Iron Making
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Lecture - 12
Iron Making

So, we talked about 4 system of important in the blast furnace.

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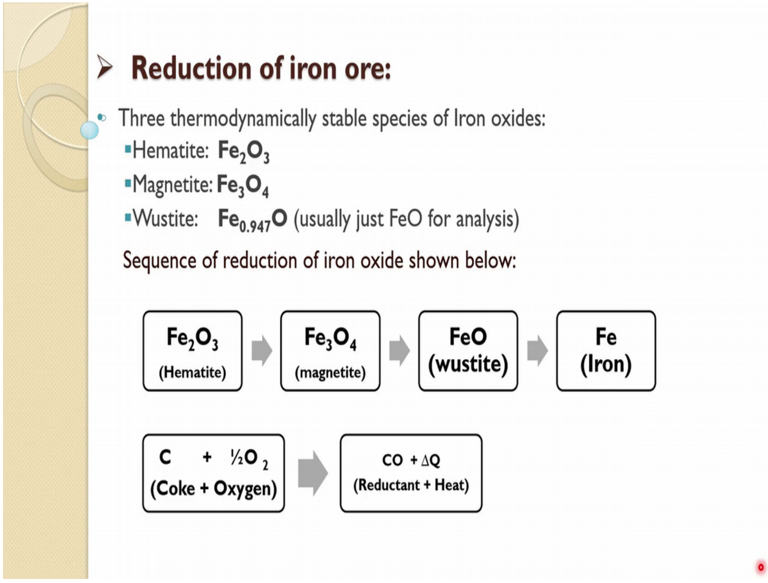

Now, we will talk more about the reduction of iron ore and as you can see that hematite and magnetite these are the 2 most stable phases of iron oxide wustite at dissociate it is not a stable below 570 degree Celsius and also you are aware that a reduction goes in a sequence hematite to magnetite to wustite and to iron and reductant for this is mostly the CO gas. So, which is produced by burning carbon attitude level with the oxygen then you get CO as a reductant gas and the heat.

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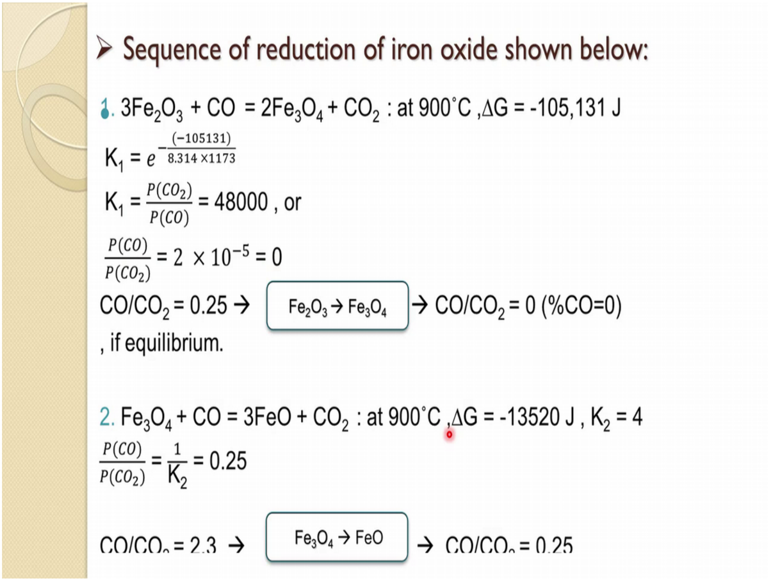

Now, the sequence of reduction which occurs with some calculation we will saw how much utilization of CO can happen um. So, from hematite or magnetite at 900 degree Celsius, your free energy is about 105131 joule.

So, you are already away aware about this delta G we can put it minus r t log K and K is the equilibrium constant for this reaction and these sort of calculations we have done before. So, we can calculate the equilibrium constant at 900 degree celsius giving this value. So, which comes equal to 48000 P CO 2 by P CO partial pressure of CO 2 partial pressure of CO that equilibrium constant for this reaction and in terms of reverse CO over CO 2 is 10 to the power minus 5. So, very very low that race off which means really very small amount of CO would be able to reduce the hematite and if you look at this is almost negligible amount this one. So, only a little CO can reduce hematite into magnetite when it is in equilibrium.

So, second at once you reduce to magnetite ah, again it further it react with the CO carbon monoxide and reduces magnetite to wustite and this is the reaction where free energy is given here, again one can calculate the equilibrium constant for this reaction which comes to 4. So, CO, CO 2 come to 0.25 and this 0.25 a. So, once this is getting reacted then this 0.25 minimum which is required to equilibrium this goes to the reduction of magnetite, oh sorry hematite to magnetite and this is sufficient enough and. So, what we are having in the in 0.25 which is coming from this reduction, in and out is almost 0 nil. So, which is quite sufficient to reduce the hematite into magnetite and, but if we will see the next one in is coming from Fe O 2, Fe 2.3 and it goes to 0.25. So, this is also quite enough to reduce magnetite into Fe O because the equilibrium constant dictates 0.25 (Refer Time: 04:34).

