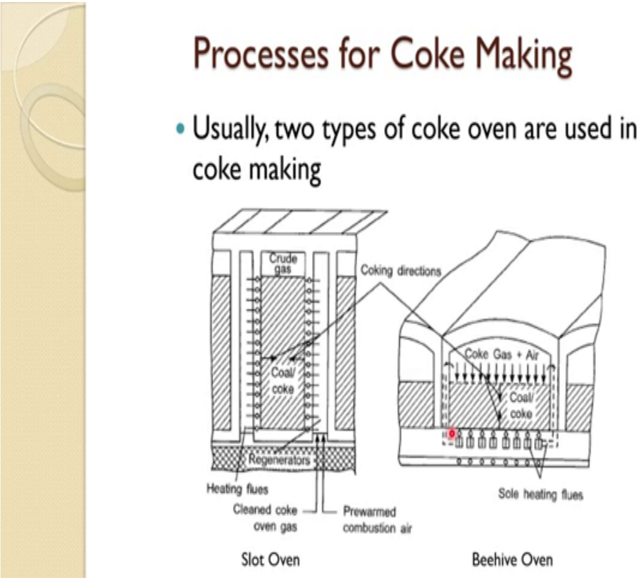
Iron Making
Prof. Govind S Gupta
Department of Materials Engineering
Indian Institute of Science, Bangalore

Lecture - 05
Iron Making Lecture 5

(Refer Slide Time: 00:16)



Processes for Coke Making

- Usually, two types of coke oven are used in coke making

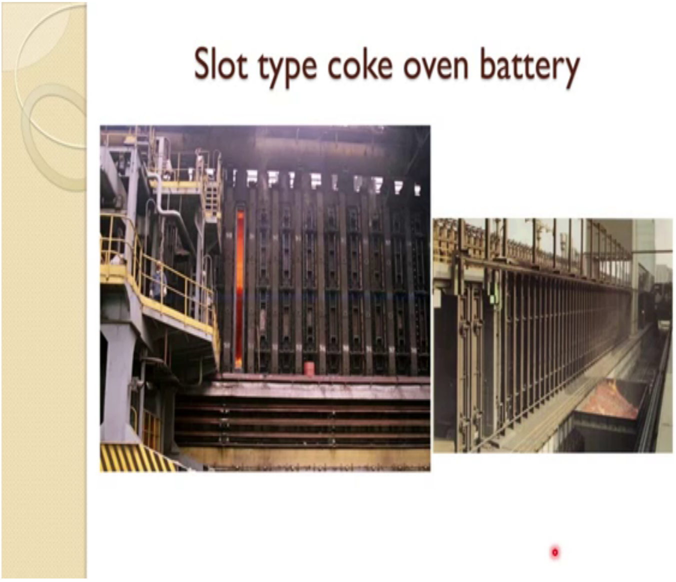
So as we have mentioned that coke is made in the coke ovens. So, usually there are two types of coke ovens used in coke making, one is slot type, and another is beehive type. Slot type coke oven where you put the coal in a chamber, and indirectly because coking has to be done in absence of air. So, indirectly you provide the heat from the side. So, these are the side chamber. So, cleaned coke oven gas or prewarmed combustion air it comes heat it up. So, from the side you are providing the heat to this coal. So, coking occurs from wall to the center in this one.

And once the coking is over this is pushed away, and taking it out. So, you have different type of ovens, you have not different time many ovens like this. So, the whole sort of ovens in a row it known as the coke oven battery so, whatever gases, and other thing which is a wall when during the coke making, these are taking away from the coke in this slot type oven beehive oven these are known as some non recovery oven also. The reason in this one when you say non recovery essentially it is not a very non recovery, but in terms of pollution (Refer Time: 02:12) reduces the pollution. So, what is happening in this you provide the heat from the bottom, and from the top and with less air. So, whatever gases which are tar or aromatic compound which are evolving during the coking process they are want at the top.

And that heat is being use the light to supply to make the coking process. So, in this one it is going out, and then you have to process them here most of them you are warning over there and utilizing heat. So, that is how these are called non recovery coke oven, and then the whatever hot gases are there they are used for electric generation and other thing. So, still you use those gases, and you have to treat them, but essentially you are using quite a lot what is coming out from the coking process in heating up the coal.

So, nowadays (Refer Time: 03:25) modern France are trying to use there non recovery coke oven beehive coke oven.

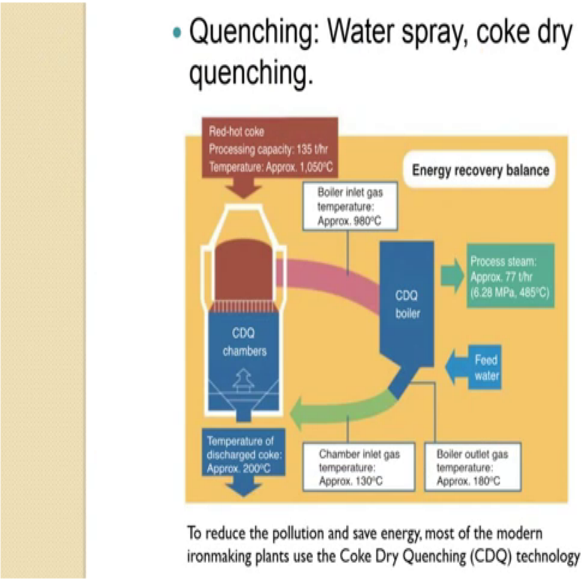
(Refer Slide Time: 03:32)



Slot type coke oven battery

This is a typical figure of one of the coke oven battery, as I said when you put series of this coke oven you usually coal name as a coke oven battery. So, this is one of the oven where coking process is occurring, and coking is almost over. So, from the side these are you supply the heating and once the coking is over. So, from the other side you push the coke the hot one, and collect it and in container. So, that is after the coking process is over you collect it here, and after that you do the quenching because you cannot leave it that it will oxidize it will react with the atmosphere.

(Refer Slide Time: 04:24)



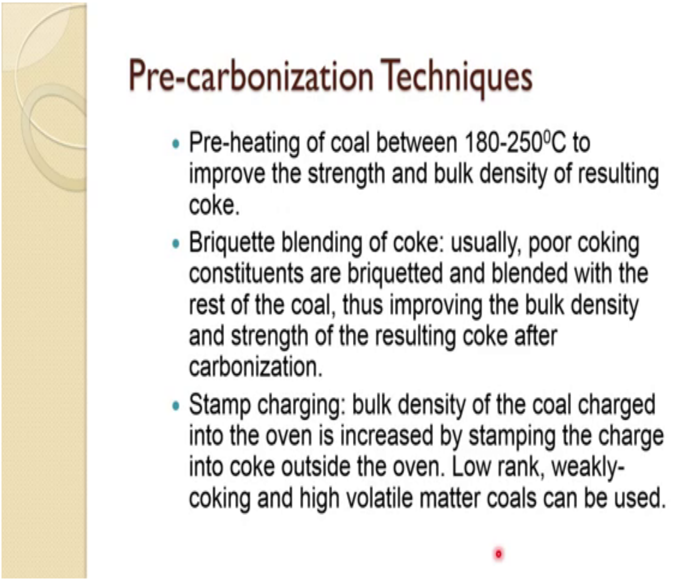
- Quenching: Water spray, coke dry quenching.

To reduce the pollution and save energy, most of the modern ironmaking plants use the Coke Dry Quenching (CDQ) technology

So, then you do the quenching, and quenching it is it the could be wet or dry. So, is the water spray or coke dry quenching water spray again it is not per environmental friendly, if you use to we done like this because it is general lots of dust, and other thing and it quenching technology has come which is called the coke dry quenching CDQ technology. So, in which the hot coke comes and that contain a you blow the inert gas through that, cold one and which cool it down to an acceptable temperature about 200 degree Celsius and that can be send sent to the blast furnace without further of oxidizing in the atmosphere, and that is hot gases are use generate electricity or any other thing steam and thing you can use it.

So, the in this way this does not generate that much dust and pollution, and nowadays people are using mostly this technology coke dry quenching the in the modern still plant, but all plant are still going with that one.

(Refer Slide Time: 05:51)



Pre-carbonization Techniques

- Pre-heating of coal between 180-250^{0}C to improve the strength and bulk density of resulting coke.
- Briquette blending of coke: usually, poor coking constituents are briquetted and blended with the rest of the coal, thus improving the bulk density and strength of the resulting coke after carbonization.
- Stamp charging: bulk density of the coal charged into the oven is increased by stamping the charge into coke outside the oven. Low rank, weakly-coking and high volatile matter coals can be used.

