Modeling of Tundish Steelmaking Process in Continuous Casting

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Lecture- 34
Analysis of Fluid Flow and Mixing in Tundish

Welcome to the lecture on Analysis of Fluid Flow and Mixing in Tundish. So, we have anyway talked about the fluid flow analysis and how these fluid flow you know parameters it I mean using that fluid flow, we calculate the mixing parameters or the different tundish volumes you know which is indicative of the mix mixing capability of tundish, you know how much there will be the total mixing inside and you know what are the dead regions, how the dead volume zone is calculated all that we will be discussing in this lecture.

So, as we discussed that we will be talking about a particular geometry.

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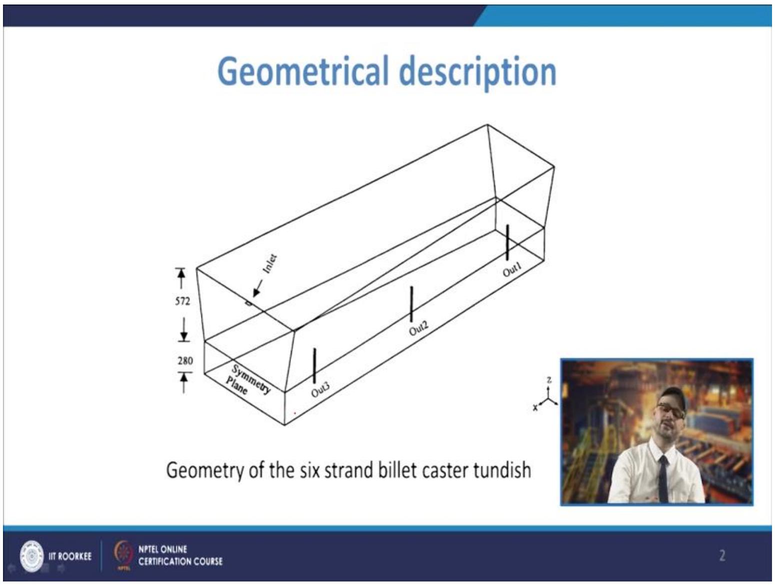

So, this is the geometry of a massive six strand billet caster tundish. This is the work which was done earlier by me, so when it is reported you know. So, what we I wish to show that how the you know how with the help of a particular problem you can solve you know you can show that how the analysis is to be carried out and how you understand these computation of different parameters inside the tundish.

So, this is a typical geometry. Again it is a six strand billet caster tundish and as you see that you will have the three outlets 3 2 1. So, you will have in this case, you are taking outlet 1 as a remote test 1 and 2 and 3 and this is your symmetry plane. It means there will be a plane which is going further in this direction and this is the impact you know this is the you know region through which the outlet is you know thoroughly through that whole you know zones. So, anyway this is zone only for that consideration that it is

showing the outlet.

Then it is dimension of the tundish is also shown as you see the height is given and the other dimensions are you know 2.95 meter of length or so.

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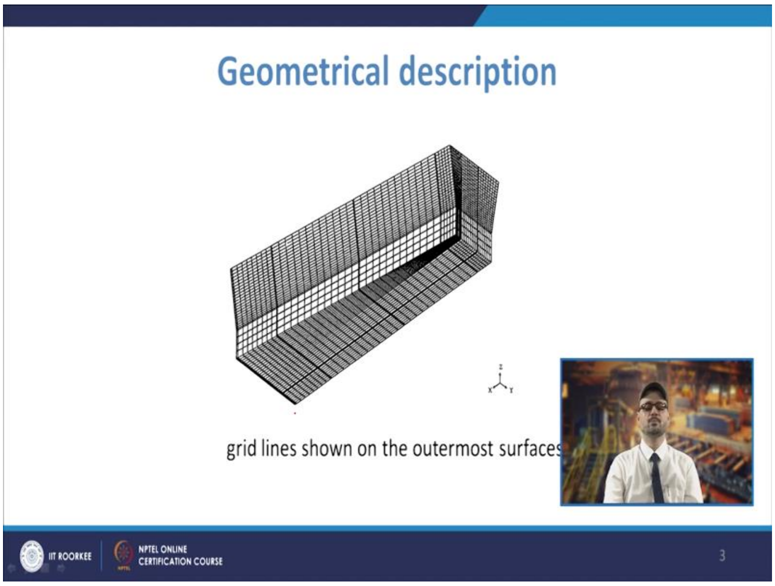

So, then as usual we again define the; you know grids in the different zones and you can have the gridded structure and further you can also use the flow modifier.

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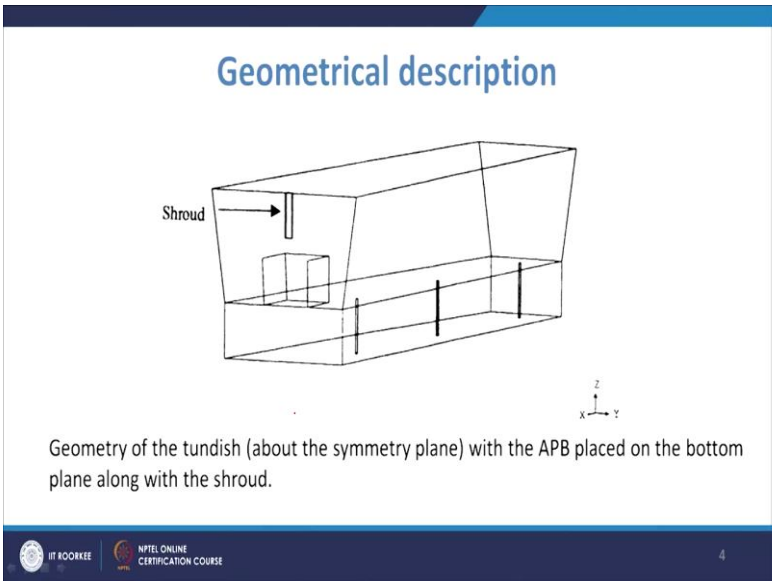

So, we have used the flow modifier as the advanced pouring box in this case. we also used the you know shroud which is there that can be used or that cannot be. So many a times we used this shroud to indicate that the metal will you know be not exposed to atmosphere and the oxidation kind of problem will not be there inside.

Now as you see this, so once you do the gridding then you can see that how the gridded structure looks like, then after that as you see that you have to solve these equations. In this case, we are not solving the temperature; we are solving only the continuity momentum in turbulent kinetic energy and rate of dissipation. Apart from that, we are also solving the concentration equation.

So, this is the equation for that concentration as it is concentration of the tracer. So, what we do; when we do the these analysis, there are two types of you know analysis which is being carried out and that is one is pulse input and another is step input. That is what I think we have talked about it earlier in that Stimulus Response Technique. So, in this case again we are going to have the discussion on that.

So, basically what we do that when we have a steady state velocity field set as we have seen in our previous lectures that you are going to solve, you have the you know geometry defined you are going to define the you know material properties, you are going to define the boundary conditions at the inlet, at the out outlets, at the walls and all that, then after that you are going to solve the equation and for that you will have these you know four you know categories will be there first.

