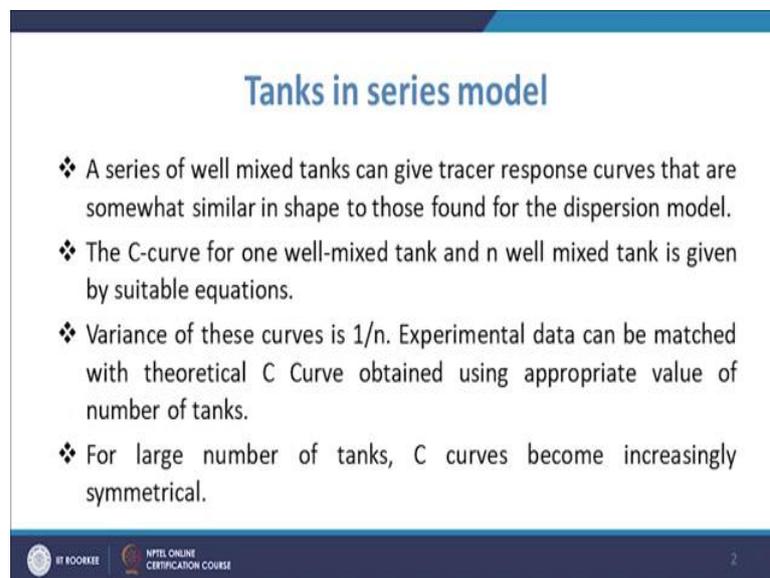


Modeling of Tundish Steelmaking Process in Continuous Casting
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Lecture – 15
Plug, Mixed and Dead Regions in Tundish

Welcome to the lecture on Plug, Mixed and Dead Regions in Tundish. So, we talked about the tank in series model. So, tank in series model.

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Tanks in series model

- ❖ A series of well mixed tanks can give tracer response curves that are somewhat similar in shape to those found for the dispersion model.
- ❖ The C-curve for one well-mixed tank and n well mixed tank is given by suitable equations.
- ❖ Variance of these curves is $1/n$. Experimental data can be matched with theoretical C Curve obtained using appropriate value of number of tanks.
- ❖ For large number of tanks, C curves become increasingly symmetrical.

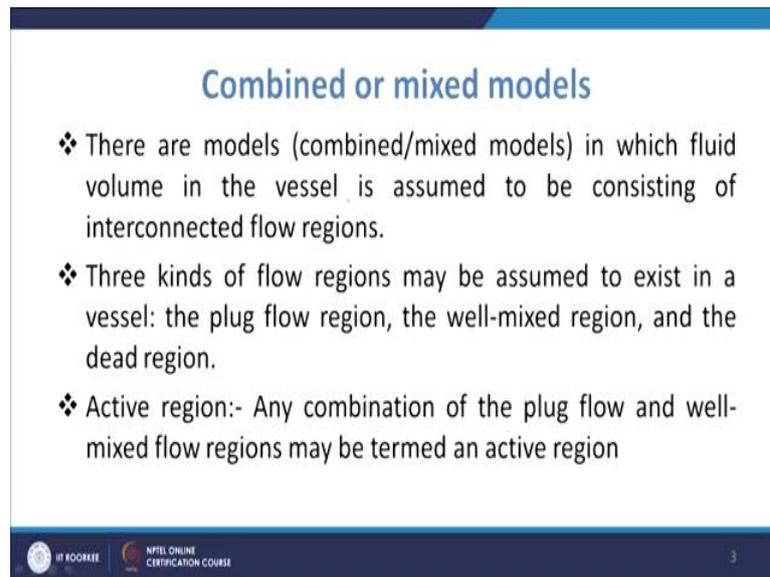
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And apart from that we also have, so in that tank in series model we have seen in the last class that it is for the case that the series of well-mixed tanks will be giving the response curves, and it will be similar to the dispersion model. Then you will have the C-curve well-mixed you know for the well-mixed tank. And you know variance of the curve is taken as $1/n$.

So, it is what similar to somewhat in the for the dispersion models. And when you take the large number of tanks, then in that case the C-curve become increasingly symmetrical, so that is what you have seen for the tank in series model.