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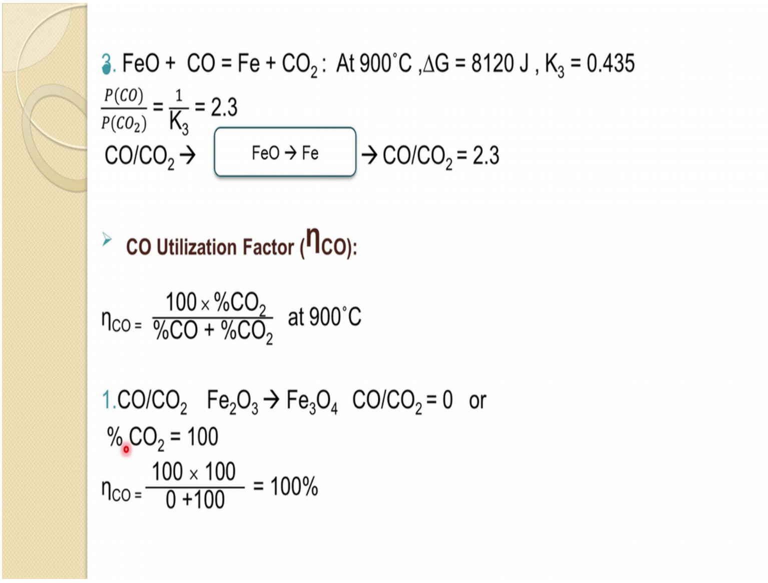

So, of this and when after wustite again for the it react with carbon monoxide and a gives iron at 900 degree Celsius and this is your free energy. So, for this the equilibrium constant and in terms of reverse ratio of CO CO 2 comes to 2.3. So, here CO, CO 2 ratio or this is the one which is coming from the 2 year and I do know we have talked about this minimum as you need it about 3.3 sort of press o to do this so, but after the reduction it comes 2.3. So, that is the minimum which you need it um. So, this is the one which is going to the upper zone, where magnetite get reduced to wustite and then that is 0.25 and that one goes to the another one, another upper zone where hematite reduced to joule magnetite. So, that is how these ratios are coming over here now. So, CO utilization factor you can easily calculate in the first case it is almost negligible. So, CO utilization is almost hundred percent then Hemet. So, CO utilization factor is given by this formula sort of as you say efficiency also percentage CO 2 divided by total percentage of CO plus CO 2 at 900 degree Celsius.

So, for the first reaction is normal negligible so CO utilization factor is almost 100 percent for that.

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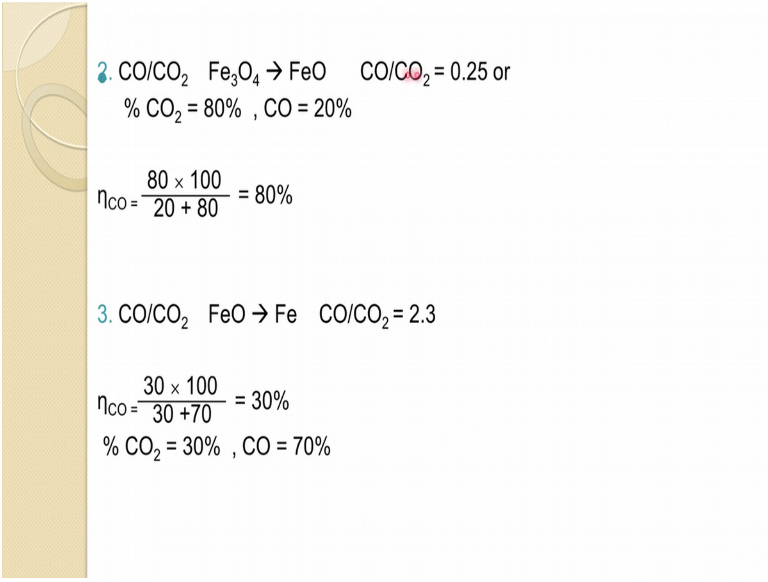

For the second reaction the ratio is about 0.25 which means 20 percent that has a CO 80 percent that has CO 2. So, utilization factor for CO is about 80 percent for this reaction magnetite to wustite and similarly for from wustite to iron found this 2.3 the ratio and if we put that one. So, this gives actually a 30 percent CO 2 and 70 percent CO it is needed and the utilization factor of CO is only 30 percent. So, really you need a very high this one and 30 percent utilization factor this CO, which we discuss about these numbers we mentioned before when we were discussing about the reduction or those system. But we did not say how did we get these values and this is the calculation by which you can show it how one can get these values 100 percent, 80 percent and 30 percent CO utilization in the reduction of iron oxide.

Now, we talked about this system.

