Steel Making

Prof. Deepak Mazumdar
Prof. S. C Koria
Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur

Module No. # 01

Lecture No. # 39

Modeling and Measurements

As I have mentioned, there is one to one similarity between transport of heat or temperature distribution and mass fraction distribution which is due to concentration gradient.

Now, chemicals similarity therefore which talks about the similarity of concentration profiles is similar to the distribution of temperature. And we can therefore, accordingly define, that chemically similar are those systems in which concentration difference, again the difference what comes exactly the same way we have defined in the context of thermal similarity in which, concentration difference at corresponding locations and corresponding times be as a fixed ratio.

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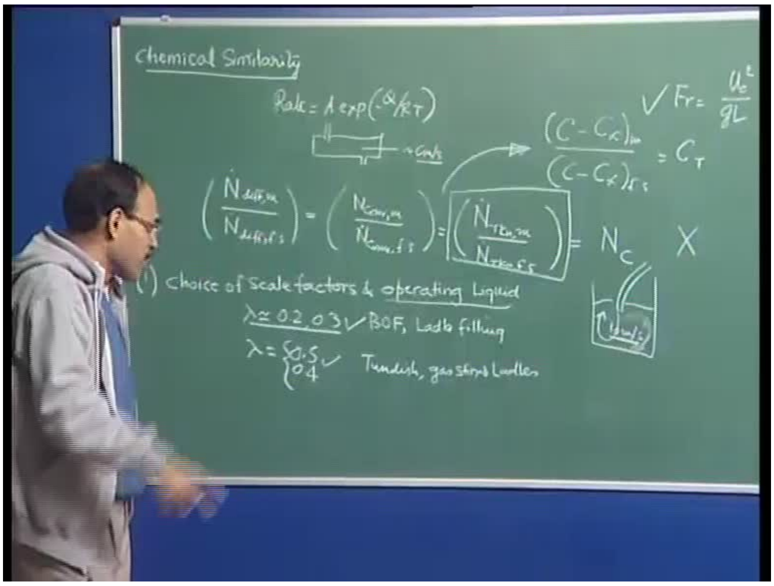

So, if I say the concentration in terms of C minus C I say some say, C infinity value with difference in the model to C over C infinity in the full scale. Let us say, this will come up with some constant in which, C may represent the concentration of any species. We can also write, instead of concentration the mass fraction of that particular species.

So, we can define in whichever units of concentration we may try to adopt. So, this is the definition of chemical similarity, concentration difference ratio of concentration difference at corresponding points from corresponding locations are identical. And exactly the same way this is going to be achieved when we have mass transport because of that we say mass or molar flux. So, N conduction or n diffusion model, N diffusion full scale is exactly is equal to N convection model by N convection full scale is exactly is equal to N convection N dot reaction model, N dot reaction.

So, this condition is to be satisfied and once if this condition is satisfied, the consequence of this is similarity in concentration profile which is defined in accordance with the equation on the right. Now we must understand that, it is very difficult to satisfy this particular equation, particularly because of the involvement of this particular term which talks about the mass transport because of our species distribution, because of chemical reaction. Because we know that, the rate of chemical reaction depends on temperature. So, therefore, if we are talking about first geometrical similarity, then dynamics similarity, then we have made similar systems thermally similar.

So, the temperature in the two systems are now different, but they are thermally similar, but that the absolute rate of the reaction depends on the temperature in accordance with the Hernias weight law we all know that, the rate of a chemical reaction is given in terms of A exponential Q by RT, activation energy and this is the temperature dependence of rate (Refer Slide Time: 03:55). Therefore, if the temperatures are not identically in the model and the prototype type systems, in that case, we are going to it will be very difficult to maintain a chemical similarity.

So, you know we have a system in which we have geometrical similarity, mechanical similarity, then thermal similarity and we try to operate this system at a similar temperature not same, but similar temperature. And yet, we would be able to satisfy this particular reaction, because we would not find species which will at that particular temperature react to, give rise to a proportionate reaction rates within the model and the prototype type. So, it will be very difficult to achieve similarity in terms of mass generated because of or depleted because of chemical reactions by carrying out the model studies at a different temperature then the full scale itself.

So, therefore, we will always carry out chemical similarity studies or mass transport because of reactions etcetera in the system with regard to a small version, but the exact system itself. Suppose, if you are talking about sulphur concentration or oxygen concentration in an oxygen steelmaking system. You know, maybe we are going to talk about that the system is small, but the temperature is exactly identical if the temperature in the full scale system because at that particular temperature, we are going to get a representative value of the reaction rates.

So, we make this conclusion that look chemical reaction is going to be very difficult to satisfy in water models or in reduced scale models, where we are talking about various kinds of similarities; we will not find reactions which will give us representative rates at the corresponding temperature. So, therefore, we are going to never study chemical similarity or rate of reactions through a different system rather than a representation of that flow system itself.

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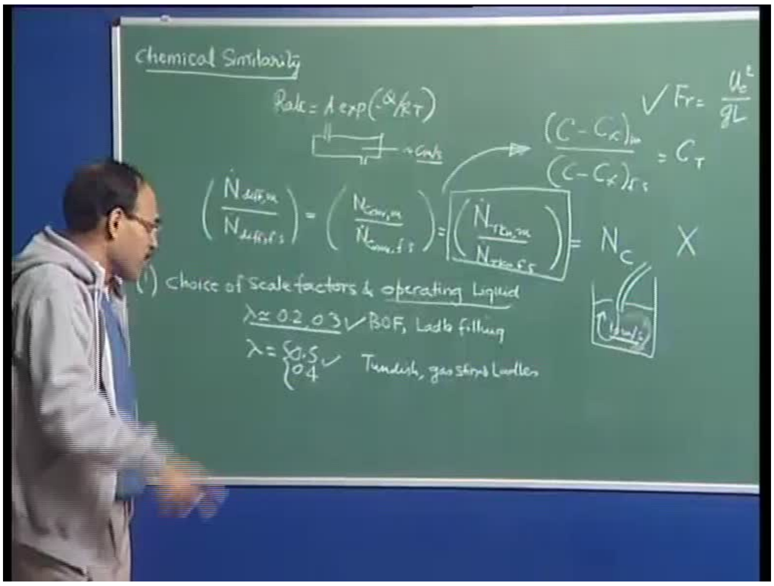

So, therefore, again we must see that we are talking about the order is right because we have said geometric similarity, then is dynamics similarity, then is thermal similarity, then is chemical similarity, because chemical similarity chemical or mass transport will depend on the absolute temperature as well as it will depend on convection which is the fluid flow part.

So, therefore, only when we can talk about fluid flow, only when we talk about thermal similarity or the role of temperature in the system, then only we can be possibly talk about the chemical similarity in the system, but we understand at the end that it is going to be extremely difficult for us to carry out any chemical similarity studies. Therefore, in reduce scale modeling studies, we will do fluid flow studies, mechanical similarity we will do even thermal similarities, even though there are some problems in thermal similarity also, but never ever we are going to carry out chemical similarity.

Now, having said so much about the principles of physical modeling, let us now look at the issues. There are several issues; we want to first see as a choice of scale factors and operating liquid. This is an important, I have already mentioned that scale factors will typically vary; it will be greater than 0 or less than equal to 1.

So, the modular has an option to go for a scale factor of 0.2, 0.3, 0.4 whatever is convenient and as I have mentioned that, if you try to build up a full scale system, in that case it is going to prohibitively expensive, it will difficult to operate also we will require more space, more material etcetera.

So, full scale modeling in laboratories perhaps not justified of course, many steel plants do have in their R and D - Research and Development laboratories, they have full scale models in the reactor because there the space and resources are no constraint, but in laboratories we would like to have a reduce scale model.

Now, whether to go for a small scale model or a relatively bigger scale model; by small scale model, I am talking about lambda values of the order of 0.2, 0.3, I have a relatively bigger scale model, I am talking about scale factor is equal to 0.5. Now in selecting the scale factor, one important thing we must remember that we need not disturb the flow regimes or missed present in the flow regimes. For example, we know that in ladles for example, or in tundishes the flow are turbulent.

Now, if you take a very small nearest the size of a tundish and try to do the experiment, what happened is because the scale is so small in that case, we may see that the flow rate is also going to be small and as a result of which velocity as well as the length scale or the dimension of the system be so small that the Reynolds number in the system is going to be not very large.