Now, apart from that you have the you know combined or mixed models also. So, in that case, what you see what you do is that you are getting basically the different zones in the Tundish.

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Combined or mixed models

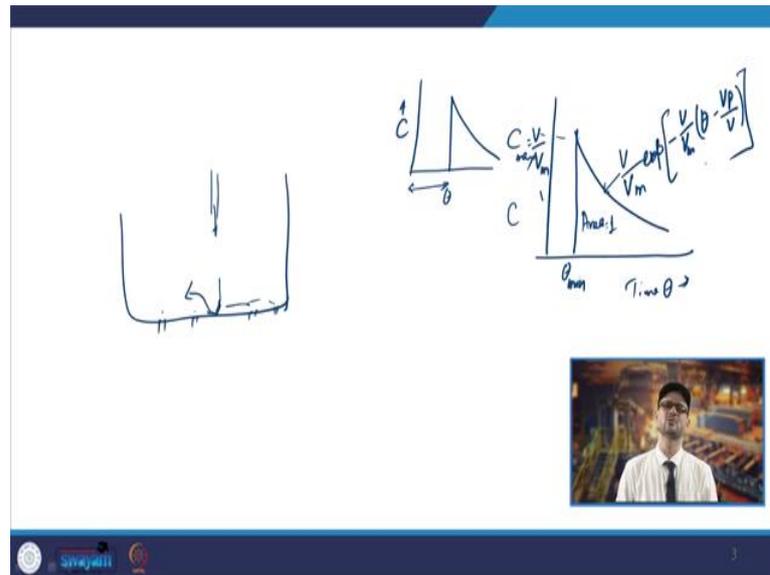
- ❖ There are models (combined/mixed models) in which fluid volume in the vessel is assumed to be consisting of interconnected flow regions.
- ❖ Three kinds of flow regions may be assumed to exist in a vessel: the plug flow region, the well-mixed region, and the dead region.
- ❖ Active region:- Any combination of the plug flow and well-mixed flow regions may be termed an active region

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So, there are models that is combined or mixed models in which the fluid volume in the vessel is assumed to be consisting of interconnected flow regions, so that will be you know in that case you are thinking that this at a tank which is in interconnected in series, but in this case what we see that you will have the interconnected flow regions in the vessel. So, you know mostly it was it has been seen that you will have a three kind of flow regions which will be present inside the vessel one is the plug flow region, region, another is well-mixed region and third is the dead region.

So, plug flow region and the well-mixed region, they are known as the active region also and if you talk about the other region that will be dead region, which is not active in one sense. So, you know what happens that plug flow you can we can have the idea about these plug flow.

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So, what happens that when you have the if you have the concentration here and this is your θ . So, this is concentration and this is θ . So, what happens that if there is no mixing taking place up to certain time of dispersal taking place, and then after that the mixing has become you know effective.

So, in that case you know if you if your mixer starts from here. So, in that case this region is the is the representative of the plug region, so and then this becomes the mixed region that is well-mixed region. So, as you see that here there is a it is a straight jump you know and then it is coming here. So, it becomes like a well-mixed zone and this becomes the plug zone. So, plug zone is there, and then you have the well-mixed zone, then also you have the definition about the even the dead zone. So, the plug zone and the well-mixed zone they are normally known as the active you know zones.

So, what happens that if you if you draw you know the C-curve for the combined model where you have we have the combined zones which are available. So, what happens you have here from here it will go like that. So, this is the maximum concentration that is C_{max} . So, this is what you are getting you know that is C_{max} . and the C_{max} is the inverse of the mix you know a volume component. So, that is normally we will be $\frac{V}{V_m}$. And this amount this will be basically indicative of the plug zone. So, this is known as the θ_{min} , θ_{min} ; this is the time at which there is a first appearance of the tracer is seems.

