Materials and Energy Balance in Metallurgical Processes

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Module No.#01

Lecture No. # 35

Additional Topics-I

Melting in Cupola.

In this course, I thought let me include few additional topics. They may not be corresponding directly to the material and heat balance in metal extraction, but they do involve a material and heat balance. So, in the series of additional topics, the first which I have thought is the melting in cupola.

There will be other additional topics; that I will introduce to you in the next few lectures. So, the first additional topic which I have thought is melting in cupola because as all of you know, pig-Iron - when it is produced from blast furnace in the cast form, is not useful at all.

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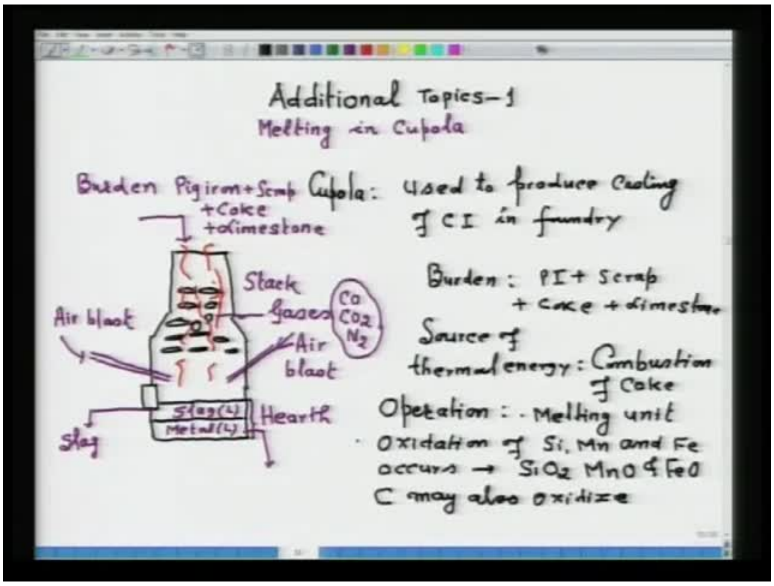

In the foundry, the pig Iron is melted in order to produce castings of cast Iron; so, in fact, if we say cupola is used to produce castings of cast Iron in foundry, in construction it is not like blast furnace as that all because it just requires to melt; no reduction is going on. So, as such, the diagram which I have shown here is a schematic diagram of a cupola. Now, in the cupola, this region is called stack (Refer Slide Time: 02:03). This is called stack and from the periphery of the cupola, air blast is introduced; this is also air blast. Now, its operation is very simple. The burden which is charged from the top consists of pig Iron plus coke, and to some extent limestone is also used. So, this burden which consists of pig Iron, coke, and lime stone descends downward and as the combustion occurs between coke and blast of air, the gases which are shown by the red color, since we are introducing Nitrogen and Carbon of Coke, will combust and so the gases will comprise of CO, CO 2, and Nitrogen also.

So, they travel upwards and there is a heat transfer and too little extent mass transfer may occur between the descending charge and ascending hot gases on the hearth. So, this portion is a hearth where the metal, which is a liquid, which is usually cast Iron, is collected at the bottom and slag is disposed. This is the outlet for slag and this is the outlet of metal. This is a very simple operation of a cupola (Refer Slide Time: 03:48 to 04:06).

Now, just for your information, I will note down few points: one - the burden consists of pig Iron plus scrap. I can also include here to some extent, you have scrap also here. Scrap plus coke plus limestone; this is the burden; it depends, if the scrap is there, you can charge because there is no problem in operation of the cupola because the source of energy is from outside.

So, there is no problem. If the scrap is there, you can charge; if not there, you can work with the pig Iron also and get it refined. So, source of energy, rather source of thermal energy is combustion of coke. You know combustion of coke generates a very large amount of energy; when Carbon combines with oxygen and forms CO_2 and CO, a very large amount of energy is released; so, this is the source of energy.

Now operation - just few points: First of all, it is simply a melting unit. As such, it just melts pig Iron scrap to produce a cast Iron of certain composition. Now, since coke and limestone are being added, that means there is some purpose for which coke and limestone is added. So, as a result of combustion of coke and blowing of oxygen, there are some oxidizing conditions; so, during the operation, point number 2, from oxidation of Silicon, Manganese and Iron occurs. As a result of the oxidation of Silicon, Manganese and Iron, you get SiO_2, MnO and FeO.

Carbon may also oxidize; so, as a result of oxidation of Carbon, some Carbon may become lower, but then because the coke is there and Carbon is there, whatever amount of Carbon is oxidized, the Carbon gets absorbed from the coke and we get to the specification. So, the oxidation of Silicon, Manganese and Iron - they are to be controlled so that no additional charge of Silicon, Manganese, or Iron is required in order to meet the specification.

If Carbon is oxidized, there is no problem; then it gets absorbed from the Coke Carbon. Another important thing is that, it is not a continuous operation because it depends on the demand. In fact, when we are producing the cast Iron castings, you have to have so many operations to be ready before you run a cupola.

