Modeling of Tundish Steelmaking Process in Continuous Casting

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Lecture – 06
Introduction to Physical Modeling

Welcome to the lecture on Introduction to Physical Modeling. So, in this lecture, we are going to talk about the principles of modeling in what different way the modeling is to be carried out you know for the Tundish Steelmaking Process.

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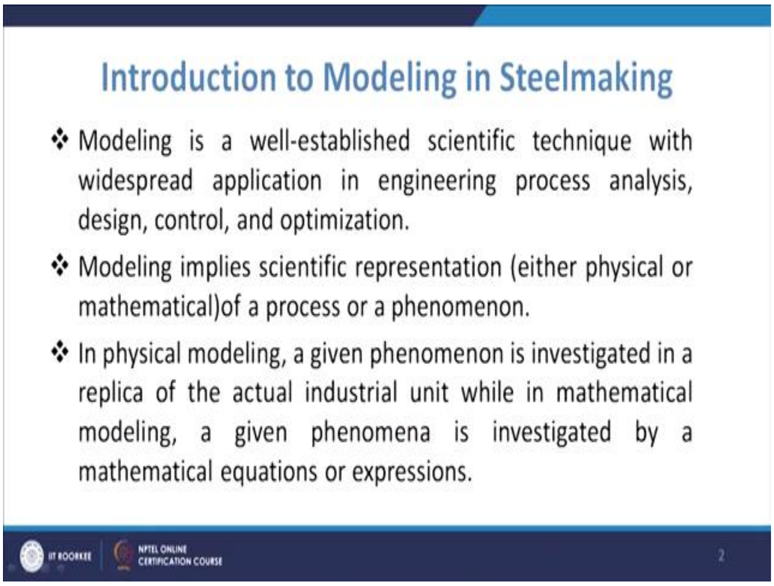

So, if we talk about the modeling term as we know that modeling is a well-established scientific technique with widespread application in engineering process analysis, design, control, and optimization. So, as we know you know modeling is very much known term nowadays most of the processes being modelled, and you know we use different scientific techniques, and its use is in the different areas. So, it is used for ascertaining the you know characteristics of the system.

Many a times we do the modeling first and then we try to have the plan for further execution of the processes. So, in the case of you know modeling, now normally when we talk about the model, so in the case of steelmaking, you have either the physical model or the mathematical model.

So, physical model will be something in which we make a physical setup. And in mathematical model, we are making a model which will be set of equations or expressions, and it will be talking about the behaviour of the system and that is used for the prediction of you know the parameters and its effect on the flow characteristics or other related you know processes. So, it implies scientific representation either physical or mathematical of a process or a phenomenon.

In physical modeling, a given phenomena is investigated in a replica of the actual industrial unit while in mathematical modeling, given phenomena is investigated by a mathematical expressions. So, as we discussed that normally whatever we try to model, many a times you know we make the small model of that particular you know experimental setup or you know often you process, and there certainly there are many kind of changes, because there is another term that is the pilot skill experiments. There also you do the experiment and there again you have the scaling done.

So, in the case of physical model basically when we talk about the steelmaking process, in the case of physical modeling not necessarily and in fact, not at all I mean we normally use the different working fluid, because it is very difficult to work with you know experimentally on the working fluid as molten steel itself. So, what we do is we take the different kind of working fluid, normally we take water as the working fluid. And if we talk about the material of the tundish or the ladle, so that material is also not the actual one which is normally you know a refractory lined vessel or so.

So, here we use it use the Perspex sheet as the tundish or the ladle, so that is your physical model. And if we talk of the mathematical model, so mathematical modeling will be carried out by representation with the different set of equations. These equations will be the governing equations and they will be you know talking about the processes conservation of you know either mass, momentum or chemical species.

So, this way you have different set of equations, and this involves the knowledge of mathematics or science and engineering to have those you know expressions which truly represent the processes which are occurring. So, that is your mathematical model. So, in that case, you have mathematical expressions which are used for the modeling. So, if you talk about the need of the model, if you look at the model, so you have the physical model, and then you have the mathematical model and in physical model you have normally scale up or you can scale down.

