Iron Making
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Lecture - 21
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You have seen in the previous video, which we just played you can see the breakage of droplets and regulate breakage of the stream liquid whether it is a matter or slag, which was coming out. And not only that you might have noticed this due to the drag of the gas, the high velocity value which it is coming from the tuyere it is able to deflect even the iron stream and droplets and revelat and one thing is very clear from this video, that it is not a continuous flow.

The liquid flow is not a continuous it is certainly in discrete nature. So, one cannot apply the continuum theory or continuous flow theory to describe the flute liquid flow especially in the blast furnace and that which we had discussed before and because this video we just saw it is more related to the raceway. So, we would be talking about the raceway.

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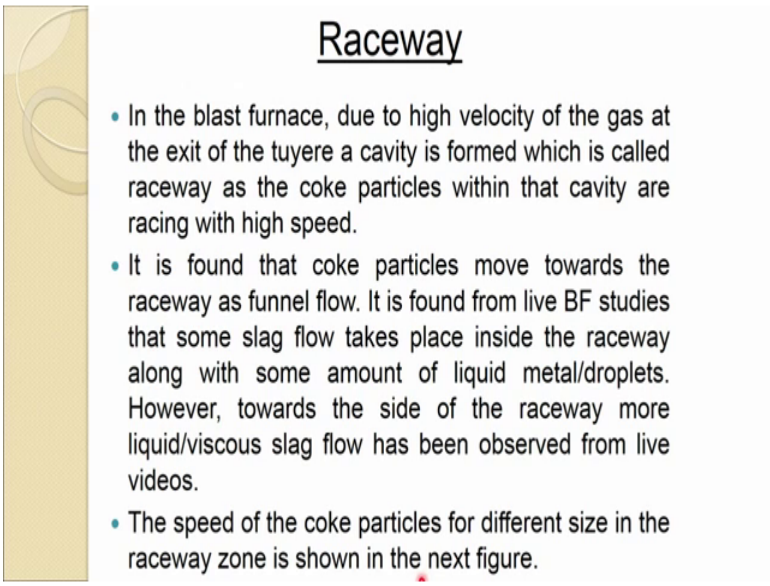

Now so, in the blast furnace due to the high velocity of gas at the exit of the tuyere a cavity is formed which is called raceway as the coke particles within that cavity are racing with high speed. So, the name raceway is coming due to the coke particles they are racing inside the cavity and that why this name is given raceway, to this cavity and it is found that coke particles move towards the raceway as funnel flow.

It is found from live blast furnace studies that some slag flow is flow takes place inside the raceway along with some amount of liquid metal droplet, which you have seen just now in the previous video. However, towards the side of the raceway more liquid viscous select flow has been observed from live video. Of course, this was not there in the video due to some proprietary thing, but the d section of the blast furnace in the live video saw there plenty of liquid which is flowing in between the to tuyere or a decide of the raceway.

So, the speed of the coke particle for different size in the raceway zone is shown in the next figure.

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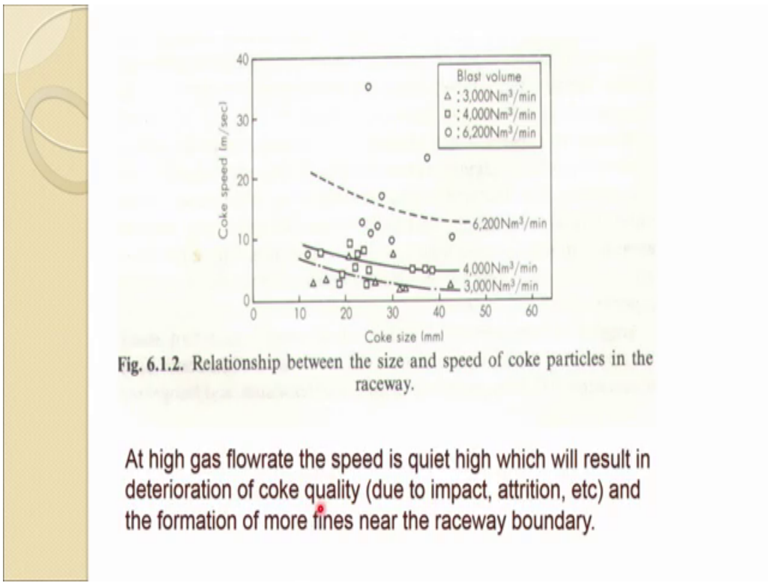