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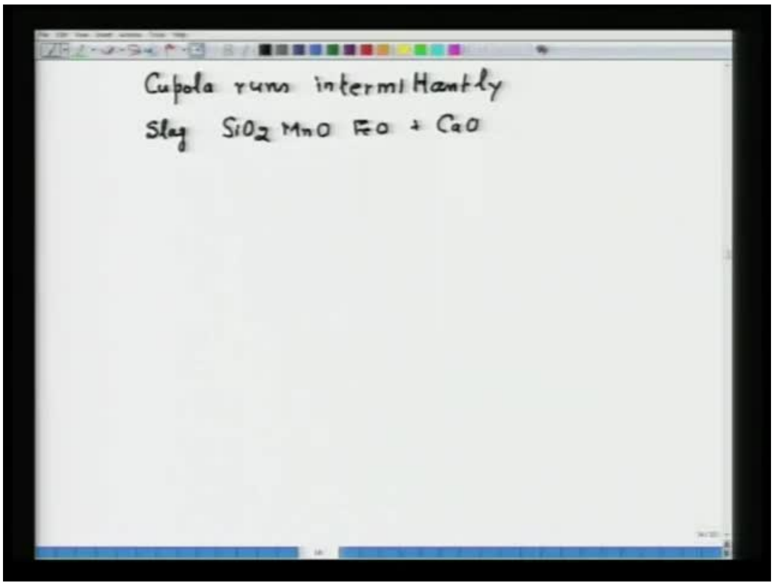

One of the operation is that mould should be ready; another, there should be sufficient market to sell that particular cast Iron. As a result of this, the cupola runs intermittently. So, in short, the various points of cupola and in fact the last point which I would like to mention , the slag which will form may contain SiO_2, MnO, FeO, and because, in order to flux this particular slag or in order to remove the slag and in order that these components will be liquid at the temperature inside the cupola, you add some Calcium Carbonate so that Calcium oxide helps to form the slag and it slags off all the impurities. It may contain sometimes, some amount of Calcium oxide. So, in short, that is what is the operation of the cupola.

Now, the further operation - what I have thought, I will illustrate through the problems on material balance in cupola. So, let me go to the material balance in cupola.

So now, I will see that there are certain few problems which I have selected so as to illustrate more about the operation of the cupola.

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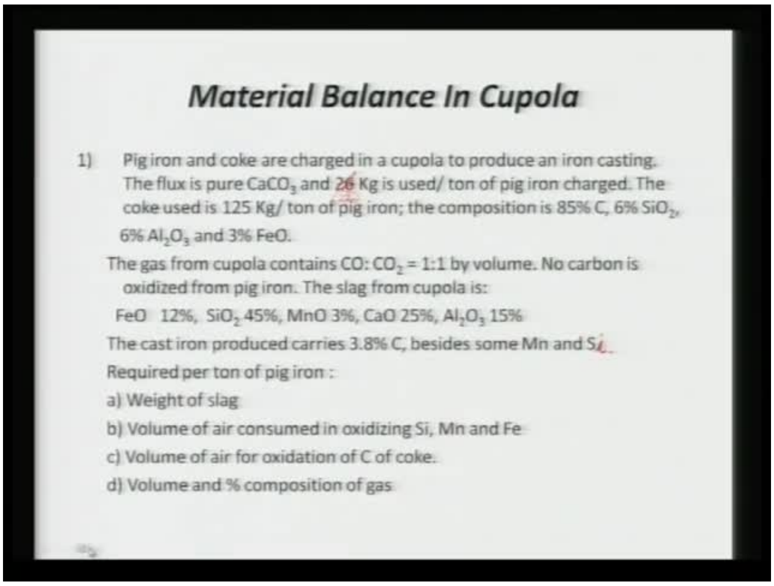

Here is the first problem; note some correction is there, instead of 26 there 22 kg is used. So, pig Iron and coke are charged in the cupola to produce an Iron casting. The flux is pure Calcium Carbonate; now it does not matter, because you are supplying an extra amount of energy. So, Calcium Carbonate may decompose to CaO and CO 2, and all of you know through the earlier lecture that Calcium Carbonate decomposition is highly endothermic. So, it does not matter, because you are supplying the source of energy from outside. It is not the process, or the cupola melting is not, in the sense, auto genius; so, you should worry for that.

You say 22 kg is used per ton of pig Iron; the coke used is 125 kg per ton of pig Iron. The composition of coke is also given over here: 85 percent Carbon, 6 percent SiO 2 and so on. The gas from cupola contains CO is to CO 2 ratio as 1 is to 1 by volume. No Carbon is oxidized from pig Iron.

The slag from cupola - its composition is given. It has FeO, SiO 2, MnO, CaO and Al 2 O 3. The cast Iron produced carries 3.8 percent Carbon, besides some Manganese and Silicon. Let me have some correction over here. So, this is not Sulphur; this is in fact Silicon. So, it has some Silicon. Now, what is required per ton of pig Iron you have to produce? You have to calculate weight of slag, volume of air consumed in oxidation of Carbon of Coke, and volume and percentage composition of gas; these are the things you have to calculate.

