Iron Making
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Lecture - 22
Iron Making Lecture 22

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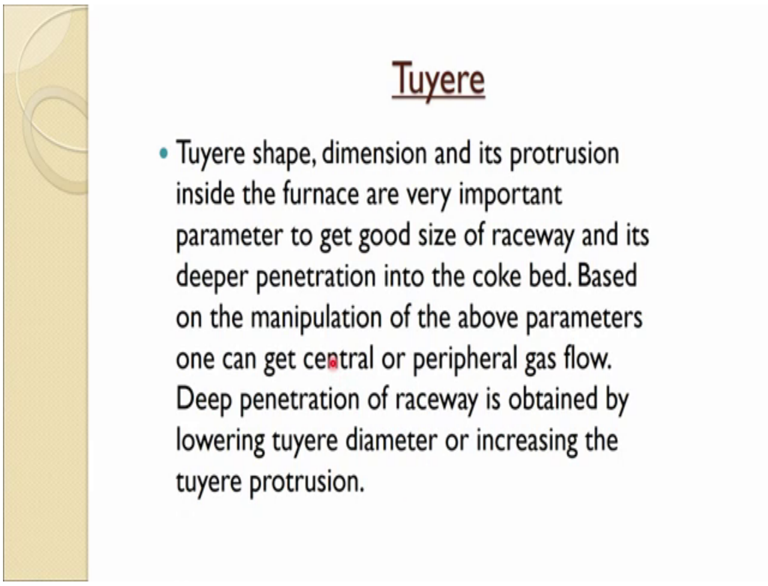

So, now tuyere shape dimension and its protrusion inside the furnace are very important parameter to get a good size of raceway and its deeper penetration into the coke bed. So, again we are talking about the raceway, and how size and shape can be controls of one of the thing is tuyere. So, based on the manipulation of the above parameters one can get the center or peripheral gas flow.

Deep penetration of raceway is obtained by lowering tuyere diameter or increasing the tuyere protrusion. But that tuyere protrusions you can increase only two certain extent. So, that again has to be optimized because too much tuyere protrusion will be really obstructing the metal flow and burning of the tuyere will occur very often.

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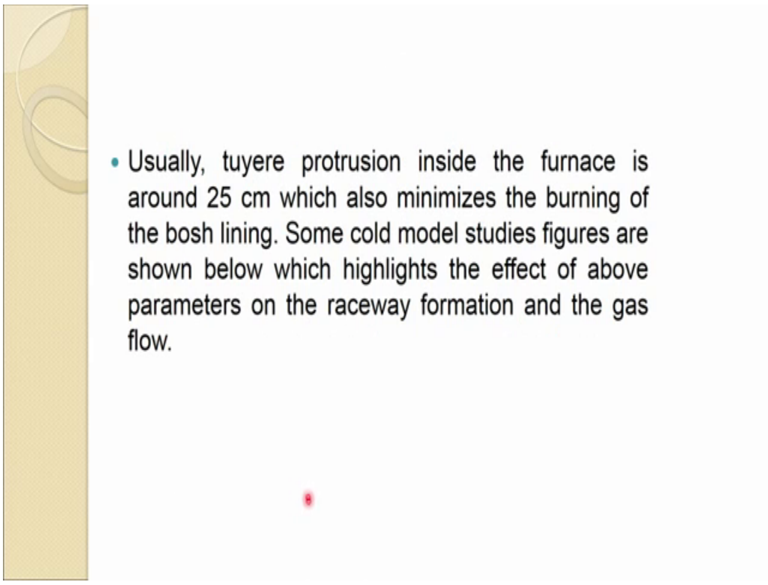

So, usually tuyere protrusion inside the furnace is around 25 centimeter, which also minimizes the burning of the bosh line. Some coal model estate now I am not sure whether to you are understanding the tuyere protrusion, and this figure I will explain you that tuyere protrusion.

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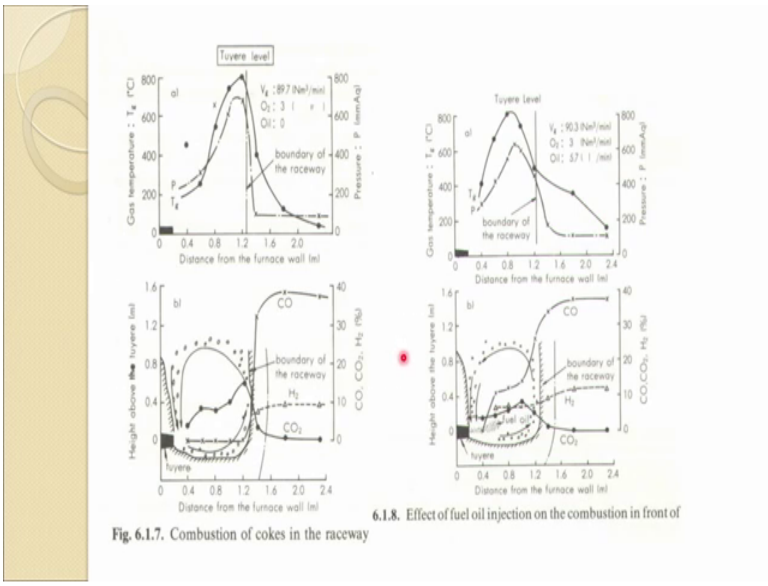

So, this is actually the furnace wall. So, this which is this is the tuyere. So, this is called a tuyere protrusion. So, the black part which is extending inside the blast furnace is known as the tuyere protrusion. So, this is very important and that also affect quite a bit raceway shape and size of the blast furnace. So, this is about the tuyere protrusion. So, some cold model studies figures are shown below which highlight the effect of ever parameter on the raceway formation in the gas flow. So, these are some cold model history of the tuyere in a two dimensional form.