So, you can see in this figure, this is the blast volume a Newton normal per meter cube per minute. So, 3000, 4000, 6000 and the coke size different coke size varying from 10 millimeter to 60 millimeter and the coke speed in meter per second. So, one can see that when the blast volume blast waste is low the coke speed is not that much, but when the blast rate is high which is sort of the trend in the modern blast furnace in fact, 6000 plus the coke speed inside the raceway is quite high and you are talking somewhere of this size of coke in the raceway.

So, it is between 10 to 20 meter per second and with this sort of velocity, when the coke particles are travelling there would be a very high impact. So, at high gas flow rate the speed is quite high, which will result in deterioration of coke quality due to impact at reason etcetera and the formation of more fines near the raceway boundary. If there are more fines near the race way boundary, it will block the space in between the coke particle. So, it will reduce the permeability and the pressure drop will increase the operation of the blast furnace will become difficult.

And that is the reason the lots of emphasis has been has been given on the coke quality we need really very high coke quality because coke is subjected to the extreme condition in the raceway region and one do not want that it should create lots of fines or deteriorate or disintegrate. So, coke what is at most important.

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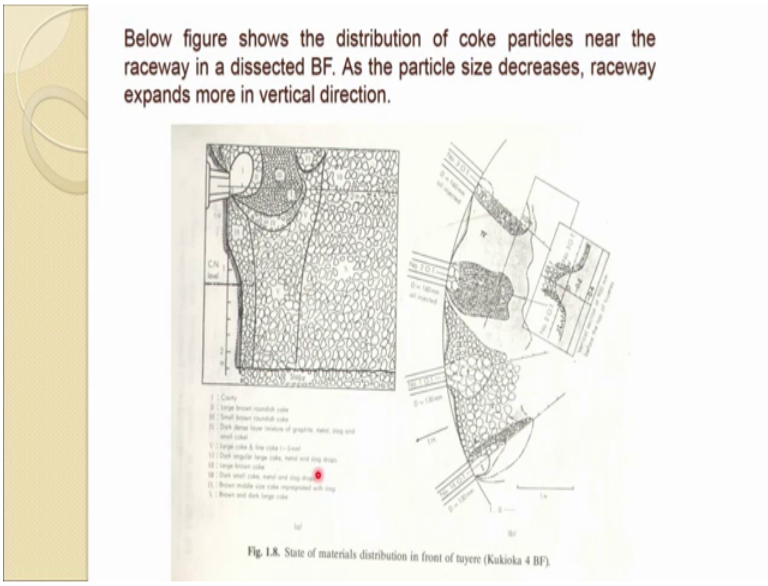

So, this figure shows the distribution of coke particle near the raceway in a dissected blast furnace. As the particle size decreases raceway expands more in vertical direction. So, you can see the raceway is expanding more in vertical direction then in the horizontal direction and this is the tuyere, and this is the cavity which what we called a raceway and the particles as you have seen even in the video the coke particle was racing around this.

So, just beside the large coke sized particle and away from this; so region three we will find a small brown type of particle which are lesser in diameter than this and in this part in fact, you get that dark dense layer. So, which is a mixture of graphite metal slag and small coke and indeed john of course, you get a large coke sized particle again, and then in this zones you get dark angular large coke particles and similarly at other places you get large brown and dark small particles, brown middle particle, in brown and dark particles. So, mostly the small particle is little away from the raceway after this large particle boundary.

