Modeling of Tundish Steelmaking Process in Continuous Casting

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Lecture – 40
Case Studies in Modelling of Tundish Steelmaking – II

Welcome to the lecture on Case Studies in Modelling of Tundish Steelmaking. So, we will be talking today about the second you know type of a case studies. We discussed few case studies in our previous lecture and these are another few examples of the case studies on modeling of tundish steelmaking.

So, in the last lecture we talked about the inclusion behavior as well as the mixing with the different configuration of tundish. So, that is what primarily we had you know discussed in that class. So, further if you try to use the flow modifiers and that too in the different configuration of tundish, then what is the effect how you are going to have the analysis of those things. So, that is what we will discuss here.

So, this will be use of flow modifier especially dam in the different configuration of tundish. So, specially you will have the effect of both the things like dam as well as the with the changing configuration of the tundish. So, as you usual we have these four configuration of tundish you know like delta boat V and T shape.

And, we have the use of the dam here and that dam is kept at three positions at the position. So, it will be A1, A2 and A3. So, 1, 2 and 3 will be related to also the height and then you have also A, B and C positions. So, C will be close to the outlet.

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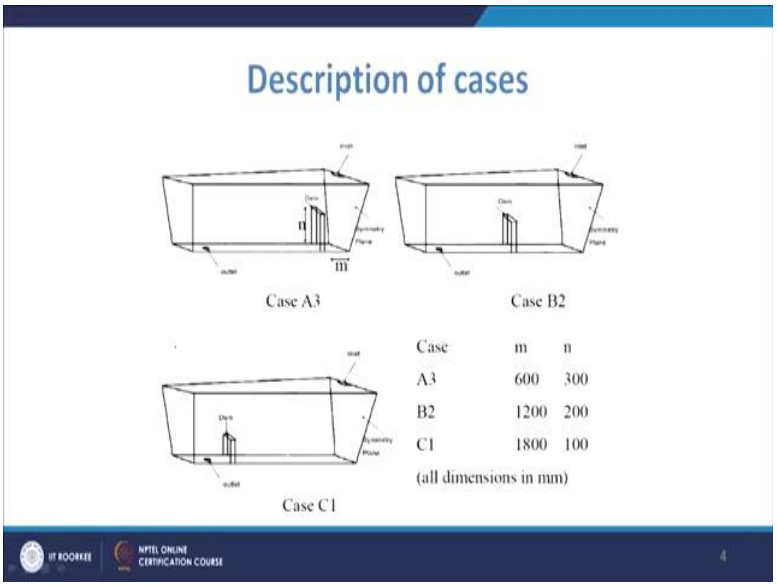

So, so that is how you see you will have these three positions. So, so, now, what we will show I think n will be here A3 is certainly 300, n is more 3 means it is 300 and 1 means it is 100.

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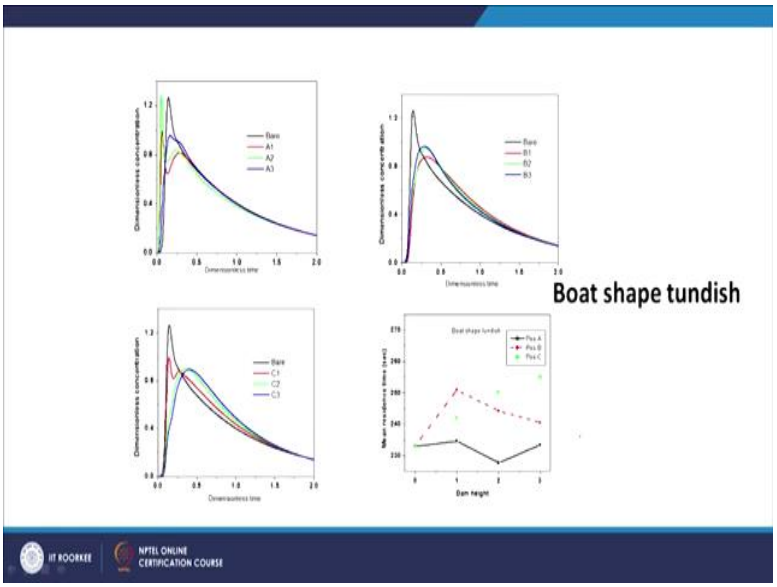

So, if you look at the boat shape so, for the bare and when you are using the you know dam at a position. So, that is closer to the inlet so, closer to the inlet what you see is you are getting the you know these are the RTD curves. So, this is closer to the inlet, this is at intermediate position and this is at the you know position which is close to the outlet.

So, that is and then you have 1, 2, 3 is with the change in the height of the dam. So, now, if you look at the mean residence time now, mean residence time is shown to be maximum for this case for the green; green is position C and this is your boat shape tundish. So, it will be at position C, and the dam height is 3.

So, if you see this one if you can look at the RTD among these RTDs you see that this is having the largest plug volume also and it has minimum of the peak. It is delayed also. So, delaying means and then you have. So, this graph that is your blue line position C. So, and that too so, for the boat shape and that too of the height 3. So, this is giving you the best you know value of the mean residence time for the boat shape tundish and, if you look at the bare case.

So, in the case of bare you see that it is normally you know this is bare. So, in certain case even it is somewhat worse also if you look at these positions so, here for the position A and for the 2 height. So, if you look at position A and for 2 height it is you can see that this is a green line. So, green line is even starting early and it has a somewhat even higher peak same peak going and then it has it is going.

So, that indicates that the mean residence time becomes very small in the case of this bare tundish. You know and that to for the second height. So, from the graph you know you can have a comprehensive understanding of what is happening, how the RTD curve is changing and by looking at the variation in the RTD curve you can have a feel that where the mean residence time will be higher or lower. So, this is about the boat shape tundish.

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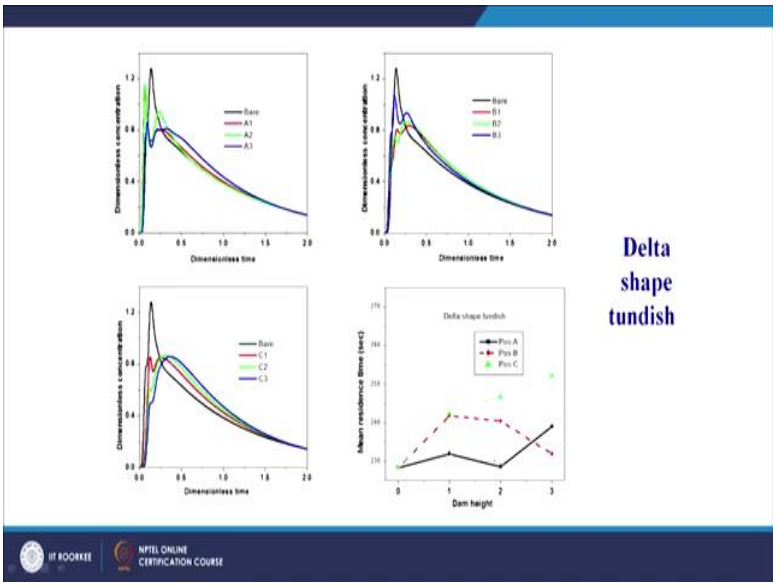

Now, if you go to the delta shape tundish. So, in the delta shape tundish again you see that similar kind of you know curve you see for the bare tundish and then you have again further the you know the changes in the C curve as you increase the dam height at different positions like A, B or C.

