Iron Making
Prof. Govind S Gupta
Department of Materials Engineering
Indian Institute of Science, Bangalore

Lecture – 20
Iron Making

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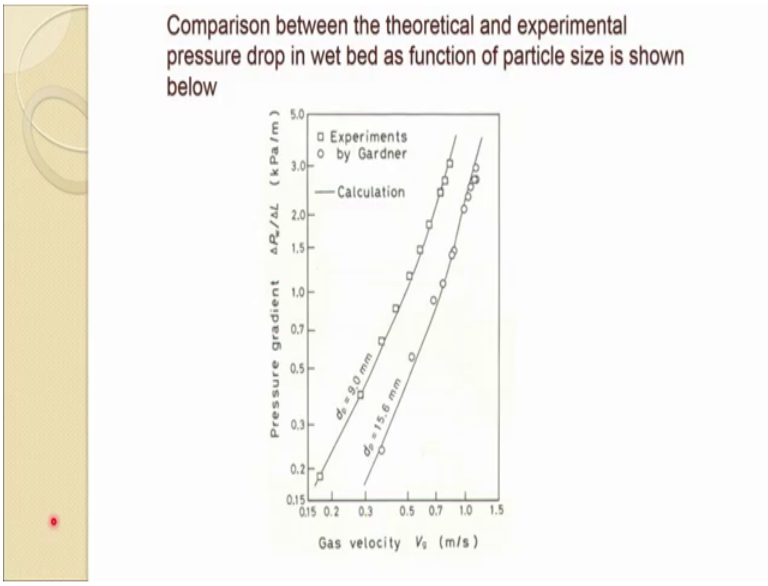

As we had discussed in the previous slides, that Fukutake et al. sort of formulated or developed the correlation for the; pressure drop in the wet condition or irrigated with the liquid for that bed. So, this is the figure which shows a comparison of that correlation, with the actual experimental data. And even with the another author with the gardener, so this is the solid line is a theoretical line predicted by Fukutake et al correlation and this square one is the experimental one and circle is the gardener a researcher who some work in this sort of flow.

So, one can see very clearly the relation developed in the previous slide and so on; can very well predict the trend in the experiment which is happening. So, one can use those correlation for the dry wet pressure drop and wet pressure drop to study the flow behavior even in the blast furnace. And as you can see from this figure higher diameters particle size packing has the lower pressure drop at the same gas velocity, then the smaller size particle, which is evident from Ergun equation and it is expected.

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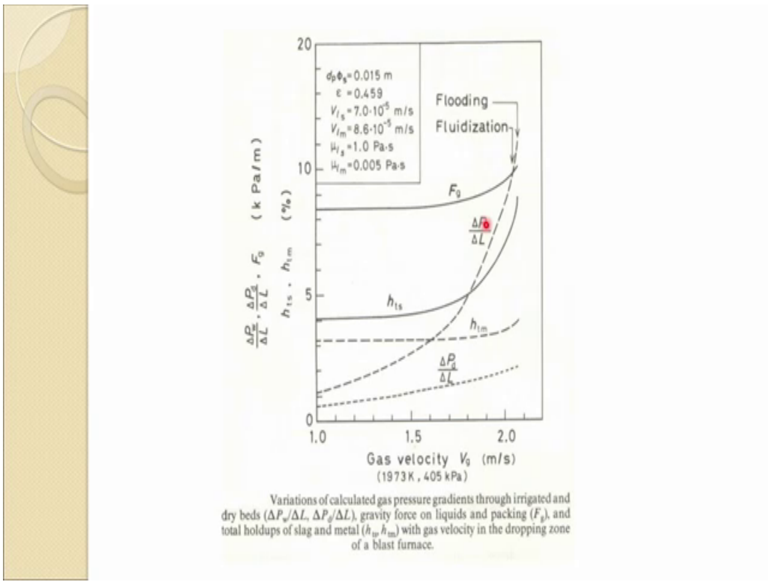

This figure shows again the relation between various quantities with respect to the gas velocity.