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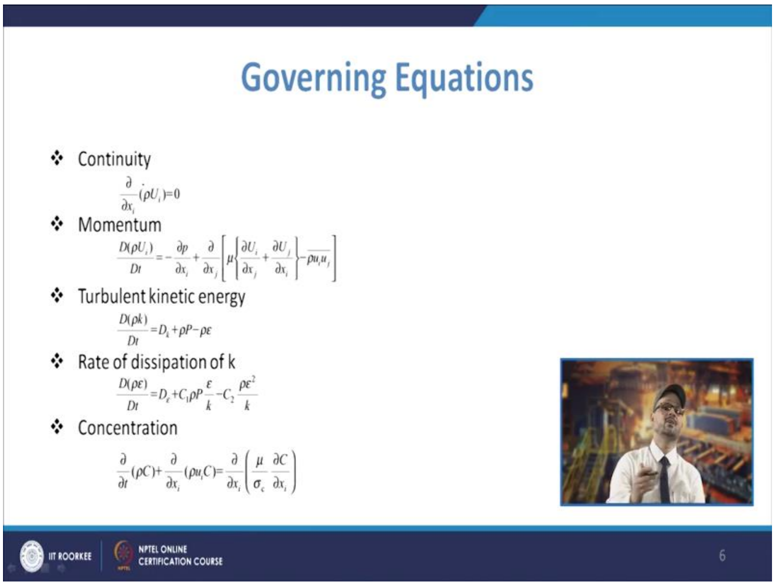

So, first you have to solve it and you will be getting a velocity field. Now after that you are going to have the you know tracer concentration solution for the concentration of the tracer. Now what we do in this case is to know that which of the tundish, how much you know good for the mixing and how the flow behavior is there, you know how the concentration is changing at the outlets, when the something which is coming through the inlet.

So, at what time it is going to start from the outlet. So, that also shows earlier we have seen that it comes through the inlet outlet which is closer to the inlet at a lesser time. So, so that certainly no you know that does not indicate a very good mixing capability because it must go into the whole tundish domain and then, it should come ideally it should take the ideal theoretical residence time. So, residence time is nothing, but volume upon the volumetric flow rate.

So, once you know the volume of the tundish and if you know the volumetric flow rate, so in that case the ideal volumetric you know mean residence time is that time which is should be spent by the fluid particle which will indicate ideal mixing will be ratio of volume to volumetric flow rate and that has to be computed.

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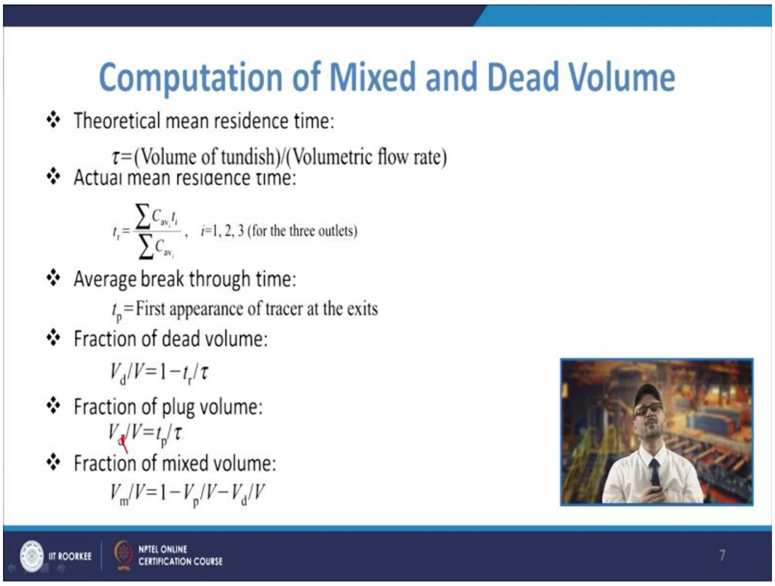

Now, in this case so you are first solving that and once you solve that and after that you are again solving for in the unsteady manner. So, in the case of unsteady you know analysis what we do is that we have to you know put the tracer which will be as some something like a dye.

So, that is you know normally we do the experimental analysis also in this case. So, what we do? We have a colored dye which is you know injected at the tundish.

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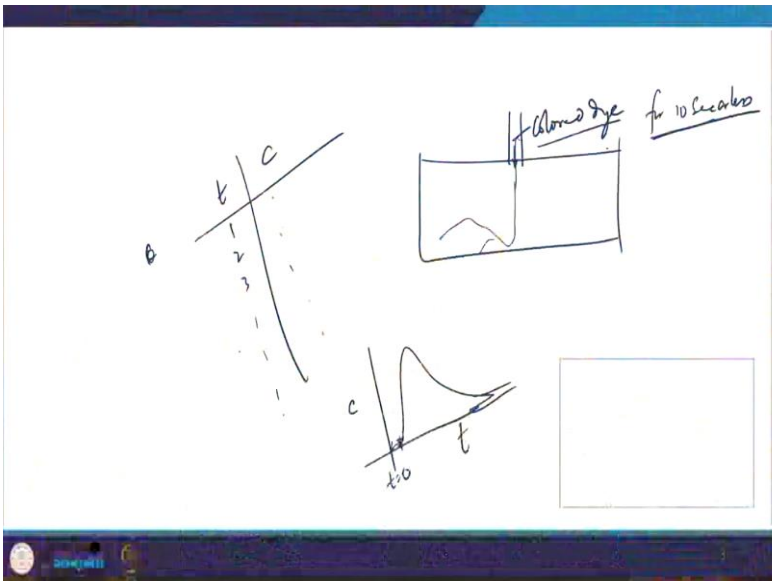

So, if suppose you have the inlet here, so you give these colored dye you know we are putting it for say 10 seconds you know and then or even 4 or less and then, so because it should not alter the flow field inside the tundish also.

So, we are putting also train in that you know same velocities which will go through that and then it is stopped and otherwise the flow continue after that the flow continues. So, the dye will come and then it will go inside and it will be coming out. Now we have to monitor this concentration of the dye because whatever quantity has come inside the tundish, it has to go out and when its first appearance is there at which outlet, so that is indicative of the you know plug component.

Similarly, if something is taking more time more than you know 2 or 3 or 4 times the mean theoretical mean residence time, then we call it as the dead component. So, if it goes into certain zone, it gets trapped and it takes large amount of time to come out, then it us a dead component. So, that we will discuss we will see. So, what is shown is that we get the theoretical mean residence time calculation by volume of tundish to volumetric flow rate.

Now we have to calculate the actual mean residence time and normally when you have only one outlet, so it will be $\frac{\sum C_i t_i}{\sum C_i}$is the concentration which is monitored at the outlet. Normally it is a dimensionless concentration divided by you know what concentration you have put in. So, that way you know amount of tracer which you have put in, so basically accordingly you get the dimensionless concentration that is there and so, we plot a graph between the dimensionless concentration and time.

And you know or we if we plot the graph between the concentration and time, so from that graph basically you can also have the calculation of the actual mean residence time. So, you get a file in normally you have to get a file which will talk about the you know these concentration which are coming out through the particular outlet with respect to time. So, you will have you know the; you know with respect to time you will have the concentration. So, you have time 1 second 2 second 3 second or so and you will have the concentration values, but will it come in here and that will be normally initially increasing and then it will be decreasing.

Now, because when it has come and will start entering that time it will be decreasing, but then slowly once it goes inside the whole domain, then slowly it has to decrease because you have only injected only a very fixed amount of tracer inside the you know inside the tundish. So,. So, accordingly you see that you get the actual mean residence time that will be $C_{avg}t_i$, $C_{avg}$is taken because if you have in the outlet, you have you know more number of cells are there.

