Steel Making

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Module No. # 01

Lecture No. # 36

Modeling and Measurements

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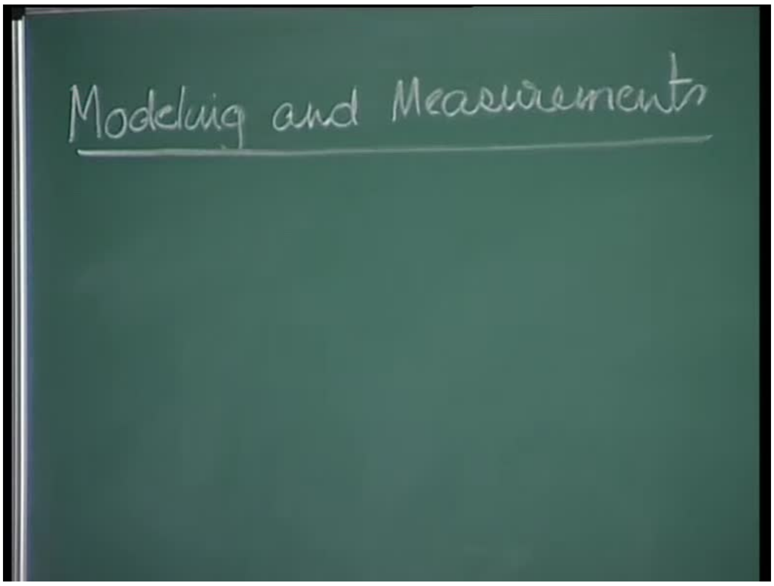

So, we will now for the next few lectures, startdiscussing modeling and measurementswhich areessential componentsofa course, of any courseon iron and steel making.As we have seen in primary and secondary steel making, thatin reactors, molten steel flows essentially, andbe it a ladle; be it a tundish; be it a tour protocol. We have interactionsamong phases.By interaction among phases,I mean that we aremay be injecting gases, the gases can be reacting like oxygen inmolten steel or non-reactingargon in liquid steel. So, we have reactingsystem; we have multi-phase flows;we have non-isothermal as system. There may be temperature gradient in the system, and the flowitself as we will show,see shortly turbulence. So, lot of complexities are therein steel making processes apart from chemical reactions, which are of course integral component of the steel making system, that facilitieschange in composition of molten steel.

Now,if you want to study all this phenomenon likeflow of molten steel inclusion floatationortemperature distribution or heat flow, in that case,direct observation is going to be not so easy, because you can imagine, I mean those of you who havegone to really visit and seen a steel plant, you look at a ladle which is filled up of 300 tons of molten steel. I mean, you know, how difficult it is to approach thatladleimmerse a sensor and then record something.

So, it is going to be, suppose we want to measuretemperature,it is not so easier job,and primarily, because the environment extremely rigid. Molten steel is bubbling; boiling it is at 1600 degree centigrade and as an extremely hazardous environment.So,therefore,direct observation in steel making system is extremely cumbersome.

It cannot be done on a daily basis, of course,the plants do it;they have their arrangements,but apart from that,when we are developing the process itselfon a sustain basis elaborate measurements are notreally possible, and one more problem also you might have come across that we require sensors,for example,which can sustain the radar environment for long time and this is a big problem in steel makingresearch that we do not have sustainable probes or sensors.For example,if I want to measure temperature, then I can dip it one time andthenmeasure the temperature, and then, after that,I can find that thermal couple is of no use;I have to bring in the fresh thermal couple.

Similarly, if I have to put some sensor from the bottom,I find that the sensors life is extremely smallparticularly in vessels like oxygen steel making systems,becauseof the tremendous amount of heat which are liberated,the steel as a result of reaction of molten carbon with oxygen, silicon, with oxygen and so on.

So, direct measurements in steel making system is very difficult and this is primarily because of large size of the reactor,and if you have a such a huge size of reactor and I want to map the temperature, then I have to keep the probe at infinite number of locations and then possibly I can map the temperature. So, it is not going to be easy.I have hazardous environment is radiating heatand of course, I do not see the visually; it is all opaque. So,I do not really see what is really happening.If the argon bubble is injected, how the bubble is going to raise to the melt?I have no way to ascertain all these things. So, since direct observation in steel making reactors is not an easy task, there is often cumbersome and that is why often we result to modeling.

Modeling is a proven branch of engineering now. Today,for example,the swim suits which are beendesigned by a speedo, they are based on some modeling bar. Design of automobiles, they are based on modeling; prediction of weather, they are based on modeling. You just name a field and you will find modeling is now extensively used.

For example, when you find out that what should be the load at which a bridge is going to be,you know, bridge will be collapsing, you do not really construct a full fledged bridge, and then, subject that much of load. We scale it down construct the small little bridge in our laboratory and then do the load testing and this is also one sort of modeling.

So, modeling is there in everywork of human life today. Without models,we reallydo not see,because models are going to eventually generate some numbers. That is the objective of modeling.It helps to quantify the subject. So, without models, we really do notsee the insight of the process, and also, we see that without measurements,the models are incomplete, because modelsgive us number and measurements give us a chance to verify those numbers. So, models and measurements they go together in every walk of human life for example.

Now, many breakthroughshave been done in steel making through modeling, and as we will advance in this topictowards the later part,I will give you specific examples,and in thatthe developmentswhich have taken place over the years, modeling has playedextremely important role.

And if you look at the history, possibly particularly with respect to steel making, modeling studies are about more than half a century old and we are expecting that in the days to comewhen we will have to design better environmentally friendly process. We have to reduce specific energy consumption; we have to device new processesand in those directions,modeling is going to play an ever increasing role.

So,no study of iron and steel making today is complete without some discussion on modeling, and as I said, models and measurements are like companions. They go hand in hand. So, when you talk of modeling, you have to talk about measurements.

Now, model is basically means representing a process, and we can represent a process either by a mathematical equation or an expression or by the physical setup itself by changing the scale, the dimension,the fluid, etcetera and so on.