So, pressure drop in wet condition in a packing in a packed bed; pressure drop in a dry condition, when there is no liquid present in the packing in the system, so this could be correlated like a stack zone in the blast furnace and this is like a drape dropping zone in the blast furnace, where a liquid iron and slag is present and here mostly the gases are there in the stack region. And this is about the gravity force; this is the total holdup of slag and total holdup of metal.

So, as one can see that when velocity is increased the pressure drop increases both in dry and wet condition and as we know in the wet condition pressure drop is always higher and this is showing that trend. Similarly, the total holdup in case of slag increases quite rapidly, then total holdup for the metal liquid metal, which increase only after that gas velocity goes beyond 2 meter per second.

And a gravity force on the liquid is also increases as the a gas velocity is increased; as the gas velocity increases the pressure drop in wet condition increases rapidly; and it crosses the gravity force which means the liquid will start hanging and so that hanging and fluidization; where pressure drop becomes equal to these the fluidization will occur. And further increase our case really it will got about a flooding condition. And under this situation, your slag and metal would be going up into the higher zone of the blast furnace, which is cooler and they will solidified and more problem will occur, then in the upper zone. So, mal distribution of gas and other things will occur.

And it will block the force in between the particles and will further reduce the permeability of the blast furnace and the blast furnace performance will deteriorate. So, which is not the good thing, but it predict a trend in a good way and one can see from this metal total holdup is about 3 percent, and a slag holdup is about 4 percent, in the blast furnace. And this is sort of has been found wide a section of the blast furnace, which is which we will see later on.

So, the property which have been used in constructing this diagram, where the particle size multiplied with the shape factor it is a 0.015 meter, bed porosity or porosity in the dropping zone 0.459 slag velocity is 7 into 10 to the power minus 5 meter per second liquid velocity; the metal velocity at 0.6 into 10 to the power minus 5 meter per second.

The viscosity of the slag is 1 Pascal second and for metal it is 0.005 Pascal seconds. As you can see the metal viscosity it is a almost 3 times lower than the slag viscosity. So, slag is quite viscous though the quantity formed the in the blast furnace a a of slag is much more than the metal one and the density difference between these two is also quite substantial.

So, for metal is about 7000 kg per meter cube, while for slag it would be about 28, 29, 100 kg per meter cube. And this leads to the different holdup of metal and slag in the dropping zone, which is evident from this figure.

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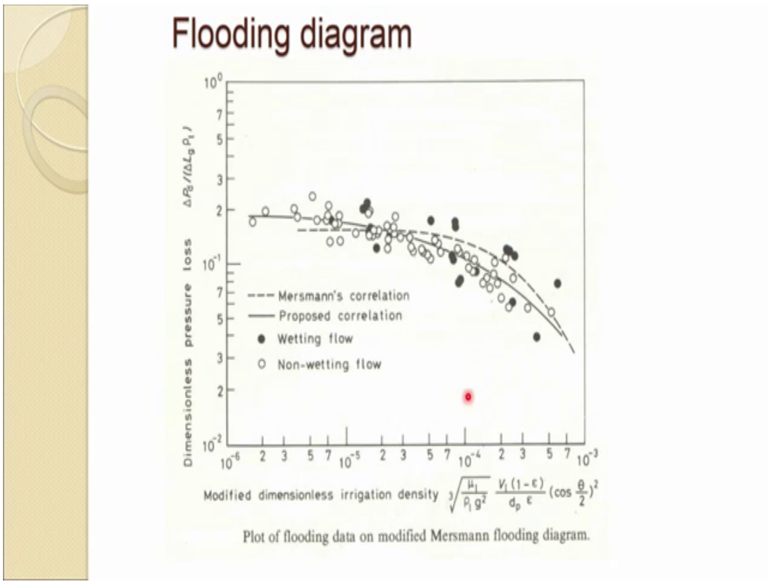

Now, because we would certainly do not want to operate the blast furnace above the flooding limit; otherwise the efficiency will degree the blast furnace will hang the operation will hang and then one had to set it down. So, lots of work has been done and this is similar to many chemical reactors, they also do not operate above the flooding point.

