Modeling of Tundish Steelmaking Process in Continuous Casting
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Lecture – 10
Consideration in Aqueous Modeling

Welcome to the lecture on Considerations in Aqueous Modeling. So, we will talk about the issues and which are considerations, which are required in the case of aqueous modeling or water modeling. So, we will talk about the different aspects in this lecture. So, coming to the issues or considerations which are required as we have discussed in the past that the first thing is the consideration about the scale factor.

So, as you know that you need to have the selection of proper scale, you have seen that if you try to have the similarity criteria using the Reynolds similarity or the Froude similarity, we have the different you know many a times you get if you talk about you know velocity of the model. So, as compared to velocity in the actual case, you will have that in the function of either $\frac{1}{\lambda}$ or $\sqrt{\lambda}$, so either λ, either scale factor.

So, you know now the thing is that many a times the both can be satisfied only when the λ is 1, so that becomes you know very, very expensive means your model has to be of the same size as that of the prototype. So, it will become very, very expensive.

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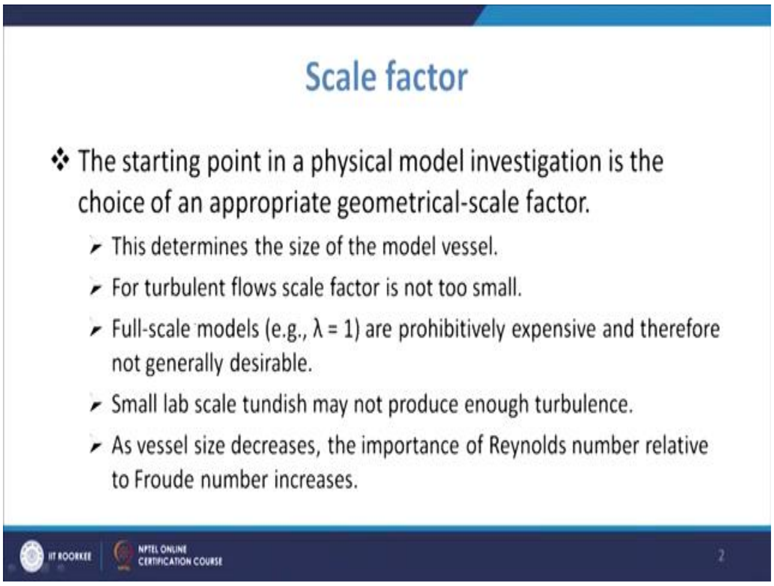

So, you know, so basically in the starting point in a in a physical model investigation is the choice of the appropriate you know geometric scale factor, and you will have that basically determines the size of the model vessel. You know for turbulent flows this fill factor has not to be very small.

Now, as we see that the full scale models, if you try to have the try to satisfy both the similarity Reynolds as well as Froude, so you will have to have the λ is 1, and then that case you will have the very large model and that will be very very expensive. Then you know when you are talking about the turbulent flow. So, if you take very, very small, you know scale factor, in that case it may not represent actually the flow which is taking place, so that is because that is you know not going to create the you know turbulence enough turbulence inside the Tundish.

So, because as the vessel size is you know decreasing, the importance of Reynolds number relative to Froude number is increasing, and that is why you will have to have you know the properly you will have to see that what should be the actually the scale factor. So, you know once you come to decide about the scale factor, then next comes the choice of the working fluid.

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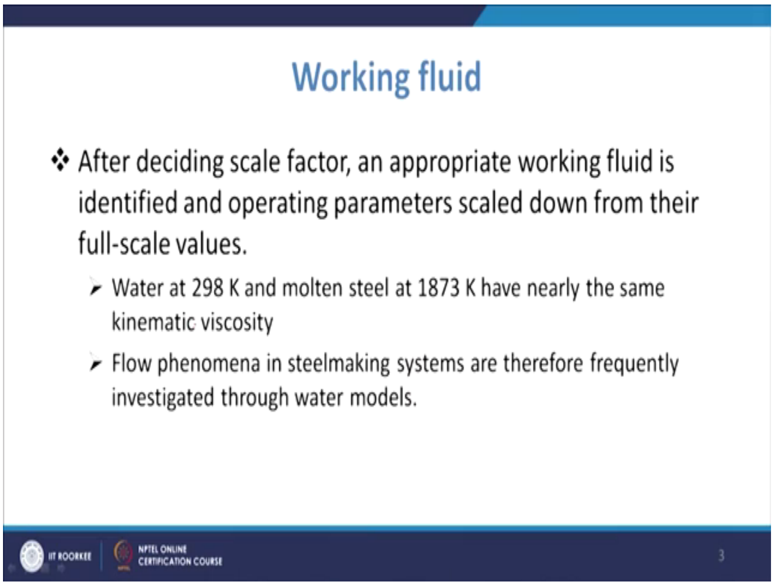