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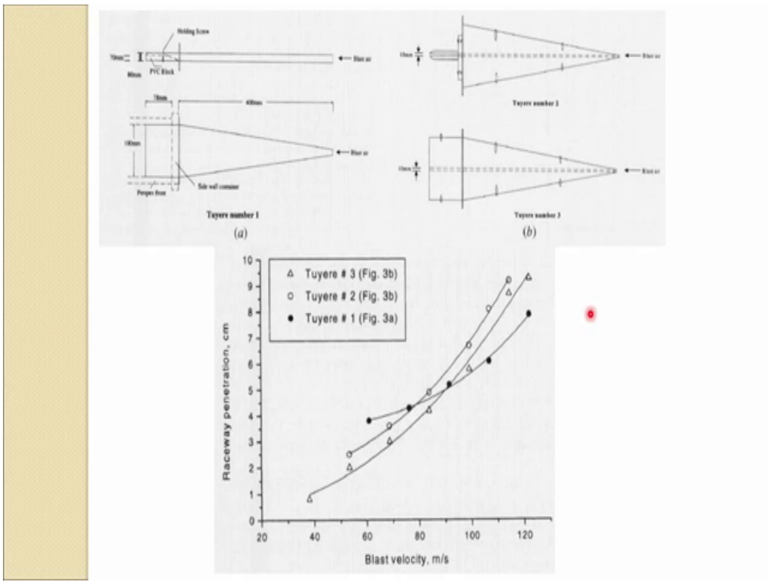

So, you have one tuyere where the cases is coming and coming out again from a small slit, but you have restricted in this way. So, a raceway is getting quite a lot support from this wall over here. In another one you are having from the central, opening is still probably a bit low in this one, but this is all solid materials. So, again that raceway is getting a support from this material. Another one again is a central injection is coming, but the tuyere its very thin actually in the in this case. So, raceway which is from in front of it does not get any support from the tuyere, which is usually the case in the blast furnace because blast furnace tuyere does not give a support to the raceway especially the tuyere wall.

So, this also is indicated in this figure. So, as the blast velocity increases you can see the raceway penetration is increasing, but in the case of this tuyere you can see its not giving such a good result and its you need a very high blast velocity even to form the raceway. Same case in this one you need a quite high velocity to form the raceway, then it keeps quite ok, but you still get a good support from the tuyere wall when actual case this is not the thing. And if you look at the third one, this is start giving you the raceway even at a lower velocity and keep on for giving a good penetration of the raceway without supporting the raceway by its wall.

So, these tuyere people have found is quite good in doing the experiment and that is also true in the actual blast for a furnace. So, that shows how the tuyere even size or support can change the raceway penetration.

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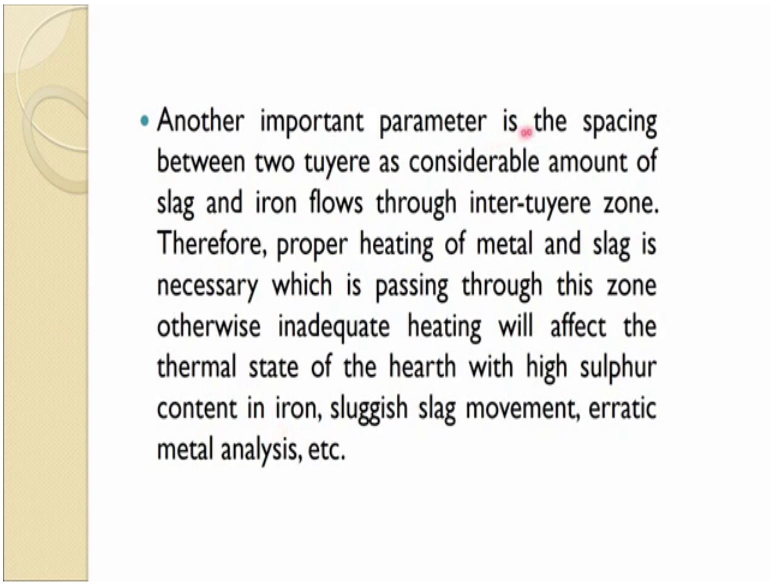

So, another important parameter is the spacing between two tuyere as considerable amount of slag and iron flows through inter tuyere zone. You will understand this in the next slide therefore; proper heating of metal and slag is necessary which is passing through this zone, otherwise in adequate heating will affect the thermal state of the hearth with high sulphur content in iron, sluggish slag movement erratic metal analysis etcetera.

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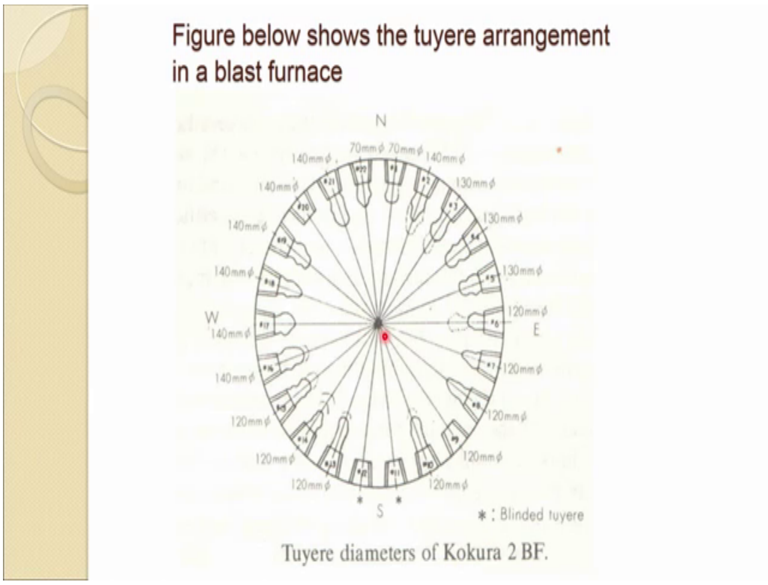

So, I think before this let me show you this. So, you can understand a bit about the entire spacing, what we are talking. So, this figure shows the tuyere arrangement in a typical blast, Japanese blast furnace, Kakora to blast furnace. So, it is about 22 tuyere across the periphery non cross sectional area, which are having of course, quite different opening if you look it. Its varying let us say here the 70 millimeter and then 140, 130, 120. So, total there are 22 tuyere and some of them also do not operate or you can switch any of them. In fact, you can switch them off or on the edge you will see this is the raceway from this tuyere this is another raceway from this tuyere.