So, lots of research work has been done and especially in chemical engineering the literature which has been filled with this flooding and other data, they have constructed a diagram called Mersmann's flooding diagram which is which look like that, and for metallurgical purpose we have put other a non wetting flow and other thing in this one and it has been modified a bit, so you can see this is there for the metallurgical one which correlation was proposed previously shown in the previous slide and this is a Mersmann's correlation dotted line.

So, the dark sphere is for the wetting flow, and a open sphere is for the non wetting flow. And in chemical engineering mostly flow is related to the wetting condition, but in a metallurgical discipline mostly it is non wetting condition; as and that is why it has been modified and it has been re plotted for non wetting condition as shown by this figure and this diagram.

So, at one side we have a dimensionless pressure loss, and on the x axis we have a dimensionless irrigation density. So, any reactors usually should be operated in this region. So, flooding should not occur; if it cause that, then it is not good it should not go into this region and then lots of operational problem will come into picture example for you to do it as ah; so using the modified Mersmann flooding diagram, calculate whether flooding occurs.

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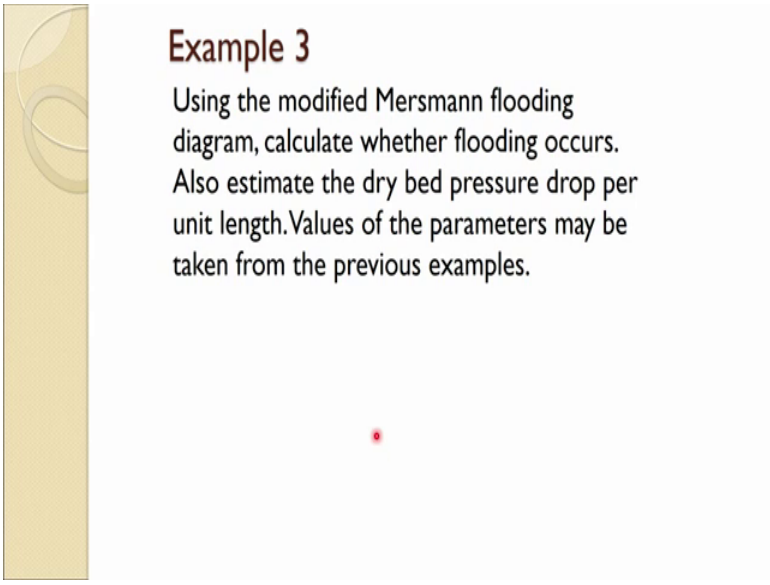

Also estimate the dry bed pressure drop per unit length. Values of the parameter may be taken from the previous example. So, as you we have done couple of example on this pressure drop and a other thing related to blast furnace dropping is on. So, values can be directly taken from those examples.

So, in this one what we will do; we will choose the modified Mersmann flooding diagram, which was shown before. So, we need the value of this parameter, where mu 1 l is the viscosity of the metal, rho l is the density of the metal, gravitational force, velocity of liquid, void fraction in the drop dropping zone, a particle size and a contact angle. And similarly here is the pressure drop per unit length, if you take delta L at across some length and rho l is the density of the liquid.

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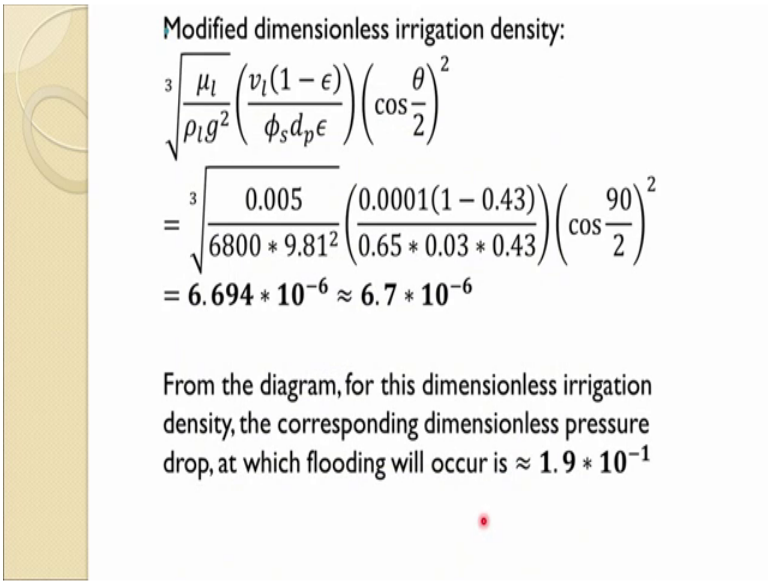