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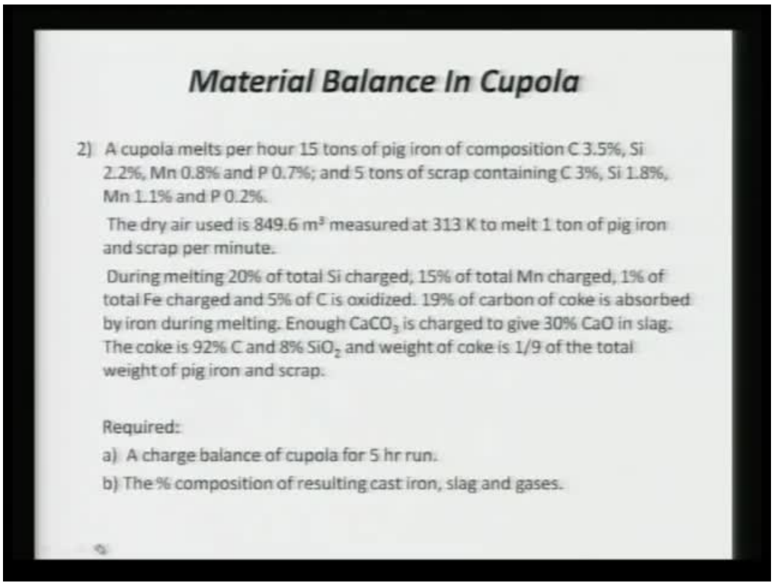

Now, here is the second problem and second problem says a cupola melts per hour 15 tons of pig Iron of composition: Carbon 3.5 percent, Silicon 2.2 percent, Manganese and phosphorus composition is given. 5 tons of scrap containing this; this is the composition of a scrap. Now, note - as I said in the burden, pig Iron plus coke plus scrap and Calcium Carbonate.

Now, you are seeing here that pig Iron is one component of the burden; another is a scrap as a tool, and the third is also coke, and fourth is a limestone. The dry air used is 849.6 meter cube measured at 313 Kelvin to melt 1 ton of pig Iron in scrap per minute.So, you should know; you should read the problem very carefully to solve this problem.

During melting, 20 percent of total Silicon charged, 15 percent of total Manganese charged, 1 percent of total Iron charged and 5 percent of total Carbon is oxidized; 19 percent of Carbon of Coke is absorbed by Iron during melting; enough Calcium Carbonate is charged to give 30 percent Calcium oxide. So, you are seeing the component of the burden as I mentioned in my introductory remark, pig Iron, scrap, limestone and coke - we are meeting all these over here. The coke is 92 percent Carbon and 8 percent SiO 2; somewhat better quality coke than the problem number 1 and weight of coke is one-ninth of the total weight of pig Iron in the scrap.

To calculate charge balance of cupola for 5 hour run: now in order to calculate charge balance, you have to know what charge balance means. That means input and output. Now, nobody will tell you what are the inputs and what are the outputs, but still, the problem demands that a total charge balance should be there - whatever is input should also be the output; that means you have to think what consists of the balance and the percentage composition of resulting cast Iron slag and gases.

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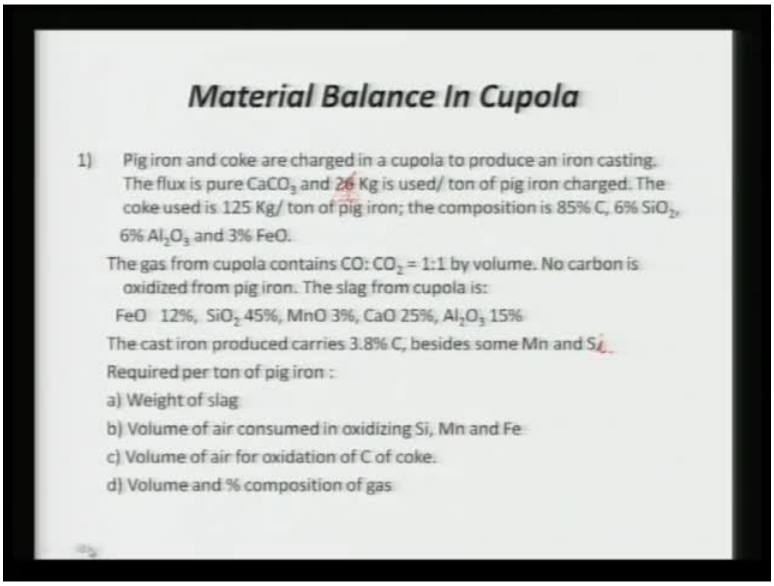

Here, these are the 2 problems. Now, let us proceed to the solution of these problems. So, here we go for the solution of these problems.

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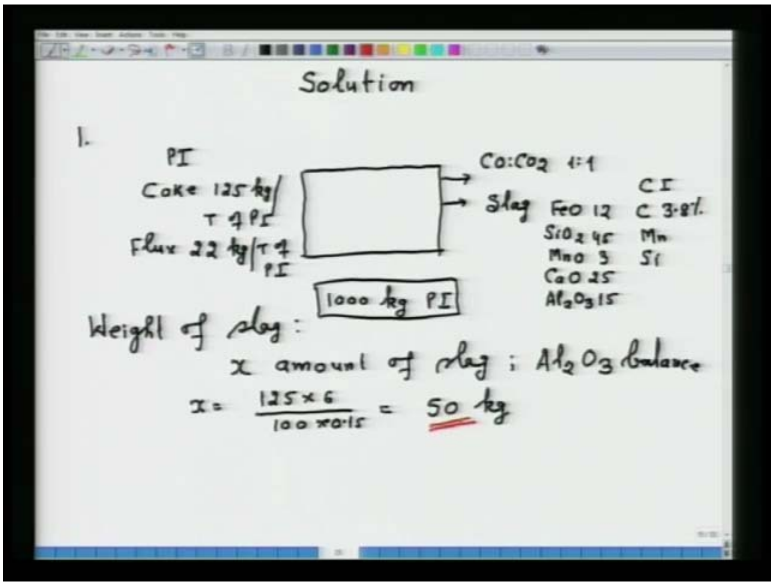

Let us take the solutions. Problem number 1 and let me represent the problem as a block diagram. So, as an input, we have pig Iron and then coke; coke amount is 125 kg per ton of pig Iron and flux we are having 22 kg again, per ton of pig Iron.