So, therefore, we can say that we have to choose such a scale factor that the characteristics of the steelmaking system are preserved well. Now, we must understand for example, we have if you are talking about a ladle filling operation for example, in the ladle filling operation we have velocities of the order of 10 meter per second.

On the other hand, if you talk about tundish for example, we have velocities of the order of centimeters per second. Thumb rule is, larger is the intensity of the system, you can go for a relatively smaller size systems because in smaller size system also the pouring rate is very large, the velocity is very large. So, therefore, what we can see this arrow should be other ways (Refer Slide Time: 10:00) this should be it will goes like this.

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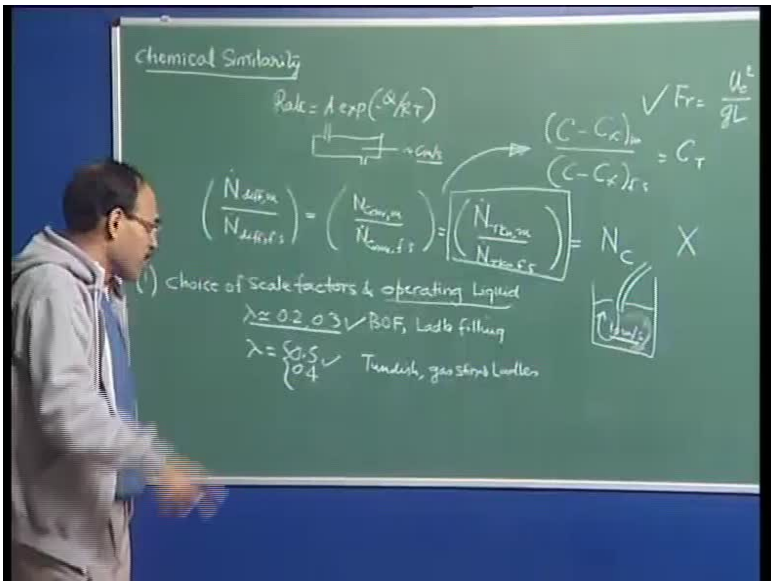

So, when the scale factor in systems where we have very large velocities or reasonably large velocities, in that case what happened? Even if you go for a reduce scale, small scale model we are going to see that the turbulence characteristics of the system is going to be preserved. On the other hand, when we are talking about velocities are such in the full scale system is very small of the order of centimeters per second. In that case, we cannot afford to go to very small size because in that case, the turbulence characteristics or other characteristics of the system are going to be totally lost.

So, as a thumb rule I would then conclude that, if the system under consideration has got reasonable intensity of ((starring)) of the order of meters per second, go to a scale factor select the scale factor about 0.2 0.3 to 0.3.

On the other hand, if you are talking about in systems where there is intensity of fluid motion as such is going to be very small, so you can use. So, I would say BOF, then ladle filling these are the operations where we can go and may be tundish, gas stirred ladles these are the systems in which you should go may be 0.4 0.5 something like that.

Operating liquid, now as I have mentioned to you, we have decided that we are in reduce scale model, we are going to use most of the time water as the representative fluid because of certain conveniences which I have already listed to you. So, having said that we are going to use water, we understand that we can only respect Froude number and not Reynolds number because of the similarities in the kinematic viscosity.

Alternatively, also if we assume that in metallurgical system, steelmaking systems for say, forget about water modeling or anything, if you look at the steelmaking system and if you make this assertion that steelmaking systems are going to be dominated by the inertial and gravitational forces, actually the bulk flow in the system is dominated by inertial and the gravitational forces. That means steelmaking systems are essentially Froude dominated that the definition of Froude number as I have shown you is, characteristic velocity square by gL and it does not talk about any dependence on the fluid properties.

Therefore, if the system, if the phenomena under consideration is governed by Froude number, in that case we can say in principle that look we can use any liquid whatever comes to our mind, but mind that the condition which is present in the system need not be disturbed by choosing any kind of fluid. For example, if I use a highly viscous plastic sort of a material to flow in a tundish in that case, the flow regimes in the tundish is going to be laminar, because turbulence is going to be very difficult to generate in such systems.

So, when I say that any kinds of fluid in principle is possible for Froude dominated system, this essentially implies that we are going to use any of those fluids, which does not disturb the flow regimes in the steelmaking unit system. So, long as that condition is satisfied, in that case we have no problem, we can go for water, we can go for wood's metal, we can go for mercury and we can do anything we want, without are provided it does not disturb the fluid flow condition itself.

We must understand that the operating liquid can be anything and as I said that, we will like to use in most of the cases, in majority of the cases water as the representative liquid because of our certain, because of certain advantages which I have already mention. And when I say water in that case, it is understood that we are talking about only one similarity, number of characteristics which would govern the process and in invariably the choice would be in favor of the Froude number itself.

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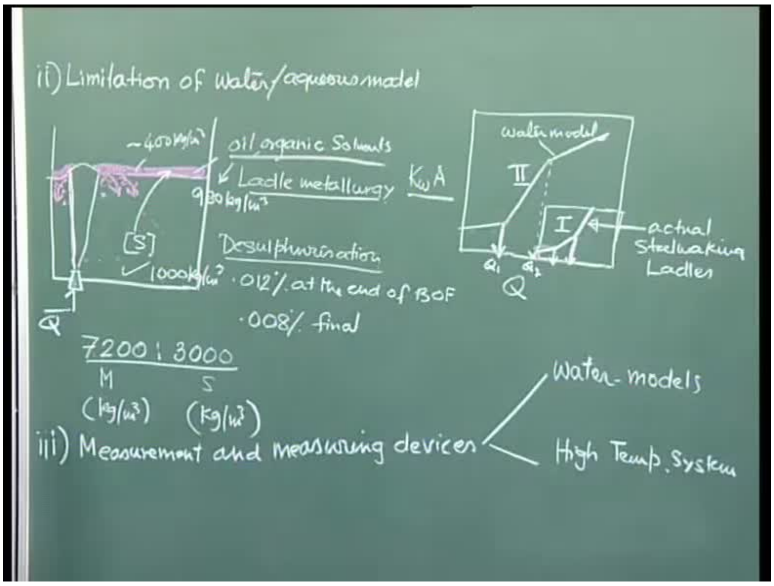

The second point that I would like to talk about is the limitations of water model. It is not that, we can solve all problems or address all problems through water model. I have already mentioned to you that modeling the word model, as I will again explain in the context of mathematical modeling, it means certain approximation, certain assumptions. And as I have indicated to you that, in building physical models there are lot of assumptions involved.

We are not even able to simulate this current geometry which develops during the steelmaking process, because of varying out of the nozzles, varying out of the refractory's, because of deposition of solid metal in the refractory well or inability to simulate the nozzle geometries correctly. So, physical model construction itself is which certain degree of assumptions and secondly, I have also said that well, if you releasing water in that case we cannot respect both the numbers unless of course, the scale is the full scale model or full scale system.

So, therefore, in reduce scale models when you use water as such, we have many approximations build in. So, therefore, we must understand and also in the thermal similarity for example, I have mentioned that well, if you are using a glass vessel in that case, although you can simulate the fluid flow part very well, but thermal similarity you are not going to be able to match. Because the actual practical rate of heat extraction through the refractory wall is not going to - you cannot get it through the Plexiglas model or through the glass model, because you cannot use water for more than 90, 95 degree centigrade.

So, therefore, the wall heat fluxes, outgoing heat fluxes through water models cannot be replicated exactly and we will not correspond to the actual industrial system. So, if I start listing, there are many assumptions and idealizations based on which we are building the water models. So, therefore, we can understand that water models may not always give us exact, accurate and all possible results which are relevant to us. And there as I mentioned to you, that the inside of a modular and experience will come out to be very handy.

So, as you will keep on doing modeling, as we become more and more experience, you will be able to conclude based on your observations on an idealize situation that what would be the possible consequences in the shop floor going to view, where you have marginally different geometry or marginally different conditions and so on.

Of greater relevance here is our inability in water model to simulate multiphase flow scenarios. For example, in most of the cases, we have if you take a vessel for say may be a ladle, it is convenient to draw a ladle and that is why I have been always drawing a ladle and you have a flume and then, on the top of the flume you have say for example, the slag layer.

