not at all there. So, it will have will be maintaining its identity and it will flow in you know on its path.

There may be some amount of transverse mixing to certain extent you know in the in that case in the case of plug flow. So, the necessary and sufficient condition for the plug flow system is that, all fluid element have identical residence time in the vessel. So, what we see that normally you have all the fluid element which is there.

So, it will go and it will exit the vessel at the time which will be same as the mean residence time inside the vessels. Everybody has every fluid element which has which is flowing in that plug manner, so it will have the same you know mean residence time. So, what you see here is that, you know the flow is going and it will come and it will be out. So, this is the example of the plug flow.

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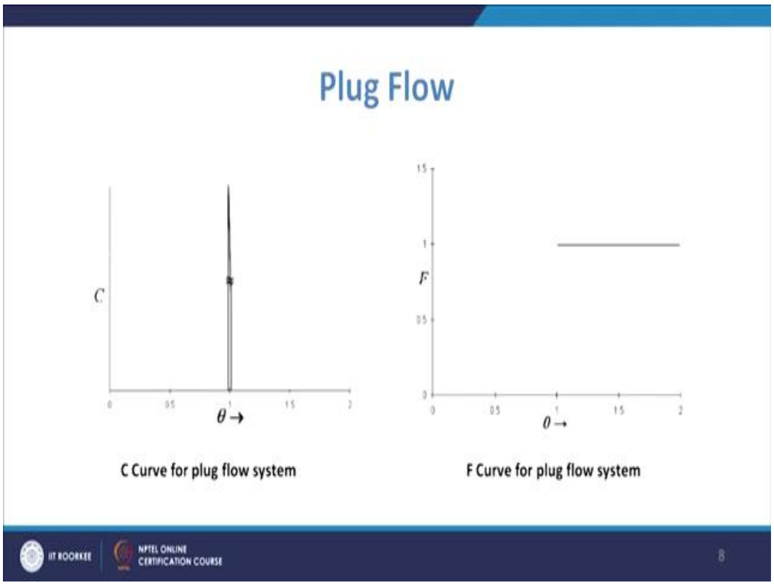

So, if you talk about plug flow system and if you talk about the C-curve. So, in the C-curve how can you schematically represent? So, what you see in the C-curve what you have seen that in the C-curve what you do is you give the sort pulse of tracer, it will go into the tundish and then it will come it will go inside the tundish at different location and then it will come to the outlet.

Now, in the case of ideal plug flow system if you talk about the C-curve what you see is, that the tracer which you have added and all the fluid element will be spending a time that is equal to θ equal to 1. So, θ equal to 1 means it is the mean residence time, actual theoretical mean residence time. So, at the theoretical mean residence time all the tracer has come out, so you see a long peak and then here itself it vanishes.

So, all the you know tracer has come out of the tundish outlet at this time that is the time of actual you know I mean theoretical mean residence time. So, this is known as the ideal plug flow, the tracer which has you know entered.

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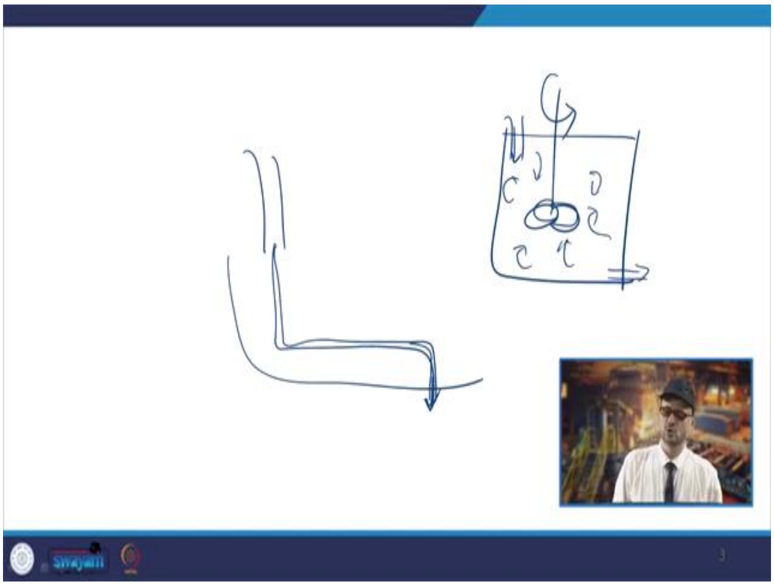

So, into the vessel and it has come and slowly it has gone and it has come out of the outlet. So, it has spent the ideal time. So, it has not interacted with you know with other fluid, so in longitudinal or in transverse manner ideally. And then it has come out and it will be or wherever it has gone it is basically volume by volumetric flow rate that is your theoretical mean residence time.