Of course, composition is given. Then, in the output we have CO is to CO 2 ratio is given to us as 1 is to 1. Then, it is also given in the output slag and the slag contains FeO, SiO 2, MnO, CaO and Al 2 O 3.

Then, we have cast Iron and it is said that in the cast Iron, Carbon is 3.8 percent. It contains Manganese and Silicon; no percentage of Manganese and Silicon in cast Iron is given. So, you cannot find out what is the percentage Iron at the moment.

Slag composition- if you wish you can write down 12, 45, 3, 25 and 15; so, first of all we are required to calculate weight of slag; so, first let us calculate weight of slag. Now, clue to calculate the weight of slag [FL] is to find out a compound which exclusively enters into the slag. Now, if you see this particular problem, you note that the Al 2 O 3 which is present in the coke directly enters into the slag; also, Calcium Carbonate which decomposes to Calcium oxide in CO 2 and CaO directly enters into the slag. So, you have an option, whether you go for Al 2 O 3 or Calcium oxide; I will see for both the options.

So, if we take say x is amount of slag, let me do first of all Al 2 O 3 balance, and of course, 1000 kg pig Iron is the basis I am taking. If we write down basis of calculation, 1000 kg pig Iron is my basis of calculation. So, if I do the Al 2 O 3 balance, then I can immediately calculate x; that is equal to 125 into 6 upon 100 into 0.15; that is the 15 percent Al 2 O 3 in the slag. So, immediately, I get the amount of slag is 50 kg. Immediately, it turns out to be amount of slag is 50 kg.

Now, let us calculate by having Calcium oxide balance; I mean both should give the same answer. However you can choose any, because you have the [FL] find out that component in the overall problem which directly enters into slag. Suppose, if you select SiO 2, you may end up in the problem because part of the Silicon is entering into pig Iron also and that is not given; so, you cannot do any SiO 2 balance. Similarly, Manganese oxide; you cannot do amino balance. FeO - you also cannot do the FeO balance. Iron balance you cannot do; it is not possible because all the requirement of the variables is not available. So, even if you select Silicon balance, then you end up in problem. So, here Al 2 O 3 and Calcium oxide are the oxides which directly enter into slag.

Even, if you have among Al 2 O 3 and Calcium oxide, because if sometimes Sulphur is present, then Calcium oxide reacts with Sulphur and forms Calcium Sulfide. You may end up in the problem, but the Al 2 O 3 is such an oxide which is very friendly; in the sense, it always enters all of it into the slag from all the sources; so, no reaction, nothing happens. So, Al 2 O 3 balance should be the key to arrive at the weight of slag by balancing it. So, that is what I thought, I will tell you. So, if you do for example, Calcium oxide balance and if you calculate x - that is the amount of slag, that will come out to be equal to 49.28 kg. We will see both values are quite close as regard to the 50 kg; so, we take 50 kg is the correct answer.

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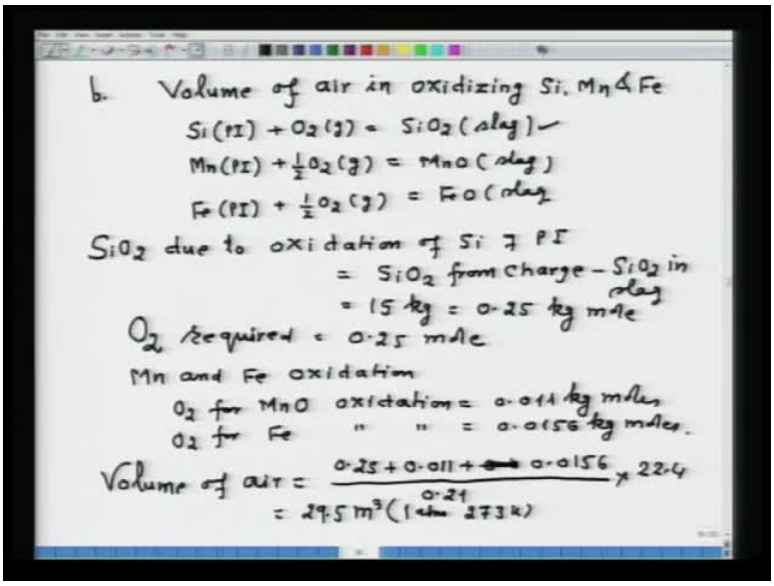

Now, second part b, you are required to calculate volume of air volume of air in oxidizing Silicon, Manganese, and Iron. Now, we can calculate the volume of air in oxidizing Silicon, Manganese, and Iron because what happens? During melting of pig Iron, some oxidation of the element takes place. Now, what are the reactions? Silicon in pig Iron reacts with oxygen; gases form and it gives you SiO 2 and slag. Similarly, Manganese in pig Iron reacts with half O 2 and gives you MnO in slag. Iron of pig Iron plus half O 2 gas gives you FeO - these are the oxidizing reactions where oxygen of air is used. There is no other source of oxygen; the decomposition of Calcium Carbonate could be, but it provides Calcium and CO 2.

