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

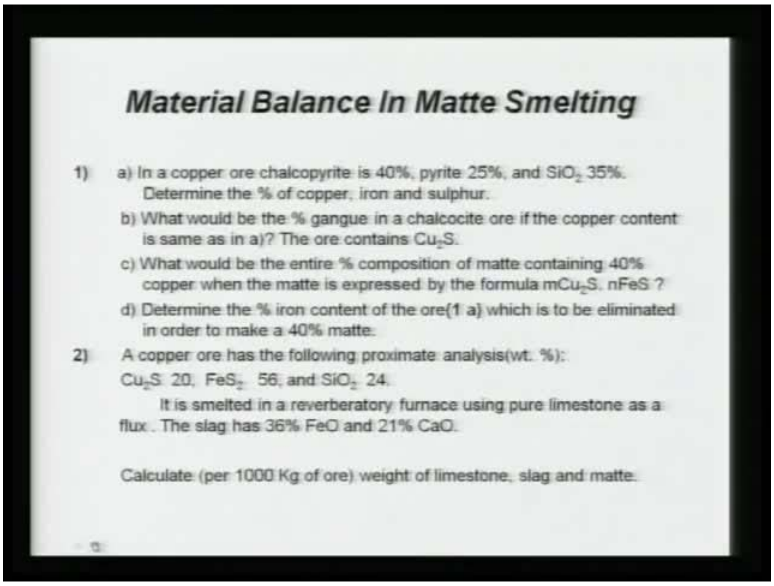
Lecture No. # 21

Exercise-I Matte Smelting

In an earlier lecture, I had given the basics of matte smelting and illustrated one example.

In this lecture, what I am going to do, what exercises I am going to do today, that I will be presenting before you. So, here are the exercises that I will be taking today in matte smelting.

(Refer Slide Time: 00:42)



Material Balance In Matte Smelting

1) a) In a copper ore chalcopyrite is 40%, pyrite 25%, and SiO_2 35%. Determine the % of copper, iron and sulphur.
   b) What would be the % gangue in a chalcocite ore if the copper content is same as in a)? The ore contains Cu_2S.
   c) What would be the entire % composition of matte containing 40% copper when the matte is expressed by the formula $mCu_2S.\ nFeS$?
   d) Determine the % iron content of the ore(1 a) which is to be eliminated in order to make a 40% matte.

2) A copper ore has the following proximate analysis(wt. %):
   Cu_2S 20, FeS_2 56, and SiO_2 24.
   It is smelted in a reverberatory furnace using pure limestone as a flux. The slag has 36% FeO and 21% CaO.

   Calculate (per 1000 Kg of ore) weight of limestone, slag and matte.

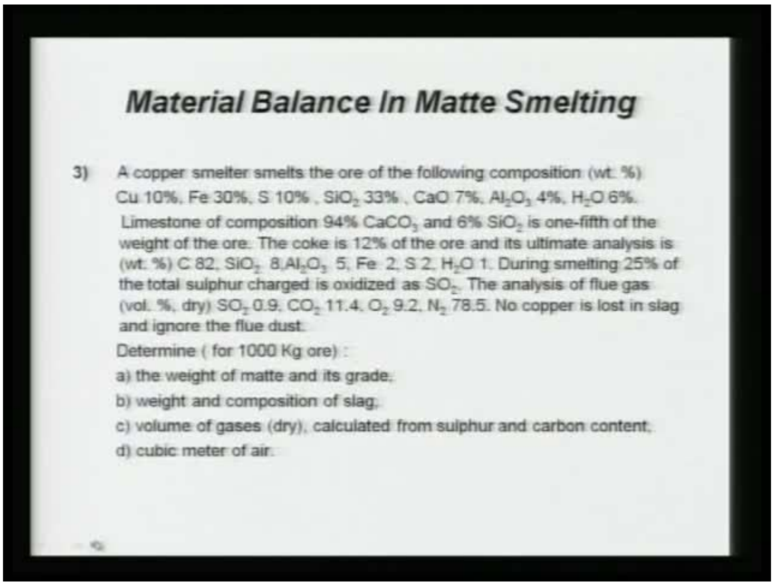
Now, problem 1, (a), (b), (c) and (d) part - we have done similarly in an earlier lecture. Here these (a), (b), (c), (d) parts- they are given for your practice.

Well, you can see and you can read, and you can say that you can do these problems also. I am not going to read this problem, because I have already done a similar type of problem in a previous lecture. So you can see and try to solve this problem.

Problem number 2: it says a copper ore has the following proximate analysis. Now, proximate analysis - on various occasions I have said that it represents the analysis of minerals, so it has Cu 2 S FeS 2 and SiO 2.

It is smelted in a reverberatory furnace using pure limestone as a flux, the slag as 36 percent FeO and 21 percent calcium oxide. Calculate per thousand kg of ore, weight of limestone slag and matte.