So, it has gone out, it has not it has maintained its identity and then it has come out without mixing. So, that is your you know plug flow in the case of the pulse input system. If you talk about the step input systems or that F-curve. For F-curve if you see, the plug flow will be represented by this curve. So, where it tells that the metal I mean the tracer which has gone into the metal, so this tracer has not you know interacted anywhere.

And then when it has spent time of the theoretical mean residence time inside the vessel that is tundish, then all the tracer has started exiting. So, basically tracer has been is continuously being put in and all the tracer is flowing. And then it will stay you know together in the tundish for the theoretical mean residence time period, and then after that they will start exiting. So, once they start exiting then their concentration will go on increasing.

So, I mean not increasing basically it has directly reached. So, its they are all coming out. So, the concentration is dimensionless concentration is 1 itself. So, this is the you know representation for the plug flow. Either be it when you talk it in terms of the C-curve or you talk in terms of the F-curve. So, you can represent these you know plug flow on these two systems like these two curves.

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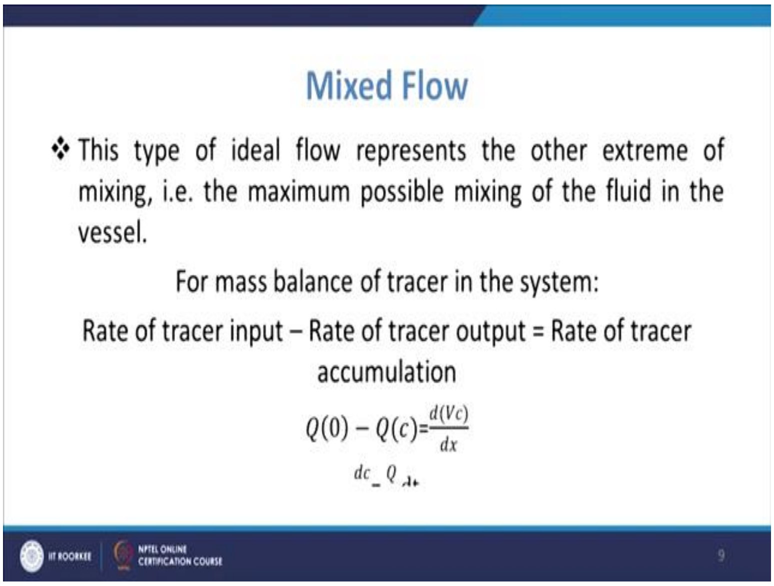

Now, next will be your mixed flow. So, the mixed flow will be the type of ideal flow that will be representing the other extreme of the missing. That is you know the maximum possible mixing of the fluid you know inside the vessel. So, to talk about the mixed flow, so in that case what we assume is that in a plug flow they are maintaining its identity whereas, in the mixed fluid is assumed that once that tracer has gone inside the vessel it has completely mixed inside.

So, you know. So, its like a system, like you know once you have any system. So, if you have you just have an impeller and you know and then you are rotating it, so you know all these things will be moving like you know everywhere. So, this will be completely mixing into it. So, this k wave you will have a completely mixed flow.

So, you have sometimes something flow in and then if you have some flow out. So, that way you will have complete mixing if you have a mixer with a stirrer or so. So this is the example of a completely you know mixed flow. Now what we know by this you know if you try to analyze these mix flow systems.