So, normally you go for a scale down, so you can go for the you know scale up or scale down. Then in physical model you can have the cold model as well as the.

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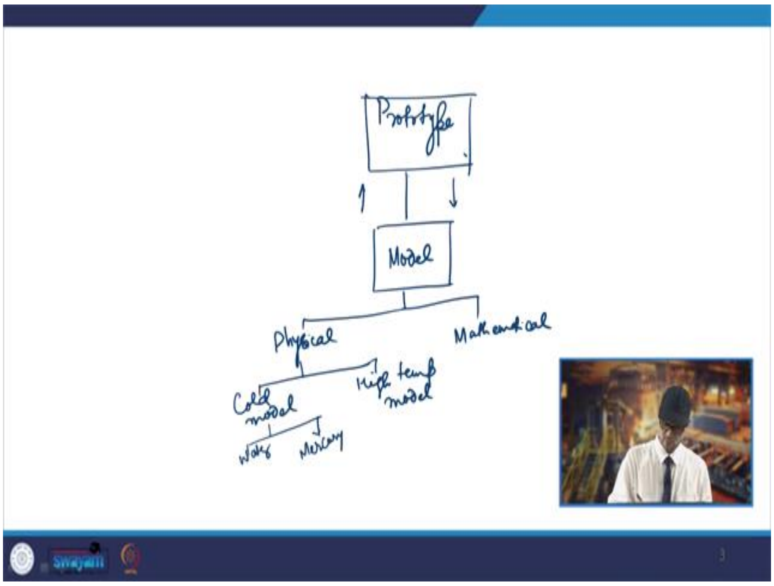

So, if you try to have the classification of the model, so if suppose you have basically you have one is prototype. So, prototype is the you know actual size. Now, in that you may have you will make a model. So, from here you will make a model, and that model may be by scaling up or by scaling down. So, you can go by scaling up or you can go by scaling down, so that way a model is made. Now, that model, so this model further will be one is physical model and another is mathematical model.

So, you know we will be talking about the physical model in this lecture and this week. And we will talk about mathematical modeling part further you know as we move forward in this course. Now, in physical model, you can go for the cold model studies, and otherwise you can also go for the high temperature model. So, that way you know you can go for the so cold model means the working fluid will be at a room temperature it a you because it is very difficult many a times to work with the working fluids which is actual that its temperature is more than 1500 degree centigrade.

Now, in that there has been working fluids which are being used. And either you can use water as the working fluid or even many a times some people have worked and taken the mercury also as the working fluid, so that way your physical modeling is carried out, and mostly we do go for the cold model.

If you go to you know high temperature model, so there are they are also done with some different kinds of you know metal and in that basically you may have you know the use of metallic melt or what we talked earlier that you have pilot-scale experimentation which go on, so they are you know part of this.

Then if you come to mathematical, so in mathematical model certainly you are making different type of you know equations you know these are conservation equations, and then we apply the boundary conditions which are subjected to the domain, and accordingly we try to predict the output parameters which are of interest to us. So, that is how these you know the you can have the idea about the development of model either physical or mathematical.

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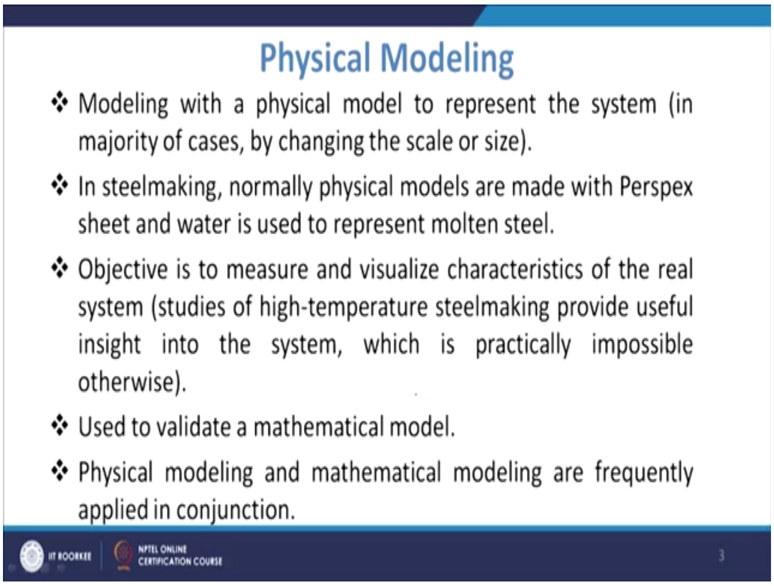