Now, in this case also it is similar to the you know boat shape it behaves and it here also you have the maximum mean residence time seen for the position C and that to for the largest dam height. So, position C and largest dam height C3 are indicated by the blue color so, that gives you the you know most delayed appearance of tracer. So, that is maximum value of the plug time.

And, then you have the smaller value of the peak and then it is slowly decreasing. If you look at the red line that is 1; so, for 1 you know for 1 here it is this value. So, certainly it is somewhat better than this one.

So, the thing is that if you see you know for this also here this is somewhat better, but then it is further increasing. So, the thing is that boat tundish and the delta shape tundish somehow behave in the similar fashion and the maximum mean residence time is seen at the position C and that is of the dam height of maximum value.

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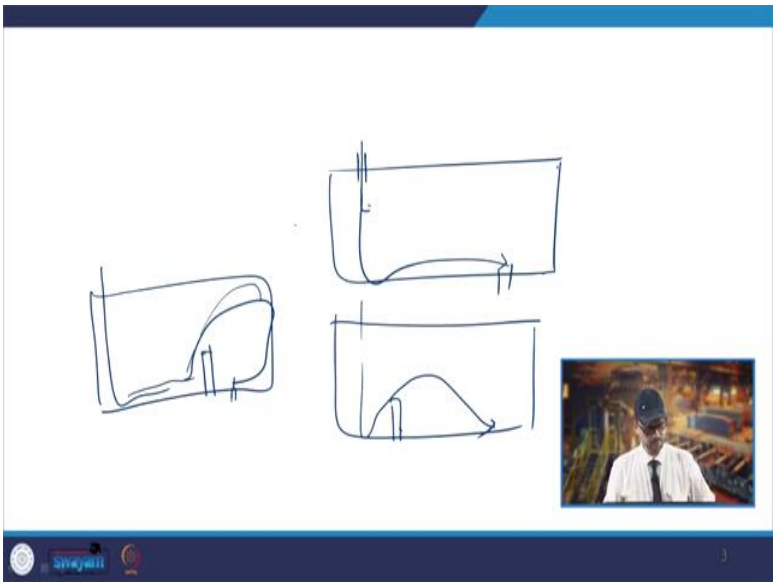

So, in this case what you can expect that the fluid which is moving so, when it is going towards the you know that you can understand like if you have a tundish and then this is your outlet and this is your inlet. So, the thing is that if you are move if you if you allow. So, in normal case it will move earlier it will be appearing.

Now, if you are having the dam you know here, so, the possible flow will be from here and it will move and then it will go like that not very much helpful. However, if you put the dam somewhat you know if your outlet is here and if you put the dam here. So, in that case you know the fluid goes and then it will be moving and then it will go and move like this.

So, basically there will be a kind of you know larger you know loop the fluid particles will cover when you are putting a dam just before the outlet that is at position C and also that to especially when you are putting that of higher dam. So, it will have a larger loop.

So, that is the reason because of which you see in these two kind of tundishes the maximum value of mean residence time at a position C and of the dam height being maximum.

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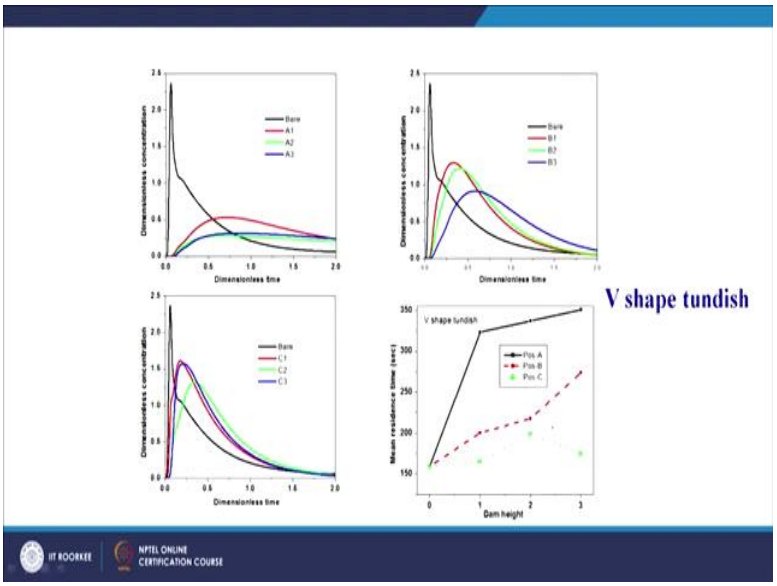

Then, you know if you look at the V shape tundish now here you see in the case of V shape tundish the contrary to the boat and delta shape you here you see the maximum value of mean residence time that is for position A means just after the inlet.

You know you are having the placement of the dam in that case it is giving the maximum amount of mean residence time. That is what is seen that if you put like that you see that it is a delayed and as well as the height is very much smaller. It means the it is completely mixing inside and only smaller value of the tracer is moving towards I mean coming out of the outlet.

So, concentration value dimensionless concentration value if you see which is very small as compared to all these cases. If you see in these cases average if you take up to 0.5 times so, it is it is going about 1.5 or may between 1 and 1.5 here if you look at it will be close to 1 and 1.2. But, here if you look at it is even less than 0.5 that indicates that in the case of V shape tundish what is happening that when the metal is moving down and then it is you know allow to go at 45 degree this way it has to be diverted.

And, suddenly if it has the dam so, maybe that by looking at the we have already seen the velocity vectors. So, basically that pushes the liquid steel to or the tracer which is there. So, it will be going towards the other sides and it will be taking a larger loop and then it will be coming out through the outlet. So, in between it has mixed and then very small amount of concentration of the tracer is observed at the you know outlet when it is just

smaller. Whereas, when and maybe that the fluid has a tendency to move towards the upper portion and then it after moving it is coming through the outlet so, it is taking larger time.

Whereas, if you are increasing moving the dam towards the outlet to B poison or even to the C position; so, for B position it looks somewhat better you know at all the dam height you know it is better than at C. So, this is because you see that you know the here the height is smaller. So, that is why these values are larger and these heights are somewhat bigger.

So, they are giving you the smallest value of the mean residence time in these cases and maybe it is because of that and the loop of the you know this is the fluid path and that is in such a way that you know in these cases your the dimensionless concentration height is becoming somewhat higher than you know the other cases other even this case.