So, if you see the you know considering consider the mass balance of tracer in the system, where you have put the you know tracer into the system. So, in that case you can write that rate of tracer input minus rate of tracer output that will be nothing but the rate of tracer accumulation. So, what you write is that you can have the $Q_0 - Q_c$, so that will be $\frac{d}{dt}(v_c)$

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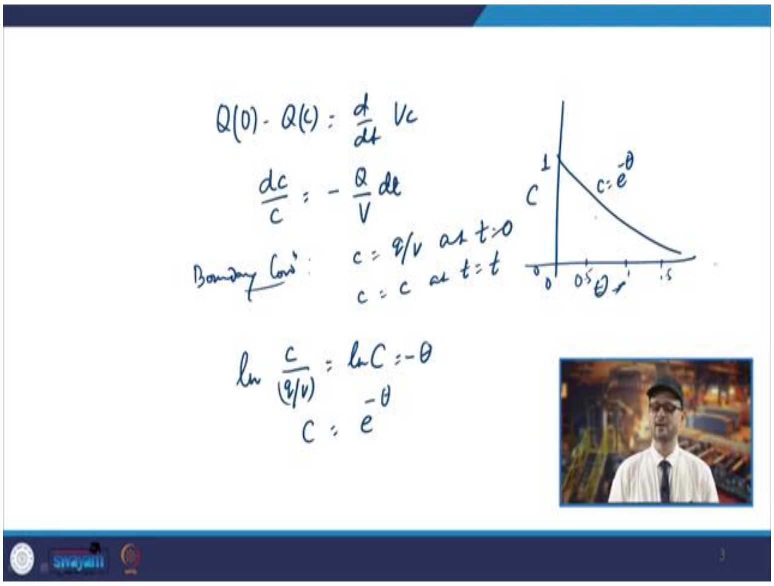

And accordingly so you can from here what you can see that if you write this you know $Q_0 - Q_c$. So, that will be you know Q_c it will be the accumulations, so $\frac{d}{dt}(v_c)$. So, what you from here you get $\frac{dc}{c}$. So, that will be you know $-\frac{Q}{V}$dv and that will be dt. So, this is Q_c, so this C you know this side you will have $\frac{dc}{c}$, so this will go and $-\frac{Q}{V}$ and then that dt will go this side.

So, you can integrate it and you can integrate it you know by having a certain boundary condition. So, if you integrate suppose and if you are giving the boundary condition like you have you know you take $c = {}^{q}/_{v}$. So, you will have $c = {}^{q}/_{v}$ at t=0 and then you have c=c at t=t. So, this being the boundary condition you can you know. So, for t you have taken the two time and what will be the concentration.

So, based on that you can further integrate. So, $\frac{dc}{c}$, so it will be $\log c$ and for the different values you will have a $c \log c$upon you know ${}^{q}/_{v}$. So, that will be equal to you know $-{}^{q}/_{v}\, dt$. So, that will be you know. So, even in this case you will have, so this is log c that will be -θ. So, you will have if you look at this C value it will be $e.^{-\theta}$

So, that way you get you know this curve this RTD curve for the well mixed flow, if you take the completely mixed flow ideally mixed flow so it will have the concentration it will go like that. And if you take theta as 0, so initially at time 0 you will have concentration as 1. And as you move with time, so you will have the you know if you try to plot so your plot will be.

So, you what you see is, this is an exponential decay type of curve is being seen. So, you will have this way your, so this is being c and this is being θ. So, in the case of well mixed flow ideally mixed flow your $c = e.^{-\theta}$. So, this being 1 and your θ is you know increasing this will 1 this will be 1.5 and then in this way it will be decreasing. So, this will be 0.5.

So, you will have 0 and 0 values on the sides. So, this curve this. So, C-curve for the well mixed flow now you know in the case of you know when we talk about analyzing the C-curve. Now if you try to go for analyzing the F-curve.