So, coming to physical modeling, modeling with a physical model to represent the system, in majority of cases by changing the scale or size. So, in fact, you have a physical model which is in front of you and you work with it and that is used for representation of the system. In most of the cases, we are changing the scale or size. So, normally we are reducing in most of the cases.

So, if suppose in industry you have a tundish of say 2 meters of or 3 meters of length, so you can have a reduced scale model physical model of 1 meter length, so that is because the handling of the larger vessel that will be problematic. So, we make the smaller you know models, but certainly necessary I mean accordingly you will have to change many things that we will discuss later.

In steelmaking, so we are normally we are using physical models with Perspex sheet and water is used to represent the molten steel. So, normally the models are made with the Perspex sheet which is transparent and that is strong also you can have the tundish made by the Perspex sheet and that can be fabricated by the fabrication techniques using glues and so. And since they are opaque I mean transparent, so you can see from outside also, and study the flow behaviour which is going on inside the Perspex tundish.

Then we use water to represent the molten steel and there are reasons for that. One is that you know water if you talk about the kinematic viscosity of water at room temperature and that of the steel at its own melting temperature they are somewhat similar, they are very much closer. So, you know when we talk about those similarities in that case when we talk about the fluid flow another analysis. So, in those cases we can go with that, so that is why water is mostly used and also water is easily available.

So, and in water also this is being transparent. So, when we do the tracer dispersal studies, you can have the visualization in a more transparent you know you can see it properly visualize it, so that is why water is used. So, objective is to measure and visualize characteristics of the real system. So, studies of high-temperature steelmaking provide useful insight into the system, which is impossible otherwise, because you cannot have the visualization on the actual system where the steel is flowing.

So, because of the very high temperature and also it is not transparent. So, what is happening when you know any kind of diffusion is taking place or any kind of alloying elements go into it or there are inclusions how they are going to float so or in which zone the steel is still showing stagnation or so.

So, these things can be seen by visualizing the flow behaviour when you have a colour contrast when we put the tracer inside and by that we can have an insight of that using the physical model, so that is why physical modeling becomes very important when we talk about the tundish steelmaking. It is used to validate also a valid mathematical model.

Many a times this physical modeling is used for the validation purpose, because as we discussed that either you will have to go for the actual plant readings or you will have to go for the pilot-scale experimentations, then only you can have the actual data, and you can have a you know prediction about the behaviour of the system. So, many a times what we do is we work on the physical model, and from there we are getting certain results, and from there we try to validate it.

So, if you we are getting the accordingly the similar kind of results for the actual cases also for certain parameter, in that case we say that the model is validated and then further the predictions of many kind can be made by using these mathematical models, so that is the you know beauty of the or usefulness of the physical model. Physical modeling and mathematical modeling are frequently applied in conjunction.

So, many a times when we are going for mathematical modeling, we do the physical modeling, so that there is you know more of the faith in the scientific you know manner can be put in onto the mathematical model. And when we do the physical modeling, so there can be infinite number of experimentation you know permutation and combinations.

So maybe we can do it using the mathematical model, and then be accordingly we can you know limit those set of experimentations to have the you know prediction the to have the prediction of these input parameters on the output performance measures. So, most of the time when we go for physical modeling, we also do the mathematical modeling; or if we have to go for mathematical modeling, we also make the physical models.