So, if more points is getting created, it will block the voids in between and then the easy passage of gases which are coming out from the raceway would be difficult. So, pressure drop would be high and operation of the furnace would be difficult this shows sort of a vertical view of the tuyere section of the blast furnace again its a of the dissected life blast furnace, as you can see different types of coal surrounded actually the around the raceway.

And so, essentially it is the same thing, which is given on the top view of the dissected blast furnace in the raceway region. So, one thing is very clear that this region is quite important for the distribution of the gases or the reaction which is taking place, which affect the whole blast furnace in the upper zone and even the lower zone of the blast furnace. So, the burden descent is controlled by the shape of the raceway.

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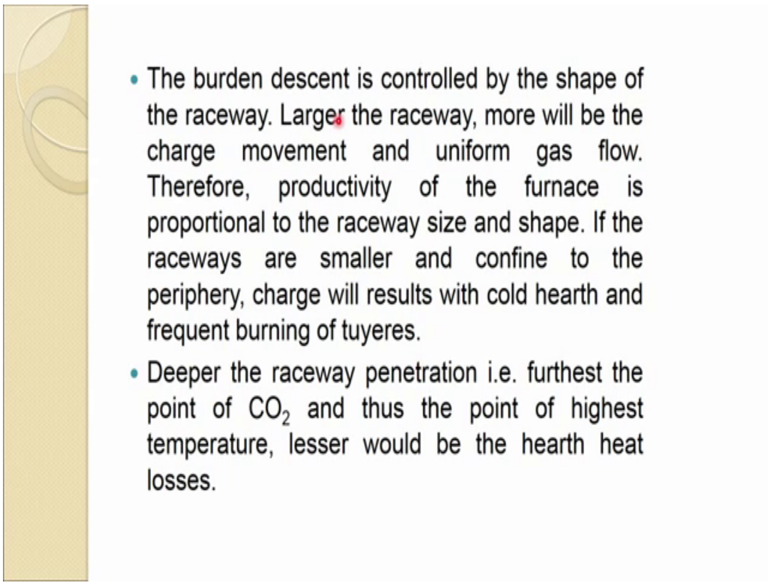

Largest race more will be the charged movement and uniform gas flow therefore, productivity of the furnace is proportional to the raceway size and shape. If the raceways are smaller and confined to the periphery charge will result with cold hearth and frequent burning of the tuyeres. So, deeper the raceway penetration this is furthest the point of CO 2 and that is the point of highest temperature lesser would be the hearth heat losses. So, this you can see this has not reached even at the middle of the blast furnace, this is a very small in comparison to this the raceway size.

So, really if you want a good sort of flow of the gases, which are coming out from the raceway what you need you need to increase this. So, deeper penetration so, that gas can come and can go up to here and distribute themselves and can react with the charge in the upper region, as you can see in this one as some more penetration of this or bigger size of the raceway means better distribution of the reducing gases and better production of the blast furnace productivity is going to increase rate directly affecting the productivity and that is why the shape and size of the raceway is very important in the blast furnace like a heart of it.

And lots of study has been done or deported only on the raceway investigation.

