Modeling of Tundish Steelmaking Process in Continuous Casting

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Lecture – 11
Introduction to Stimulus Response Techniques

Welcome to the lecture on Introduction to Stimulus Response Techniques. So, we talked about the continuous casting unit and in that we talked about the role of tundish. And, in this lecture we are going to have the discussion about those techniques by which we will be knowing about the flow behavior inside the tundish. So, that we can quantify in quantifiable terms we can have the idea that how good some tundish is or how good the flow is for obtaining certain you know output or certain results.

So, coming to the you know genesis of this. So, first of all let us know that why you know we need to have certain approach. So, that we can understand you know the flow behavior inside the tundish and then we can know the methods by which you can you know quantitatively understand or interpret the things which is happening inside the tundish.

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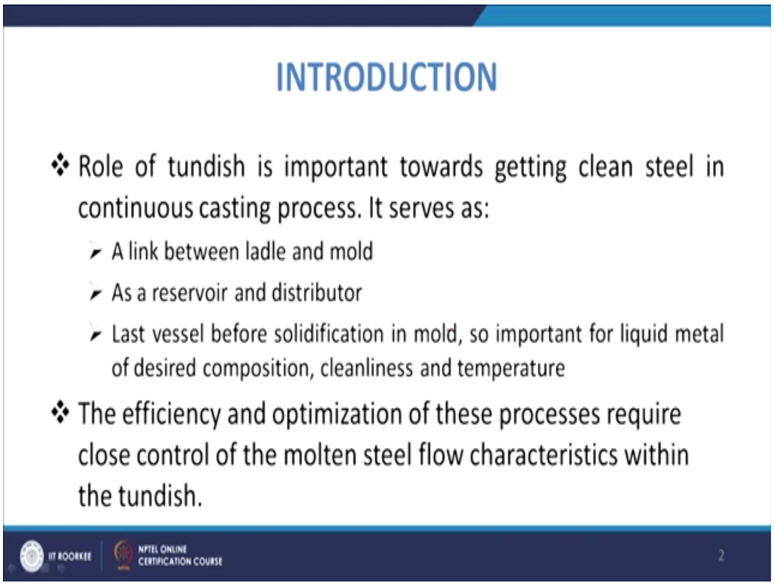

So, we know that the tundish is very important in the continuous casting setup and mainly it has many roles and first is that it is a batch type of vessel. So, it is a link between the ladle and mold. So, it will have the role as a buffer vessel. So, the ladle will be emptying the you know steel into the tundish and then the tundish will be supplying to the mold. So, you know the so, the mold which is getting the metal it is directly getting from the tundish.

So, ladle from ladle it will be entering into the mold and then depending upon the tundish geometry the metal which is coming into the tundish so that has to flow through the tundish outlets and then it has to go into the mold. So, you know that way it is important that how which type of flow is there inside the tundish because ultimately the mold is receiving those metal which is ultimately going to solidify and you are going to have the cast billets or slabs whatever to be.

Then it is also as working as a reservoir and distributor. So, it is collecting the liquid metal from the ladle and then it is distributing to the strands to the molds. So, its function is like a reservoir and then it is distributing to the different strands or different molds. Then another more important you know why tundish becomes important is the fact that it is a last reservoir you know before the mold before the metal enters into the mold.

So, after that the metal which is going to the mold it has to solidify and if the liquid has any kind of issues then that issue will not be you know cannot be addressed. So, whatever issues are to be addressed like inclusions need to be floated or the temperature you know has to be adequate and all that is to be seen in the tundish itself. Otherwise, you know after that once it leaves into the molds of there if something is there some external entity is there inside the liquid melt or so.

So, it does not have any chance further you know to be skimmed off although there may be somewhat, but then you know this is the last vessel before the metal goes into the mold for solidification. So, you need to have you know the considerations for the liquid metal to have the desired composition when it is going to enter into the mold or it is free from any kind of defect like you know it is a clean. There is no you know inclusion of any you know type inside the tundish, and also the metal which is being you know which is going out of the tundish outlet they are of adequate temperature.

So, there should not be you know unnecessary temperature drop inside the tundish because that will also be hampering the quality of the you know cast product. So, the thing is that tundish becomes very important and you need to have the you know proper flow you know flow characteristic proper flow pattern inside the tundish. So, that the requisite properties or requisite quality of the cast product be ascertained.