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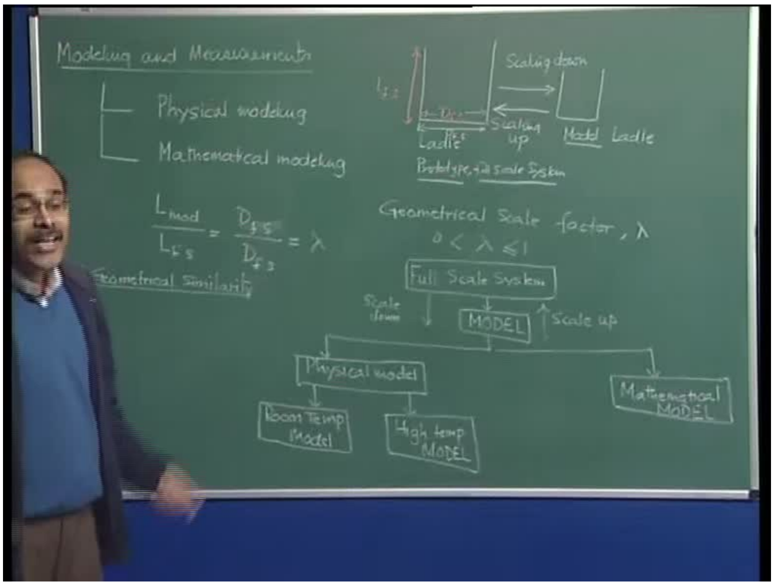

So, we can have physical modelingand we can have mathematicalrepresent the process. It is smaller scale of course most of the time. Physically represent the process in terms of a mathematical equation or expression.I will discuss both these one by one. Let us first talk about physical modeling.

So, we have a system which is in place. Let us say a full scale ladle.So, this may be the industrial system, and the industrial system I can say is aprototype or full scale systemand I want to make replicate the industrial system and I say well this is my physical model, and as it is clearly shown that the physical model is smaller than the actual industrial system.

Now, this is called the scaling down.On the other hand, if I have a model ladle, suppose when I amdeveloping a new process,that time, the industrial rector does not exist. So,I have carried out some observation in a replica, in a reactor, and then,I want to design the industrial system at this movement, in this direction is the opposite of scale down and it is scaling up.As I am indicated in this figure, the industrial system is bigger, the model is smaller. So,I would to say it is a reduced scale model of the actual industrial system. Note that I have used a physical replica.

So, imagine a cylindrical vesselof a ladle in the industry, and in my laboratory,I have constructed this big size a ladle and that is what it is, and this model that I have constructed is a reduced scale of the actual industrial system. One have an option to buildthe full scale model also,but that is going to be more expansive, because you will require more material;it will be more difficult to handle and so on.

So, when you talk of laboratory scale investigation, we basically talk of reduced scale model. Now, the question is that we have a characteristic length, how do you fabricate this physical replica? We fabricate by converting the characteristic length of the system or mapping the characteristic length of the system in terms of a chosen geometrical scale factor. Now,for example, I can say this ladle may be the diameter of the ladle.I can say is this up full scale.

So, this is the diameter of the ladle. The suffix is always, and this is the height of the ladle,which I can say is L sub f;these are known to me.I want to construct this level,this ladle, and before I can start constructing this ladle,I have to as a modeler specifyone parameter which I say is the geometrical scale factor.

So, this is a modeler chosen.Depending on my resources,I am going to choose this scale factor and this scale factor basically in steel making literature is denoted by lambda and the value of lambda is greater than 0,but typically less than or equal to 1. The modeler has an option to choose this value; he will decide depending on his resources that whether lambda should be 0.3,0.5,0.7 or 1. Having chosen the value of lambda, now I can saythat my full scale model;so, for every point in the full scale system,there is a corresponding point in the model itself.

It should look geometrically identical, and for this, if I know the scale factor,I will be immediately able to find out that what is this diameter and I will be immediately able to find out that what is this height of the ladlen my model once the scale factor is chosen. So,I said two objects are going to be geometrically similar. If for every distance or for every scale length scale, there is a corresponding length scale in the system, by the what corresponding means,there is a constant ratio which in this case is equivalent to lambda.

Now, we can construct a physical model by considering the shape of the ladle itself, and this, whatever I have discussed so far comes under the category of geometricalsimilarity. There are various states of similaritybutthis is what we have to first consider that physical modeling on terms with construction of physical replica and the physical replicas are going to be derived on the basis of geometrical similarity.

But how you are going to operate the model ladle?For example,if there is an argon injection here, at what rate argon I am going to inject. If there is steel here,what kind of a liquid I am going to say? The geometrical similarity does not talk about it; there are other states of similarities which I am going to come.

Now, physical modeling going back to physical and mathematical modeling, so,I can say that we canthink of the picture like full scale system.Then, we get model,and as I mention to you that this is my scale downand this is my scale up. Then, we have physical model and we can have mathematical model.The physical model that we have constructed can be a room temperature model or may be a high temperature model also. We will see what these are room temperature modelor it could be a high temperature model.

For example, in room temperature model,I can operate this ladle made in the laboratory either with mercury which is liquid at room temperature or with water. Now, why I am saying mercury? Why I am saying water? What are the basis for it? We are going to see in a minute.

On the other hand, when you talk of high temperature model, we have various options. We can have a small little systemfilled up with molten steel. We can have a pilot scale system, which of course will have a lambda value may be 0.5, 0.6 or 0.7 of the full scale reactor. Laboratory scale model may have a scale factor of 0.3, 0.2.

So, we can have a laboratory scale system filled with molten steel. We can have a pilot scale system filled with molten steel or alternatively we can have a laboratory scale small system filled with woods metal. So, these are all molten, dealing with molten metal.Therefore,we can group them under high temperature modeling, and on the other hand as I said, room temperature model will comprise of mercury base model as well as water based model or water model.

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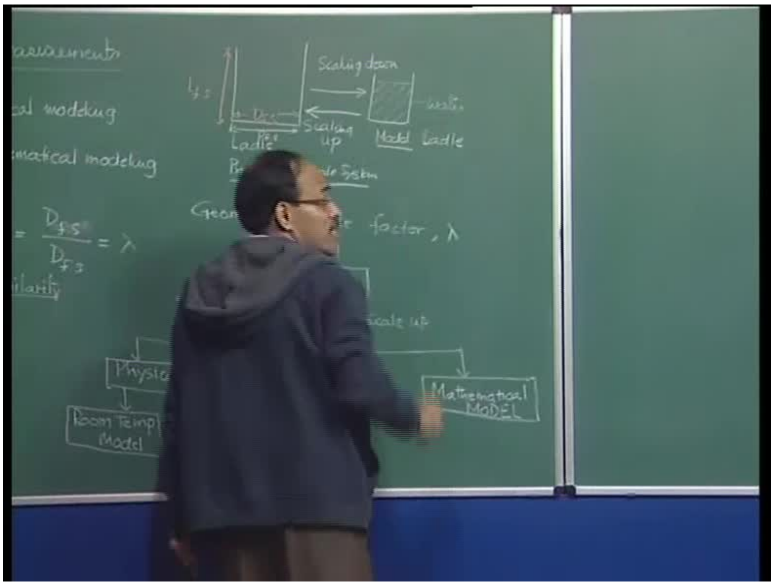