So, what we have to do? We have to first calculate this x axis. So, irrigation density, which is given by this; so viscosity is 0.005 Pascal second from our previous example, density of the liquid 6800 kg per meter cube, and the gravitational constant 9.81, then you have the velocity of the liquid 0.0001 meter per second.

So, which boils down to point 1 millimeter per second and the void fraction in the previous example we have taken 0.43, it was given shape factor was 0.65, particles I 0.03 meter, which is about 3 centimeter and the contact angle between the liquid and coke or liquid and a particle in the blast furnace is coke in the drape in the dropping zone, because everything else is in a liquid form.

So, that contact angle 90, which gives you the irrigation density about 6.7 into 10 to the power minus 6. So, if we look at the; that 6 point this quantity, so 6.7 into 10 to the power minus 6 is coming somewhere here. So, which actually we look at the these; so this gives a flooding limit somewhere here.

So, around 1.8 or like this; so, from this if we calculate the flooding will occur, if we have a dimensionless pressure drop about 1.9 into 10 to the power minus 1. So, now, what we have to do we have to check, whether this quantity is closer to this or not.

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Dry bed pressure drop per unit length:

$$\frac{\Delta P_d}{\Delta L} = \frac{\left[150\left(\frac{1-\epsilon}{d_p\phi_s}\right)^2 \mu_g v_g + 1.75\frac{1-\epsilon}{d_p\phi_s}\rho_g v_g^2\right]}{\epsilon^3}$$

$$= \frac{\left[150\left(\frac{1-0.43}{0.03*0.65}\right)^2 (5.44*10^{-5})1.03 + 1.75\frac{1-0.43}{0.03*0.65}(0.2)(1.03)^2\right]}{0.43^3}$$

$$\therefore \frac{\Delta P_d}{\Delta L} = 226.84\frac{N}{m^3}$$

Non-dimensional pressure drop is:

$$\frac{\Delta P_d}{\Delta L \rho_l g} = \frac{227}{6800*9.81} = 3.4*10^{-3}$$

As the calculated value is lesser than the flooding value, we can conclude that **flooding does not occur**.

So, to calculate now this pressure loss dimensionless; we you are already familiar with this equation, which we discussed in 2 2-3 lectures before. So, this is the pressure drop for dry bed, where essentially a Ergun equation. So, in this one we substitute the appropriate value void fraction, particle size, shape factor, gas viscosity, this also in one example we calculated and then gas velocity all are things are available be there.

So, if we substitute these values into this; we get the pressure drop in the dry bed 226.84 normals per meter cube. And of course, in non dimensional form we divide this one with the density of the liquid and the gravitational force; it gives us about 3.4 into 10 to the power minus 3. So, if you look at for flooding to occur, we need this sort of pressure it should; if your pressure drop is coming up to this and more, then certainly pressure flooding is going to occur, but our calculation shows the pressure drop is 3.4 into 10 to the power minus 3, which is really coming somewhere below here.

So, we are operating somewhere here, which is quite below to the flooding limit. And we are very safe in that case, to operate the process using under these operating condition. So, this says the calculated value is lesser than the flooding value we can conclude that flooding does not occur. So, you can see is the calculated value is less than the flooding value. So, we can conclude that flooding does not occur in this case. So, this is the way the trigram is very useful in the industry to know whether the operation is below the flooding limit.