(Refer Slide Time: 01:47)



Material Balance In Matte Smelting

3) A copper smelter smelts the ore of the following composition (wt. %) Cu 10%, Fe 30%, S 10% , SiO_2 33% , CaO 7%, Al_2O_3 4%, H_2O 6%. Limestone of composition 94% $CaCO_3$ and 6% SiO_2 is one-fifth of the weight of the ore. The coke is 12% of the ore and its ultimate analysis is (wt. %) C 82, SiO_2 8,Al_2O_3 5, Fe 2, S 2, H_2O 1. During smelting 25% of the total sulphur charged is oxidized as SO_2. The analysis of flue gas (vol. %, dry) SO_2 0.9, CO_2 11.4, O_2 9.2, N_2 78.5. No copper is lost in slag and ignore the flue dust.

Determine (for 1000 Kg ore) :

a) the weight of matte and its grade,

b) weight and composition of slag,

c) volume of gases (dry), calculated from sulphur and carbon content,

d) cubic meter of air.

Problem 3: a copper smelter smelts the ore of the following composition - copper, iron sulphur, SiO 2, calcium oxide, Al 2 O 3, H 2 O all their compositions are given.

Limestone of composition 94 percent calcium carbonate and 6 percent SiO 2 is used and it is one-fifth of the weight of the ore.

Remember, as in the basics of matte smelting we have always said that flux is used. Flux here is a limestone and generally in most of the metal extraction industry limestone is used as a flux. Limestone has calcium carbonate and SiO 2; normally it may have some Al 2 O 3 also, but mostly it is calcium carbonate. But when the heat is supplied from outside, then calcium carbonate is used. But if heat is not supplied from outside or there is a problem with the heat management, then lime is used- because calcium carbonate is a highly endothermic process. So here we are using limestone and of this composition:

the coke is 12 percent of the ore and its ultimate analysis given, it contains all carbon SiO 2, Al 2 O 3 iron and so on.

Now the important thing here is smelting- 25 percent of the total sulphur charge is oxidized as SO 2. That means, 75 percent is remaining in the system in the form of whatever matte or whatever the case maybe.

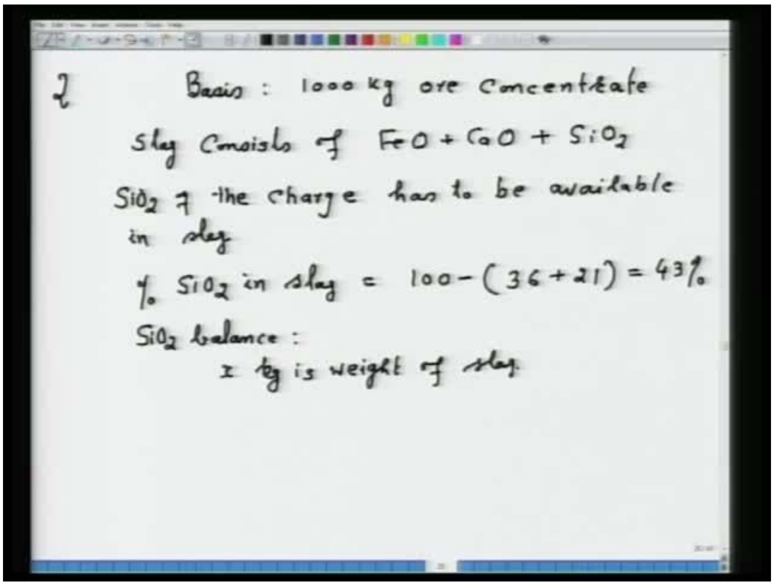
The analysis of flue gas volume percent dry- SO 2, this one, CO 2, O 2 and nitrogen. Mind you, this is a dry analysis and as I have said repeatedly, though I mention here volume percent, but the volume of gases are always given on volume basis.

In a very few cases - I do not remember any case where weight percent is given - however, you can give in weight percent, but volume percent is a common way of giving the analysis of few gases; so, that is given. No copper is lost in slag and ignore the flue dust; that means, whatever element they are carrying in the flue dust, you ignore those things.

Determine per 1000 kg of ore the weight of matte and its grade; (b) weight and composition of slag; (c) volume of gases dry, calculated from sulphur and carbon content. That is you have to do from both the balances and (d) cubic meter of air. These are the problems that I will be doing for you today and plus one problem I will illustrate during the lecture on heat balance of this smelting operation and I will go little in detail.

So, we will proceed to the solution of this problem. Here problem 1- I have already done a similar type of problem that was solved in a previous lecture. So I will not be taking problem 1, you try and get the solution.

(Refer Slide Time: 04:51)



2

Basis : 1000 kg ore Concentrate

Slag Consists of $FeO + CaO + SiO_2$

SiO_2 of the charge has to be available in slag

% SiO_2 in slag $= 100-(36+21) = 43\%$

SiO_2 balance :

x kg is weight of slag

Problem number 2: now problem number 2 says - this is an ore, a sort of copper, ore is smelted, composition is given and you have to find out the weight of limestone slag and matte. Let us take the basis of calculation as 1000 kg ore concentrate. This is the basis. It is always good to write it in the beginning, you rather clarify, the basis of your calculation. You may take 1000 kg basis, you may take 1 kg basis, you can take 1 ton - whatever you like; this is absolutely your choice.

Now, the problem says or according to the problem-- and if you know a little bit about the chemistry of matte smelting, as I have said, then you can easily recognize that - the slag in this particular problem, it will consist of Fe O plus Ca O plus SiO 2. No other component will be entering the slag because the problem clearly says that no copper is lost anywhere and so on.