Now, if you talk about the working fluid, so this is a very important you know consideration, because there are many kind of fluid, but then you will have to look into those aspects that which is readily available and which satisfies those conditions. So, you know you know water at 298 K now it has been found that when you take water and which is at 298 K or about 25 degree Celsius that is your normal room temperature. And if you take the molten steel at 1873 K, so what has been seen that they have nearly the similar kinematic viscosity that is $\frac{\mu}{\rho}$, and that is why it very much you know you know helps you know ensure that you have the similar flow regime you know established in both the model as well as in the actual Tundish. Then also flow phenomena and steel making systems are that is why they are frequently investigated through these water models.

So, so water is taken as a very you know most acceptable kind of fluid, which is used for the modeling studies in case of the steelmaking operations. So, there are many reasons for water being selected as the fluid working fluid.

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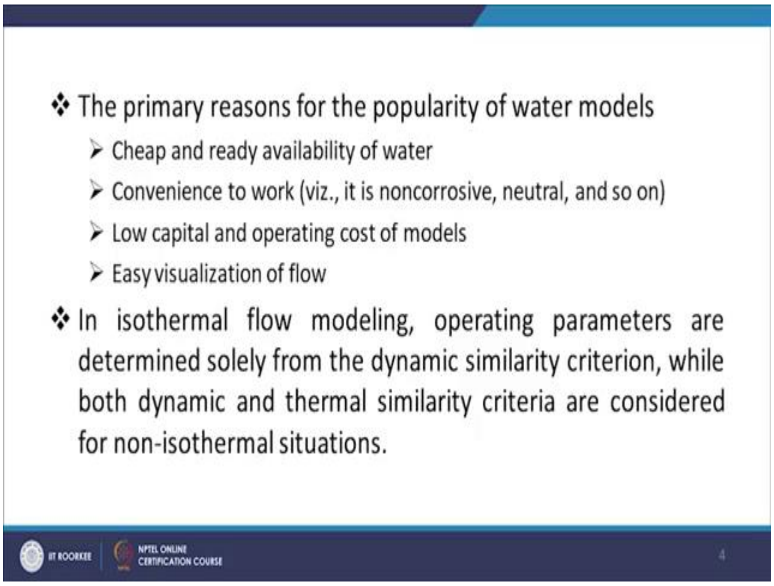

And those reasons are that water is cheap and also it is readily available. So, you can have water at all the places, so you know that is why it gives you a very good choice to have the water; otherwise other things will be costly. It is convenient to work with water, because it is non-corrosive it is also neutral, and it has many you know of the qualities which make it very very you know good for handling.

So, you know you can use it with much of ease and that is why it has lot of advantage over other fluid. It has low capital and operating cost of the model. So, if you are making the model with working fluid as water, then certainly you have the requirement of low capital cost as far as the working fluid is concerned and also you will have a low operating cost of the model.

Also this is also one of the very important you know property of the water that you because being the transparent; if you keep that system, if you make the you know physical model with the Perspex sheet, in that case you know you can have easy visualization of the flow if a water flowing inside the vessel. So, that you know that is further giving you another added advantage and that is why these are the reasons because of which you are you are taking the water as the most popular you know working fluid.

So, in isothermal flow modeling, the operating parameters are determined solely from the dynamic similarity criterion, while both dynamic and thermal similarity criterion are considered for the non-isothermal situations you have already we have discussed that when we talk about the isothermal system. In that case you have the dynamic similarity criterion solely to be you know taken into account, but when we talk about the non-isothermal situations in those situations, what we see is that you will have to have the thermal similarity you have to whether you whether you know non-dimensional numbers coming into picture and they also that condition also need to be met you know in those situations.

So, you know what we see is that normally what we see that when we talk about the Froude number, so it is a function of the velocity and length. So, you know that the Froude number which is nothing but the ratio of the inertial to the you know, the gravitational force. So, you will have the velocity and length you will be there. And you will have the thermo physical properties which are they are like velocity or density.