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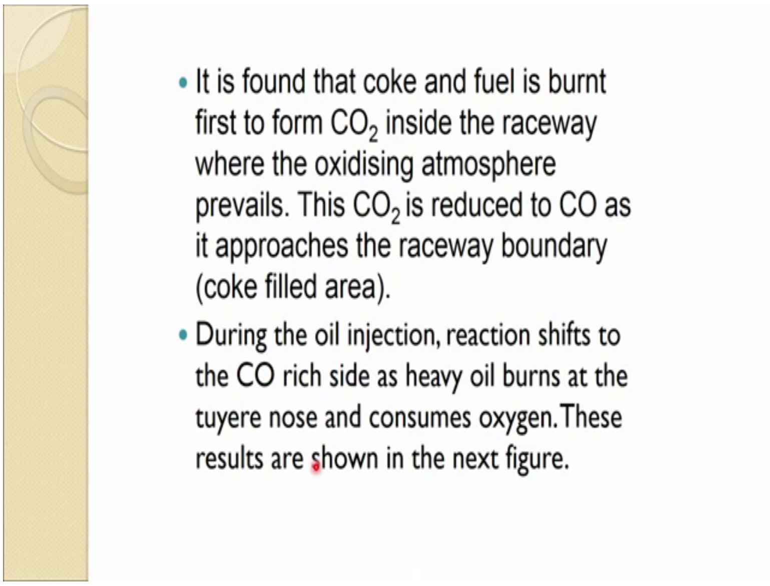

About this reaction we will be talking a little bit in the coming slide. So, it is found a coke and fuel is burnt first to form CO 2 inside the fresh wave where the oxidizing atmosphere prevails. So, remember inside the raceway CO 2 this form because you are injecting a which has on or even if you are injecting an oxygen rich air then you would be having more than 20 percent oxygen in the gas and you have some carbon.

So, carbon in form of coke is less. So, essentially form CO 2 because there is a deficiency of the carbon and so, inside the raceway, but as it comes toward the periphery of the raceway or the boundary of the raceway it comes in contact with more coke. So, immediately it form CO. So, this CO 2 is reduced to CO as it approaches the raceway boundary coke filled area.

So, inside the raceway say oxidizing atmosphere sort of and then it becomes reducing up there. So, during the oil injection reaction shift to the CO rich side because oil has many other component methane at carbon content components. So, you get the carbon inside the raceway. So, that is why reaction shift to the CO rich side as heavy oil burns at the tuyere nose and consumes oxygen. So, these results are shown in the next figure.

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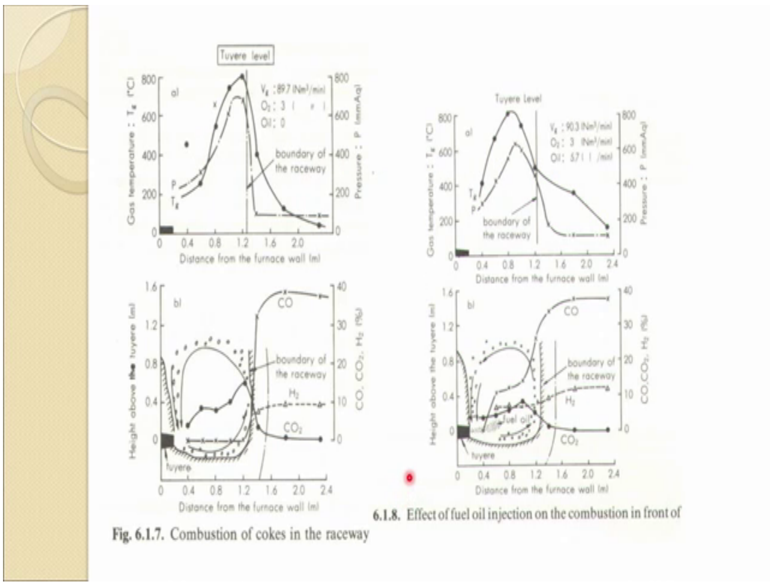

So, if you look at this figure. So, in this one we have distinct from the furnace wall.

So, this is actually tuyeres. So, away from the furnace wall you will see this is the boundary of the raceway and this is the gas temperatures, you can see the gas temperature is increasing as long as CO 2 is formed that exothermic reaction. So, gas temperature increasing and as soon as CO start forming, which is more endothermic the temperature drops down at the boundary and you can see in this one the distribution of the various species. So, this is CO. So, you can see almost negligible CO till the raceway boundary. So, see the figure when blast is having only air. So, as soon as it reaches near the raceway boundary more carbon is available.