Now, the liquid is flowing around it and it is flowing through this and so, same way from this raceway, it is also flowing in between. So, this is the one which we are talking in the previous slide that liquid and slag is flowing between the entire spacing of the tuyere. So, this is an interfacing of the two tuyere and certainly if this is high interfacing, then heat penetration here would be low and that is where you have to have a minimum at least interfacing.

So, that the liquid metal ions should not get solidified or affect adversely this is space otherwise if it gets solidified it becomes more viscous, then you are having a more problem with respect to permeability and flowing of the gases and the liquid. So, this inter spacing between the liquid is very important. And this is what it says flow through the inter tuyere zone and proper heating of metal and slag is necessary which is passing through the zone, otherwise inadequate heating will affect the thermal state of the hearth with high sulfur content in ions sluggish slag movement, erratic metal analysis.

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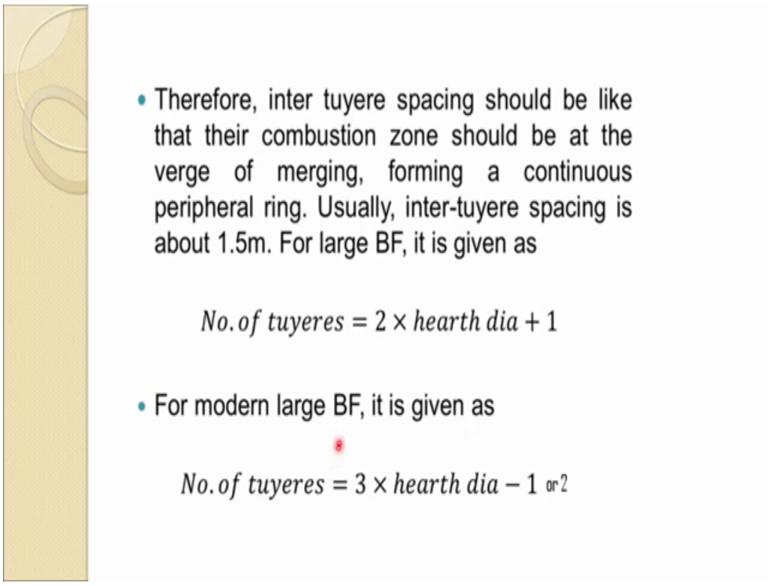

So, therefore, inter tuyere spacing should be like that, their combustion zone should be a diverge of merging forming a continuous peripheral ring usually inter tuyere spacing is about 1.5 meter for large blast furnace, it is given like a number of tuyeres is equal to the 2 multiplied by the hearth diameter plus 1. From modern blast furnace it is a three multiplied by hearth diameter minus 1 or 2. This is again sort of a rough idea which says this sort of inter spacing should be there between the two tuyere. So, it says spacing is about 1.5 meter.

So, if you look at this if this is 1.5 meter and in large one usually if you are having a 1.5 to 2 meter raceway size. So, so what do you are having about 0.75. So, these are almost merging over here. So, so zone is very hot. So, there adequate heat would be there. So, liquid iron and slag will not freeze and hearth will not get cold, sulphur content will not increase. So, you need and that is why this what type of flow around the tuyere we call like a peripheral ring. In fact, this ring in fact, we say peripheral ring through which the gas flow or reducing gases are coming out.

So, almost all of the region here the gases are coming out. So, they are sort of raceway sort of they are merging to each other in this.

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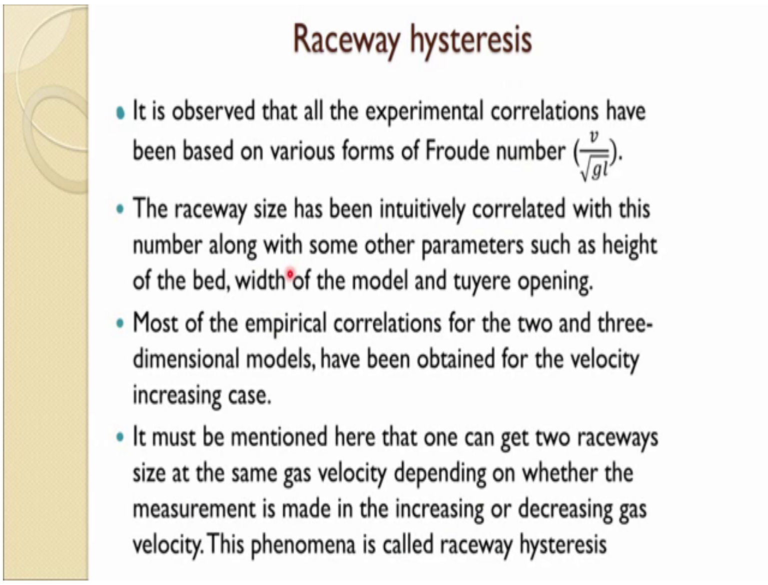

So, beside that is now there is a fun phenomena called the raceway hysteresis. So, it is object that all the experimental correlation have been based on various form of Froude number.