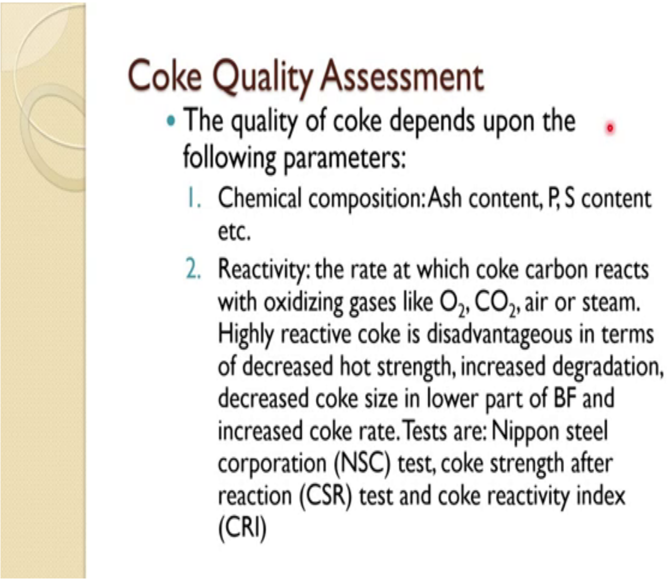
So, pre carbonization technique so, pre heating so now before we do the cooking, they are some other thing which one has to do depending, if you do not have a very good quality coal, or you can increase the efficiency of the coking or make a good quality coal using these technique. So, one is pre heating of coal between at 180 to 250 degree Celsius to improve the strength, and bulk density of the resulting coke.

So, when you do the pre heating moisture and other thing goes away so, in that way the bulk density. So, it becomes more compact when you put it strength increases. So, naturally you get a little higher bulk density of the resulting coke, briquette blending of coke. So, when you do not have a very good quality coal, then you use this briquette blending of the cokes with the poor coking constituent are briquetted, and blended with the rest of the coal. So, improving the bulk density, and strength of the resulting coke after carbonization. So, this again increases the bulk density briquetting is like a making a sort of a cylinder by applying the pressure into that. So, you increase the density of the material.

And that is the one in then you charge it, stamp charging again they bulk again to increase the density of the coke final, you apply this other technique, because they bulk density is also quite important this gives raise strength to the coke. So, stamp charging bulk density of the coal charged into the oven is increased by stamping the charge into the coke outside the oven. So, what you do you take a coal you stamp it and outside the oven actually, and once this is ready then you dump it in the oven. So, this all are done outside the oven.

So, low rank weakly coking and high volatile matter coal can be used to make the coke for that purpose. So, especially when coal is not very suitable, then one of these techniques or some all of them can be used to make them suitable for the blast furnace.

(Refer Slide Time: 08:42)



Coke Quality Assessment

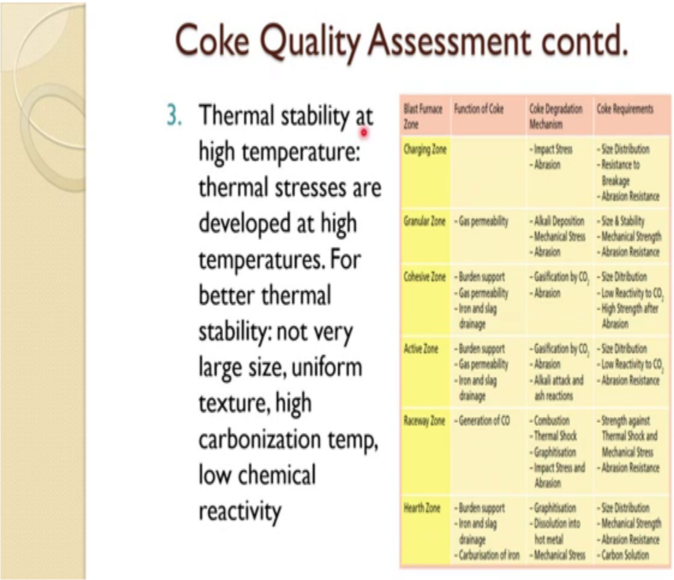
- The quality of coke depends upon the following parameters:
  1. Chemical composition: Ash content, P, S content etc.
  2. Reactivity: the rate at which coke carbon reacts with oxidizing gases like O_2, CO_2, air or steam. Highly reactive coke is disadvantageous in terms of decreased hot strength, increased degradation, decreased coke size in lower part of BF and increased coke rate. Tests are: Nippon steel corporation (NSC) test, coke strength after reaction (CSR) test and coke reactivity index (CRI)

Coke quality assessment so, that depends on many parameter as we discuss many test for the iron, ore, sinter, pellet, similarly for coke some of them are the same which we discussed before, but some of them are different chemical composition. So, as we said these are done with approximate and ultimate analysis, which is important to determine the ash content another elementary content, if you it has a higher sulfur content and like that.

ah One cannot use because that will create the problem later on reactivity of the coke the rate at, which coke carbon reacts with oxidizing gases like oxygen CO 2 air or stream. So, really we do not need a very high reactive coke if highly reactive coke is there, then it has to travel from the top from this top from this third to the tuyere level, and if it is highly reactive why they time it will reach to the tuyere level it may not have sufficient strength, and the permeability or porosity to briston that one and give a proper. So, (Refer Time: 10:11) for the gases to escape.

So, what we needed not a very high reactive coke, because this is in terms of design for hot strength increase degradation, decrease coke size, in the lower part of blast furnace, and that will also increase the coke rate. So, tests are Nippon steel corporation test NSC coke strength, after reaction CSR or coke reactivity index, these are the few important test which are required to see the coke has the desired reactivity.

(Refer Slide Time: 10:52)



Coke Quality Assessment contd.

3. Thermal stability at high temperature: thermal stresses are developed at high temperatures. For better thermal stability: not very large size, uniform texture, high carbonization temp, low chemical reactivity

Blast Furnace Zone	Function of Coke	Coke Degradation Mechanism	Coke Requirements
Charging Zone		- Impact Stress - Abrasion	- Size Distribution - Resistance to Breakage - Abrasion Resistance
Granular Zone	- Gas permeability	- Alkali Deposition - Mechanical Stress - Abrasion	- Size & Stability - Mechanical Strength - Abrasion Resistance
Cohesive Zone	- Burden support - Gas permeability - Iron and slag drainage	- Gasification by CO_2 - Abrasion	- Size Ditribution - Low Reactivity to CO_2 - High Strength after Abrasion
Active Zone	- Burden support - Gas permeability - Iron and slag drainage	- Gasification by CO_2 - Abrasion - Alkali attack and ash reactions	- Size Ditribution - Low Reactivity to CO_2 - Abrasion Resistance
Raceway Zone	- Generation of CO	- Combustion - Thermal Shock - Graphitisation - Impact Stress and Abrasion	- Strength against Thermal Shock and Mechanical Stress - Abrasion Resistance
Hearth Zone	- Burden support - Iron and slag drainage - Carburisation of iron	- Graphitisation - Dissolution into hot metal - Mechanical Stress	- Size Distribution - Mechanical Strength - Abrasion Resistance - Carbon Solution

Thermal stability at high temperature, thermal stresses are developed at high temperature, and that can actually take repetition can happen.

So, for better thermal stability not a very large size uniform, so you do not need a very large size coke uniform texture high carbonization temperature, and low chemical reactivity, these are the important thing for the coke to become a feed material for the blast furnace. So, like in the charging zone coke goes into this impact stress abrasion. So, what you need size distribution resistance to breakage abrasion resistance granular that say stake region, again the gas permeability is very important, reaction pre heating all those things are occurring.

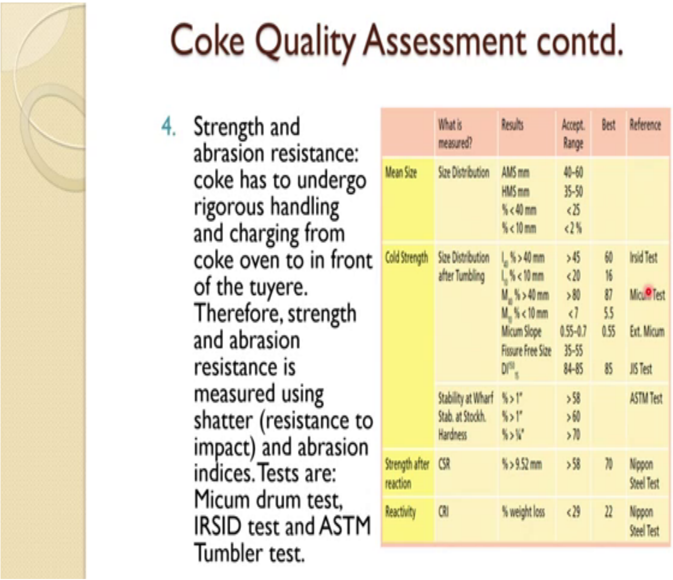
So, alkali deposition mechanical stress abrasion through this it goes through. So, what you need size and stability, it should maintain the size, and stability mechanical strength abrasion resistance.

Cohesive zone very important here is the gas permeability it gives burden support it gives iron, and slag drainage. So, gasification by CO 2 and abrasion this resistant to this it is very important, if it does not have you know what will happen now gas will pass through the furnace, and very high pressure drop it would be and then you have to stop the furnace and some cases. So, proper size distribution low reactivity to carbon dioxide high strength after abrasion active zone, again these are the function of the coke.

So, degradation in this one CO 2 abrasion, alkali attack, and ash reaction. So, size distribution low reactivity abrasion raceway zone, combustion occur here, thermal shock graphitization impact stress and abrasion. So, strength against thermal shock, because thermal shock is due to the thermal stresses is comes, and due to that it may disintegrate you do not want that, when we were looking at the picture of dissected blast furnace, you have seen up to the raise to reason you see quite a big deposit of small particle coke that is mostly why abrasion disintegration that occurs.

So mechanical stress, abrasion resistance. So, these are the requirement of the coke in hearth zone of course, it gives a burden support iron slag drainage carburization of iron, graphitization dissolution into hot metal mechanical stress the requirements, size distribution mechanical strength, abrasion resistance, carbon solution. So, mostly you can see the size distribution, abrasion resistance, mechanical strength low reactivity these are very important.