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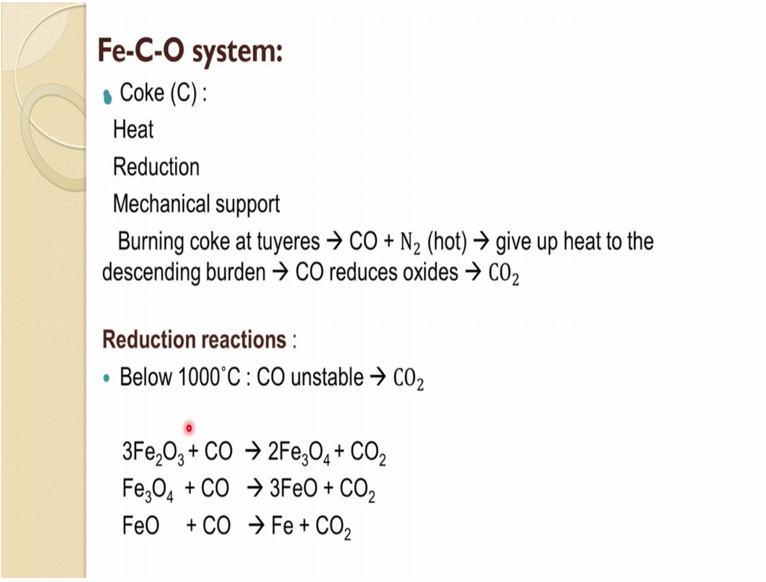

Now, we will talk in terms of different way about the reduction. So, as you know usually coke is execute for heat reduction in mechanical support and it wants tuyeres level and give the heat nitrogen is mostly that getting heated up and take the at the sensible heat and this CO gives heat to the descending burden which reduces the oxide and CO 2 is form. And these are some of the reaction which you are already familiar now and below 1000 degree Celsius CO is unstable that we saw in carbon and oxygen diagram also system.

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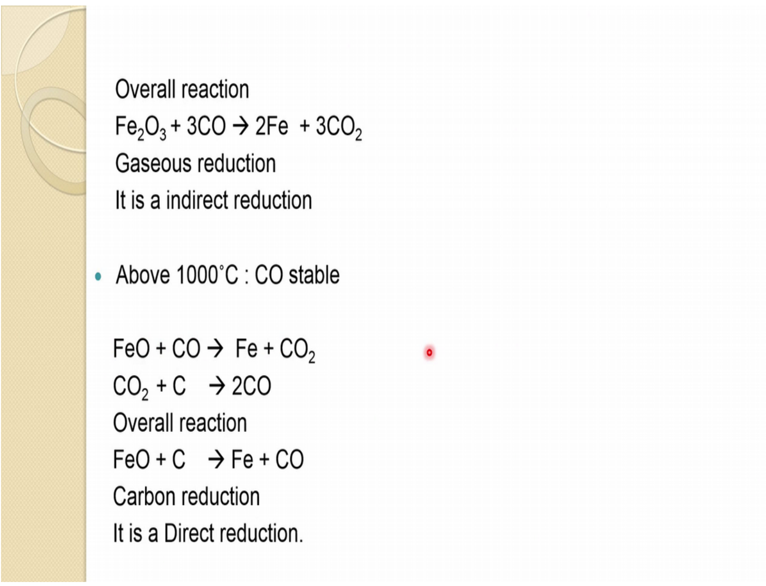

So, overall reaction if we put it this also you are familiar, familiar. So, this is known it gaseous reaction because from carbon monoxide gas it is getting reduced. So, cases reduction and you also call it the indirect reduction, but ever 100 degree Celsius CO is stable and this CO reduced Fe O into on and it gasify the carbon carbon gasification of Woodard reaction which we discussed before this is. So, it again from the CO so overall reaction is Fe o plus c equal to Fe plus c o. So, this is actually called the direct reaction where it is not the carbon which is reducing directly iron oxide or wustite it is, via gaseous phase it is getting reduced and that is why we said direct reduction otherwise it is not that through carbon b r or carbon solid carbon is reducing it directly that is not the case as we had discussed before also. This reaction may happen just near the boss where liquid iron and in which you have some Fe O present travelling on to the coke matrix with the direct contact with the solid carbon then this may occur, but this is negligible.

So, mostly it is in the form of our gaseous phase.

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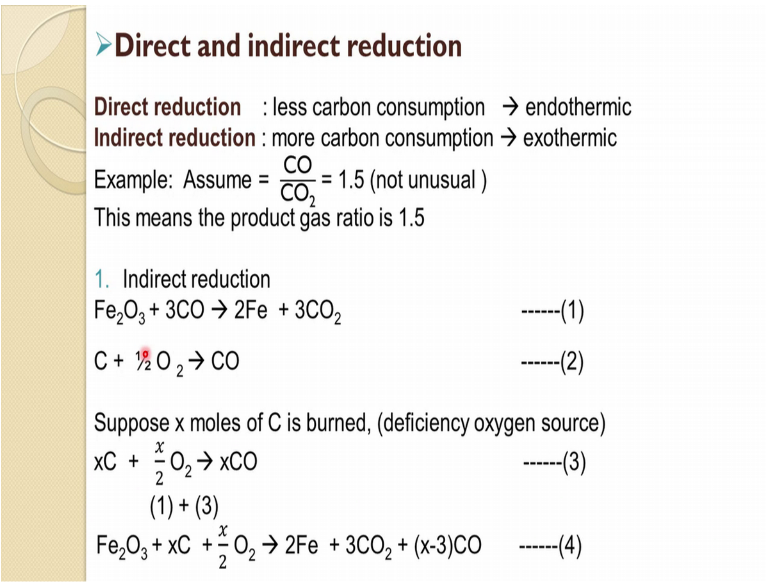

And now we will talk quite a bit about direct and indirect reduction um. So, as you know directly reaction we need a less carbon consumption it is an endothermic. So, they need the heat in direct reduction more carbon consumption exothermic and as you know in the blast furnace carbon is the main reductant and the aim always is to reduce the consumption of carbon that is coke and that is a very important thing. So, from that viewpoint its maybe direct reduction would be useful.