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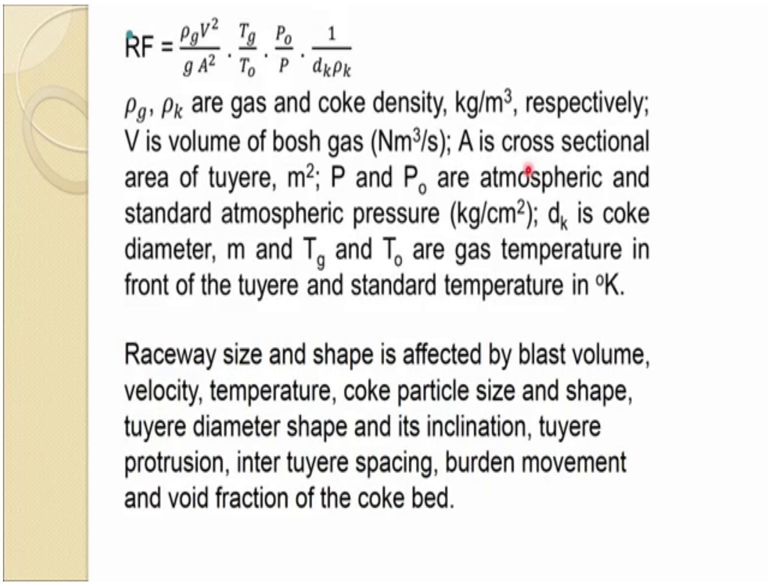

Even if you look at the previous one which we said this is also sort of a Froude number v square g l. So, that is a Froude number.

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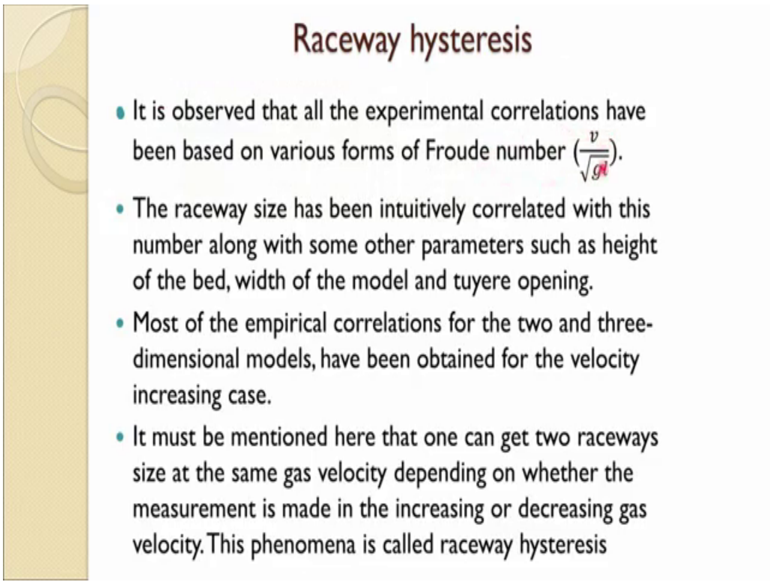

So, most of this thing has been based on the Froude number v is the velocity acceleration and the characteristic length.

So, the raceway size has been intuitively correlated with this number along with some other parameters such as height of the bed, width of the model and tuyere opening. So, most of this history have been done in the cold condition at room temperature in at laboratory scale. So, most of the empirical correlation for 2 and 3dimensional model have been obtained for the velocity increasing case is must be mentioned that one can get two raceway size at the same gas velocity depending on whether measurement is made in the increasing or decreasing gas well velocity. This phenomena is called the raceway hysteresis, you will understand from the actually next slide about the hysteresis.

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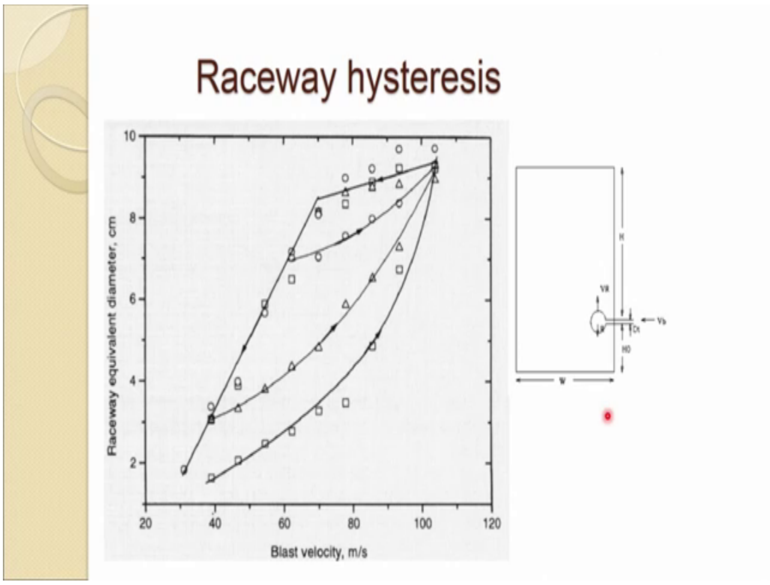

So there is no at the gas velocity increase, the raceway size or the cavity will increase.

So, if you plot this with respect to the blast velocities you will find and this is the raceway equivalent diameter, the raceway size is continuously increasing as you increase the velocity and its certain velocity to hold it and you start now you hold it at that velocities we start now decreasing. So, when you start decreasing the velocity, what you find? The size of the raceway, which you are getting almost 9 and a half at not reducing much its almost constant up to a certain velocity and after that velocity they start decreasing more as a linearly.

So, does not matter you and again you stop somewhere you start again its going to follow when you start increasing, but when you start decreasing the velocity is follow the linear path and when you are increasing its following a non-linear path. So, if you take a typical velocity let us say 50 meter per second what do you get? You are getting about two centimeter raceway, when you are increasing the velocity and it also crosses this which is about 5 centimeters plus. So, so really what do you are having you are getting a two raceway size at one velocity.

So, one is in the decreasing case and one is in the increasing case and that. So, this is the typical phenomena is known as the hysteresis as you can see is the hysteresis sort of curve and that is the one which is and discussed about the hysteresis that has been formed and two raceway size at the same case velocity one its fine finding and what of.