(Refer Slide Time: 14:27)



Coke Quality Assessment contd.

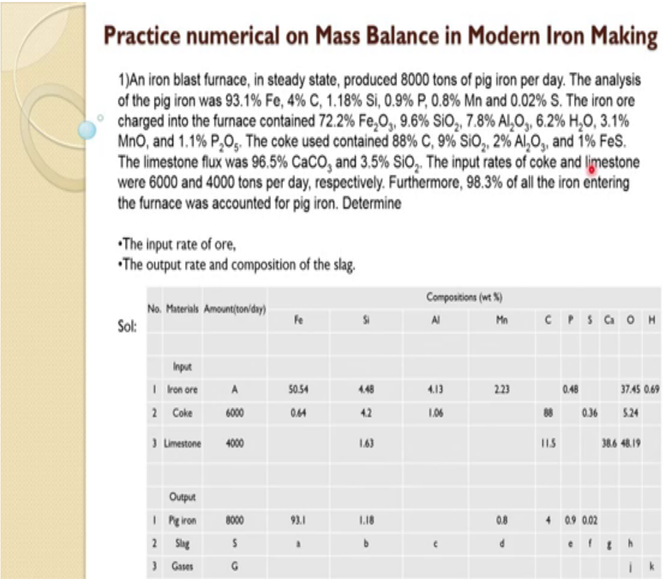
4. Strength and abrasion resistance: coke has to undergo rigorous handling and charging from coke oven to in front of the tuyere. Therefore, strength and abrasion resistance is measured using shatter (resistance to impact) and abrasion indices. Tests are: Micum drum test, IRSID test and ASTM Tumbler test.

	What is measured?	Results	Accept. Range	Best	Reference
Mean Size	Size Distribution	AMS mm	40-60		
		HMS mm	35-50		
		% < 40 mm	< 25		
		% < 10 mm	< 2 %		
Cold Strength	Size Distribution after Tumbling	I_{40} % > 40 mm	> 45	60	Irsid Test
		I_{10} % < 10 mm	< 20	16	
		M_{40} % > 40 mm	> 80	87	Micum Test
		M_{10} % < 10 mm	< 7	5.5	
		Micum Slope	0.55-0.7	0.55	Ext. Micum
		Fissure Free Size	35-55		
		DI^{150}_{15}	84-85	85	JIS Test
	Stability at Wharf	% > 1"	> 58		ASTM Test
	Stab. at Stockh.	% > 1"	> 60		
	Hardness	% > ¼"	> 70		
Strength after reaction	CSR	% > 9.52 mm	> 58	70	Nippon Steel Test
Reactivity	CRI	% weight loss	< 29	22	Nippon Steel Test

For proper blast furnace coke to become a feed material, now strength and abrasion resistance has to undergo a rigorous handling, and charging from the coke oven to in front of the tuyere therefore, strength and abrasion resistance is measured using the shatter index or abrasion indices.

So, this a of course, we have discussed repeat in iron ore sinter pellets here, especially for the coke, the test is Micum drum test IRSID test or ASTM 1 and these are the typical size distribution, you get it accept keep range harmonic mean size arithmetic mean size, and the cold strength these are sort of test you do it, and the best values indicated over here. Similarly stability in the stockyard, and other places strength after the reaction. So, cold strength reactivity this NSC test reactivity NSC test, and the best value of those so these summarizes what the good coke to become a feed material for the blast furnace should have the values. So, this is very important.

(Refer Slide Time: 15:56)



Practice numerical on Mass Balance in Modern Iron Making

1)An iron blast furnace, in steady state, produced 8000 tons of pig iron per day. The analysis of the pig iron was 93.1% Fe, 4% C, 1.18% Si, 0.9% P, 0.8% Mn and 0.02% S. The iron ore charged into the furnace contained 72.2% Fe_2O_3, 9.6% SiO_2, 7.8% Al_2O_3, 6.2% H_2O, 3.1% MnO, and 1.1% P_2O_5. The coke used contained 88% C, 9% SiO_2, 2% Al_2O_3, and 1% FeS. The limestone flux was 96.5% $CaCO_3$ and 3.5% SiO_2. The input rates of coke and limestone were 6000 and 4000 tons per day, respectively. Furthermore, 98.3% of all the iron entering the furnace was accounted for pig iron. Determine

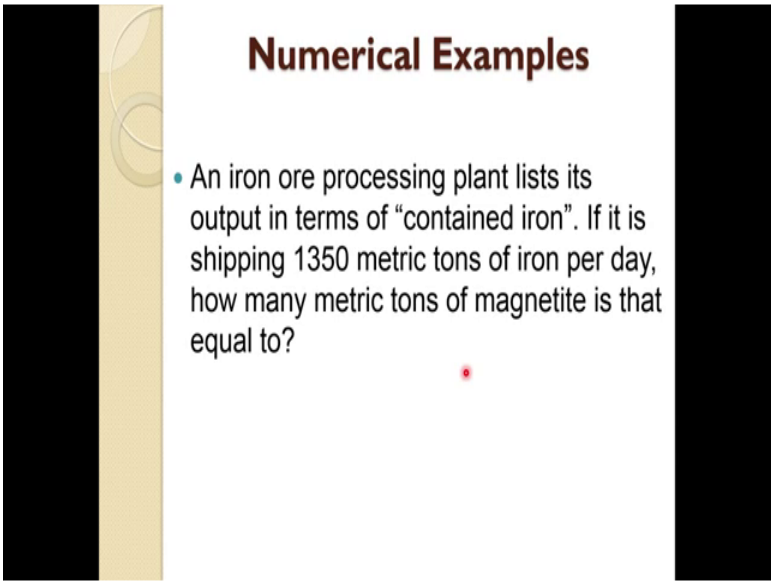
- The input rate of ore,
- The output rate and composition of the slag.

Sol:

No.	Materials	Amount(ton/day)	Compositions (wt %)									
			Fe	Si	Al	Mn	C	P	S	Ca	O	H
	Input											
1	Iron ore	A	50.54	4.48	4.13	2.23		0.48			37.45	0.69
2	Coke	6000	0.64	4.2	1.06		88		0.36		5.24	
3	Limestone	4000		1.63			11.5			38.6	48.19	
	Output											
1	Pig iron	8000	93.1	1.18		0.8	4	0.9	0.02			
2	Slag	S	a	b	c	d		e	f	g	h	
3	Gases	G									j	k

ah Will keep you a 1 practice numerical on mass balance in modern iron blast, the furnace or iron making.

(Refer Slide Time: 16:14)



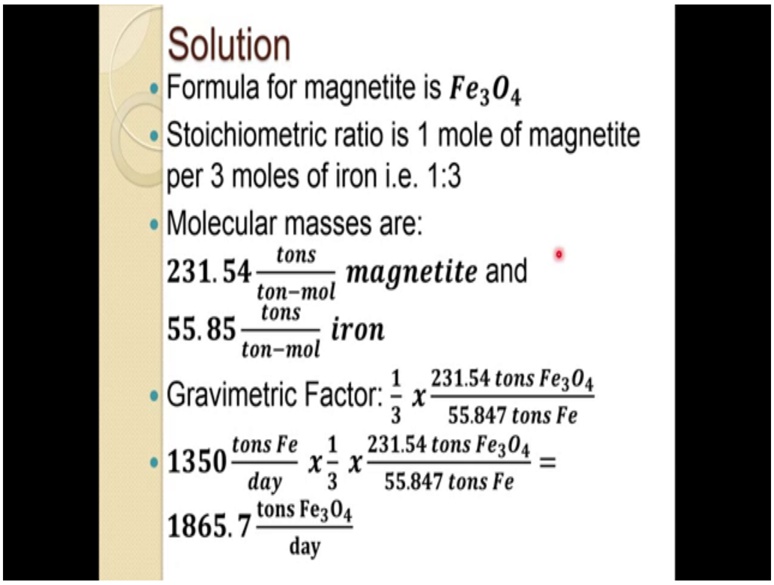
Numerical Examples

- An iron ore processing plant lists its output in terms of “contained iron”. If it is shipping 1350 metric tons of iron per day, how many metric tons of magnetite is that equal to?

We will take now few numerical examples, the first one is an iron ore processing plant related, as you know all theory a usual if they can be put into practice, and that is why these numerical example have been taking from the real practi from the real plants. So, the first one tells about the an iron ore processing plant lists it is output in terms of contained iron.

If it is shipping 1350 metric tons of iron per day, how many metric tons of magnetite is that equal to so, many time this sort of problem comes in the plant that they toke in some other unit, and which probably you do not know in a proper way. So, how do you convert in terms of the right unit. So, 1350 metric tons of iron in terms of magnetite.