So, it will be averaging those you know concentration values in the all the elements in the outlet you know domain, then we calculate these different parameters like now from these concentration and time graph a typical concentration curve will look like this. So, it will go like that. So, you will have concentration time to see dimensionless concentration and this delay basically initially because there will be when you are this is at t equal to 0.

So, at t equal to 0 the tracer has entered, it will say take some time to appear through the outlet. So, that that time you know that is known as the you know the time you know that from that is indicative of the you know plug volume. So, that is your break through time and that is t_p. So, that is first appears of tracer are the exits. So, you know and you know you can get these different you know fractions. So, once you get the t_p where the first appearance of tracer is recorded, from there you know you can get the plug volume.

So, that is this is v_p not v_d. So, basically this is v_p . So, $\frac{v_p}{v}$will be $\frac{t_p}{\tau}$. Now you know that this is theoretical mean residence time. Now what we do is that once you have the theoretical mean residence time defined and once you calculate the actual mean residence time, so the dead volume will be computed as $1 - \frac{t_r}{\tau}$. So, basically we calculate that as the dead region because any you know fluid particles is taking more time than the mean residence time, they are said to be the dead regions you know and that is indicative of those zones which are not effectively being you know they are not in the indicating the effective utilization of the whole volume of the tundish.

So, once you get these dead volume and the plug volume, then the you know difference I mean some of these values and then you take 1 minus that value that will be talking about the fraction of the mixed volume. So, you have three kind of generally volume component inside the tundish; you have a plug volume, dead volume and mixed volume. So, plug volume will be that volume as we have already discussed that it will go without interfering with other things.

So, it will be go quietly and it will be quite flow and then you have the dead volume. So, dead volume as you see that in the case of dead volume you have that indicates that this is actually it should be minimum. So, if it is minimum in that case your mixed volume will be higher that indicates the mixing you know capability of the tundish inside. So, because that is required to have a homogeneous temperature inside the tundish and also you know the proper you know if something is you know coming suppose through the tundish you know if there will be no you know mixing or you know tendency, what happens that if some inclusion comes inside and if they directly go by short circuiting process towards the outlet, so it will go to the mold.

Now in this case if you are trying to have a loop inside the tundish, there will be chance that this inclusion will be having a tendency to float up. So, that is also another way of another way which we in which we can see that how you can increase you know the productivity of the tundish. So, coming to the results.

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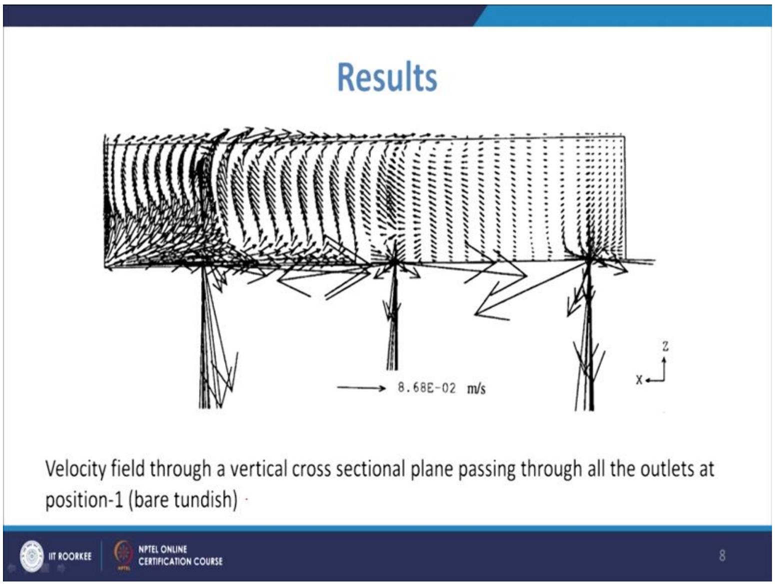

So, if you first see the velocity vectors as we have seen earlier, so you have a you know the outlet plane and on this if you see the velocity vectors. So, what you see that on this outlet which is near to the inlet, your velocities quite high. It will come and then it has also the tendency to go up and then it is moving like this.

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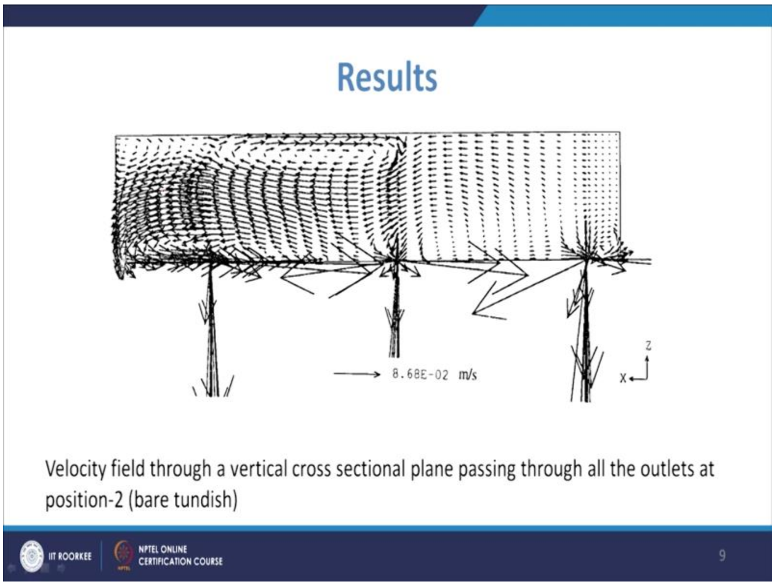

So, this is you know through all the outlets at now in this case we have also changed the position. So, that is why we have 2 and 3. So, position will be one as you have seen earlier that position 1 2 and 3 can be seen earlier if you see the results. So, in that case it will be shown here.

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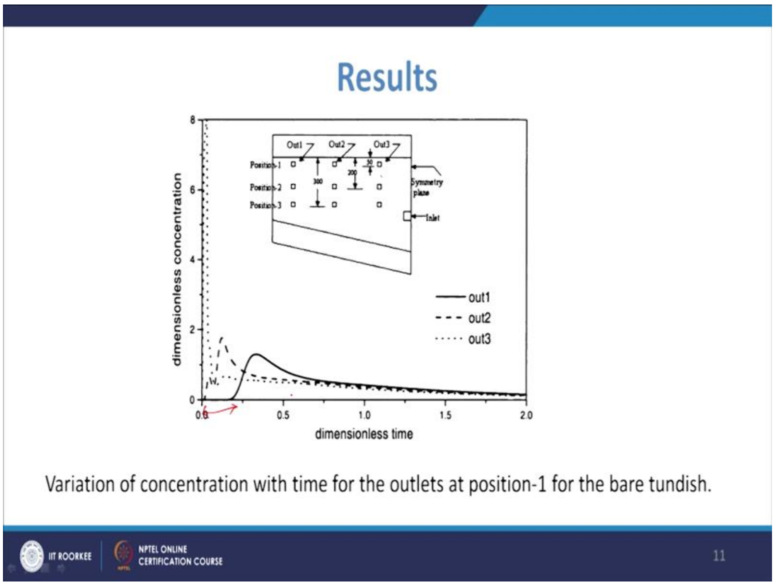

This is a position 1 is close to the wall, 2 is in away from the wall and 3 is near the inlet plane itself. So, that way you have these three positions just to show you know what you see that in position 1 this which is close to the wall what you see it is going towards the wall on the top and then, it is moving from there. As we move away from the wall a little bit to position 2, then what you see that you will you see a type of you know loops also is shown and you know it is very evident that you have larger velocities in this zone which is closer to the inlet and this is near the inlet plane.

