

Materials and Energy Balance in Metallurgical Processes

Prof. S.C. Koria

Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur

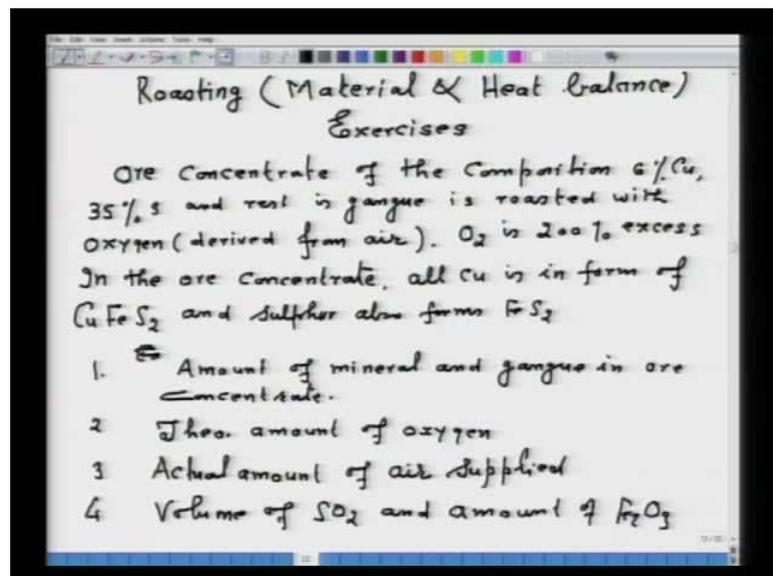
Module No. #01

Lecture No. #16

Material Balance in Roasting illustration

This lecture and further few lectures, I will be devoting on material and heat balance in roasting. I will be solving few problems and giving few problems for your practice. So let us see, first of all, how these problems on roasting are tackled.

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So, I am taking problem number one like say, ore concentrate of the composition 6 percent copper, 35 percent sulphur and rest is gangue is roasted with oxygen - of course derived from air. Now, here oxygen is 200 percent excess, this means we are using 300 percent theoretical air for the roasting process.

Now, in the ore concentrate, all copper is in form of $CuFeS_2$ and sulphur also forms FeS_2 mineral, so this is what is given.

Now, remember the composition of the concentrate is given in terms of ultimate analysis. It is in terms of elemental analysis and hence, you should not do 6 plus 35 and you subtract this from 100 - that will give you the amount of gangue; no, it will be wrong, so that point is to be clear.

Number two, this roasting takes around 300 percent theoretical air, that is what given in the problem. Now, first, you have to find out say, calculate amount of mineral and gangue in ore concentrate; second you have to calculate theoretical amount of oxygen. Now, remember, we can also call theoretical amount of oxygen, stoichiometric amount of oxygen; they mean the same thing that means you have to write down a balanced chemical equation.

Then, whatever you calculate based on the balance chemical equation as I have illustrated in the lecture on stoichiometric that is mean by theoretical amount, in this particular case of oxygen. Third, you have to calculate actual amount of air supplied; fourth, you have to calculate volume of SO₂ and of course, amount of Fe₂O₃ is a relatively very simple problem, I must starting a simple problem.

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Sol.

6% Cu
35% S
Gangue

Gangue does not contain Cu, S or Fe

Basis 1000 kg ore

Roasting

Cu = 64
Fe = 56
S = 32
O = 16

$$\% \text{ CuFeS}_2 = \frac{6 \times 184}{64} = 17.25\%$$

S in CuFeS₂ = 6% ∴ 29% S is as FeS₂ mineral

$$\% \text{ FeS}_2 = 54.375\%$$

CuFeS ₂	17.25%	172.5 kg
FeS ₂	54.375%	543.75 kg
Gangue	28.375%	283.75 kg

} Ans 1

Let us go with a calculation, so let me say solution; let me illustrate by a box which tells you about the inputs and outputs. Here is the box, I have now 6 percent copper, 35 percent sulphur and I have the gangue.

So, also it is stated in the problem that the gangue does not contain copper, sulphur or iron; please understand that also, that the gangue does not copper, sulphur or iron.

So the roasting is going on, here is the roasting (Refer Slide Time: 06:06). We have to find out: number one, the amount of mineral and gangue. Let us consider, first of all basis 1000 kg ore and the atomic weights that I will be using for copper I am using 64, for iron I will be using 56, for sulphur I will be using 32, and for oxygen I will be using 16, that is what I am going to do it.