(Refer Slide Time: 17:31)



Solution

- Formula for magnetite is Fe_3O_4
- Stoichiometric ratio is 1 mole of magnetite per 3 moles of iron i.e. 1:3
- Molecular masses are:

$231.54\frac{tons}{ton-mol}$ $magnetite$ and

$55.85\frac{tons}{ton-mol}$ $iron$

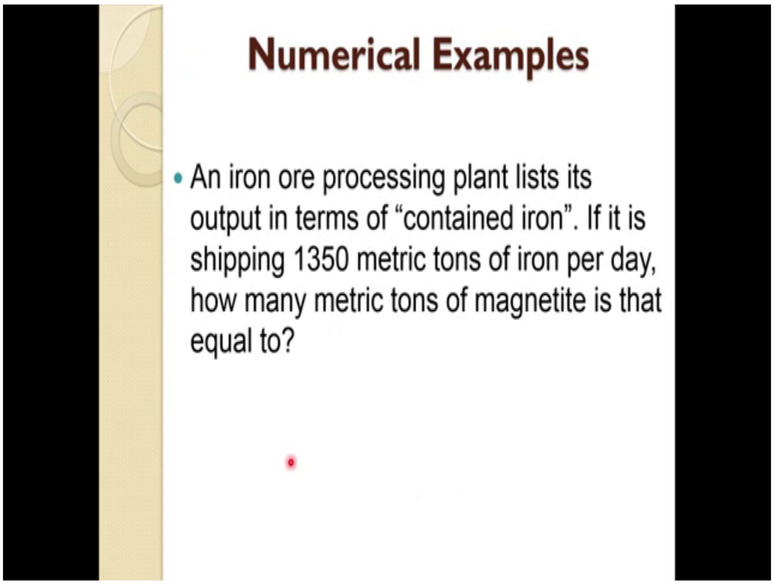
- Gravimetric Factor: $\frac{1}{3}\ x\ \frac{231.54\ tons\ Fe_3O_4}{55.847\ tons\ Fe}$
- $1350\frac{tons\ Fe}{day}\ x\ \frac{1}{3}\ x\ \frac{231.54\ tons\ Fe_3O_4}{55.847\ tons\ Fe} =$

$1865.7\frac{tons\ Fe_3O_4}{day}$

So, what essentially you do you know the formula of the magnetite considering this Fe 3 O 4 as a pure compound.

So, stoichiometric ratio as you can see 1 mole of magnetite is having a 3 mole of iron. So, molecular masses of this 1 would be for magnetite it would be 231.54 tons per ton mole, you can put it like kg per kilomole gram per gram mole, these are the normal unit which you put the molecular masses, and for iron it is 55.85, tons per ton of mole . So, gravimetric factor what it gives because we have a 3 moles of iron. So, molecular weight of or molecular mass of the magnetite divided by molecular mass of iron by one-third.

(Refer Slide Time: 18:49)



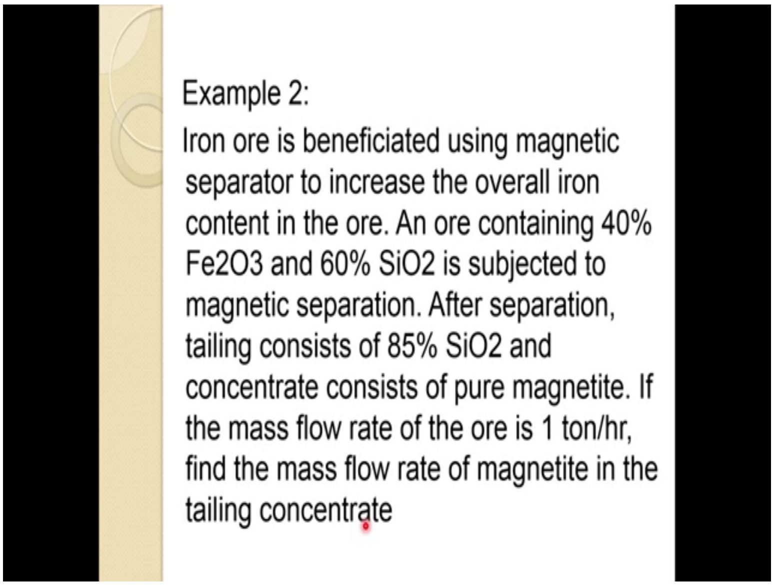
Numerical Examples

- An iron ore processing plant lists its output in terms of "contained iron". If it is shipping 1350 metric tons of iron per day, how many metric tons of magnetite is that equal to?

So, we have 13 in the example 1350 metric ton of iron per day. So, 1350 metric tons iron per day, and you multiply with this gravimetric factors. So, essentially what you will get 1867.7 tons magnetite of per day.

So, the question is how many metric tons of magnetite is that equal to so, that will give you the how many tons of magnetite per day which is shipping, state a one very simple example, but very useful in the industry and converting into the proper unit. So, one can understand.

(Refer Slide Time: 19:45)



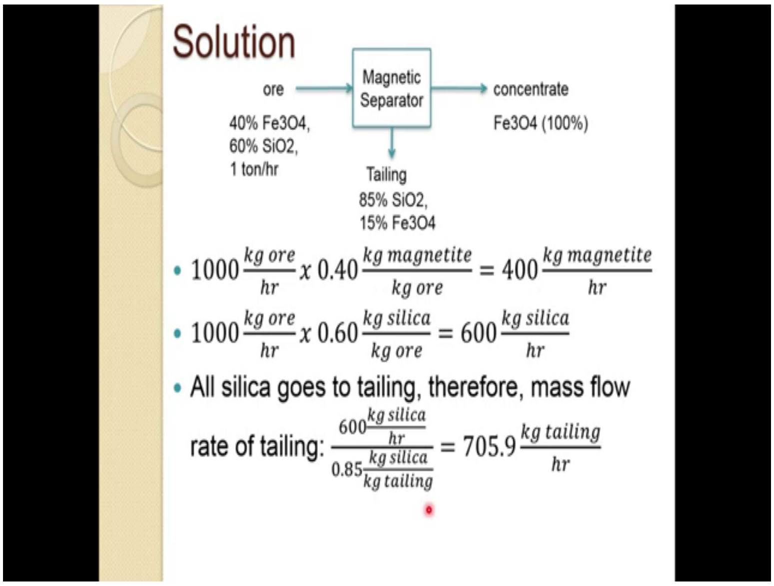
Example 2:

Iron ore is beneficiated using magnetic separator to increase the overall iron content in the ore. An ore containing 40% Fe_2O_3 and 60% SiO_2 is subjected to magnetic separation. After separation, tailing consists of 85% SiO_2 and concentrate consists of pure magnetite. If the mass flow rate of the ore is 1 ton/hr, find the mass flow rate of magnetite in the tailing concentrate

Is another example which is more related to beneficiation, and this is iron ore is beneficiated using magnetic separator to increase the overall iron content in the ore, we have already discussed about magnetic separated during beneficiation when ore lean, and we want to increase the concentration of the iron content in the ore.

So, usually we take various type of beneficiation processes. So, one is magnetic separator. So, this is related to that the problem. So, an ore containing 40 percent hematite, and 60 percent silica is subjected to magnetic separation, because already the so already you will see the percentage of hematite is quite low. So, we have to increase that. So, after separation tailing consists of 85 percent silica, and concentrate consists of pure magnetite, if the mass flow rate of the ore is 1 ton per hour, find the mass flow rate of magnetite in the tailing. I am sorry (Refer Time: 21:19) this is a magnetite.

(Refer Slide Time: 21:23)



Solution

ore → Magnetic Separator → concentrate

40% Fe_3O_4,
60% SiO_2,
1 ton/hr

Fe_3O_4 (100%)

Tailing
85% SiO_2,
15% Fe_3O_4

- $1000\frac{kg\ ore}{hr}x\ 0.40\frac{kg\ magnetite}{kg\ ore} = 400\frac{kg\ magnetite}{hr}$
- $1000\frac{kg\ ore}{hr}x\ 0.60\frac{kg\ silica}{kg\ ore} = 600\frac{kg\ silica}{hr}$
- All silica goes to tailing, therefore, mass flow

rate of tailing: $\frac{600\frac{kg\ silica}{hr}}{0.85\frac{kg\ silica}{kg\ tailing}} = 705.9\frac{kg\ tailing}{hr}$

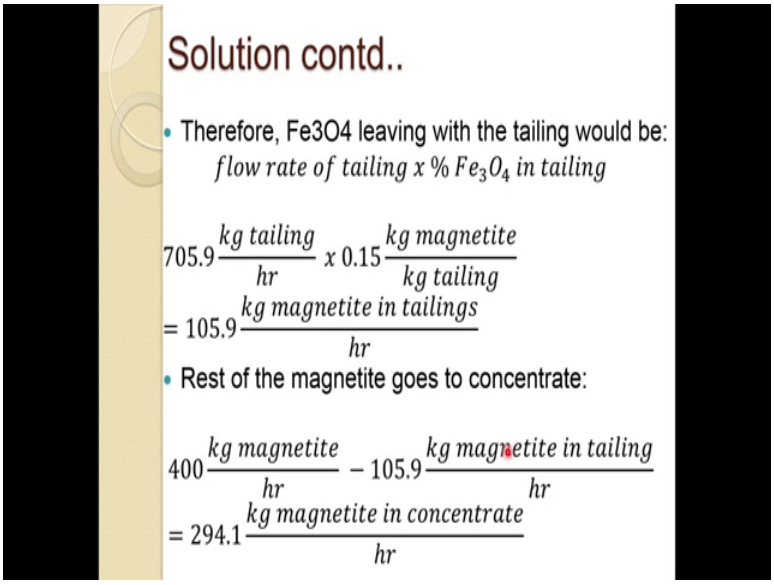
So, we have this magnetic separator. So, 40 percent magnetite 60 percent silica that is input. So, always when you do any sort of a material. So, mass balance or heat balance it is it is good to have a sort of a box, and indicate, what is in and what is out, that gives a very good idea what is going on in into the reactant what is coming out. So, you can do a proper either materials balance or heat balance.