Now, we will see how the consumption of coke may occur in this reaction or the combination of these 2. So, let us take an example for first the indirect reduction. So, as usually CO, CO 2 ratio is about 1.5 and blast furnace which we can assume that it is a quite G as usual. So, that a product gets raised oh. So, indirect reduction so if we assume this now hematite is getting converged into iron directly the overall reaction as we said in this one. So, and the carbon what we see or what we get it is getting by burning of the carbon.

So, suppose x mole of carbon is born and complete oxygen is utilized. So, essentially x mole of carbon reacting with so many mole of oxygen giving you the x mole of CO and this. So, this x mole of carbon and this reaction and if you combine what you get it Fe 2 O 3 x C half O 2 equal to 2 Fe plus 3 CO 2 plus x minus 3 CO that is the adding them up this is the total reaction by which you will get the iron.

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But $CO/CO_2 = (x-3)/3 = 1.5$

Then, $x = 7.5$

from------(4)

$Fe_2O_3 + 7.5C + 3.75O_2 \rightarrow 2Fe + 3CO_2 + 4.5CO$ ------(5)

$\Delta H^{\circ}_{1000} = -200$ Kcal.

2. Direct reduction :

$Fe_2O_3 + 15/7C \rightarrow 2Fe + 6/7CO_2 + 9/7CO$ ------(6)

$\Delta H^{\circ}_{1000} = +73$ Kcal

	C consumption (Kg)	Heat (Kcal)
Indirect reduction	0.81	+1790
Direct reduction	0.23	- 656

So, now CO, CO 2 ratio can be calculated from this x minus 3 divided by 3 CO c o 2 ratio and that as we have said 1.5 the ratio go to 1.5. So, x come to 7.5 it means seven. So we now, we can substitute this into the overall equation here. So, Fe 2 o 3 plus 7.5 carbon, plus 3.75 oxygen gives to 2 mole of iron, 3 mole CO 2 and 4 point and half mole of CO.

And a 1000 degree celsius the (Refer Time: 14:04) is about minus 200 kilo calorie. Now, if we take the direct reduction which we said in the previous one or directly when or directly Fe 2 O 3 it is reducing, let us say with the carbon instead of wustite we know that CO c o 2 ratio is 1.5. So, maintaining that you can balance the reaction easily. So, here you will see the CO, CO 2 ratio is 1.5 and then remaining you can balance it as. So, here and helping is a 75 K calories, now in if we convert this one in terms of per Kg what will be find for indirect reduction you need about 0.81 Kg of iron and for directory reduction you will need about 0.23 Kg to produce per moles. So, and so which means that indirect reduction is giving quite high carbon coke consumption.

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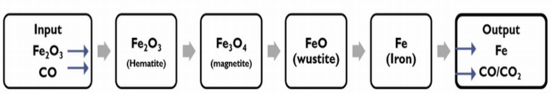

Mass balance	Input	output
Fe_2O_3	1	-
Fe	-	2
CO	x	y
CO_2	-	x – y

Now, we will talk about another point here and that is again we are taking an indirect reduction, but now what we would be considering, we would be considering different process. So, different process when we say one is you know blast furnace it is a counter current reactor. So, gas is coming from the bottom, going up and the charge is coming from the top. So, it s a counter current reactor, now suppose both gas and the charge you are feeding from the top or from the bottom 2 then usually you call it co current process. So, now, we are considering that Fe 2 O 3 and CO.

So, before coming to this now Fe 2 you need a CO, CO 2 ratio all almost negligible to reduce hematite or magnetite then you need 0.25 from magnetite to wustite and wustite to iron 2.3 at 900 degree Celsius assuming the ratio and the product case is 1.5. So, in co current process when hematite and carbon monoxide these are being fed together from the top. So, that is how the input is then it had to of course, reduced hematite, magnetite and wustite and then iron and remember when if you have to reduce the iron your CO, CO 2 ratio has to be minimum here that one. So, product can come to 1.5. So, you have to maintain this from here to here this must ratio though your hematite magnetite reduction they do not need this high ratio, but because it is going in a co current basis. So, here when it reaches it has to have a very high ratio. So, now, if we do it sort of a of a mass balance on per mode basis. So, from let us say Fe 2 or 3 to Fe 3 or 4. So, one mole of a hematite and x mole of CO is reacting with this giving 2 mole of iron and y more of a these upwards you can see from one of this reaction which we had before. So, giving y mole of CO and x minus y mole of so, CO 2.

So, that is a normal mass balance you can do it, now wait on this you can do the oxygen balance and CO c o 2 CO 2 balance.