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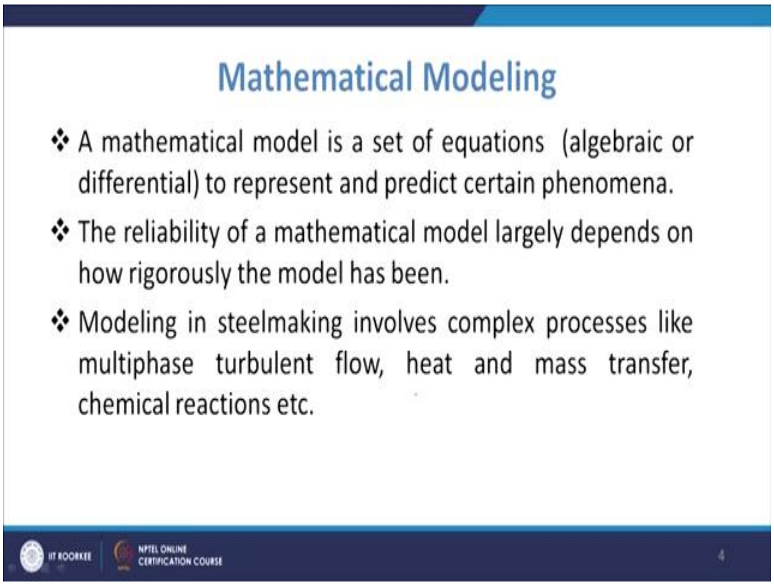

If we talk about the mathematical modeling, so as we know it is a mathematical model is a set of equations algebraic or differential to represent and predict certain phenomena, so that is how the mathematical models are made. And these equations are you know the equations which govern which are governed by certain principles just like if you go for the flow in the tundish, so it will be governed.

So, since the molten steel is a fluid and is flowing inside, so for that you will have certain conservation equations. So, they are used. So, you will have you know continuity equation or you may have the momentum conservation equation or so. Reliability of the mathematical model largely depends on how rigorously the model has been made. So, how rigorous the model is or how rigorously you have made the model, because many times when we are making the model.

If we try to replicate the true conditions, so many a times these conditions are very very complex and it may be also very difficult, and many a times impossible also to take the complete whole set of actual conditions. So, there are many compromises also made, there are some assumptions made and accordingly the model is made.

So, but if you the larger to the larger extent you make you know to take the account of you are taking the account of these you know realistic conditions, the more rigorous the model is and more reliable it will be, so that is about the reliability of that model.

You can have the you know use of modeling in steelmaking involving which will be involving complex processes which are like multi-phase turbulent flow, heat and mass transfer, chemical reaction, so these are the different domains you know where the modeling is being carried out like you have the modeling of the turbulent flow. So, flow of the liquid in the tundish is turbulent.

So, there you will have to have those turbulence quantities it taken into account, you will have to have different type of turbulence models taking into account, we should be predicting the close to the values of actual like velocities or turbulence quantities or pressure or so. Like similarly the heat and mass transfer because heat is being transferred towards the wall and towards the surroundings.

Similarly, there is mass transfer diffusion taking place or chemical reactions are also taking place, then relatedly you have the different you know domains inside the tundish and all that. So, all these you know are the areas where the mathematical modeling is being used.

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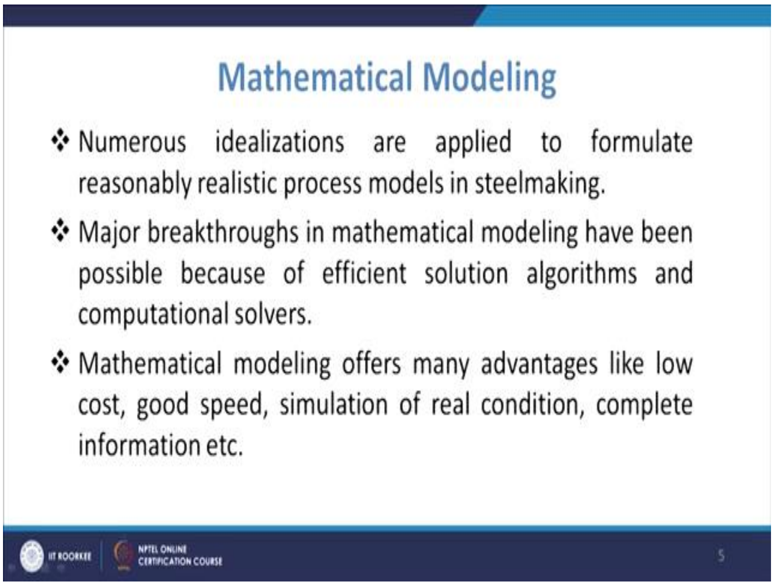