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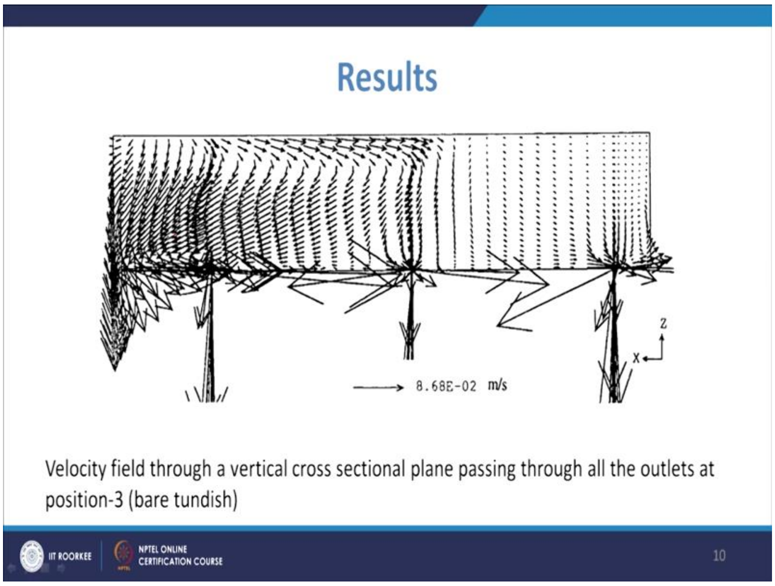

So, as you see further the velocity near the inlet is quite high. It is becoming closer to the inlet plane you know along the length direction. So, you see that there will be changes in these velocity vectors. This Q can you know draw. Now once you draw you do the you know transient analysis you are having the tracer concentration for some time going through the inlet and then you stop it after the after some time. In that case you are getting the concentration of concentration variation with time at position 1.

Now position 1 is you know as you see this is near to the you know inlet. So, near to the of this wall this side. So, what you see that now you can see this is a called so-called C curve. So, this is you know concentration with time. So, as it is known as C curve, now what you see that this is you know out one out 1 is away from the inlet and out, 3 is close to the inlet.

So, out 3 close to the inlet were to see there is a large increase in the dimensionless concentration peak and then immediately so it is at no time you see these values and then it has start decreasing and then it is slowly decreasing and moving towards you know these as you move towards the time.

Now the thing is that you know we take up to two times of dimension less time and we do the analysis. So, what we see that this larger you know peak means that there is a short circuiting being taken place and whatever is coming through the inlet, it is in no time, it is just reaching most of the part most of you know it is just going through the outlet.

So, that is swing shown by a very large peak in that concentration value similarly as we see for the second outlet. So, what happens that the fluid will be entering striking at the wall bottom and then it will move. So, it will be some passing move will be through the near outlet and then some will move. So, so from here you can see some lag is there from here it is at zero time, it is increasing and here it is maximum. Now here it is delayed because it is farther or somewhat farther from the outer edges closer to near.

Now, in this case it starts little late and you see that your peak also is somewhat you know positively at very smaller value. This is indicative of the you know some of some amount of the plug volume and in this case as you see you might recall that if you talk about a pure you know mixed flow, the pure mixed flow will be like this and the plug will be like this.

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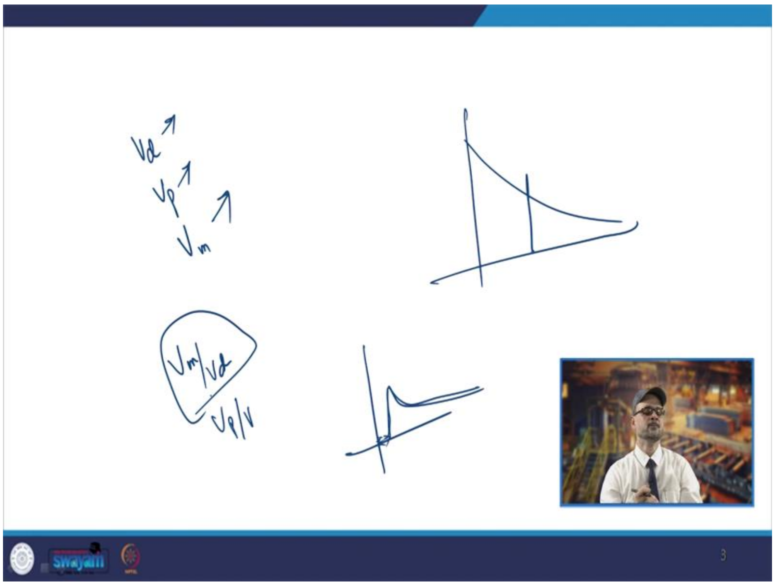

So, as you see here do you see you know in this case like this. So, basically you have this is the plug component and from here you go for the mixed components is this. So, you know as the peak will be increasing. As the other will be higher and higher peak values, it is indicating of the poor mixing capability of the tundish and large numbers of circuiting is being taken place and your dead volumes in that case will be likely to be higher because the active metal which is coming from the tundish, it is not able to move with higher velocity towards the remote places inside the tundish.

So, you can see that you will have a large peak here and for you know outlet 2, it is smaller than outlet 3, it has taken a large delay. So, and then what you see is that is quite a good mixing characteristic is being shown slowly, it is coming down. So, you know so that is indicative of now because of this you will have the different value of the mean residence time for the you know three outlets, but we take the average of them.

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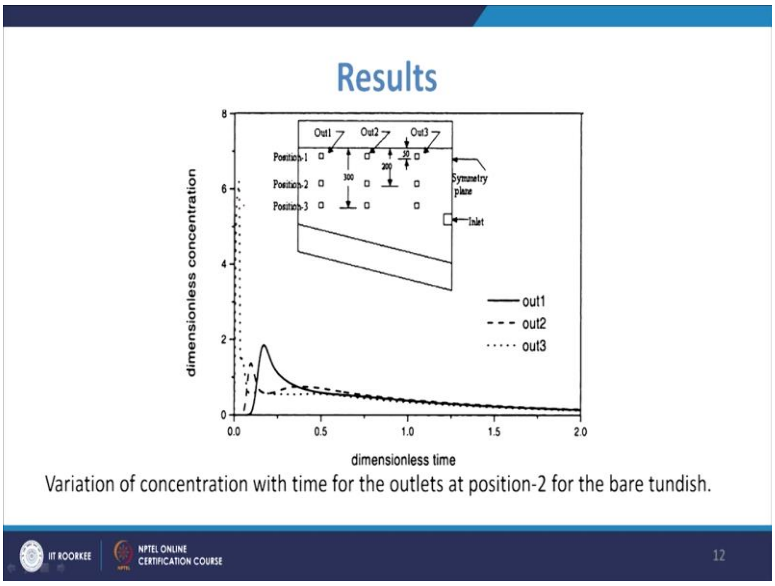

Variation of concentration with time for the outlets at position-2 for the bare tundish.

So, if you change the outlet position somewhat away from the you know wall, in that case that is how you see that this the earlier peak which was 8 you know it was not close to the wall. Once you have taken away from the wall, it has come down to close to 6. So, and then your. this is your 6 you know C curve for the other two outlets which looks like this.