So, you know so they are expected to exert a lot of you know effect you know on the flow which is Froude dominated, so that is why you know we what we see is that you know that any liquid in principle can be used to represent these molten steel flow in that Froude dominated flow regime.

Now, many a times as we as we have discussed that we are taking the water as the most acceptable you know working fluid. So, we what we do is we do the scaling, and then you know we do make the models, the physical models built on those scaling factors. So, for example, you know if you see that you may be having you know situation like you are told that you are to make a physical model, and you are given the scale factor also.

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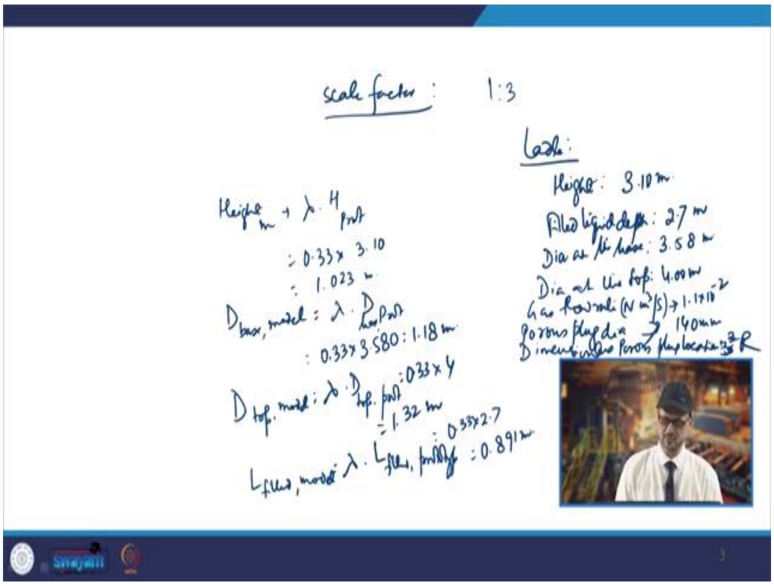

So, suppose you are given the scale factor, and you are you are going to make a $\frac{1}{3}$ model. So, $\frac{1}{3}$ means 0.33 is the scaling. So, suppose you have you have to make one you know industrial ladle. So, for the ladle if you know if the for that industrial sized ladle, you know if the height of the ladle is given as 3.1meter. Similarly, if you are you know filled liquid depth, so that is given as suppose say 2.7 meter, so that will be total height is 3.1, and the height up to which the liquid has been filled that is your 2.7 meter. Then if you say it is given that if you dia at the base it is given as 3.58 meter, similarly dia at the top so it is given as the 4 meter.

So, and then you have the gas flow rate. So, that is in case of that is Newton meters cube per second and that is given as $1.1x10^{-2}$, then you have a porous plug dia which is there in this case, so that is given as 140 you know and mm. So, this is in terms of millimeter. And also you have dimensionless plug location porous plug location, so that is $\frac{2}{3R}$.

So, now if you talk about the making the model, in that case if you take these scaling factors, you can have the you know height as height of the model ladle, it will be something like you will have $\lambda * H_{Protype}$. So, it will be 0.33 multiplied by 3.10.. So, it will be so you will have or $\frac{1}{3}$, you can have or if you multiply with point $3.1 * 0.33$, so it will be 1.023 something like meter.

So, if you go to the diameter of the diameter at the base of the model, so you will calculate as again $\lambda * D_{Protype}$at the base. So, diameter at the base of the prototype is given as 3.58. So, it will be $0.33 * 3.58$, so it will be 1.18 meter. Similarly, you will have calculation of other you know parameters like you have with the diameter at the top of the model, it will be a $\lambda * Top\ D_{Protype}$. So, diameter at the top of the prototype, they will be 4 meters, it will be $0.33 * 4$, so it will be 1.23 meter.

Similarly, the liquid filled in the up to white up to what height in the model it will be again $\lambda * Liquid\ filled_{Protype}$.. So, this way you can calculate. So, it will be liquid filled is up to the height of 2.7, so it will be $0.33 * 2.7$ Newton, so it will be 0.891 meter. So, this way you can have the value of these model. What you see that in this case the location will be still maintained at $\frac{2}{3R}$, because you are anyway changing.