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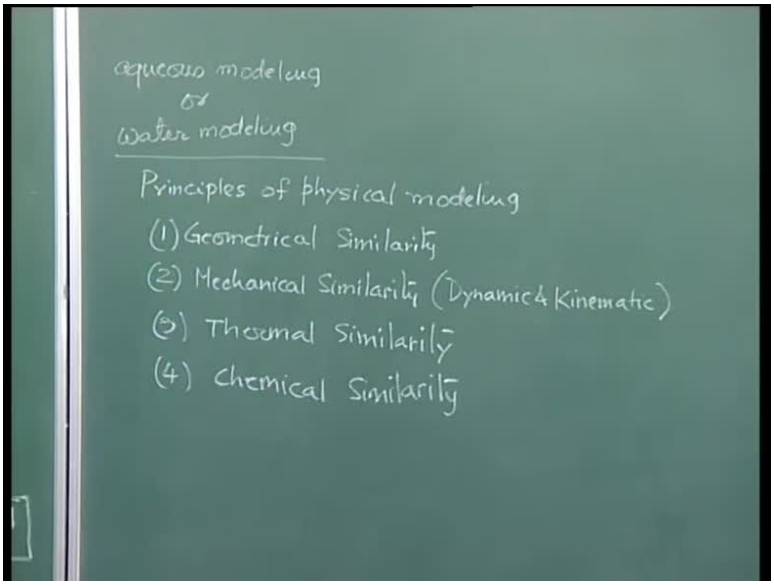

Now, water models or water based room temperature models are extremely popular in steel making. Why it is so will be clear to you, and this is when you have water as the bulk liquid simulating molten steel,if you have water here, then I will say that what we are doing is nothingbutaqueous modeling or water modelingand this is extremely popular in today’s context,most of the progressive steel plants havegot extensive water modeling facilities. Many of the new designs,for example,tundish furniture’s, tundish turbo stop, tundish dam, etcetera are evolved on basis of aqueous modeling or water modeling.

Now, coming back to the essence of or the principles of physicalmodeling, whether we have room temperature or high temperature model does not matter. The basis of physical model from or the principles of physical model stems out fromone is geometrical similarity.I have already mentioned a little bit;I am going to continue that discussion. Geometrical similarityis essential. Then, we talk about mechanical similarities, and in mechanical similarity,we will see there are various sub divisions, and of the sub division, what is important to us is basically dynamic and kinematic similarity.Third is thermal similarityand fourth is chemical similarity.

Mechanical similarity following geometrical similarity, we have mechanical similarity which talks about the forces acting in the system. Thermal similarity steel is all the time in motion; steel is subjected to various kinds of forces in the reactors. So, geometricalsimilarity and mechanical similarity will always be considered. Thermal similarity may or may not be consider depending on what we wish to study.For example,if I say that molten steel in this system is we can treat it to be basically isothermal in nature.

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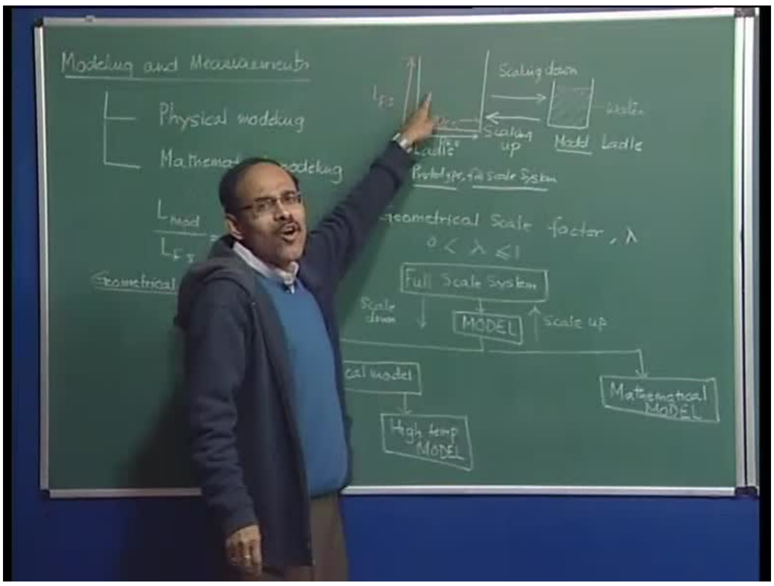

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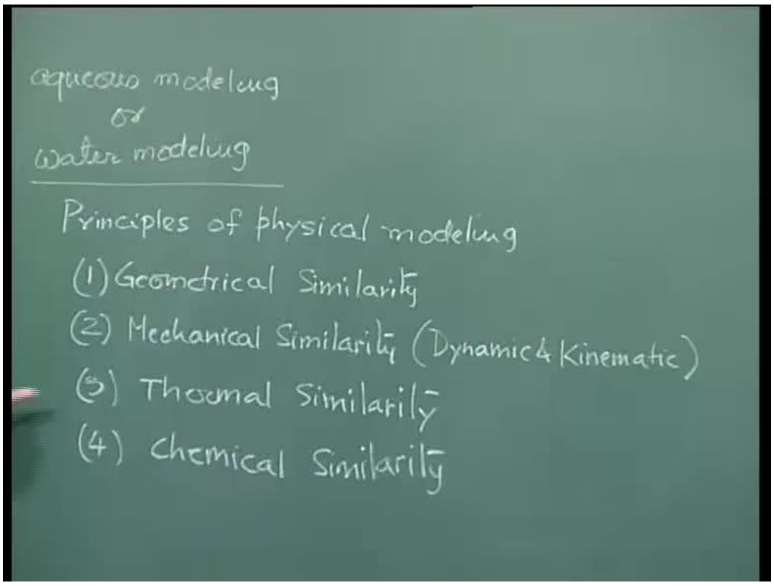

So,I can say that while if you are talking about isothermal, behavior of molten steel we can very well. There is no scope for any thermal similarity studies, because there is no transport of heat involved in process itself.Similarly,if you are talking about that look, there is not much chemical reaction going on.I am studying inclusion floatation in that case chemical similarity will not come into picture.

