

Materials and Energy Balance in Metallurgical Processes

Prof. S.C.Koria

Department of Materials Science and Engineering

Indian Institute of Technology, Kanpur

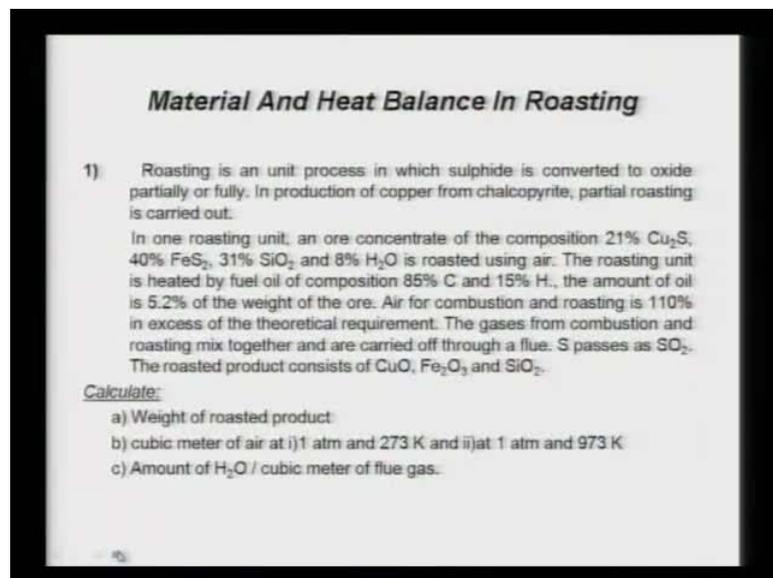
Module No. # 01

Lecture No. # 18

Exercises on Roasting

Let us take today some of the problems on Materials and Heat Balance in Roasting. So, what I have planned - first of all, I will project all the problems in the form of slide to you. I will read out the problem so that you can understand and you have enough time to think, and then I will proceed to solve the problems.

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Material And Heat Balance In Roasting

1) Roasting is a unit process in which sulphide is converted to oxide partially or fully. In production of copper from chalcopyrite, partial roasting is carried out.

In one roasting unit, an ore concentrate of the composition 21% Cu_2S , 40% FeS_2 , 31% SiO_2 and 8% H_2O is roasted using air. The roasting unit is heated by fuel oil of composition 85% C and 15% H., the amount of oil is 5.2% of the weight of the ore. Air for combustion and roasting is 110% in excess of the theoretical requirement. The gases from combustion and roasting mix together and are carried off through a flue. S passes as SO_2 . The roasted product consists of CuO , Fe_2O_3 and SiO_2 .

Calculate:

- Weight of roasted product
- cubic meter of air at i) 1 atm and 273 K and ii) at 1 atm and 973 K
- Amount of H_2O / cubic meter of flue gas.

So, here, you go with the problem number 1. Problem number 1 states - roasting is a unit process in which Sulphide is converted to Oxide partially or fully; that is what we have seen in the roasting. In production of Copper from Chalcopyrite, partial roasting is

carried out. In production of Copper from Chalcopyrite, always partial roasting is done; that means it is not deadly roasted.

Now, the problem is as follows: In one roasting unit, an ore concentrate of the composition 21 percent Cu_2S , 40 percent FeS_2 , 31 percent SiO_2 and 8 percent H_2O is roasted using air. You need an oxidizing medium, and Oxygen is derived from here uses as an oxidizing medium. The roasting unit is heated by fuel oil of composition 85 percent Carbon and 15 percent Hydrogen; the amount of oil is 5.2 percent of the weight of the ore. Air for combustion and roasting is 110 percent in excess of the theoretical requirement.

As I have said, the excess air can be given in two ways: either I say 210 percent of the theoretical air or I say 110 percent of the excess air. So, whichever way, one should be clear about how much amount of excess air is used. So, in this particular problem, the air for combustion and roasting - that is both combined, the requirement of air for combustion and roasting is given, which is 110 percent in excess of the theoretical requirement - for both combustion as well as roasting.

The gases from combustion and roasting mix together because when combustion and roasting occur simultaneously in a reactor, then the gases which are generated mix together and are carried off through a Flue. Flue means a passage through which the gases are carried out of the reactor. Now, Sulphur passes as Sulphur di oxide; that means there is no formation of Sulphur tri oxide - that is what the problem says.

The roasted product consists of the CuO , Fe_2O_3 and SiO_2 . Calculate: a) Weight of roasted product b) Cubic meter of air at 1 atmosphere and 273 Kelvin; second - at 1 atmosphere and 973 Kelvin; this I have given just to illustrate the volume of air that will be in a reactor because you are carrying out the roasting at high temperature. Third - amount of H_2O per cubic meter of flue gas. This is the problem number 1.

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Material And Heat Balance In Roasting

2) The flue gas in one particular roaster analyses (volume: %) is CO_2 2%, SO_2 7.4%, H_2O 0.6%, N_2 80% and O_2 10%.

The ore concentrate analyzes 10% Cu, 34% Fe, 15% SiO_2 and 41% S. During roasting 80% S is removed. The fuel is coal containing 75% C. The ore and fuel are separate, but the resulting gases mix.

Calculate:

- Amount of roasted product assuming it to contain Cu_2S , FeS, Fe_2O_3 and SiO_2 .
- The cubic meter of flue gases.
- Amount of fuel used.
- % excess air used for combustion and roasting.
- Theoretical ratio of air required for roasting to combustion.

Let us go to the problem number 2. Problem number 2 states – The flue gas in one particular roaster analyzes, say the analysis is given in volume percent. Now, wherever I have not given the analysis of gas and I have not written volume percent, the analysis of gases is always given in volume percent, unless otherwise stated. If it is stated, it is fine, but if it is not stated, then you have to take the volume of gases; they are given as volume percent. Whereas, the percentage composition of solid is given on weight percent, needless to mention. So, the flue gas in one particular roaster analyzes CO_2 - 2 percent, SO_2 - 7.4 percent, H_2O - 0.6 percent, Nitrogen- 80 percent, and Oxygen -10 percent.

The ore concentrate analyzes 10 percent Copper, 34 percent Iron, 15 percent SiO_2 and 41 percent Sulphur. During roasting, 80 percent of Sulphur is removed. The fuel is Coal containing 75 percent Carbon. The ore and fuel are separate, but the resulting gases mix. **What this means is that you are supplying through different inlets, the required amount of ore and required amount of fuel.** But then, the gases which are produced as a result of roasting and combustion mix together, and the volume is discharged from the reactor together.

Now, you have to calculate the following amount of roasted product, assuming it to contain: (a) Cu_2S , FeS, Fe_2O_3 and SiO_2 because this particular statement has to be given; otherwise different roasting products can be formed there. So, one has to specify what type of roasted product we are looking for in a particular problem. So, this

particular problem states that you have to calculate the amount of roasted product assuming it to contain whatever is written over here.

