Iron Making
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Lecture – 15
Iron Making

Couple of examples based on this.

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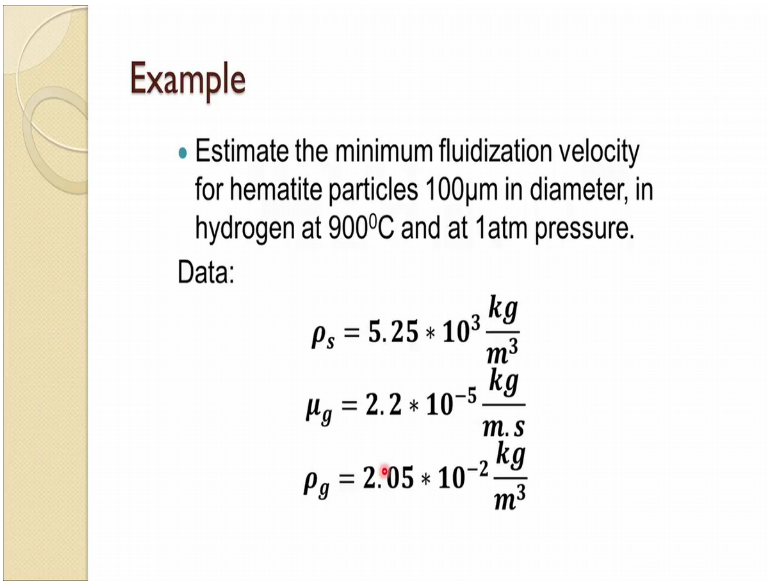

So, estimate the minimum fluidization velocity for hematite particle 100 micron meter in diameters in hydrogen atmosphere at 900 degree Celsius and it 1 atmosphere. So, this sort of things happen like a reduction of hematite in fluidize bed because that is also one commercial established process. So, for that it is very important to know what would be the minimum fluidization velocity.

So, data are given the hematite density is a viscosity of the air we have hematite temperature and density of the air, it is also commit.

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Solution

Galileo number:

$$Ga = \frac{\rho_g(\rho_s - \rho_g)gD_p^3}{\mu_g^2}$$

Therefore,

$$Ga = \frac{2.05 * 10^{-2}(5.25x10^3 - 2.05 * 10^{-2})9.81(100x10^{-6})^3}{(2.2x10^{-5})^2}$$

$Ga \approx 2.1814$

Now, Reynolds number of fluidization is related to Ga as:

$$Re_{mf} = \sqrt{(33.7)^2 + 0.0408Ga} - 33.7$$

Substituting the value of Ga:

$Re_{mf} \approx 1.3 * 10^{-3}$

Therefore,

$$u_{mf} = \frac{Re_{mf} * \mu_g}{\rho_g * D_P} = \frac{1.3 * 10^{-3} * 2.2 * 10^{-5}}{2.05 * 10^{-2} * 100 * 10^{-6}} = 0.01\frac{m}{s}$$

So, essentially you know the Galileo number you have to calculate Galileo number. So, Galileo number is you know it is given by this and do you know is these values you can substitute sort of Galileo numbers come to this. Now either you can calculate Reynolds numbers by substituting this Galileo number over here or you can even directly calculate from these it is you have the your Galileo number is about 2.18, so which is really somewhere here.

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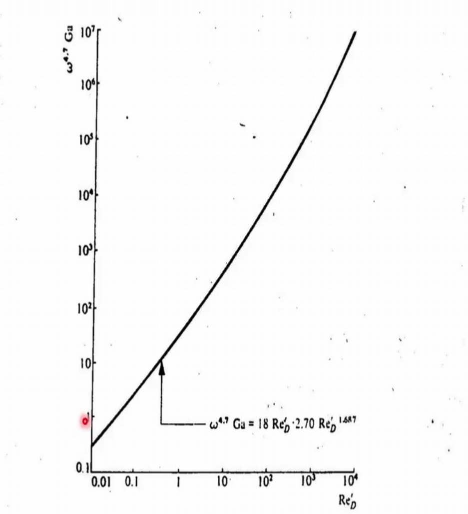

6 Generalized correlation between the particle, bed, and fluid characteristics for a l bed. (Taken from Wen and Yu, *ibid.*)

So, that will be giving you the Reynolds number somewhere here in also quite low and if you look at Reynolds numbers calculated from these of these it comes to 1.3 into 10 to power minus 3 is a 0.001. So, this is the Reynolds number at the minimum fluidization veloc city. So, we once we know the Reynolds number we can calculate the minimum fluidization velocity, as you know Reynolds number is defined by Rho u mf Dp divided by mu is. So, rearranging that one. So, Reynolds numbers given, that viscosity is given, density is given and the particle size is given. So, fluidization velocity is 0.01 meter per second.