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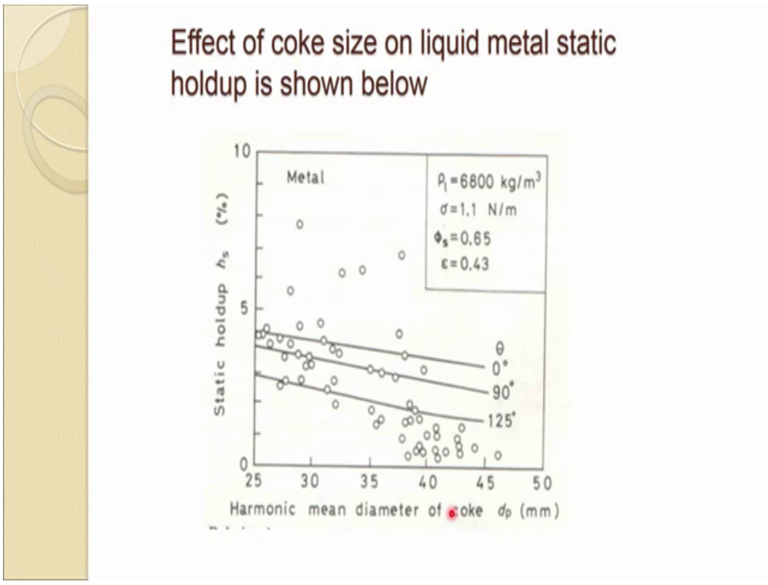

So, efficiency of the reactor does not affect. This figure shows the effect of coke size on liquid metal static holdup. So, you can see this is actually let me tell you, the actual live blast furnace result when I say the live which means the blast furnace has been quenched and dissected and then the data were collected. So, it is in the actual blast furnace.

So, in the that case the static holdup is saying about the total static holdup of liquid metal not this like liquid metal, these are the condition that the of the blast furnace, when it was quenched and dissected a density of the liquid was 6.8 grams per centimeter cube; and surface tension 1.1, shape factor 0.65 and void fraction 0.43.

And the harmonic mean diameter of the coke, because it is changing from one location to another location and that is why; the diameter of the coke changed from 2.5 centimeter to 5 centimeter. So, you can see at the diameter of coke, is increasing the esthetic holdup of the metal is decreasing one thing. Second thing also you will find that here it is shown theta, which is the contact angle 0 degree, which is totally wetting conditions the liquid spreads over the solid 90 degree, which is said that the non wetting starts and more is the angle after this more is the non wetting effect.

So, one can clearly see, the especially in the blast furnace the condition are mostly lying under the non wetting conditions. The liquid metal and a coke really having a sort of non wetting flow in that, because most of the data are in this one in which are quite wet fitting with the non wetting line. So, of course, when the coke size is lower the holdup is more and as it decreases the holdup becomes lower and lower. So, this is the condition near the a raceway their finer size is there, but little away you may get a bigger size also. So, this is the actual blast furnace condition, how the holdup occurs; and it is catalyst also shows effect of the contact angle.

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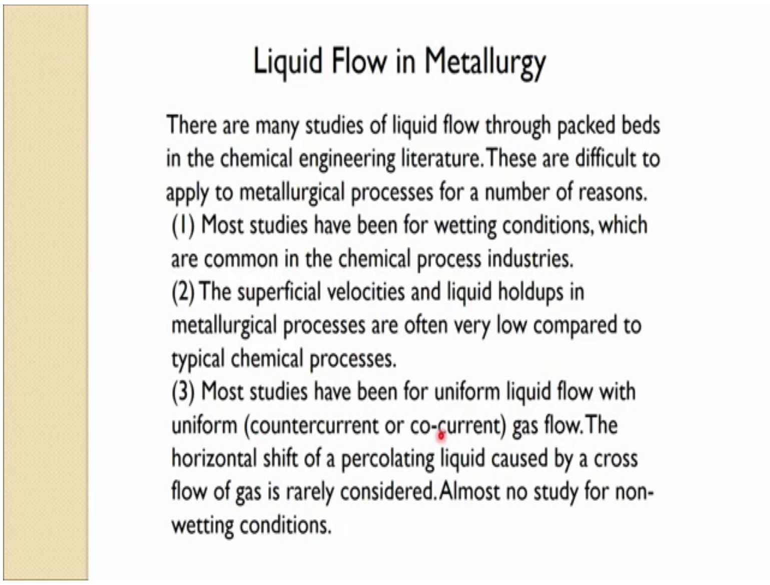

So, flow is mostly non wetting in nature. Now, this brings out another aspect of the liquid flow in metallurgical discipline as such and in particular in the blast furnace. So, there are many studies of liquid flow through packed bed in the chemical engineering literature.