And so, the efficiency and optimization of these processes require close control of the molten steel flow characteristics within the tundish. So, that is why the tundish becomes very important you need to have you know proper control of the flow inside the tundish.

So, basically the characterization of flow is important you need to understand the flow, what way the flow is there inside the tundish, the metal, which is coming inside the ladle, how it is flowing out of the tundish. So, where it is striking the wall or whether it is going into all the corners of the tundish, whether any reason of the tundish is there, where the metal has gone in it and it is a dead region which is getting cold or so.

So, all these things need to be you know understood and for that there should be proper methodology, proper way of experimentation even by which you should understand that. So, for that you know for the detailed characterization of the fluid flow. So, for the detailed characterization of metal flow in the tundish or in any flow system requires knowledge of the complete fluid flow pattern. So, you need to have the understanding of the complete fluid flow for the detailed characterization of that metal flow inside the tundish.

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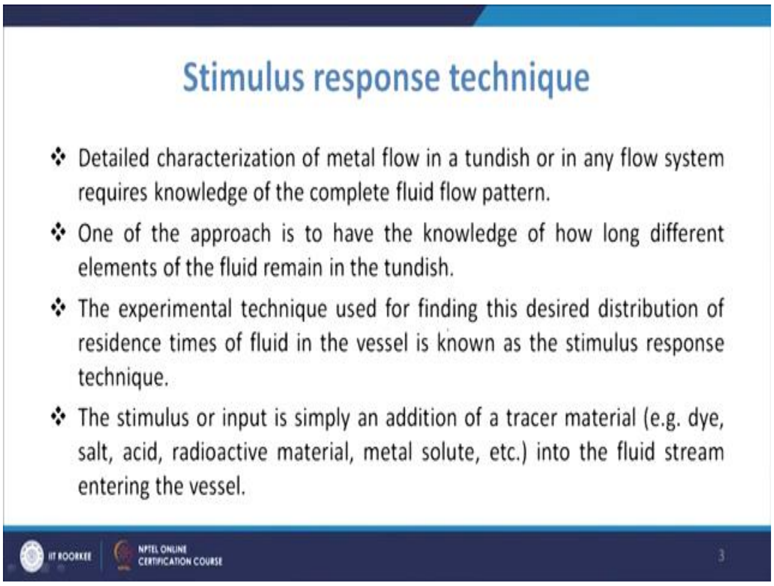

Now, for that there are may be many approaches and one of the approach is that you should have the knowledge of how long different elements of fluid remain in the tundish. Basically, you know that the high temperature molten metal will be coming from the ladle and it will be staying for sometime in the tundish and then it will be leaving to the mold.

So, once it goes into the mold. So, there you will have the solidification starting and then from the mold continuously the metal getting solidified will be taken out. So, the thing is one of the approach you know to study that how it will behave inside the tundish. So, is to also in by taking in the way that you should know that how long the different elements of these fluid you know. So, they are remaining inside the tundish, some of the elements may stay longer some of elements may you know stay very less amount of time.

So, that approach so, for that we have an experimental technique which is used for finding this desired distribution of residence times of the fluid in the vessel. So, what we do is that in that we normally try to have the definition of one property like residence time. So, for how much time the fluid particle is residing inside any vessel that is your residence time.

So, we have certain experimental techniques by which we try to find the distribution of the residence time of the fluid in the vessel and this is known as the stimulus response technique. So, what this stimulus response technique means? So, stimulus or the input basically it is nothing, but it is simply an addition of the tracer material.

So, normally what we do is we put a tracer material that tracer will be in the form of a dye or it may be a salt or acid all are radioactive material or a metal solute it may be anything. So, that is basically added into the fluid stream you know and that will be entering into the vessel so that is and its responses taken.

So, you are basically you know adding this tracer material that is that will be in the form of any you know of these materials, it will be going into the stream and then you know its output is basically recorded. So, that will be its information about its stay inside the vessel that will be you know recorded. So, that is how its response is taken.