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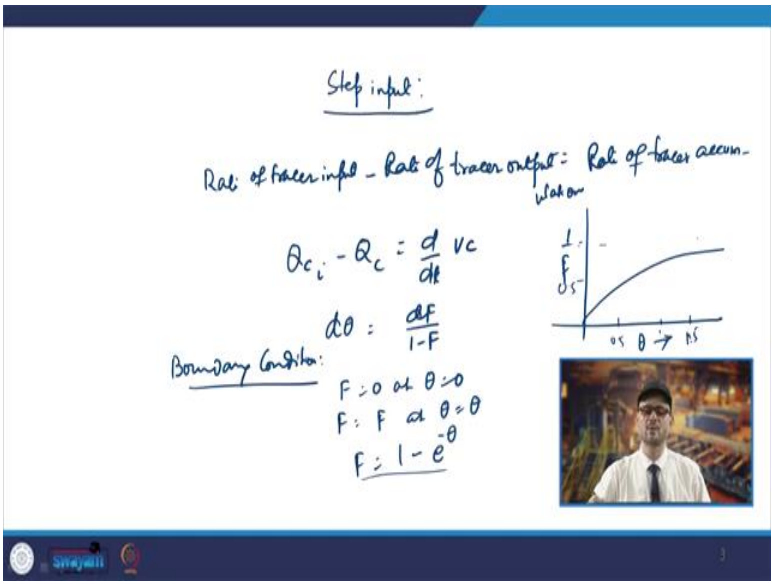

So, suppose we are talking about the step input. So, you have seen that in the case of step input for the plug flow it has there is nothing till t=θ=1 and then your concentration value is dimensionless concentration value is 1, altogether. Whereas, if you talk about the step input case you know for the well mixed flow. Now, in that case you know again you can have the analysis like you have the rate of tracer input and minus rate of tracer output. So, that will be rate of tracer accumulation.

So, this is normally now what is we have seen also in the case of you know, pulse input also where we found the well mixed flow expression. So, here also this conservation principle. So, this is the top tracer input minus top tracer output that will be rate of tracer accumulation.

Now in this case what will be happening you will have a $Qc_i - Q_c = \frac{d}{dt}$. So, that will be $\frac{d}{dt}(V_c)$. So, that is your conservation principle this will lead to this value. Now what we get to we get the my parameter dθ. So, this d theta will be nothing but it will be you know $\frac{dF}{1-F}$.

So, if you try to you know integrate now for these cases, so you will have the boundary conditions. So, if you apply the boundary condition you know in these cases. So, boundary condition will be that you will have F=0 at θ=0. So, at time of 0 your F becomes 0 obviously. Then your F becomes F at θ= θ. So, if you try to have the you know the integration, so what you see is you get the integration, by integration you get $F = 1 - e^{-\theta}$.

So, this curve which you get that we will be you know giving you the F-curve for the well mixed flow. So, if you draw the well mixed flow you know curve. So, that curve will be looking $1 - e^{-\theta}$. So, its nothing but 1 minus there, so this will be exponential curve. So, you will have if you draw the F-curve for the well mixed flow, so you will have F here and this is your θ. So, it goes like this.

So, certainly this will be approaching to here it would be 1 and this will be 0.5. Similarly, you will have 0.5, 1, 1.5 like that it will be moving. So, this RTD curve that will be you know that will be given by this expression it will be represented by this line. So, the thing is that what you see from this curve and the F-curve which you have seen for the plug flow. Now, in the case of plug flow, what you see is that there is no increase in this pressure concentration till this point. And then here directly you have this value coming, horizontal value coming.

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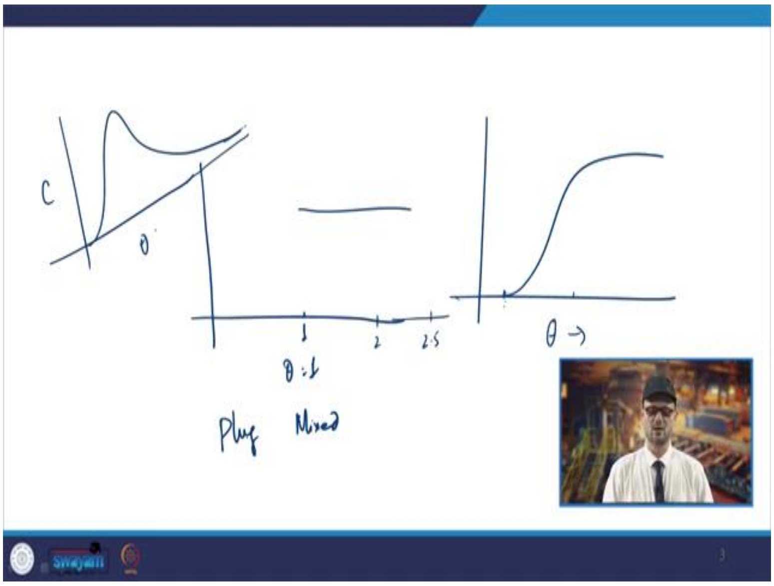