Now, if you want to calculate, say SiO 2 due to oxidation of Silicon of pig Iron, now, first of all, you have to find out how much Silicon content is over there. So, that will be equal to SiO 2 from charge minus SiO 2 in slag. We know both the quantities; so, we can calculate SiO 2 from charge.

Now, consider from all sources from where SiO 2 is entering and SiO 2 in slag is already given; you have found out the amount of slag. So, you can find out that quantity; so, this quantity comes to around 15 kg and this is equal to 0.25 kg mole; Silicon gets oxidized. So, oxygen required would be - O 2 required would be how much? As a result of this reaction, 1 mole Silicon, 1 mole oxygen; so, 0.25 mole; you require 0.25 moles of oxygen. 0.25 moles of oxygen required.

Similarly, one can also calculate Manganese and Iron oxidation because you know FeO content of slag, you know MnO content of slag and from that you can calculate; so, oxygen for MnO oxidation you can calculate. I am giving you the value that is equal to 0.011 kg moles and O 2 for Iron oxidation comes out to be equal to 0.0156 kg mole. So, now there is no problem; volume of air, as required in the problem will be equal to say 0.25 plus, 0.011 plus let me say plus 0.0156. If you divide it by 0.21, multiply by 22.4. So, volume of air will be say 29.5 meter cube at 1 atmosphere and 273 Kelvin. So, that is is the answer for this.

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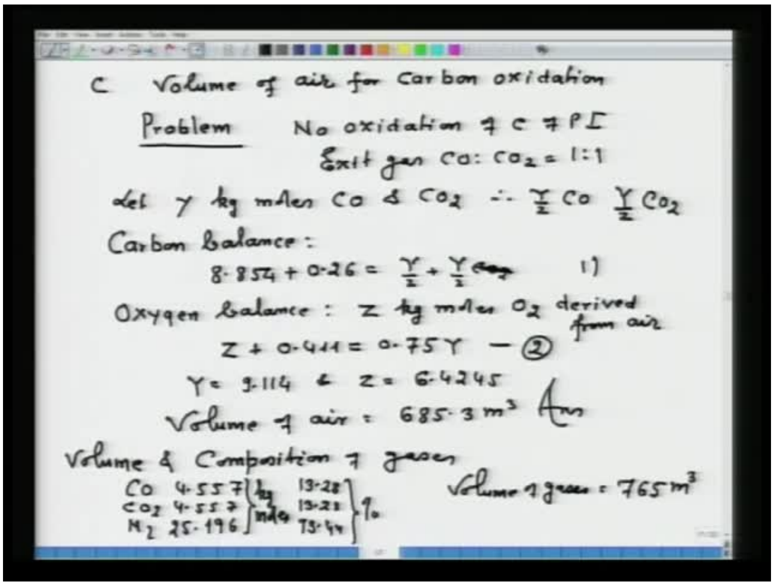

Now, the next which is asked C, say volume of air for Carbon oxidation. Now, here again, the clue to solve this particular problem, first is that it is oxygen of air blast; it reacts with Carbon of coke. That means something; you have to think in terms of to find out oxygen of the air blast because that reacts with the Carbon of the coke; another thing is that CO, CO 2 ratio in the top gas. Now, you have to think that CO, CO 2 ratio in the top gas will comprise of what? It comprises of oxygen of the blast as well as oxygen which you are getting from reduction of SiO 2, MnO, and so on. You are also getting oxygen from Calcium Carbonate. Also, Carbon you are getting from Calcium Carbonate. So, these are the various things that you have to consider, while calculating volume of air for Carbon oxidation.

Now, the condition the following problem says no oxidation of Carbon of pig Iron, so it becomes that much simple, no oxidation of Carbon of pig Iron. The problem also, says the exit gas CO is to CO 2 ratio that is equal to 1 is to 1. So, we have got a clue, what I am going to do, we have to do Carbon and oxygen balance. So, let us take the y kg moles, CO and CO 2; therefore, Y by 2 kg mole CO, and Y by 2 kg mole CO 2. Now, you have to do Carbon balance; you have to do first of all Carbon balance; see that, from all sources, from wherever Carbon enters the Carbon of the coke, Carbon of Calcium Carbonate, and it exits Carbon in cast Iron and so on. You have to do all this balance and the balance will result in this particular equation; 8.854 plus 0.26 that will be equal to Y by 2 Carbon in CO and Y by 2 Carbon in CO 2. That no need to write, this is our equation number 1.

Second is the oxygen balance and let us take that Z kg moles oxygen derived from air; again here you have to do oxygen balance. So, this will give you Z plus 0.411; that is equal to 0.75 Y say Y by 2 moles in CO 2 and Y by 4 moles in CO - this is my equation 2. Now, we can solve equation 1 and 2. So, by solving equation 1 and 2, I will be getting, say Y that is equal to 9.114 and Z that is equal to 6.4245 kg moles. So, one can immediately find out volume of air in that 6.4245 divided by 0.21 multiplied by 22.4; this will be equal to 685.3 meter cube that is the answer for this problem.