So, so that is why you see that the mean residence time will be maximum here then followed by this that is your position B and then finally, at C. So, basically we have seen in the case of you know the boat and V shape. So, what you see that it is coming closer to the 345 or 50 whereas, the maximum value here it is smaller. So, what you see in these two cases it is smaller, but in case of boat and in the V shape it is becoming maximum.

So, when your you know the dam is closer to the inlet and also it is maximum among that also when the height is the maximum.

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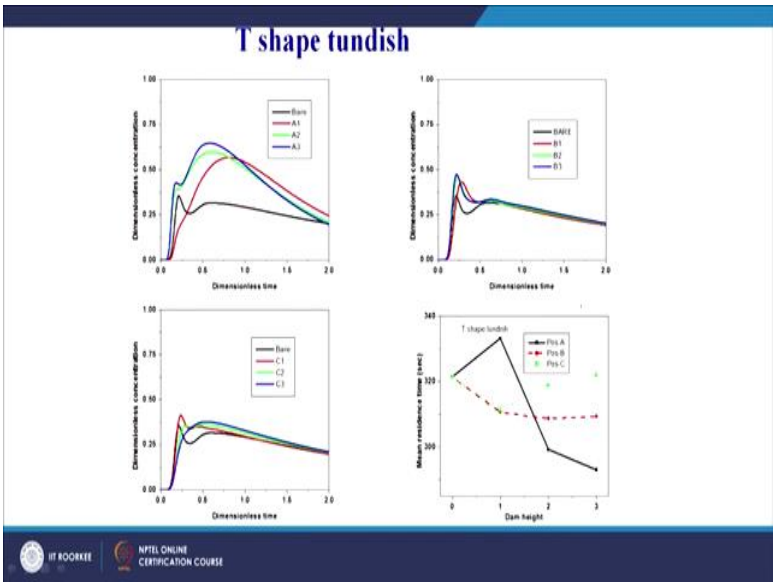

Coming to the T shape tundish as you see now in the case of T shape tundish if you see except for this position A where there is improvement over the bare shape and that to with a smaller dam height so that can be seen here that is bare. And, A1 is somewhat delayed, so, it is going here, but except that if you look at all the case in all the cases the mean residence time is seen to be smaller and the maximum value is certainly coming closer to 335 or so.

But,, but what you see here is that even for the you know bare case your value is quite high 320 whereas, in this case your when you use the dams you get these value of close to 320 or so. So, in this case you are getting for the bare itself 320 and maybe 335 you are going but, for bare tundish if you look at the best one is as far as the mean residence time is concerned the best configuration tundish is the T shape where in the bare case itself you got close to 320 or little bit more than that value of the mean residence time in seconds.

And, in this case what you see is that you are not going to have much of the advantage by having the placement of dam. So, if you are placing the dam you know and that to you see that how adversely it is affecting when you are increasing the height of the dam especially at position A. So, in that case you know it is completely coming down, maybe still it is better than boat and all. But, if you look at the boat here you are getting having not even that, but you know this is your.

So, this is it is getting smaller. So, that is what we mean to say that for the T shape it is coming down with the help of flow modifiers. So, for the T shape what we suggest that it is better not to use the dams or the flow modifiers it works in a bare way better than all the configuration of tundishes whereas, in case of V shape you should use the flow modifiers at the position A and for the you know boat and delta shapes you should use it at position C closer to the outlet.

So, that is what the is the outcome of these configuration of tundishes and with the use of flow modifiers. If you go for the percentage inclusion removal for these boat and delta shape what you see normally the trend looks somewhat similar except that when you have 10 microns. So, that way for the delta shape it is having maximum removal otherwise they have a similar kind of trend for the boat and the delta shape.

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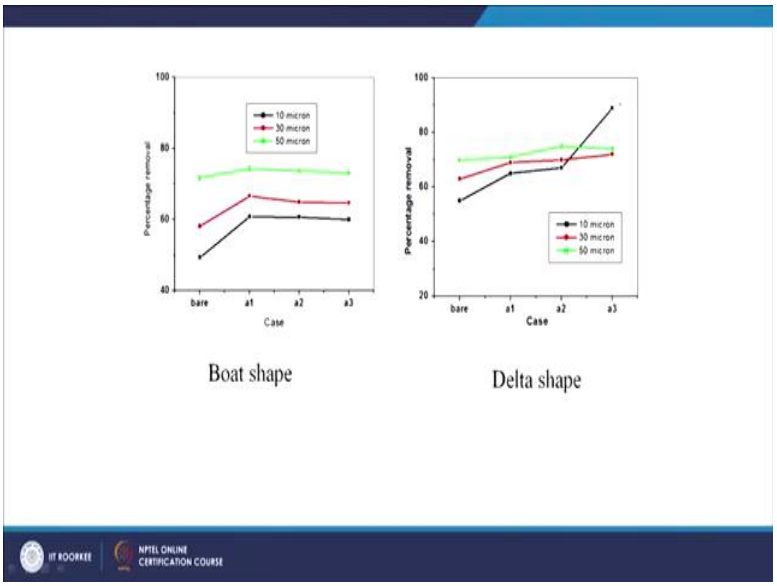

And, the only one trend which you see normally is that if you have the increased diameter of the particle so, removal chances are more because they will be expected to have more buoyancy and more strokes velocity. So, that way.

Now, the next kind of study which has been done is related to the influence of the tundish shape on the wall shear stress. So, if you have a tundish which is you know of you know different shapes in that case what will be the effect on the wall shear stress. Now, wall shear stress: why it is important because many a times we have the tundish lining and that lining has a particular life and that will be depending upon how much shear stress it is experiencing because of the flow of the metal over that.

So, it has been done for these tundishes and if you look at the you know this is how typically the velocity vector looks like. You see that how the metal is approaching over the you know walls. So, how they have the vector you know this vector. So, that they are having that kind of. So, that way they will also go on the walls and then they will have a shear stress because the velocity will be more.

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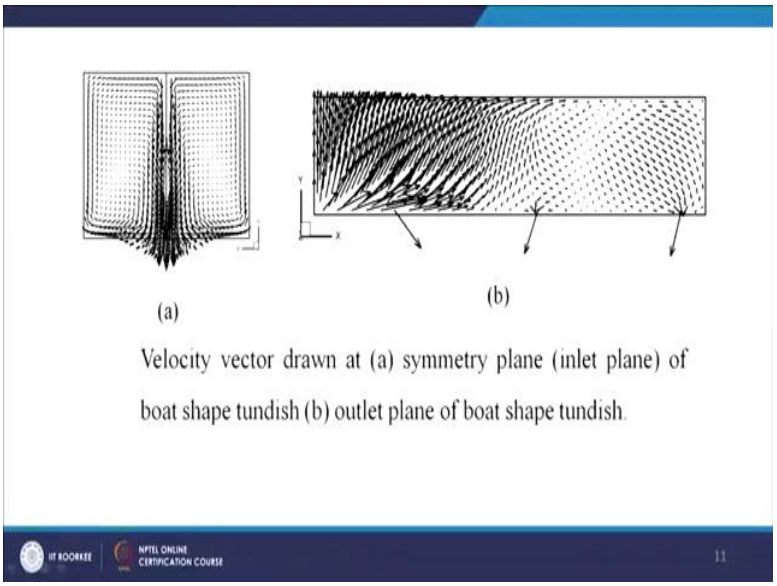

So, more velocity gradient that will lead to the larger value of the shear stresses. So, this is for the boat shape tundish and you see that it is moving and then you have a loop here and then metal is going out.