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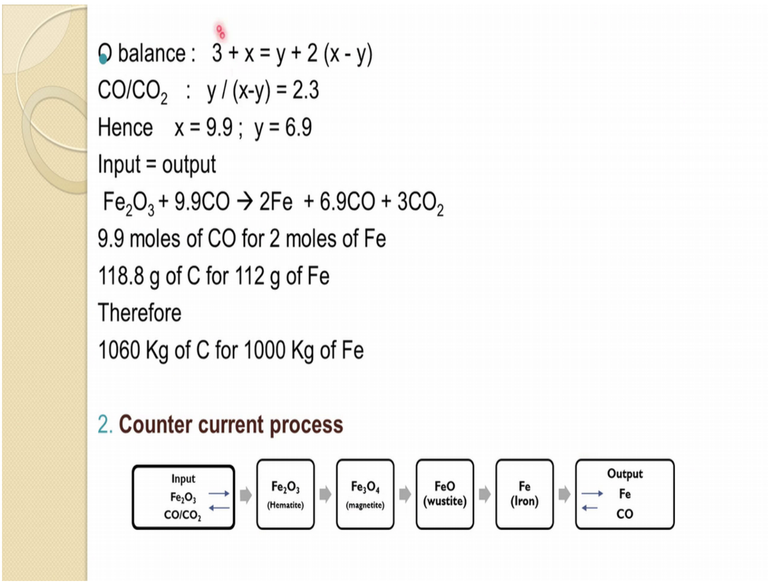

So, oxygen balance here 3 and 1 in the c o. So, 3 plus x equal to y output plus 2 x minus y. So, 2 come with a 2 x minus y. So, similarly you can do the CO, CO 2 ratio and that is as we mentioned it 2.3. So, and if you solve these 2 equation now, oxygen balance and CO c o 2 from this what we get x 9.9 and y 6.9. So, this is when hematite is getting reduced to iron unique 9.9 mole of CO and 6.9 mole CO of comes out and 3 moles of CO 2. So, 9.9 moles of CO for 2 moles of iron, which means most 118.8 gram of carbon for 112 gram of iron; so, which is about 1060 Kg of carbon for 1000 Kg of iron. So, you need this much not actually this much coke, coke would be higher because in the coke you have around 80, 70, 80, 80 percent fixed carbon.

So, if you are talking in terms of coke that would be quite high, but as such in the carbon form you need more than one thousand Kg almost eleven hundred Kg of carbon to reduce to get 1000 KG of iron for if you are to going on a co current basis in that. So, that very expensive and not a good process, now if on the other hand with the way blast furnace work, it works more on a counter current basis. So, where they you are in output oxygen as you can see CO is feeding in from the iron site and hematite is feeding from the top and CO c o 2 is coming out and so, you have to maintain and because the burning of coke is occurring here and which produce CO with very high percentage. So, you already have that high put CO, CO 2 ratio, so which reduced the Fe o into iron.

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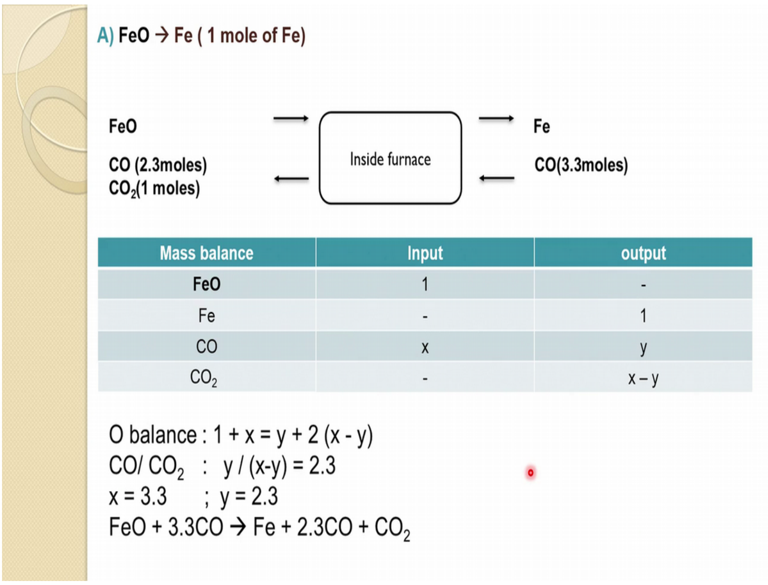

So, if we look at now in that way. So, FeO to Fe 1 mole of iron. So, that is input and CO is the other coming from the other direction. So, Fe O is coming from the top and CO is coming from the bottom and if you know the as I said before also is it need 3.3 moles to reduce it in that one and by the time it comes it can be 2.5. So, and because this CO is coming from the to a levels. So, to have a very high CO atmosphere which is coming. So, that easily satisfy this requirement. So, now, we do the mass balance or 1 more 1 model of an x mole of CO is giving you 1 mole of iron and y mole of CO and x minus y mole of CO 2. So, if we do again like oxygen balance. So, 1 plus x equal to y plus 2 x minus y 2.

So, and similarly CO, CO 2 it is a from here it comes out 2.3 as we had mentioned before. So, this ratio is 2.3. So, it gives you x 3.3 and y 2.3. So, Fe o to Fe do you need 3.3 moles CO to react to give 1 mole of iron.