And these are difficult to apply to metallurgical processes for a number of reasons. One the most studies have been done for wetting condition, which are common in the chemical process industries. So, we have heavily borrowed the data, literature from chemical discipline and not much work has been done by a metallurgist.

So, the and the superficial velocity and liquid holdup in metallurgical processes are often very low compared to the typical chemical processes, which has a very high flow rate or liquid holdup. Then most studies have been for uniform liquid flows with uniform counter current or co current gas flow.

This is a mostly in the chemical discipline, the horizontal shift of a percolating liquid caused by a cross flow of gas it rarely considered. So, in the blast furnace you are having a cross flow the lateral injection of the gas the is protruding inside the blast furnace. So, from the side you are injecting the gas and liquid is flowing down.

So, it is a cross flow condition, which we had discussed be before, when we were talking about a counter current, co current and cross flow. So, in blast furnace we have mostly the cross flow condition and this is rarely dealt in the literature. So, almost no study for non-wetting condition in fact, is hardly any study in the chemical literature under non-wetting condition, which are prevailed in metallurgical field. And this is very important, so we cannot directly apply these chemical principles to metallurgical reactors.

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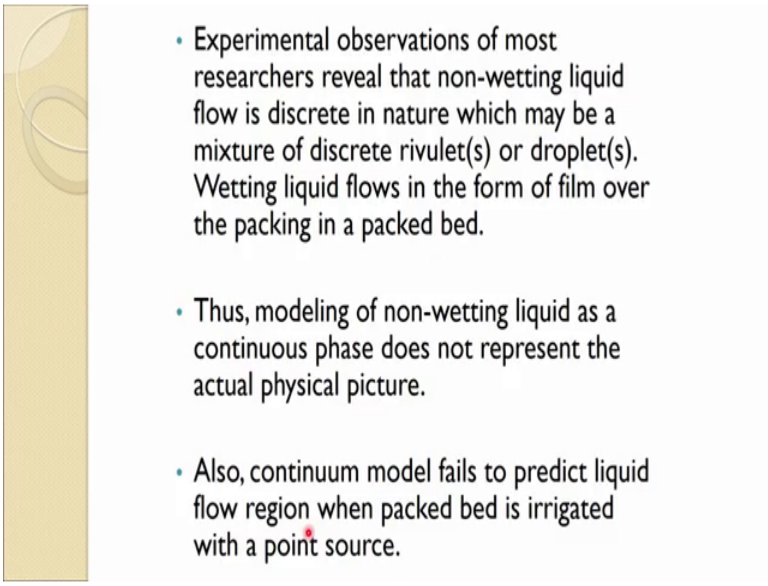

So, experimental observation of most researcher reveal that non-wetting liquid flow is discrete in nature which may be a mixture of discreet regulate or droplets. Wetting liquid flow in the form of film over the packing in a packed bed; so, as you know the when we say wetting you must be aware about the; liquid flow on a glass.

So, which usually spread over very easily and that sort of flow, what we call the wetting flow or the film flow; however, in metallurgy flow are more discrete in nature and not continuous. So, thus the modeling of non-wetting liquid as a continuous phase does not represent the actual physical picture. Also, continuum model fails to predict liquid flow region when packed bed is irrigated with the point source.

So, these are quite big difference between the chemical and metallurgical reactors in terms of liquid flow. And the theory which is suit by chemical engineers to describe the liquid flow in the packed bed cannot directly be used in metallurgical reactor.