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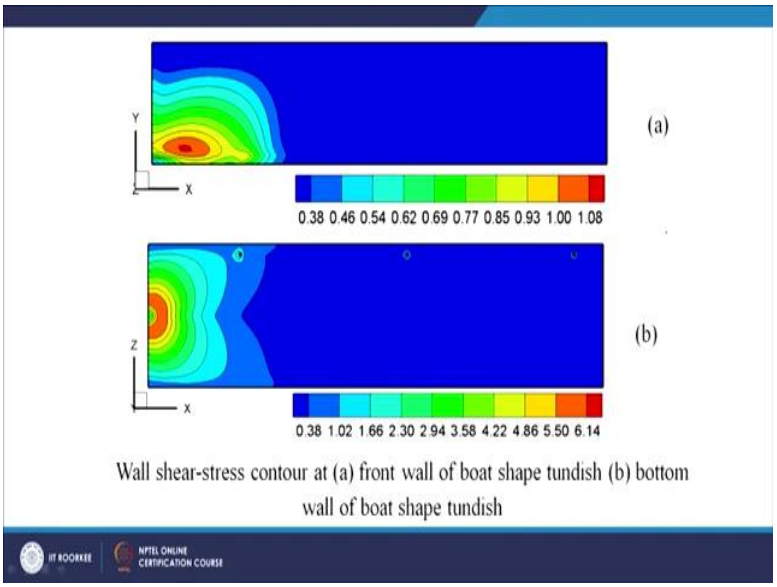

And, if you calculate these shear stress values wall shear stress values at the front wall and the boats of the boat shape tundish and also the bottom wall of the boat shape tundish. So, this is your bottom wall and this is your front wall.

So, if you see that in the on the front we have seen that it is it is raising. So, that way you know it is increasing the value now what do you see that on the bottom these values are quite high as compared to the value on the front wall because it is it is getting some time it is going and then it is moving towards the wall. So, that way it is taking that.

Now, on the bottom when it is hitting it is splashing and there is large value of shear stress that is generated. Now, you see the maximum value here 1 Pascal here. So, that indicates that the bottom wall is subjected to very high value of wall shear stress. And, that is the reason many a times we provide the impact pad type of you know arrangement so that the kind of erosion it is likely to generate because of this large velocity you know at the bottom and then splashing on all the sides and having the generated large value of wall shear stress.

So, this you know variation tells that you have the chance maximum chance of erosion of the you know the wall refractory on the bottom side and that is on the boat shape tundish.

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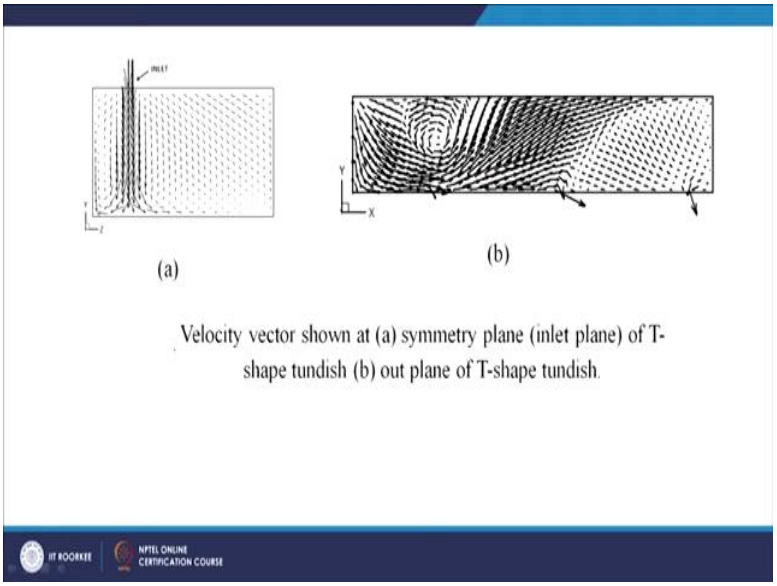

Come to the you know the T shape tundish and we have seen that how the velocity vector looks like you know on the symmetry plane if you see so, you will have this is the velocity vector and this is the you know velocity vector on the T shape tundish.

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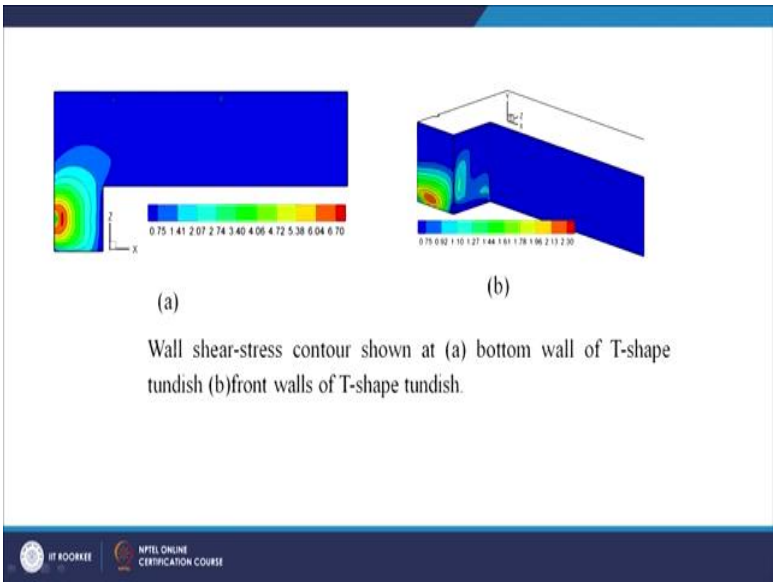

And, here when it was drawn the you know wall shear stress contours on the you know bottom wall as well as on the front wall. So, what you see that it is coming little bit higher as compared to the boat shape tundish this is 2.30 there it was 1.08 or so.

Now that is because the out inlet is here and this is closure. So, it will have a larger you know if you had their inlet with somewhat distant that will certainly be creating less amount of wall shear stress on the front wall. But, the most notable feature is the wall shear stress value again in this case on the bottom wall and on the bottom wall what you see is that this is your maximum value of the wall shear stress which is close to 6.7.

So, again in this case 2 you are likely to have the very large value of the you know wall shear stress and also more chances of the erosion from the bottom wall coming to the this is the velocity vector for the T shape tundish.