Numerous idealizations are applied to formulate reasonably realistic process models in steelmaking, so that is what we discussed that you will have to have many kind of you know you will have to make certain adjustments, you will have to you know take the assumptions and all that and then you I mean you get some process models in a realistic manner. So, many kinds of added relations are applied.

And nowadays the mathematical modeling is a very good tool it is very much popular, it is because of the efficient solution algorithms, and also you have very good computational solvers. So, because of these things nowadays we have the freedom to go for the mathematical modeling, we do it in a very small time, we try to reach to the actual results.

So, basically that is you know because when we talk about mathematical models, in that case there will be errors. These errors will be depending upon you know a certain kind of assumptions, we take or certain round of errors will be there because of the you know truncations which we do in all the truncation errors are there in those governing equations. So, based on that there will be certainly certain errors.

So, you know so many at times we make the grids very very smallers that takes more computational time. So, because of the you know evolution of very good solvers as well as very good machines computers which are extremely fast nowadays, we are in a position to do good you know modeling studies of the real systems.

Mathematical modeling will be offering many advantages like low cost. So, if you are comparing with a system of the actual experimentation, then the these cost on those mathematical modeling where you need one computation system, and then there may be certain programming softwares or programming tools. So, they are actually very very small as compared to what we do actually in actual cases the experiments with actual system. So, you will have very low cost, good speed.

In normal case, if you want to do the experiments, it will take large amount of time to set up the experiment and then getting the results properly it will take large amount of time. Whereas, in the mathematical modeling you can do it very quickly I mean as compared to that. Then you can have the simulation also of real conditions you can give all the inform, you can get most of the information whatever you feel from the mathematical model by changing your programs, you can have the informations about the output parameters, so that way these are the advantages of the mathematical modeling.

We talked about another kind of you know trials or models which are made, so that with pilot-scale trials. So, as we discussed that many times you have to use the similar fluid. So, in the case of physical model we do not use the same fluid. So, we are making a physical setup normally a scaled down up you know models, and we do with water.

However, you know we do the real scale experimentation, so but then I mean real scale experimentation is not done, but we do on a smaller scale, so that is known as pilot-scale.

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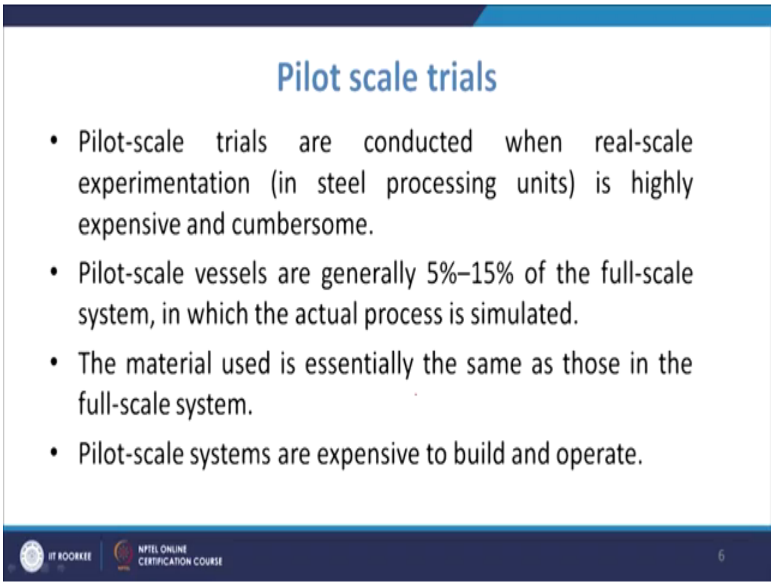