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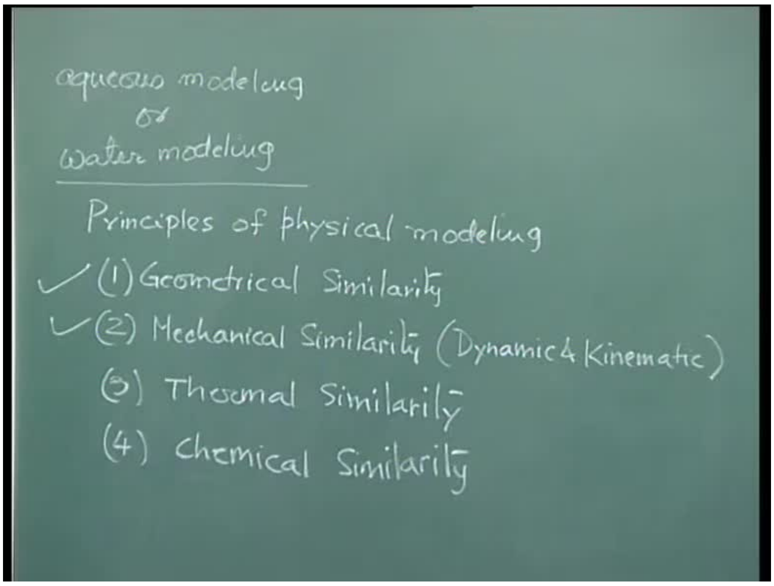

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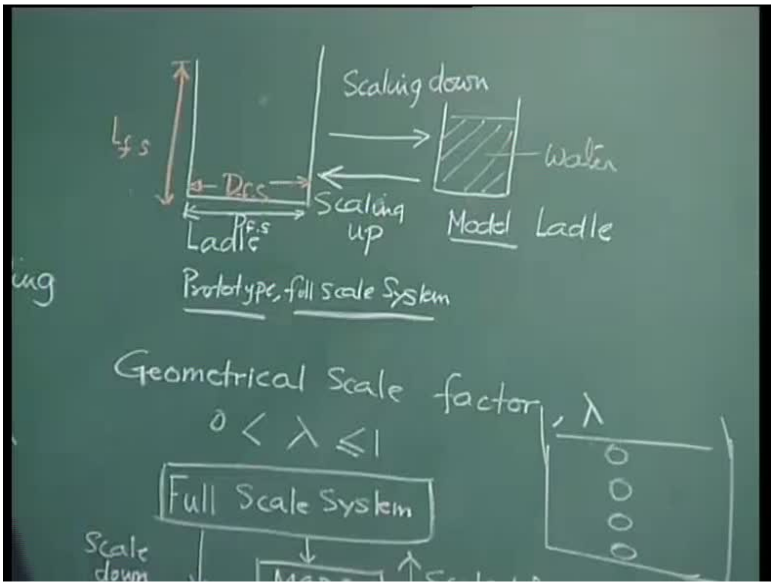

So, these are always encountered and these are encountered specific cases, and the way I have written 1, 2, 3, 4, the ordering is very important. You know,you should not interchange the order as itis going to be clear to you in a minute. Now, when you talk of geometrical similarity,I have talked about the similarity of the shapes and I have try to impress on you that all the characteristic dimensions need to be scaled properly,but it is always not necessary to scaleall the dimension, because some dimensions may be redundant. For example,I can have a vessel and say that I want to study the raise of an inclusion.So, raise behavior of an inclusion I wish to study in this particular system.

Now, the raise velocity will depend on the inclusion material; raise velocity will depend on the bulk density; raisevelocity will depend on the viscosity; it will depend how much time it is going to take will also depend on the depth of liquid in the system. The diameter of the vessel has really no role to play as for asthe raise behavior of the inclusion is concerned.

So, in order to carry out a laboratory scale simulation, raise of inclusion,for example,in ladle,I want to simulate. In that case,I may find out that this as the dimension or depth of the liquid in the system that needs to scaled up or scaleddown,butthe diameter of the vessel is really a redundant parameter.

So, in that case, you may think that the model really looks little bit distorted, because I am talking about a ladle in actual scenario,butI am using at the same time, a vessel for the l by d ratio is not same as the l by d ratio, because I know that it is not so important dimension as for as raising behavior of an inclusion is concerned, and in that context,therefore we can work out with a distorted model. So, model becomes now physically a little bit distortedbutthat distortion does not have any consequence on the final outcomeof the modelingstudy.

So,it is perfectly okif our understanding is appropriate to work out at many instances with a distorted model and yet get many instances. Now, it is very easy to draw this kind of a cylindrical figure and say that this representsa physical model of this particular system. Now, you imagine a tundish,for example,or the tundish has the refractories and I wish to consider the tundish;I want to do a water modeling. So,I may consider the material tundish with any material, and typically what we do is - we fabricate tundish with flexi glass which is basically a plastic,and is see through plastic so that we can see really when you use water, how the water flows the within the tundish and so on.

Now, in the actual tundish, we have refractory linings; we have tundish nozzles. Now, these nozzles they undergo typical various kinds of demand extent of hydro dynamic wayduring the process. Also we have refractory linings which are varying out as a function of the number of the heats. So,I have started with the tundish. In the first heat itself, it looks perfectly ok, but as the process goes on, the geometry of the nozzle changes, the lining shape changes, there may be some sky formation or there may be some solidification. So, the geometry of tundish, actual industrial tundish or the ladle may not be same all throughout the process.

So, by taking an engineering drawing of the system and fabricating a model, actually may not be truly represent in the industrial system itself. So, there may be some element of uncertainty because of the very nature of the steel making process itself. So, that can introduce some observations, some differences in observations, some distortion, and here, the insight of a modular is of great value.The modularmust be experienced enough in order to conclude that if from an idealizedsystem,I can obtain this kind of a result. What would be the implications in terms of the actual reactor of which is little bit old, which is little bit worn out,but the geometry is not what I have considered here.

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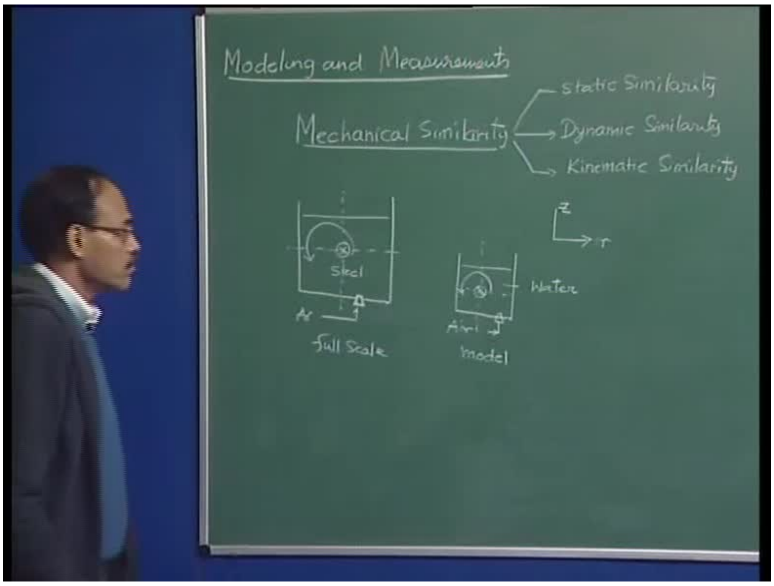

So, there can be some differences between the actual geometry and the geometry that we are using in the laboratory. We must understand and the name will be clear to you that when you talk of modeling, there are certain assumptions; there are certain idealizations, and we must be knowing that if the model is entirely accurate, entirely predictive or the model is resting inherently on certain assumptions.