So, in one way to. So, this is the minimum fluidization velocity to have operate this reactor, you know you need minimum this velocity, but practically really you do not what you need you need a you have this terminal velocity or elutriation velocity because your u mf, what let us say we calculate here it not sufficient really to fluidize this is theoretical one. There are many other forces are resistant which are acting on this, as we saw before even coming to minimum fluidization velocity to pressure drop is higher. So, interlocking and other thing I had to come out and so, in practice usually it is higher than this velocity and in a true sense in fact it is lie bet between the your alliteration or terminal velocity and the minimum fluidization velocity.

So, fluidized bed usually operate between these 2 limit.

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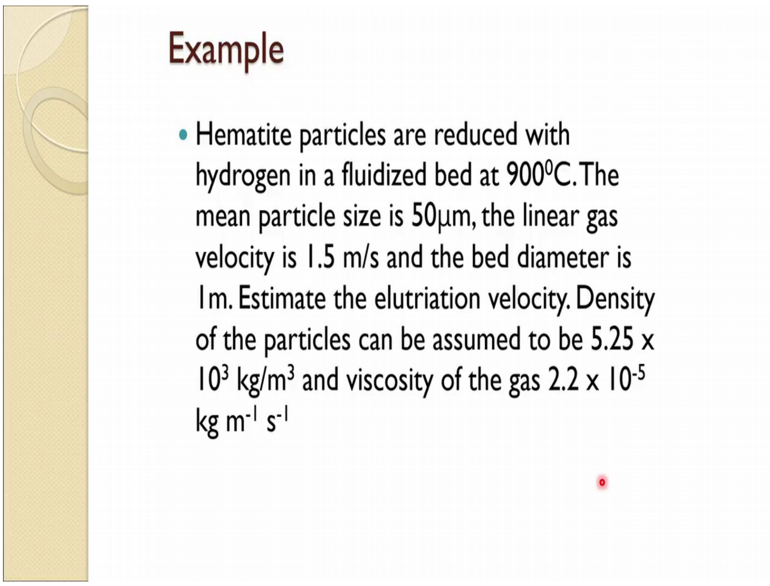

Their another example fit. So, hematite particle are reduced with hydrogen in fluidized bed at 900 degree Celsius. The mean particle size is 15, 50 micron meter, the linear gas velocity is 1.5 meter per second and the bed diameter is 1 meter. So, estimate the elutriation velocity, density of the particle can be assumed 5.25 into 10 to the power 3 kg per meter cube and viscosity is 2.2 to 10 to the power minus 5 kg per meter second.

So, here is what we need, we need the elutriation velocity and that is like a terminal velocity.

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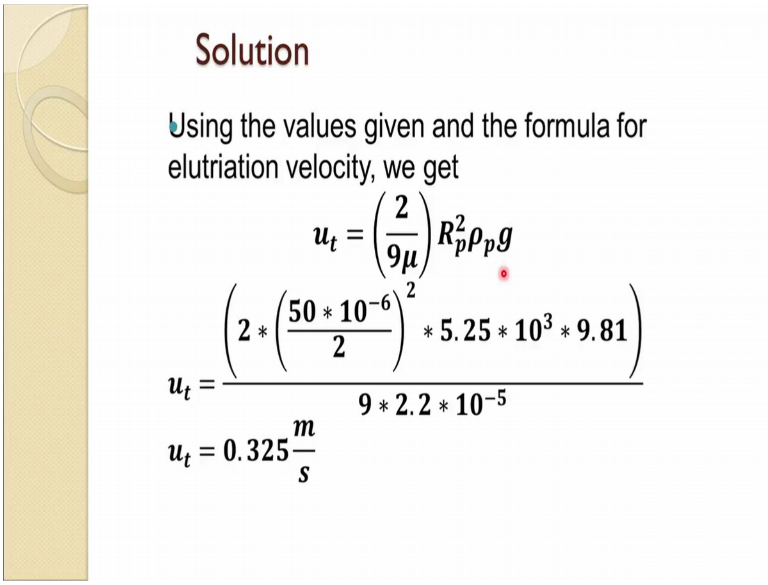

So, for which we know the expression like a 2 by, this is mostly from these talks law.

What you might have read in your in school and other under graduating. So, it is that equation by which you get it. So, that nothing say elutriation velocity we call it and this is valid when the Reynolds number actually is low about 0.4 or so, so less than 0.4 and so, under that condition if you put the values of particles radius, density and the gravity, it is an acceleration and the viscosity you get the fellows elutriation velocity about 0.325 meter per second.

Now, if you look at these 2 examples here, particle size is 50 micron and here the particle size is 100 micron. We had 0.01 meter per second, the minimum fluidization velocity. So, actually it is a little higher because minimum fluidization velocity also depends on the particle size and this is in fact a smaller particle size for the bigger particle size, the Ut infact would be higher, maybe point 6 or so, meter per second.

So, if you look at the value 0.01 and 0.3 at least 1 order magnitude difference there between the minimum fluidization velocity and the elutriation velocity. So, your fluidized bed in practical situation is operate between these 2 limits. It should cross the more than 1 magnitude, either of a estimation if you get the minimum fluidization velocity.