So, they will be normally smaller, but then the working fluid or the you know material of the equipments or so, they will be actual like they will be normally if you 5 to 15 percent of the full scale system, but then the actual tundish will also be a refractory lined vessel similarly ladle will also be refractory lined vessel or so. So, you will have the material which is used will be the same as those in the full scale system, but it is smaller.

So, the handling is somewhat easier, the cost involved is somewhat less as compared to the actual system on which we have to get the details. Pilot-scale systems are inexpensive to build and operate. So, basically as their sizes are smaller. So, you will have you know to invest less amount of you know money or less amount of resources for building these pilot-scales. And you can have the feel of the actual system running.

So, you will be looking at the you know those looking into those aspects also which you are not able to see in the physical model using suppose water as the working fluid. So, suppose about the heat transfer, you can have the actual data in the pilot-scale experimentations. However you cannot get it for the you know physical models.

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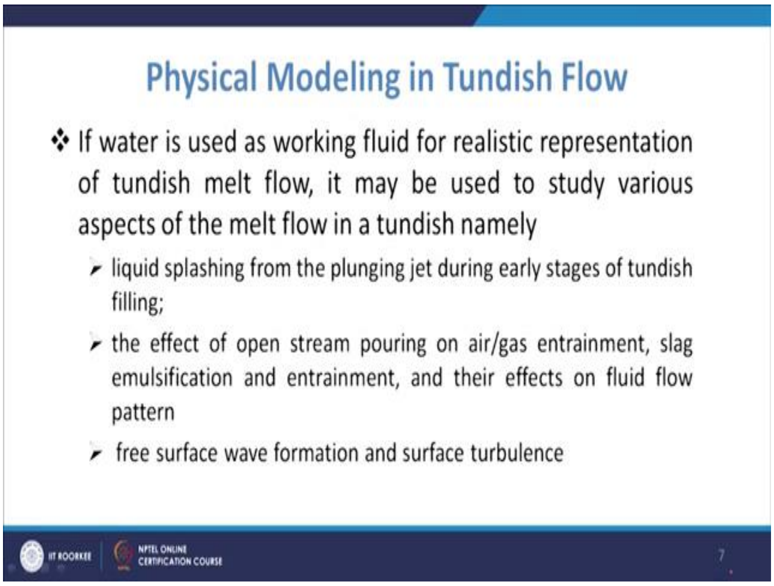

If we talk about the physical modeling in the tundish, so as we discussed that we are using water as the working fluid for the realistic representation of tundish melt flow, so when we use this water, so we can use it for studying the various aspect of the melt flow. So, these various aspects are namely like you have a liquid splashing from the plunging jet during early stages of tundish filling. So, you will have the plunging jet and then it will be coming and then there will be liquid splashing, so that can be studied.

Effect of open stream pouring on air or gas entrainment, slag emulsification and entrainment, and their effects on fluid flow pattern, so this is another area on which you can have the physical model preparation. Similarly, on the free surface of the tundish you can have the wave formation. So, these you know can be studied. And even there is surface turbulence, so they can be seen using the physical models.

You may have the flow visualization in different areas of the tundish. So, you know in the different areas whether you have the different dome like you have different volumes like come can be computed by the proper flow visualization, whether the domain is active or not the tracer which has gone which is going to the certain section or not. So, that can be seen using the flow visualization. And also we have nowadays tools by which you can even see the velocity vectors in different plains or so.

