# Modeling of Tundish Steelmaking Process in Continuous Casting

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## Lecture - 37
## Modeling Considerations for Inclusion Removal in Tundish

Welcome to the lecture on Modeling Considerations for Inclusion Removal in Tundish. So, we discussed about the various aspects, the way Tundish performs. And one of the important you know work that is desired from Tundish is the inclusion removal. As we know that in the continuous casting process the ladle will be delivering the steel to Tundish and then from Tundish, it will go to the mold.

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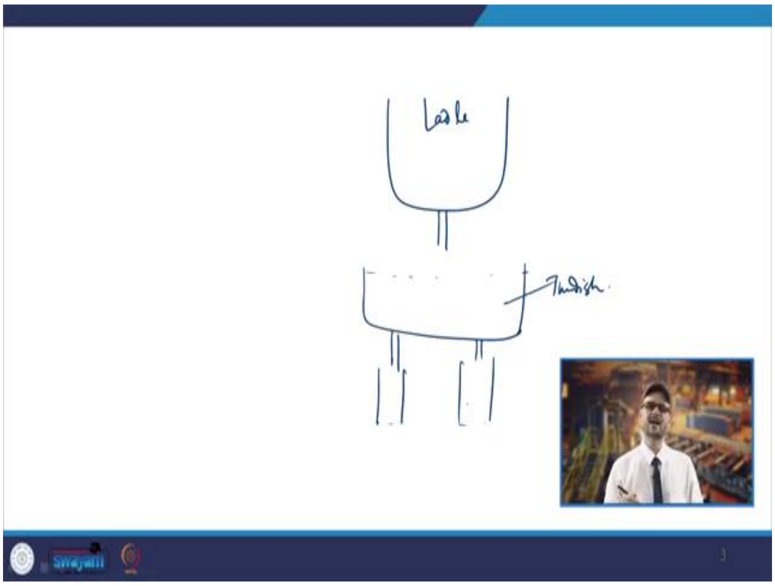


So, basically when you have, you know if this is the ladle and then as it from here it will be going to the Tundish. So, you know this is your Tundish and then from here it will be going to different molds.

So, basically you know the inclusions may be there in the Tundish that may come from the ladle that may be formed also, because of the reaction products that may be formed, because of the erosion from the you know Tundish lining. So, there may be you know different regions you know, because of which there may will be inclusions that will be there in the Tundish.

The thing is that Tundish needs to be taken care of I mean Tundish needs to take care of the inclusion in the way that if this is the last reservoir after that if the Tundish you know, if that inclusions in the Tundish goes through this outlet and in the mold then it is likely that it will go into the cast product and that will be you know permanent damage basically that will be basically leading to the rejection of the product. So, this is the last reservoir and that is why its function becomes very important that it should remove the inclusions from here.

Now, as we know that the inclusions you know will be of normally, they will be of lighter density then the, you know then the steel and they will have very fine sizes. So, in the micrometer ranges, you know their sizes will be varying. So, they so, basically it is to be understood that what are those mechanisms, what are those theory which will govern the removal tendency of the inclusion or the flotation tendency of the inclusion, because this inclusions you know depending upon the flow configuration inside the Tundish, they will be it will be desirable that they float towards the top free surface and on the top free surface they are likely to be trapped, because you have a slag layer. So, that may trap these inclusions.

So, that is most likely else you know they may go and stick to the walls also depending upon you know conditions which is prevailing inside the Tundish. So, basically you know being lighter you know then the liquid which is there inside, it will be subjected to the buoyancy and that force will be acting on it.

So, they will have the tendency to float up that is what we discussed in our last class also that you know gravitational effect and the buoyancy effect will be very much applicable in these cases,.

Then you know, so, you will have basically the, the way on the inclusions one will be forced, because of the velocity of the existing liquid which is there in that it is there is you know these particles. So, because of that fluid velocity component of the fluid another will be, because of the rise velocity of the you know, this inclusion.

So, there are two components which will be responsible for you know it is you know; for the so, they will be interacting each other they will be interacting on the inclusion particle. And accordingly, you know in a resultant manner the inclusion will move inside the domain and then either they may go through the you know Tundish outlet or we will feel that we will it will be desirable that it goes towards the top free surface.