(b) The cubic meter of flue gases. Now, this cubic meter of flue gases is very important in order to design the flow passage because that much amount of flue gas must flow out of the reactor.

(c) Amount of fuel used.

(d) Percent excess air used for combustion and roasting.

(e) Theoretical ratio of air required for roasting to combustion.

This is what problem 2 is. I hope you must be able to grasp the problem and understand the problem before you proceed to solve them.

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Material And Heat Balance In Roasting

3) A zinc concentrate of composition ZnS 76%, PbS 7%, FeS₂ 7% and rest inert is roasted continuously with dry air. Assume ZnS converts to ZnO, PbS to PbO and FeS₂ to Fe₂O₄ and all S to SO₂ and SO₃, the gases leaving the system analyses 7% SO₂ and 2.5% SO₃ (volume basis)

Calculate: a) Rate of blowing of air (m³/min) when 100 tonne concentrate is roasted in 24 hrs b) excess air c) Analysis of flue gases.

d) Perform heat balance of the roasting/ton of concentrate, when reactants enter at 298 K. The products leave at 1100 K. Roasting is carried out at 1100 K.

4) In a multiple hearth roaster, copper concentrate of composition CuFeS₂ 33%, Cu₂S 7%, FeS₂ 34%, SiO₂ 19% and moisture 7% is roasted. All iron is oxidized to Fe₂O₃, and 50% of Cu oxidizes to CuO and rest to Cu₂S. The furnace gases analyze 12% O₂ and leaving the furnace at 900 K. The roast product is also discharged at 900 K. reactants enter at 298 K. No fuel is used.

Calculate:

- Weight of roasted product per tonne of concentrate
- % S in the roast product and express it as % of original S.
- Volume of air and excess air.
- Composition of the gases, &
- Heat balance of the process.

Problem number 3: A Zinc concentrate of composition Zinc Sulphide -76 percent, Lead Sulphide - 7 percent, FeS₂ - 7 percent and rest inert is roasted continuously with dry air. Assume Zinc Sulphide converts to ZnO, PbS to PbO, FeS₂ to Fe₃O₄, and all Sulphur to SO₂ and SO₃. Now, while solving the problem, this condition of roasting must be kept in mind because it is only through this condition that you can calculate the amount of roasted product. So, accordingly, you have to assume or you have to consider the

formation of the following products under the following condition: That means, ZnS converts to ZnO, PbS to PbO, FeS₂ to Fe₃O₄, and all Sulphur to SO₂ and SO₃. You cannot take it that all Sulphur is going to SO₂ while solving the problem because the problem says that the Sulphur is converted to SO₂ and SO₃ - both; that is an important thing.

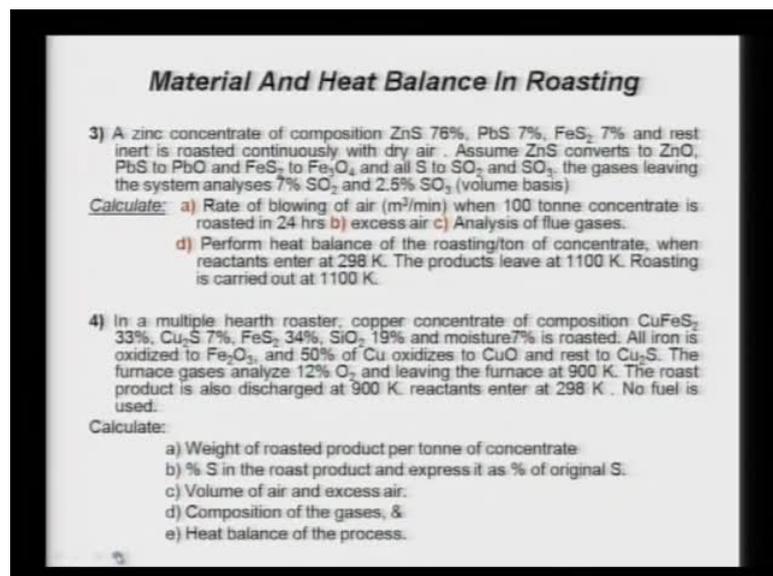
The gases leaving the system analyses 7 percent SO₂ and 2.5 percent SO₃ on volume basis. Calculate: (a) rate of blowing of air in meter cube per minute when 100 ton concentrate is roasted in 24 hours.

(b) Excess air - of course, excess air in percent, or you can report fraction also; does not matter.

(c) Analysis of flue gases.

(d) Perform heat balance of the roasting per ton of concentrate when reactants enter at 298 Kelvin. The products leave at 1100 Kelvin and roasting is carried out at 1100 Kelvin; that means, I mean whatever the temperature of the roasting, the products leave at 1100 Kelvin. Now, here the products consist of roast product as well as gases. So, both the products are leaving at 1100 Kelvin and the reactants enter at 298 Kelvin.

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Material And Heat Balance In Roasting

3) A zinc concentrate of composition ZnS: 76%, PbS: 7%, FeS₂: 7% and rest inert is roasted continuously with dry air. Assume ZnS converts to ZnO, PbS to PbO and FeS₂ to Fe₃O₄ and all S to SO₂ and SO₃, the gases leaving the system analyses 7% SO₂ and 2.5% SO₃ (volume basis)

Calculate: a) Rate of blowing of air (m³/min) when 100 tonne concentrate is roasted in 24 hrs b) excess air c) Analysis of flue gases.

d) Perform heat balance of the roasting/ton of concentrate, when reactants enter at 298 K. The products leave at 1100 K. Roasting is carried out at 1100 K.

4) In a multiple hearth roaster, copper concentrate of composition CuFeS₂: 33%, Cu₂S: 7%, FeS₂: 34%, SiO₂: 19% and moisture 7% is roasted. All iron is oxidized to Fe₂O₃, and 50% of Cu oxidizes to CuO and rest to Cu₂S. The furnace gases analyze 12% O₂ and leaving the furnace at 900 K. The roast product is also discharged at 900 K. reactants enter at 298 K. No fuel is used.

Calculate:

- Weight of roasted product per tonne of concentrate
- % S in the roast product and express it as % of original S.
- Volume of air and excess air.
- Composition of the gases, &
- Heat balance of the process.

Problem number 4 is also on the heat balance. In a multiple hearth roaster, Copper concentrate of composition Chalcopyrite that is CuFeS_2 - 33 percent, Cu_2S which is Chalcocite is 7 percent, FeS_2 - 34 percent, SiO_2 - 19 percent, and moisture 7 percent, is roasted. Multiple hearth roaster is a typical roasting reactor for Chalcopyrite concentrate. It consists of several hearth and material from one hearth fall into other hearth before the roast product discharge at the other end of the roaster.