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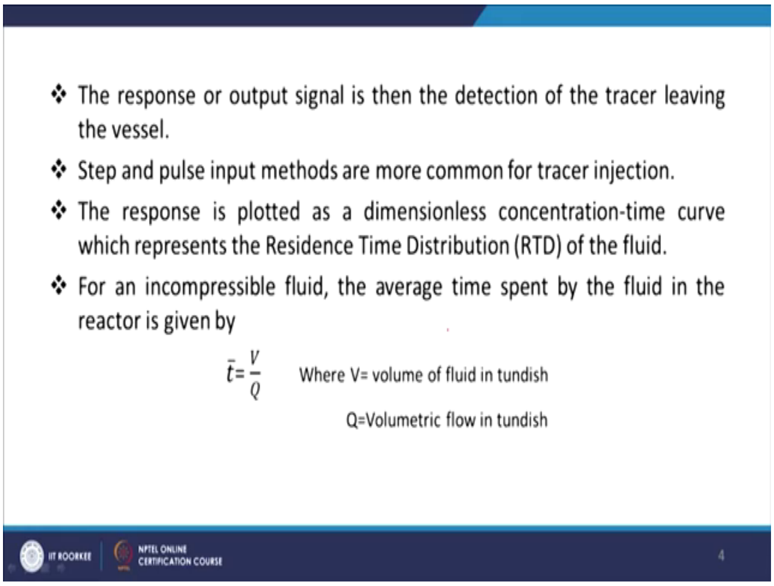

So, the response or output signal once there of you have injected these tracer inside the vessel as the input. So, once you have put that then the response or output signal is then the detection of the tracer leaving the vessel. So, the vessel will go into the tracer will go into the vessel, it will stay for some time and then it will leaving the vessel.

So, the output signal or the response that will be so, that will be measured. So, that it will be detected that when the it is leaving the vessel. So, that is the basically the stimulus response technique. So, we are basically injecting something and then we are seeing that how long it is staying, where it is going, how it is flowing. So, these are the stimulus you know this is known as the stimulus response technique.

Now, what happens that this response is plotted as a dimensionless concentration time curve which is known as the residence time distribution curve of the fluid. So, which will be representing. So, what happens that when you are putting these tracers? So, it will be going and then you are monitoring its stay inside the vessel and then you are plotting a graph. And, in the graph you will have on the x axis you will have the time and on the y axis you have the concentration of that tracer.

So, and that is dimensionalized sorry, that is made dimensionless by certain ways. So, that we will discuss and then basically this curve which you get. So, in that you know it tells it represents the time spent by the fluid particle inside the vessel; so, how the concentration will be changing with time. So, you know that the curve which you get that curve is known as the residence time distribution.

So, you know if you look at in a normal way. So, for the incompressible fluid the average time spent will be nothing, but the ratio of the volume to volumetric flow rate. So, as you know that the you have a volumetric flow in the tundishes Q and if the V is the volume. So, t will be the average time which is spent by the fluid in the reactor so on. On an average the fluid particle is going to spend this much some of the particle will spend less time than this, some of the particle will spend more than this.

So, you know that defines again the different trades off the vessel also. So, that will be that we will be discussing that they will be representing, different cases different types of regions inside the vessel or so. So, then so, if you talk about the residence time distribution. So, this $\bar{t}$ which we have seen here $\bar{t} = \frac{V}{Q}$; V is the volume of the flow, I mean fluid in the tundish and the Q is the volumetric flow in the tundish.

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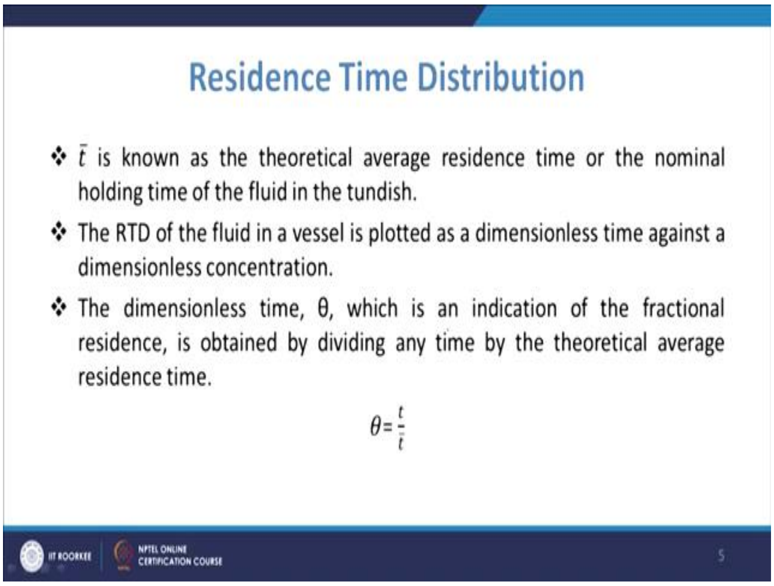

So, this $\bar{t}$ which you get this $\bar{t}$ is known as the theoretical average residence time or the nominal holding time of the fluid in the tundish. So, we call it as the theoretical average residence time. This is a theoretical value in actual and the fluid particle some of the fluid particle may stay long, some of the fluid particle may be spending less time than this. But, if you take the average it will be coming closer to this is basically the ideal kind of value.