So, we will talk about it now why it is. So, that is way we need to also do the modeling of this we need to also develop the similarity criteria for that. We need to know the you know the you know parameters which are of significance. How we should take the you know density or you know how they, depending upon the scale factors how you know these inclusions removal tendency can be predicted or can be modeled using water modeling or even mathematical modeling.

So, that needs to be you know studied and there needs to be, you know some concept on this topic. So, if you talk about you know the, studies of inclusions. So, what happens that you know inclusions you will have the normally the nonmetallic inclusions and they will be varying in sizes. And also that can be modeled by the water modeling technique also you know, we can do in our laboratories where we make the Perspex, you know Tundish; Tundish from Perspex seats.

And they are also we can think of having these inclusion particles, as you know either these polyethylene particles or so, or maybe when isoline or so, that has been reported by the researchers that these particles are used. And they have also size ranges so that can be used for the study and people can you know inject it in the form of.

So, the simulation of the removal of inclusions in water model has been carried out with different particles in the size range of 20 to 150 microns. So, that is reported in the book written by Sahai and Emi.

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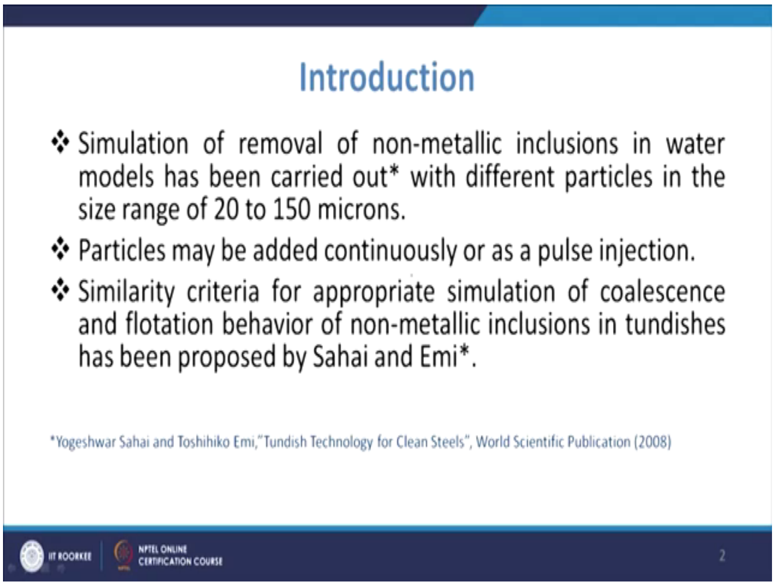


And they have reported that they have you know done also they have they have also done these simulations. And there they have you know varies those size ranges from 20 to 150 microns.

Now, in that they have either given the continuous injection of these particles or maybe the pulse injection. The purpose is that when they go inside you know their path will be tracked normally. We also make it all different color so, that you can visualize the movement of these inclusions and you know either there may be a pulse injection or the continuous type of injection of these you know particles.

Then we need to know that what will be the; you know similarity criteria for these appropriate simulation of the collisions and flotation behavior of non metallic inclusions in tundishes.

So, that has been proposed by even Sahai and Emi and basically what happens that there is the coalescence of the inclusion particles is also important, because they coalesce they become bigger and then they float so, because the that tendency also depends upon the size of the inclusion.

So, you know so, so for that you have the different criteria that needs to be you know understood and especially as we discussed that we need to start from that velocity of fluid for the model for the prototype similarly velocity of the rise, you know that is terminal rise velocity which it which it is assumed to you know go up all these inclusions inside the domain so, that rise velocity. So, if you are doing for you know the water modeling so, you have the fluid as water, if you do for the steel you will have the fluid is steel. So, you have inclusions maybe for the prototype and for even for the model.

So, then that intensity difference what should be those density differences, what should be the size differences, all these things. And what is its bearing on the you know inclusion you know flotation behavior or inclusion of removal mechanism that we will try to understand.