So the slag will have only this particular thing. So that means the SiO 2 of the charge, say whatever you have, SiO 2 of the charge has to be available in the slag because no where SiO 2 is rather entering anyway it has to go to slag. SiO 2 of the charge has to be available in the slag.

We are given the Fe O and Ca O percent; so, we can immediately write down that percent. SiO 2 in slag - that will be equal to 100 minus 36 plus 21, that will be equal to 43 percent.

Once you know the SiO_2 percent then we can perform SiO_2 balance. Let us say here x kg is the weight of slag. Now, here I will have to tell you something: that little bit of chemistry of matte smelting is important to know, because unless you know what the chemistry is, how the slag forms and what slag forms consist of and so on, it will be slightly difficult to solve this problem, because the problem only says that the composition of Fe O and CO is given.

Here you must know, seeing this problem, seeing the analysis, reading the problem you must be able to judge judiciously, logically, what slag can have. So the slag can have Fe O CO and SiO_2 and that is the clue to solving this particular problem. That is what I thought I will tell you, that the chemistry of matte smelting is very important. To know how the matte smelting is commencing, what are the inputs, how the inputs are entering into the system and how they are exiting the system.

For example, SiO_2, Al_2O_3, calcium oxide, whatever you charge, they all will be available in the slag as it is. No reaction is going to take place; so, that is an important thing over there, but copper, it may go as Cu_2S at Cu O also it depends on the problem; iron, it may go as Fe S also, as Fe O also, or Fe_2O_3 or Fe_3O_4.

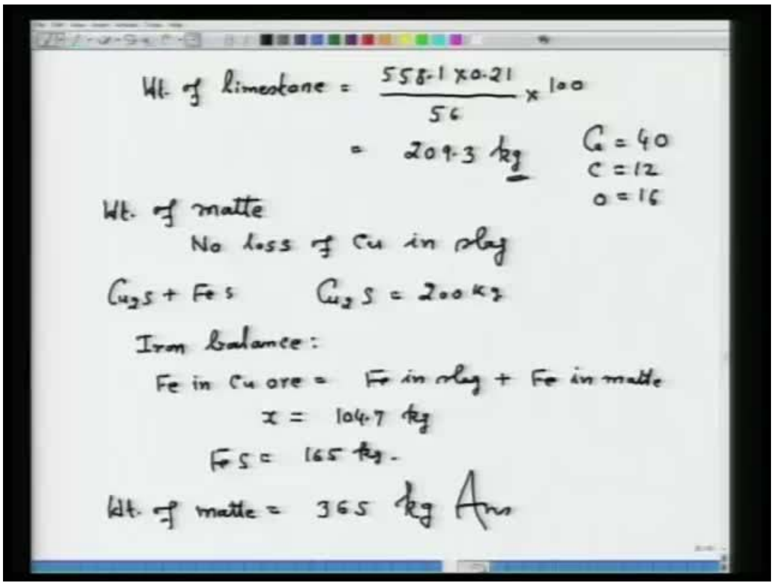
So these two elements - iron and copper - one has to be careful while solving this problem. Because, depending on what is given in the problem, the copper may enter into the slag as Cu O or it may enter into the matte. Similarly iron, it may enter into the matte as Fe S or it may also enter into slag as Fe O or Fe_3O_4 depending upon the statement of the problem.

But as regards to SiO_2, Al_2O_3, calcium oxide, N g O whatever, these are present, they all of them, they transfer to the slag. So that point, to that extent it is required to know. We should also understand why this happens, because SiO_2, Al_2O_3, they have very high melting points and there is no reaction as such which occurs with either copper or iron or so on. That is important because the problem says Fe O and Ca O; I am straight away using SiO_2, because SiO_2 cannot go anywhere except in the slag; so, that is an important thing.

Now x kg is the weight of the slag; I have to do the material balance that says 240 that is equal to 0.43 x. I can immediately find here - x - that will be equal to 558.1 kg and this is the weight of slag, as the answer.

Now, once I know the weight of slag, I can immediately find out the weight of limestone. Now, weight of limestone would be - I think you can tell me yourself - the weight of limestone, how are you going to solve? We will find out the calcium oxide in the slag. You cannot find out calcium oxide from anywhere because the input says only 95 percent or whatever percent is there. The input says nothing about the limestone, it is a pure limestone.

(Refer Slide Time: 11:02)



Wt. of limestone $= \frac{558.1 \times 0.21}{56} \times 100$

$= 209.3$ kg

Ca = 40
C = 12
O = 16

Wt. of matte

No loss of Cu in slag

$Cu_2S + FeS$ $Cu_2S = 200$ kg

Iron balance:

Fe in Cu ore = Fe in slag + Fe in matte

$x = 104.7$ kg

FeS = 165 kg.

Wt. of matte = 365 kg Ans

Whatever calcium oxide is there it will transfer into the slag. Weight of limestone you can find out, because once you know the weight of the slag then it will be 558.1 into 0.21, upon 56, into 100; that comes out to be equal to 209.3 kg. This is the weight of limestone.