So, what happens that when you have you know a Tundish, and suppose you have a different outlets on both the sides, and this is your inlet suppose. So, inlet after coming here it will, will go like this. So, it will come here, and then it will come here. So, it similarly, it will go here first and then it will go here. So, it will be going first to these two on these two sides on these two outlets, and then later on it will be going on these two outlets. So, you know the appearance of tracer suppose for this outlet may be after only 5 seconds, whereas the appearance of this tracer at this outlet will be maybe 25 seconds, so that 5 second and 25 second will talk about you know the plug zones or so.

So when more appropriately you can say that when you have only one outlet then in that case you can say that when it is first appearing at the Tundish outlet, so that way you will have this is as the θ_{min} that is the time at which it is first appearing and you know as we know that the integral of the $Cd\theta$ will be normally 1. So, your area becomes you know one here in this case. So, and this is time θ and this is your C . So, C_{max} is $\frac{v}{V_m}$.

And what you see is that this line can be having we will be having that expression. So, this will be having a can be represented by this function that $\frac{v}{V_m} \exp[-\frac{v}{V_m}(\theta - \frac{v_p}{v})]$, so that way this is how this you know this you know graph can be represented. Now, coming to the these two regions basically you can define them as the two reasons like you have the active region as well as the dead region.

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Active Region

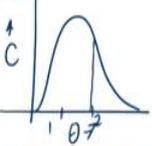
Plug region (plug flow) + well mixed flow regions } Active region

Dead Region:

- Completely stagnant region
- fluid particle stays for more than twice the theoretical mean residence time.

mean of C curve upto cut off point of $\theta = 2 \tau_c$

$\bar{\theta}_c = \frac{\text{measured } \tau_c}{t}$




So, you know the once you talk about the active regions. So, active region will be the region which will be represented by the plug region as well as the well-mixed region. So, combination of plug region, so plug flow that is you know or plug flow you can write plug the flow where is taking place plus you have well-mixed flow regions. So, this gives rise to the active region.

Now, active region is basically that region where fluid particle you know is going and through that region it is passing. And if there is any region where the fluid particle is not going, or if it is going and it is getting you know its appearance from there is at a very late time, so in that case those regions are said to be you know the dead region.

So, as we see that you will have this plug region and you will have the well-mixed flow region and the plug flow zone that will be related to the time at which the tracer of first appears. So, and then you will have the peak that will be inverse of that you know well-mixed volume. So, that way you will have the representation of these two plug flow as well as the well-mixed flow.

If you come to the dead region, so apart from these two regions, you will have the dead regions. So, if you take the tundish volume, so if you say plug volume and if you have the well-mixed volume, so the difference of the whole tundish volume, and if you take the subtract these summation of the plug and mix, so that will give you the dead region. So, the in the dead region means that the metal I mean it is not participative that region is not participative. So, you will have, you may have two types of dead regions. Now, there may be region which is a completely stagnant. So, you may have the completely stagnant region. So, you know fluid will you know will be moving very slowly, and the fluid remains in that vessel in that vessel for a very much longer time.

So, what happens that you will have to have one you know criteria that what should be the time if the liquid is stays if the particle stays for more than that time, then it may be called as the dead region. So, normally some of the authors have taken 2 times the theoretical mean residence time, some of them may you may take even on the 3 times the mean residence time.

So, accordingly you measure the you know the dead volume, and you classify the dead results based on you know that volume component when where the time is spent by the

fluid particle is more than suppose say 2 times the theoretical mean residence time. So, that way we compute these dead regions.

So, you can have also in the definition like when the fluid particle is stays for more than twice the theoretical mean residence time, so they accordingly you can have the definition of these you know dead region. So, if you look at a typical C-curve, so suppose you have you have such kind of the you know C-curve, so this is C and this is your θ . So, suppose this is your this becomes the so θ is here suppose 1 and this is your 2. So, the liquid particle which is staying more than this two times, so this region can be said to be the dead region.

So, and you will have, so you will have active region as well as dead region. So, this region becomes the active region, whereas this region will be as soon as the dead region. So, if you have suppose if you see that your, if you are taking the two times the value as the one after which you are categorizing as the dead region.