So, in this case 46 percent this is going in, at per ton in 1 ton per hour, and the concentrate which is coming out is magnetite which is 100 percent, as it is given in the problem and tailing is having 85 percent SiO 2, and 15 percent magnetite. So, now because we have a 1 ton per hour which is 100 kg per hour and 40 percent magnet magnetite. So, we can now how much magnetite per hour. So, point 4 and 0 kg magnetite per kg ore 4. So, that is going to give you about 400 kg magnetite per hour, which is going through the magnetic separator.

Similarly, we can get the silica iron terms of kg per hour so, 1000 kg ore per hour with 0.6 or 60 percent so 0.6 kg silica per kg ore that is going to give you 600 kg silica per hour. So, this is sort of a mass flow rate of both the species. So, all silica it is given it is goes to the tailing, because the concentrate is a pure 1. So, which means the all silica is going to the tailing and which forming the 85 percent of it. So, rate of tailing so, 600 kg silica per hour we have already find it out. So, 85 percent actually it is going an in the tailing, a tailing is containing 85 percent.

So, which means the flow rate of this tailing would be 7; so, you divide this 600 kg silica per hour, with 85 percent silica, because this constitute 85 percent of the tailing will give you the tailing flow rate, and once you know the tailing flow rate.

(Refer Slide Time: 24:18)



Solution contd..

- Therefore, Fe3O4 leaving with the tailing would be:

  $flow\ rate\ of\ tailing\ x\ \%\ Fe_3O_4\ in\ tailing$

$$705.9\frac{kg\ tailing}{hr}\ x\ 0.15\frac{kg\ magnetite}{kg\ tailing}$$

$$= 105.9\frac{kg\ magnetite\ in\ tailings}{hr}$$

- Rest of the magnetite goes to concentrate:

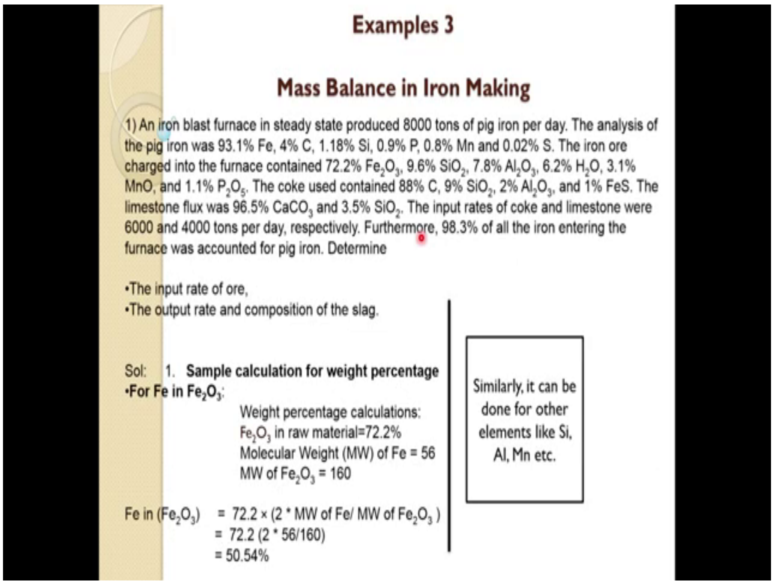
$$400\frac{kg\ magnetite}{hr} - 105.9\frac{kg\ magnetite\ in\ tailing}{hr}$$

$$= 294.1\frac{kg\ magnetite\ in\ concentrate}{hr}$$

Then you can calculate the magnetite which is leaving with the tailing. So, this is the flow rate of the tailing 705.9 kg tailing per hour, and you multiply with the 15 percent remaining magnetite which is with the tailing 0.15 will give you the magnetite which is going into the tailing per hour.

So, 105.9 kg magnetite in tailings per hour it would be going. So, rest of the magnetite naturally it is going as a concentrate. So, concentrate would be having than 400 kg minus 1 105.9. So, about 294.1 kg magnetite, and concentrate per hour. So, that is a very simple mass balance by which you can calculate how much magnetite is going to the concentrate, and how much it is going into the tailing and you can easily calculate that 1. So, these are few simple example I gave, now another example which is coming in more realistic example.

(Refer Slide Time: 25:37)



Examples 3

Mass Balance in Iron Making

1) An iron blast furnace in steady state produced 8000 tons of pig iron per day. The analysis of the pig iron was 93.1% Fe, 4% C, 1.18% Si, 0.9% P, 0.8% Mn and 0.02% S. The iron ore charged into the furnace contained 72.2% Fe_2O_3, 9.6% SiO_2, 7.8% Al_2O_3, 6.2% H_2O, 3.1% MnO, and 1.1% P_2O_5. The coke used contained 88% C, 9% SiO_2, 2% Al_2O_3, and 1% FeS. The limestone flux was 96.5% $CaCO_3$ and 3.5% SiO_2. The input rates of coke and limestone were 6000 and 4000 tons per day, respectively. Furthermore, 98.3% of all the iron entering the furnace was accounted for pig iron. Determine

- The input rate of ore,
- The output rate and composition of the slag.

Sol: 1. **Sample calculation for weight percentage**

- **For Fe in Fe_2O_3:**

Weight percentage calculations:
Fe_2O_3 in raw material=72.2%
Molecular Weight (MW) of Fe = 56
MW of Fe_2O_3 = 160

$$\text{Fe in } (Fe_2O_3) = 72.2 \times (2 * \text{MW of Fe} / \text{MW of } Fe_2O_3) = 72.2\,(2 * 56/160) = 50.54\%$$

Similarly, it can be done for other elements like Si, Al, Mn etc.

Which related to iron making blast furnace which we have talk till now, and the question is in this one, and iron blast furnace in steady state produce 8000 ton of pig iron per day.

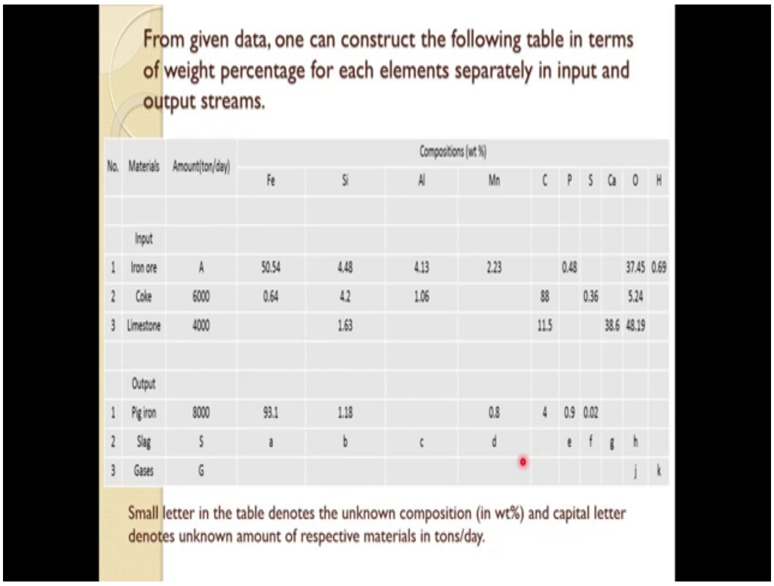
The analysis of the pig iron was 93.1 percent iron, 4 percent carbon, 1.18 percent silicon, 0.9 percent phosphorous, 0.8 percent manganese, and 0.02 percent silica or sulfur. So, iron ore charged into the furnace contained 72.2 percent hematite, 9.6 percent silica, 7.8 percent Al 2 O 3, 6.2 percent water 3.1 percent manganese oxide, and 1.1 percent phosphorous pentoxide.

So, the coke used contained 88 percent carbon, 9 percent silica, 2 percent alumina, and 1 percent iron sulphide, we also put the flux. So, the limestone flux having composition 96.5 percent calcium carbonate, and 3.5 percent silica, the input rate of coke, and limestone was 6000 and 500 tons or 4000 tons per day respectively, and furthermore 98.3 percent of all the iron entering the furnace was accounted for pig iron.

So, the you have to find out the input rate of iron ore, and output rate and composition of the slag. So, in this one again you can make a box diagram of materials balance where, you can show input and output, but it would be good you work out this thing in the form of table and use some excel sheet or something, and that will facilitate the calculation. The way probably which we can do it every represent all these value in terms of weight percentage of all the element for example, hematite. In this one we can represent iron in terms of weight percentage. So, iron in Fe 2 O 3. So, it is 72.2 percent Fe 2 O 3 there in raw material, and we know the molecular weight of iron is about 56, and molecular weight of hematite is 1.60 that we are considering as pure.

So, iron in hematite or Fe 2 O 3 would be 72.2 into 2, because there two moles of iron this of course, we did in the previous example also we showed this one. So, 2 into molecular weight of iron divided by the molecular weight of hematite 160. So, that gives you the iron in hematite 50.54 weight percentage. So, similarly you can do the calculation for other elements silica alumina hydrogen phosphorous manganese calcium sulfurs. So, whatever other element which are present in this example, one can make similar calculation for weight percentage.

(Refer Slide Time: 29:48)



From given data, one can construct the following table in terms of weight percentage for each elements separately in input and output streams.