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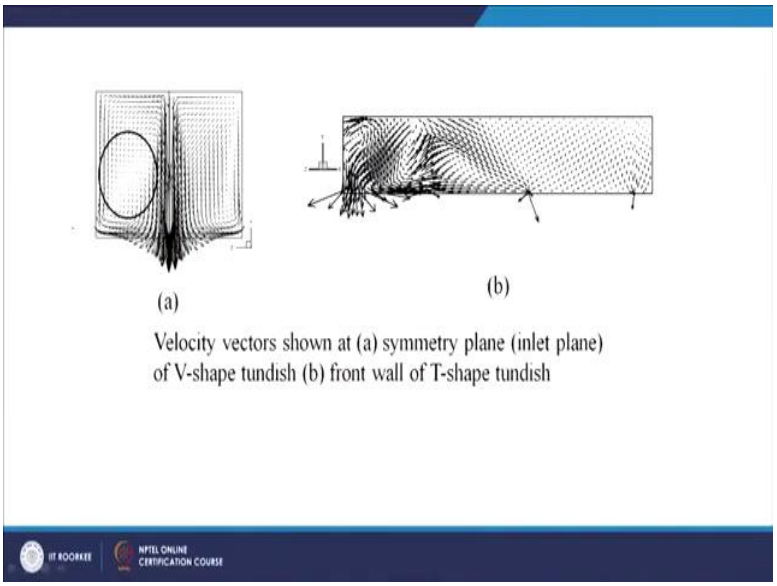

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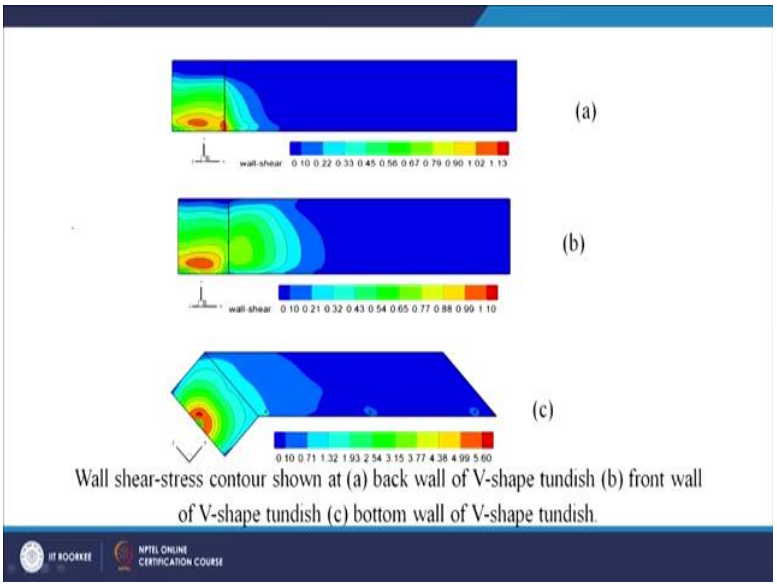

And, this is again this is for the V shape tundish and for V shape tundish as you see we have got the V shape tundish is this is the back wall and then you have the front wall and this is the bottom. So, on the bottom it is somewhat smaller than other two kind of tundishes and on the back walls it has somewhat of the similar order as you see in the case of the boat shape tundishes or delta shape tundishes. So, it is coming closer to that order. And, this value is also somewhere coming of the similar order, but somewhat less in the case of V shape tundish.

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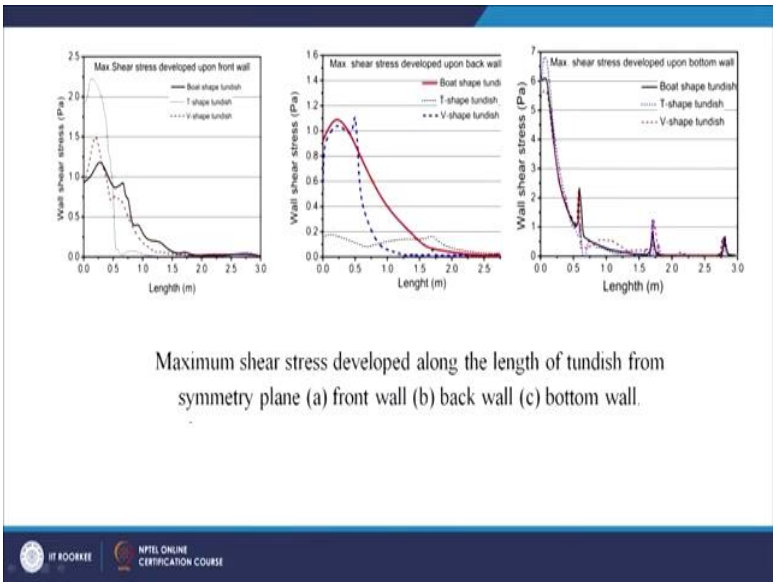

So, that is what we see that normally you can predict depending upon that you can have the prediction of the learning lap and even in those places you can have and additional you know refractory lining so that your lining life becomes more in the tundish than in the usual case.

So, that has been even you know studied with the help of the these graphs and you see that you have the maximum wall shear stress. So, that is in the T shape tundish that is what you see in these cases on the front wall. So, here also T shape tundish it will be seeing somewhat you know away so, maximum is in T shape.

And, if you look at the bottom you see that it is quite high in the case of T shape tundish as compared to other cases. So, with the length you can have that measured that how your you know wall shear stress value is varying. So, by that you can have one you know understanding and you can suggest in the plant.

Next part is about one of the work which the group has done is related to the influence of nozzle blockage on flow behavior. And, what happens that many a times you have the situation that you have to open close certain caster in the continuous casting unit. So, one of the because of clogging or because of maybe you know other reasons like a productivity you has to you have to slow down the process or so.

So, in that case it was it has seen that how the you know tundish behaves in that case and how the RTD behavior will look like and how the tundish will perform. So, that is because of that transitory opening case.

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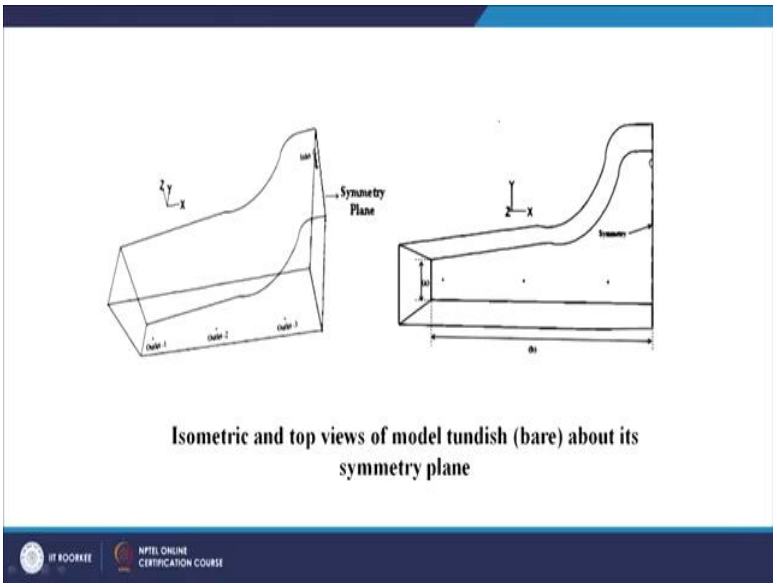

It is a curved type of you know tundish which is a typical industrial size tundish.