Now, here as I have said - I am using Ca - carbon is 12, oxygen is 16 and Ca is 40. These are the atomic weights used. Now, we have to find out weight of matte.

Now, the problem says no copper loss in slag; that is one - all copper will enter into the matte. Now, you could argue, ‘Sir, why cannot we calculate the amount of matte flux first, then slag and then limestone?’ Now, you will not be able to calculate, because you do not know how much amount of iron is entering into slag, because iron is getting divided here between matte and the slag. First you have to calculate the amount of slag, so that you know what the amount of iron that is entering into the slag is. Then, you will do that iron balance and then you can find out the so-called Fe S. So that is where.

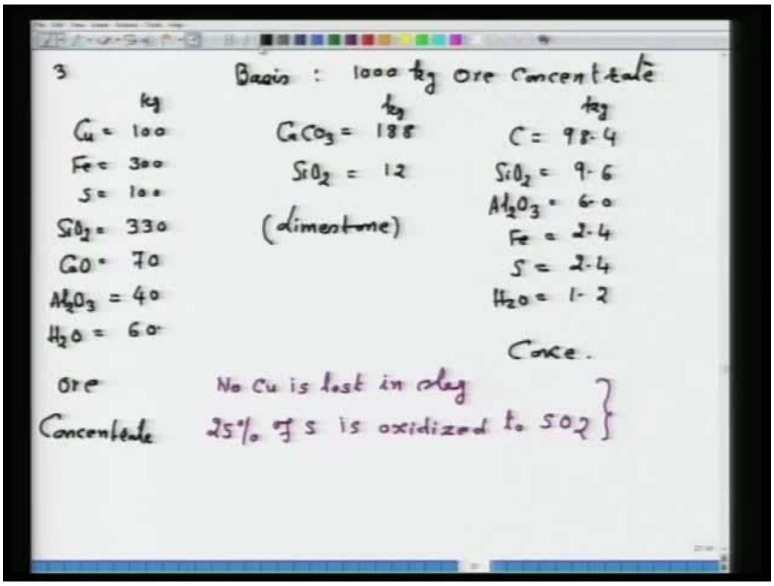
So, no loss of copper in this slag. Matte will consist of Cu 2 S plus Fe S; so immediately we can calculate amount of Cu 2 S; that will be 200 kilogram.

Now, we have to do iron balance and from the iron balance you can say- iron in copper ore that will be equal to iron in slag, plus iron in matte. That is what you want to know; rest everything is known to you.

If you do this thing, then x which is the amount of iron, if I take rather, x is the amount of iron in matte, then it will come 104.7 kg and from here I can take or I can calculate Fe S would be 165 kg. Weight of matte - that would be equal to - you have to weight both of them and you will get the answer 365 kg. That is how you will be calculating the problem number 2.

The tip here is only that you should understand chemistry of matte smelting very well in order to try this particular problem. So, that is an important thing over here.

(Refer Slide Time: 14:17)



3 Basis : 1000 kg ore concentrate

kg	kg	kg
$Cu = 100$	$CaCO_3 = 188$	$C = 98.4$
$Fe = 300$	$SiO_2 = 12$	$SiO_2 = 9.6$
$S = 100$	(limestone)	$Al_2O_3 = 6.0$
$SiO_2 = 330$		$Fe = 2.4$
$CaO = 70$		$S = 2.4$
$Al_2O_3 = 40$		$H_2O = 1.2$
$H_2O = 60$		Coke.
Ore Concentrate		

No Cu is lost in slag

25% of S is oxidized to SO_2

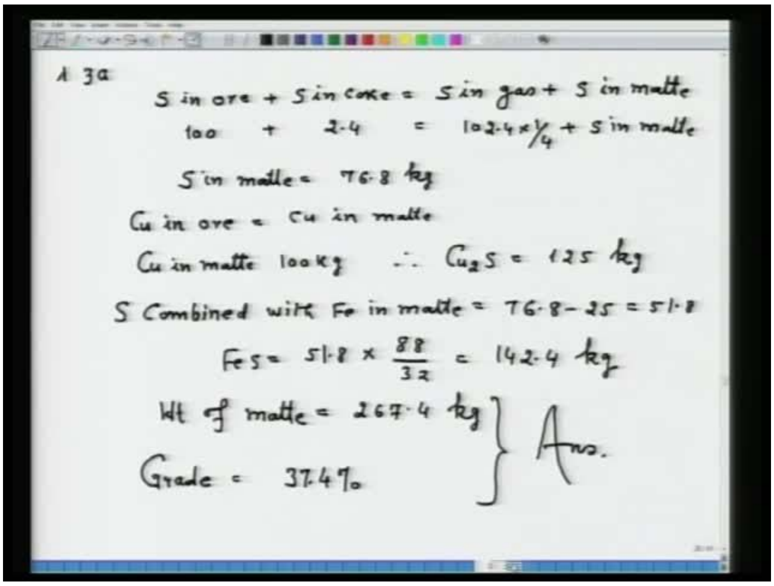
Now, let us take problem number 3. Again, we take basis of calculation is 1000 kg ore concentrate. Say if I take 1000 kg ore concentrate, then I write whatever is given, say I am putting now copper- that is equal to 100 kg, iron- 300 kg - input, I am writing - sulphur say 100 kg, SiO 2 - 330 kg, calcium oxide - 70 kg, Al 2 O 3 equal to 40 and H 2 O that is equal to 60. Now the problem for this is that the limestone this is, the this I will put ore concentrate in kg

Now, limestone is one-fifth of the weight of the ore; so, the limestone, I am straight away writing calcium carbonate, will be equal to 188 kg and SiO 2 - that will be 12 kg. That is what it says in the problem.