So, maximum you may go to 1 meter per sec, 1 meter per second or maybe lifting up, that gives you some idea about that, but actually this duty is quite a hyper or would be high if we take the right size 100 micron meter and our velocity also if you look at is the 1.5 meter per second and the velocity over here is that is we are finding it out, but velocity would be probably a little mu.

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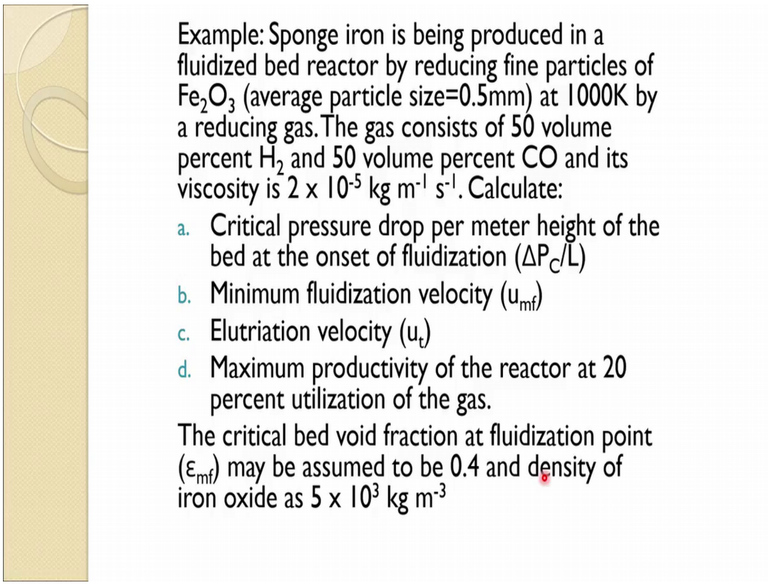

It is another really good example of the application, these farc fluids (Refer Time: 9:00) in terms of iron making.

So, a sponge iron is being produced in a fluidized bed reactor by reducing fine particles of hematite, average size is 0.5 millimetre at 1000 Kelvin by reducing case the gas consists of 50 volume percent hydrogen, 50 volume percent CO and this viscosity, it is about 2 into 10 to the power minus 5. So, one had to find it out the critical pressure drop per meter height of the bed at the onset of fluidization, minimum fluidization velocity, elutriation velocity, maximum productivity of the reactor at 20 percent utilization of the gas. So, gas utilization its 20 percent.

So, that one what would be the maximum productivity of the reactor. So, void fraction the fluidization you can assume 0.4 and density of the iron oxide is given this. Now, we have to make a few assumptions in this.

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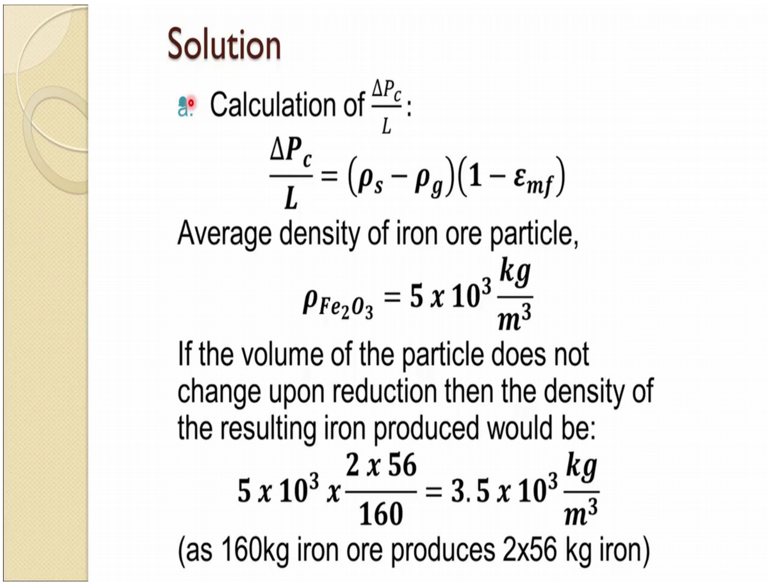

You are producing is point iron and iron oxide is given. So, do you have to know, you can assume this hematite is converting into iron and. So, for that one we have to find out the density. So, average density is given for the hematite, but when it changed into iron. So, what we are assuming, volume of the particle does not change upon reduction because we do not have any information available in the numerical nothing is given. So, that is the assumption which we have made and the density of the is resulting and produce would be recalculate it in this way from the hematite density because we know 160 kg iron or the hematite produces or gives about 112 kg iron.

So, by than that you can get this density and then probably it is not true, you can probably have the average density of that.