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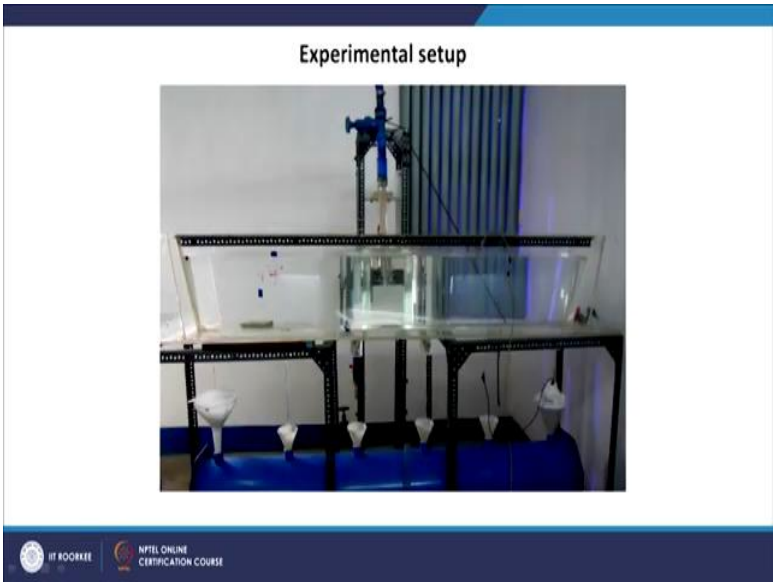

And, you know in that you know this is how some experimental work was done for the validation work.

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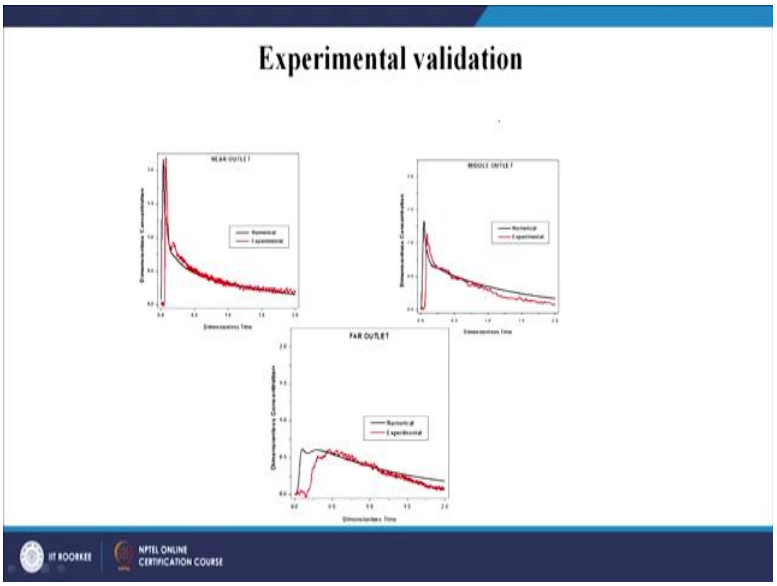

So, that was seen that validation is somewhat better in these two tundishes outlets.

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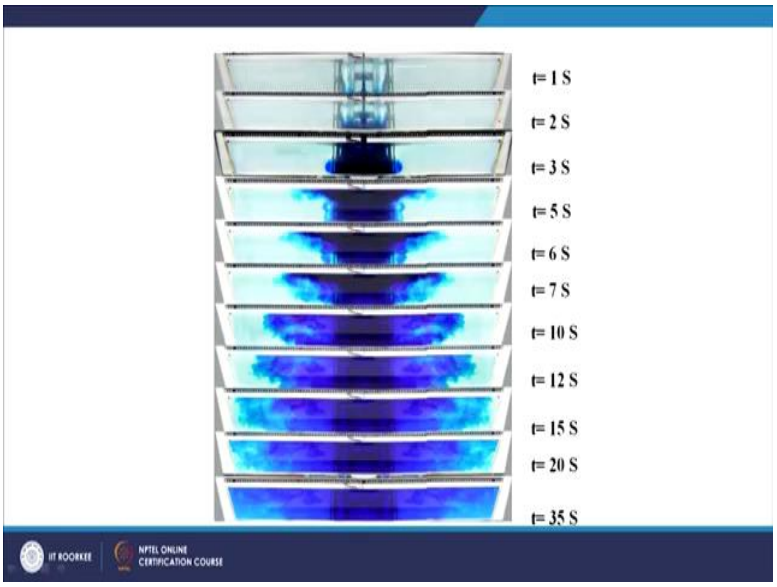

So, this is one part of the numerical modeling when you do. So, you do the validation and you can have also the feel when you do the physical modeling. So, how the dye is you know dispersing on both the sides. So, that is seen you know in this case. So, that is and one of the study.

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Different cases and conditions to perform simulation

Case	Outlet closed					
	Outlet – 1 (Far Outlet)	Outlet – 2 (Middle Outlet)	Outlet – 3 (Near Outlet)	Outlet – 4 (Near Outlet)	Outlet – 5 (Middle Outlet)	Outlet – 6 (Far Outlet)
1						
2	√					
3		√				
4			√			
5	√			√		
6	√				√	
7		√	√			

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However, then what we mean to say that what we did is there are few cases like one is when all the outlets are open in that case 2 you open outlet 1 which is the farthest one; in case 3 I mean you close it in case 3 you are closing outlet 3 that is middle outlet- middle outlet you are closing and in this you are near outlet you are closing. And, 4, 5, 6 is you are open closing two outlets 1 and 4 similarly you have 1 and 5 and you know 3 and 4 like that. So, you have these you can have different cases.