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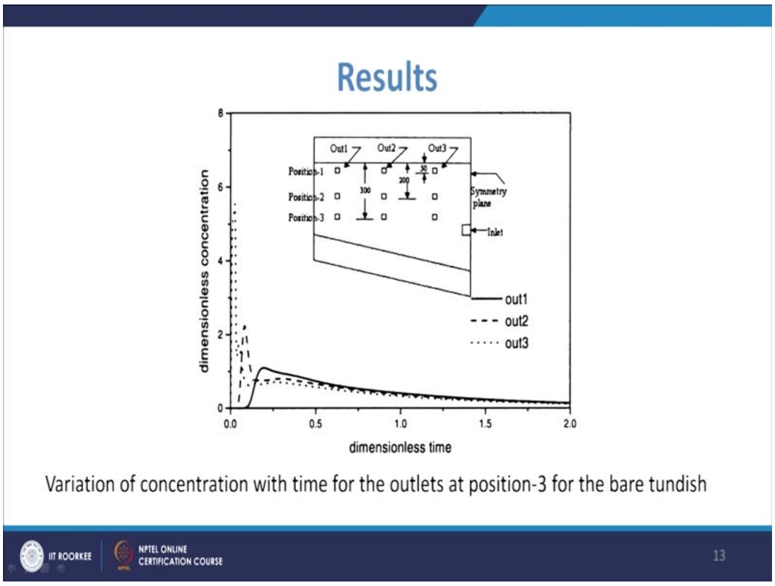

So, if you have far further changing towards the inlet plane you see that is even smaller and then that is how, so you find the value of the mean residence time in these cases and you just see that how much because 1 minus mean residence time actual divide by exist mean residence time theoretical will give you the dead volume region which should be minimum you know.

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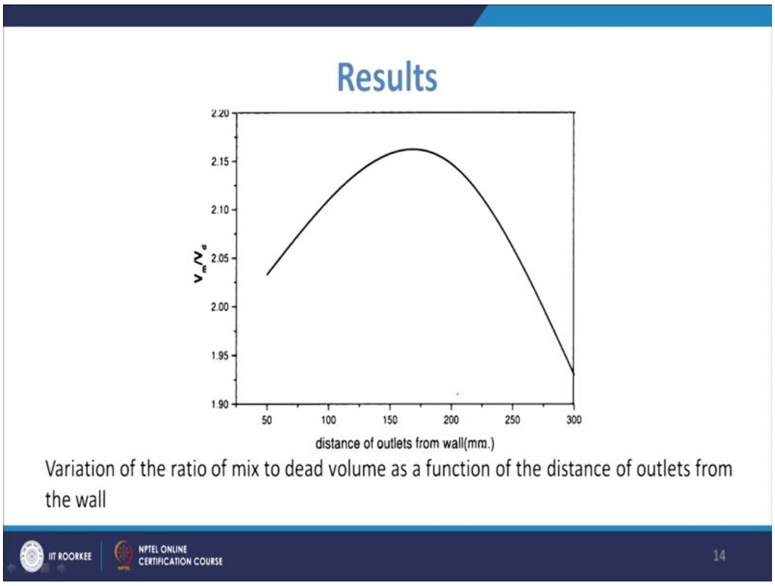

So, if you go to find the variation of the ratio of mix to dead volume, now after this what we do is that we calculate the you know mixed or dead volume. So, that will be on minus actual mean residence time divided by critical mean residence time, then you also calculate the plug volume.

So, that will be indicative of the breakthrough time. So, when you have the first appearance of tracer which is being appearing and then accordingly you will have the calculation of the mixed volume also. So, once you know the V_m and V_p, you get the mixed volume and you for a for the blending in terms of fraction we can have a $\frac{V_m}{V_d}$. You can have $\frac{V_p}{V_d}$, I mean $\frac{V_m}{V}$. In fact, we calculate as $\frac{V_m}{V_d}$ is one of the parameter you know which tells that we try to increase V_m and we try to reduce V_d.

So, that will be representing a larger amount of you know mixing inside the tundish and it is more desirable feature in that case. So, you will have $\frac{V_m}{V_d}$ and $\frac{V_p}{V_d}$. Also we can plot and we try to increase this value of $\frac{V_m}{V_t}$and in this case we have tried to show that how there will be variation in the case of you know $\frac{V_m}{V_d}$and how their ratio is going to you know change. So, larger value of $\frac{V_m}{V_d}$is largely desirable for tundish because it will be indicative of the larger you know mixed zone and the smaller you know dead zone inside tundish.

So, you have values of mix as you see that once you change the outlet position is at 50 second is at about 200 and third is about 350 or so 300.

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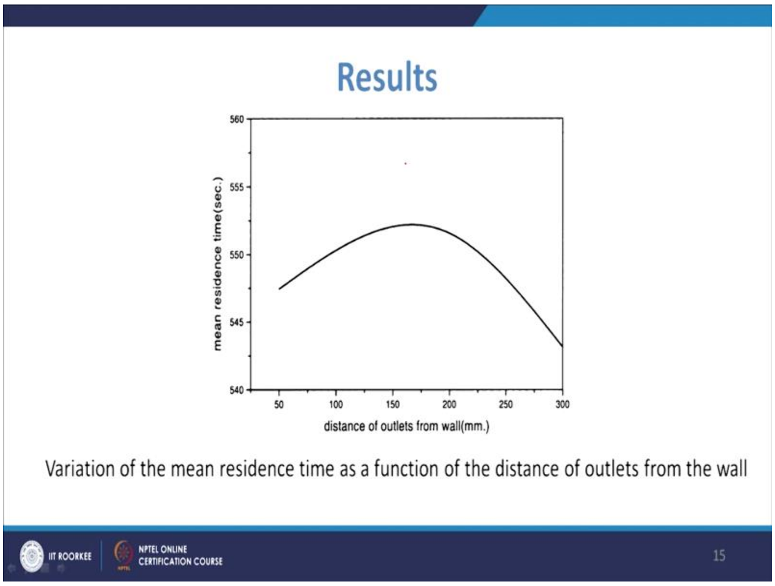

So, in that case what you see is an intermediate position you get this value as the maximum.

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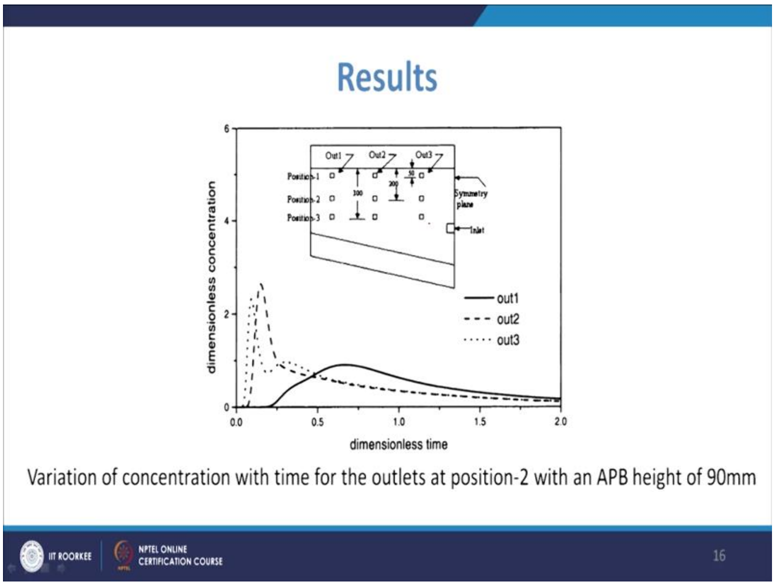

Similarly, you have mean residance time also what you see that is a maximum. So, that is you know so what we saw that at position 2, you can have the maximum value of the mixing parameter calculation.