However, these porous plug this diameter, so the you know this need not be changed because the this is basically you know if this diameter of that injection gas injection device that need not be changed, because you know what happens that these stud ladles are normally the potential energy driven. So, we can have the there you know value as the same one.

And what you can see that you can have the calculation of the you know Froude similarity, so you can have the Froude similarity criteria and you can see that how they are matching, so that is the use of these scaling factors in finding and if you try to have the value of you know other parameters also you can calculate like even calculate for the you know Q also. So, you also can be calculated and even the isothermal and non-isothermal you know conditions may also be taken into account. So, so this way the use of these scaling factors is there in the case of modeling.

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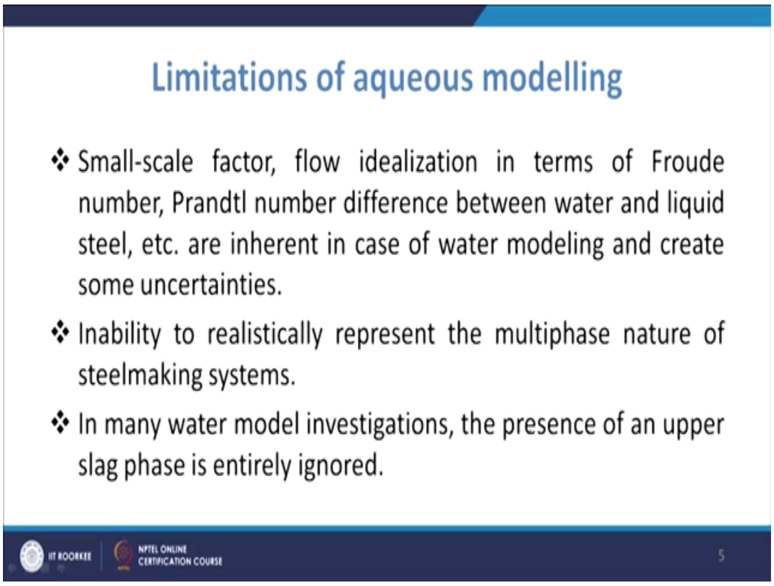

Now, coming to the limitation of the aqueous modeling so, now there are certain limitations to these water modeling also, because many a times we are taking, so as we discussed that on many accounts we have to have certain compromises. So, small scale factor flow idealization in terms of Froude number, Prandtl number difference between water and liquid steel etc. are inherent in case of water modeling and they create the uncertainties. Because, if you look at the physical properties of water and steel, so you will have the differences in these number values, and they are going to inherently cause certain kind of uncertainties in the case of aqueous modeling when we are taking water as the working fluid.

Inability to realistically represent the multi phase nature of a steelmaking system. So, as we see that when we talk about the you know steelmaking system, so what we see there that you have the molten steel at the bottom, and then you will have the presence of the slag, and then you have the air also and they will be interacting. So, if they will have interfaces in between them, so it is basically a multi phase system kind of you know environment which is there.

Now, you cannot realistically you cannot go very close to the actual system, because it is very difficult to have the similar kind of system because that is at a very high temperature where you will have the molten steel, and then above the steel you will have the molten slag. So, you know you cannot realistically represent these you know multiphase nature of the steel making system in a very realistic manner, so that is basically one challenge which is there or one you know concern, so that is the limitation.

So, many people have tried to even you know take into consideration you know things like a you give certain wood floor or so at the you know at the surface of the water. So, that may represent you know the slag which is there in the steel making vessel like Tundish or ladle, but that is not the true representation that will not truly represent the situation which will be there inside the Tundish, so that becomes you know a challenge in the case of the aqueous modeling.

In many water model investigations, the presence of an upper slag phase is entirely ignored. So, what we do normally that we are ignoring this slag level. So, when we are going for the solution, because when we do the physical modeling, so based on the physical modeling results and we also so these results are used to validate first, and then we try to have the results from the numerical investigation.

Now, as in the normal case you will have the slag present above the molten steel and that is basically ignored in most of the cases. So, so ignoring this slag phase is the only way by which you can you know ease the computational method or solution methodology when you at modeling through the numerical you know means. So, so, so in many water model because you do not have actually that kind of you know material which should represent, in fact, the slag which would very much replicate the kind of you know event or the kind of activity which is you know done by the slag at the top level of the steel.