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Therefore, $\rho_s \approx$ average density of iron ore and iron.

$$\rho_s = \frac{5\,x\,10^3 + 3.5\,x\,10^3}{2} = 4.25\,x\,10^3\,\frac{kg}{m^3}$$

ρ_g = density of gas mixture

$$\rho_g = \frac{0.5\,x\,2 + 0.5\,x\,28}{22.4}\,x\,\frac{273}{1000} = 0.183\,\frac{kg}{m^3}$$

(as 1 kg mole of gas at STP occupies 22.4 m^3)

Putting these values in equation 1,

$$\frac{\Delta P_c}{L} = 2550\,\frac{kg}{m^3} = 2550(9.81) = 2.5x10^4\,\frac{N}{m^3}$$

So, average density ah, it better to take it because it 100 percent nitrogen. So, every density you get this one Now, similarly for the mixture gas mixtures you can calculate the average density because the 50 percent is ah, as you can save 50 volume percent hydrogen and 50 volume percent CO is given. So, do you have to calculate the average density of that and knowing that 1 kg gas STP occupies about 22.4 meter cube. So, you can these are the molecular weight of the respective cases. So, essentially you get the density of the gas mixture is 0.183 kg per meter cube and once you know this [noise, then this you have seen the power formula we applied for the incipient fluidization.

So, you can put the respective density and the void friction. So, what you get it is 2.5 into 10 to the power 4 normal per meter cube because you are calculating delta P over L, otherwise it has sorry Newton per meter cube. So, otherwise it would be Newton per meter square if you multiply this with the length, then you will get the pressure drop Newton per meter square and that is the first part of the problem to calculate the pressure drop.

Now, second part comes about the minimum fluidization velocity. This of course, we have done before.

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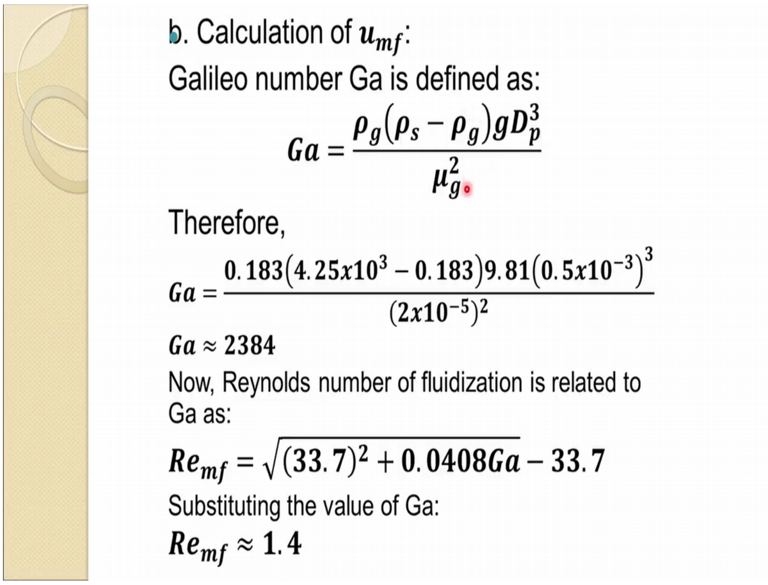

So, we can use the Galileo number, all of these are known to us including the particle size and viscosity. So, Galileo number comes to around 2384. So, either we can use the graphical figures to get the Reynolds numbers at minimum fluidization or please use this equation this gives you the minimum fluidization Reynolds number 1.4 and once you know this you can calculate the minimum fluidization velocity by rearranging this and putting all these values which are known, the minimum fluidization velocity in this case is about 0.3 meter per second.

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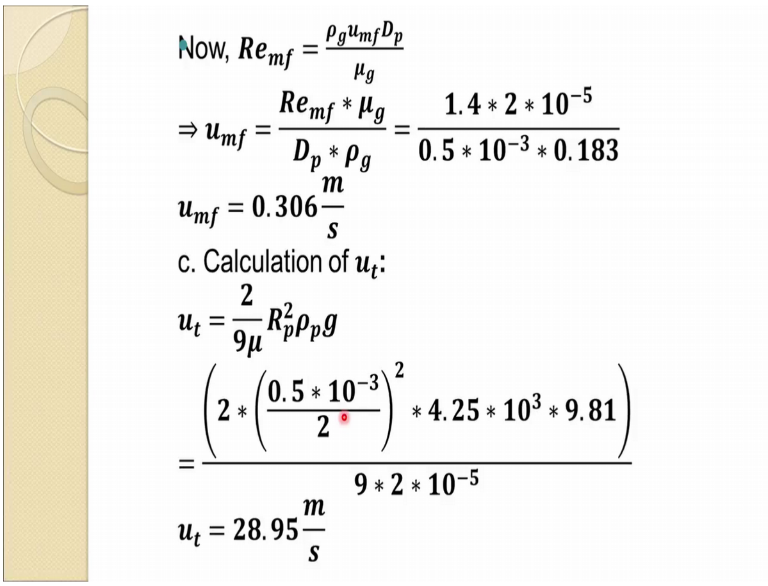

So, here if you look at the what thing one is the particle size, particle size is quite big. It is about your 500 micron and if you look at in the previous pro[problem]- problem, in this one 100 micron size particle and about the density was also quite different hydrogen and then it was giving 0.01.