Now, as regards, say coke is also charged. This is the limestone, which is one-fifth of the weight of the ore. Now, coke is also being charged - say coke is 12 percent of the weight of the ore that is 120 kg. I am straight away writing: carbon that is equal to 98.4 kg, SiO 2 - 9.6 kg, Al 2 O 3 - 6.0, iron - 2.4, sulphur - 2.4 and H 2 O that is equal to 1.2 and this is the coke. I just converted the percent into kg.

Now, the problem further says two important things. First is that, the problem says, no copper is lost in the slag - that is point number one. Point number two - it says that 25 percent of sulphur is oxidized to SO 2. These are the two important statements of the problem, which will help us to solve the problem.

(Refer Slide Time: 17:56)



A 3a

S in ore + S in coke = S in gas + S in matte

$100 + 2.4 = 102.4 \times 1/4$ + S in matte

S in matte = 76.8 kg

Cu in ore = Cu in matte

Cu in matte 100 kg $\therefore$ Cu_2S = 125 kg

S Combined with Fe in matte = $76.8 - 25 = 51.8$

$FeS = 51.8 \times \frac{88}{32} = 142.4$ kg

Wt of matte = 267.4 kg

Grade = 37.4%

Ans.

Now, first you have to calculate weight of matte and its grade; that is problem 3, part (a). We have to calculate weight of matte and grade.

For weight of matte I will be proceeding this way - sulphur in ore plus sulphur in coke; that is equal to sulphur in gas plus sulphur in matte. What am I trying to find out? First of all, I am trying to find out what the total amount of sulphur is in the matte. If I do all this balance, then I will be getting sulphur in ore is 100, in coke it is 2.4, sulphur in gases that will be equal to 102.4 into 25 percent, that is 1 by 4 plus sulphur in matte.

I can find out from here, sulphur in matte that will be equal to 76.8 kg. Since no copper is lost in the slag, so copper in ore is equal to copper in matte. No copper is lost in the slag, no copper in the flue. that nothing else Whatever copper you are charging, it will be entirely available in the matte, I mean there is no doubt about it.

Now, we can calculate copper in matte -that is equal to100 kg, as what we have calculated earlier. Total amount of copper – it will transfer to the matte, therefore amount of Cu 2 S will be equal to 125 kg. Do you know how I get it? I have to multiply by 160 divide by 128 then I will be getting 125 kg.

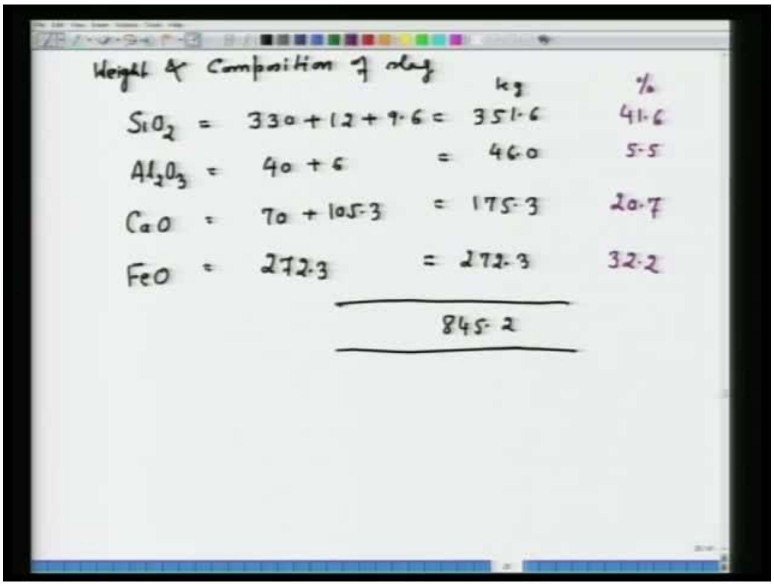
Now, in order to calculate the weight of matte it must click to you that at further first you have to do the sulphur balance, in this particular problem, where you do not know how much amount of sulphur is entering into the matte. Here copper and iron is given and some of the iron- that may also go into slag, so you cannot do anything unless you know how much amount of sulphur is entering into this slag.

Now I know the amount of sulphur, I know Cu 2 S is around 125 kg. Here I have to find out how much amount of sulphur is in this Cu 2 S. From that I will find out the amount of sulphur which can go with iron and from there I will find out the amount of Fe S. Therefore I will find out now, sulphur combined with iron in matte- that will be equal to 76.8 minus 25 that is equal to 51.8 kg.

Once I do this, I now know the amount of Fe S; amount of Fe S will be 51.8 into 88 upon 32 that is equal to 142.4 kg. Now I got it, I have got it now, so weight of matte is equal to- I have to add it- that is 267.4 kg.