So, the normally these nonmetallic inclusions which we take you know they are lighter than the molten steel which is found in the steel. And they will be once they go inside then you know, you will they are and also they have the varying sizes. So,, and also they will be rising with the stokes velocity.

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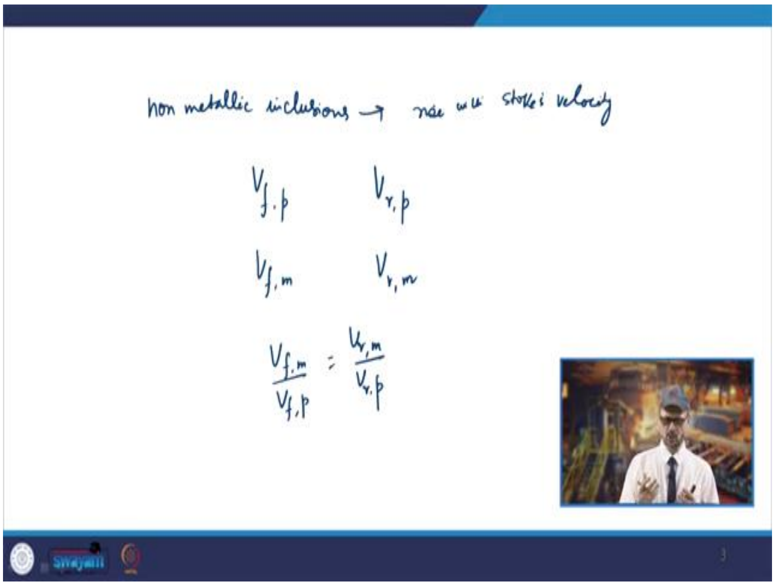


So, these nonmetallic inclusions, so, they rise with stokes velocity. It is just assumed that they rise with this absolute velocity. So, you have the velocity of the fluid also and then you have the rise velocity. So, if you talk about the velocity of the fluid and in the prototype, so, we call it as velocity of fluid in the prototype that is and in the prototype tundish. Similarly, you will have the velocity of the rise in the prototype tundish.

Similarly, velocity of fluid in the model and you will have a velocity of rise in the model. So, you know so, this you will have the similarity of particle trajectories that is what you would like to you know get. So, you would like to have this simulation in such a way that the similarity of trajectories is also found and for that a condition needs to be satisfied and that is that we you know $\frac{V_{f,m}}{V_{f,p}}$. So, that should be same as $\frac{V_{r,m}}{V_{r,p}}$.

So, basically velocity of the fluid you know and that is you know that and, and that that is within the fluid. So, that and so, inclusion will be carried with this fluid velocity so, that is $V_{f\,m}$. And then you know $V_{f\,p}$'s that is for the prototype. So, this ratio should be same as for the rise velocity for model as well as the prototype.

So, you know you will have furthermore certain assumptions and you will be assuming that there will be Reynolds' as well as the Froude similarity criteria being satisfied. And you will be going for reduced scale you know model. And then what you see that you will try to you have to go for the appropriate material of the inclusion which should be taken as the inclusion material for the model, because for the prototype you know and you also know the liquid that is steel. So, from there you know the changes in the density of the inclusion as well as of the medium.

Similarly, when you know the density of the, you know working fluid in water modeling that is water. Then accordingly, you can have you know you can have a thinking of over what should be the, you know particle we should be taken for the water modeling studies. Similar will be the size considerations. So, what should be the, the size of those particles that should be you know maintained and so, that these you know criterions are satisfied. So, if you take you know a reduce scale you know experiment so for a reduced scale experiment.