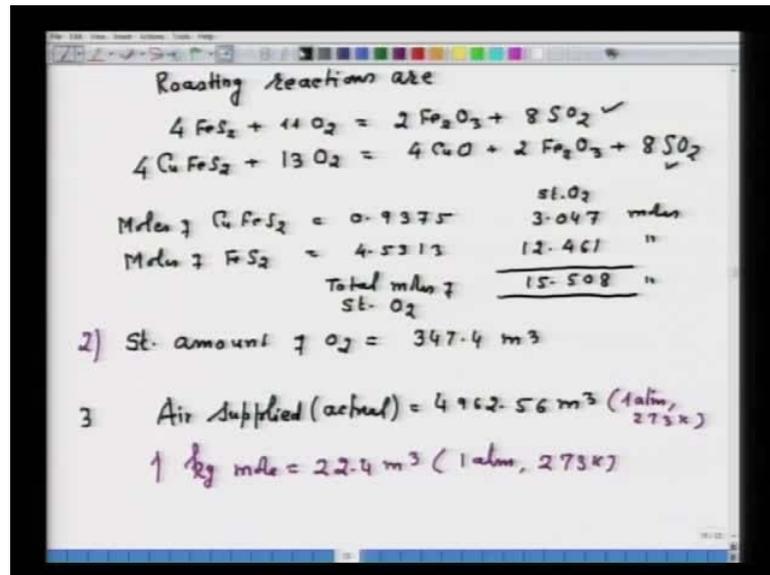
First of all we have to find out, the amount of mineral and gangue and it is said that all copper is the form of Cu Fe S_2 and some Fe S_2 is also forming. So, first you can find out, say percent Fe S_2 percent Cu Fe S_2 , that will be equal to 6 into 184 upon 64, that will be equal to 17.25 percent. Now, we have to find out sulphur in Cu Fe S_2 that will come to be equal to 6 percent, you can find out by percentage and then, that means 29 percent sulphur is as Fe S_2 mineral.

Now, straightaway I can write down this 29 percent sulphur is Fe S_2 mineral. Therefore, the percent Fe S_2 will be equal to how much? Percent Fe S_2 will be equal to 54.375 percent because 29 into 88 by 32, that will be the percent Fe S_2 .

Now, I can calculate the amount; so the Cu Fe S_2 , then Fe S_2 and then gangue. So, Cu Fe S_2 is 17.25 percent, Fe S_2 is 54.375 percent and rest gangue of course, 100 minus this, that will be 28.375 percent. So in terms of their weight, I have here now 172.5 kg of the 100 kg ore is the basis, this will be 543.75 kg is Fe S_2 and 283.75 kg, this is the gangue and this is the answer for one; that is how you will be calculating the amount of mineral.

Now, next is theoretical amount of oxygen; now theoretical amount of oxygen can be determine by writing the balance roasting reaction. So in this case, the oxidation will occur of Fe S_2 and that of chalcopyrite that is Cu Fe S_2 . So all that we have to write down, the equation or the balance chemical equation and from there we can find out the amount of oxygen.

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The roasting reactions are say $4\text{FeS}_2 + 11\text{O}_2$ that is equal to $2\text{Fe}_2\text{O}_3 + 8\text{SO}_2$. Similarly for CuFeS_2 , $4\text{CuFeS}_2 + 13\text{O}_2$, that will be equal to $4\text{CuO} + 2\text{Fe}_2\text{O}_3 + 8\text{SO}_2$. So, these are the roasting reactions and there is no other mineral present in the ore concentrate that requires oxygen.

So all that we have to find out, the moles of FeS_2 and the moles of CuFeS_2 and then a straightaway you know, how much amount of oxygen would you required. Now remember, I am rather very comfortable by solving the problem by converting into moles. However, you can do with kg, whichever way you want to do it; all that we are interested is in the answer.

I am very much comfortable if I convert these things into mole and then solve the problem. So I will convert the moles, so moles of CuFeS_2 that comes out be equal to 0.9375 and moles of FeS_2 that comes out be equal to 4.5313 straightaway kg divide by molecular weight, you have the moles.

So I can be straightaway find out from here, the stoichiometric amount of oxygen or you can also call theoretical amount of oxygen, whichever way you want to understand; that is the oxygen which is required for the equation this and for the this equation (Refer Slide Time: 12:09).

So you see according to equation one, 4 moles of Fe S 2 requires 11 moles of oxygen. According to equation of roasting, Cu Fe S 2 and oxygen 4 moles of chalcopyrite require 13 moles of oxygen. So, straightaway I can calculate the moles of Cu Fe S 2 0.9375 multiply by 11 by 4 then I will be getting here 3.047 moles of oxygen and here I will be getting 12.461 moles of oxygen that will be required.

Total moles of oxygen of course, stoichiometric oxygen that will be 15.508, then stoichiometric amount of oxygen that is supplied multiply by 22.4 and this is equal to 347.4 meter cube, this is what is asked in two, where you require to calculate theoretical amount of oxygen.

Now, you have to calculate actual amount of air, so 3 actual amount of air is 300 percent that of theoretical air; so actual air supplied will be equal to 4962.56 meter cube. Here it is important to remember, that 1 kg mole is equal to 22.4 meter cube at one atm and 273 kelvin, as such this value is at one atm and 273 kelvin that is what is important.