Here, the problem says that all Iron is oxidized to Fe_2O_3 - this condition you have to keep in mind; 50 percent of Copper oxidizes to CuO and rest to Cu_2S . The furnace gases analyses 12 percent Oxygen leaving the furnace at 900 Kelvin. The roast product is also discharged at 900 Kelvin; reactants enter at 298 Kelvin; no fuel is used. Here, we are not using any fuel in this particular problem; however, in a particular problem, how the fuel can be used, accordingly it can be considered.

What you have to calculate: (a) Weight of roasted product per ton of concentrate.

(b) Percentage of Sulphur in the roast product and express it as percentage of original Sulphur.

(c) Volume of air and excess air.

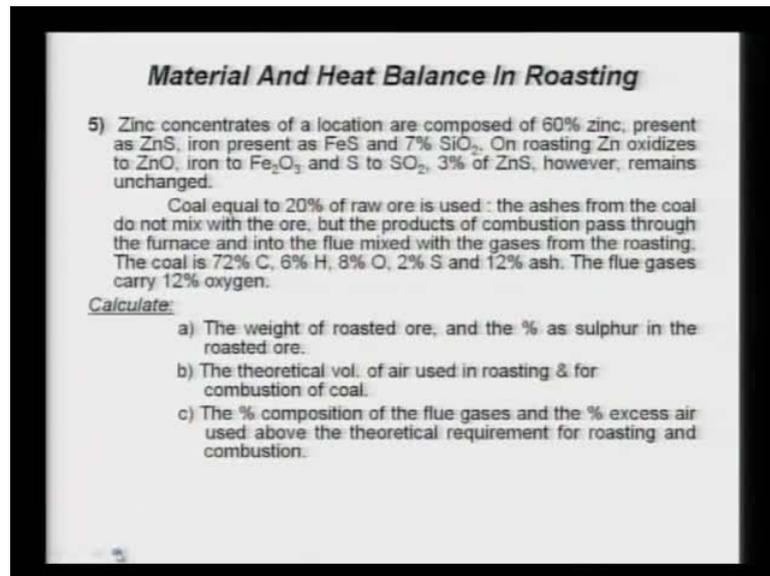
(d) Composition of the gases.

(e) Heat balance of the process.

So, these two problems - problem 3 and 4, they are given to train you in the heat balance aspect of the roasting.

I hope you must be remembering the heat balance. Heat input has to be calculated and heat output has to be calculated; both has to be balanced to see whether heat deficit is there or heat excess is there - That is the objective of roasting.

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Material And Heat Balance In Roasting

5) Zinc concentrates of a location are composed of 60% zinc, present as ZnS, iron present as FeS and 7% SiO₂. On roasting Zn oxidizes to ZnO, iron to Fe₂O₃ and S to SO₂, 3% of ZnS, however, remains unchanged.

Coal equal to 20% of raw ore is used: the ashes from the coal do not mix with the ore, but the products of combustion pass through the furnace and into the flue mixed with the gases from the roasting. The coal is 72% C, 6% H, 8% O, 2% S and 12% ash. The flue gases carry 12% oxygen.

Calculate:

- The weight of roasted ore, and the % as sulphur in the roasted ore.
- The theoretical vol. of air used in roasting & for combustion of coal.
- The % composition of the flue gases and the % excess air used above the theoretical requirement for roasting and combustion.

Problem 5: Zinc concentrates of a location are composed of 60 percent Zinc present as ZnS. Iron presents as FeS; mind you not FeS₂, and 7 percent SiO₂. On roasting, Zinc oxidizes to ZnO, Iron to Fe₂O₃, and Sulphur to SO₂. 3 percent of Zinc Sulphide however remains unoxidized; please keep in mind while solving the problem, 3 percent of Zinc Sulphide remains unoxidized or unchanged, whichever way you want to say. Coal equal to 20 percent of raw ore is used; the ashes from the Coal do not mix with the ore, but the products of combustion pass through the furnace and into the flue, and mix with the gases from the roasting. The ashes generally mean ash plus percentage Carbon.

What the problem says is that you are not to bother about where the ash will go. So, the problem simply says - the ashes and the Coal do not mix. They remain in the reactor or somewhere else, but the products of combustion pass through the furnace and into the flue, and mix with the gases from the roasting.

The Coal is 72 percent Carbon, 6 percent Hydrogen, 8 percent Oxygen, 2 percent Sulphur and 12 percent ash. What is said here is that you need not bother about the ash content because whatever ash is falling into the reactor is not being carried away by the products of roasting as well as combustion. The flue gases carry 12 percent Oxygen.

What you have to calculate: (a) The weight of roasted ore and the percent of Sulphur in the roasted ore.

(b) The theoretical volume of air used in roasting and for combustion of Coal. Remember - it is said theoretical volume of air. What is meant by theoretical volume of air? That means, you will be writing down the stoichiometric reactions - that is balanced chemical reaction. Then, from the balanced chemical equation you will be calculating; whatever is required to calculate. (c) The percent composition of the flue gases and the percent excess air used above the theoretical requirement for roasting and combustion. So you have to calculate the (c) also there; some amount of thinking is required.

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Material And Heat Balance In Roasting

6) Galena concentrates are composed of PbS , FeS_2 , and SiO_2 . The moist concentrates contain 8% H_2O , 28% SiO_2 , and 11% S. They are roasted down to 4% S, the roasted ore being composed of FeS , PbS , and PbO and SiO_2 , the last two combined as a silicate.

The furnace is fired with coal containing: 72% C, 4% H, 8% O, 3% H_2O , 13% ash. The furnace gas (analyzed dry) are 3% SO_2 , 3.5 CO_2 , 10.5 O_2 . Neglect moisture in the air.

Calculate: Per ton of moist concentrates:

- The weight of roasted ore.
- The volume of furnace gases, including moisture.
- The weight of coal used.

Problem sixth: Galena concentrates are composed of Lead Sulphide, FeS_2 and SiO_2 . The moist concentrate contains 8 percent H_2O , 28 percent SiO_2 and 11 percent Sulphur. They are roasted down to 4 percent Sulphur. The roasted ore are being composed of FeS , PbS and PbO and SiO_2 , the last two combined as a silicate.

The furnace is fired with Coal containing: 72 percent Carbon, 4 percent Hydrogen, 8 percent Oxygen, 3 percent H_2O and 13 percent ash. Needless to say again, ash does not mix with the products of roasting or combustion because ash is a solid product and it just falls down. The furnace gas analyzed dry are 3 percent SO_2 , 3.5 percent CO_2 , and 10.5 percent O_2 . Neglect moisture of the air.

Calculate: Per ton of moist concentrate:

(a) The weight of roasted ore. You can call the weight of roasted ore or weight of roasted product; they all convey the same meaning; or even sometime weight of teslin()
- that is also a term used for roasted product.