So, to have you know better characteristics in terms of mixed dead volume by altering the flow behavior as we had discussed in our last lecture that we use certain type of you know flow modifiers and in this case, we have used the advanced pouring box as we had just shown and what is shown is that which usually advanced pouring box of a height of 90 mm. In that case it was the reported that you know you see now when you use the advanced pouring box and you see out 3 is the one which is close to the inlet.

In that earlier case it had gone close to 6, but it has now come down to close to 3 or so, not even less than 3. It indicates that when you pour it now you put a barrier before the near outlet before they have 3 in this case, then the fluid goes and it will go into the other part of the tundish fast and what you see that you also see a breakthrough time increased. In the earlier case, it has started from here, but in this case you start from here and there is also delay on this and as well as on this ah.

So, it means the first appearance of the tracer is delayed. So, that tells you the plug volume also and the lower peak will be indicative of the larger you know a smaller dead volume and ultimately, you get larger mixing parameters mixed dead volume and mean residence time. So, then even you can change the height of the APB. So, that was also changed.

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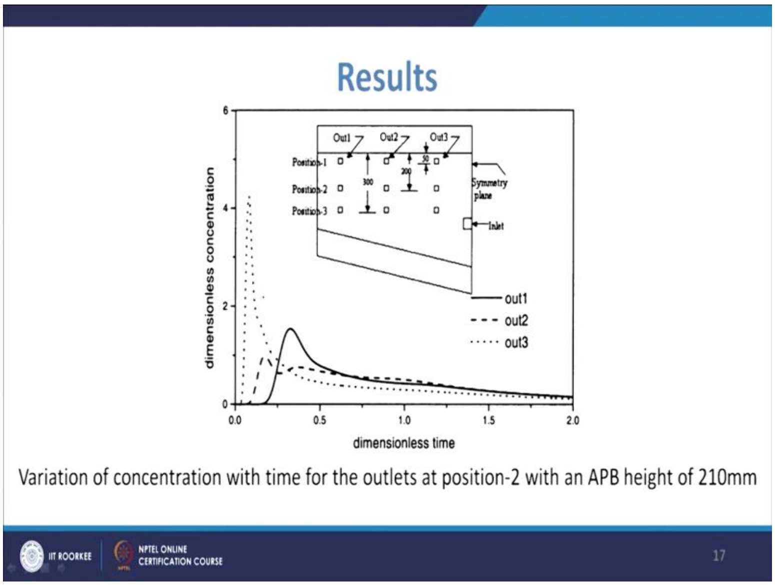

And as you see that once you change the height it was for somewhat increased in this value.

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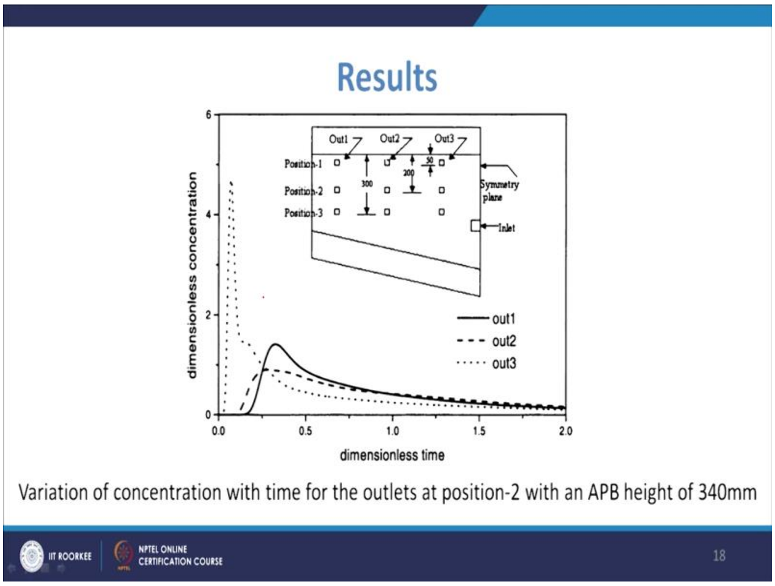

And further increased it will give you a larger value, but then the value of the mean residence time and we mixed mix to dead volume will be more indicative of what is the mixing parameters that can be computed.

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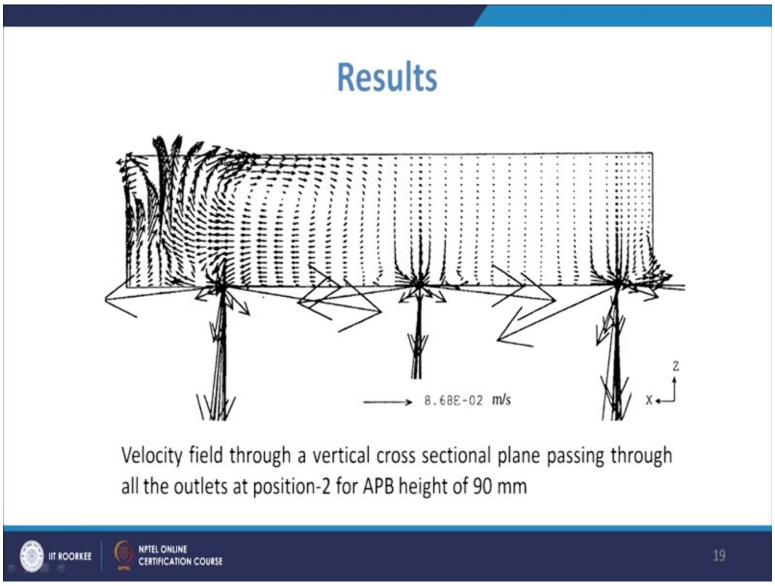

And you can also see the change in the velocity field.

So, when you use the advanced pouring box, so you can see that you will have the more you know velocity moving towards the upper side and then, it is moving. You will have some recirculation also it tells that in homogenization and mixing also of the fluids. So, that is a good indication and it shows that your mixing is improved in this case.

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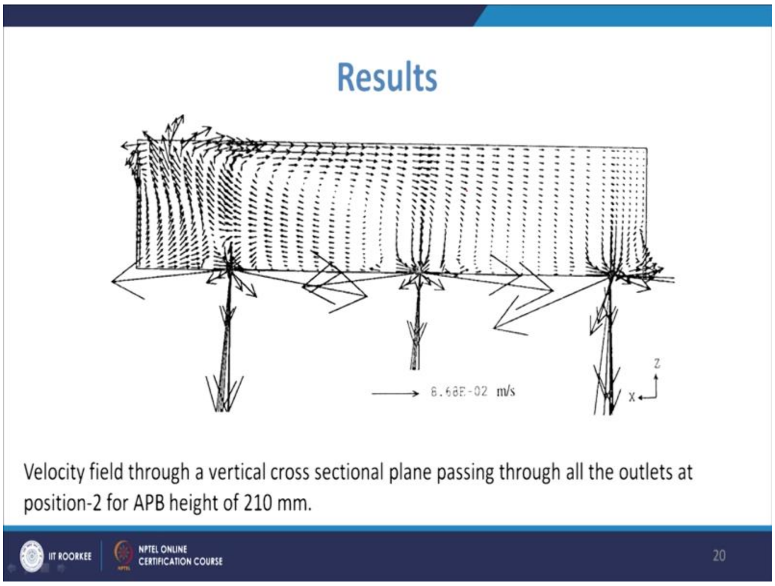