No.	Materials	Amount(ton/day)	Compositions (wt %)									
			Fe	Si	Al	Mn	C	P	S	Ca	O	H
	Input											
1	Iron ore	A	50.54	4.48	4.13	2.23		0.48			37.45	0.69
2	Coke	6000	0.64	4.2	1.06		88		0.36		5.24	
3	Limestone	4000		1.63			11.5			38.6	48.19	
	Output											
1	Pig iron	8000	93.1	1.18		0.8	4	0.9	0.02			
2	Slag	S	a	b	c	d		e	f	g	h	
3	Gases	G									j	k

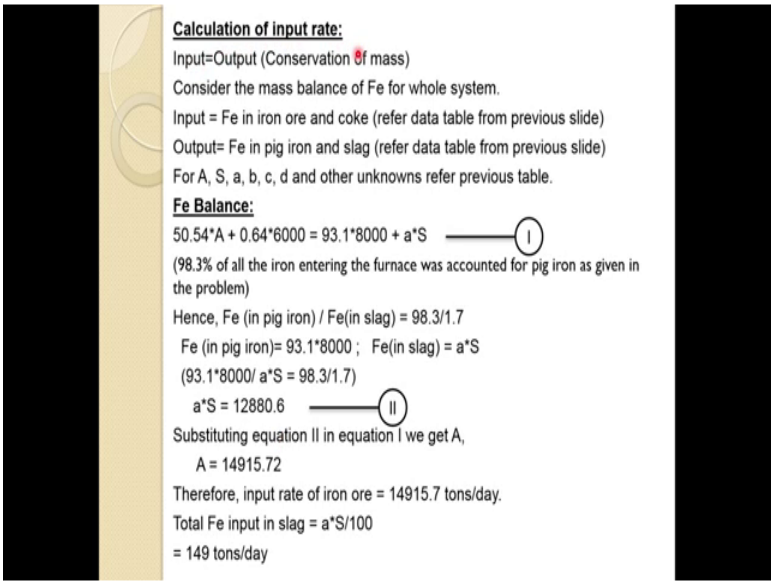
Small letter in the table denotes the unknown composition (in wt%) and capital letter denotes unknown amount of respective materials in tons/day.

And which can be put in tabulated form like this. So, the data from this data construct the following table in terms of weight percentage. So, here you put the material input. So, input is going iron ore coke limestone, and output is pig irons slag, and gases. So, amount ton per day which we are putting we do not know iron ore that we have to find it out, that is given in the question, but coke rate is a given 6000 tons per day limestone, 4000 pig iron production 8000 ton per day slag ewe do not know, and gas also we do not know, but that is anyway not required is not the question, but we need about the slag output we have to know amount, and then if you write it in terms of weight percentage as we have shown in the previous slide, these element you can put it.

So, in iron ore you have iron, silica, alumina, manganese, phosphorous, oxygen, and hydrogen, but like in coke you or in the coke you are having some sulfur. So, a sulfur is also coming and limestone you have calcium is also coming over here. Similarly pig iron composition is giving you have iron, silica, manganese, carbon, phosphorous, and sulfur, slag we do not know the composition of any of these elements so, we have to find out. So, a small letter in the table denotes the unknown composition in weight percent, and capital letter denotes unknown amount of respective materials in tons per day.

So, once we construct this table in terms of weight percentage, I think is easy to do the mass balance now. So, what is let us say for iron. So, mass balance for iron would be irons coming. So, input is from iron ore, the iron is coming. So, this into this from coke iron is coming. So, this into this and this from nowhere as the iron is coming, but iron is going out in terms of pig iron. So, this into this so, this should be equal to this into this plus this into this, also iron we are getting not in slag.

(Refer Slide Time: 32:46)



Calculation of input rate:

Input=Output (Conservation of mass)

Consider the mass balance of Fe for whole system.

Input = Fe in iron ore and coke (refer data table from previous slide)

Output= Fe in pig iron and slag (refer data table from previous slide)

For A, S, a, b, c, d and other unknowns refer previous table.

Fe Balance:

$50.54*A + 0.64*6000 = 93.1*8000 + a*S \quad \text{———} (\text{I})$

(98.3% of all the iron entering the furnace was accounted for pig iron as given in the problem)

Hence, Fe (in pig iron) / Fe(in slag) = 98.3/1.7

Fe (in pig iron)= 93.1*8000 ; Fe(in slag) = a*S

(93.1*8000/ a*S = 98.3/1.7)

$a*S = 12880.6 \quad \text{———} (\text{II})$

Substituting equation II in equation I we get A,

A = 14915.72

Therefore, input rate of iron ore = 14915.7 tons/day.

Total Fe input in slag = a*S/100

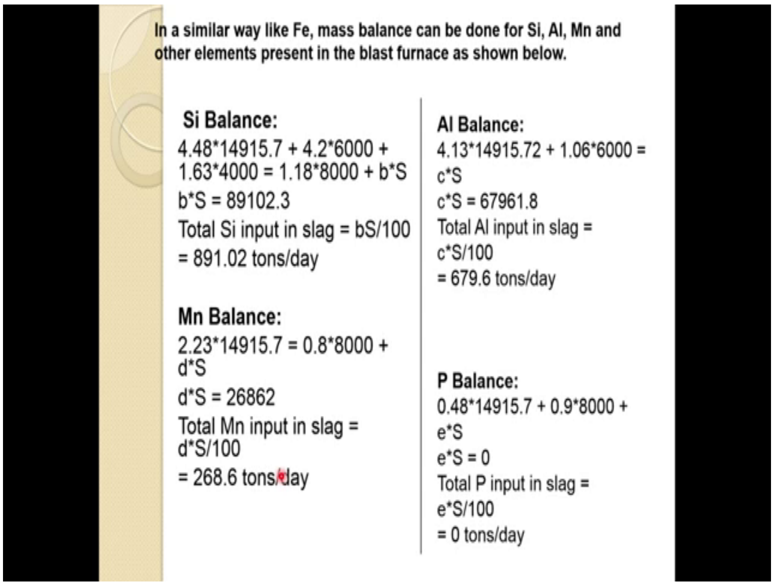
= 149 tons/day

So, that is a calculation so, input equal to output conservation of mass. So, material balance which we do it. So, consider the mass balance for iron. So, iron in iron ore and coke similarly output iron in pig iron and slag.

So, showing you in the previous table. So, this would be the balance for the iron now, 98.3 percent of all the iron entering this furnace was accounted for pig iron as given in the problem. So, this is already given to us. So, hence iron in pig iron divide by iron in slag should be in this ratio. So, remining 1.7 percent goes into the slag, where 98.3 going into that. So, this gives you when you do the calculation the iron in slag is and by solving these 2 equations, you can get the amount of iron ore input.

So, you get the input rate of iron ore in that way 14915.7 tons per day, once we know that then we can calculate the iron in the slag, finding that suppose you get it 149 tons per day.

(Refer Slide Time: 34:29)



In a similar way like Fe, mass balance can be done for Si, Al, Mn and other elements present in the blast furnace as shown below.

Si Balance:

4.48*14915.7 + 4.2*6000 + 1.63*4000 = 1.18*8000 + b*S

b*S = 89102.3

Total Si input in slag = bS/100 = 891.02 tons/day

Mn Balance:

2.23*14915.7 = 0.8*8000 + d*S

d*S = 26862

Total Mn input in slag = d*S/100 = 268.6 tons/day

Al Balance:

4.13*14915.72 + 1.06*6000 = c*S

c*S = 67961.8

Total Al input in slag = c*S/100 = 679.6 tons/day

P Balance:

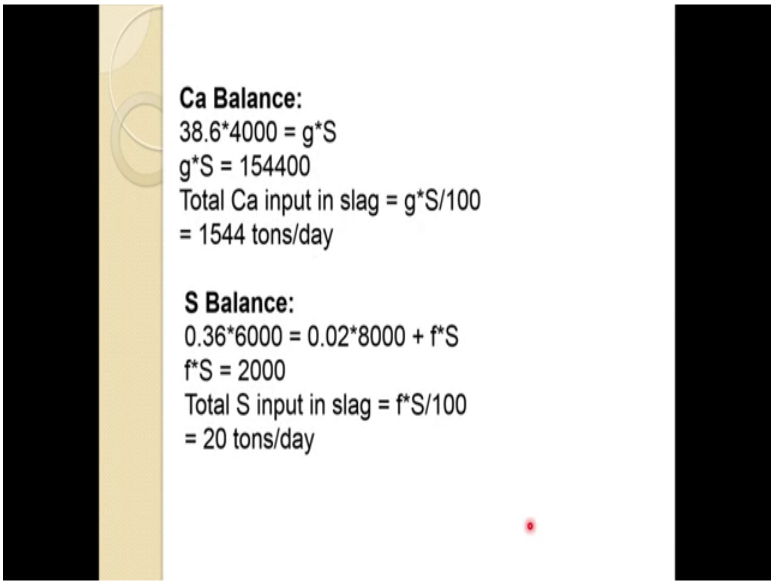
0.48*14915.7 + 0.9*8000 + e*S

e*S = 0

Total P input in slag = e*S/100 = 0 tons/day

Similarly you can calculate other elements, present in the blast furnace for silicon you can do the mass balance, and then silicon input in the slag manganese input in the slag aluminum phosphorous, and phosphorous all the phosphorous, goes as we will see in this one, all the phosphorous is going to the pig iron. So, really you do not get phosphorous in slag.