So, the slag it go something like this, typically the gas stirred ladle. So, the slag which serves as a protective covers also does many things for example, when you are talking of desulfurization, suppose in your primary steelmaking you have been able to get desulfurization up to 0.01 0.012 percentage at the end of BOF process.

Now, you are talking about say this is your target final. So, you will have to know, you have tap the metal from the BOF, you have not been able to achieve the correct sulphur and you have to remove further sulphur and the possibility of removing further sulphur is in secondary steelmaking or in ladle metallurgy.

Now, desulfurization as you all know is a slag metal reaction. So, you have sulphur sitting here in the metal and you would like to go let that sulphur goes to the slag phase and that is essentially the desulfurization process.

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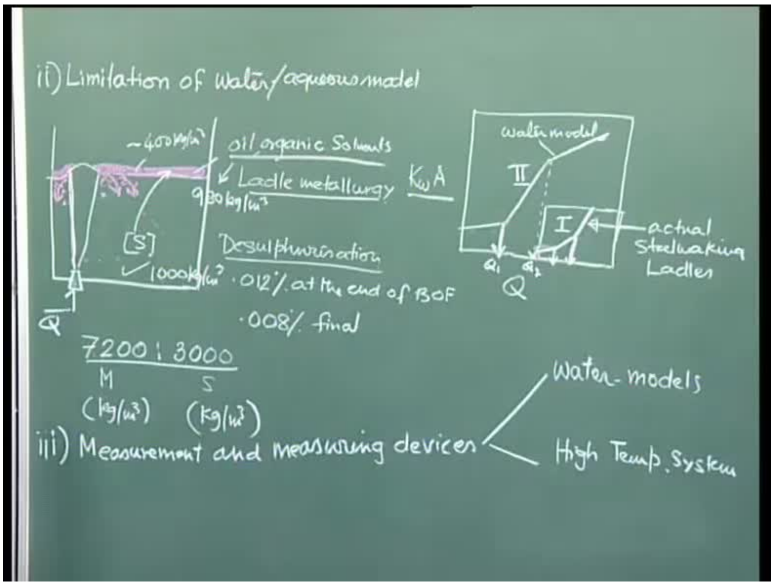

So, therefore, in the ladle what you do? In the ladle you blow argon at a high rate and as a result of which the slag layer now gets disturb and you have droplets of slag founds this continuous entrainment of the slag layer, particularly in the vicinity of the flume. This creation of large surface area adds in desulfurization reaction, because if it is interfacial reaction, heterogeneous chemical reactions are strongly dependent on the interfacial area because it is on the interface that the heterogeneous chemical reaction takes place.

Homogeneous reaction as I have already mentioned, it takes place within the entire volume of the reactor, but hydrogenous reactions takes place only at the surface.

So, therefore, more is the surface area more is going to the rate of reaction. So, when you have a planer slag metal interface, we have you know is the nearly the area of the pi r square or the area of the circle that you see from the top, but when you have infinite number of droplets or very large number of droplets in that case, that pi r square has now many question into 100 times or 1000 times more area and as a result of which desulfurization is exacerbated.

So, therefore, this sort of a feature the entrainment of the droplet, it is the creation of the surface area these are strongly dependent on the thermo physical properties of the slag. Now the slag and the metal for example, their density ratio is of the order of 7200 is typical about, this is a typical value (Refer Slide Time: 21:00). This is the metal density, this is the slag density in kg per meter cube, this is a typical value this could be 24 500 or 26 100 depending on the composition of the slag.

Now, this density ratio is very difficult for us to achieve in the case of a laboratory steel water model because in our case, we have this is fixed at 1000 kg per meter cube because this is water therefore, we would like to have a liquid which is roughly about 400 kg per meter cube and so on.

So, it is very difficult to match the density ratio, to match the viscosity of the slag, to match the interfacial tension of the slag in through an aqua's model or a water model system. Therefore, many of us have to try to investigate slag metal reaction kinetics by using oil or organic solvents that is done in the laboratory, but we know that oil and organic solvents for example, the oil has a density of about 980 kg per meter cube and you see the density of water is about 1000 kg. So, this density ratio is absolutely much different from the density ratio of the actual slag and metal systems and similar values can be said, similar things can be said about viscosity and interfacial tension as well.

So, therefore, the actual slag metal system cannot be replicated through water models in a laboratory scale system and this inability to represent the actual slag metal system brings us to a point, when we could say that well multiphase interactions, the slag metal interactions, the slag metal reactions etcetera really cannot be replicated in laboratory by means of a water model.

Now, we can get some idea some qualitative idea that, if slag is there then what kind of a behavior. For example, today it is well known that if you have a slag layer sitting on the top of water bath or a slag layer which is sitting on the top of a molten steel bath in that case, the slag the presence of a slag for a given gas flow rate will cause the liquid to recirculate at a relatively slower rate.

So, if there is no slag, in that case where liquid is going to recirculate faster, if there is a slag present the liquid is going to recirculate at a slower rate because the slag will eat up a part of the energy. And this is a well-known, but how much of energy is going to be eaten up in reality that on a one to one mapping, we will not be able to do because of the mismatch of thermo physical properties. This is proved very well when people have studied that, you have volumetric mass transport coefficient in an argon stirred ladle which is K w A in a water model, what it is this? This is mass transport coefficient which is meters per second, this is area. So, this is meter cube per second and this is termed as the volumetric mass transport coefficient.

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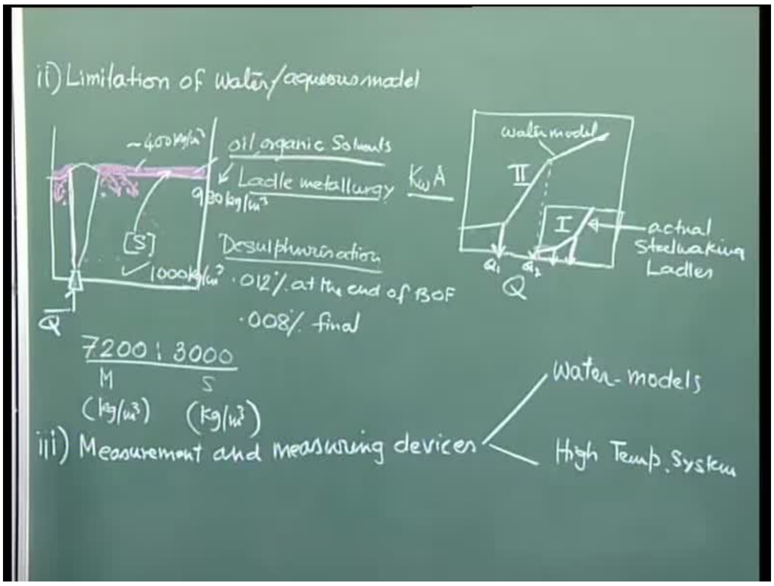

As a function of argon gas flow rate, in a gas stirred ladle and people have studied this by taking benzene and water, benzene as the top liquid and water as the bulk liquid and studied the partitioning of benzoic acid in between the two to calculate the mass transport, volumetric mass transport coefficient and it was found that well, it goes like something like this and then it goes like this (Refer Slide Time: 24:40).

This is about the slope is 0.07, the slope is about 2.5, the slope is about 1.4, this is the list slope, this is the maximum slope, this is still the intermediate slope as I have drawn. But, if the same experiment is carried out in a say, I will draw it in an inset it looks like that well the slope go something like this.

So, therefore, while the slope gradually increases, the list slope is here then, the intermediate slope is still bigger and then finally, in the third region these are the 3 characteristics argon flow rate, this is the argon flow rate 1 this is Q 1 and this is Q 2.

So, we do see 3 distinct regions as we see in the water model. So, the bigger plot is for water model and the smaller plot is for actual steelmaking system, steelmaking ladle. So, the similarity that I see here, in this system what is used? In this system, we have used benzene at the top, liquid benzene is lighter than water, water is the bulk liquid and we have studied a partitioning of benzoic acid between slag and water which to study the partitioning of sulphur between slag and metal. This is the actually gas stirred system where you have the slag a basic slag melt or the bulk liquid is steel and we have studied the partitioning of sulphur as a function of argon flow rate.