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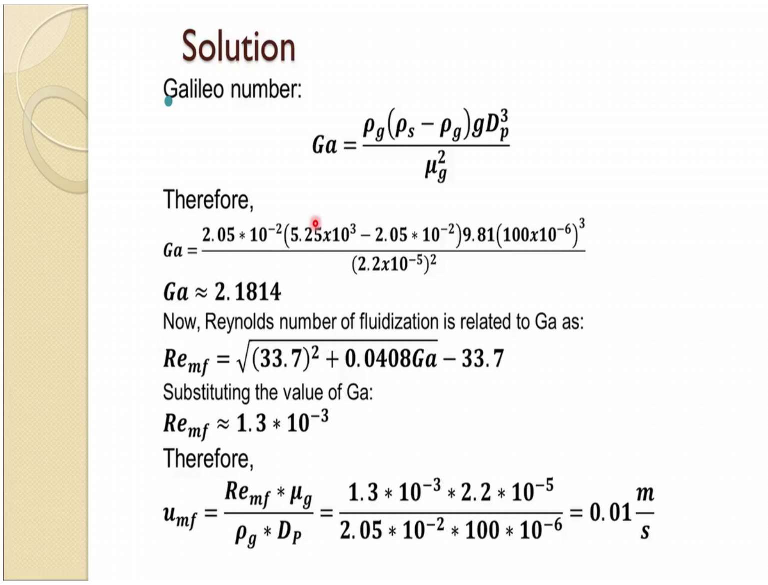

So, particle size also makes a big difference in the minimum fluidization velocity. So, this is the second part of the question which be answered and the third one is about that filtration velocity and this is once we know minimum fluidization velocity in elutriation velocity had we calculated before.

So, 2 by 9 mu Rp square, Rho pg, the terminal velocity putting the value into this equation, radius of the particle and then density, gravity and the viscosity we get the nutrition velocity 28.95, that is again quite high if you look at for 50 micron we got it 0.325, the density of the case was quite low 0.3. So, particle size again is making a big difference as you can see, almost 1 order magnitude difference in the retrace and velocity. So, that answers our third part of the question. The fourth one is the maximum productivity and the condition is 20percent utilization of the gas. So, that for this what we need.

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d. Calculation of maximum productivity of reactor:

The reactions are:

$$Fe_2O_{3(s)} + 3H_{2(g)} = 2Fe_{(s)} + 3H_2O_{(g)}$$

Or

$$Fe_2O_{3(s)} + 3CO_{(g)} = 2Fe_{(s)} + 3CO_{2(g)}$$

Therefore,

$22.4 * 3 * \frac{1000}{273}\ m^3$ of consumption of gas at 1000K leads to production of 2x56 kg iron. Again, utilization of reducing gas is only 20%. Therefore, $\frac{100}{20} * 22.4 * 3 * \frac{1000}{273}\ m^3$ of gas is required to produce 2x56 kg iron.

So, we know this reaction which is going to work either with the hydrogen or with CO because you have to get 2 moles or pine. So, he since it is you are getting 3 moles of that, any of this gas. So, in terms of volume you can convert that. So, that much consumption of the gas at thousand Kelvin lead to the production of 112 kg iron.

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Since the maximum productivity would be obtained at maximum fluidization velocity, we have, $m_{max} = u_t * \alpha$

Where, α is the kg of iron produced per cubic meter of reducing gas passed at 1000K. From the preceding discussions, we have,

$$\alpha = \frac{2 * 56}{\frac{100}{20} * 22.4 * 3 * \frac{1000}{273}} = 0.091 \frac{kg}{m^3}$$

Thus giving,

$$m_{max} = 0.091 * 28.95 = 2.6 \frac{kg}{m^2 s}\ of\ iron$$

So, 3 moles. So, again now utilization factor for this reducing gas is only 20 percent. So, this you multiply it with that, then this is the volume which out the gas which you need to produce 112 kg iron and since the maximum productivity also is related with the maximum fluidization velocity. So, this you can write in this form. So, make the maximum product productivity with a maximum fluidization velocity and alpha is the kg of iron produce per cubic meter of the reducing this at 1000 Kelvin. So, we know already have for 112 kg, how much gas is needed that we calculated.

So, per kg we can calculate we calculate it. So, for per kg it comes to this from over this previous calculation this was one 112. So, for per kg this put with the value of alpha and if we put this and make them fluidization velocity sort of a elutriation 1 we can take it. So, this is the one which we calculated. So, if you multiply with that this skips you the maximum productivity in kg per meter square second of iron.

So, this is a very good productivity, but not that good looking at 20 percent on the utilization it can be increased, but you must remember a limitation in this we are using duty and usually this is quite high value, it will even further reduce if we it should not be operated, that it should be below this other way everything will go out of this reactor and we do not know what would be the residence time. If we calculate the residence time, then we can see whether this velocity is the right or we should reduce it to get the maximum productivity by the time your and hematite particles should reduce a 100 percent because the hematite particle it is about 500 micron here.