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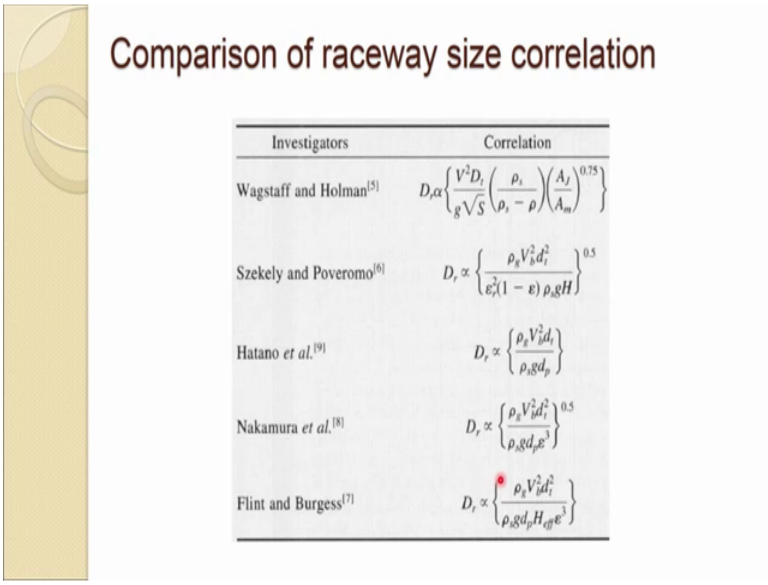
Comparison of raceway size correlation

Investigators	Correlation
Wagstaff and Holman[5]	$D_r \alpha \left\{ \frac{V^2 D_t}{g\sqrt{S}} \left(\frac{\rho_s}{\rho_s - \rho} \right) \left(\frac{A_J}{A_m} \right)^{0.75} \right\}$
Szekely and Poveromo[6]	$D_r \propto \left\{ \frac{\rho_g V_b^2 d_t^2}{\varepsilon_r^2 (1 - \varepsilon) \rho_s g H} \right\}^{0.5}$
Hatano *et al.*[9]	$D_r \propto \left\{ \frac{\rho_g V_b^2 d_t}{\rho_s g d_p} \right\}$
Nakamura *et al.*[8]	$D_r \propto \left\{ \frac{\rho_g V_b^2 d_t^2}{\rho_s g d_p \varepsilon^3} \right\}^{0.5}$
Flint and Burgess[7]	$D_r \propto \left\{ \frac{\rho_g V_b^2 d_t^2}{\rho_s g d_p H_{eff} \varepsilon^3} \right\}$

The experiment is usually is done in the increasing case, as you can see now we talked about the Froude number.

So, this Froude number is changing with various sort of exponent. So, and all these exponents are changing by various investigators. So, they are not constant. So, certainly something is wrong, if you compare your raceway size with one correlation then the other correlation does not give you the same raceway size. So, D r is the raceway diameter these are standard parameter gas density, blast velocity, tuyere diameter, solid density a acceleration due to gravity, void fraction and this is the bed height and the particle diameter.

So, the same thing, but each of these correlation are different and they give totally different raceway diameter. So, they do not really talk to each other in one way. So, certainly there is a problem and that problem actually is because they were doing the experiment and probably one is mostly in the increasing case and could be in between also, but never the less they were not doing in this decreasing condition.

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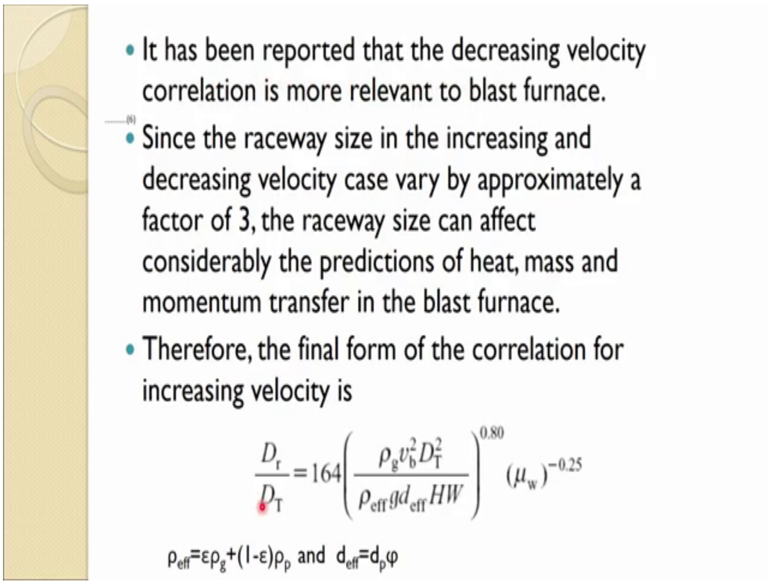

So, it had been reported that decreasing velocity correlation is more relevant to the blast furnace since the raceway size in increasing and decreasing velocity case very approximately factor of three the raceway size can affect considerably the prediction of heat mass and momentum sum of transfer in the blast furnace.

So, when we say raceway size is more relieved and the decreasing velocity correlation is more relevant to the blast furnace, the reason is in the blast furnace because the coke is getting consumed here in the raceway. So, the whole burden in descending down and in the decreasing one when you go to a maximum value of the raceway and you start decreasing the gas velocity, again the burden at the top of it start moving down because the raceway size is decreasing. So, that corresponds almost the same condition as in the blast furnace, when the solid is moving down and that is the reason this statement is made the decreasing velocity correlation is more relevant to the blast furnace. And this has been found true and it has been shown and that is where was the problem.

So, therefore, the final form of the correlation for increasing velocity is given. So, in this and you can see it is a sort of a non-linear Froude number it still is there, but its giving a little bit non-linear behavior in the increasing velocity case, and it includes also the friction coefficient the frictional properties of the material, which is very important and raceway is quite dependent on that. Sparameter rho effective its a defined in this form void fraction gate density and particle density and d effective is particle diameter.