So, what we see that yes there are indeed 2 characteristic gas flow rates this is also exhibited, but there is some gross difference between the behavior because here what we see, that the slope gradually increases and the final region at the largest flow rate should gives us the highest exponent, but here the slope increases abruptly in the second region and then its slows down. So, it is slower on the left hand side, it is slower on the right hand side, but intermediate gas flow rates are the most steepest dependence of volumetric mass transfer coefficient on Q.

So, there is it is some dissimilarity between that these two graphs 1 and 2 even though the characteristic flow rates seem to be depicted to some extent, replicated to some extent in the water model itself.

So, you see this is one flow rate, but the slope changes this is again the second characteristic flow rate, but the slope changes again what you see here that this is the first flow rate, but the slope changes, this is the second time the slope changes. So, this behaviors are actually identical even though the exact slopes may not be identical and this precisely tells us at this is a confirmation of the fact that we really cannot replicate or exactly cannot replicate the multiphase characteristics of water model systems with a multiphase characteristics of a steelmaking system with water model itself.

Let us now talk about the third point, which is very important for us is measurements and measuring devices measurement and I have said that, models and measurements are like friends. So, without companion measurements no model study is accurate or no model study can give us any meaningful information because, we do not know even that whether the models are correct or not.

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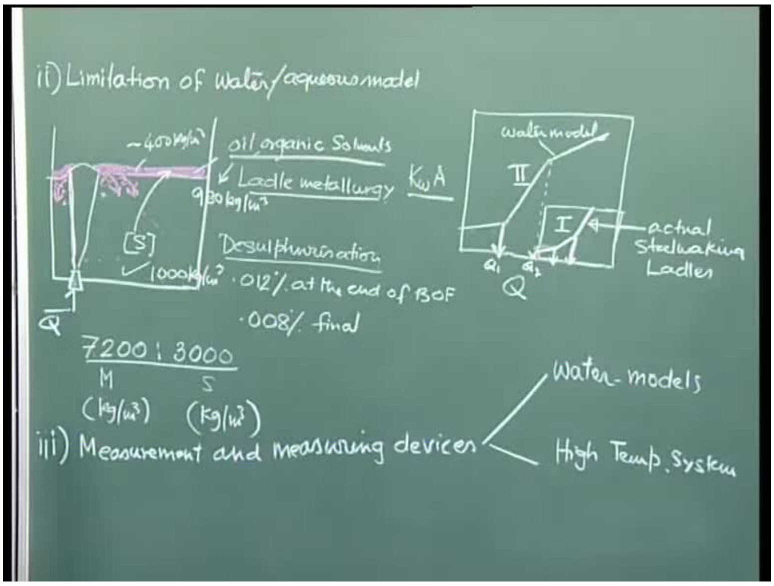

The models are going to generate some number and we have to physically verify that number with the aid of measurements. So, modeling and measurements are true companion of an accurate or realistic investigation.

Now, when you talk of measurements and measuring devices, we can talk this in terms of there will be one set of observations or equipment’s and techniques which are going to be used in water models and we are going to use in high temperature system.

What do we measure? For example, in steelmaking systems, we measure phases whether it is a slag or it is metal; we can measure temperature, we can measure mass flow rate, we can measure activities or concentrations, we can measure weight through a load cell. So, there are lots of measurements which are carried out routinely in a steel plant.

We must understand that measurement and steel plant is on a sustain basis is very difficult because the probes capable of performing at high temperature, sustainable probes capable of performing at high temperature are not readily expensive and this is a way are not readily available and these are in at some sense very expensive as well.

So, I will first talk a little bit about measurements in water models and then we will identify the corresponding equipment's and techniques in the actual steelmaking systems.

Now, in physical model studies measurements, we can do various types of measurements; the most important kinds of measurements is the observation of the flow pattern or flow visualization. So, flow visualization, flow measurements then measurements of mass transport coefficient, measurement of melting rates and as I said that we will not like to do measurements on the full scale on the model system and scale it up.

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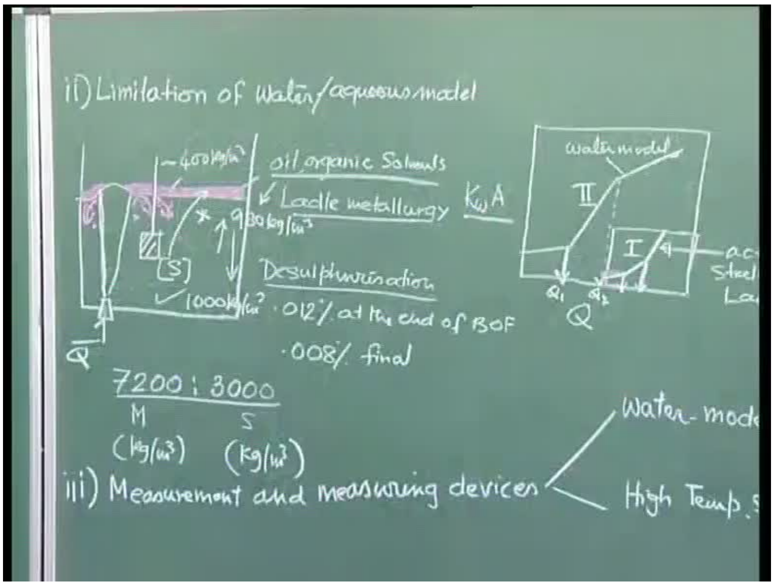

We may wish to carry out some measurements and some studies in the system without scaling of the result, we just want get insight of the phenomena. For example, I can put in a solid inside and study the dissolution of solid as a function of the gas flow rate and try to understand that if I increase the gas flow rate, then whether the dissolution of the solid, this is a solid, which is immersed into the liquid, if I increase the gas flow rate whether the dissolution increases or not (Refer Slide Time: 31:05). I can study this behavior of dissolution on a fundamental scale without bothering that I would like to scale it up with the actual system itself.

So, many a times we do measurements, we carry out investigations, we do some representative studies in the physical models in order to gain useful insight of the process, without considering that we are going to directly extrapolate the result to the full scale system itself.

So, we can various types of measurements are actually carried out and I am going to briefly talk about first the four visualization. Now, four visualization because we are using water, we are using a Plexiglas model. So, therefore, this is the great advantage to us this, we can physically see that what is the flow pattern, we can understand that which are the regions for the flows are very strong, which are the regions for flow is weak, how the flow is circulating or re-circulating in the system, which are the regions where that volumes are present. So, this entire feature can be carried out by studying or visualizing the flow itself.

How do we visualize flow? We can add some tracer elements into the water, what could be the tracer elements? That tracer element may be coloring agent for example, potassium permanganate, if you draw one spoon of potassium permanganate into water from the top, you will be able to see how the potassium permanganate disperses in the system giving you an idea, the overall flow pattern in the system itself.

Indeed, some localities you can inject potassium permanganate and when see that how does the velocity for example, I can take a syringe and through a syringe I can inject in this particular region to find out that whether the flow near the wall is vertically downward or the flow near the wall is vertically upward.

So, visualization of the flow and flow pattern is very conveniently done by tracer injection. Also, we can take neutrally one particle for example, we have glass spears very tiny glass spears which are of the micron size and if you add those particles inside in that case, the particles follow the stream line of the fluid and then give you the recirculating pattern. So, therefore, if you can illuminate the system properly, you can take a camera and capture the movement of those glass particles, tiny glass particles - micron size glass particles in the system and then, look it on the computer screen or on the TV screen and find out that what is the overall flow pattern in the system.

How do you measure the flow? This is the qualitative part, so visualization is the qualitative part. Now, we are talking about flow measurements, we have various types of measuring equipment’s as far as water modeling is concerned, we must understand that there is no way, you can see the flow pattern in the steel system, because steel is opaque.

So, you really do not know how the flow is going on and that we have been able to create a representative physical model. So, since, we have respective geometric similarity and dynamic similarity, that dynamic and kinematic similarity conditions are fulfilled within the model in the full scale. So, therefore, we can understand that the flow pattern that we are going to see in the model system is going to be exactly the same flow pattern in the full scale system, but I mention or repeat again that, there is no way that we can find out what is the flow pattern in the system. Similarly, there is a very little scope of measuring the velocity in the full scale system also.