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An Amount of $\text{Fe}_2\text{O}_3 = 437.5 \text{ kg}$
 Amount of $\text{SO}_2 = (4.531 \times 2 + 2 \times 0.9375) \times 22.4$
 Volume of $\text{SO}_2 = (4.531 \times 2 + 2 \times 0.9375) \times 22.4$
 $= 245 \text{ m}^3$
 An

Volume of gases	%
$\text{SO}_2 = 245 \text{ m}^3$	5.0%
$\text{N}_2 = 3920 \text{ m}^3$	80.7%
$\text{O}_2 = 615 \text{ m}^3$	14.3%
<u>4860 m³</u>	

Next, you have to calculate volume of SO 2 and amount of Fe 2 O 3. So, we can calculate say amount of Fe 2 O 3. Well, you can just calculate because the equations are there which says on roasting of Fe S 2, 2 moles of Fe 2 O 3 are forming, on roasting of Cu Fe S 2, 2 moles of F e 2 O 3 are forming, so you can do that and amount of Fe 2 O 3 will come 437.5 kg.

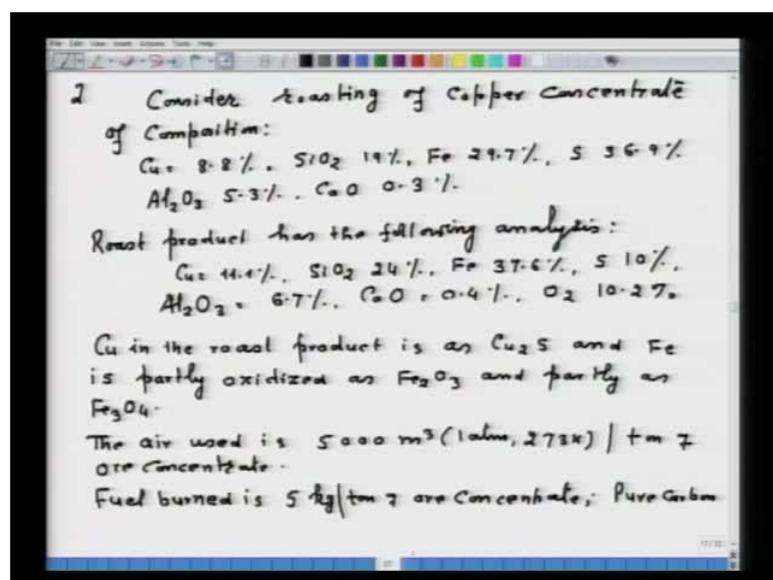
Similarly, amount of SO₂ if you see the balance chemical equation, that will be 4.531 into 2, plus 2 into 0.9375. Now, volume of SO₂ that will be equal to 4.531 into 2 plus, 2 into 0.9375 multiplied by 22.4 mind you, this is in kg moles. Now, this in meter cube so this amount comes, 245 meter cube (Refer Slide Time: 15:55). So this is the answer for fourth one and this is also the answer for fourth one.

Now addition, what I done, we can also get the information of the volume of gases and their composition. So if you want to know, the volume of gases they just an additional calculation that I am doing because the output of the roasting is the roast product plus gases.

So, volume of gases one can find out, say SO₂ we have already determine 245 meter cube then, the nitrogen that will be equal to 3920 meter cube. Since you have used excess air, so there will be excess oxygen, there will be also in the gases and this will be equal to 695 meter cube, so the total amount of gases that will be forming around 4860 meter cube.

So as such their percent say SO₂ will be 5 percent, N₂ will be 8.7 percent and oxygen is 14.3 percent. So, that is how this problem can be understood and can be solved. I will again illustrate with one more problem, that is little detail problem. Let us see that problem number two.

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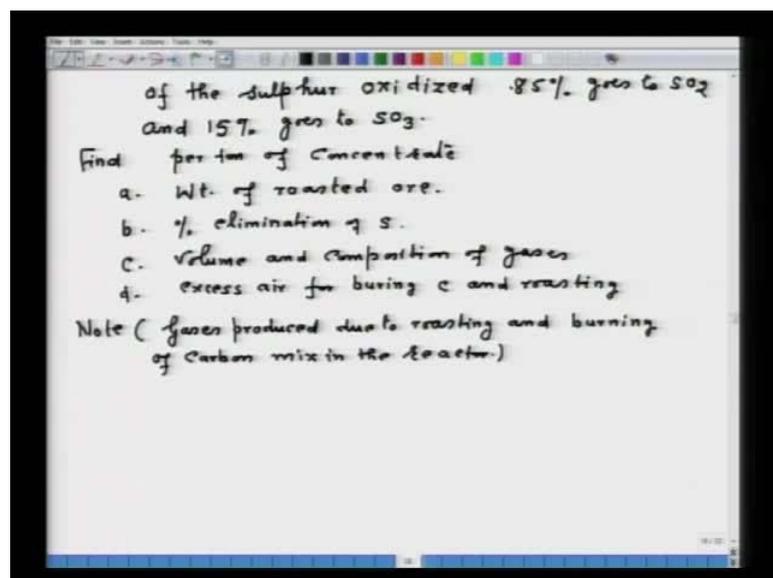