So, CO 2 react with more carbon form CO and suddenly CO suits up and inside the raceway CO 2 is forming and as it reaches near the boundary, CO 2 decreases tragically and reaches almost to 0. So, that is how this is mod oxidizing atmosphere inside the raceway, but outside its more reducing. However, if one uses the oil fuel oil in along with the air then because the carbon is already there in the fuel oil. So, it will react with that extra carbon. So, CO will start forming. So, that is a fuel oil. So, now, even inside you can find that some percentage of CO in the raceway, but of course, more carbon is available at the boundaries. So, CO concentration increases quite high at the boundary again, but see it CO 2 concentration is not as I as it was in the pure air case.

So, that is go to a little peak and then it is comes down. So, here it is about 10 percent, but in this case is about 18 percent or. So, and similarly the temperature as I said the CO formation is an endothermic reaction its need takes more heat. So, temperature actually high temperatures actually shifted more within the raceway because add more carbon is availability start reacting and so, a temperature within the raceway start dropping down which shows into this figure.

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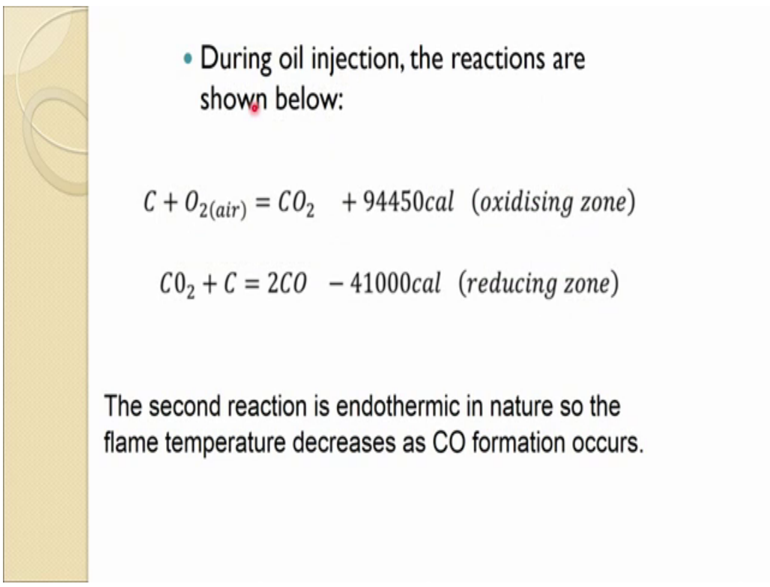

So, during oil injection the reactions are. So, this is with the air and this is be that CO 2 is reacting with the carbon and that carbon, it could be at the boundary or it could be some other source like fuel oil and other things. So, this is a highly endothermic reaction. So, it needs hits at prime temperature decreases as CO formation occurs, which we have seen in the previous slide.

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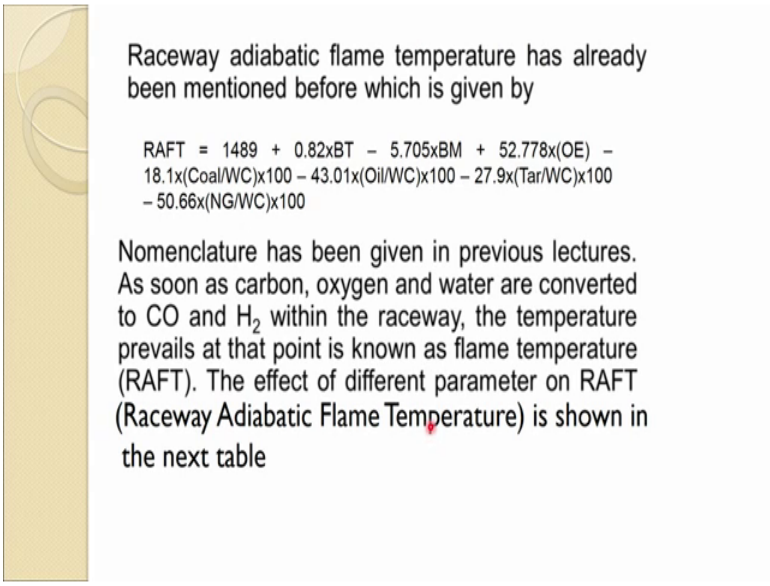