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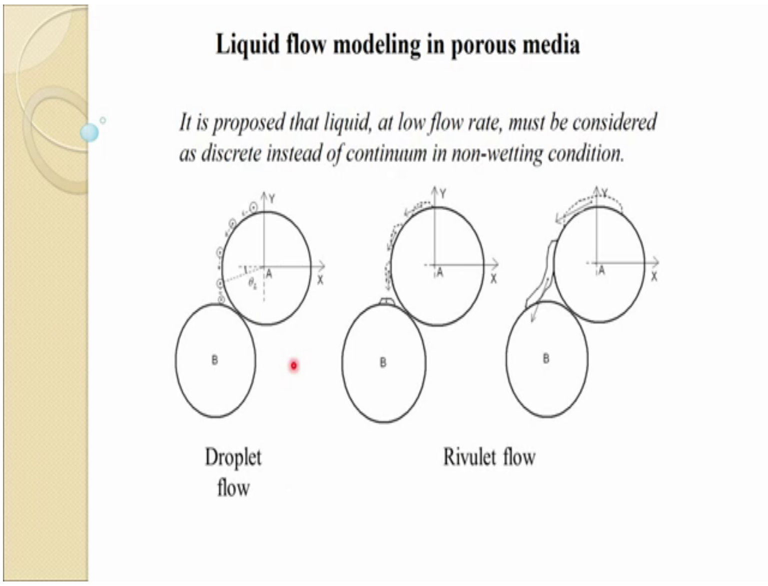

So, another theory has been proposed for this; so it is proposed that liquid, at low flow rate, must be considered as discrete instead of continuum in non-wetting condition. So, we said about the discrete liquid flow. So, when we said discrete, which means this like in a not a continuous way, it is in breaking form.

So, like here you can see the drop let us coming 1 by 1 and falling on a particle; let us say on a coke particle and traveling down and goes to other either this side or that side and or you can have a bigger sort of regulate, which travels and is in contact with the particles, but not a continuous one again in a discreet manner; different different separate separate you can have even a large regulate depending what sort of conditions are there.

So, that you can have a big regulate which is go going through looks like a continue continuous flow, but again this could be after some time could be breaking somewhere; so you again you end up in a discrete manner.

So, this is a basic difference between the continuum and discrete flow. Here the liquid is breaking in between; so you cannot treat this one as a continuum some modeling this flow as a continuum would be program. So, based on this concept the theory developed on the literature, where it is said that if gas flow is coming from this direction and the liquid flow and this is the packing through which the liquid is flowing.

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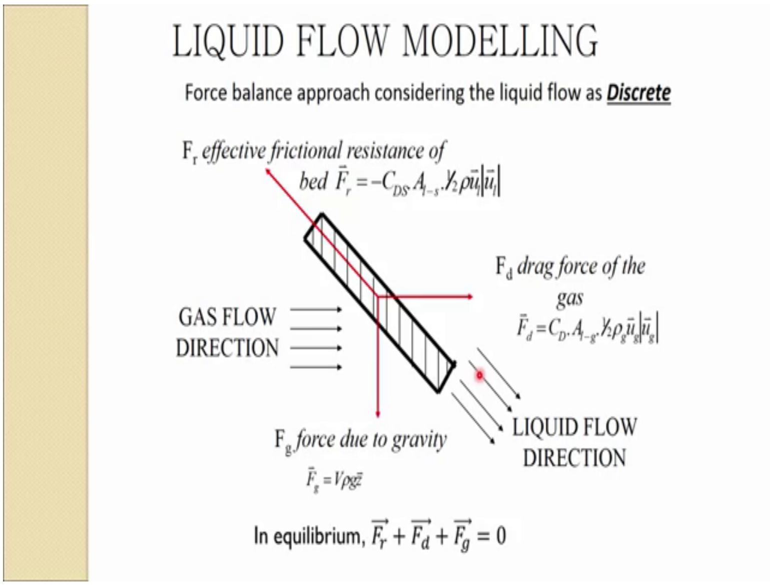

So, essentially you have three resistance; the effective frictional resistance of by the packing that is what you called the bed resistance, then you have the gate drag force, which is acting on the liquid.

So, liquid is facing the resistance from the packing facing the resistance or drag force from the gas and a force on the liquid is acting by the gravity. So, once these three forces are in equilibrium; that is going to give you the direction of the liquid flow; So, using that this simple force balance approach people are able to model the liquid flow in the blast furnace.