So, that is many investigators have try to do it through the use of either you know wood floors or so, but then in most of the cases we try to ignore it. So, so that certainly leads to certain kind of error and that is one of the limitation of this aqueous modeling which is seen you know which is a still researchers are trying to have the you know they have cases by which they can replicate these you know slag flow also, it is like can be taken into account, so that is one challenge.

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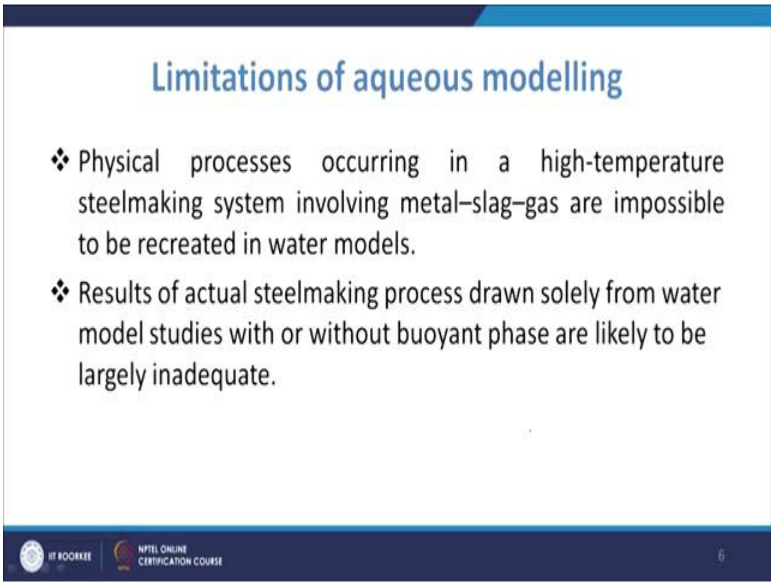

Physical processes occurring in a high temperature steel making system involving metal slag gas are impossible to be recreated in water models. So, as we discussed that it is very difficult to have the recreation of that system which is in actual present in the steelmaking case like you have the metal, then you have the slag and also you have the gas. So, it becomes a three phase kind of system which is nothing but the multi phase system, and you cannot make in water models.

Because you know that the gas system is anyway impossible you know in such cases, so that is becoming one of the you know limitation of the aqueous modeling. You have results of actual steel making process drawn solely from water model studies with or without buoyant, buoyant phase are likely to be largely inadequate.

So, many a times we go for the isothermal analysis, we are not taking the thermal analysis into account, because when we if we talk about the actual system, so when the ladle basically is supposed ladle when ladle is there is ladle change over the steel which the other ladle has given or the temperature which is there of the still in the Tundish, and the steel temperature of the coming ladle they may be entirely different. And that may result into the buoyancy forces, and these buoyancy forces they affect the fluid flow which occurs inside the vessel.

So, when we are talking about the water modeling, so in most of the cases, we talk about the isothermal analysis and in those cases we are neglecting these buoyancy forces and that may not be truly representing the kind of phenomena which is going you know to take place inside the Tundish. So, that is another you know limitation of this water modeling when we do in the case of these aqueous modeling. So, these are the limitations in the case of water modeling.

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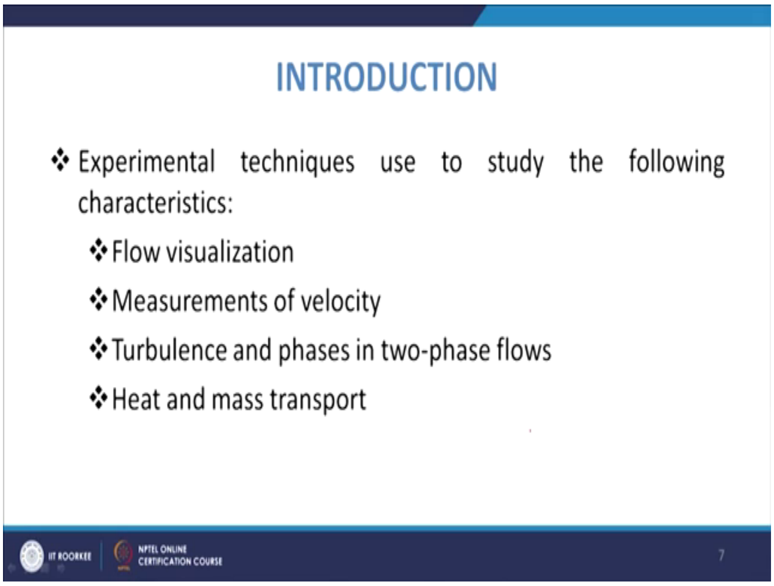

So, introduction to the experimental techniques which are you know used to study you know in the aqueous modeling. And you have many experimental techniques which are used for studying these flow modeling is the flow visualization, then you have measurement of velocity, you have turbulence and phases in two-phase flows and then you have heat and mass transport. So, these are the things which you need to study using the experimental techniques.