So, raceway adiabatic flame temperatures this, what is called wrapped has already been defined or mentioned before it is again reproduce here. So, wrapped or a flame temperature in salt what we call just a flame temperature is given why this which was given before and I think all the nomenclatures and other thing has been given in the previous lectures.

So, you can go through that and you can find out all the nomenclatures. So, as soon as carbon oxygen and water are converted to CO and hydrogen within the raceway, the temperature prevailed at that point is known as flame temperature. So, the effect of different parameter on draft is shown in the next table. So, just pay attention on this. So, as soon as carbon oxygen and water are converted to CO and hydrogen within the raceway the temperature prevails at that point is known as the flame temperature.

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Table 17.3 **The effect of various factors on the flame temperature (FT)**

Parameter	Increase by	Change in FT (°C)
Blast temperature	100 °C	+60 … 80
Oxygen in blast	1%	+45 … 50
Moisture in blast:		
Range 1–9% H_2O	1%	−40 … 45
Range 10–20% H_2O	1%	−30 … 35
Natural gas	100 m^3/tHM	−320 … 450
	1%	−45 … 55
Coke oven gas	100 m^3/tHM	−200 … 250
Oil	100 kg/tHM	−270 … 340
	1 g/m^3	−4 … 6
Pulverized coal:		
Low-volatile matter	100 kg/tHM	−0 … 130
High-volatile matter	100 kg/tHM	−150 … 220

So, this is quite important and it should not exit through certain limit, and the effect on flame temperature of various factors is given here. So, as you see if we increase the blast temperature by 100 degree Celsius, our flame temperature increases between 60 and 80. 1 percent increase in oxygen in the blast air or whatever it is gives rise to 45 to 50 degree Celsius in flame temperature. Similarly one percent moisture in the blast because certainly moisture we reduce it for not increase.

So, it resists reduces the flame temperature between 40 and 45 and if higher percentage of this then it is reduce it to that. Similarly the natural gas; so 1 percent or 100 meter cube per ton of hot metal is introduced with the blast then it reduces the flame temperature tremendously. in 1 percent 45 to 55 in that range and 100 meter cube per ton of hot metal 320 to 450 so that huge decrease in the flame temperature which is not desirable.

So, certainly when natural gas we receive in few other like coke oven and oil this all should be used along with oxygen to maintain the blast of flame temperature. So, coke oven gas again of the same or a natural gas you put it, it has a little lesser effect again nevertheless it is a very big effect having on flame temperature. So, between 200 and 250 it reduces the flame temperature. Oil again 100 kg per ton of hot metal reduces the flame temperature in the range of 270 to 340 degree Celsius pulverized coal, which is quite prevalent pulverized coal and the oil are quite prevalent in the blast furnace to use along with the air blast air. So, low volatile pulverized coal if one uses about 100 kg per ton of hot metal, it reduces the flame temperature between 0 to 130 and high volatile between 150 and 220.

So, all of these should be accompanied with the oxygen in order to maintain the flame temperature. So, that this is it giving you an idea how these various injectors with blast air may affect the flame temperature. In fact, nowadays even some municipalities waste plastic these are also being used. So, same sort of effect they can have in a big range. So, all of these had to be used along with the oxygen in the blast to maintain the flame temperature.