So, suppose the mean of the C-curve up to cutoff point of theta equal to 2 be θ_c . So, suppose it is you know θ_c , in that case theta c will be, so this will be measured t_c , so that is what you have a $\frac{\text{measured } \bar{t}_c}{\bar{t}}$. So, that way you measure this θ_c . So, θ_c will be $\frac{\bar{t}_c}{\bar{t}}$.

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$$\theta_c = \frac{\bar{t}_c}{\bar{t}} = \frac{V_a/Q_a}{V/Q} = \frac{V_a}{V} \cdot \frac{Q}{Q_a}$$

$$\frac{V_a}{V} = \frac{Q_a}{Q} \cdot \bar{\theta}_c$$

Dead volume fraction:

$$\frac{V_a}{V} = 1 - \frac{Q_a}{Q} \bar{\theta}_c$$

$\frac{Q_a}{Q} \rightarrow$ represents area under C-curve from $\theta = 0$ to $\theta = 2$

So, if you take the θ_c it will be $\frac{\bar{t}_c}{\bar{t}}$..., so it will be you know V_a you know V_a/Q_a , and this that will be divided by V/Q . So, that is a is for the active region, and Q is the flow rate.

So, you will have the active volume and this is the Q for the you know flow rate. So, accordingly you will have, so it will be having $V_a Q / Q_a V$.

So, V_a/V can be you know $(Q_a/Q) * \bar{\theta}_c$. So, you can have the calculation of the dead volume. So, dead volume will be nothing but the 1 minus the active volume component that is V_a/V . So, if you have the to find the dead volume fraction, so dead volume fraction will be you know V_d/V , and V_d/V will be $1 - (V_a/V)$. So, it will be $1 - (Q_a/Q)\bar{\theta}_c$. So, that way you will have you can calculate the fraction of the dead volume in if you have the RTD curves you know with you.

Now this Q_a/Q term this will be you know the this will be representing, so it represents area under C-curve from θ equal to 0 to θ equal to 2 that is you have taken as the active region. So, that will be from θ equal to 0 to θ equal to 2. So, you know if you have, so after that region will be you know the dead region. So, for them you know, if your dead region is completely stagnant, so because there may be dead region where the fluid is not at all flowing, so that will be completely stagnant, then your volume is basically effectively the volume is you know reduced.

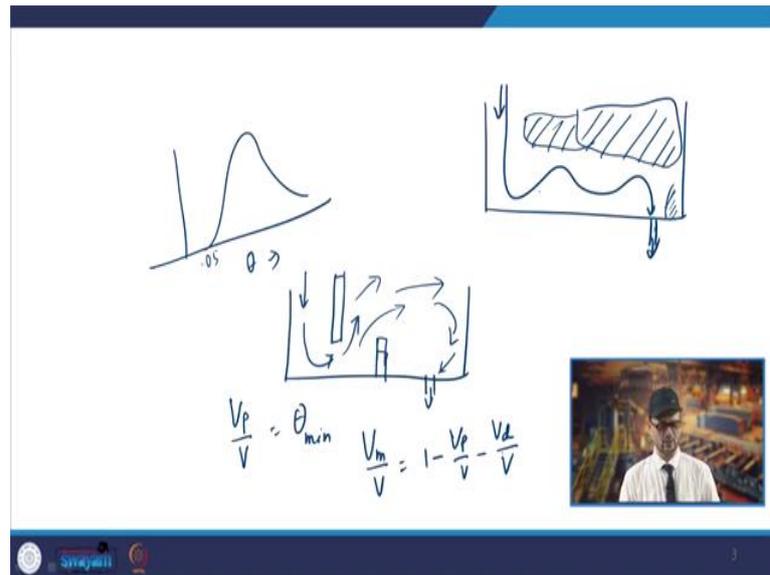
So, you will have the effectively the volume will be reduced to V_a only effective vessel volume will be only V_a . So, that V_d part is completely unutilized. So, if you have suppose a tundish and your this region is completely you know this is here which is completely stagnant, in that case effectively you have only this is the, so this is only the you know V_a , so, that is another you know aspect of the dead region. So, that tells that, so that is why we try to have the minimization in the dead regions in the tundish so, because that will be a loss to the productivity of the tundish.