So, what you see is that in the idealized plug flow you will have simply at this point θ=1, so here you will have increase. Now in this case you are seeing that it is in the well mixed flow it is simply increasing from here. So, the thing is that as soon as it has entered, the tracer has entered it has started mixing with the flow. So, its idealized mixing and that is why the pattern is like this.

Now what happens in actual case if you talk about the actual case? The actual path curve will move like this. So, you know as you see that this part is basically the reason which is talking about deep and the plug flow conditions. And then you know you have the then the mixing has started. So, ideally you are mixing has; so if I had it been 1 here that theta have had it been this θ=1 here, so ideally that it has to start from here.

But in actual case there is no flow which is ideally plug flow or ideally the mixed flow. So, this part will be represented by the plug listen. And accordingly, we will also you know study that you will have the plug volume also will be you know a component inside the vessel. So, you will have this plug component and then you will have the you know mixed component. So, that we you have plug flow and mixed flow.

Now, the thing is that when you have the plug zone and also you have the mixed zone then what are the other zones inside the tundish. So, as we have discussed, as we see that when we talk about these curves, so it will be 2 and then we go to 2.5 or so. Now, if you talk about the normal RTD curves you know inside the tundish or in any system, so what we see that you know when we talk about you know the C-curves where you have C and this is your θ

So, what you see that this is going and you may go you know to a very large time. So, till that time that is somewhat coming out or so. It means that some part you know it is taking very this staying very long time inside the tundish. So, you know we have to have certain reason; where if the metal goes from there while coming you know it takes a long time to come out of it. So, apart from this plug flow.

And so plug flow will talk about the plug volume and mixed flow will be representing later on we will be studying, that we will be talking about the mixed you know volume inside the tundish. Apart from that you will have another zone that will be dead zone. So, that zone normally in the vessel we try to have a three kind of zones.

So, you will have plugs zone, you have mixed zone. And then apart from that, so in plug it is not able it has not you know mixed it is has maintained its identity. So, it has not mixed longitudinally or so. Now, in mixed zone means it has completely mixed. But then there are certain zone which has which is staying for very long time. So, that is basically representative of certain zones inside the tundish, where if the metal gets trapped or the tracer getting trapped it will be having very you know large time retaining inside and it will be coming after a very long time.

So, that is basically the dead regions you know they are represented by the dead regions inside the tundish. And in that case you will have the calculation of the plug volume, you have calculation of mixed volume and the rest volume. So, that will be dead volume. And that will be basically you know we will be calculating it. So, you have the way to calculate and there are different ways to calculate and different you know θ is also considered for that.

So, you may define that those particles which are taking you know more than twice the mean residence time that you may bring into that category, or sometimes maybe three times you know staying more than the theoretical mean residence time, that may fall into that category of the you know dead region.

So, accordingly, we try to you know define the different you know type of volume zones inside the tundish based on you know these analysis. So, you will have we discussed about you know these you know plug and the mixture you know flow which is happening inside the tundish.

So, what is meant to be said that the to these two you know extremes, that is idealized plug flow idealized mixed flow there are the two extremes, but the actual flow will be staying in between these two kind of flows. And you know, so the actual flow needs also to be characterized. And for that you have the different kind of models are developed to characterize basically the actual flow conditions; actual flow which is you know occurring inside the tundish which will be the combination of the plug as well as the mixed flow.

So, you have the plug component as well as the mixed component. And based on that you know we further we try to analyze these reactor or the vessel you know and judge its effectiveness; how well it is going to you know be used or to respond to the metallurgy as a metallurgical reactor or as a batch reactor or a batch vessel when we are using it in the continuous casting tundish. So, that we are going to study in our coming lectures.

Thank you very much.