So the problem number two, let me first of all make the statement. Consider roasting of copper concentrate of composition: copper 8.8 percent, Si O 2 19 percent, iron 29.7 percent, sulphur 36.9 percent, Al 2 O 3 5.3 percent, calcium oxide 0.3 percent. Roast product has the following analysis; now, the roast product contains copper 11.1 percent, Si O 2 24 percent, iron 37.6 percent, sulphur 10 percent, Al 2 O 3 6.7 percent, calcium oxide 0.4 percent and oxygen 10.2 percent.

Now mind you, roast product the analysis shows oxygen is also there but, always remember as I said, though element analysis are given but, the ore concentrate always contain the so called minerals. Similarly, in the roast product also the analysis of copper, iron, sulphur is given; it does not mean it contains copper, iron or sulphur as it is, but it is always in the form of minerals. So, that is an important thing you should understand.

Now some conditions are given, say copper in the roast product is Cu 2 S and not iron is partly oxidized as Fe 2 O 3 and partly as Fe 3 O 4. Second thing is that the air used is 5000 meter cube expressed at 1 atmosphere and 273 Kelvin per ton of ore concentrate. Fuel is also used, so fuel burned in the roasting process is 5 kg per ton of ore concentrate and that is fuel burned is 5 kg per ton of concentrate and which is here, pure carbon fuel; we will consider pure carbon.

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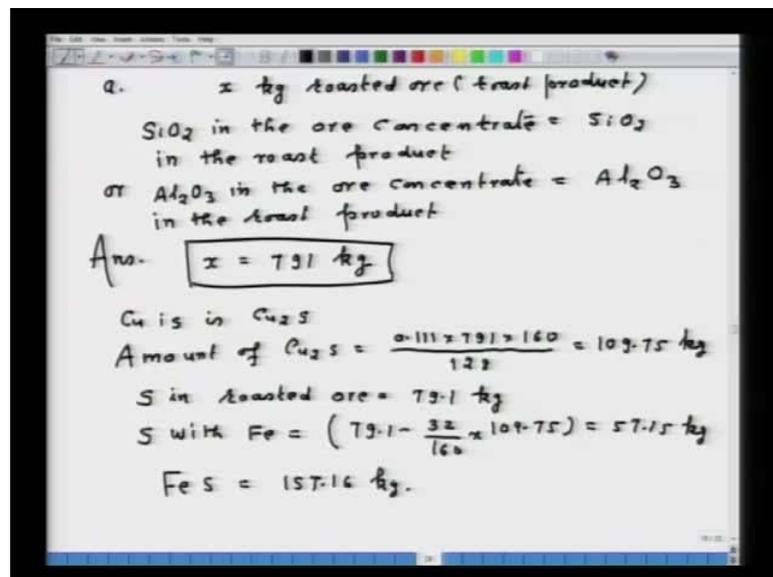


Another condition is given, of the sulphur oxidized 85 percent goes to SO 2 and 15 percent goes to SO 3, these are the conditions. Now, what you have to do? You have to

find per ton of concentrate, a: you have to find out weight of roasted ore, b: percent elimination of sulphur, c: volume and composition of gases and finally, you have to find excess air for burning carbon and roasting.

Note: gases produced due to roasting and due to burning of carbon, they mix in the reactor and the mixture goes out of the system; that is also a thing I must mention it over here. Now say first of all, either straightaway we can go to the solution of the problem. First, we have to calculate weight of roasted ore (per ton) of concentrate.

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Now here, let us consider x kg roasted ore or you can call roast product, they are one in the same thing. Remember you recall in the roasting, I have said that roasting takes place in the solid state, there is no melting type of anything occurs. The reactants are in the solid state, the products are also in the solid state, number one.

Number two, roasting is essentially an oxidizing process. When we call this is an oxidizing process, then all other oxides like SiO_2 , Al_2O_3 they are not oxidized that means, whatever SiO_2 in the ore concentrate, it will be totally available in the roast product. Whatever Al_2O_3 will be in the concentrate thus, the same amount, the same thing will also be available in the roast product, though there amount will be different and the percentage will also be different, because the weights will be different, but as regards, the copper or iron or sulphur they will be changing because of oxidation process.