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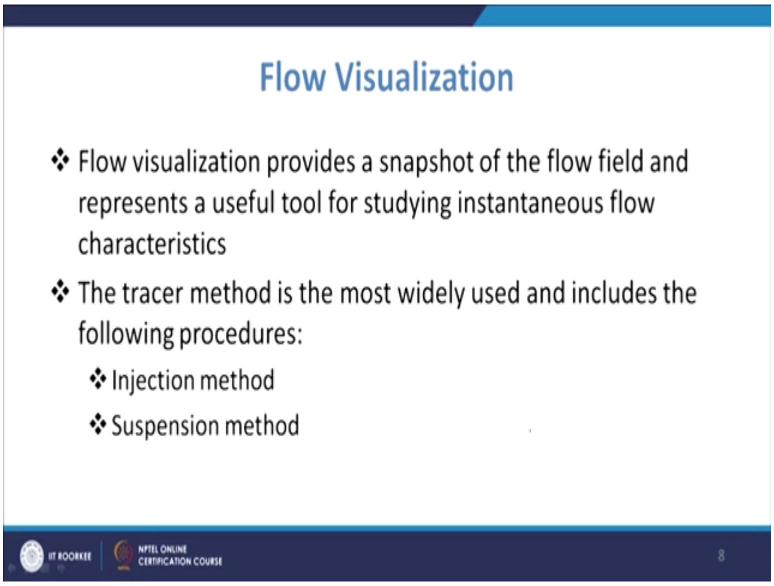

So, if you come to the flow visualization, so you know what happens that in the if the flow visualization, it will be providing you the snapshot of the flow field and it will be representing a useful tool for studying the instantaneous flow characteristics. So, what we do is that we normally make the Tundish model or the ladle model using a Perspex sheet which is transparent, so that you can visualize the flow. And what we do is normally we put the tracer so and then the tracer method is most widely used and for that there are different procedures. So, you have the different way.

So, one is the injection method. So, what we do is that in this case we inject certain tracer, and this tracer once injected it will go and it will be dispersed inside the vessel, so that vessel is you know either it is Tundish or ladle. So, it will be going inside, and it will you know dispersed will diffuse inside the Tundish, and it is concentration will be monitored you know at different points inside the vessel or at the outlet of the vessel the Tundish or the ladle.

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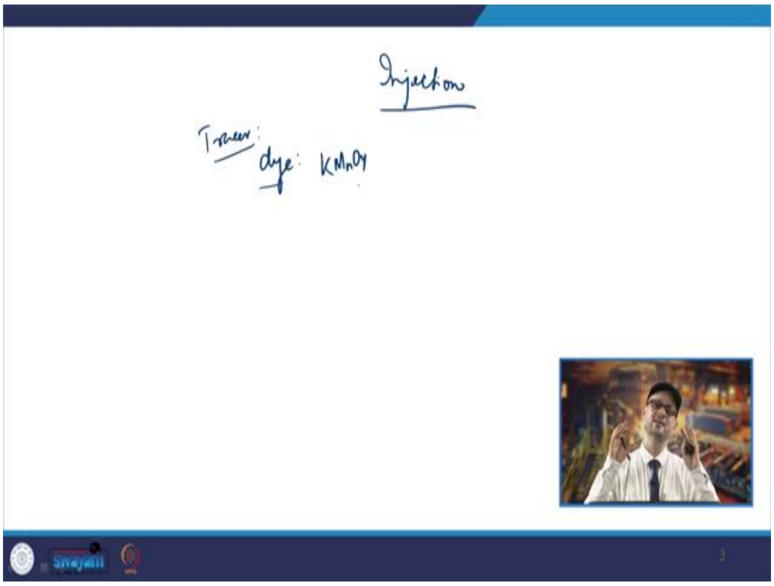

So, normally when we talk about the you know this injection method, so in that we use certain tracer and this you know tracer is normally a dye, so that is you know this we use a tracer or a dye. So, this typically it is a dye that is $KMno_4$. So, this is $KMno_4$ solution or you have you know other you know neutral kind of buoyant fine particles which are used as the, you know these tracer particles. So, there will be you know it may be silver coated you know glass bubbles also, so that will be going into it, and there will be there will be floating. So, they will be injected into the flow and then they are you know flow is observed. So, and you know that is being traced.