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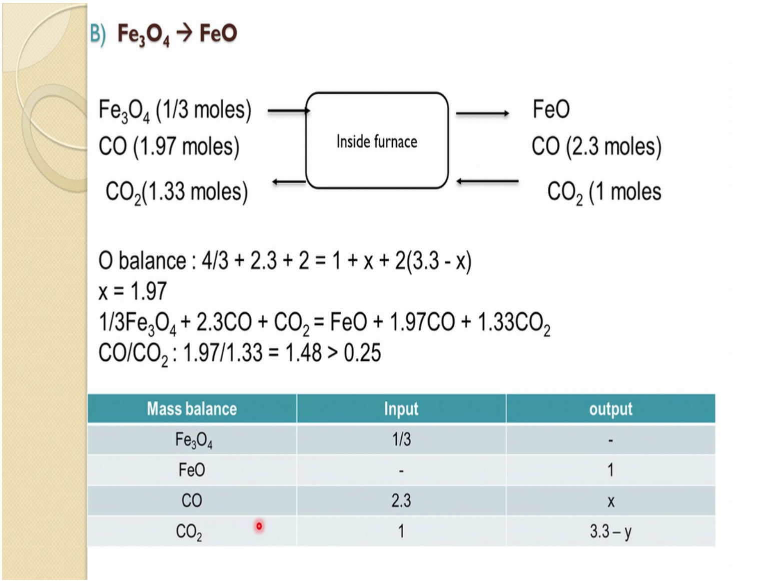

Mass balance	Input	output
Fe_3O_4	1/3	-
FeO	-	1
CO	2.3	x
CO_2	1	3.3 – y

And now, we go from Fe 3 o 4 to Fe o. So, again now CO 2 is or CO c o 2 is coming in from this side and magnetite is coming from the top and the output of this is Fe o and output of this CO, CO 2 of that. So, now, again we have to do the oxygen. So, this we know and now we have to calculate what we are going to get at the output of the gas. So, if you do again the oxygen balance for this in the same way you will get 4 y 3 and this is a little stable for y 3 and 2.3 this is because we are already previous calculus and we know how much CO is coming in. So, that is 2.3 moles that we just calculated it, 2.3 is coming in. So, and 1 mole of c CO 2 is coming that is why we have put this and. So, we know input what is there and output we do not know how much c I utilized and so remaining put be the CO 2.

So, if we do the oxygen balance. So, that 4 y 3 then 2.3 into 2.3 it is a oxygen plus 2 equal to 1 oxygen plus x plus 2 into 3.3 minus y um. So, if we do this balance we can get the value of x. So, that is going to give me give us about this equation, when we balance it and CO, CO 2 ratio of this after the magnetite, when it comes out it is about 1.48 and when it comes out what it is required about 0.25. So, this is much greater than that so it satisfied even that condition of a reducing Fe 2 or 3 to Fe 3 or 4 the that one.

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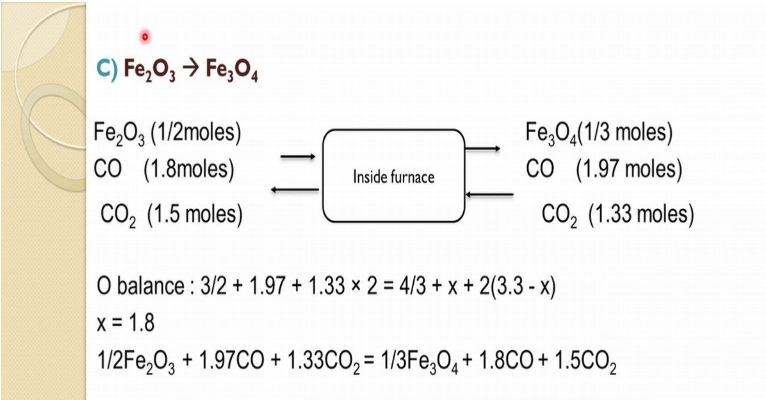

Mass balance	Input	output
Fe_2O_3	1/2	-
Fe_3O_4	-	1/3
CO	1.97	x
CO_2	1.33	3.3 – y

So, Fe o 2 or 3 to have it now record these moles from here. So, that these input Fe o 2 or 3 to Fe 3 or 4 and we can. So, our input is this is actually this is a season one up for no one mole basis. So, because it is 2 moles so half. So, it could be that time same thing about here and these values are coming from our previous calculation and same way we can do it our output one as we did before and we do the oxygen balance then x comes to 1.8 and y them can be calculated. So, this gives you this equation where 1.97 moles of CO is being used to reduce hematite into magnetite.

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Overall Balance:

Mass balance	Input	output
Fe_2O_3	1/2	-
Fe	-	1
CO	3.3	1.8
CO_2	-	1.5

3.3 moles of CO for 1 mole of Fe
3.3 g atoms of C for 1 mole of Fe
3.3 × 12 g of C for 56 g of Fe
Hence, Carbon requirement = 707 Kg C/1000 Kg Fe

Direct reduction
$Fe_2O_3 + 3C \rightarrow 2Fe + 3CO$
3.3 × 12 g = 2 × 56 g
Carbon requirement = 322 Kg C/1000 Kg Fe

And, if we do this. So, this is overall mass balance of that one when we get it if we put it all these values. So, this will be the overall mass balance of on mole basis and. So, you can see 3.3 moles of CO for 1 mole of iron and 3.3 gram atoms in 1 race for 1 mole of iron or 3. So, many gram of carbon for 56 gram of iron.