Now, next I have to calculate volume and composition of gases. Now, volume already we have calculated; now, that is CO which is half of 9.114; that is 4.557. CO 2 - same 557, and Nitrogen - that will be 25.196 all in kg moles. So, that will be 13.28, 13.28 and 73.44 they are all in percentage where, this is in kg moles. Now, say volume. It is easy to find out volume of gases; that will be 765 meter cube.

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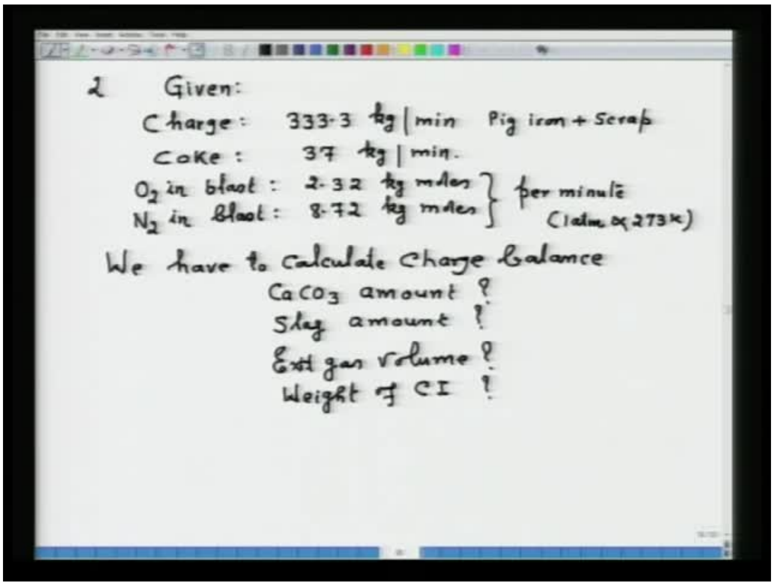

Now, let us go to the second problem. Now, in the second problem, it is given to us. It is important that you read the second problem carefully.

The charge of 15 tons pig Iron and 5 tons of slag are given per hour, but the blast rate is given per minute. So, that point should be clear. Number 2 - the blast rate is given at 313 Kelvin. So, I did some conversion and you should also do that conversion; so, in that I will write now, in terms of per minute. You can also calculate in terms of per hour; the choice is up to you, but then, whether you calculate per minute or you calculate on the basis of per hour, it should be consistent.

So, what I have done? I am calculating now, per hour. So, per hour charge is 333.3 kg per minute. The charge, I mean it has pig Iron plus scrap; that is what a charge per minute is. Coke also I have to calculate per minute; coke per minute is 37 kg. Then, I have to calculate oxygen in blast; oxygen in blast - that is 2.32 kg moles, and Nitrogen in blast - that is equal to 8.72 kg moles. Now, both of these I have written on per minute basis and also the volume flow rate which was given at 313 Kelvin; I have converted and these values are at 1 atmosphere and 273 Kelvin.

So, you can choose the basis way, you like. You can calculate on per hour basis or 2 hour basis. Whatever you do, it is only the thing that I wanted to tell. It is that you should be consistent in your calculation. Now, what you have to calculate? We have to calculate charge balance. We have to calculate charge balance and what charge balance comprises of. When we talk of balance input and output - that means in this particular problem, what you should calculate is not specifically asked.

Only hours make a charge balance that means your balance should be complete; no quantity should be missing in the input and output side. So, if you see the problem, what it says - it is the amount of Calcium Carbonate that has to be calculated. Then you are also required to calculate slag amount; that is also not known. So, here, I mean these types of calculations tell you whether you understand the material balance of cupola or not. Here, it is not specifically asked, what you should calculate? Or What you should not calculate?

You should still calculate completely so that input and output match each other. So, slag amount is also not known and exit gas volume is also not known. Then, weight of cast Iron is also not known or amount of cast Iron is also not known. So, these are the quantities that you have to calculate. Now, say, Calcium Carbonate amount we cannot calculate unless you calculate the slag amount.

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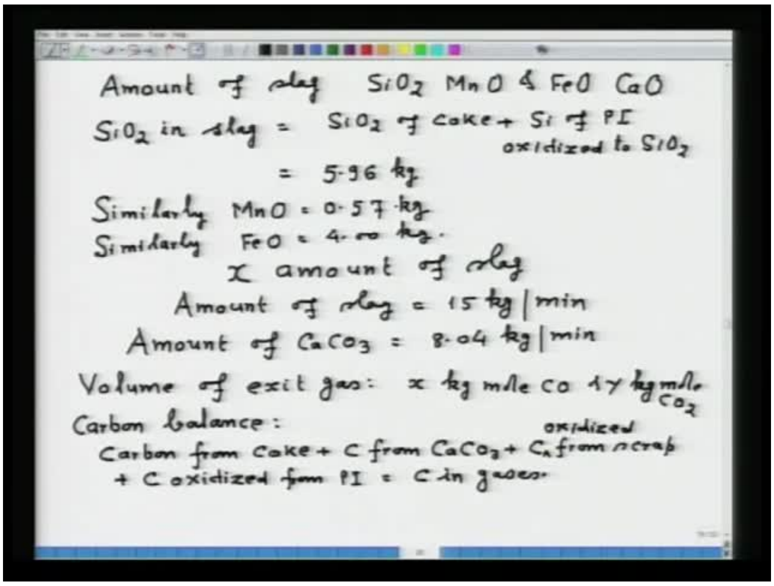

So, our first thing is that, we have to calculate amount of slag, let us calculate first amount of slag. Now, here you are not given any percentage or nothing you are given; you have to read the problem, do the balance and see what is happening to what element?