So far as geometrical similarity is concerned,I would not like tomake any more any further statement rather than saying that we should make every efforts to have as close a geometrical similarity as possible. If it is notforthcoming, in that case, we must understandthe limitation and then possibly try to draw inferences on the impact of the differences between the shape of the two of an industrial reactor and the model in terms ofthe result that we are deriving from the study.

Now, coming to mechanical similarity,three subdivisions are possible here and these three subdivisions are basically one is called static similarity,dynamic similarity,and the third is called kinematic similarity.Geometrical similarity is the similarity of shapes and sizes. When you talk of mechanical similarity, we are talking about similarity of forces acting on the two systems, and what are those two systems? The model and the proto types.

Static similarity is not of much importance to steel making. Static similarity is that of extremely importance,for example,in civil engineering,particularly in loads and buildings, loads and bridges, these are all static structures. So, the various forces acting on the static structures,they fallor they are extensively usedin civil engineering. In metallurgical engineering, apart they are not so important except for one or two situations.For example,static similarity would bewe would require static similarity analysis in order topredict that what would be the force which will be acting on the wall of a steel making reactor ladle tundishor a basic oxygen furnace.

Similarly, if you have a ladle holding ladle, and then, we would like to pull that ladle and then find out that how much the free surface will oscillate as a result of this pulling. So, we will apply from rest. You want to accelerate the vessel and then you lift the entire mass ofwhich is sitting on a car or a train,they are,the force is necessary and its consequence on the meniscus oscillation that can be addressedthrough static similarity.

So, static similarity basically the forces on the structures,but we are not concerned about forces on the structures. We are concerned about forces acting on molten steel which is moving molten steel and it is this movement of the molten steel, which causes heat transfer, mass transfer, chemicalreaction,take products from one point to another point, bring reactants from one point to another point.

So, it is the motion of the liquid that we are concerned about and this motion of the liquid within the vessel is as a result of application of various forces. So,that is what is within dynamic similarity, and when you talk of dynamic similarity,thereforewe are going to talk about the similarity of forces which are acting on molten metal and on molten steel and not onthe furnace or the ladle.

Kinematic similarity talks about the similarity of velocities. This talks about similarity of forces; these also talks about similarity of forces; this is on static structure; this is on moving liquid and kinematic similarity when you are talking about in dynamic,because we are talking about velocity similarity. So, essentiallythey are interrelated - dynamic similarity and kinematic similarity as we see later on.

Now two systems,so, let us again draw thatwe have a ladle model. So, for the timing being, let us see that we have molten steel here and how the molten steel is being agitated. So, suppose we are putting in some argon here and thismovement. Similarly, we have molten steel here; we have putting in some gas. So, we have not molten steel. Let us say water and there we have steel. So, let us accept for the time being, we can use water.I am going to explain that to you in a minute. So, you inject water. So, if we can use,for example,air also.

We cannot use possibly carbon dioxide, because carbon dioxide if you use, then carbon dioxide will dissolve in water.So, it is going to be reacting system. This is an inert system argon does not dissolve insteel; so, the air alsoif the water is assume to be saturated, in that case, does not dissolve nitrogen and oxygen not too much.So, we can assume that this constitutes an inner system.

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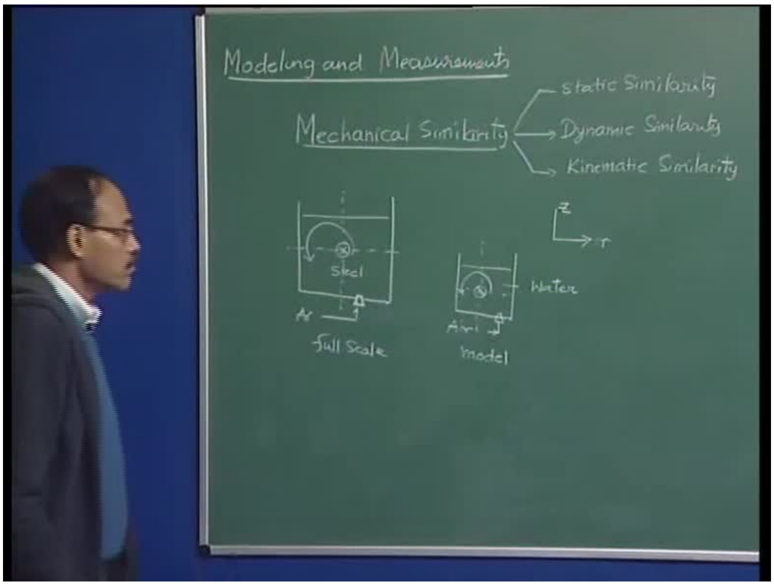

Now, this system and this system or the flow of water in this; the flow is going to be the systems. When you talk of systems, it is the molten steel contained in the ladle is now the system. The systems are dynamically similar if at corresponding points. So, let us say understand this. This is the line of symmetry; this is a center point of the system. This is r is equal to 0,z equal to, and if this is the code unit system that is been used,this is the radius and this is the z. So, this point corresponds to this is an index of r is equal to 0, it, at the axis of symmetry and z is equal to mid bath depth position. So,I can also have here this location, which is r is equal to 0 and z is equal to mid bath depth. So, at this point are corresponding points.

So, for every point in the model, because I have scaled it geometrically by a single scale factor, so, for every point in the full scale, there exists a corresponding point in the model. So, this is full scale and this is model at corresponding locations and at corresponding times. The ratio of the forces acting on the system must be identical.