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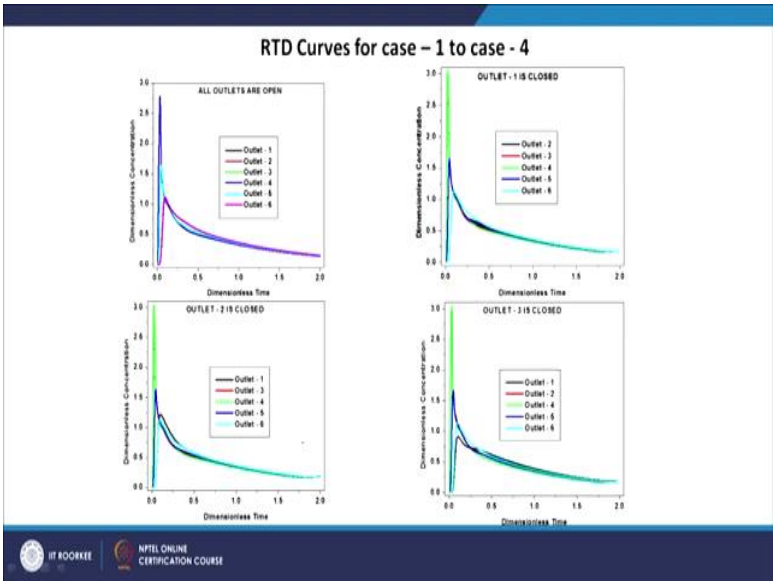

And, you can do the RTD analysis. So, this is RTD when you are having the outlet 1, 2 and 3 you can see 1 is the far outlet so, black one and then you will have. So, and then you will have the 3 and 4 will be you know green and blue. So, they will be because it is symmetry. So, green and blue you know will be together and you see that this is the bigger height.

Similarly 2 and 5 will be same. So, that is 2 and 5 will be this one and 1 and 6 will be by this one. So, that way you have the three these outlets on these outlets if you draw the RTD it behaves like this. Now, if you close the outlet 1 so, in that case you see that the outlet 4 which is near the inlet.

Now, in that case you see that there is increase in the peak you know at value more than 3. So, in earlier case it was less than 3 it was quite to 2.75 or so. So, it is decreasing and otherwise it looks somewhat similar, but then that is affecting it means it is affecting the fluid flow pattern. Now, in this case you are keeping outlet 2 closed, 3 closed.

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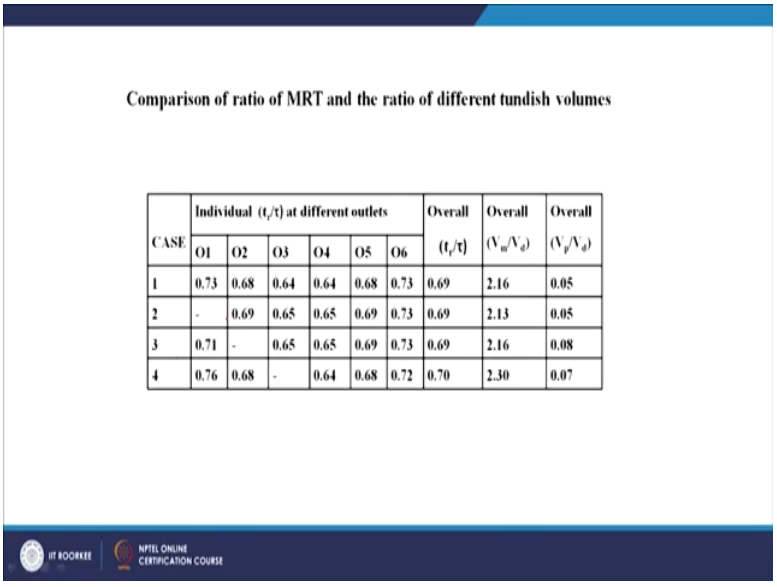

So, this way you know if you change then your overall ratio of the mean residence time you can have the calculation and you have to see that overall $\frac{V_m}{V_d}$ is maximum when you are closing 4 outlet four. So, outlet 4 when you are closing that is close to outlet the 3 basically in case 4 that the outlet 3 is closed this is the case which is giving you the best result because this is a near outlet and that leads to the best result.

So, because that you know that avoid short circuiting and that is how your $\frac{V_m}{V_d}$ is maximum.

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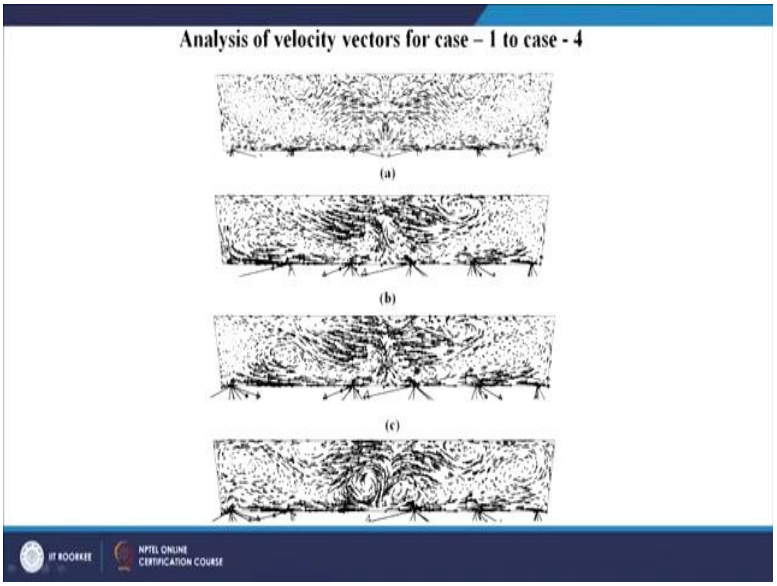

So, that is you can have the velocity vector you can see this is all the outlets are open here, you have closing this, then you have just closed this and then you have close this. So, your velocity vector you can have the analysis and you can see that how you know changes are there in the you know you see that this is a symmetrical case you have here and here and here you have all that symmetrical you have a closed loops.

Now, in this case after why you when you close it on this side you see a loop whereas, on this side you do not see. So, here similarly you do the closing here you see a loop here. So, like that in the smaller one in the larger region. So, this is like you know the change in the velocity vector which you observe in such cases.

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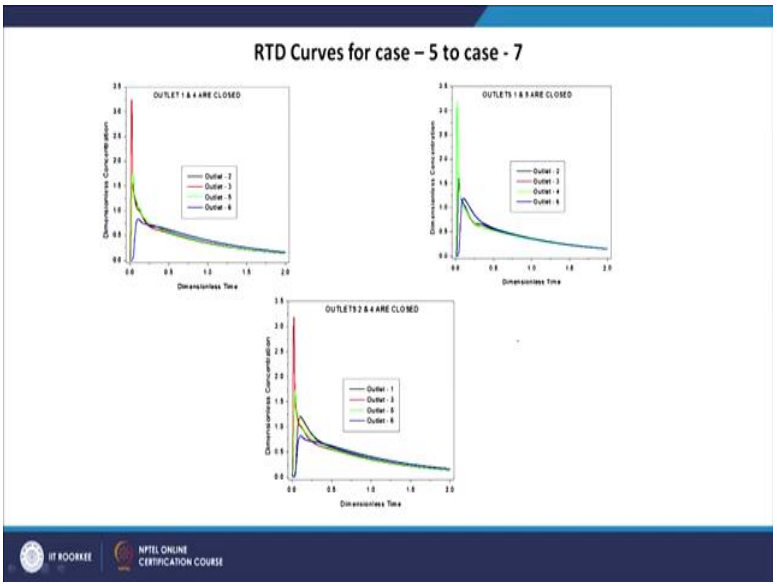

So, for 5 to 7 also when two outlets you are closing. So, you know in that case how your velocity vectors RTD is changing.