So, seeing the problem and looking into the introductory remark of my lecture on cupola melting, the slag will consist of, this situation consists of SiO_2, MnO and FeO, So, we have to calculate SiO_2 in slag. SiO_2 in slag will be equal to SiO_2 of coke because whatever SiO_2 is present in the coke, it will go to slag plus Si of pig Iron oxidizes to SiO_2 and there is no other source, from where SiO_2 is entering in the slag. So, if you calculate all these things, we get SiO_2 in slag; that will come out to be 5.96 kg. So, in doing this type of balance, you should be very cautious that you do not forget any source, from where SiO_2 is entering the problem. You have forgotten to calculate or to consider.

So, that way the problem reading in between the lines is very important. Little bit of knowledge of the operation of the cupola say physico, chemistry of the physico cupola, what is oxidized and what is not oxidized - that is also necessary. So, SiO_2 in slag is this one.

Similarly, we can find out say MnO because the source MnO is only oxidation of Manganese and there is no other source. So, that will be equal to 0.57 kg. Similarly, one can calculate amount of FeO - that will be 4.00 kg. So, in addition to the amount of slag which I have wrote SiO_2, MnO and FeO, it will also contain Calcium oxide.

Because if you read the problem, the problem says that the slag contains 30 percent of Calcium oxide. Now, if we consider x is the amount of slag, say if we consider x being the amount of slag, then 70 percent consist of SiO_2, MnO and FeO because 30 percent is Calcium oxide. So, if you sum total and divide by 0.7, then we get amount of slag that is equal to 15 kg per minute. Now, once you get amount of slag equal to 15 kg per minute, then we can calculate amount of Calcium Carbonate because 30 percent Calcium oxide in the slag. So, 15 into 30 by 100 - that will be Calcium oxide converted to Calcium Carbonate. So, this will be equal to 8.04 kg per minute. This is about the amount of slag and amount of Calcium Carbonate.

Now, we are also not given what is the volume of exit gas? So, we have to calculate the volume of the exit gas. To calculate volume of the exit gas, now, we adopt the same procedure as we adopted in earlier problem. Here, let us consider now, say x kg mole CO_2, x kg mole CO, and y kg mole CO_2. So, let us first of all do Carbon balance.

Now, Carbon balance: write down say Carbon from coke plus Carbon from $CaCO_3$ plus Carbon from scrap plus Carbon oxidized from pig Iron; in fact, also Carbon oxidized from scrap.

Whatever oxidation, all will be in the exit gas; the total Carbon balance has to be there and that will be equal to Carbon in gases because that amount of Carbon will not enter into the gases which have dissolved into the pig Iron; rest from all sources because input should be equal to output. So, this is about the Carbon balance.

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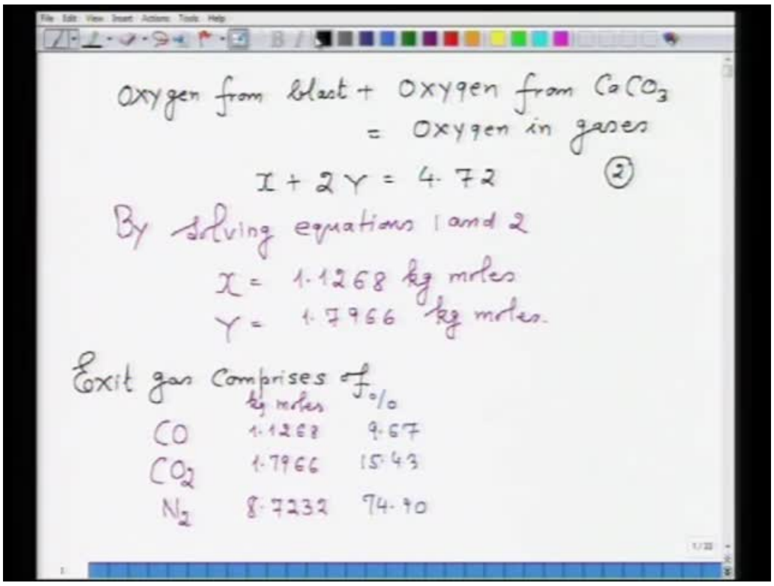

Now similarly, we have to do the oxygen balance. So, I am performing oxygen balance and this oxygen balance is oxygen from blast plus oxygen from Calcium Carbonate that is equal to oxygen in gases. Now, I will just write down in terms of the equation. So, the equation becomes x plus 2Y that is equal to 4.72 and this is our equation number 2.

Now, by solving equations 1 and 2, you know they are simultaneous equations; 2 equations and 2 variables; it can be solved. So, by solving equations 1 and 2, we get x that is equal to 1.1268 kg moles and Y that is equal to 1.7966 kg moles. Now, the exit gas comprises of Carbon monoxide, Carbon dioxide, and of course Nitrogen because air is used for blowing purposes.