In order to solve such problem, you have to always catch hold of that particular mineral which is not undergoing any chemical reaction, number one; number two, which is not undergoing in the process of formation of compound. Now, in this particular problem and several problems will be coming now to you, the Si O_2 and Al_2O_3 they do not form any chemical compound, they do not react at all.

In this change, calcium oxide is also another compound, which neither react nor forms a chemical compound, but you can also do the material balance now. You can say, Si O_2 in the ore concentrate that should be equal to Si O_2 in the roast product. Now our basis is 1000 kg, because per ton you have to calculate. So, Si O_2 in the ore concentrate that is equal to Si O_2 in the roast product or we can also take Al_2O_3 in the roast product sorry Al_2O_3 in the ore concentrate that should also be equal to Al_2O_3 in the roast product.

Here calcium oxide in the ore concentrate should also be equal to the calcium oxide in the roast product, but the problem in the calcium oxide is that the analysis is mostly rounded off and the percentage calcium oxide is very small. So the balance which is, if it is done by taking calcium oxide in the account, it is liable to be error; that is why my suggestion would be to take Si O_2 and Al_2O_3 as the balance and to do this in order to find out the weight of roasted ore.

So if we do that, we do either Al_2O_3 or Si O_2 balance, the value of x it comes to be equal to 791 kg, this is the answer for part a. Now second, we have to calculate percentage alumination of sulphur and so on, volume and percentage composition of the gases and excess air and so on. Second we have to calculate, b part we have to see now. Since it is said that copper is as Cu_2S , so amount of Cu_2S that will be equal to 0.111 into 791 into 160 divide by 128 , so amount of Cu_2S that will be equal to 109.75 kg.

Now what I am determining? I am determining the composition of the roast product. The weight we have determine 791 kg, so it will have Cu_2S this one. Now the problem says, iron is partly oxidized to Fe_2O_3 and partly oxidized to Fe_3O_4 . In order to know how much iron is gone to Fe_2O_3 or Fe_3O_4 , we have to do the sulphur balance also. So, sulphur in the roasted ore that is equal to 79.1 kg.

Therefore, sulphur with iron because the sulphur in the roasted ore can go either with copper or with iron and there is no other, take care of sulphur. So Cu_2S you already

determine if I subtract the amount of sulphur that is gone in Cu_2S from the total sulphur contained in the roasted ore, then I will know sulphur with iron and that is exactly what I am going to do, 79.1 minus 32 upon 160 into 109.75, so that will give me 57.15 kg sulphur is with the iron. Therefore, I can find out now, amount of Fe S that will be equal to 157.16 kg.

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a. x kg roasted ore (roast product)
 SiO_2 in the ore concentrate = SiO_2
 in the roast product
 or Al_2O_3 in the ore concentrate = Al_2O_3
 in the roast product

Ans. $x = 791 \text{ kg}$

Cu is in Cu_2S
 Amount of $\text{Cu}_2\text{S} = \frac{0.111 \times 791 \times 160}{128} = 109.75 \text{ kg}$
 S in roasted ore = 79.1 kg
 S with Fe = $(79.1 - \frac{32}{160} \times 109.75) = 57.15 \text{ kg}$
 Fe S = 157.16 kg.

It also says some amount of iron is oxidized to Fe_2O_3 and some amount to Fe_3O_4 . We have to know how much amount of iron now remaining, because some iron as gone to the formation of Fe S. So, the iron which forms Fe_2O_3 and Fe_3O_4 that will be equal to total iron is 297 minus 157.16 is the Fe S amount, divide by 88 into 56. So this particular iron with the Fe S, if I subtract that then I will be getting 197 kg.

What is this 197 kg? This 197 kg of iron is forming Fe_2O_3 and Fe_3O_4 . Now we have to find out what is the weight of Fe_2O_3 and Fe_3O_4 ? Here comes little bit of thinking, a conceptual thinking. If you look the analysis of roast ore, the roast ore says it contains 10 percent oxygen. Now if you again look down very seriously the roasted ore, you will find that the roast ore, free oxygen cannot be there if iron is there.

So, iron can be either in the form of Fe S or in the form of Fe_2O_3 and Fe_3O_4 . So here, the clue for solving this particular problem is the 10 percent oxygen is given to you which is present in the roasted product, roasted ore or roast ore one and the same thing that means the 10 percent oxygen is combining with Fe_2O_3 and Fe_3O_4 .

So I can form two equations, I know the amount of iron which is going to Fe_2O_3 and Fe_3O_4 . Now I know amount of oxygen which is going to Fe_2O_3 and Fe_3O_4 . If I form two simultaneous equations, I can solve and I can get their respective amounts. So, that is what I am going to do it.