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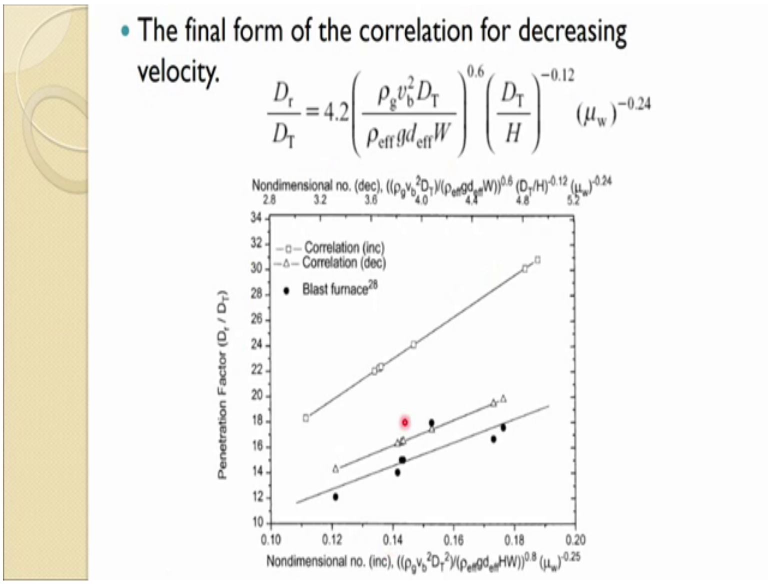

And the separate factor and the decreasing condition it is defined in this and which as you can see is more or less linear 0.6 only and that is with a your Fourier number. So, that how it keeps the linear profile in the decreasing case, but again this friction coefficient is there. So, frictional effects are dominating and this.

So, the validity of these correlation. So, this is the raceway diameter and this is the tuyere diameter. So, it is a comparison of these; so one with the blast furnace of the Japanese blast furnace. So, these are the actual data of the operating blast furnace of the raceway, and the these are the prediction made by the decreasing correlation and these are the prediction made by the increasing correlation so; obviously, decreasing correlation keeps and satisfies and reasonably can predict the raceway size in the operating blast furnaces. So, now, we have some sort of robust correlation for raceway diameter to predict in the operating blast furnace.

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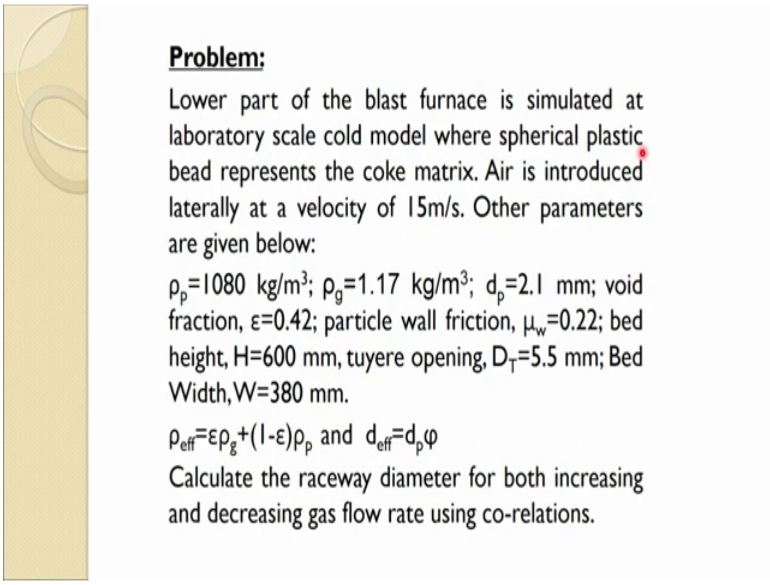

So, there is a one problem based on this, the lower part of the blast furnace is simulated at laboratory scale coal model, where a spherical plastic b represent the coke matrix. Air is introduced laterally at a velocity of 15 meter per second, other parameters are given below. So, particle density its a 1080 kg per meter cube your gas density 1.17 kg per meter cube, the particle diameter is 2.1 millimeter void fraction 0.42, particle wall friction is 0.22, bed heights 600 millimeter, tuyere opening 5.5 millimeter bed width is about 380 millimeter.

And it we know that all effective is given by this and d effective is given by this. So, calculate the raceway diameter both for both increasing and decreasing gas flow rate using the correlations which were discussed before.

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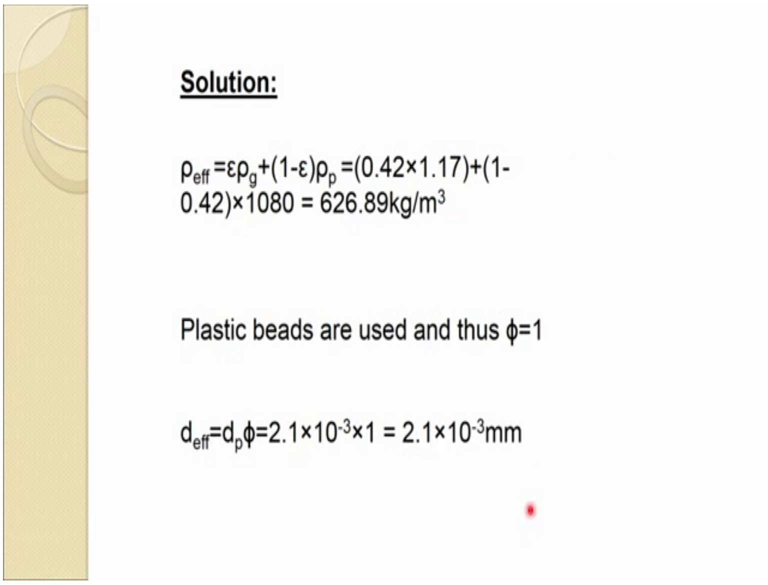

So, the effective density of the charge would be substituting the value as given in the example, gives you about 67 kg per meter cube and because the spherical plastic beads are and so, separately we take 1. So, that gives you the effective diameter 2.1 into 10 to the power minus 3 millimeter.