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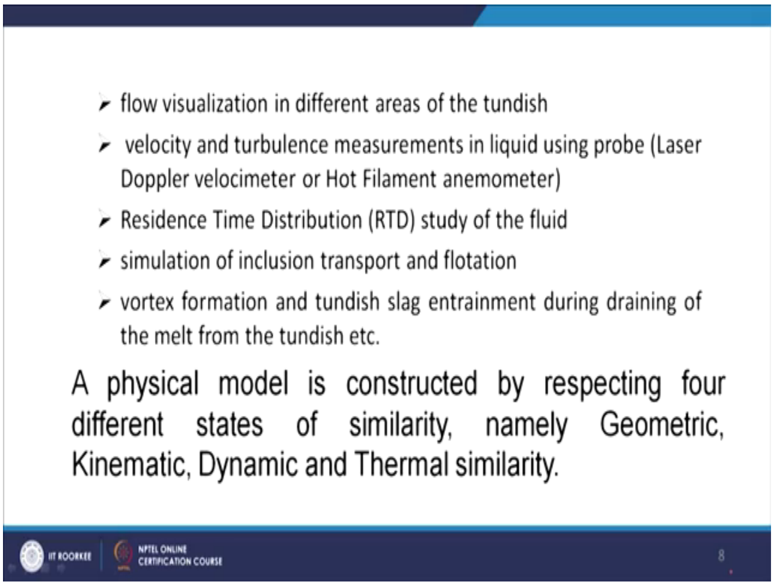

Velocity and turbulence measurements in the liquid using probe, so as the flow inside the liquid is normally turbulent I mean inside the tundish is normally turbulent. So, you can even measure these velocity and turbulence quantities in the tundish or in any vessel using the proper probes like you have Laser Doppler velocimeter so the or you have a hot filament anemometer. So, these are basically the turbulence measuring you know instruments that can be used.

You can do the RTD study of the fluid. So, RTD is the residence time distributional study. So, basically that we do by the tracer dispersal studies, and by that you can have the feel of the time for which the individual you know fluid particles are trying to stay or on an average what will be the stay time of the fluid inside the tundish, so that is your residence time distribution. So, you can have that at a different points inside the tundish.

Simulation of inclusion transport and flotation, so that also can be done using the physical models, you can make a model and you can have inclusions of different shapes and sizes of different material which can float inside the liquids, accordingly you will have to have the density of that inclusion also been taken, how they are transported to different reasons of the regimes of the tundish, and how they are floating up. So, they these can also be predicted.

Vortex formation and tundish slag entrainment during draining of the melt from the tundish. So, many a times when we are draining the liquid metal from the tundish, you know to the mold, so the there are many vortex formation as we had discussed earlier. So, when it will reach below certain level, then the vortexing may occur.

So, and in that case there may be slag which may go from the tundish toward the mold or for that matter from any you know vessel if you if it goes you know into the nest vessel, so that also can be physically modeled. So, you can have a slag kind of layer at the top of the water and then you can do the experiment and you will see the emergence of these vortex as the level goes below certain critical value critical height.

So, these all things basically can be modeled using the you know physical models. So, physical modeling that way is very very you know efficient efficiently you can do with the proper experimentation and you can further predict. So, when we make the physical models, at that time you will have to have certain concentrations to be kept in mind and these are about the similarity issues.

So, you will have the four different states of similarity I mean normally what we try to you know maintain. And they are basically defined as the you know you have the geometric similarity, you have the kinematic similarity, you have the dynamic similarity, you have the thermal similarity. So, basically this would be similar I mean if you talk about the geometric parameter geometric similarity, so, the ratio of these you know geometric dimensions of the model and the actual, so they should be same. So, it should be a constant value.

Similarly, when we talk about the you static or you have the dynamic similarity where the forces are taken into account, thermal similarity where the heat transfer issues at any point between the in the model as well as in the actual system. So, all these so we will discuss it about it in our coming lectures that these are the different similarities which we need to keep in mind while talking about the you know making the physical models.

So, these should be satisfied, then only we can ensure that there is you know proper more I mean physical model is there and the prediction which is made by the physical model it will be representing. And the in actual the you know the process parameters or output parameters which will be taking place in the industries that will help the steel makers to decide about the choose of proper you know process parameters. So, the about this we are going to have the discussion in our coming lectures.

Thank you very much.