So, dead volume fraction with you know if you talk about the for the tundish, so the dead volume fraction you can also have you know you can, so Q_a/Q if you look at, so in that case Q_a/Q will be normally equal to unity, so that can be V_d/V will be $1 - \bar{\theta}_c$. So, in the case of stagnant system, you will have $1 - \bar{\theta}_c$, so that way you will have the calculation of the V_d/V in such cases.

So, you can have you know the different kind of you know tundish furnitures. So, you can have there may be use of flow modifiers to alter the flow behavior in the tundish, so that you can decrease the dead region, so that is what the aim is in the tundish that you should

have the minimum of the you know dead region inside the tundish. So, one is, so that can be if you look at the C-curve you will have a long tail that is going on. So, that also is a one of the representative of the dead zone, whereas you know so some of the zones where it does not go even and that is completely stagnant. So, that is also, but, so the anyway that volume itself is not being utilized.

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So, for that what we what is being done is normally you have if you look at the situations like, if suppose you have an inlet from here and you have outlet from here. So, what is done if, so in normal case when in normal case when the flow will come, so it may go like and it will be coming like this. So, basically all these zones they all these all zones become sort of you know dead zone. So, either they do not take part or if they it goes it comes very slowly. So, once it will go this will have very small velocity. So, slowly it will come, and it will have a very long residence time inside the tundish, and then it will be coming out.

So, what we do normally that we use these tundish furnitures. So, many a times what we do you have inlet from here. So, we use the different tundish furnitures like here then you may use the dam here. So, what happens that the metal which goes so it will be coming up and then it will be moving in this direction.

Now, from here it will move like this and if suppose it is of this, so from here it will go to in into even this direction, and then from here it will come out and you have outlet here.

So, if you what you see you have in this case you have many zones all these zones which are like a dead zone. And when this zone comes like a dead zone, now you can see the by that by the use of these tundish furnitures like dams or weirs which we use you are effectively utilizing all these places.

Now, what may happen because of the these dead regions? So, in those cases if it is not the fresh steel is not going that may give rise to the decrease of temperature, and many a times become stagnant and then there may be the solidification also taking place in those regions, so that may be harmful you know in such cases. And if you look at these two situations, what you see that the whole of the volume of the tundish is being utilized for the metal to flow.

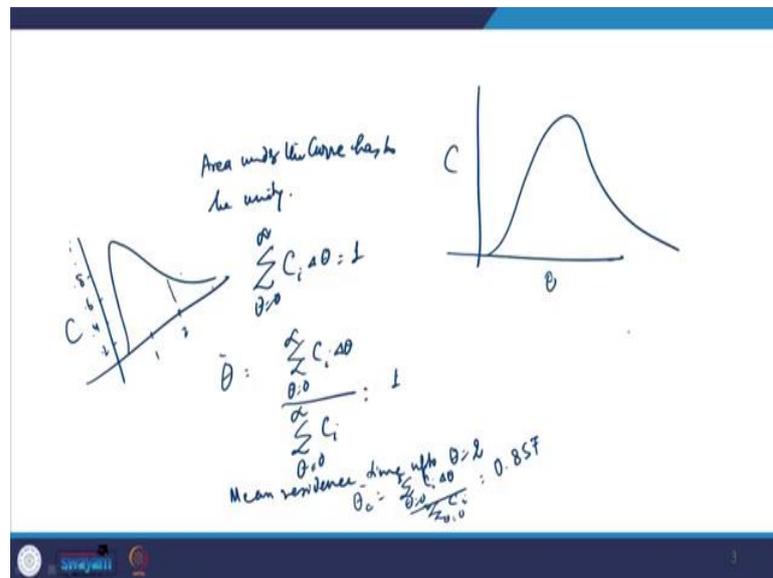
Now, in this case also your θ_{min} , so in this case it is, so the theta min that is appearing, so that also is you know being you know increased, so your plug volume also is basically increasing that way. So, you can have you know some equations you can use for the calculation of these volumes like you have the plug volume, so V_p/V that will be θ_{min} . So, what you do is normally when you get the time and concentration values.