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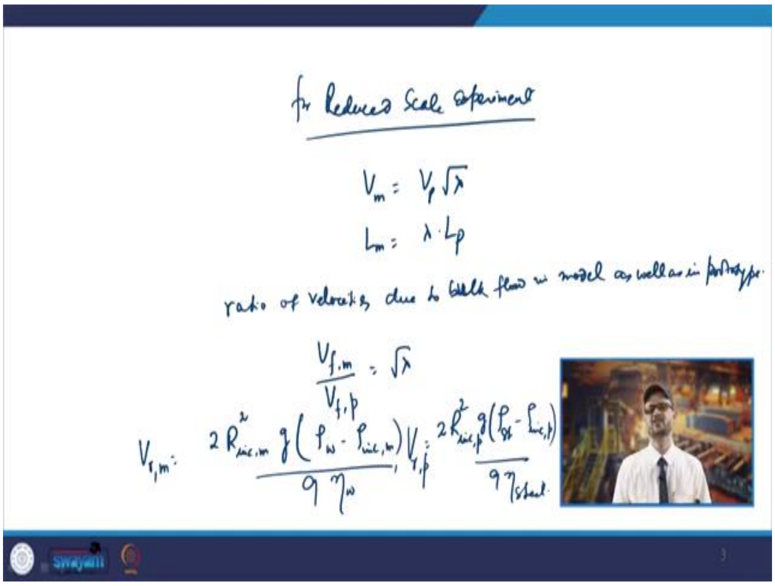


So, you know so, you based on these fraud similarity assumption. So, what you see in these cases you get $V_m = V_p\sqrt{\lambda}$. So, that is what we have earlier seen that when you maintain this Froude similarity, you will have the velocity in the model that will be under root lambda times. So, that will be the $V_p$

Similarly, your if you take the length you know. So, $L_m = L_p\lambda$.. So, that is what you see when you go for the Froude similarity, you know in those cases. Now what we do initially we in this study they have it has been reported that the density you know the density ratio that is for the inclusion which is taken for the water modeling. So, density ratio between that inclusion to the water. So, it was you know, taken. So, it should have the same density ratio and also about the size. So, you know size also appropriately if you talk about the idealized, you know condition size should be as per you know the geometric similarity.

So, it should be reduced by a factor of $\lambda$, but then you, you have to have the analysis for that. So, if you try to have you know same rate of flotation or removal of the inclusions. In that case, your ratio of velocities that that needs to be the same so, you need to have that ratio of velocities due to bulk flow in model as well as in prototype.

So, that basically you know that needs to be maintained. So, for that what we do is if you talk about the bulk flow liquid bulk flow. So, you will have $\frac{V_{f,m}}{V_{f,p}}$.. So, that will be as we know that the velocity will be basically having the ratio $\sqrt{\lambda}$.

So, you if you talk about the you know, Stoke's rise velocity for the inclusions. So, for the water and for the; you know for the prototype, it is said to be. So, for the for the water that is in the model tundish, you will have $\frac{2R^2_{inclusion,m}\, g(\rho_w - \rho_{inclusion})}{9\eta_w}$. So, that is your, you know $V_{f,m}$ that is stokes rise velocity and that is for the model.

And similarly, the, the, V for the prototype for that rise velocity. So, that will be can be taken as equal to $\frac{2R^2_{inclusion,m}\, g(\rho_{steel} - \rho_{inclusion})}{9\eta_{steel}}$.

So, you know for the similarity and, and, for the same trajectory you know these ratios what we obtain you know that should be same.

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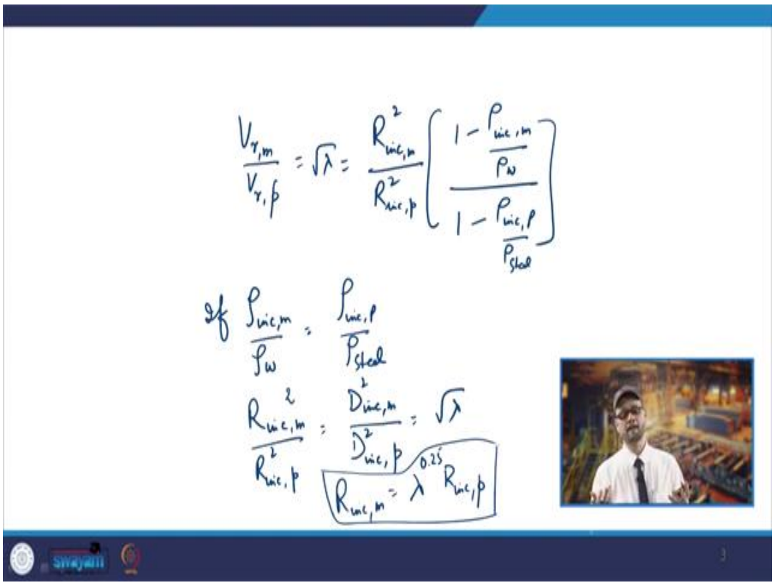