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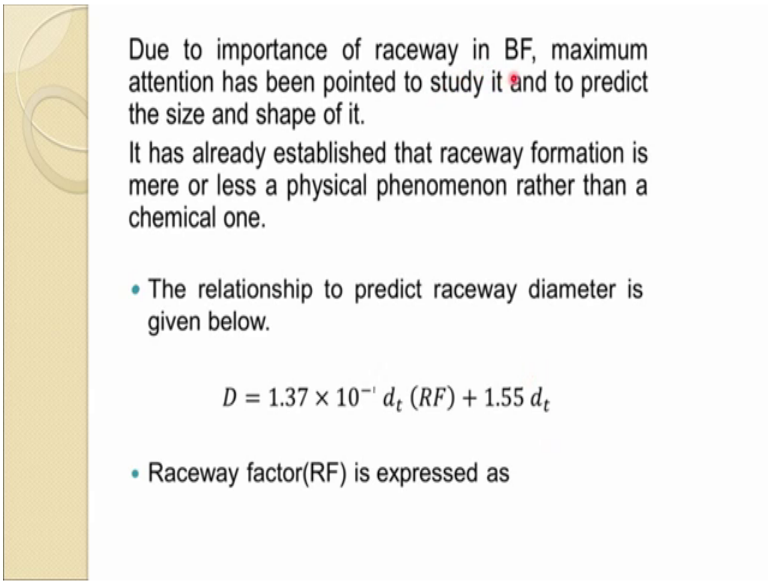

So, due to importance of raceway in blast furnace, maximum attention has been paid to study it and to predict the size and shape of it. As I mentioned before that the size and shape of it are directly related to the productivity of the blast furnace. So, these are very important parameter.

So, it has already stability the raceway formation is more or less a physical phenomenon rather than a chemical one. So, that has been found that it is more like a physical phenomenon, the higher the velocity probably you can have a good size of raceway and maybe even safe; so it is not that much dependent on the chemical. So, it is more a physical phenomenon. The very all relation to predict raceway diameter is given by this.

So, where dt is the tuyere diameter and RF is the raceway factor which is expressed again from this.

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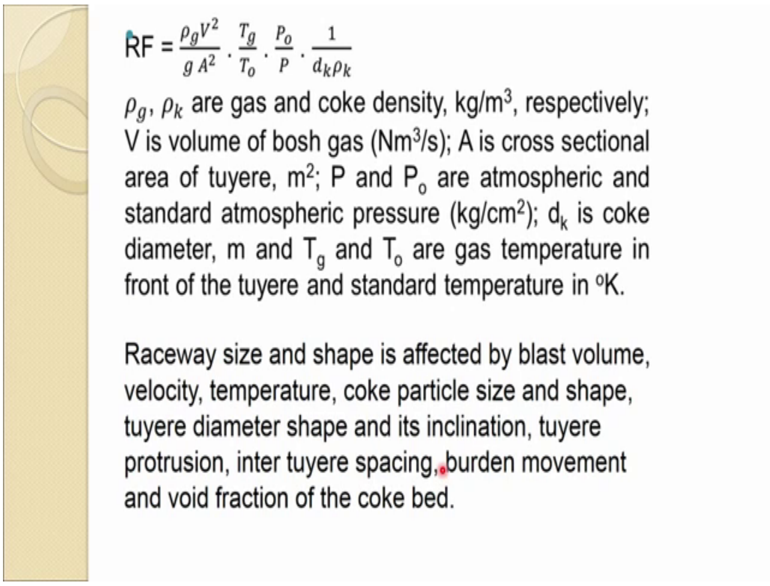

So, rho g is the gas density in rho k is the coke density g acceleration a V is the volume of the bosh gas in normal meter cube per second and a is the cross sectional area of the tuyere p and pin a p naught are the atmospheric and standard atmospheric pressure in kg per centimeter square d k is the coke diameter, and tg and t naught are gas temperature in front of the tuyere and standard temperature in degree Kelvin.