(b) The volume of furnace gases including moisture.

(c) The weight of Coal used.

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Material And Heat Balance In Roasting

7) The lead concentrate of a particular plant analyzes PbS 83.1%, FeS 7.9%, SiO₂ 3% and remaining CaCO₃. The concentrate is treated by roast-reaction method to produce Pb. The reaction during roasting stage are:

$$2\text{PbS} + 3\text{O}_2 = 2\text{PbO} + 2\text{SO}_2$$

$$\text{PbS} + 2\text{O}_2 = \text{PbSO}_4$$

$$4\text{FeS} + 7\text{O}_2 = 2\text{Fe}_2\text{O}_3 + 4\text{SO}_2$$

At the end of roasting stage all FeS is oxidized, but some PbS remains. The formation of PbSO₄ and PbO is in the ratio 1:3 by weight. During the reaction stage following reactions occur:

$$\text{PbS} + 2\text{PbO} = 3\text{Pb} + \text{SO}_2$$

$$\text{PbS} + \text{PbSO}_4 = 2\text{Pb} + 2\text{SO}_2$$

Both of the above reaction continues till all PbS, PbO, PbSO₄ has been consumed.

Find:

- Weight of the ore at the end of roasting stage and its proximate analysis/1000 Kg concentrate.
- % S eliminated at the end of roasting stage.
- Gases formed during: (i) roasting stage (ii) reaction stage in m³ at 1atm and 273 K.

The seventh problem: The lead concentrate of a particular plant analyzes PbS - 83.1 percent, FeS - 7.9 percent, SiO₂ - 3 percent and remaining is Calcium Carbonate. The concentrate is treated by roast reaction method to produce lead. Now, there is earlier used the method which is called roast reaction. Roasting is followed by a reaction to produce slag.

The reaction during roasting stages are: 2 PbS plus 3 O₂ that is equal to 2 PbO plus 2 SO₂, PbS plus 2O₂ equals PbSO₄ and 4 FeS plus 7O₂ that is equal to 2Fe₂O₃ plus 4SO₂. At the end of the roasting stage, all FeS is oxidized, but some PbS remains. The formation of PbSO₄ and PbO is in the ratio 1 is to 3 by weight.

During the reaction stage, following reactions occurs: PbS plus 2PbO that is equal to 3Pb plus SO₂ and PbS plus PbSO₄ that is equal to 2Pb plus 2SO₂. Both of the above reaction continues till all Pb, Sulphide, PbO, PbSO₄ has been consumed.

Now, here, in order to solve the problem, you have to read between the lines. Be very careful while understanding whatever is said in the problem because the problem solving trick or the key to solve the problem is inherent in the statement of the problem, provided you read the problem carefully and you understand in between the lines - that is important.

Find: a) Weight of the ore at the end of roasting stage and its proximate analysis per 1000 Kg concentrate. Now, proximate analysis, as I have said earlier also, that means you have to find out the analysis in terms of minerals because when you have the solid product, there is no free Sulphur or free Oxygen, or whatever is there. So, you have to find out the percentage of minerals.

b) Percentage Sulphur eliminated at the end of roasting stage

c) Gases formed during: a) roasting stage b) reaction stage in meter cube at 1 atmosphere and 273 Kelvin.

So, this is the seventh and I believe it is the last problem. The next slide - as usual it gives you the data on material and heat balance in roasting because you may be requiring several data in order to do the heat balance. You may find some data are more and some data as less, but all the data are given over here.

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Material And Heat Balance In Roasting	
<i>Use the following data in all the problems:</i>	
$Zn + \frac{1}{2} O_2 = ZnO$	$\Delta H_R = -83500 \text{ kcal/kg.mol}$
$Pb + \frac{1}{2} O_2 = PbO$	$\Delta H_R = -52500 \text{ kcal/kg.mol}$
$3Fe + 2O_2 = Fe_3O_4$	$\Delta H_R = -266000 \text{ kcal/kg.mol}$
$S + O_2 = SO_2$	$\Delta H_R = -70940 \text{ kcal/kg.mol}$
$S + 1.5 O_2 = SO_3$	$\Delta H_R = -93900 \text{ kcal/kg.mol}$
$Cu + \frac{1}{2} O_2 = CuO$	$\Delta H_R = -38500 \text{ kcal/kg.mol}$
$2Fe + 1.5 O_2 = Fe_2O_3$	$\Delta H_R = -198500 \text{ kcal/kg.mol}$
$2Cu + S = Cu_2S$	$\Delta H_R = -18950 \text{ kcal/kg.mol}$
$H_{1100} - H_{298} ZnO$	$= 9500 \text{ kcal/kg.mol}$
$H_{1100} - H_{298} PbO$	$= 10800 \text{ kcal/kg.mol}$
$H_{1100} - H_{298} Fe_3O_4$	$= 40350 \text{ kcal/kg.mol}$
$H_{1100} - H_{298} SO_2$	$= 9397 \text{ kcal/kg.mol}$
$H_{1100} - H_{298} SO_3$	$= 13860 \text{ kcal/kg.mol}$

For example: the formation of Zinc oxide, lead oxide, Fe₃O₄, SO₂, SO₃, CuO, Fe₂O₃ and Cu₂S - they are all given in terms of delta H R; their respective values are shown and given to you. So, you may use those values in order to do the heat balance.

At the same time, what is been done over here, the products of roasting as well as gases, that means roast product and the gases - their heat content is given at the temperature at which they are leaving. Otherwise, you could have solved by using: the CP value of ZnO, CP of PbO, CP of Fe₃O₄, CP of SO₂, CP of SO₃; appropriate integrate from 298 to the temperature at which they are discharging and you get the heat content.

Here, instead of that, just to illustrate the problem, because if I do that problem by taking CP into consideration, it will take a very long time. That is why I have selected the path to give you the heat content directly because the objective is to illustrate the heat balance. However, it is quite possible that if the product leaves in between temperature, for example, 1150 degree Kelvin, then you have to integrate from 298 to 1150 and get the value of heat content.

So, here, just to cut short, I have given you the value of heat content directly at the temperature of discharge of roast product as well as gaseous product. So, these values are given; so, ZnO, PbO, Fe₃O₄, SO₂ and SO₃.