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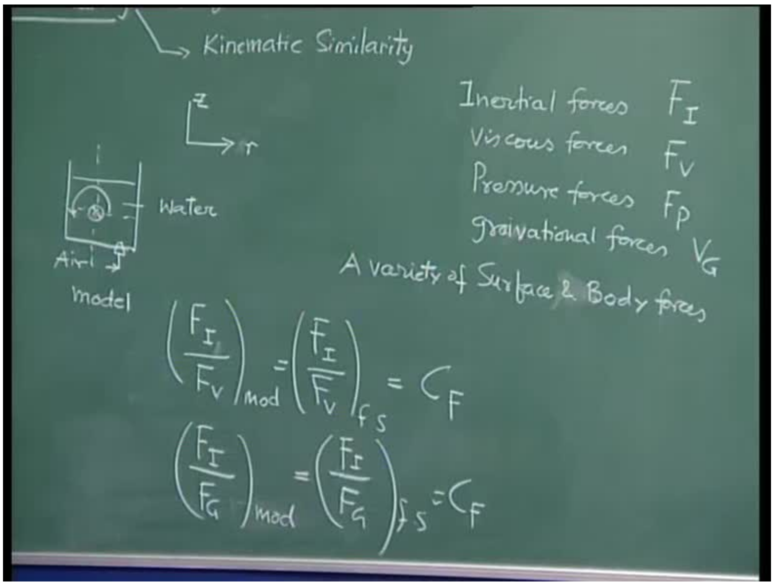

So, suppose, if there are similar forces, now common forces which acts on fluids are inertial forces,viscous forces, pressure forces, gravitational forces, surface tension forces or I can say a variety of surface and body forces. So, these are the common types of forces. When I talk of surface forces,I can talk about surface tension forces. When I talk about body forces for example,I can talk about something like an electromotive force which areacting at a system.

So, there may be depending on the system itself. There may be various kinds of,but these are always there. You talk of a fluid flow or moving fluid, moving liquid. You have inertial force, viscous force, pressure force, gravitational force, and many other types of forces which will depend on the system configuration itself.

So, at corresponding locations and at corresponding time, the concept of corresponding time I am going to explain you in a minute, at corresponding locations and at corresponding times, the ratio of the forces must also correspond. So,therefore,I would say the ratio of inertial to viscous force at this point must be is equal to the ratio of the inertial to viscous force at this particular point should be,therefore, I would say the ratio of viscous to pressure forces at this particular point must be equal to the ratio of viscous to pressure forces. Here, the ratio of pressure to gravitational forces here must be equal to, so, any combination I can take and I can say all the ratios of the forcesmust boil down to a constant itself.

So, that is the essence of the dynamic similarity, and I would thereforesummarize that two systems are said to be dynamically similar. If at corresponding points and at corresponding time, the forces acting in the system also, forces acting on the two points also correspond.

So,therefore,mathematically I would say if I can represent this as inertial force, this as viscous force, this as pressure force, this as gravitational force, let us not talk about the, if I can explain thesefour different forces,I will be able to explain withall other forces also; this isnotmeaningful at this particular stage.

So, what I am saying is that the ratio of inertial to viscous forces in model must be is equal to ratioof inertial to viscous force scale, and if this ratio comes out to be C sub F, we will say that inertial to gravitational forceand I can write down many saturations.I will show you the consequence of this,butthe first point is how do you know that what are the forces that are acting on the system.

So, we can find out the forces acting on the system by physically examining the process, or alternatively if you say that we know the governing equation thatdescribes flow in the system, then by looking at the flow equation itself,I should be able to find out that what is the forces which are acting in the system.

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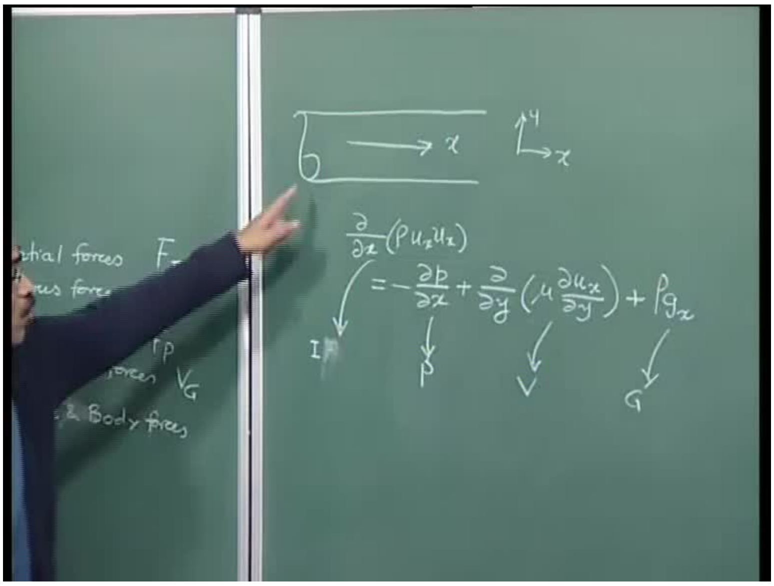

For example, let us take this pipe flow, with which, you all know. So, let us consider the fully developed pipe flow problem.So, let us not make that constraint. Let us write down only the 1-D equation. So,I would say that steady state, so,I would write down. If I write down this is the x component, then I would say that rho u x u x inertial forces. There will be other components of inertial forces also along the y direction, z direction that is now there. Similar terms can be there on the left hand side also. Then you have the pressure gradient.

Then, if this isy and this is x and then we have mu.Similarly,other components of the diffusion term may also be there, and then, we have rho g sub x. For a homogeneous fluid flowing through a pipe, this is the form of the equation written in a very simplified way.I have not written the corresponding transport along y and the z direction.I have not written the corresponding transport along the y in the z direction for the sake of simplicity.

If I look at this equation, so,I know the pipe flow problem.I look at the equation and I find out that (( )). This time is nothingbut the inertial force, inertial term. This is the pressure term;this is the viscous diffusion term and this is the gravitational term. So,I can immediately say that look the fluid which is flowing through the pipeis the result of four different kinds of forces - inertial forces, pressure forces, viscous forces and the gravitational forces.

So, therefore, I want to say that if the governing equation of flow is known to us, in that case, we should be able to immediately identify by looking at the equation that what are the kinds of forces, and then, say that dynamic similarity demands that the ratio of this forces are going to be identical at corresponding point, at a corresponding times.

If you say sir I do not know the equations that are applicable to the system, in that case, we have to carry out in laborite analysis, dimension analysis, carry out some experiment, and then, find out that which are the meaningful forces, and it is only when we know that what are the meaningful forces which are acting in the system. We can now proceed to develop the dynamic similarity right away.