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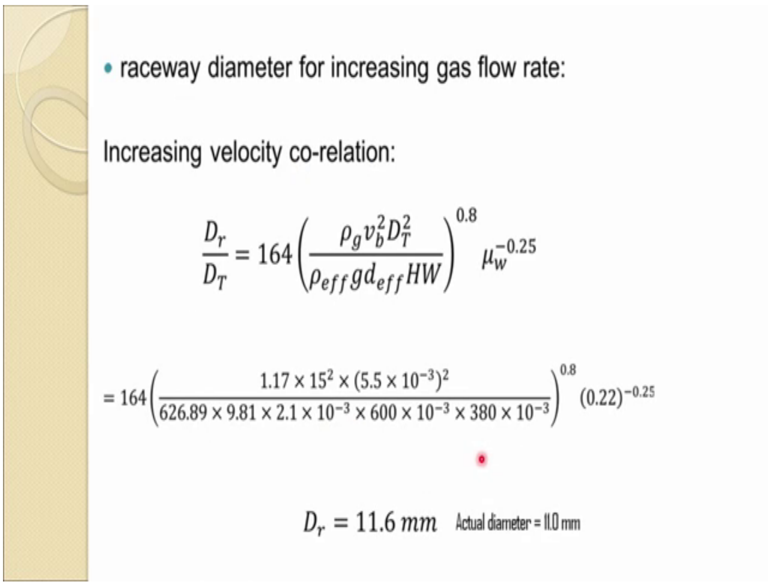

And raceway diameter for the increasing gas flow rate we know it can be given by this correlation and its the question of substituting the appropriate values, which all are given the gate density blast velocity tuyere opening even the effective density, we calculated effective diameter we calculated gravitational constant height and weight and the frictional coefficient. So, by substituting this parameter into this correlation, essentially what we get D r equal to 11.6 millimeter and actual really diameter is about 11. So, very close match, but that is for the increasing gas case.

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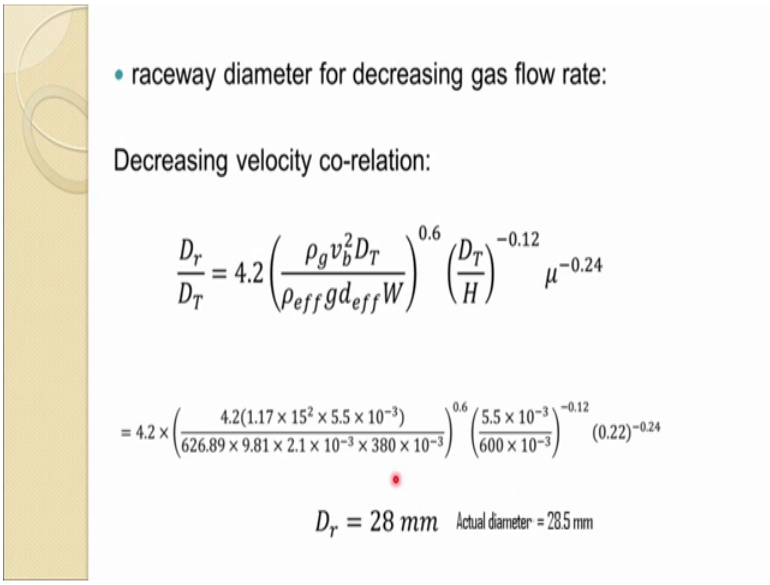

If the same thing we can do for the decreasing gas flow rate. So, under the decreasing velocity correlation, accords you have a different indices. So, again you can substitute these value appropriate one, which are given in the example and one can calculate then the raceway diameter about 28 millimeter an actual time it is 28.5 again a very close match.

So, these correlation gives a very good predictions about the raceway diameter whether it is in the cold conditions or it is in the actual blast furnace condition, which we had seen here. So, at least for the blast furnace size, we have some sort of the correlation which can predict reasonably well and it the size of ok.

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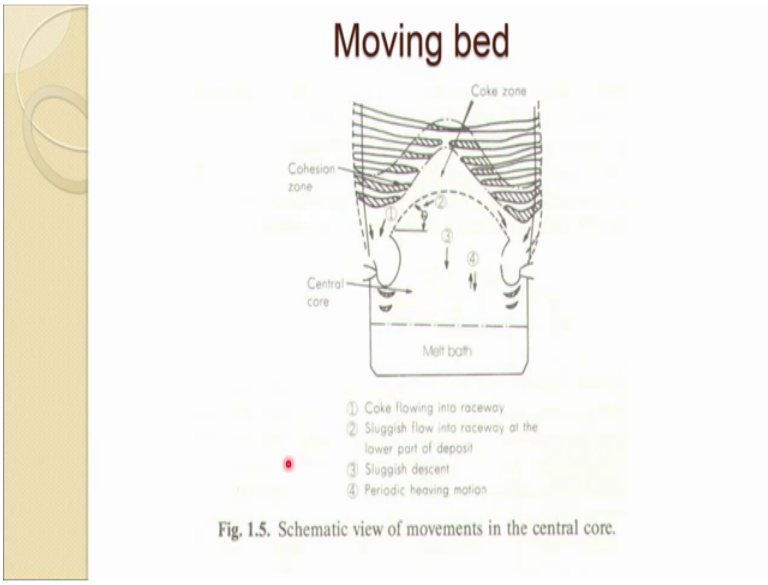

Now, the next one is about the moving bed. As you know in the blast furnace the burden is continuously moving down toward and we have talked all about this since we started this course. So, essentially what is happening in front of the tuyere coke is getting consumed. When the coke is getting consumed then the void is formed and it has to be replaced for by the surrounding solid.

So, mostly from the top then coke comes down and replace at coke which got consumed in the raceway. So, the whole burden start ascending down it this is not yet only this one even the your slag and liquid is forming in this region which also reduces; so porosity. So, the whole burden is coming down, but most of the coke conjunction is occurring and coke is replenished from the top, if you remember in one of the slide I have mentioned that a funnel type flow exists above the raceway.