So, you will draw the time concentration plot, you will be getting the theoretical mean residence time that will be volume by volumetric flow rate, so that will be used for finding the dimensionless time. So, the all the time will be divided by that dimensionless time. So, you will have that in mean residence time. So, you will have the dimensionless time theta on the x-axis; and on the y-axis as you see you will have the Q/V , so that way you are dividing and then you are getting the concentration dimensionless concentration value on the y-axis.

So, the V_p/V will be theta min. So, wherever you are getting the θ_{min} value wherever the so suppose here it is coming, and if suppose θ is this is θ and this value is point zero or suppose say 5, so it may come like that. So, it means 5 percent we call it as the plug volume. Then you will have the calculation of the dead volume. So, dead volume as you see that you calculate by seeing that which of the how many where the theta is more than 2, so that you will have the calculation of the dead volume. And once you have the calculation of the dead volume, then you have the well-mixed volume and that will be $1 - V_p/V - V_d/V$.

So, that way you know you calculate. So, you will have the you know mean residence time coming in actual, and based on that basically so for the 2θ values you can calculate the residence time and then you can have the fraction of the dead volume. So, that will be dead region and you know the plug region, so accordingly you can have the calculation of the well-mixed zone in that case. So, that way you are a different you know different component of the you know plug the region, then mixed well mix region as well as the dead region is being found out.

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So, you can we can understand you know like if suppose you if you try to have the solution of certain problem. So, what you do is you have a typical you know you may have typical residence time so and then you know one is that you have the area under the this curve is has to be unity. So, your area under the curve has to be unity. So, what happens that, so you have $\sum_{\theta=0}^{\infty} C_i \Delta\theta = 1$.

So, you will be calculating the mean residence time of the whole you know curve. So, mean residence time for the whole curve that has to be you know, so theta bar, so that you will we will have theta equal $\frac{\sum_{\theta=0}^{\infty} C_i \Delta\theta}{\sum_{\theta=0}^{\infty} C_i} = 1$ so that has to be basically 1.

So, we are calculating the mean residence time up to $\theta = 2$, so for that you will have the θ_c . So, suppose you are taking the mean residence time up to theta equal to 2, so you will have θ_c , so that will be a computed and that will be $\frac{\sum_{\theta=0}^2 C_i \Delta\theta}{\sum_{\theta=0}^2 C_i}$. Now, the thing is that if you,

so that is done for the curve which we had earlier seen where you had the data that was there where we have suppose you get the curve like this. So, you will have the C values and then you will have like 0.2, 0.4 you know 0.6, 0.8 and so, and then on this side you will have you know 1, 2, 1, 2, 3, so this will be. So, at this it will be that is taken for calculating the actually the dead volume calculation.

So, if you know if it is, so for this problem when you computed this $\sum C_i \Delta \theta$ upon $\sum C_i$, So, it came as 0.857. So, 0.857 is coming as the θ_c prime and that is why your you know if you neglect this Q/Q term in that case the dead volume will be $1 - 0.857$. Suppose for this problem it is coming as, so that can be computed when you have the C and θ value. So, suppose it is coming at 0.857, so in that case it will be coming as about 14.3 percent as the dead volume.

And if suppose you are having the area of the curve, so if you take that curve and if you take the area of the curve up to θ equal to 2, so you will have the based on that also you can calculate these $\frac{Q_a}{Q}$ values and that may have some different value. So, and then you can also calculate the dead region maybe $\frac{V_d}{V}$, so that will be again $1 - \theta_c$. So, if you take $\frac{Q_a}{Q}$ into account, so in that case that may be even later, so that can be understood when we solve the problems when we take one example.

So, suppose you do the experiment and you have these data, so based on that you can calculate you know these different volume values of the suppose say plug volume mixed volume as well as the dead volume of the tundish. So, this is about you know the you know calculation, and we can we can further discuss in our when we will talk about you know the analysis of the cases in that case we will be seeing that how the different kind of curves are generated, and how these curves are different when we use the flow modifiers and how we calculate these different tundish volumes.

Thank you very much.