Then you have the suspension method. So, here you will have the suitable you know suspended particle is there. So, you will have suitable tracers like small pieces of silk, so its movement will be you know traced, so that is also another one by suspension you can have its trace, so by that you can have the study of the flow.

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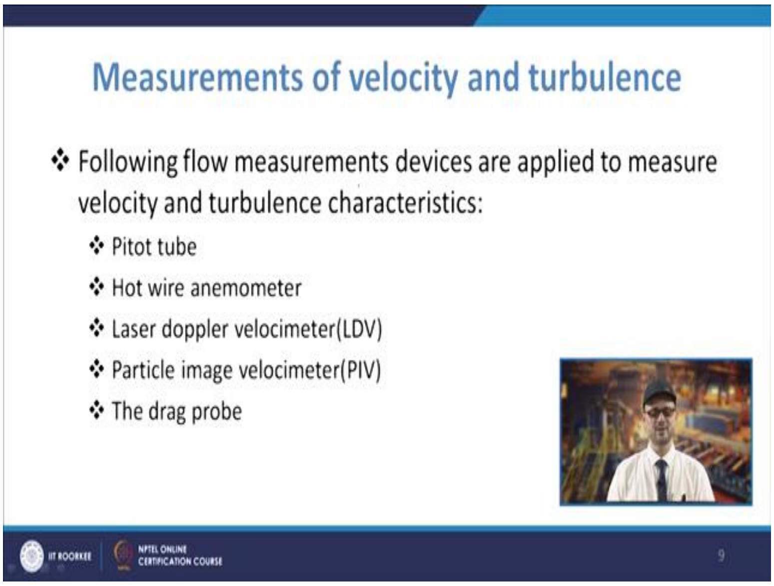

So, apart from that you will have the different flow measurement devices are applied to measure the velocity and turbulence. And in that you have pitot tube, you have hot wire anemometer, laser doppler velocimeter, the PIV is very much used in the case of physical modeling, where you try to have the you know velocity profile at certain section, so drag probe. So, these are the different you know ways by which you measure these you know velocity and flow profile.

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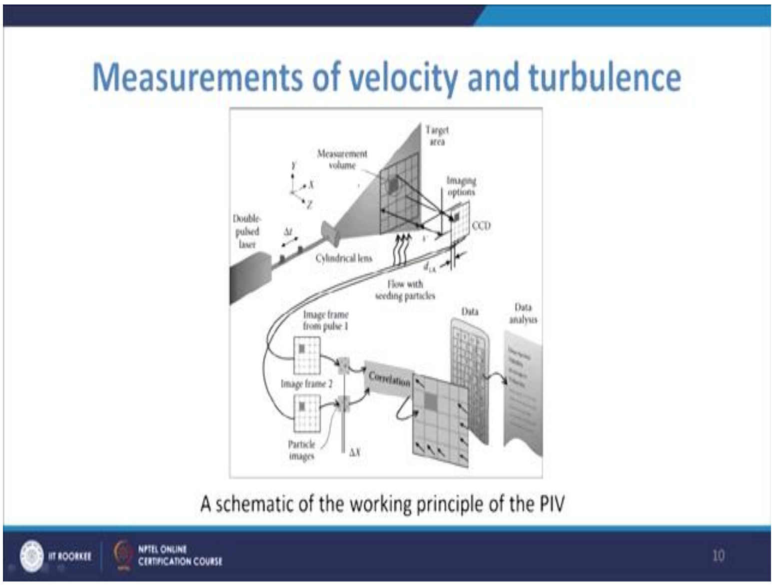

So, this is how your velocity and turbulence and PIV setup looks like. So, in that case you find the, you know the velocity profiles inside the vessel. So, this is about the, you know physical modeling aspects, the issues and challenges with that. And when we talk about the case studies and when we talk about other aspects, then we will have further you know discussion about these topics and we will have a more clarity in our, you know understanding.

Thank you very much.