So, because raceway shape is more toward the upward side then horizontal side and coke is coming in this raceway reason from the top. So, this is like a funnel type of flow the very little coke comes from the side and the most of the coke flow is occurring from the top which is like a funnel type of flow coming into this region and here the coke movement is almost nil a very little.

And that is the reason this region is known as middle one the dead man zone almost there is no coke movement here of a little. So, essentially if you look at in one way the whole burden is descending down up to here. So, this is not any stationary bed, its a moving bed and that is where actually one has to look at whatever experiment and things are being done it has to be done under moving bed condition. So, coke flowing into the raceway sluggish flow into raceway at lower part of deposit, sluggish descent periodic heaving motion.

So, this periodic heaving motion when you are taking or draining out the liquid whether its iron or slag, that time the whole this dead man zone it comes down which is floating on this. So, that is how the heaving periodic heaving motion and as when you close the tapping hole it is start building. So, due to buoyancy it goes up and that. So, moving bed has a very different some different properties not very different.

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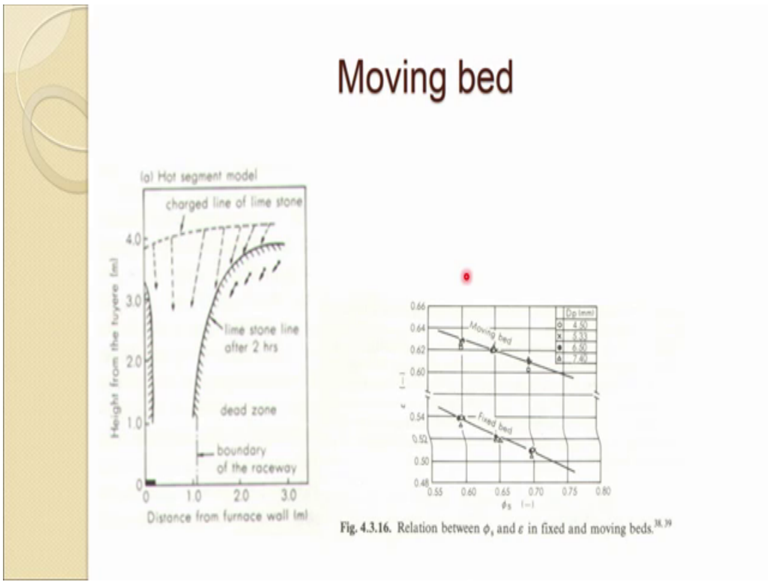

So, this is a larger view of the funnel flow. So, this is the raceway boundary and chart line you can see mostly the flow what is all of job in a hot metal experiment that in a very narrow part or near the raceway the flow of the coke and lime is occurring and away from the raceway boundary in horizontal direction is a dead man zone and that coke does not participate in to the combustion of the things.

So, essentially this part is sort of the moving part and movement of the charge is taking place mostly the coke in this region because the other thing is in the molten stage and this figure shows that the void fraction, which varies because the permeability is very important thing in the blast furnace for the smooth operation and good productivity. So, for a fixed bed the void fraction is about 0.5 and for moving bed the void fraction is around 0.6 or 0.62. So, you can see in the moving bed the void fraction is quite high than the fixed bed and one way this is a good thing for the permeability.

So, one cannot take the void fraction of fixed bed for solving the problem in the moving bed. So, one has to be very careful and of course, this if you look at this with the diameter of the particles, it did not change much of course, with the safe factor the void fraction gets affected a bit, but with the size of the particle it does not change much, but certainly the moving bed is giving a higher voice than the fixed bed.

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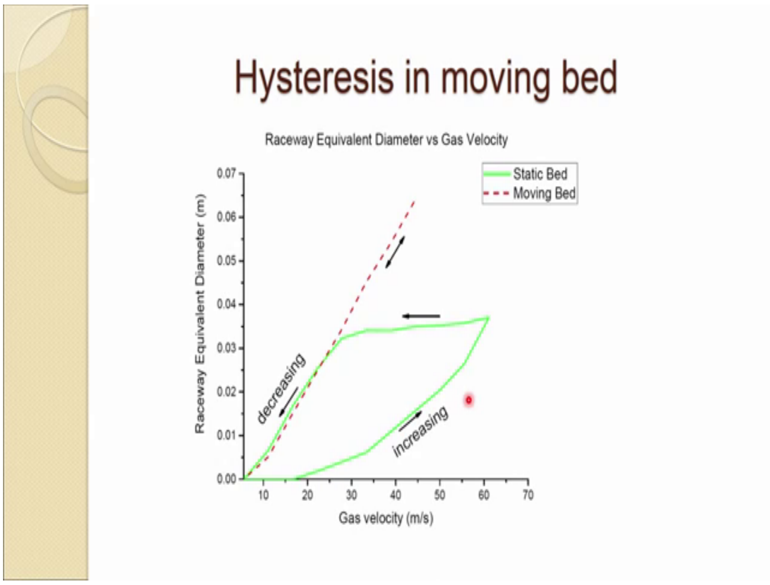

And as we were talking also about the experiment in the stationary bed and a moving bed and we saw this figure we came across where an increasing case, it follows this path and while we decrease the velocity is fellow follows this path and.

The experiment which were done in case of moving bed, what did it found that, it does not matter whether you do the major the raceway size, under increasing case or decreasing case that same size you get it in both; and in both the condition if the bed is moving. So, moving and one more thing it is saying. So, these moving bed raceway sizes correspond to the decreasing bed raceway size of stationary one.

So, the thing which was said the decreasing velocity correlation are relevant to the blast furnace raceway is quite accurate quite correct because the moving bed and the decreasing one they are coinciding. So, they give the same raceway and that is where these decreasing size correlations are fitting well with the actual blast furnace and giving the right predicting the right raceway. So, it is a very important finding that decreasing and moving bed gives the same raceway diameter.