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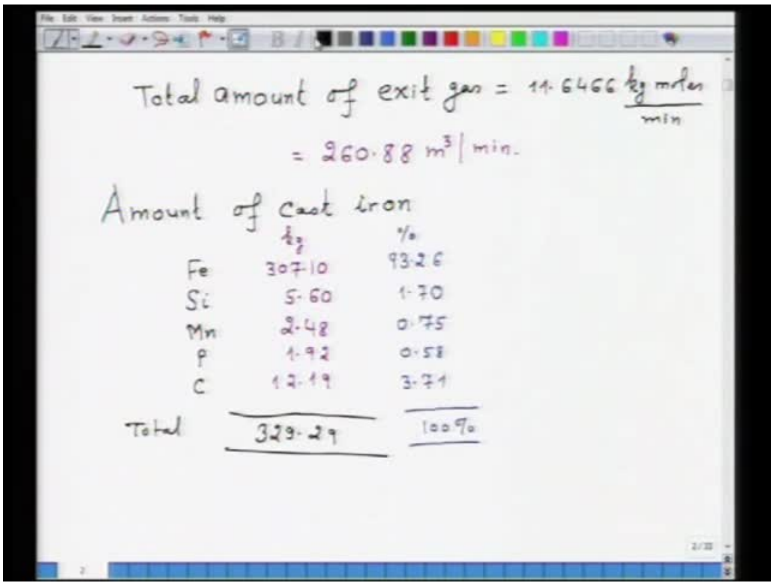

So, first I will write in kg moles. So, Carbon monoxide is 1.1268, CO 2 1.7966, and Nitrogen 8.7232 and in percent, this becomes 9.67, 15.43 and 74.90. Now, we can calculate total amount of exit gas; of course, we have to sum total and that will be equal to 11.6466 kg moles per minute and this becomes equal to 260.88 meter cube per minute.

So, that is what the question which was asked. Now, we can also calculate the amount of cast Iron. Now, we have to calculate the amount of each individual element in cast Iron and all of you know it comprises of Carbon, Silicon, Manganese, phosphorus, Carbon, and of course, Iron.

So, I will write: Iron, Silicon, Manganese, phosphorus and Carbon. Their amount in kg say Iron is 307.10, Silicon - 5.60, Manganese - 2.48, Phosphorus - 1.92 and Carbon - 12.19. This makes total weight of cast Iron - 329.29 and we can also calculate in percent. So, in percent, it becomes 93.26 Iron, 1.70 Silicon, 0.75 percent Manganese, 0.58 percent Phosphorus and 3.71 percent Carbon, and this makes total as 100 percent.

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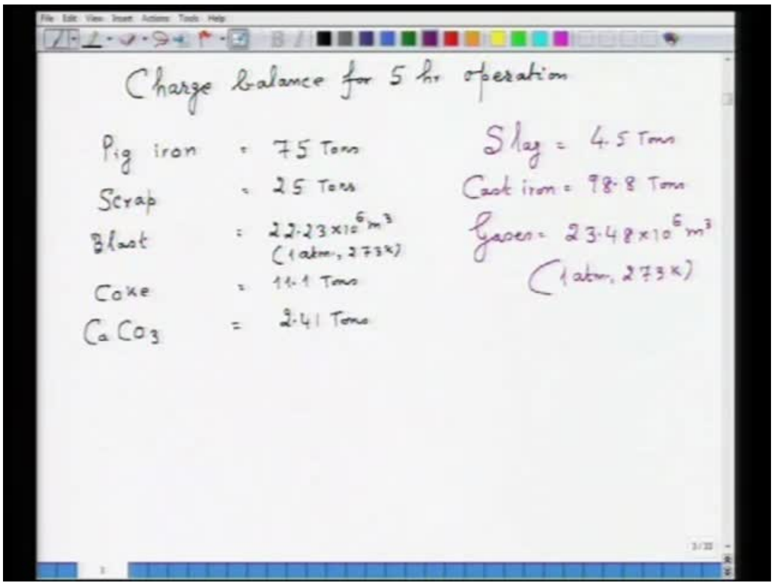

Now, it is also being asked, what is the charge balance for 5 hour operations? So, I am making now charge balance for 5 hour operation. That means, if suppose the cupola operates for 5 hours, how much charge we have to keep in reserve? So, this can be calculated. So, we will be needing pig Iron; that we will require 75 tons, scrap 25 tons.

Then blast, that is air blast, will be requiring 22.23 into 10 to the power 6 meter cube, which is measured at 1 atmospheric pressure and 273 Kelvin. Coke - we will need 11.1 tons; Calcium Carbonate - that will be equal to 2.41. Now, as a result of 5 hour operation, the output we have to calculate; also, we can schedule our entire operation after tapping cast Iron from the cupola. So, the slag will be produced; amount of slag will be equal to 4.5 tons. Cast Iron will be equal to 98.8 tons and gases that will be produced is 23.48 into 10 to the power 6 meter cube, measured at 1 atmosphere pressure and 273 Kelvin.

Now, it is very important to express temperature whenever you want to express the volume of the gas. If you want to calculate at 298 Kelvin or any other temperature, then this volume will not be same.