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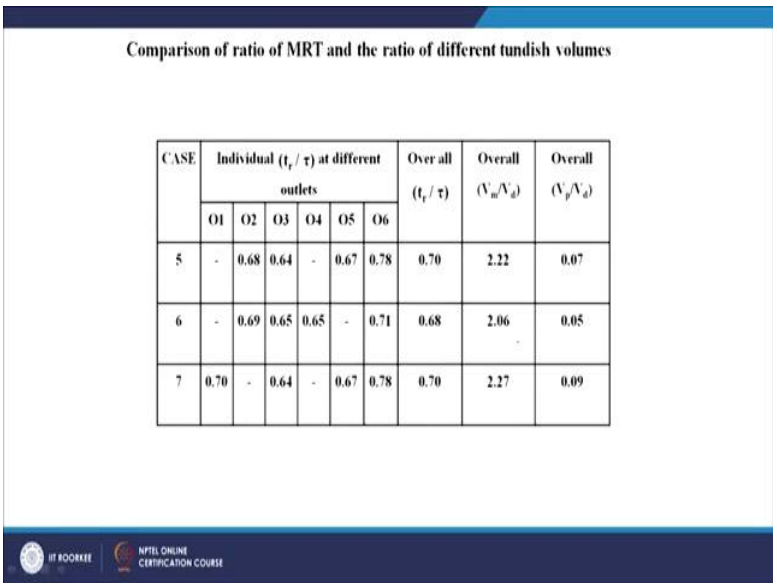

CASE	Individual (t_r / τ) at different outlets						Over all (t_r / τ)	Overall (V_m/V_d)	Overall (V_p/V_d)
	O1	O2	O3	O4	O5	O6			
5	-	0.68	0.64	-	0.67	0.78	0.70	2.22	0.07
6	-	0.69	0.65	0.65	-	0.71	0.68	2.06	0.05
7	0.70	-	0.64	-	0.67	0.78	0.70	2.27	0.09

And, how their effect will be there on the overall $\frac{V_m}{V_d}$ you see maximum value here in the case of 7.

So, this is one of the you know case where you can have certain studies on these cases this is about the analysis of velocity vectors that is changing.

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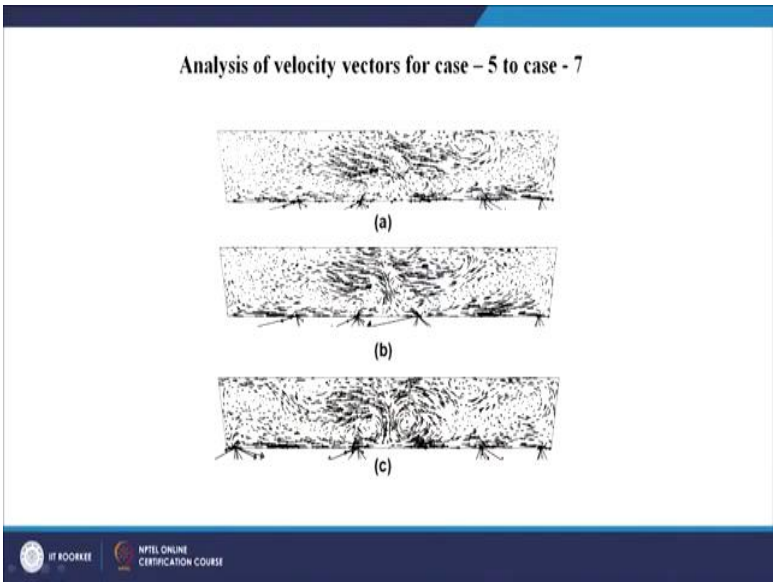

Now, in this case you are changing these two outlets and this and this outlet and then this and this outlet like that.

Now, there is another work which is very much going in the tundish is of importance is the interface level fluctuation and that is done using the VOF model and that is also one of the work which has been done by our group.

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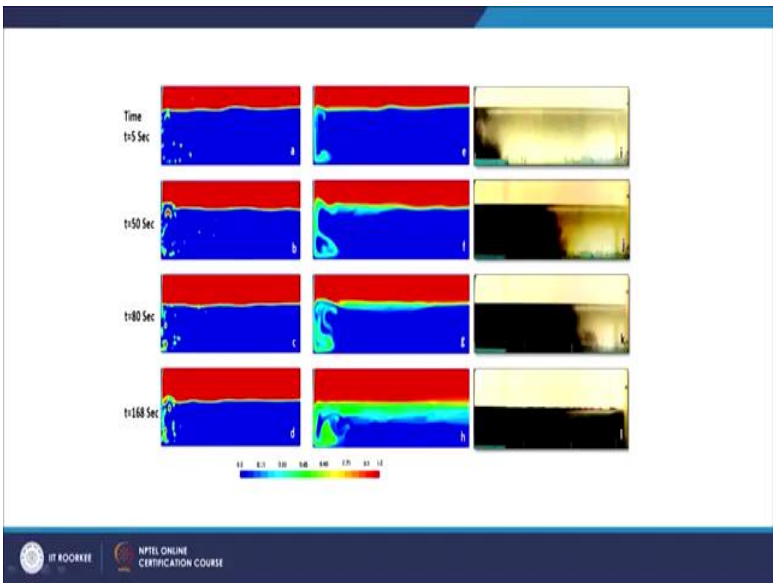

So, it is about you know the prediction of this level. So, as you see that you know this is was done for the grades and analysis and as you see that level is decreasing and you can

see that here also the level is being decrease and you can have you are having an interface. Now, that is with different scheme you know now you are predicting that interface.

And, for that also you have the different kinds of scheme which are available like you have the you know HRIC scheme high resolution you know image capturing the scheme and you have the geo recurs schemes. There are many a schemes where available in the softwares like fluent also there. So, you know and other softwares like you have the phonics and all other softwares are there. So, they will have the different you know schemes.

So, you can have the prediction and what you see that you see this sharp interface in this case. So, that is what is observed you know. So, these are you know some of the examples of the you know the work case studies which are done on the tundish and you can have the these modelling work you can practice and have more and more confidence and you know work for the industry or they or for the or you know own research.

So, thank you for the patient listening to the lectures and I hope that you are going to get benefit and you are having satisfaction of the lectures which has been told. But, what I feel that you should have a practice of on the course and either developed by you or on the you know software codes and you should try to solve these problems you know live you solve the problems and try to get the solution. So, that will increase your confidence and you will be benefiting most out of these courses. So, thanks once again.

Thank you very much.