Then the residence time distribution of the fluid in a vessel is plotted as dimensionless time against dimensionless concentration. Now, the as we have already discussed, now the dimensionless time that is θ. So, that is indicated by θ, this θ is indication of the fractional residence that is and this is obtained by dividing any time by the theoretical average residence time. So, the time which you are representing on the x axis.

So, the time it will be divided by the you know theoretical average residence time. So, that way you get the you know x axis that is your you know dimensionless time, then you also have the dimensionless concentration on the y axis.

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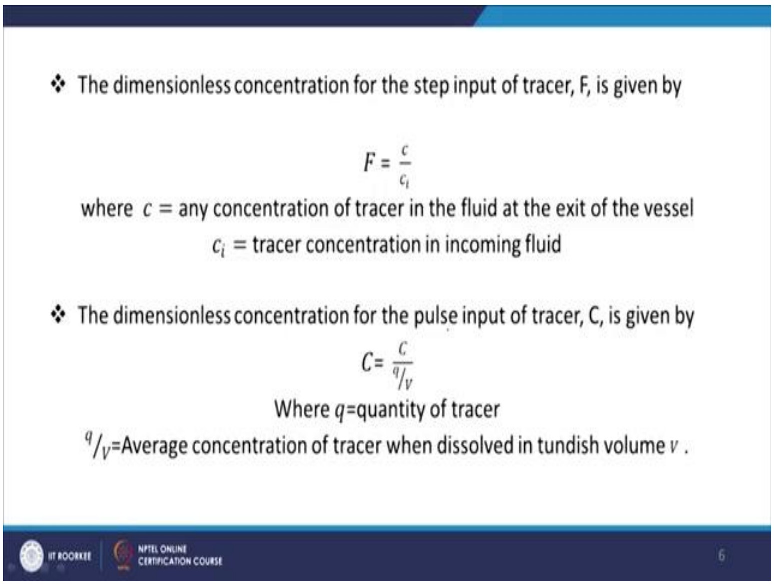

And on the y axis basically you get the concentration also by dividing with certain concentration. So, that way you get the dimensionless concentration. Now, the thing is that there are two types of input of this tracer inside the tundish. So, you know one is the step input and another is the pulse input.

So, in the step input what we do is we are constantly applying this tracer and it will be going into the tundish constantly; so, continuously. So, that is your step input and that is also known as the F curve the curve which you get.

So, the dimensionless concentration for the step input of tracer F; $F = \frac{c}{c_i}$. So, as you know that c will be the any concentration of tracer in the fluid at the exit of the vessel. So, that is your you know c, and then c_i with which you will be dividing that c it will be the tracer concentration in the upcoming incoming fluid.

So, the you are dividing that c which you are getting with the tracer concentration in the incoming fluid. So, that way you will get one you know dimensionless value of the concentration and that will be F you know in that case. So, that is your giving you the step input.

Then, if you go to the you know so, if you have try to understand we will see that how this F curve looks like; similarly, the when you go talk about the dimensionless concentration for the pulse input. So, pulse input means you are giving the tracer only for in a in a pulse manner. So, you are just giving some tracer some amount and then you are living.

So, this tracer which is going into very small amount, it will be going inside the tundish and then it will have its path inside the tundish. So, with the bulk flow of the steel or whatever you are allowing to flow inside the tundish. This tracer will move and then its concentration will be also monitored at the outlet. So, that is known as the pulse input of tracer.

So, pulse input of tracer in that case the dimensionless concentration which is on the ordinate you know that is y axis. So, that will be c and it will be by $\frac{c}{Q/V}$. So, what we do is in that whatever concentration you are getting it will be divided by Q/V. So, Q you have you know quantity of tracer which you have supplied and V is the volume. So, that is you know Q/V is the average concentration tracer when dissolved in tundish volume V.