We can may be with great difficulty measure at one location, but if I am talking of a huge vessel which is 3 meter by 3 meter and then, at every point measuring the velocity is going to be very typical.

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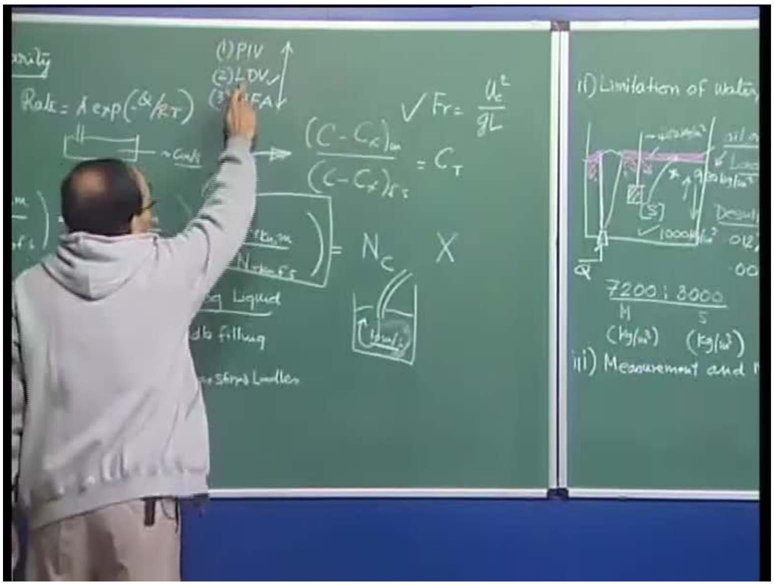

On the other hand, I can say that it is there are many equipment's which we can use to map the velocity filled in a water model system and most important today are, all the PIV Particle Image Velocimetry of course, we have Laser Doppler Velocimetry also LDV, we have Hot Film Anemometer also HFA and these are the common, this is the old techniques, so that is the way the development took place.

So, presently very few people would be using hot film anemometer particularly for all kind of a system, because these are all point by point measuring techniques, which essentially tells us that will measure point by point. On the other hand, PIV we can have a two-dimensional PIV or a three-dimensional PIV and with the three-dimensional PIV, we can map a plane in one short or we can map the three-dimensional flow patterns in the system in one go.

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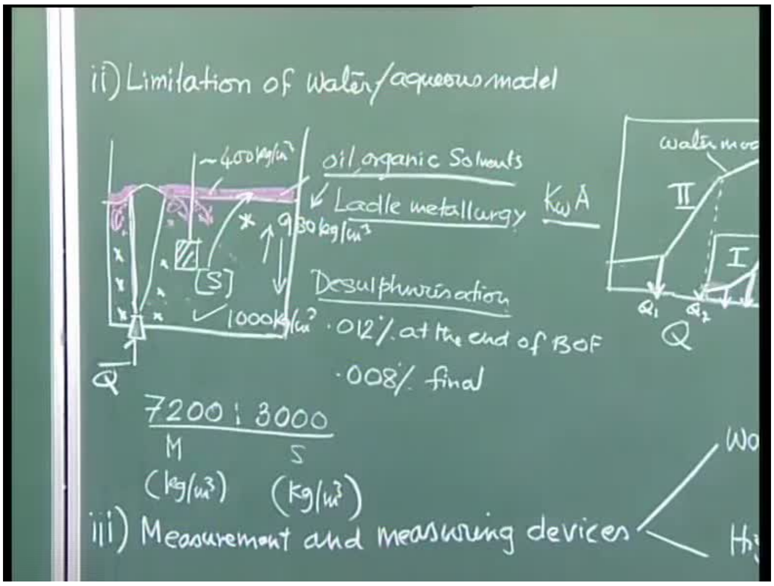

So, this is a very quick method of mapping the entire flow field in the system very quickly, for laser Doppler Velocimetry for example, you have to take it from one point to another point to make the measurement. So, to move the equipment up and down or in this particular direction, in order to find out and the velocities of the location and you can imagine how many such planes are going to be there.

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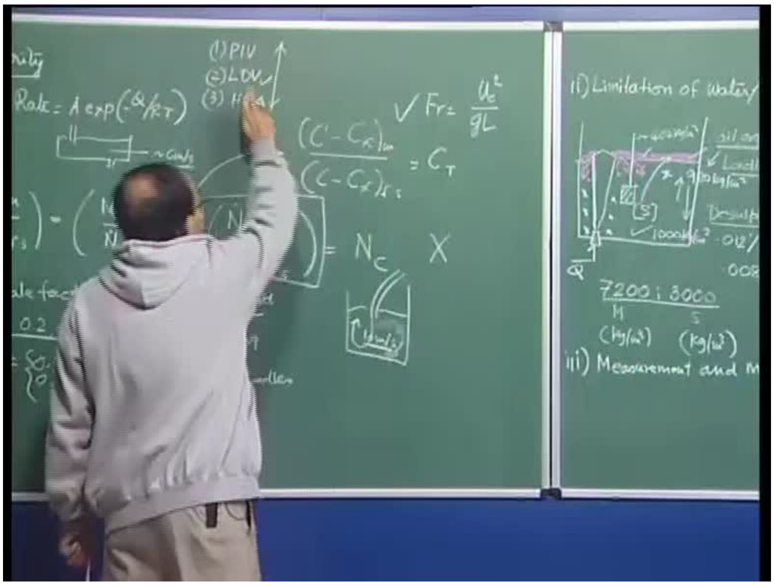

So, it is going to be an extremely tedious task to map even the velocity field prevalent in a water model on the other hand, with PIV you can do it possibly in one-tenth or onehundredths of a time. So, there is much equipment which is available. I repeat again, particle image Velocimetry, laser Doppler Velocimetry, hot film anemometer these are the standard techniques, if you are interested about this measure flow measuring techniques and you can look at the internet or certain some text books and know about this.

Apart from this we have other techniques also, which I am going to now describe this melting techniques, then mass transport, tracer dispersion and so on.

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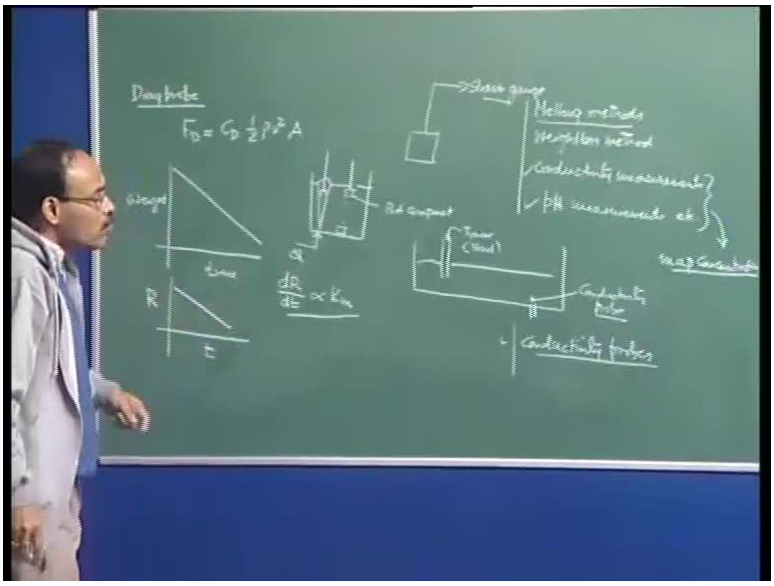

So, before I proceed to discuss the melting methods, weight loss method, conductivity measurements, pH measurements, etcetera let me talk about, so before I will discuss this, but I want to talk about one probe which is called as a drag probe; that is used to measure the flow field or velocity at a location, I would not say flow field, it is a velocity at any particular location in a steel melt.

So, that probe essentially implies that you take advantage of this is C D into half rho v square into area that is a drag force. And the drag force is related to the coefficient of drag, velocity and area which is perpendicular to the direction of the flow. Now, there are standard drag probes which are immersed into molten steel bath. See, if you have a drag flow which is connected to a strain gauge and assuming that you know the drag coefficient, because the probe is a fixed area, if you can somehow measure the force, so the measured force can be converted to the corresponding velocity very conveniently.