(Refer Slide Time: 35:10)



Ca Balance:

38.6*4000 = g*S

g*S = 154400

Total Ca input in slag = g*S/100

= 1544 tons/day

S Balance:

0.36*6000 = 0.02*8000 + f*S

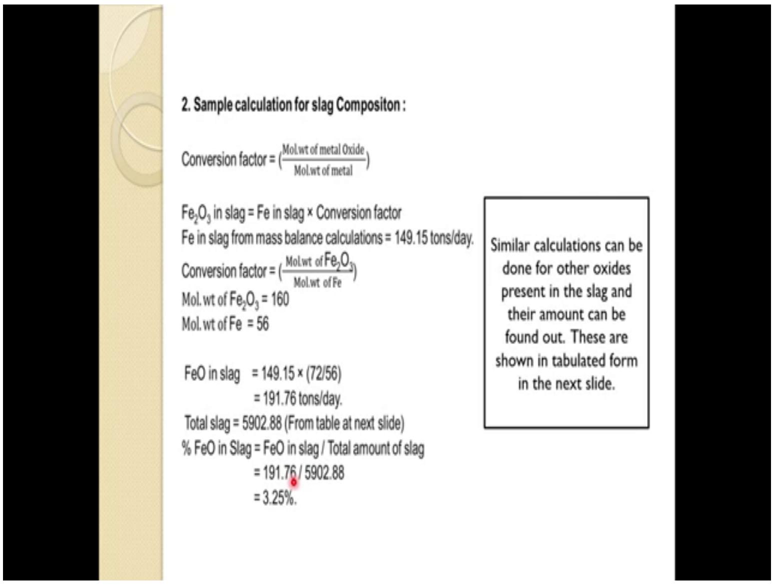
f*S = 2000

Total S input in slag = f*S/100

= 20 tons/day

Calcium as you can get that, and sulfur also you can get in a similar way.

(Refer Slide Time: 35:22)



2. Sample calculation for slag Compositon :

Conversion factor = $\left(\frac{\text{Mol.wt of metal Oxide}}{\text{Mol.wt of metal}}\right)$

Fe_2O_3 in slag = Fe in slag × Conversion factor

Fe in slag from mass balance calculations = 149.15 tons/day.

Conversion factor = $\left(\frac{\text{Mol.wt of } Fe_2O_3}{\text{Mol.wt of Fe}}\right)$

Mol. wt of Fe_2O_3 = 160

Mol. wt of Fe = 56

FeO in slag = 149.15 × (72/56)

= 191.76 tons/day.

Total slag = 5902.88 (From table at next slide)

% FeO in Slag = FeO in slag / Total amount of slag

= 191.76 / 5902.88

= 3.25%.

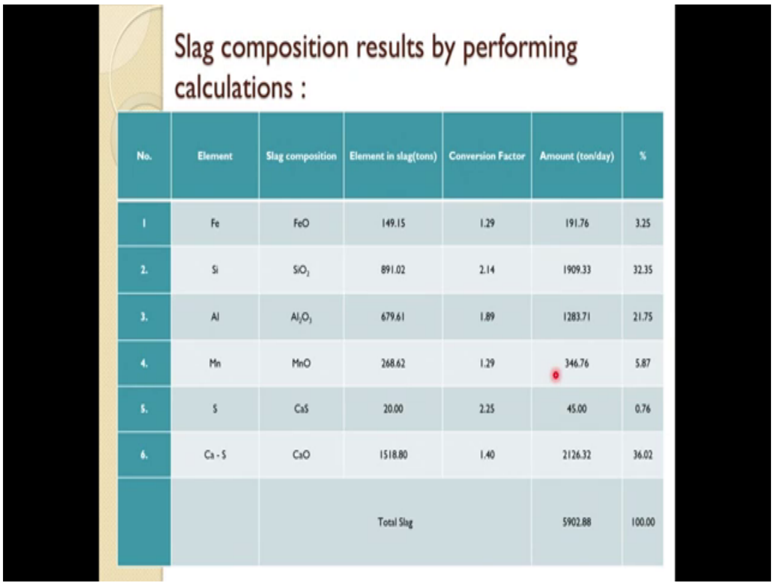
Similar calculations can be done for other oxides present in the slag and their amount can be found out. These are shown in tabulated form in the next slide.

So, so once you get the this you can calculate even the percentage form. So, now in terms of composition, what we need we need a sort of a conversion factor. So, molecular weight of metal oxide and molecular weight of the metal so, in terms of hematite in slag. So, iron in slag to conversion factor. So, iron in slag from mass balance, we know 149.15 tons per day.

So, conversion factor because this is coming from Fe 2 O 3. So, 160 divided by 56 is go it is going to give you so, no actually though this is this one, but actually iron in the slag in the form of FeO. So, you have to consider about the FeO. So, molecular weight of metal oxide FeO it is 72 divided by molecular weight of metal 56 multiplied with this iron in slag. So, it is going to give you FeO in slag 191.76 tons per day. So, total slag that when you convert a in terms of percentage the this thing you will find from the table in the next slide is about this amount.

So, when we know the total slag we can convert the percentage. So, FeO in slag is this and total amount of slag is this that is going to give you 3.25 percent FeO in the slag, similar calculation we can do for SiO 2 for CaO.

(Refer Slide Time: 37:36)



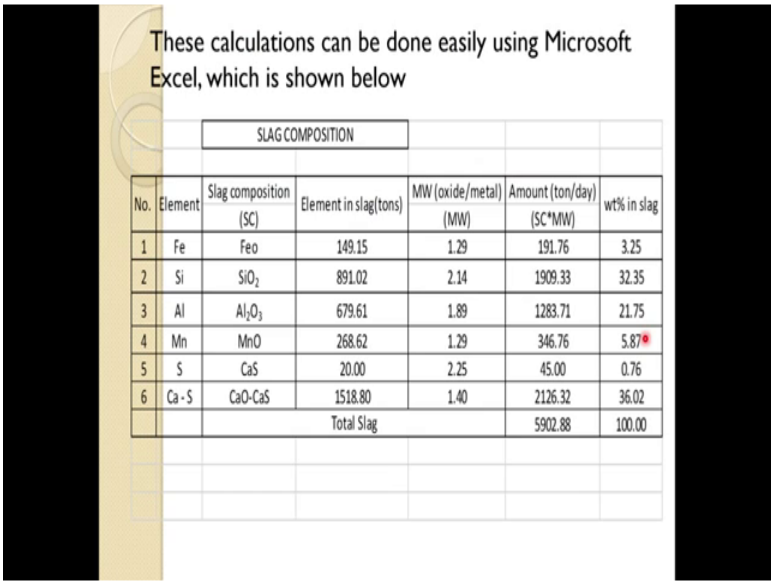
Slag composition results by performing calculations :

No.	Element	Slag composition	Element in slag(tons)	Conversion Factor	Amount (ton/day)	%
1	Fe	FeO	149.15	1.29	191.76	3.25
2.	Si	SiO_2	891.02	2.14	1909.33	32.35
3.	Al	Al_2O_3	679.61	1.89	1283.71	21.75
4.	Mn	MnO	268.62	1.29	346.76	5.87
5.	S	CaS	20.00	2.25	45.00	0.76
6.	Ca - S	CaO	1518.80	1.40	2126.32	36.02
			Total Slag		5902.88	100.00

And other oxide which are present in the slag so, mostly FeO so, we go 3.25 percent, then you have SiO 2 you have Al 2 O 3 manganese oxide, calcium sulfide, and calcium oxide these are the slag which are present in the slag. So, in a similar way we do the calculation for these other oxide you can the calculate the percentage of these oxide into the slag.

So, as we said once we no tons per day. So, we can calculate tons per day for all of these oxide, and we can add them up. So, we can get the total slag. So, total slag actually is made of these, and that is how then this divided by this we get the percentage this divided by total amount of slag you get this percentage. So, like this you can get a percentage for each of the oxide which comes around 100 percent. So, you can see there silica and the lime, is the major silica lime and alumina is the major constituent of the slag in this example, and this actually can be done more easily, if you use the microsoft excel program.