Now the problem also says you have to find out grade of the matte. The grade you have to find out by weight of copper upon weight of matte; that will come to 37.4 percent. So this is the answer for part (a). This is how you will be calculating the part (a,) answer.

(Refer Slide Time: 22:17)



Weight & Composition of slag

		kg	%
SiO_2 =	330 + 12 + 9.6 =	351.6	41.6
Al_2O_3 =	40 + 6 =	46.0	5.5
CaO =	70 + 105.3 =	175.3	20.7
FeO =	272.3 =	272.3	32.2
		845.2	

Now another says weight and composition of slag. So what we have to find out is weight and composition of slag. It is straight forward- the slag will have SiO 2, it will have Al 2 O 3, as I have said in the beginning, it will have Ca O and it will have Fe O. All that you have to see is that whatever iron is in the matte, you have to subtract it and get it.

So straight away I will be writing SiO 2- 330 kg from ore concentrate, 12 from limestone and 9.6 from coke so that makes 351.6- they are all in kg.

Al 2 O 3- whatever the sources in this problem- 40 plus 6 that makes 46.0, calcium oxide 70 plus 105.3, because of the calcium of carbonate, so that makes 175.3.

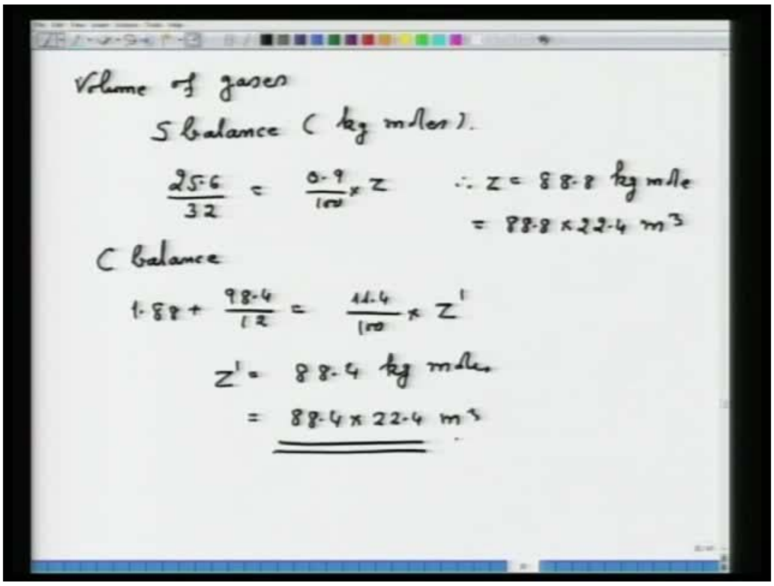
Fe O- you have to calculate how much amount. Total iron, subtract iron into the matte. That iron will be in the slag, make it 72 by 56, that will give you weight of Fe O. So that calculation you do it, if you do that it will come to 272.3 that is equal to 272.3.

Now the total is 845.2 and the composition in terms of percentage, SiO 2 is 41.6, Al 2 O 3 is 5.5, Ca O is 20.7 and Fe O is 32.2.

You can further analyze this, but if you see the slag- the slag has SiO 2 -41.6 and calcium oxide is 20.7. So normally, the term basicity is defined as calcium oxide upon SiO 2. Here the basicity is far less than 1. This means the slag is slightly acidic in character.

However, a basic slag is not needed here because no refining reactions are going on. Therefore acidic slag is done and you can also see that the basicity, in terms of Ca O upon SiO 2 is also giving you the value as less than 1, which means that the slag is highly acidic in character- just an analysis of the result so that you are aware.

(Refer Slide Time: 25:10)



Volume of gases

S balance (kg moles).

$$\frac{25.6}{32} = \frac{0.9}{100} \times Z \qquad \therefore Z = 88.8 \text{ kg mole}$$

$$= 88.8 \times 22.4 \text{ m}^3$$

C balance

$$1.88 + \frac{98.4}{12} = \frac{11.4}{100} \times Z'$$

$$Z' = 88.4 \text{ kg mole}$$

$$= \underline{\underline{88.4 \times 22.4 \text{ m}^3}}$$

Now you have to calculate volume of gases. The volume of gases you have to do from sulphur balance as well as from carbon balance. If I take sulphur balance- S balance, I am doing in kg moles. So sulphur balance is 25.6 upon 32- that is equal to- 0.9 upon 100, into Z. If Z is the kg moles of gas, then the value of Z is equal to 88.8 kg mole. This is the volume of gas as done by the sulphur balance.

If you are interested in meter cube, naturally, say 88.8 into 22.4- that will be in meter cube. You can convert it.