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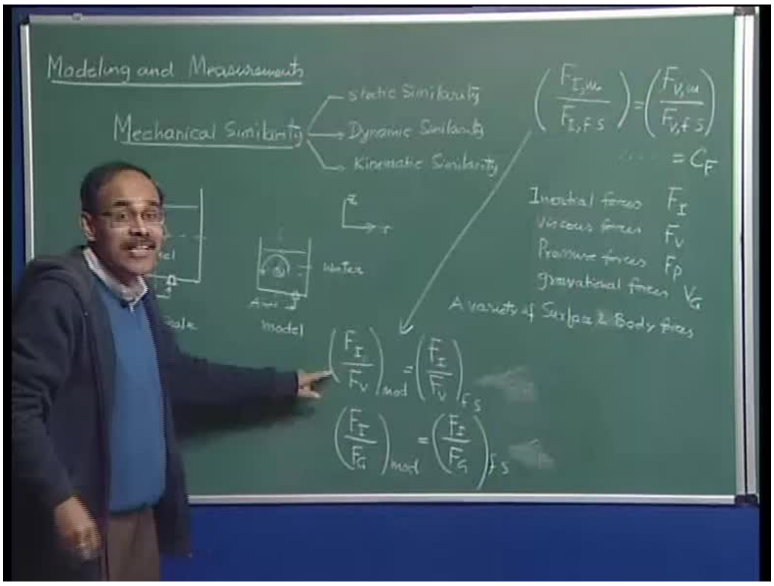

Now, this ratio of the forces can be arranged also in a little bit different manner.For example,if I sayinertial to gravitational forces,this equation should not been actually written in terms of,I would say this is the second step. The inertial forces in the model to inertial forces in the full scale, that is actually full scale is equal to viscous forces in the model to viscous forces in the full scale.

So, this is from the definition of the dynamic similarity, which can also be cast into this particular form.I just take out inertial forcesby viscous force in the model, and then,I write inertial force by viscous force. So, the transposingthese terms from here,I should be able to come at this particular point. So, this is the fundamental statement of the dynamic similarity. The ratio of the forcesthese are the ratio of the same forces at corresponding locations at corresponding times must be equal.

So,therefore, I would say that this is really going to be C sub F. So, let me make this small little corrections,of course, it does not changethe conclusion from whatever. So, the fundamental statement of dynamic similarity is this, and from this,Ican derive this particular expression, and this you see that this is more convenient for us to deal, because what is the ratio of inertial to viscous forces? The ratio of inertial to viscous forces is nothingbut the Reynolds number. The ratio of the inertial to gravitational forces is nothingbutFroude number.

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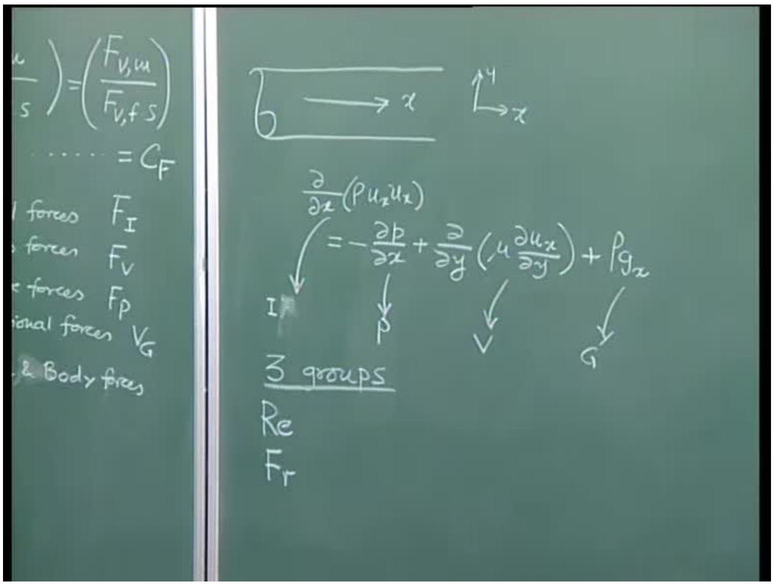

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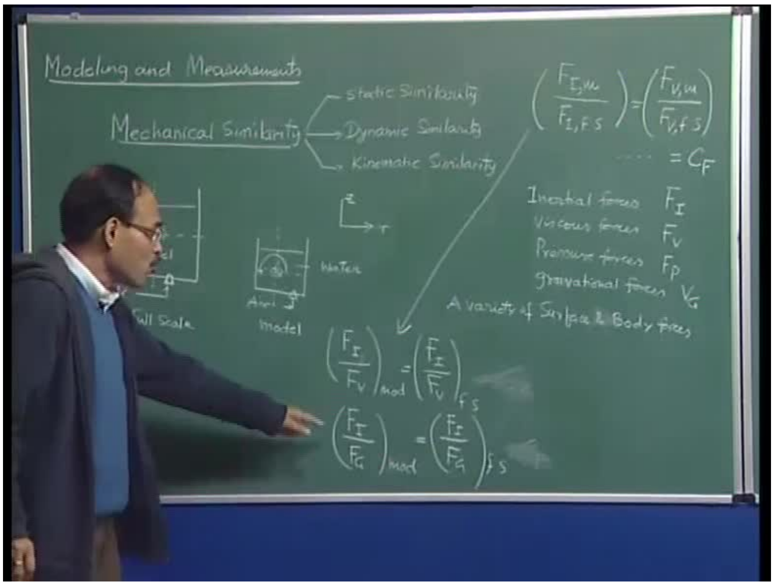

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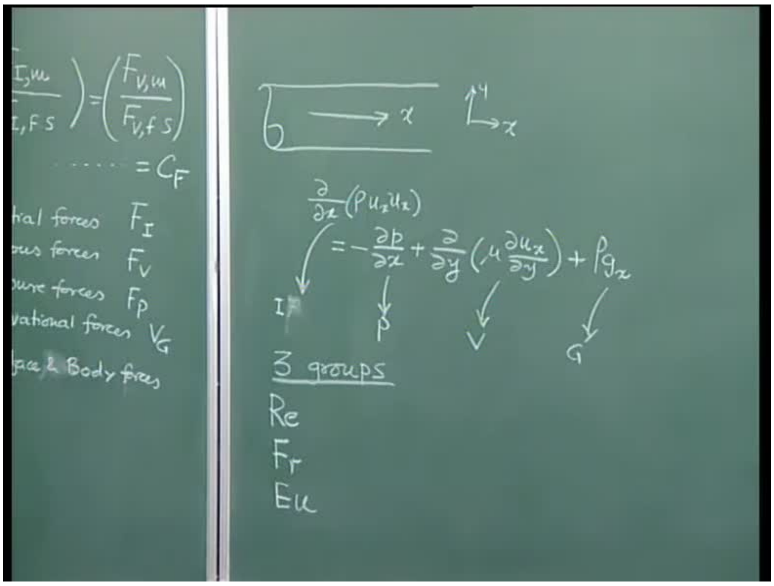

So,therefore,we can see that the ratioof the corresponding forces can be manipulated in such a way as to yield some characteristic dimensionless groups, and in this particular case, when inertial pressure viscousand gravitational forces are only significant.In that case, we will see that there are three dimensions, three groups which will going to follow and two of the groups I have shown you Reynolds number and Froude number, and we have the third group is actuallythe pressure force to inertial force ratio and that pressure to inertial force ratio is nothingbutEuler’s number.