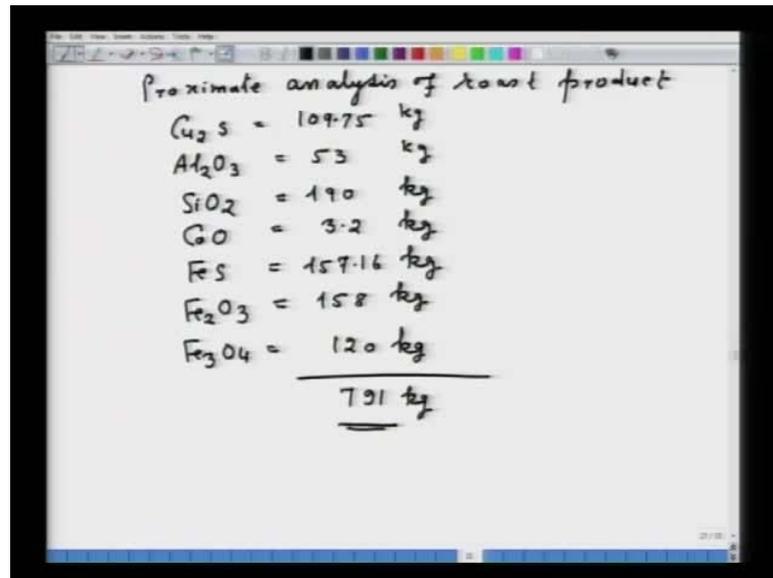
Let us consider now, let x kg Fe_2O_3 and y kg Fe_3O_4 this is what the thing x kg Fe_2O_3 and y kg Fe_3O_4 . Hint I already given to you, so what we have to do? Have you got what I am going to do now? Now I am going to do, first the iron balance and iron balance will give me $0.7x$ plus $0.72y$ that is equal to 197, this is my equation one.

Next, what I am going to do? Probably, you got a hint that is I will be doing oxygen balance. If I do oxygen balance it comes $0.3x$ plus $0.28y$ that is equal to 81, this is my equation number two. Now I believe, you must be an expert in solving these two simultaneous equations x and y two variables, two equations, you can find out. So x it comes out to be equal to 158 kg, which is the amount of Fe_2O_3 and y that will be equal to 120 kg this will be amount of Fe_3O_4 .

This particular problem is bit tricky, but if you think one gets the feel how to do this particular problem or the problem which will come next. Now the problem says or some of the problems on roasting that may also tell you that find out the proximate analysis of the roast product. There are two types of analysis; one is the ultimate analysis another is the proximate analysis.

In the ultimate analysis, we report the elemental analysis, but when we say report proximate analysis that means, you have to report the analysis in terms of percentage minerals; so that is what the proximate analysis mean.

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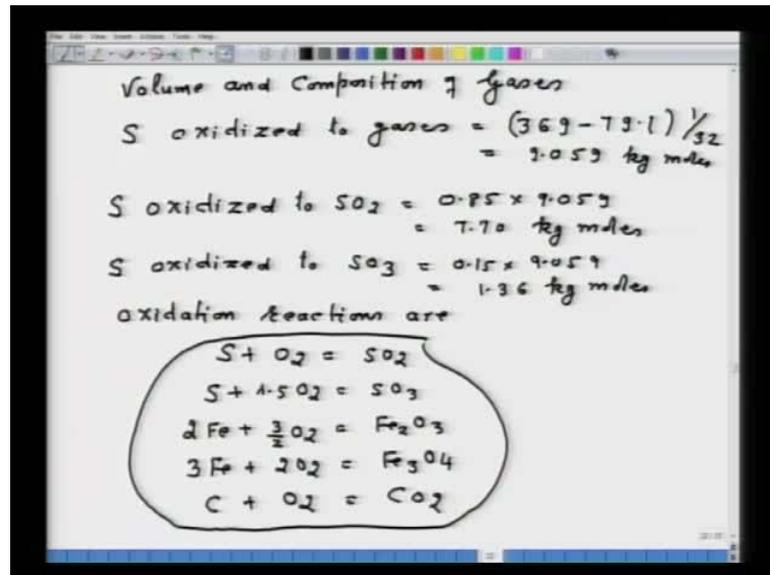


So, proximate analysis of roast product that we know, all the product; now all SiO_2 of the ore concentrate will enter into roast product, all Al_2O_3 of the ore concentrate will enter into roast product, all calcium oxide will enter into roast product.

We have known now all the weights. So, I can write down Cu_2S that is equal to 109.75, Al_2O_3 equal to 53 - these are all in kg - SiO_2 equal to 190 kg, CaO 3.2 kg, FeS 157.16 kg, Fe_2O_3 just now we have find out 158 kg, and Fe_3O_4 that is equal to 120 kg, do sum total and this sum total will give you 791 kg.

We want to find out percentage, it is very easy to find out the percentage of each and every thing, this is about what is asked. Now, you have to find out say volume and percentage composition of gases.