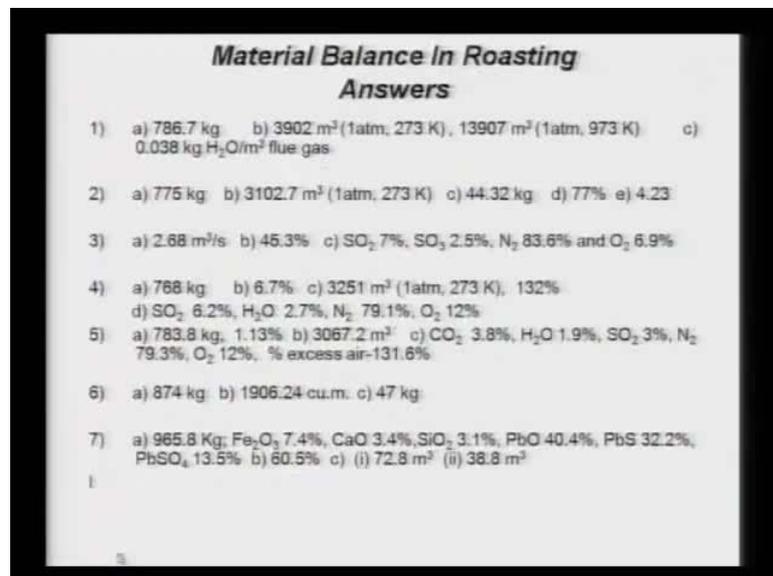
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Material And Heat Balance In Roasting		
$H_{1100} - H_{298}$	Zn	= 7400 kcal/kg.mol
$H_{1100} - H_{298}$	Pb	= 6640 kcal/kg.mol
$H_{1100} - H_{298}$	Fe	= 7160 kcal/kg.mol
$H_{1100} - H_{298}$	S	= 6860 kcal/kg.mol
$H_{1100} - H_{298}$	O ₂	= 6208 kcal/kg.mol
$H_{1100} - H_{298}$	N ₂	= 5916 kcal/kg.mol
$H_{900} - H_{298}$	N ₂	= 4358 kcal/kg.mol
$H_{900} - H_{298}$	O ₂	= 4602 kcal/kg.mol
$H_{900} - H_{298}$	H ₂ O _(g)	= 15762 kcal/kg.mol
$H_{900} - H_{298}$	SO ₂	= 6843 kcal/kg.mol
$H_{900} - H_{298}$	SiO ₂	= 8950 kcal/kg.mol
$H_{900} - H_{298}$	CuO	= 7320 kcal/kg.mol
$H_{900} - H_{298}$	Fe ₂ O ₃	= 20020 kcal/kg.mol
$H_{900} - H_{298}$	Cu ₂ S	= 11730 kcal/kg.mol
$H_{900} - H_{298}$	Cu	= 7170 kcal/kg.mol
$H_{900} - H_{298}$	Fe	= 4680 kcal/kg.mol
$H_{900} - H_{298}$	S	= 5102 kcal/kg.mol

Next, all values are given. Here also, you will find the various values of the product which are been discharged, or for example, Zinc, lead, Iron, Sulphur, Oxygen, Nitrogen and H₂O; all values you will find; they are given over here.

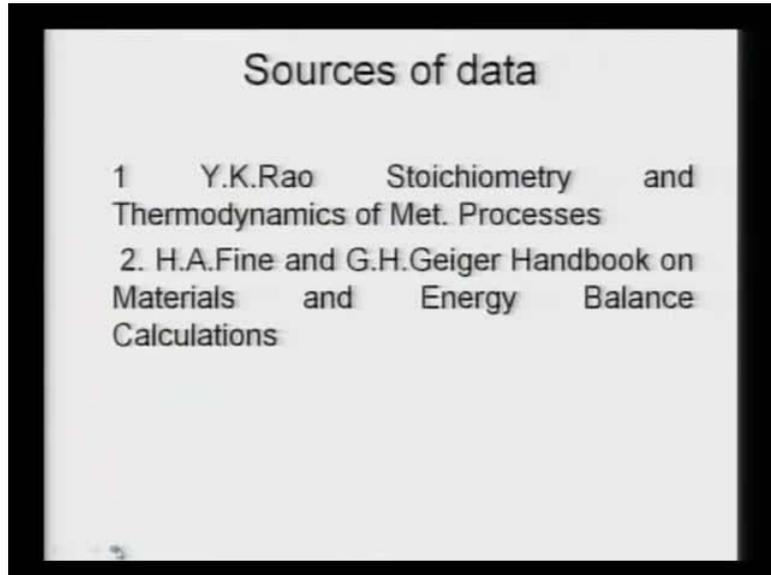
So, as and where you require solving the problem, you can take these values, or if you want to do further good practice, I will suggest you to go to the standard book, the reference I am giving you after this, and get the value of CP; integrate the CP value from 298 to the respective temperature of discharge of the product and get the heat content in that. That is also the most correct way to do that.

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So, the last slides give you the answers which I believe you will not be seeing before you solve the problem. The last slide gives you the references which you can use to find out the data.

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If you want more data or if some data I have missed, I do not think I have missed any data, you can see the data from these particular books. Particularly, the book of Y.K.Rao, it also gives you data of CP. H.A.Fine and G.H.Geiger - These two books you can consult for the data.

Now, I will go one by one and discuss these problems, and wherever I feel the need, I will solve the whole problem for you.

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1) 1000 kg ore concentrate

Input	kg
Cu_2S	210
FeS_2	400
SiO_2	310
H_2O	80

Fuel oil: 85% C, 15% H, 52 kg

Roasted Product:

CuO	
Fe_2O_3	
SiO_2	

Flue gas:

CO_2	
N_2	
O_2	
SO_2	
H_2O	

Atomic weights: $\text{Cu} = 64$, $\text{Fe} = 56$, $\text{Si} = 28$, $\text{S} = 32$, $\text{O} = 16$

Chemical equations:

$$\text{Cu}_2\text{S} + 2\text{O}_2 = 2\text{CuO} + \text{SO}_2$$
$$2\text{FeS}_2 + 5\text{SiO}_2 = \text{Fe}_2\text{O}_3 + 4\text{SO}_2$$

Results:

CuO	= 210 kg
Fe_2O_3	= 266.7 kg
SiO_2	= 310 kg
Total	786.7 kg

Ans

So, here, let us see the problem number 1. The problem number 1 says - you are given the composition of the concentrate and the roasted product which are to be formed. So, if I just illustrate in the form of a block diagram, this goes this way (Refer Slide Time: 21:00). That means, here, let me take the basis as 1000 Kg ore concentrate. Now, I am directly writing Cu₂S, FeS₂, SiO₂ and H₂O. So, Cu₂S is given 210 Kg, 400 Kg, 310 Kg and 80 Kg for FeS₂, SiO₂ and H₂O respectively. The problem also says that fuel oil is used. Fuel oil composition is 85 percent Carbon and 15 percent Hydrogen. Its amount is 52 kg.