So, they are quite big. So, probably you have to reducing it mole as residence time for the reaction in this. So, your velocity elutriations probably if it should be less ah, but these 3, I think gives you an idea how, whatever we had discussed about the pressure drop and fluidization are applied to the blast furnace or iron making area. So, and one would really appreciate about this application. Now, we come to the blast furnace application.

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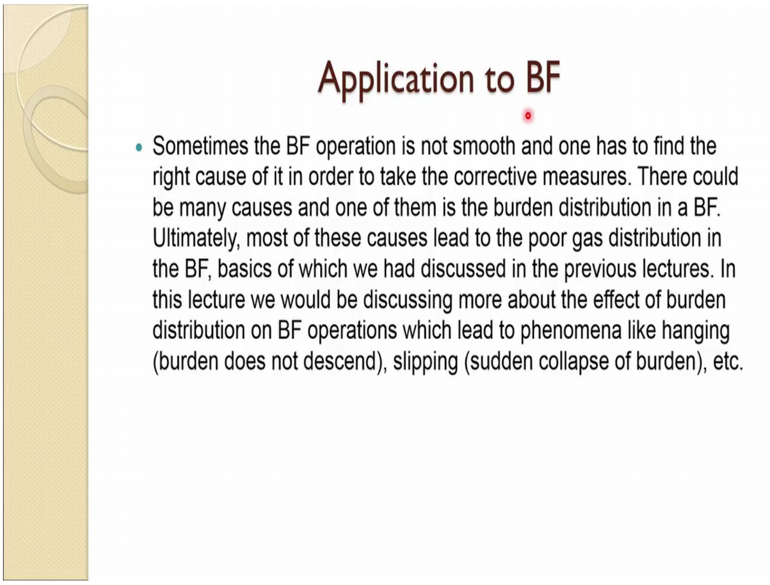

So, sometimes the blast furnace operation is not (Refer Time: 22:08) smooth and one has to find the right cause of it in order to take the corrective measures.

So, there could be many causes and one of them is the burden and distribution in a blast furnace. Ultimately all of these causes lead to the poor gas distribution in the blast furnace, basics of which we had discussed in the previous lectures. So, in this lecture we would be mostly discussing about the effect of burden distribution on blast furnace operation operations which lead to the phenomena like hanging and hanging it like event burden does not descend, slipping sudden collapse of burden, changing etcetera we would be discussing in this.

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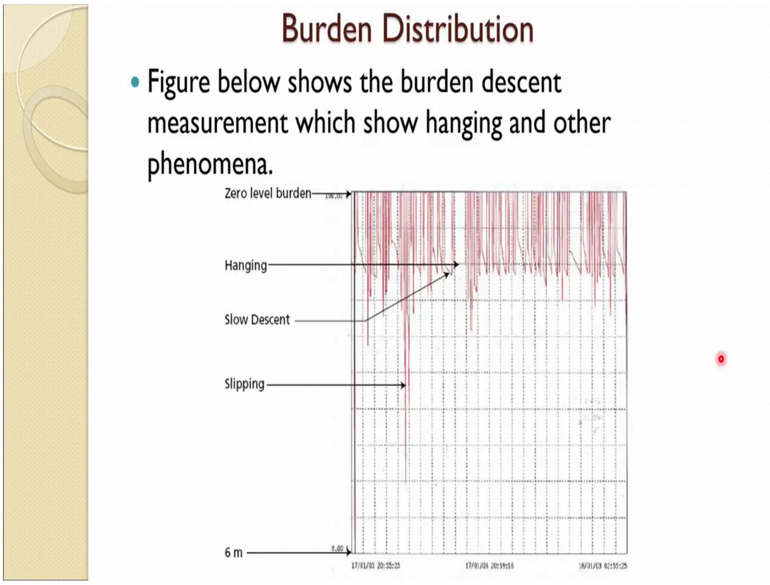

So, we will discuss these phenomena in terms of whatever you have learnt in the previous slide or lectures and we will try to correlate with that. So, if you look at the burden distribution. So, this is the figure, as usually in the blast furnace they have many probes and one probably about the burden design measurement and this whole divergent design measurement graph and it is showing, if you look at this one this is such a sudden burden design. So, naturally a slipping phenomenon I had occurred here. Here if you look at nothing is happening it not descending.

So, hanging up the furnace, here very slow descent. So, if this is a 0 level of the burden. So, by analyzing this is a continuously monitor one operator can get the idea what is happening in the furnace,the slipping and hanging is happening. Operator has to take the corrective measures otherwise the furnace will be having a retic where your metal quality not only metal and slag quality even the furnace would not work in a proper in a proper way, the operation will become very erratic. So, one has to continuously analyze these things and that is where the control and measurements are very sincere in the blast furnace and the modern blast furnace they are very cute with these sort of measurement to keep an idea about what is happening inside the blast furnace.