So, drag probe has been developed for steel bath and the force exerted by the flowing fluid on this probe which is measured by strain gauge is directly converted into the velocity. And this is come out handy in many laboratory scale measurements, but I really do not know of any situation, where such a probe has been measured in an industrial system on a sustain basis to know the flow or the intensity flow in the system itself.

Now, melting methods are basically used to understand the melting behavior of solids in the steel. For example, in the water model you can take an ice and study the melting of ice as a function of flow rate, as a function of vessel geometry, as a function of location in the system and so on. Thereby understand that, what are the conditions that experates melting, what are the condition that retards melting.

Similarly, weight lose method is also carried out to understand the rate of dissolution for example. So, you can immerse for example, a benzoic acid compact in a water bath and let that compact get dissolve, because benzoic acid will dissolve in water. So, as a result of the dissolution of the benzoic acid what happens is, its weight will continuously go down.

So, suppose I immerse the benzoic acid and then it is connected to a load cell, so it is recording continuously the weight of the benzoic acid compact immersed in the water bath and as time goes on what happens is that the weight decreases. So, I would say weight versus time and then you say that the weight - I am just drawing it for the sake of convenience may be decreasing linearly, because as a result of dissolution of benzoic acid in the bath. So, I have the benzoic acid compact here and this is benzoic acid compact (Refer Slide Time: 40:00).

So, it is dissolving as a result of which its weight is continuously decreasing and that behavior is replicated in this particular… This if the compact is of cylindrical shape, I can convert this weight in terms of a corresponding radius, because I know the density, so the volume is correlated with the length as well as the radius. And that I know already the density of benzoic acid, so therefore, the weight can be converted in terms of a radius. So, I can also draw that well, radius varies something like this.

Now, once I know R versus t then I can calculate that for example, dR over dt the rate of change in the radius and this rate of the change of the radius is actually proportional to the mass transport coefficient which one can very conveniently show.

So, therefore, by carrying out this weight loss method with suitable species or solid compacts, we should be able to determine that what is the mass transport coefficient and find out that well, how does the weight changes as a function of time if the argon flow rate changes, if the liquid becomes more taller or deeper or the diameter of the vessel becomes more wider or this point actually moves down to this particular location. In that case, we can study all the effect of operating conditions on the weight, which can be converted to corresponding radius and based on which the mass transport coefficient can be calculated and we can say that.

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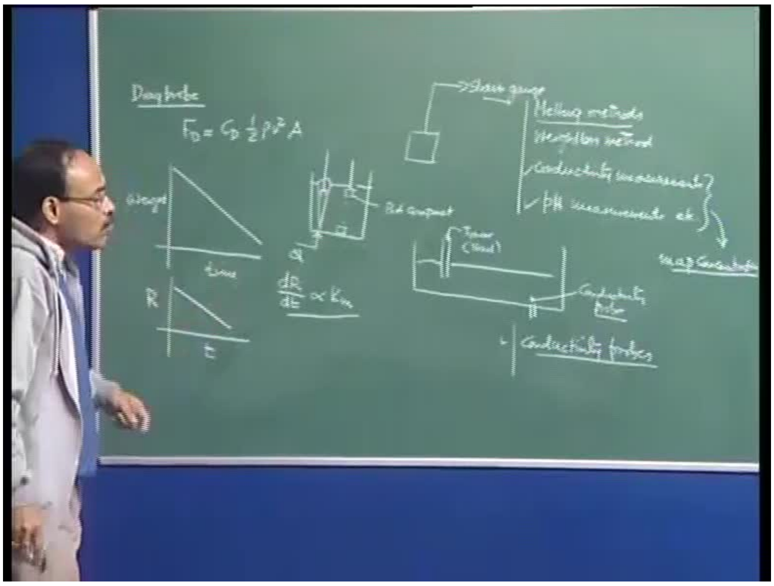

Well, based on the weight loss method we can study that well, whether the dissolution of the solid is going be expatriated under certain condition, under which condition and retarded under which condition that we will be able to find out based on weight loss method.

Conductivity measurements basically a pH measurement both of them are basically used to map concentrations. You remember I talked about the residence time distribution in the tundish. So, in the water model if I have a tundish like this, the fluid is coming here (Refer Slide Time: 43:15).

Now, I have injected a tracer here and I want to monitor the concentration here that is the residence time distribution studies talks about, that you inject a tracer and monitor the concentration here. The bath is water, I have to inject a tracer here and monitor the concentration, how do we do it? So, suppose if I use sodium chloride as my sodium chloride solution as my tracer.

So, sodium chloride is an ionic solid. So, lot of you knows that, we will have higher conductivity as sodium chloride gets into the solution. So, if I have here a conductivity probe, that conductivity probe can give us direct information about the concentration of sodium chloride at the exit itself and it will help us.

This conductivity probe will give us conductivity which can be converted to the concentration of sodium chloride, because conductivity and concentration in most of the cases, we see are directly proportional. Also, it is possible to inject an acid for example here, instead of a sodium chloride solution, we can inject acid permissible, if it does not affect the walls of the waste plastic glass vessel and then we may not use a conductivity probe but we can use pH measurement probe, pH measuring devices. And that can be there and with this we should be able to find out that how much of acid is coming here. And as a result of that, we should be able to find out that from the pH that what is the concentration hydrogen and what is the concentration of acid.

So, therefore, distribution of tracer or concentration profiles in the system can be obtained by… (Refer Slide Time: 45:00). We also have a technique like electrical conductivity technique which is used, conductivity probes basically which are used in two phase flows in gas stirred ladle system; for example, you inject bubble here.

So, if we use a two needle conductivity probe, these two needle conductivity probe will give rest to some signal in terms of conductivity based on which we can distinguish between bubble and liquid. So, as I mentioned to you that within the flume region what you have? You have bubbles which are disperse 2 to 5 percent of the volume of the flume is going to be occupied by bubble. So, therefore, at some point of time the probe is like this, the bubble will come hit the probe and then the bubble goes away and next behind the bubble comes water and water strikes.

So, intermittently you have sometimes water striking, sometimes bubbles striking, sometime water striking sometimes bubble striking. And this is going to create a different kind of a signal and based on that you will be able to find out that what the bubble rise velocity is. So, discrimination of the two phase characteristics of the gas liquid flumes in water model can be very conveniently done with conductivity probes.

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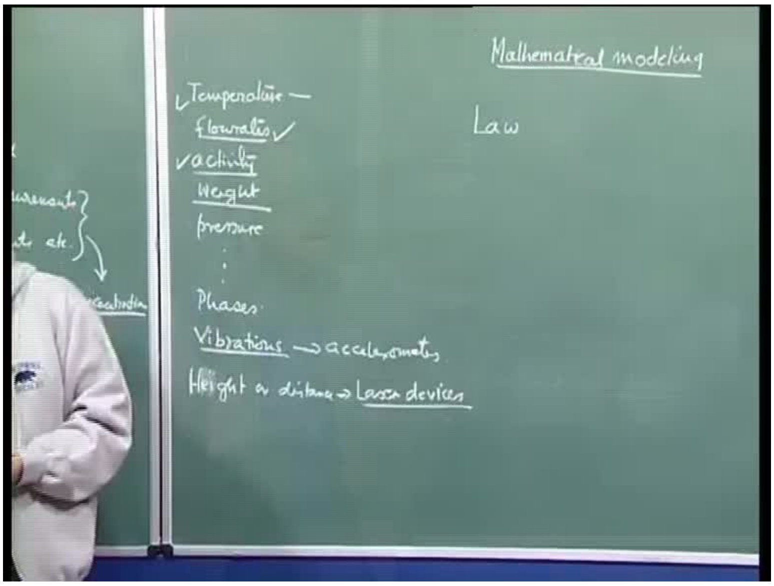

If you come to full scale system or steel processing system, in that case we find that this sort of probes is very difficult. Of course, some probes have been generated for laboratory scale studies, but in industry as I have mentioned to you that we mostly measure temperature, we measure flow rates, we measure activity, we measure weight, we measure pressure, many things phases for example.

So, flow rates for example, flow rates of argon which is coming your flow rates of oxygen which is getting into the oxygen steelmaking converter, no problem because this is outside the bath, if their flow meter is not going to be exposed to the environment, a steelmaking environment it is going to be away from the reactor. So, therefore, measuring flow rates is absolutely no problem, it is going to be similar to what we have done in the case of water models for example, you can use rotameters or orifice meters in order to calculate under the flow.