(Refer Slide Time: 39:02)



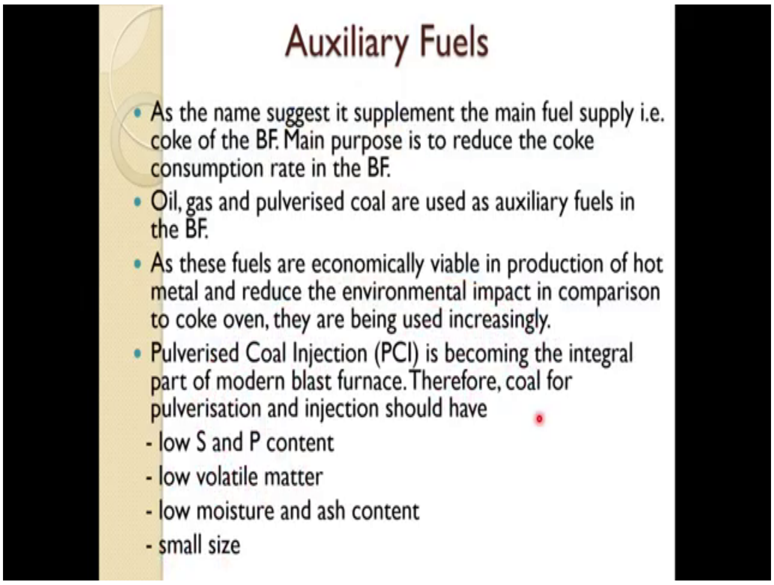
These calculations can be done easily using Microsoft Excel, which is shown below

SLAG COMPOSITION

No.	Element	Slag composition (SC)	Element in slag(tons)	MW (oxide/metal) (MW)	Amount (ton/day) (SC*MW)	wt% in slag
1	Fe	Feo	149.15	1.29	191.76	3.25
2	Si	SiO_2	891.02	2.14	1909.33	32.35
3	Al	Al_2O_3	679.61	1.89	1283.71	21.75
4	Mn	MnO	268.62	1.29	346.76	5.87
5	S	CaS	20.00	2.25	45.00	0.76
6	Ca - S	CaO-CaS	1518.80	1.40	2126.32	36.02
		Total Slag			5902.88	100.00

So, an excel sheet you can easily do this thing you put the values, and conversion factor another thing, and you put the formulas and you can immediately get the results of that. So, put be good for complex problem like this, one should use the Microsoft excel program, and that would be much easier to solve the problem after putting the things, and even the composition changes you can see the effect of various element, also if you change it what would be the composition of the slag and like that.

(Refer Slide Time: 39:52)



Auxiliary Fuels

- As the name suggest it supplement the main fuel supply i.e. coke of the BF. Main purpose is to reduce the coke consumption rate in the BF.
- Oil, gas and pulverised coal are used as auxiliary fuels in the BF.
- As these fuels are economically viable in production of hot metal and reduce the environmental impact in comparison to coke oven, they are being used increasingly.
- Pulverised Coal Injection (PCI) is becoming the integral part of modern blast furnace. Therefore, coal for pulverisation and injection should have
  - low S and P content
  - low volatile matter
  - low moisture and ash content
  - small size

So, now we will come to the next topic, which is about the auxiliary fuel, and as you know the we talked about coke, as a this x as a fuel, but as we mentioned coke is very expensive, and environmentally not friendly to make the coke, that is that is why there are worldwide effort to substitute coke with other fuels, and that is why this topic is auxiliary fuel. So, they are many attempts going onward by to substitute coke, we other fuel like oil, coal, plastic, biomass, natural gases.

So, we would be talking some of this thing over an under this topic, because the coke making is a very nastive process, and environmentally star again it, and it not only that we know it is a quite a pollutant, and we have to find out some sort of alternative to the coke. And one of this to use the auxiliary fuels true the tuyere, because coke cannot be currently replace 100 percent because it provide the mechanical support to the burden, whenever blast furnace is so, high, there is no other material which can give that sort of support, and which can withstand also that high temperature. But certainly we can reduce the amount of coke, and that is the effort which is being made, and we will be discussing in this.

So, auxiliary fuel when we say the name suggest, it supplement the main fuel supply that is coke of the fuel coke of the blast furnace. So, main purpose is to reduce the coke consumption rate in the blast furnace, and you can reduce only up to a some extent. So, that is the effort that how much we can reduce, we will actually do some more calculation on that that how much coke really, we can substitute by others supplement fuel, because not 100 percent coke can be substituted by this, oil gas and pulverized coal are used as auxiliary fuel in the blast furnace.

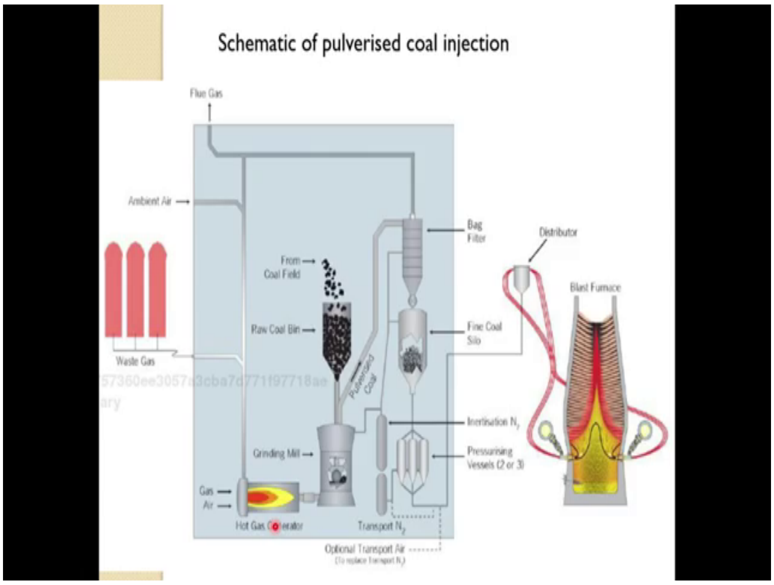
ah Nowadays even this natural gas or biomass municipality based treating them and using it as is going on at few places. So, as these fuels are economically viable in production of hot metals, and reduce the environmental impact in comparison to coke oven, they are being used increasingly. So, pulverised coal injection is becoming the integral part of the modern blast furnace therefore, coal for pulverisation and injection should have the following properties.

So, PCI injection in fact most of the modern blast furnace it is the integral part now, unlike a coke oven or cleaning of the gas and like this. Similarly this is also now becoming a part of the blast furnace, but to inject the pulverised coal is should also have some qualities, first one is the low sulfur and phosphorous content that is very important, to control the chemistry of the slag, and chemistry of the iron, pig iron, and subsequent operation of steel making under, we have discussed before during the iron ore and coke preparation. Low volatile matter it should have then it should also have the low moisture, and ash content and it should have small a smaller size.

So, ash content certainly is a always a problem as we discuss in coke also. So, ash because it will increase the volume of slag and create some other problem. So, ash should be low and moisture should be low we do not want to use the fuel, just to heat it up and go back, and this and size has to be very small. So, this is a very critical parameter, and PCI, because the injection of that PCI when we do it in the blast furnace through tuyeres, it has to burned within millisecond, because the velocity is very high and due to that within 4 5 millisecond it has to 1.

So, size is a very critical requirement for pulverised coal injection, if size is higher, then it will deposit in the upper part of the blast furnace, and we reduce the permeability, and operation problem will come.

(Refer Slide Time: 46:13)



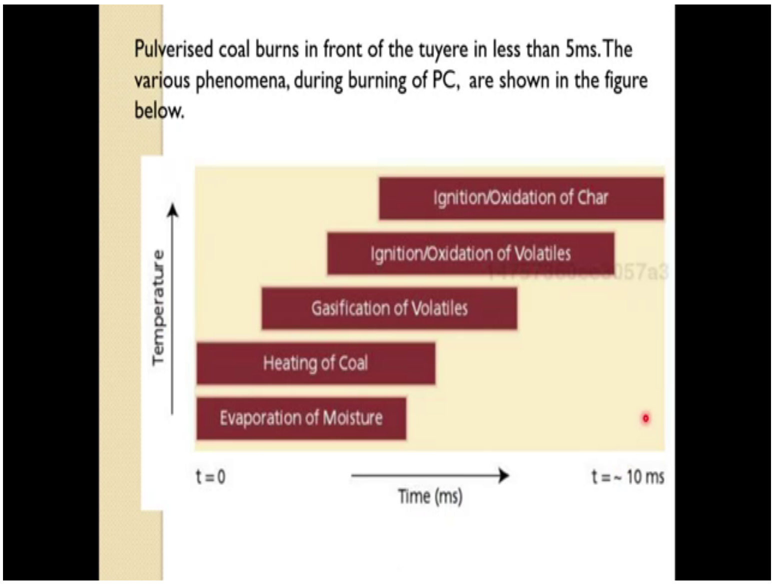
Schematic of pulverised coal injection

So, usually size is about between 75 to 100 micron so, this is a schematic of pulverised coal injection unit. So, you can see the waste gases, and other thing comes over here coal field not going to talk much into that, but main thing after this fine coal silo pulverised coal is comes, it goes through the transport air to the distributor, and this is also a very critical part.

Because this distributor has to make sure, they coal which is being delivered to all the tuyere should be consistent. So, the amount which is being delivered to all of them should be consistent, and proper as you might have in fact, this thing we discussed during the dissection of the blast furnace. And we saw even a one coke one tuyere a job, there is big difference in the internal structure of the or internal aerodynamics of the blast furnace.

In the similar way if the right amount is not being fed from each tuyere, then the chemistry and aerodynamics will change of the blast furnace. So, this is a very critical part of the pulverised coal injection system, that it much delivered to all the tuyere in a right amount.

(Refer Slide Time: 48:10)



Pulverised coal burns in front of the tuyere in less than 5ms. The various phenomena, during burning of PC, are shown in the figure below.

Ignition/Oxidation of Char

Ignition/Oxidation of Volatiles

Gasification of Volatiles

Heating of Coal

Evaporation of Moisture

Temperature

t = 0

Time (ms)

t = ~ 10 ms

And you will see in this slide the coke it takes about less than 5 millisecond to burns so, and during that 5 milli second you can see what happen evaporation of moisture take place, heating of coal gasification of volatiles, ignition oxidation of volatiles, ignition and oxidation of char. All these thing has to happen of finish within 5 millisecond. So, it is very critical the it should have a proper size, proper hardness, and other property we have discussed few of the properties during the coal selection, and other same sort of properties it goes here.