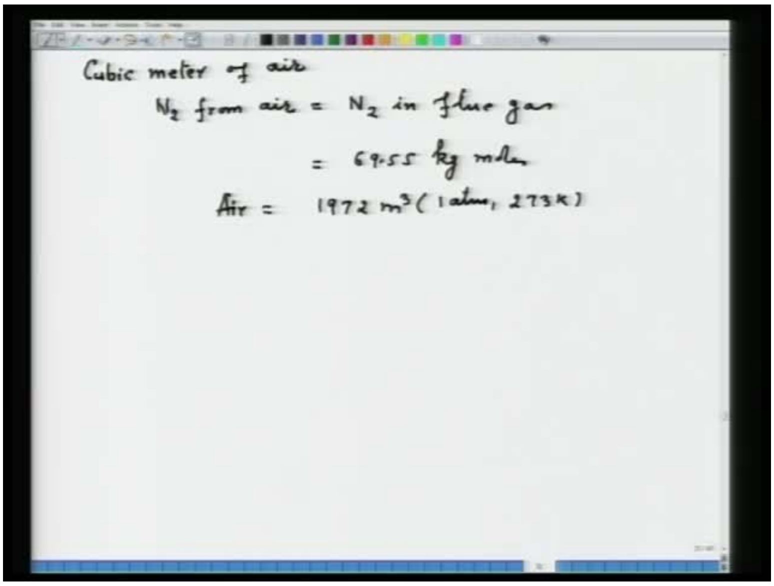
You can also do by carbon balance because in the flue gauge it is given CO 2 is equal to 11.4 percent. So this source of CO 2 is the carbon- carbon of coke as well as carbon of limestone.

So if you do carbon balance then it will be 1.88 plus, 98.4 upon 12 that is equal to 11.4 upon 100, into let us say Z dash and the value of Z dash is equal to 88.4 kg moles.

There is a slight difference between the two sources- that could be some error in the analysis or whatever the case may be, but the values are very close so you can say, well the sulphur balance and carbon balance both give more or less the same value; however, a slight difference may arrive due to the analysis or some other factor, but it is very negligible.

Here also you can convert into the cubic meter- 88.4 into 22.4, you have to help me, how much would the answer be? And this is the answer in meter cube. Now the next thing you have to calculate is cubic meter of air.

(Refer Slide Time: 27:48)



Cubic meter of air

N_2 from air = N_2 in flue gas

= 69.55 kg moles

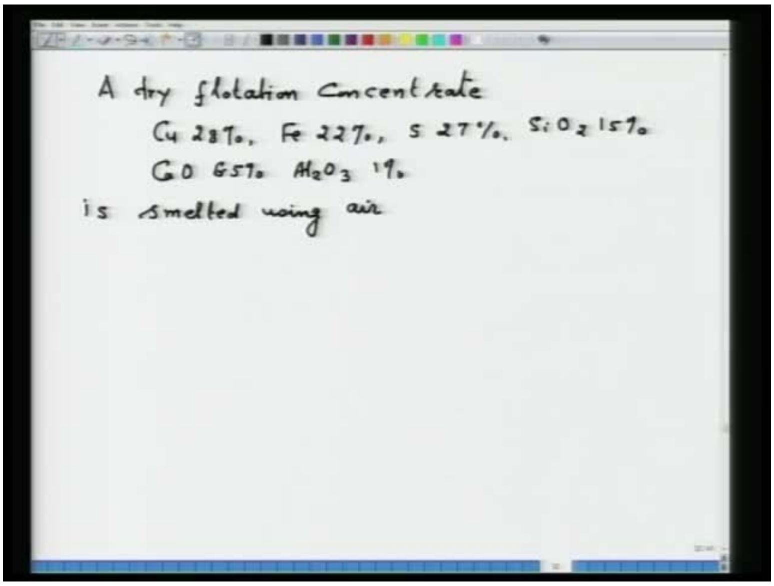
Air = 1972 m^3 (1 atm, 273 K)

Well, you know the amount of flue gas. How will you do it? Nitrogen from air is equal to nitrogen flue gas. While you are doing this balance, nitrogen from flue gas or nitrogen from air, whichever way you want to write first, that is equal to nitrogen in flue gas. Well you have to do. You know the nitrogen flue gas and nitrogen is given as 78.5 percent. The kg moles of flue gas you know, so if you do the balance, then nitrogen from air, I am leaving it to you, 69.55 kg moles, so the amount of air will be 1972 meter cube at 1 atmosphere and 273 kelvin.

Now through these two problems I have tried to illustrate to you the ways of solving the problems of material balance, where you are required to solve weight of matte, weight of slag, weight of gas, cubic meter of air, volume of gases, percent composition, all things you have to add.

Now you can see that it requires little bit of trick and little bit to read between the lines of the problem.
The next that I am going to illustrate is about a material cum heat balance problem of the smelter.

(Refer Slide Time: 29:21)