Activity for example, if you want to find out that what is the activity of iron oxide in the slag; in that case, you have to collect the slag. And also there direct intervention with the melt comes into play and therefore, you can use for example, some kind of a probes celox probe for example, which you can immerse it; it can give you the temperature and it can give you the activity of oxygen simultaneously, based on which you can calculate the iron oxide content on the slag itself.

But note that since now your probe is going to be intervening with the high temperature system, you may use it only for once and then for the second time if you use to measure it, you have to use a separate probe itself.

So, the issue of repeated usage becomes a very big problem. Weight, what typically we do? Weight we measure by putting material in the load cell. So, we have load cells which are available to us, on the base of the tundish the load cell can be there and that can monitor continuously the rate of change of weight in the system.

We have pressure transducer or accelerometers are also there, we can find out the vibrations for example. So, you can accelerometers will accelerometers, we have laser devices are also there, as I have mention to you that we have a laser gun that senses the height of the melt surfaces. So, that measures what they measure? It measures the height or distance h e i g h t height or distance you have laser devices.

So, there are devices which are non-intervening with liquid metal systems. So, for those we have no problem they will last for long, but those which will directly intervene with the molten steel for example, temperature. If you want to measure the temperature, the probe is to inside the melt itself.

And in that case, you may have a problem because the probe may not function properly at that particular temperature, it may give erroneous result, it may be faulty, it may develop cracks and other things, and lot of problem can take place really at high temperature system.

So, using of probes to measure temperature, activity, etcetera, on a sustain basis of course, temperature can be measured through non contacting devices also like optical radiation pyrometers, but if you use an immersion thermo couple type of a device, in that case you have problem because you are interacting with the melt itself.

So, I would not like to say anything beyond that, now I would like to talk about the next important part of modeling, which is the mathematical modeling, but before you proceed I would like to very briefly summarize whatever we have done in the physical modeling section.

So, I told you that there are some principles which you have to respect or some similarity criteria which we have to respect in order to make physical models. This I have explained to you, the geometrical, mechanical, thermal and chemical similarities are important issues.

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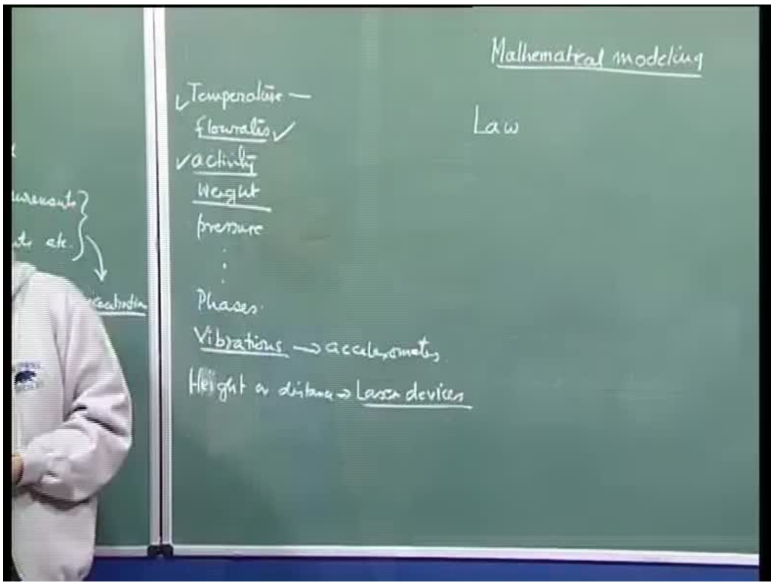

Now, geometrical and mechanical similarities are will always be satisfied, there is no problem about it, but in reduce scale models I have told that, it is really going to be difficult, particularly when you use water as the representative fluid to satisfy all the numbers. So, therefore, fortunately since the metallurgical or steelmaking processes appear to be Froude dominated.

So, we can say that well, we can use water without any problem and water also has the same type of a kinematic viscosity. So, we do not disturb the flow patterns, if you scale it up, if the flow pattern in the system full scale system is turbulent, since water has the same sort of a kinematic viscosity and the corresponding scale also on the reduce scale, the features, flow features are going to be also similar to the full scale system itself.

Now, thermal similarities are going to be little bit difficult to maintain and chemical similarities perhaps are going to be impossible to respect. And all this similarity criteria I have told you that, they can be derived starting from the governing equation if they are known or they can also be derived from moving the fundamentals of the process itself, if the governing equation is not applicable, in that case you can find out by carrying out a dimensional analysis which of course, we have not talked here, but you may have been exposed already to dimensional analysis. So, through two-dimensional analysis we should be able to generate Froude number, Reynolds number, Fourier number, etcetera or these numbers can be generated from the governing equation.

So, all the similarity criteria's are going to be can be generated by considering the governing equations. I have try to emphasize repeatedly that physical model cannot be used for everything and model word itself implies that this is the some sense of accuracies involved or idealization involved and I have mention that throughout.

So, we must understand the potential and limitation of water models particularly. And I said the biggest advantage of using water model is our ability to measure the flow as well as see the flow pattern itself, this is the single most advantage of water modeling which is un-parallel. And because we have been able to match dynamic and dynamic, kinematic and geometrical similarity realistically well. So that, you get a nice representative scenario of the actual steelmaking through system as well as flow are concerned.

Multiphase flow we are not sure, we cannot quantitatively analyze, but we can get some qualitative information of the slag metal interactions and behavior in actual system. And I have also categorically mention and shown you that, to what extent one can get the representative observations or some observe meaningful observations which may not be accurately representative of the full scale system.

And finally, I have also talked about the choice of a fluid scale factor, in scale factor I have emphasized that when you have intensity of the flow very appreciable, you can go for a relatively smaller scale factor. And when you have intensity of flow very weak, you can go for a little bit higher scale factor. So, that you do not disturb the flow pattern itself.

And finally, I have tried to give you some idea about the measurements and trying to emphasize that. If you would do modeling at any stage, please go for companion measurements, because without measurements our models are incomplete, we do not see the reality. And there is enough scope of carrying out measurements in full scale as well as the experimental systems. And in full scale systems, I have mentioned that our steel processing systems that because the high temperature, where we are going to have measurements, but the measuring device is going to directly intervene with the fluid which we called as evasive and non-evasive techniques.

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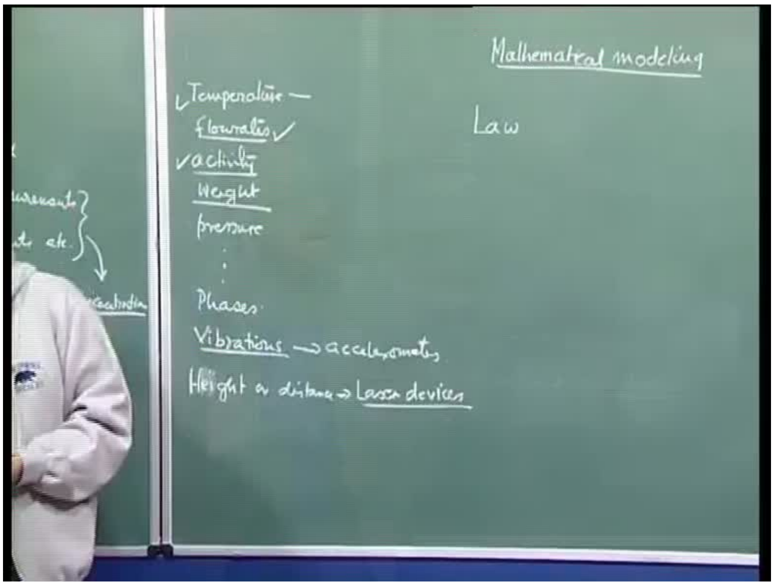

So, non evasive techniques have no problem, because they are not going to be exposed to the high hazarders a high temperature condition, but evasive techniques like emersion thermo couples, emersion oxygen probe they are going to be problematic to some extent particularly when you have a huge reactor size.

Laboratory scale is no problem you have this much reactor, you can put in a slug flow very easily, but imagine if you have a 300 ton ladle or a 300 ton oxygen steelmaking furnace you know, putting an oxygen probe you have weight automated devices and so on. So, it is little bit tricky, but on the other hand, as for as the physical modeling is concerned, we can carry out numerable type of measurements.