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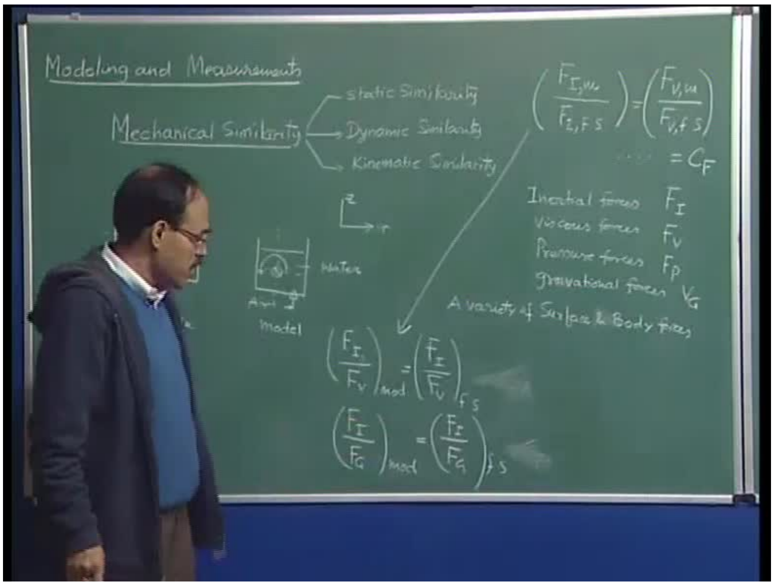

So, we have four different kinds of forces. So, four different forces can be rearrange in terms of three different ratios inertial to viscous, inertial to gravitational and inertial to pressure, and if you to do that, there inertial to viscous is nothingbut the Reynolds number at the top. Inertial to gravitational is nothingbut the Froude number, the second one, and inertial to the pressure force is nothingbut the Euler's number.

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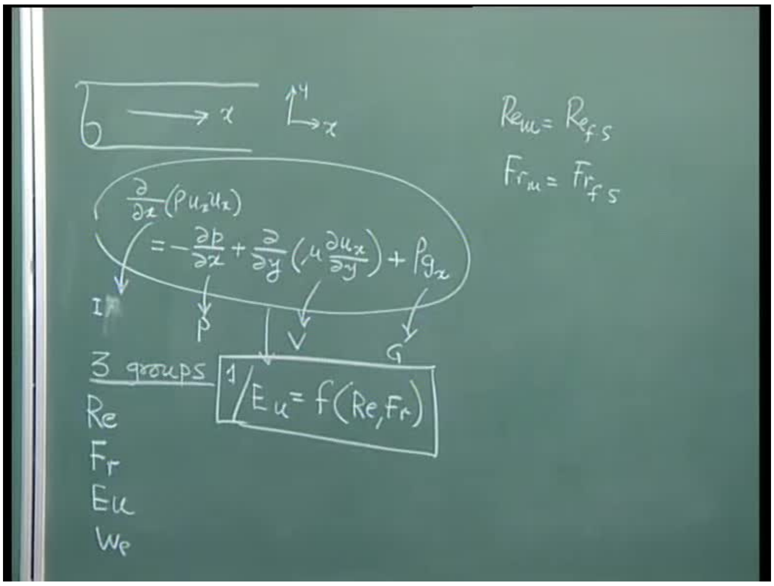

So,therefore,I can say also that thisequation which is written in a dimensional form can also be written in a non-dimensional form which is Euler's number,1 over Euler'snumber as a function of Reynolds and a Froude number. This is a non-dimensional representations of the governing equation of flow in which inertial pressure viscous and gravitational forces are only relevant.

If you have for example,say sir I have one more force surface tension forces, then what happens?I get one more number here and that number is going to be the Weavon number. So,I will have 1 over Euler’s number or aEuler number is a function of ReynoldsFroude, and Weavon number in which not only inertial pressure viscous and gravitational forces are relevant,but also the surface tension force is important.

So,therefore,the essential condition for dynamic similarity I can now summarize that we require Reynolds modelmust be is equal to Reynolds full scale Froudemodel must be is equal to Froude full scale.

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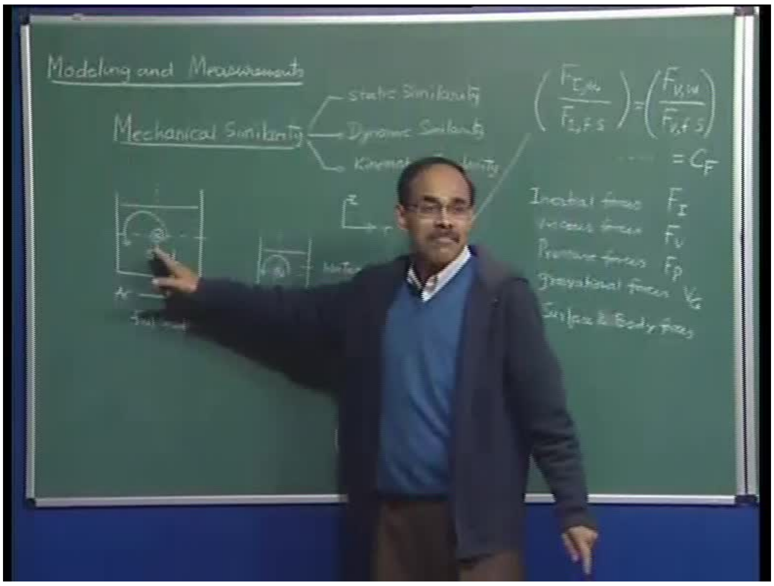

So, if you are retain this to, in that case, automatically the Euler’s number is going to be 12,of course,I am dealing with a situation, in which, the Weavon number or surface tension force is not important. So, the situations in which inertial gravitational viscous and pressure forces are relevant.If I can maintain this equality between the model and the full scale, in that case,Reynolds similarity as well as Froude similarity in that case, I can say yes. Few of the system - the model ladle as well as the full scale system, they are going to be dynamically similar.