So, for 1000 Kg you need about 707 Kg of carbon. So, what it is telling in an indirect reduction in a counter current condition you need only 707 Kg carbon to get 1 ton of iron. So, that is a quite almost more than 30 percent reduction what we have for the indirect reduction for co current condition. So, counter current that is why we used the counter current reactor to produce carbon such a blast furnace, now if we go to the direct reduction.

So, directly reduction as we talked about this equation you can directly calculate how much is the coke requirement for 1 ton of iron. So, you get about 322 Kg the carbon for 1 ton of iron. So, that is looking at it for counter current indirect reduction and ah, direct reduction there is a big difference again in the coke consumption. So, this coke you can save it. So, in one way directly the reduction is quite beneficial in terms of saving the coke of carbon then indirect a reduction.

So, here we assume 100 percent indirect reduction, here we are assuming 100 percent direct reduction, but you need heat supply for this. So, if we put a summary all together.

So, co current we need 1060 Kg per ton of iron for counter current we need about 707 for direct reduction we need about 322.

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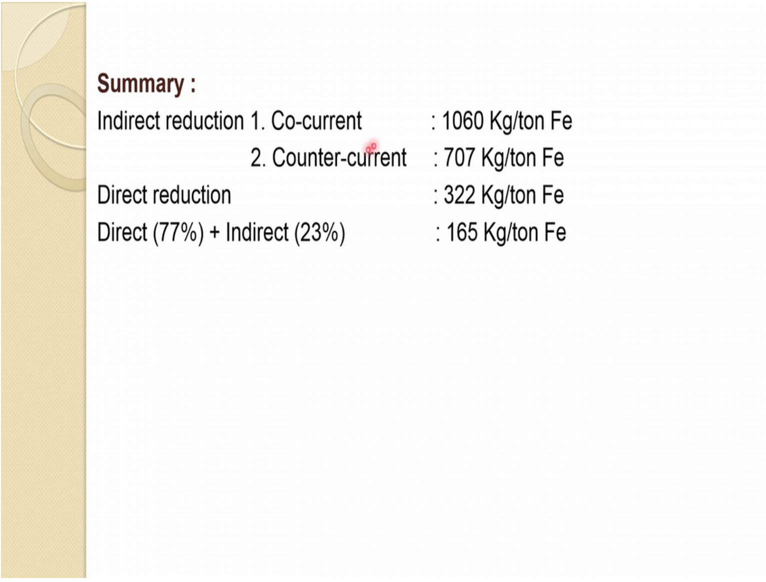

And if we put a combination of these direct and indirect you may see probably we can substantially reduce the carbon consumption we will not see this calculation how do we arrive on this 165 kilo Kg of carbon per ton of iron.

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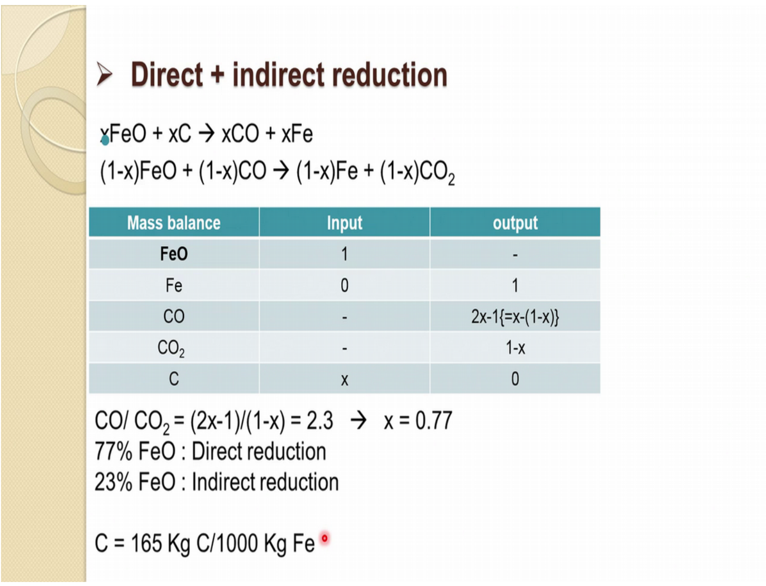

Mass balance	Input	output
FeO	1	-
Fe	0	1
CO	-	2x-1{=x-(1-x)}
CO_2	-	1-x
C	x	0

So, this is now for the direct plus indirect detection combination of both.

So, if we say x a mole of carbon is directly reducing iron oxide to iron and remaining of course, would be the or indirect reduction that the CO could be read reducing wustite to iron. So, now, if we do the balancer again we can make the mass balance intervals of one mole like your input if we do for this x moles of carbon you get the output 1 mole of iron actually. Finally, when its reduce is to combine it and you will get c CO x if you combine these 2 then you can do the mass balance then you get x minus 1 minus x equal to 2 x minus 1 CO 2 is 1 minus x and 0 carbon in output.

So, now if we look at CO, CO ratio for the this you know you have to maintain about 2.3 as we did before the we had mentioned about it. So, that gives you x equal to 0.77 which means about the say 77percent Fe O will get reduced directly with carbon and it gives you that and remaining 23 percent of you will be reduced y carbon monoxide that is in direct reduction.