Now, coming to mathematical modeling, in physical model we have represented the process in terms of an actual physical replica. That replica is having different scale; it is having different material, now we need to represent a given phenomenon, the system and the given phenomenon in terms of a mathematical model. So, therefore, if you pushed incomes I want to represent l d converter in terms of a mathematical model.

So, I would say that what in an l d converter you would like to represent in terms of a mathematical model. So, the phenomena under question will be represented or the process under question is going to represent in terms of a mathematical model, which is either a differential equation or an algebraic equation.

Now, the word model I come back to this critical point, which I have been mentioning the word model implies that there are certain inherent approximations and assumptions involved. Now, mathematical expressions for example, there are mathematical expressions for example, ohm’s law you write down current voltage resistance relationship or you have Fourier’s law of heat conduction.

So, these equations are also mathematical expressions, but we call them law. On the other hand, the mathematical expressions that you are going to write for steelmaking system, we are going to call them as models, because we are going to build those mathematical equations with certain assumptions and approximation.

Laws are what that corresponds exactly with a reality. Whatever I observe, whatever the law says, there is one to one correspondence. On the other hand, whatever I seen and whatever the model predicts, there may not be any one to one correspondence; the model will have harden differences from the observation. If the models repeatedly produces results which are exactly regardless of geographical boundaries or any locations or any constraint, because ohm’s law is valid here also in other continents as well same as Fourier law of heat conduction.

So, if my model of a particular steelmaking process is found to produce exactly the same result, in different steel plants all over the globe, then you can say possibly that this model is now as good as a low, because there is no approximation involved, there is no idealization involved. And hence, the model predicts whatever we are observing in reality there is one to one correspondence and hence, so yesterday's model may become tomorrow's law.

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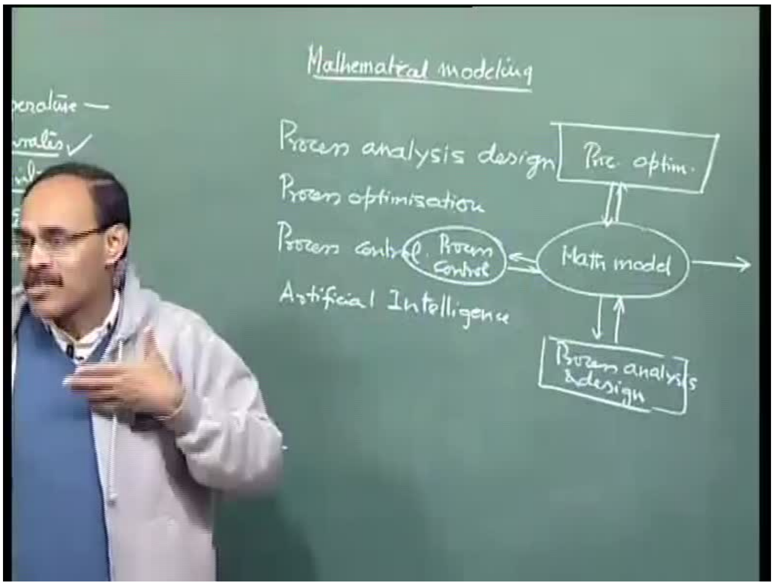

So, what do the models do in steelmaking, what is the purpose? There are various jobs the models do; the models can carry out two models process analysis and design. This is one job of analysis and design, we can do process optimization, we can do process control and we can do artificial intelligence. So, I will draw this figure and show you that this is my mathematical model. So, this is process optimization, this is process control, this is artificially more and this is process analysis (Refer Slide Time: 59:00).

Process control, so mathematical models this I have explained in the context for example of flow rate control in a tundish. And I said that well, how was the aperture nozzle of the tundish adjusted? It was based on a control algorithm which is a mathematical model, which may be the boundary layers equation.

So, that equation correlates with the opening of the apertures on the flow rate and adjusts or controls the movement of the motion. So, therefore, process control models are going to be mathematical models which are going to use for control and these models are going to be very simplistic because we have to perform the model or the models has to perform in very small amount of time or in a realistic time way. During rolling, the role gap is to be change dynamically, what controls it? There are control algorithms, there are control mathematical models are going.

Process optimization, so this is process control is done on an online fashion; it is interacting on a one to one basis in real time frame. Process optimization, process analysis and design are done on an offline fashion.

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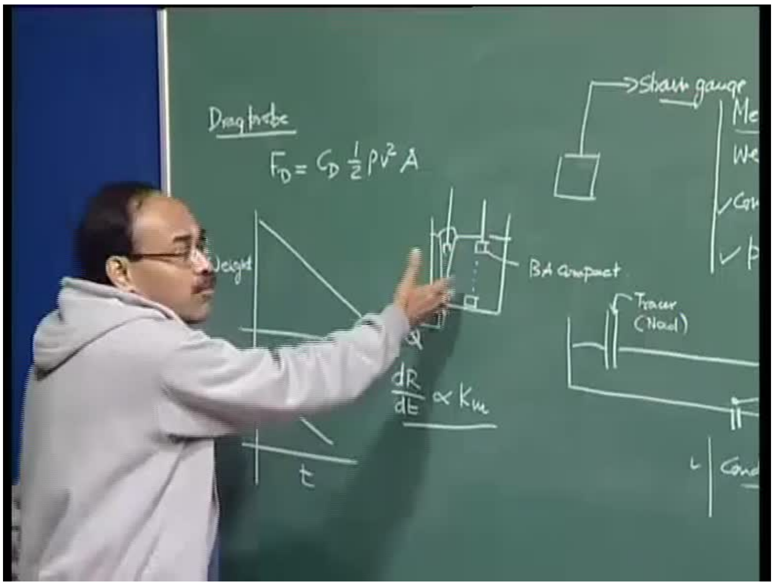

So, I can optimize the process sitting in my laboratory and tell that well, you change the flow rates, you change this, you change that and then you get an optimum condition itself. Similarly, process analysis and design these all can also be done in the case of in an offline fashion. And I can say that well at what should be the ideal l by d ratio for your plant, what should be the capacity of the ladle for your plant? All this sorts of design calculations, I should be able to do based on solving some mathematical equations sitting in the laboratory also. And my mathematical model can also interface with artificial intelligence and provide information.

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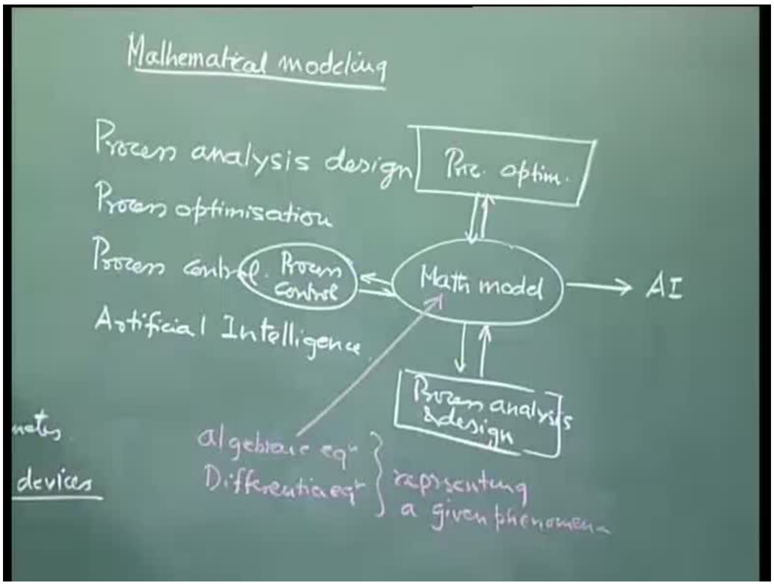

So, this mathematical model that I have here as I mentioned that, it is either an algebraic equation or differential equation representing a given phenomenon. So, unless and until, I say what is that phenomena, we cannot develop the model, we cannot formulate the algebraic equation or the differential equation.

So, merely saying, I want to have a mathematical model of an l d converter is an ambiguous statement. You have to specifically mentioned that what is the process of the phenomena and then try to represent the process and then see, whether you want process control to be done process optimization process analysis and so on.