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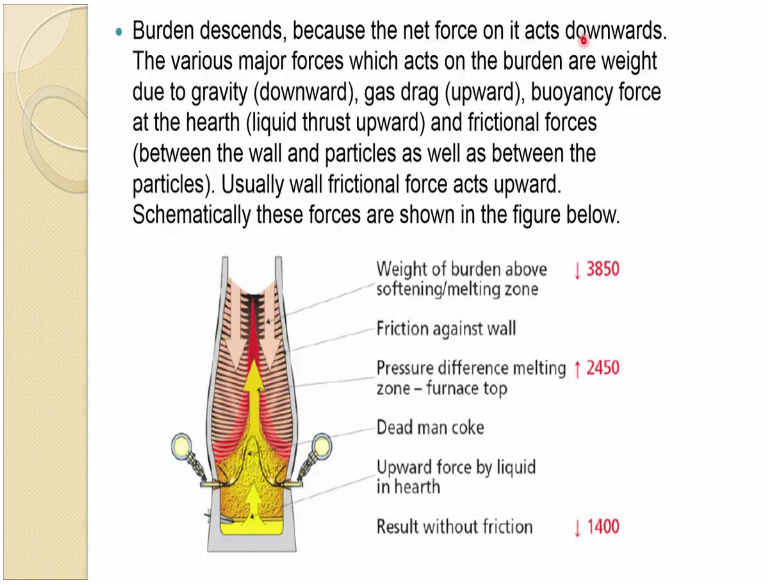

So, we will not discuss more in detail about this why this is happening and how does it happen. So, burden descend because the net force on it act downward naturally, otherwise will not descend and what are those force forces. So, various major forces which acts on the burden are, number 1 of course the weight, which is due to gravity and that will always act downward, the gas drag which we discussed before take their in fluidization and that will always act.

Then, buoyancy force at the hearth or liquid thrust. So, this I think you do not know and this one as you know the dead man is there sitting here, dead man is mostly the medic inactive coke particles which are not taking part into the combustion or descending or in the reaction. So, mostly the inactive portion is called the dead man which is made of the coke particles and this coke particle as you know the density of this is quite low about if you are talking right density about 600 kg per meter cube of dead and the liquid which is coming down iron density is about 7000 per kg per meter cube and select density would be around 3000 kg per meter cube.

So, really as the liquid drips and is collected at the bottom and keep on accumulating the level is rises and this co column is sitting on it. So, the brain supports keep on increasing and it meant infected manipulated times it has been found it is just floating on the liquid matter the whole this dead man coke way column. So, essentially it liquid thrust is giving schematically these force is pushing the material up and as this level keep on increasing this force keep on increasing and not only this force is also pushing the on the whole dead man column upwards which is very close to the raceway and that also disturbed the raceway and which disturbed the gas flow.

So, everything is getting affected due to that. So, you have a liquid thrust upward and then you also have a frictional force between the particle involved and between the particles. So, this it will descent only when your gravity force is higher than these forces. If these forces become higher burden will not descend and so, proper dra [drainage]- drainage is casting is very necessary and at the right time it should be done or infect high productivity furnaces, you have a sort of a continuous drainage because the productivity is very high. So, quite a lot liquid and slag amount comes. So, do you have a continuous drainage in that?

So, do those furnaces they operate smoothly, where you have intermittently one has to be very careful because these forces play the important part and the gas distribution would be quite different at its process and then this can create lots of other problem including the chemistry of the your net melt. So, this a diagram soul is kinetically some rough sort of forces, weight of the burden, it is taste friction force, pressure difference, that we talked about the drake, that the dead men coke, thrust to run from the liquid and if you combine the these 2, this is coming almost the balance once.

So, probably this will consume only it will descend otherwise it will not it will hang.

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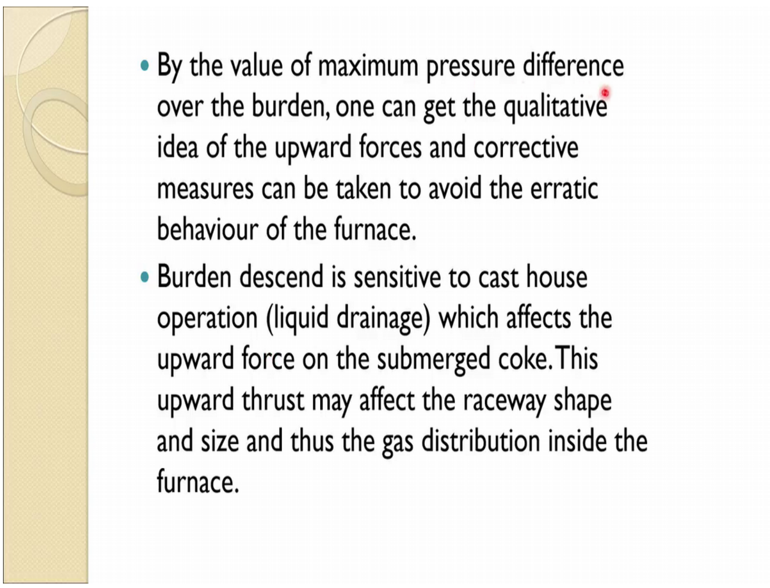

So, by the value of maximum pressure difference over the burden, one can get the qualitative idea of the upward forces and corrective measures can be taken to avoid the erratic behaviour of the furnace. As we saw from this probe about the burden designed, one can get quite a good idea what is happening in the same way knowing the pressure force or pressure different at the top of the burden one can get the idea of these forces and the corrective measure then can be taken to avoid this erratic behaviour of the furnace.