And if you try to do that so, what we get so, you will have the $\frac{V_{r,m}}{V_{r,p}}$ it should be same as the $\frac{V_{f,m}}{V_{f,p}}$ that is $\sqrt{\lambda}$. So, it should be $\sqrt{\lambda}$ and it should be it will be same as. So, once you, you know take the expression of from that earlier you know expression.

So, if you take the ratio so, it will be $\frac{R^2_{inclusion,m}}{R^2_{inclusion,p}}\left[\frac{1-\frac{\rho_{inclusion,m}}{\rho_w}}{1-\frac{\rho_{inclusion,p}}{\rho_{steel}}}\right]$. So, that is what this ratio is coming.

Now,, if we take this $\frac{\rho_{inclusion,m}}{\rho_w}$, so, if these ratios are taken same in that case they will be same. So, you will have 1 by 1. So, you will have you know this radius can be expressed as in the form of the scale factor.

So, basically it will be $\lambda^{1/4}$. So, that $R^2_{inclusion,m} = \lambda^{1/4} R^2_{inclusion,p}$ . So, then you can have the selection of the inclusion sizes you know accordingly.

So, so, that is what it, came. So, if you are considering you know $\frac{\rho_{inclusion,m}}{\rho_w} = \frac{\rho_{inclusion,p}}{\rho_{steel}}$. In that case your thing becomes like $\frac{R^2_{inclusion,m}}{R^2_{inclusion,p}} = \frac{D^2_{inclusion,m}}{D^2_{inclusion,p}} = \sqrt{\lambda}$.

So, you can write also, if you take this again square root on both the sides, you can say that $R^2_{inclusion,m} = \lambda^{1/4} R^2_{inclusion,p}$ . So, this you know relationship indicates that if you do the water modeling in those cases or even the modeling using the you know mathematical formulation.

So, basically for maintaining that you know, similarity if you use those if you are trying towards the similarity you know establishment. So, in that case if the you know if that density ratio is same in that case the you know ratio this radius of the inclusion will be lambda to the power 0.25 times. So, $R^2_{inclusion,p}$ .

So, suppose you are going to have the modeling for the inclusion using the water modeling and your inclusion is and you are having a one third scale of the you know water model. In that case lambda will be $(1/3)^{1/4}$.

So, if you take once it's square it will be close to 0.55 and another time it will take. So, something close to 0.76 so, for a one third scale model the inclusion of the model, it is size should be about 0.76 times the diameter of the you know inclusion in the steels, that tells you the relationship between the steel inclusion and the inclusion, particle which you are, I to have this simulation using the or the modeling using the water modeling approach.

Now, it may be so, that sometimes this rho inclusion, so, these there density ratios may not be the same. So, that may be different. So, if you know.

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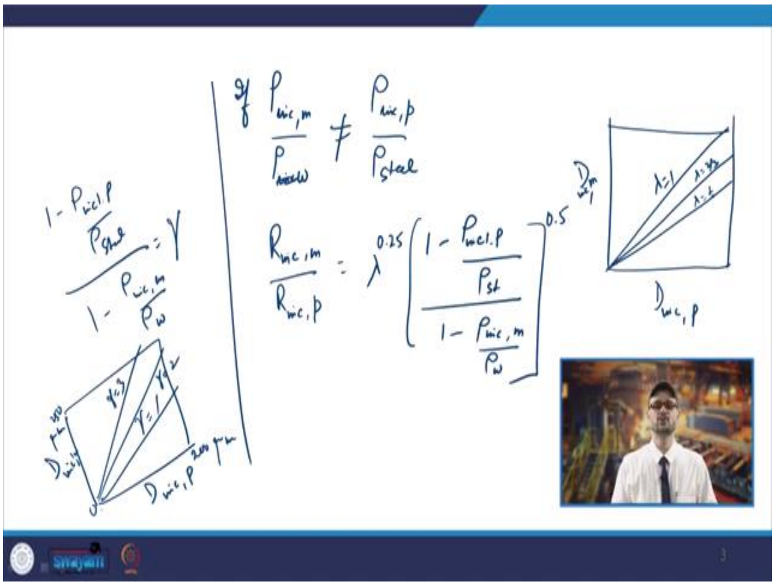