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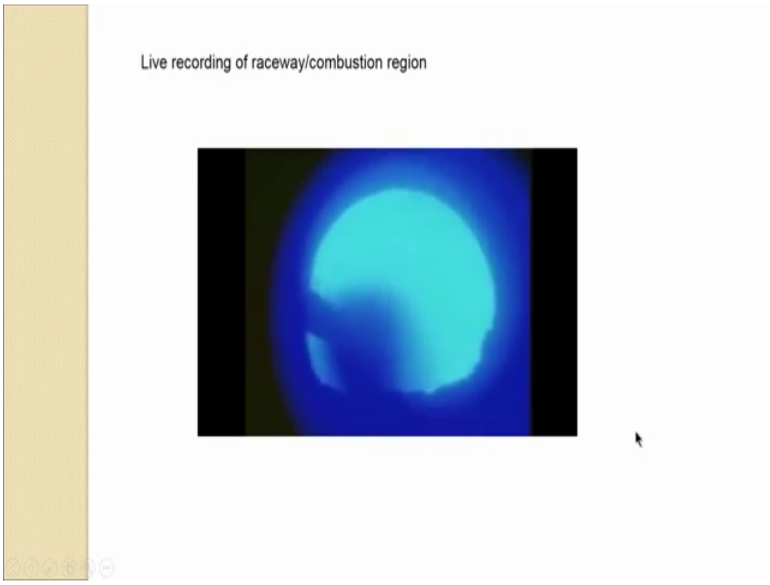

In fact, this video probably can give you a little idea about this flow; so this video it is about the liquid flow in the raceway zone or raceway or combustion zone gas is injected into the blast furnace from the side, and combustion occurs in front of the through where the gas is injected and that is the hottest region which we had discussed before also and we will discuss more into about this region.

So, oxygen and air is their coquette can, because with the high velocity it comes, so it forms a cavity and which is a known as the raceway. So, combustion occur and that region temperature is very high. So, all the melting of the liquid iron and a slag is there and one can see clearly in this picture, how it is happening.

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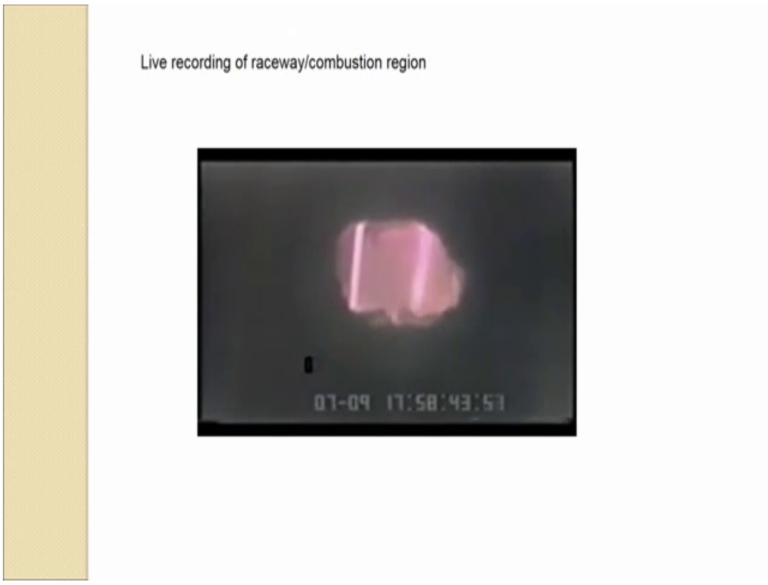

So, this is a inside that combustion zone, in the raceway and a when gas is flowing you can see the coke, which is burning and tumbling around coming in between in a shrilling form and you can see the liquid metal, which is dripping down this is in the raceway zone and you can see clearly it is in the form of regulate or droplet is breaking up again combining.

So, it is not a continuous one and this is the live video of the furnace, when furnace is in operation and when this thing is happening. So, certainly it is not a continuous flow you cannot modulate as a film flow and one has to go in a discrete a liquid theory to model this sort of flow we will stop here.