So, that way you are trying to you know have a ratio of $\frac{c}{Q/V}$. So, that will give you the you know dimensionless concentration and dimensionless time as you see that will be same thing like time will be divided by the average theoretical mean residence time; so, that will be your you know x axis. So, that way you can have the you know the c curve.

So, in this case the curve is like inverted c type so this way; so, that will be as far it is known as a c, it is represented by a c and in this case it is going like this. So, normally we call it as a F curve or you know a step input or F the quantity which we try to see. So, if you try to see that how these curve looks like.

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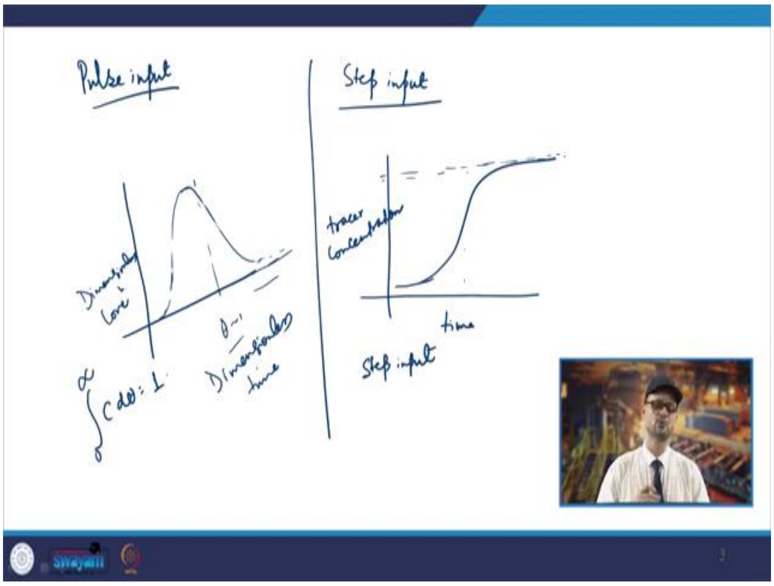

So, suppose if you are talking about the step input. So, you know in the case of step input what happens that you know you have you know initially you give the tracer and then that tracer will be continuously given.

So, at the outlet the tracer concentration will go on increasing. So, its value goes on increasing and you know and when you draw these you know curve for the step input. So, that comes like you have the value so, which will be increasing and then you will be going like this. So, this way you know when you do the you know step input.

So, in the case of step input you know so, this is your time and this is your tracer concentration. So, this concentrate tracer is basically continuously supplied and you know so, it is concentration will go on increasing at an at one point of time. It will approach you know so, it will be approaching you know unity you know at some time. So, you know you will have θ. So, this is if you take this is a dimensionless. So, it will be close to one or so.

So, if you go to more than you know twice the residence time, in that case critical residence time in that case it will be approaching one. So, basically its nothing, but you know many are there are many you know examples of such systems like if you talk about the flow of liquid steel in the tundish.

So, is in that case you can think of that case where the tundish has certain grade of steel and then you are having another steel which is coming from the different ladle. So, that will be coming and then it will be going through the inlet.

So, now that will be continuous. So, in that case, the next grade steel which is coming through the ladle and going into the tundish that is a tracer. So, this tracer initially if it goes inside its concentration at the outlet will be very small, but as the time progresses the new steel will be its concentration will go on increasing.

And after some time its concentration will be maximum as it will be coming through the outlet you know mostly it will be new grade tundish; I mean steel which will be coming through the tundish outlet. So, that is the example of the step input and normally when we do the grade transition analysis.

So, many a times you know we try to see that after how much time what fraction of the old grade and what fraction of new grade steel is coming out. So, these analysis can be done using these F curve. So, that is your you know step input.

Then we are talking about the you know c curve that is your pulse input. Now, in the case of pulse input what happens that you are just giving the pulse or certain input of the tracer. So, if you come to the you know pulse input. So, in the case of pulse input you are just giving some amount of tracer. So, you are giving for short pulse thats why it is tracer will be injected as a short pulse; so, that is why it is known as the pulse input.

Now, in this case what is happening is that you know the tracer will start appearing you know so, it will start appearing after some time and then it will reach to a maximum and then its concentration will go on decreasing. So, that will be you know that that will go.