The problem says that the roasted product contains CuO, Fe₂O₃ and SiO₂. Now, by seeing the roasting process and the various elements that are involved, one can see that the flue gases will comprise of CO₂, N₂, Oxygen, SO₂ and H₂O; that is what the problem says. Now, you have to find out the roasted product. What will I do? I have to just write down the stoichiometric equation. For example: if I see, say Cu₂S plus 2O₂ that is equal to 2CuO plus SO₂ and 2FeS₂ plus 5.5 O₂ that is equal to Fe₂O₃ plus 4SO₂.

Now, let me tell you that the atomic weight which I am using in this problem - for Copper - it is 64, for Iron, I will be using 56, for silicon, though you may not need, but still 28, Sulphur - 32, and Oxygen as 16. These are the atomic weights that I will be using to solve this problem.

Now, straight away, you can convert into mole or whichever way you want. I mean writing down straight away because this is very simple. CuO - that comes 210 Kg, Fe₂O₃ is equal to 266.7 Kg. Always remember - because roasting is an oxidation process, if the ore concentrate contains SiO₂, Al₂O₃ or Calcium oxide, or whatever these type of oxides, they will be transferred as it is into the roasted product because there is no opportunity to react anywhere; they neither oxidize; at the most, they can combine here and there. So, as such, the SiO₂ of the ore concentrate will directly go to the roasted product; so, it will be 310 Kg. So, the total of roasted product is equal to 786.7 Kg and this is what the required answer is.

So, we have to calculate now, cubic meter of air that is required for roasting and combustion. Well, it is straight forward. I had already written the chemical equations and according to stoichiometric equation, you can straight away calculate the moles of

Oxygen for roasting. Similarly, you can write down the combustion equation. The combustion equation contains Carbon and Hydrogen. So, C plus O₂ is equal to CO₂ and H₂ plus half O₂ is H₂O. So, I will leave this exercise to you so that you should be able to do it.

(Refer Slide Time: 26:05)

(Theor): Total moles of O₂ required for
Combustion & roasting = 17.42 moles (kg).

Theo. air = 1858 m³ (1 atm, 273 K)

Actual amount of air = 3902 m³ (1.1, 273 K)

kg moles

Flue gas	CO ₂	3.68
	N ₂	13.8
	O ₂	19.16
	H ₂ O	8.34
	SO ₂	8
		<hr/>
		177.18 kg moles.

So, what I will be getting now? Total moles of Oxygen required for combustion and roasting, I am writing this, so the total moles will be 17.42 moles; rather, I will say Kg moles, per Kg moles. So, mind you these are the theoretical; I have put it theoretical. So, from here, we can calculate the theoretical air that will be equal to 1858 meter cube at 1 atmosphere and 273 Kelvin.

Now, the problem says cubic meter of air and also it says that you are using some 110 percent air. So, if you want to calculate total amount of air, you cannot calculate unless you calculate the theoretical amount of air. That was the need of calculation of theoretical amount of air because it is 110 percent excess here; so, that means 210 percent of the theoretical air. Now, the actual amount of air which the problem wants to know will be equal to 3902 meter cube; of course, at 1 atmosphere and 273 Kelvin. That is the answer for the problem 1, part b.

Now, the part c says amount of H₂O per cubic meter of flue gas. Now, without calculating the amount of flue gas, you cannot calculate the amount of H₂O that is

present. So, this exercise also, I will leave on you. I will just write down the flue gas that will comprise of CO₂, N₂, O₂, H₂O and SO₂ - all that you can calculate. The necessary information is already given in Kg moles and that will be 3.68, Nitrogen - 138, Oxygen - 19.16. Now, remember this is the excess Oxygen because theoretical Oxygen will not be appearing in the gases; it will be utilized for the roasting and combustion. Only the excess Oxygen will appear in the flue gases. So, H₂O is 8.34 and SO₂ is 8. So, if you sum total it, then it will be 177.18 Kg moles.

Now, we have to calculate the amount of H₂O per cubic meter of the gas. So, you have to multiply by 22.4 and accordingly you will get the answer. So, the answer is 0.038 Kg H₂O per meter cube of flue gas.

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Ans 0.038 kg H₂O | m³ flue gas

$\frac{2}{2}$ 10% Cu = 34% Fe 15% SiO ₂ 41% S	<div style="border: 1px solid black; width: 100px; height: 100px; margin: 0 auto;"></div>	flue gas CO ₂ 2% SO ₂ 7.4% H ₂ O 0.6% N ₂ 80% O ₂ 10%
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1000 kg ore Concentrate

Amount of roast product

SiO₂ = 150

S oxidized to SO₂ = 328 kg

82 kg of S is in roast product

So, let us go to problem number 2. The problem number 2 is that the flue gas in one particular roaster, analyses; the analysis is given. So, here, let me again illustrate a material balance box. So, here the flue gas analysis is given.

Flue gas is analyzing CO₂, SO₂, H₂O, N₂ and O₂. Now, CO₂ is given 2 percent, SO₂ is 7.4 percent, H₂O is 0.6 percent, Nitrogen is 80 percent, and Oxygen is 10 percent. Also the problem says, the concentrate is analyzing: 10 percent Copper, 34 percent Iron, 15 percent SiO₂, and 41 percent Sulphur. Let us get the basis; so, basis is again 1000 Kg ore concentrate.

Now, first of all, you have to calculate amount of roast product. So, let us first calculate the amount of roast product. Now, remember, for this calculation, you have to read the problem in between the lines because there are several conditions given. So, first of all the SiO₂ which is 150 Kg, all SiO₂ will enter into roast product; about Sulphur, some conditions are given.

So, we can say, first of all Sulphur is oxidized to SO₂ and that is equal to 328 Kg. Therefore, 82 Kg of Sulphur is in roast product according to the problem. It is in roast product because of the statement which is given in the problem.

(Refer Slide Time: 32:51)

Handwritten calculations on a whiteboard:

$$\begin{aligned} \text{Amount of Cu}_2\text{S} &= \frac{160}{128} \times 100 = \underline{125 \text{ kg}} \\ \text{S in Cu}_2\text{S} &= 25 \text{ kg} \\ \text{S with FeS} &= 82 - 25 = 57 \text{ kg} \\ \text{Amount of FeS} &= \frac{57}{32} \times 88 = \underline{156.75 \text{ kg}} \\ \text{Fe in FeS} &= 99.75 \text{ kg} \\ \text{Fe with Fe}_2\text{O}_3 &= 340 - 99.75 = 240.25 \text{ kg} \\ \text{Amount of Fe}_2\text{O}_3 &= \underline{343.2 \text{ kg}} \\ \text{Amount of roast product} &= 774.95 \text{ kg Ans} \end{aligned}$$