So, if you are you know $\frac{\rho_{inclusion,m}}{\rho_w} \neq \frac{\rho_{inclusion,p}}{\rho_{steel}}$.

Now, in that case if you look to you know this equation if this is not the same. So, what you will get, you will get $\frac{R^2_{inclusion,m}}{R^2_{inclusion,p}} = \frac{D^2_{inclusion,m}}{D^2_{inclusion,p}} = \sqrt{\lambda}[\frac{1-\frac{\rho_{inclusion,m}}{\rho_w}}{1-\frac{\rho_{inclusion,p}}{\rho_{steel}}}].^{0.5}$, because it will be getting the you know square root on both the sides. And you will have you know 5 that is what you know you can have this one. So, this will go to that side so, that will be reversed. So, that will come down for the model and you know for the model it will be down and for the prototype it will be up.

So, that way you can have this expression that is ρ. So, then you can have the this ρ radius of the inclusion for the model and, for the prototype that will be the kind of the co-relationship. So, you can have even you know the graph also being plotted. And that graph will tell the, you know relationship between the inclusion in the water model and in the steel. So, that can be you know obtained and, that has also been obtained by Sahai and Emi. And it was seen that you know if you look at the if your, this is your model inclusion size. So, that is your $D_{inclusion,m}$ and this will be $D_{inclusion,p}$ . So, that is for the prototype.

So, in that case if you are you know lambda is becoming you know if you have the different $\lambda$ and you will have. So, if you take the $\lambda$ as the 1. So, you can have you know from the earlier expression which we got here. So, these, depending upon the different value of the scale factor you can have the relationship between the diameter of the inclusion which is used in the water model and in the prototype tundish that is in the steel you know tundish.

So, for lambda equal to 1 as you see it will be the slope of 1. So, it is basically it will be the same graph. And I mean this is this line and you may have the different you know values like if you go for the other values. So, suppose maybe for $\lambda$ is $2/3$, here then you will have $\lambda$ is $1/2$ or so.

So, this way your this relationship can be removed can be presented. Similarly, it has also been you know shown that if you take this ratio as a parameter. So, if you take the ratio you know like, if you take $\frac{1-\frac{\rho_{inclusion,m}}{\rho_w}}{1-\frac{\rho_{inclusion,p}}{\rho_{steel}}}$.

So, if you take this as one parameter. So, you can have you know a you know and also if you take this $\frac{\rho_{inclusion,}}{\rho_{steel}}$. So, in that case you know if you take certain values so, you can have. Now in the in this case if you know some of this value. So, you can have the value of this if you know the λ and even you can have a generalized graph which may so, the size you know relationship between the model sizes of the inclusion. So, you will have the inclusion m and then you will have $D_{inclusion,p}$ .

So, in that case for the particular value of Y you know our gamma you can say this is Y gamma so, this for that you will have a different kind of you know. So, you will have 0 to 250 micrometer. And similarly, you will have 0 to 200 micrometer. So, in that case you will have a graph like this will be γ equal to 1. Similarly that will be γ equal to 2 and it has been reported like this will be γ for 3.

So, so, accordingly you know for different conditions, you will have different type of you know these graphs by which depending upon the value of γ, you can predict the diameter of the inclusion which can be taken for water modeling. If you know the diameter of the you know inclusion which is used in the steel

So, we will have to, we will have to further see that when we do the mathematical modeling analysis, in that case you will have you know these considerations as well as some other considerations to be kept in mind as far as the, you know boundary conditions are there or the you know other you know operating conditions. So, that we can discuss and see the results on you know some of the cases studies which has been carried out. So, that can be done in our coming lectures.

Thank you very much.