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Let us find out now, volume and percent composition of gases. Here it is also important that is which gases will form. Now air used is given to you 5000 cubic meter per ton of ore, we do not know whether it is excess air or it is just theoretical amount of air whatever air it is, so at the moment we can say only that gases will be comprising of SO₂ and nitrogen.

Because when air is used for roasting nitrogen has to be there, because nitrogen is not reacting anywhere; whether the excess gases will have excess oxygen are not in this particular problem, we have to see or we have to find out whether there will be excess oxygen or not. Now how do we go ahead, let us do little bit of exercise. First you have to find out sulphur oxidized to gases, that is equal to 369 is the total amount of sulphur that is supplied.

In the roast product it is 79.1, so oxidizing to gases if I divide by 32 then, I will be getting 9.059 kg moles that as gone to the gases. Now, the problem says 85 percent to SO₂ and 15 percent to SO₃. Have you understood what I am trying to do? Now I am trying to do? How much amount of stoichiometric amount oxygen would have been required if I want to roast 1000 kg of ore concentrate to the composition that we have found out.

If I calculate the stoichiometric amount of oxygen or stoichiometric amount of air and then I compare with the amount of air that is used in the process. Then I will know

whether the roasting process is with excess air or stoichiometric amount of air. For that I have to find out, what those roasting reactions or where oxidation is taken place? So one oxidation is sulphur to SO₂ and S O₃ is also forming.

So it is telling now here, we can say sulphur oxidized to SO₂ that will be equal to 0.85 into 9.059 that is equal to 7.70 kg moles. Then sulphur oxidized to SO₃ that will be equal to of course, you can subtract this one, this or whichever way I can also put it 0.15 into 9.059 that should give the same thing which I am going to write 1.36 kg moles.

Now we have to see, what other oxidation reactions. I will write down now all the oxidation reaction seeing the problem, so oxidation reactions are S plus O₂ that is equal to SO₂, S plus 1.5O₂ that is equal to SO₃. Now you know, have to list all oxidation reaction; 2Fe plus 3 by 2O₂ that is equal to Fe₂O₃, then 3 Fe plus 2O₂ that is equal to Fe₃O₄, then the one more reaction will take place because you are combusting carbon and 5 kg per ton of ore, so carbon plus oxygen that is equal to CO₂.

These are all the oxidation reaction that is occurring in this particular problem (Refer Slide Time: 44:00). So you have to find out, the stoichiometric oxygen required for all these reactions that is only we can find out. So for SO₂ and SO₃, we can straightaway find out 1 mole sulphur, 1 mole oxygen, 1 mole SO₂ and so on 1 mole sulphur, 1 and half moles of oxygen SO₃ and so on.

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Handwritten calculations on a whiteboard:

$$\begin{aligned} \text{St. O}_2 \text{ required} &= \underbrace{7.70}_{\text{S-SO}_2} + \underbrace{1.36 \times 1.5}_{\text{S-SO}_3} + \underbrace{\frac{158}{160} \times 1.5}_{\text{Fe-Fe}_2\text{O}_3} + \underbrace{\frac{120}{232} \times 2}_{\text{Fe-Fe}_3\text{O}_4} + \frac{5}{12} \\ &= 12.667 \text{ kg moles} \end{aligned}$$

$$\text{Actual O}_2 \text{ supplied} = \frac{5000 \times 0.21}{22.4} = 46.875 \text{ kg moles}$$

$$\text{Excess O}_2 \text{ in gases} = 46.875 - 12.667 = 34.21 \text{ kg mole}$$

$$\text{N}_2 = \frac{5000 \times 0.79}{22.4} = 176.34 \text{ kg moles}$$

So I will be writing down, stoichiometric oxygen required; now repeatedly I am telling if I say stoichiometric or I say theoretical amount its one and the same thing. So that will be equal to $7.70 + 1.36 = 1.5$, plus $158 / 160 = 1.5$ plus $120 / 232 = 2$ plus $5 / 12$. Now this is for S to SO_2 , this is for S to SO_3 - oxygen required, this is for iron to Fe_2O_3 , this is for iron to Fe_3O_4 and this one is for C to CO_2 . So this total, that is equal to 12.667 kg moles (Refer Slide Time: 45:10).

So we know that, that much stoichiometric amount of oxygen will be required to carry out the roasting and burning of carbon both reactions. Now, we are very clear that this much amount of oxygen would have been required if a stoichiometric amount of air would have been use for roasting, as well as for burning of carbon.

Now let us see, how much amount of oxygen is supplied actually? So, actual oxygen supplied how will you find out? I have given you the total amount of air that is 5000 meter cube, I multiply by 0.21 this is meter cube of oxygen and if I divide by 22.4 meter cube then, I will be getting 46.875 kg moles.

What does it mean? That means we have supplied 46.875 kg moles of oxygen to carry out roasting and combustion reaction. We were requiring only 12.667 kg moles of oxygen; therefore the system has excess oxygen in the roast gases. Therefore, excess oxygen in gases that will be equal to $46.875 - 12.667$, that will be equal to 34.21 kg mole.