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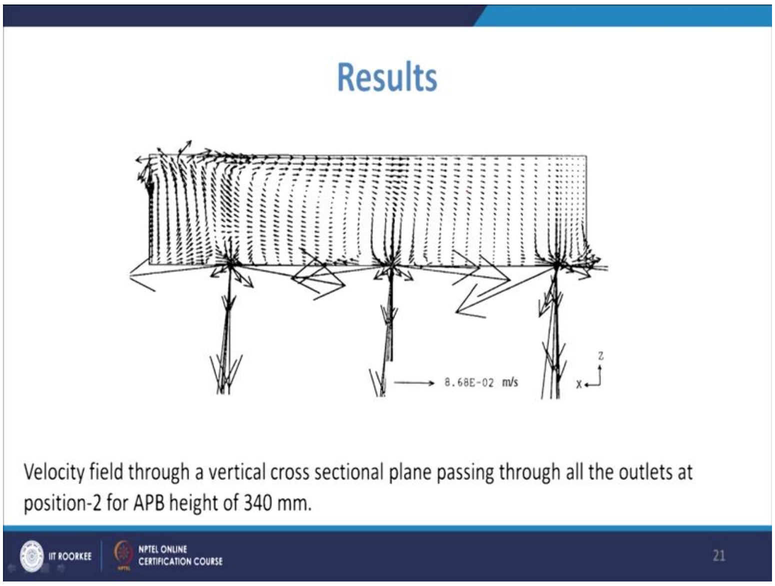

Velocity field through a vertical cross sectional plane passing through all the outlets at position-2 for APB height of 340 mm.

So, that is shown with these you know three types of the heights.

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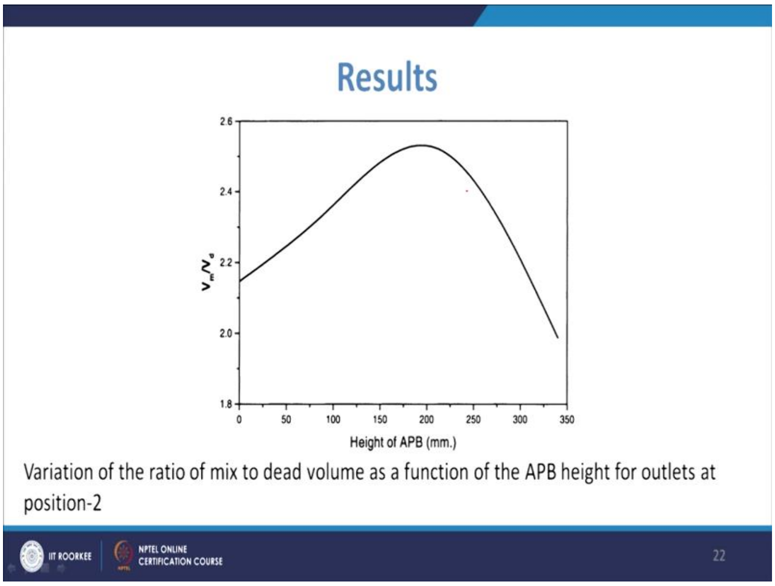

Variation of the ratio of mix to dead volume as a function of the APB height for outlets at position-2

And if you look at the variation of the ratio of mixed dead volume, what is shown is that at the middle you know height your mix dead volume ratio is said to be you know better, although that was having the you know the peak was somewhat higher for one of the outlet, but otherwise if you look at the overall calculation of the mean residence time, it was larger in that case and then the dead volume was smaller.

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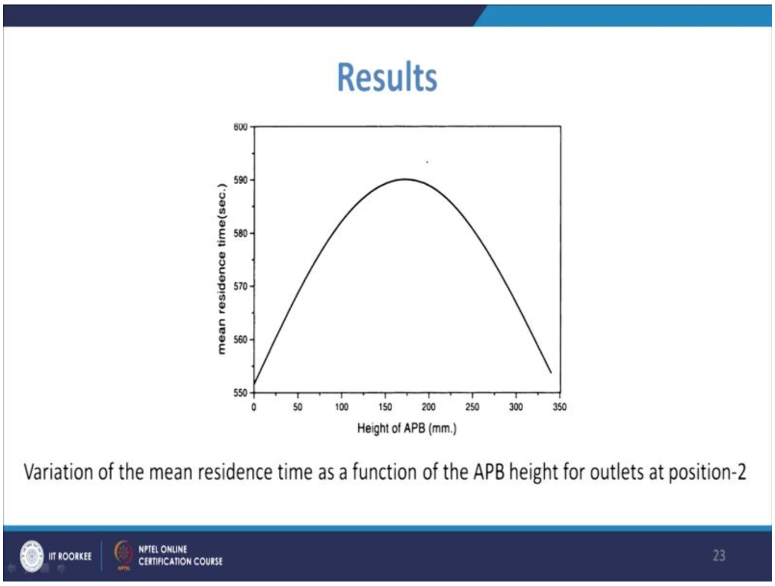

So, that is why in this case you get a better variation of the you know the mean residence time.

So, you see that for the smaller and for the larger height, it was small mean residence time whereas, it was more for the medium height.

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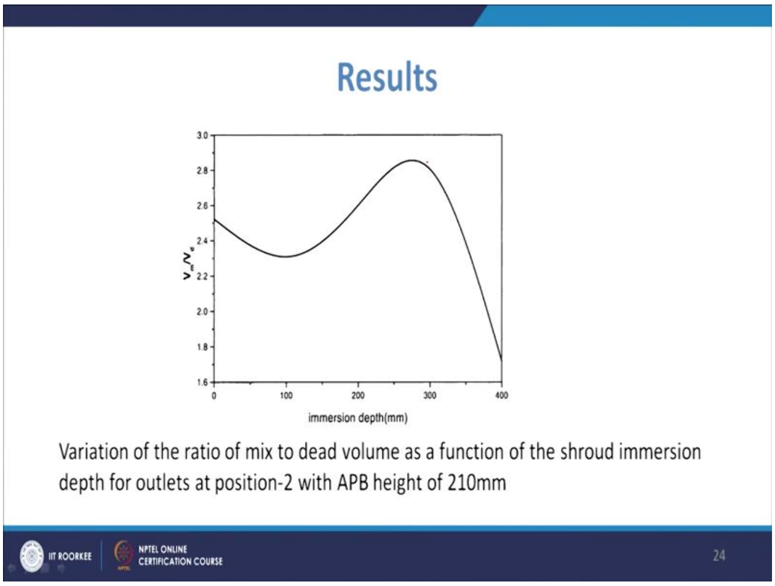

Then there can be study on the shroud immersion. As we discussed if you do the shroud immersion from the inlet, so accordingly you will have you have to do the analysis, every time you have to find the concentration and time and from there you have to calculate these you know mixed dead volume, you know function of the shroud immersion depth and that is for the different positions you can have these volumes.