So, and when you put this value then you will get 165 Kg of iron is needed per ton of Kg of carbon is needed for per ton of iron and that is the most beneficial economical reaction, but how to achieve this is a challenge in the blast furnace. How can you control say that 77 percent should be Fe o and 30 by direct reduction in 30, 23 percent should be by indirectly did reduction, but one can play around with this figure and can certainly achieve a good saving in the coke consumption if you look at now the modern blast furnace between large and large and they are trying to reduce the coke consumption playing with the this sort of figure.

So, as you can see now the coke consumption is about 300 Kg or. So, in the modern blast furnaces and then of course, you have a p c I injection. So, which is if you look at if the lower then probably sometime of this you are directly reduction.

So, in that way probably you are playing between these 2 direct and indirect reduction and trying to optimize, but certainly there is always a room where this can be optimized and carbon consumption can brought it down further to save the coke consumption in the blast furnace.

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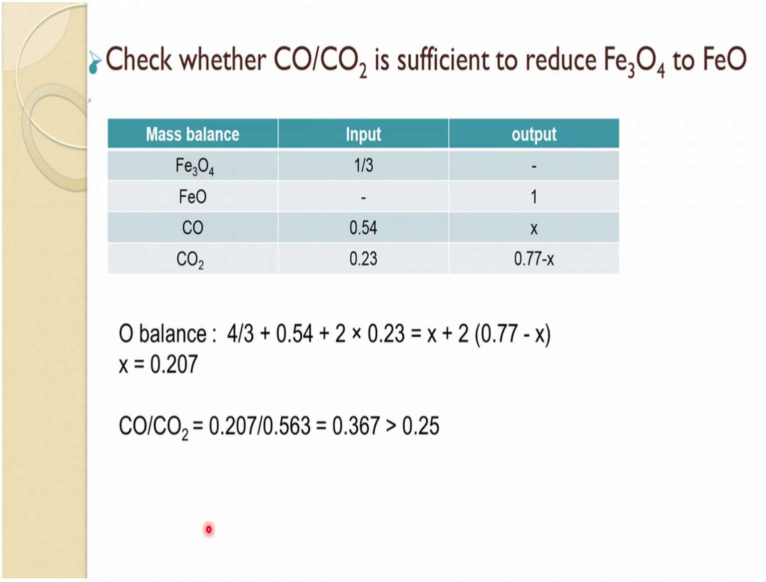

So, now so again checking whether this whatever we have discussed the CO, CO 2 is sufficient to reduce magnetite to Fe O ah, we can do the balance based on what we got it here 0.77 and point 2 3 then should be the c CO 2 this balance can be easily done as we have done before. So, I will not go much into the detail oxygen balance and would be this ok, I think one should be here which is missing. So, that will give you 0.207 um. So, and when we look at the CO, CO 2 ratio is about 0.367 which is greater than what is required. So, that even CO, CO 2 ratio is sufficient to reduce the magnetite in to wustite and certainly then it would be possible even to reduce the hematite into magnetite.

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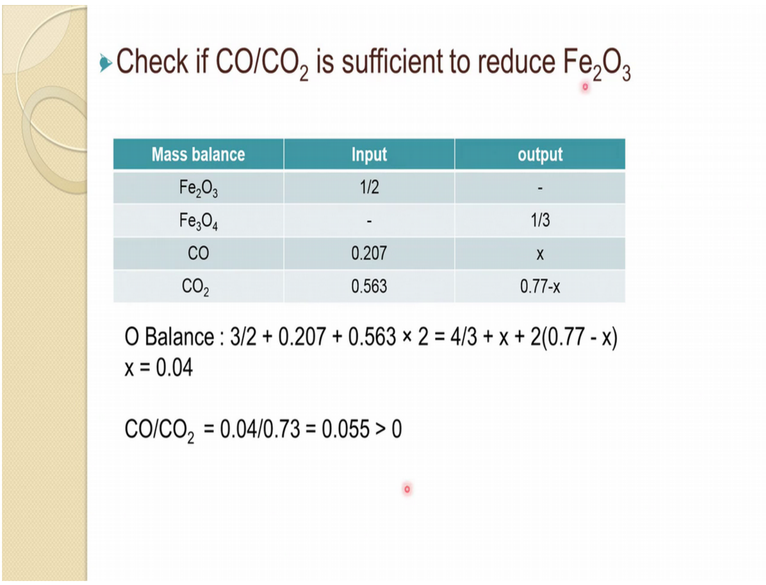

So, this is again checking after this is it sufficient to reduce the hematite into magnetite, again if we do the balancing act we will come to the same thing. So, here 3 by 2 the oxygen which we are getting an output before y 3 and this should be the um. So, x can 0.04, if you do CO, CO 2 ratio then 0.04, 0.73 it come to 0.055 and just really it is a more than negligible what we needed from hematite to magnetite. So, it is quite enough the trace or to reduce the hematite into magnetite. So, with this sort of 77 percent and 23 percent ratio from talk from hematite to iron do have sufficient CO utilization factor or sufficient CO to reduce it from top to bottom and get the iron by consuming only 165 Kg carbon to get per ton of iron.