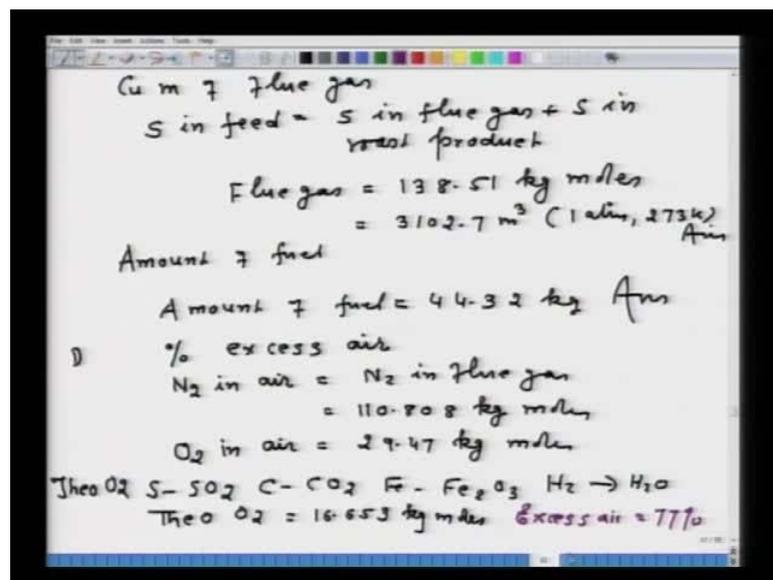
Now, since 82 Kg of Sulphur is in the roast product, so from here, we can find out amount of Cu₂S because the roast product will contain Cu₂S; so amount of Cu₂S will be 160 upon 128 into 100; 100 Kg is the Copper. So, amount of Cu₂S - that is equal to 125 Kg.

Now, you have to find out Sulphur in Cu₂S. After finding out Sulphur in Cu₂S, you have to find out Sulphur with FeS. So, Sulphur in Cu₂S will be 25 Kg. Then Sulphur with FeS - 82 Kg of Sulphur is in the roast product; 82 minus 25 - that is equal to 57 Kg. So, this Sulphur will be in the form of FeS. So, the amount of FeS is equal to 57 upon 32 into 88 - that will be equal to 156.75 Kg. This is the amount of FeS; this is the amount of Cu₂S. (Refer Slide Time: 34:08)

Now, Iron is as Fe_2O_3 . So, we have to find out now, how much Iron left over so that it can form a Fe_2O_3 . So, for that, to find out Iron in FeS - that will be 99.7 Kg. So, how will you find out Iron with Fe_2O_3 ? You know the total Iron which is 340 Kg. If you subtract this 99.75 Kg, so this Iron has to go as Fe_2O_3 . So, Iron in Fe_2O_3 will be 340 minus 99.75. So, that makes 240.25 Kg. That Iron will go as Fe_2O_3 . So, amount of Fe_2O_3 will be equal to 343.24 Kg. That means, all that you have to multiply by the molecular weight of Fe_2O_3 and so on. This is the amount of Fe_2O_3 that will be in the roast product. So, we have calculated all the amounts. So, the amount of roast product, you have to sum total all the roast products: Fe_2O_3 , Cu_2S , FeS and SiO_2 ; so, that will be equal to 774.95 Kg and that is the answer for this particular part.

Now, next we have to calculate cubic meter of flue gases.

(Refer Slide Time: 35:59)



Now, for this, you have to do Sulphur balance. That is Sulphur balances are Sulphur in feed is equal to Sulphur in flue gas plus Sulphur in roast product. So, if you do this balance, then the amount of flue gas - that you can do yourself. This balance that comes out to be equal to 138.51 Kg moles because you assume x is the amount of flue gas and accordingly you can proceed with the balance. So, this will be equal to 3102.7 meter cube at 1 atm and 273 Kelvin.

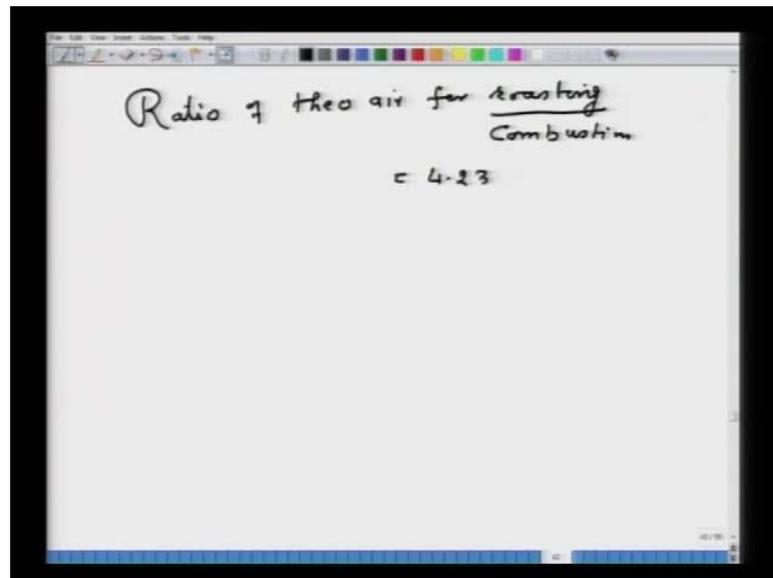
Next, you have to find out amount of fuel. How will you find out amount of fuel? In that, you calculate the amount of CO₂ because the CO₂ is solely coming from combustion of Carbon of the fuel. So, from that, you can find out the amount of fuel. I am straight away writing the answer and I leave it on you. Amount of fuel will be equal to 44.32 Kg. All that you have to find out CO₂ and do with the Carbon balance and you can find out d part, this is the answer and this is the answer for b part.

Now, the d part (Refer Slide Time: 35:59) you have to calculate percent excess air. Now, in calculating percent excess air, first of all you calculate the total amount of air; that is you do Nitrogen balance, say, Nitrogen in air that is equal to Nitrogen in flue gas. So, if you do that balance then Nitrogen in air comes 110.808 Kg moles.

Now, you can find out Oxygen in air. This is the actual amount of Oxygen which is being used - that will be 29.74 Kg moles. Now, this is the total amount of Oxygen which is supplied. In order to know the excess, what you have to do? You have to find out the theoretical amount of air. Now, the theoretical amount of air consists of combustion of Sulphur to SO₂, Carbon to CO₂, then Fe to Fe₂O₃ and H₂ to H₂O. Now, mind you, this H is on the fuel.

So, if you calculate all of these, then, that will give you the theoretical Oxygen. If you do this calculation, then you will get theoretical Oxygen and this theoretical Oxygen will come out to be equal to 16.653 Kg moles.