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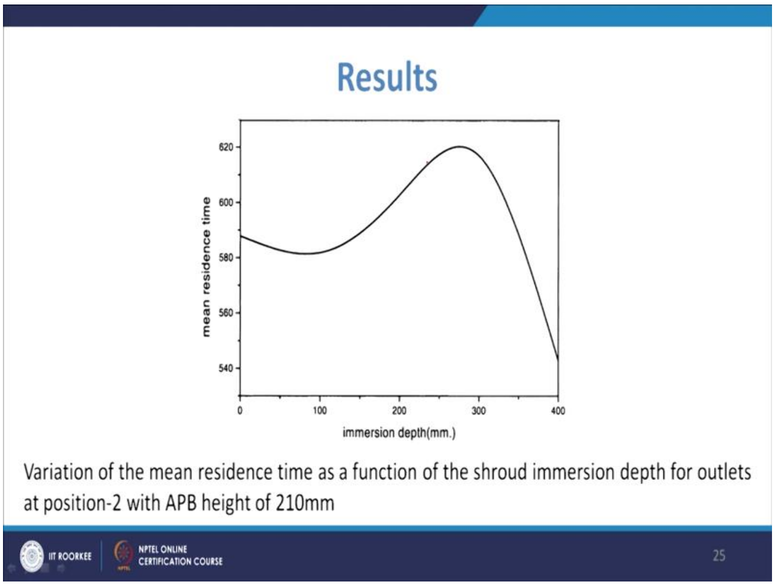

So, that we what we see that what this should be the optimum shroud immersion and that also can be computed.

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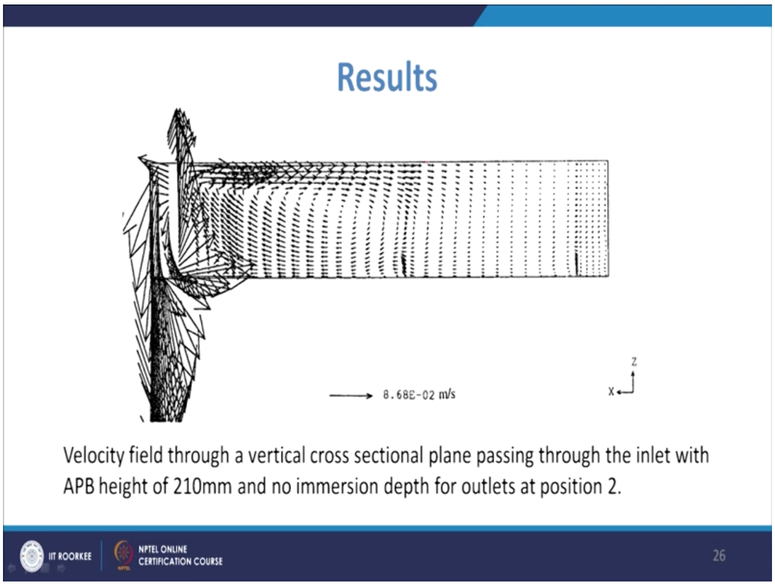

With shroud immersion how the; you know velocity fields are changing. So, that can also be seen that you know immersion depth of a with no immersion, this is how the APB with a height of 210mm.

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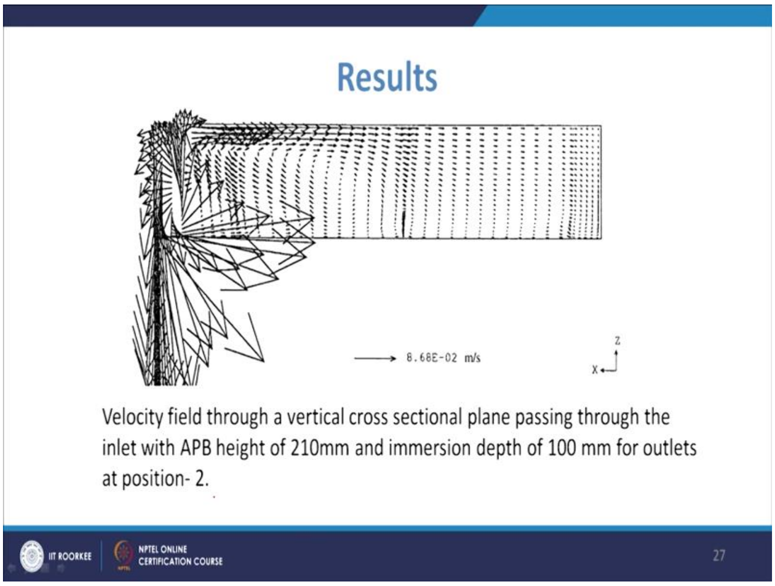
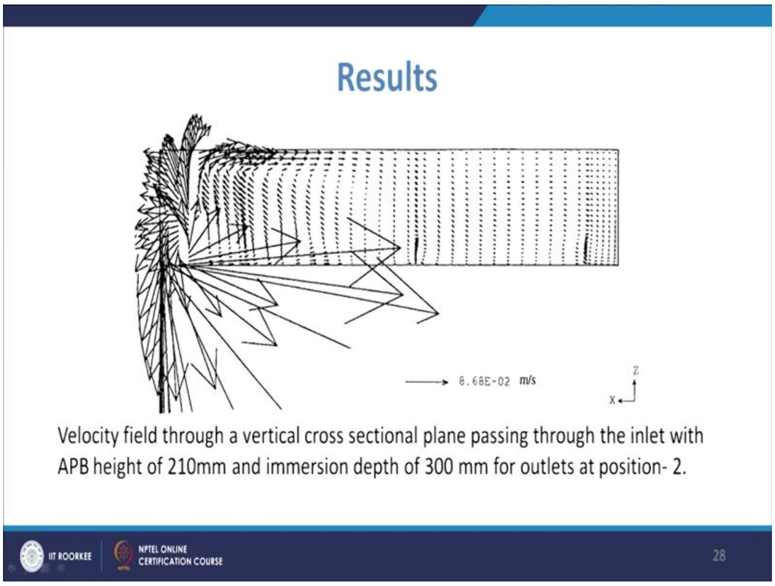


But if you do the immersion, then how the velocity field is changing?

(Refer Slide Time: 32:05)



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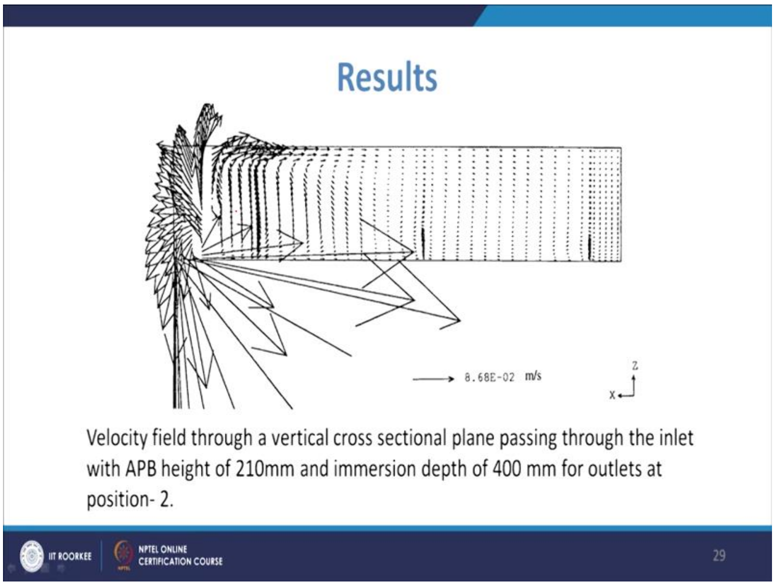

So, they before the velocity field which will be seen with these different immersion depths and once you immersion, so it shows that how the velocity is velocity field is seen changing with the box. So, that can be seen.

So, what we see ultimately that when you do the analysis of fluid flow, then and you do the tracer disposal analysis with that. You can have the calculation or these missing parameters different you know volume components inside tundish like plug missed and dead zones inside the tundish which is showing the effectiveness of the tundish.

Thank you very much.