Now, burden descent is very sensitive to cast house operation, the liquid drainage which we said because this affect the upward force on the submerged coke. This upward thrust may affect the raceway shape and size and thus the gas distribution inside the furnace and that is undefeated changes. So, instead of gas going this way, gas might be preferentially going to other way and that will change the reduction pattern and the chemistry of the mole which is coming out.

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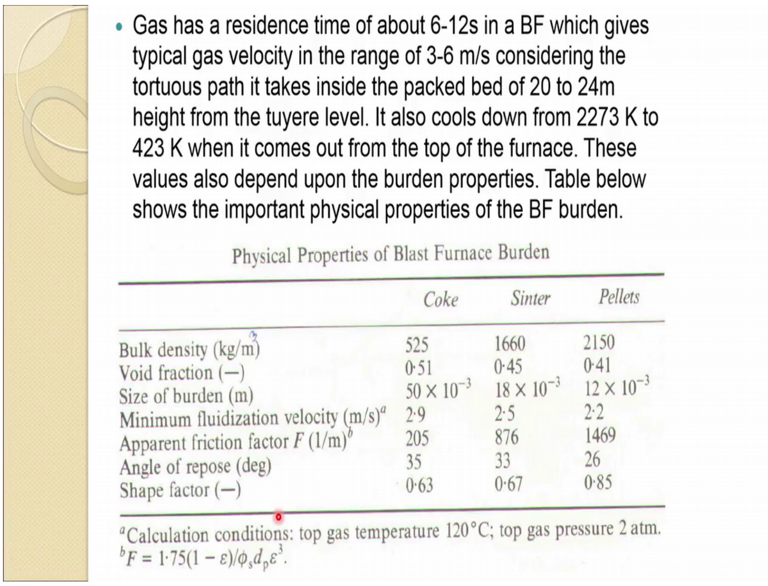

- Gas has a residence time of about 6-12s in a BF which gives typical gas velocity in the range of 3-6 m/s considering the tortuous path it takes inside the packed bed of 20 to 24m height from the tuyere level. It also cools down from 2273 K to 423 K when it comes out from the top of the furnace. These values also depend upon the burden properties. Table below shows the important physical properties of the BF burden.

Physical Properties of Blast Furnace Burden

	Coke	*Sinter*	*Pellets*
Bulk density (kg/m^3)	525	1660	2150
Void fraction (—)	0·51	0·45	0·41
Size of burden (m)	50×10^{-3}	18×10^{-3}	12×10^{-3}
Minimum fluidization velocity (m/s)[a]	2·9	2·5	2·2
Apparent friction factor F (1/m)[b]	205	876	1469
Angle of repose (deg)	35	33	26
Shape factor (—)	0·63	0·67	0·85

[a]Calculation conditions: top gas temperature 120°C; top gas pressure 2 atm.
[b]$F = 1{\cdot}75(1 - \varepsilon)/\phi_s d_p \varepsilon^3$.

So, gas has a residence time of about 6 to 12 second in a blast furnace. We skip typical gas velocity in the range of 3 to 6 meter per second considering the tortuous path it takes inside the packed bed of 20 to 24 meter.

So, if you have that sort of height and residence time of that sort of you can calculate the velocity of the gas, but remember this is not that high and you have to consider the tortuous path which it is taking that would be longer than this. So, an[and]- and that is from Tuyere level. It also cools down from 2273 Kelvin to 423 Kelvin, when it comes out at the top of the furnace. So, when it comes out from the top of the furnace. So, these values also depend upon the burden properties. So, this table shows important properties of the blast furnace burden.

You can see the bulk density of the coke about 525 of 500 to 600 pellets between dates, sinter is around 1660 and pellet in the highest one 2150. Void fraction for coke is the highest one and for pellet is the lowest one, the size of the burden, again coke is the highest because this is the one which gives the permeability more void fraction and for sinter the size is medium and were pellet as we said during palletization its about 12 millimetre and for this also be you know about it.

Now, minimum fluidization velocity 2.9, 2.5, 2.2 look looking at the size of it its quite do are familiar now with this void and you can even calculate the minimum fluidization velocity is you can assume some of this sort of velocity and you can easily calculate.

So, minimum fluidization velocity for coke of this size is about 2.9 and 2.5, 2.2 for platelets and which is 12, but the density is quite high. So, it is coming within 2 meter per second 2 to 3. So, apparent friction factors which is calculated using this it is quite high for the pellet with low for the coke. angle of repose is 35 to 26. We will talk about it later in the lecture because this is very important again the property of the material and we will talk about it later. Shape factors, you already know about it in the lecture we said when the particle are not a spherical do you have to multiply that with the set factor. So, for coke it is about 0.63, for sinter 0.67 and for pellets is about 0.85.