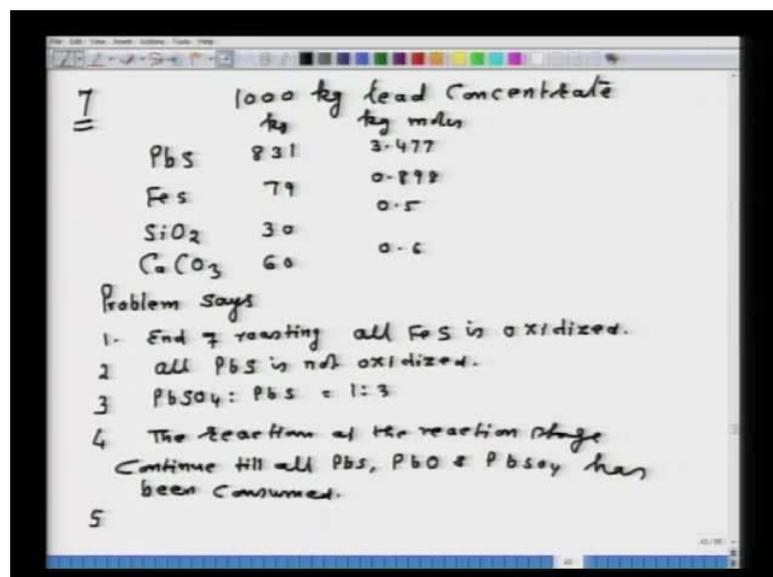
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So, now the excess air will be... you have to divide both. That will be around 77 percent; that will be the excess air. You have to calculate the ratio of theoretical air, say, ratio of theoretical air for roasting upon combustion. This you can do yourself; I will leave it on you. This ratio will come out to be equal to 4.23; so, that is the problem number 2.

Now, I illustrate straight away in this sequence of material balance, the problem number 7.

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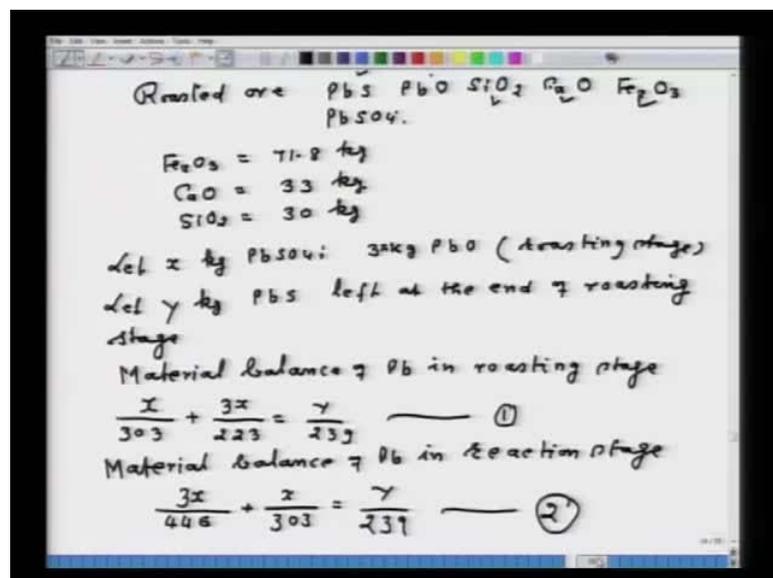


Now, the problem number 7 is typically a so called roast reaction method to produce lead. Lead concentrate analysis is given; roasting and reaction stage equations are given; further conditions are given. So, let us consider 1000 Kg lead concentrate. Now, again I am telling you, this problem needs very careful reading in between the lines - that is very important. So, I can write here, PbS, FeS, SiO₂ and calcium Carbonate.

PbS is 831, FeS is 79, SiO₂ is 30 and calcium Carbonate is 60 those are in Kg; here, I am writing in Kg moles - PbS is 3.477, FeS is 0.898, SiO₂ is 0.5 and calcium Carbonate is 0.6. Now, the roasting stage reactions are given and reaction stage equations are given.

Now, the problem says the following: first - end of roasting stage - all FeS is oxidized. Second - it says all PbS is not oxidized; that is what the problem says. Third - it says that the PbSO₄ is to PbS; the ratio is 1 is to 3 by weight; that is what the problem says. Fourth - it says that the reactions at the roasting and at the reaction stage continue till all PbS, PbO and PbSO₄ is consumed. So, the reactions at the reaction stage continue till all PbS, PbO and PbSO₄ has been consumed. Now, this is all given in the problem. I am writing so that you understand.

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Again fifth problem says, all PbS is reduced to lead by reaction stage. All PbS is reduced to Pb by the equations which you have been written under the reaction stage. Now, I proceed say, roasted ore will contain PbS, PbO, SiO₂, CuO, Fe₂O₃ and PbSO₄.

Now, say, I can calculate straight away Fe_2O_3 - that will be equal to 71.8 Kg; you can calculate; there is no problem. Calcium oxide will go as it is - 33 Kg, now SiO_2 - that is equal to 30 Kg.

So, we know SiO_2 , we know Calcium oxide, we know Fe_2O_3 , but the calculation of PbS , PbO and PbSO_4 requires a careful thinking because you have to consider both reactions, So, let us consider now, x Kg PbSO_4 which means $3x$ Kg; $3x$ Kg is PbO at the roasting stage - that is given in the problem.

Now, let us say, let y Kg PbS left at the end of roasting stage, what will I do now? Now, you have to do material balance of lead in both the stages; in the roasting stage as well as the reaction stage. So, material balance of lead in roasting stage is x upon 303 plus $3x$ upon 223 plus y upon 239 and that is equal to 831 upon 239 - that is equation 1.

Now this equation, remember it is done on the lead balance. This x upon 303 is for PbSO_4 , this is PbO , this is lead Sulphide and this is what the total lead in the charge one (Refer Slide Time: 47:10). So, material balance of lead in reaction stage is equal to $3x$ upon 446 plus x upon 303 and that is equal to y upon 239 - this is equation 2.

Now, if you solve both the equations simultaneously, then you will get the value of x and y . Now, these two are the important things. These two equations which I have formed for you, that you can also form, provided, you read the statement of the problem very clearly and understand what is given in the problem. Otherwise, you may get some difficulties. Now, we have equation 1 and 2. Now, we can solve those equations. If I solve this equation, then x comes out to be equal to 130 Kg. This is the weight of PbSO_4 . Y is equal to 311 Kg. This PbS is left and PbO is 3 is to 1; that is, 3 into 130 - that is equal to 390 Kg.

So, I mean, you know, how to calculate Sulphur which was there earlier and now how much it is eliminated? Whatever is there in the roasting ore, you have to subtract that. So, percentage of Sulphur eliminated as asked in the problem is equal to 60.5 percent; this is the Sulphur. Now, the gase formed during the roasting stage is equal to 72.8 meter cube and the reaction stage is 38.8 meter cube.

Now, with regard to percent Sulphur eliminated, you can also calculate percent PbS which remains unchanged at the end of roasting stage. You can also calculate that; it will come out to be equal to 37.4 percent. So, this is the solution from problem 7.

I appeal to all of you that, please attempt the problem yourself before looking into the solution of the problem.