Now, the gases will also nitrogen; remember, nitrogen is only gas which is inherit, it does not take part in any reaction. So therefore, the nitrogen in the system can be straightaway find out, $5000 / 0.79 = 22.4$ that will be equal to 176.34 kg moles.

So my dear friends that is how, the amount and that is how, the volume of gases are calculated. Remember, it is always there that is the key to solution of this problems is just consider stoichiometric amount of oxygen but, that is what you can calculate and then proceed with the problem.

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Gas	kg moles	%
SO ₂	7.70	3.50
SO ₃	1.36	0.63
O ₂	34.21	15.54
N ₂	176.34	80.14
CO ₂	0.42	0.19
Total	220.03	

Volume of gases = 220.03×22.4
 $= 4928.67 \text{ m}^3$
(1 atm & 273K)

Now, we can we can make the problem complete. So, volume of gases and composition we can find out both of them together, for example, SO₂, SO₃, O₂, N₂ and carbon dioxide. So here, that are in kg moles 7.70, 1.36, 34.21 176.34 and 0.42, this total it makes 220.03. Now percentage I can always calculate divide by this thing, straightaway we can do it 3.50, 0.63, 15.54, 80.14, and 0.19. I like to draw your attention, on the nitrogen content of the gases which are going out of the system.

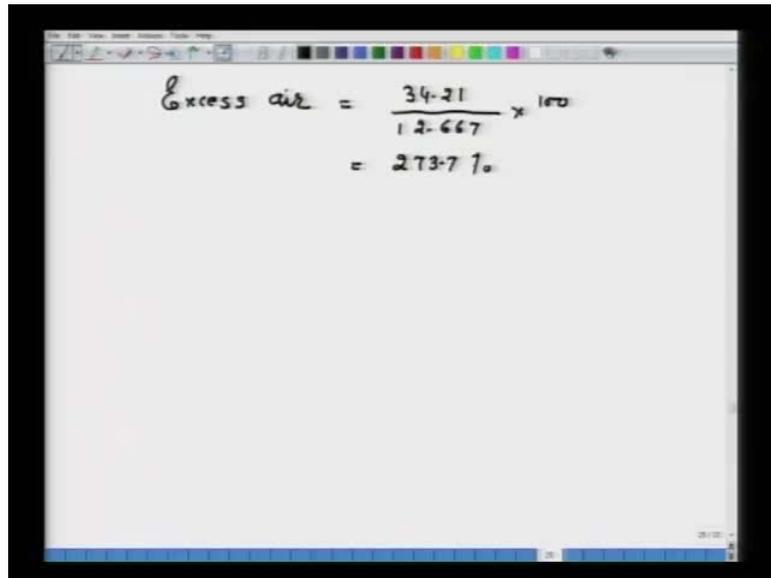
Remember though we have not performed at the moment heat balance, but you can understand now the heat which is taken out by the inherit gases. Now here, nitrogen is inherit you are carrying out roasting for example, 1000 degree celsius or 900 degree celsius, so this 80.14 percent of nitrogen will carry a large amount of feed from the roasting reactor.

So that is what the use of air, how much amount of excess air you will be using? It is a very important thing in case of pyro-metallurgical extraction, where oxygen for oxidation is derived from air.

Remember, so nitrogen is a substantial percentage and it will take substantial amount of heat; amount of the heat that is produced in the reactor. This is an important thing to understand the roll of air, the control of air because you are deriving oxygen from air and air contains 21 percent oxygen and 79 percent (()).

So this is the percentage, now we have to find out volume of gases volume of gases that is straightaway you can find out, 220.03 into 22.4 that will be equal to 4928.67 meter cube mind you, one atmosphere and 273 kelvin. Also you must have noted in this particular problem, that amount of air is more or less same to that amount of few gas. You had seen amount of air was 5000 meter cube, here 4928.67 meter cube, because part of the sulphur has gone to the Cu₂S and FeS.

(Refer Slide Time: 52:00)



The image shows a digital whiteboard with a toolbar at the top. The handwritten text on the board is:

$$\begin{aligned} \text{Excess air} &= \frac{34.21}{12.667} \times 100 \\ &= 273.7\% \end{aligned}$$

Now, next thing you have to calculate excess air. You have to calculate excess air and the excess air will be straightaway you can calculate 34.21 divide by 12.667 into 100 that will be equal to 273.7 percent.

In general, always excess air is calculated in terms of the theoretical air; so excess air will be either you say, excess air upon theoretical air or actual air minus stoichiometric amount of air divide by theoretical amount of air into 100, that will be excess air in percent or you can also report the excess air in terms of fraction, whichever way you want to call it but, excess air is always reported in terms of percentage theoretical air.