. So, as I have mentioned because the size and shape is very important of the raceway, to know the performance of the blast furnace. So, many attempts have been made and this is just one of the expression very odd almost 40 years ago was sort of proposed and its written there, but lots of work has been done after that. So, raceway sizing serve is affected by blast, volume velocity temperature, coke particle size and say tuyere diameter shape and its inclination, tuyere protrusion inside the blast furnace inter tuyere spacing, burden movement and void fraction of the coke way. So, there are host of factors on which the raceway size and shape depends.

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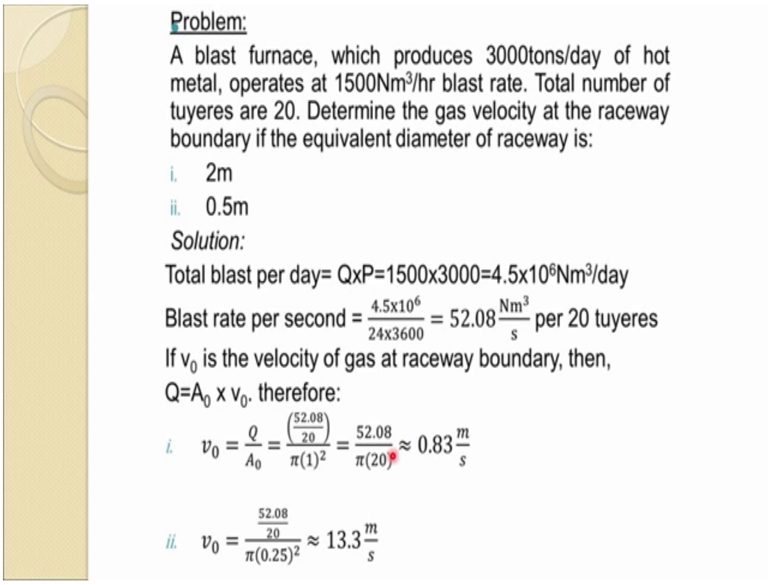

So, there is one problem. So, a blast furnace which produces 3000 tons per day of hot metal, operates at 1500 normal meter cube per hour blast rate.

The total number of tuyeres are 20, determining the gas velocity at the raceway boundary if the equivalent diameter of the raceway is 2 meter or 0.5 meter. So, two cases many in some of the blast furnace they have a that is a sort of even raceway diameter and many of them operating at high productivity have this sort of diameter. So, we know the in the solution total blast per day would be we know 3000 ton that is the per day the productivity and blast rate is 1500. So, total blast per day would be multiplying these two that will give you the normal meter cube per day and blast rate per second which if we convert that that is going to give you 52.0 at normal meter cube per second for 20 tuyeres. So, this is actually for 20 tuyeres as it says the total number of tuyeres are t20.

So, this is also the total blast rate. So, V naught is the velocity of the gas at the raceway boundary we assume, then normally you can have it volumetric flow rate which is nothing this should be equal to the area into the velocity at the raceway boundary. So, we can calculate the velocity at the raceway boundary. So, Q is 52.08 now we are doing at the raceway boundary. So, there would be a 20 raceway. So, naturally we are talking about the one tuyere. So, this has to be divided by twenty. So, which we have done it here so, that would be sort of a volumetric flow rate from the one tuyere and divided by the area of the raceway.

So, in the first case it is two meter given. So, pi 1 square. So, that gives you the velocity which is coming out from the raceway boundaries point at 3 meter per second same calculation if we do it for the second case, then it comes 13.3. So, it is a more than one order magnitudes; how high then the previous case. So, you can understand how much difference it is going to make, this high velocity can create a very a big problem in the blast furnace. This is crossing the fluidization velocity of the coke and coming near to the alliteration velocity of the coke.

So, that is a will give sort of a not a smooth operation in the blast furnace, then this and certainly the Reynolds number would be very high in this case. So, that tells you a little idea how the size is going to affect the velocity, which of the gases will be there coming out through the raceway boundary.