So, this way you know what is seen is that it is it is normally seen that is sum over θ is somewhere close to one here, and then as you move ahead with time so, the concentration further goes on decreasing. So, the tracer concentration is seen to initially increase and then it will reach to a maximum and then further it will go on decreasing and then it will come asymptotically it will decrease to 0. So, you will have you know the you know dimensionless concentration on this side. So, you may have and this is dimensionless time.

So, your it will go 2 or 2.5 and in this case maybe 1 2 or so; so, it may be more than even 1 many a times. So, as you know that in this case this is how the curve looks like in this case. Now, what is happening in this case this is also known as the delta function.

So, the output concentration will be reaching to certain value and then it will be decreasing to you know to 0. So, that you know that 0 case will come when all the tracer has exited the tundish; so, that is the case of 0.

Now, if you plot on the dimensionless scale then in that case the area under this curve is always going to be unity. So, we normally represent as if you take the area under the curve. So, $\int_0^\infty c d\theta = 1$ so, that is how we try to show these you know pulse input cases. Now, this pulse input will be useful for those cases when we try to you know find out the different tundish you know regions like suppose you have you may have the tundish.

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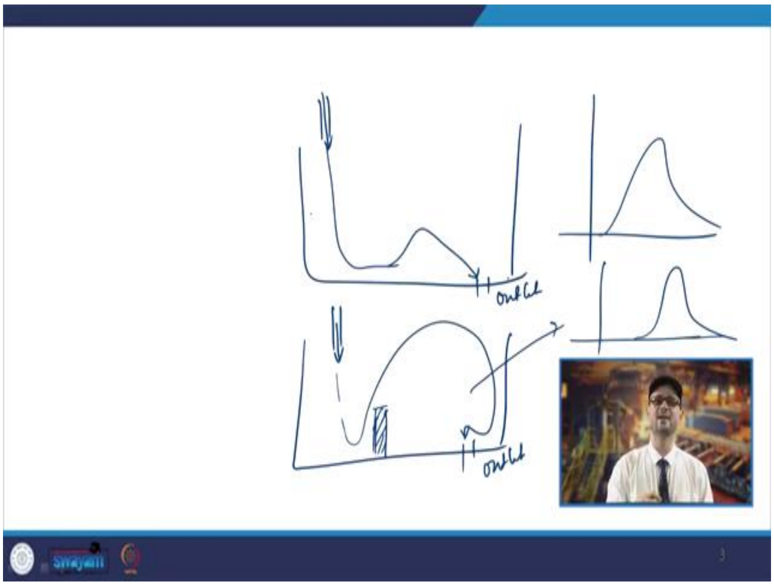

So, if suppose you have a tundish like this and in one case you have put in the tundish so, this is your inlet. So, this is from where the liquid steel is coming. Now, in this case and this is your outlet so, suppose this is the outlet, now the thing is that when you are basically giving the pulse you know that is tracer from here.

So, in this case the it will come and then it may go like and it will come. So, maybe after the time of 30 second or 50 second or 40 second it has come out of this tundish outlet. So, you will have you will have some it will go like this.

Now, what is happen what happens that in some case you can have some kind of dam here. So, then liquid metal will come and then it will go here and then it will come after and then remove. So, in that case it may lead to the change. So, the tracer may appear late and it may go and then it may come like this. So, the thing is that you know this wave the c curves will be changed.

So, now this is used you know now what we do in this case with the help of c curve, we also know that you know the fluid particle is coming in how much time when the concentration has there is no concentration coming out. And based on that basically we also we will you know study that we try to have the characterization of the you know space inside the tundish. We divide them into like maybe like different tundish volumes like dead regions or mixed regions or plug regions or plug flow or mixed flow or you know dead region.

So, the thing is that it will all depend upon how, so, this will be found out using these you know pulsed input. So, if something has gone depending upon the flow pattern inside the tundish, how that is going to flow and when its you know concentration at the outlet can be monitored properly. So, that can be understood with the help of these c curves. So, this is basically these are the you know uses of the F and the c curve which is used for the flow characterization in the tundish.

So, in the coming my lectures, we will be talking about you know how to represent these different kind of regions inside the tundish, what are the different types of flows which normally take place you know without interacting or how well it mixes inside and all that. So, that we will be able to you know study in our coming lectures.

Thank you very much.