A dry flotation concentrate

Cu 28%, Fe 22%, S 27%, SiO_2 15%

CaO 65% Al_2O_3 1%

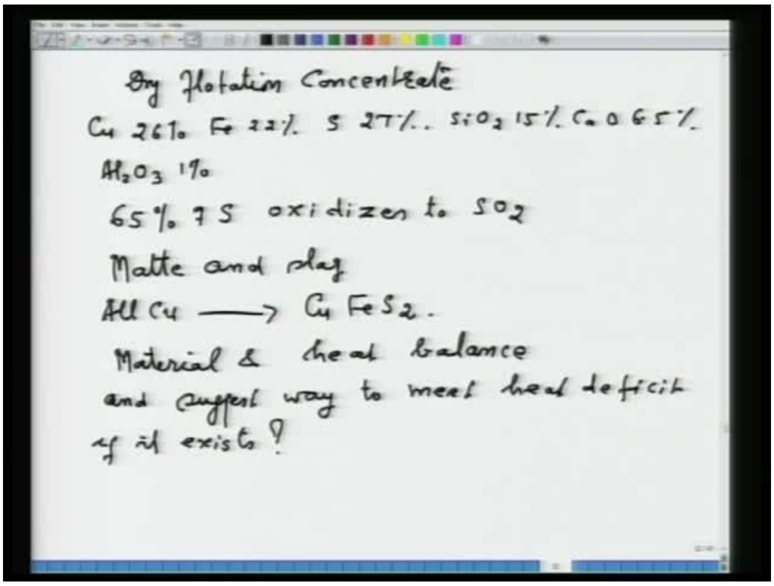
is smelted using air

For that I am going to write the problem. For example a dry flotation concentrate- its analysis is given, say copper 28 percent, iron - 22 percent, sulphur - 27 percent, SiO 2 - 15 percent, calcium oxide - 6.5 percent and Al 2 O 3 is 1 percent.

Normally the concentrate air all these all these say what should I say impurity other than copper. This concentrate is smelted in the reverberatory smelter is the smelted valve does not matter where but reverberatory smelter using air

In our problem it does not matter where you smelt, all that you have to provide is sufficient amount of heat.

(Refer Slide Time: 30:37)



Dry flotation Concentrate

Cu 26% Fe 22% S 27%. SiO_2 15% CaO 6.5%

Al_2O_3 1%

65% of S oxidizes to SO_2

Matte and slag

All Cu $\longrightarrow$ $CuFeS_2$.

Material & heat balance

and suggest way to meet heat deficit

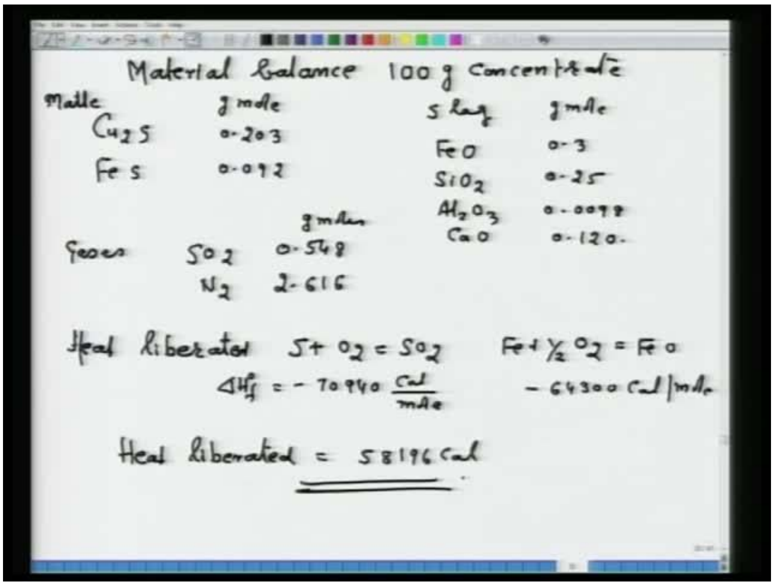
if it exists?

Now I will illustrate the heat balance problem which is as follows: say we have a drive flotation concentrate whose composition is given as- copper 26 percent, iron 22 percent, sulpur 27 percent, SiO 2 15 percent, Ca O 6.5 percent and Al 2 O 3 - 1 percent. It is smelted in a smelter and it is said that 65 percent of sulphur oxidizes to SO 2- that means 35 percent it goes to the matte.

The other products which are formed are, matte and slag. That means the product of smelting are matte, slag and gases.

All copper is present in the system as Cu Fe S 2. You have to perform material and heat balance and suggest ways to meet heat deficit, if it exists in the problem.

(Refer Slide Time: 32:36)



Material Balance 100 g Concentrate

Matte	g mole	Slag	g mole
Cu_2S	0.203	FeO	0.3
FeS	0.092	SiO_2	0.25
		Al_2O_3	0.0098
		CaO	0.120

Gases		g moles
	SO_2	0.548
	N_2	2.616

Heat liberated $S + O_2 = SO_2$ $\quad Fe + \frac{1}{2} O_2 = FeO$

$\Delta H_f = -70940 \frac{cal}{mole}$ $\quad -64300\ cal/mole$

Heat liberated $= \underline{\underline{58196\ cal}}$

That means you have to do heat balance and see whether heat output is more or heat input is more, that is what the problem is. I straightaway start, first of all the material balance. Since I have done material balance, I will not do material balance in detail now, you can do it by yourselves. The basis- remember I am taking here 100 gram concentrate. basis I am doing 100 gram concentrate remember

So matte I will calculate Cu 2 S and Fe S that will be in gram mole- Cu 2 S that will be 0.203, Fe S is 0.092. Then slag another Say this is the matte, another output is slag and slag consists of Fe O, SiO 2, Al 2 O 3 and calcium oxide- you calculate it. I am writing it down again as gram mole 0.3, 0.25, 0.0098 and 0.120.

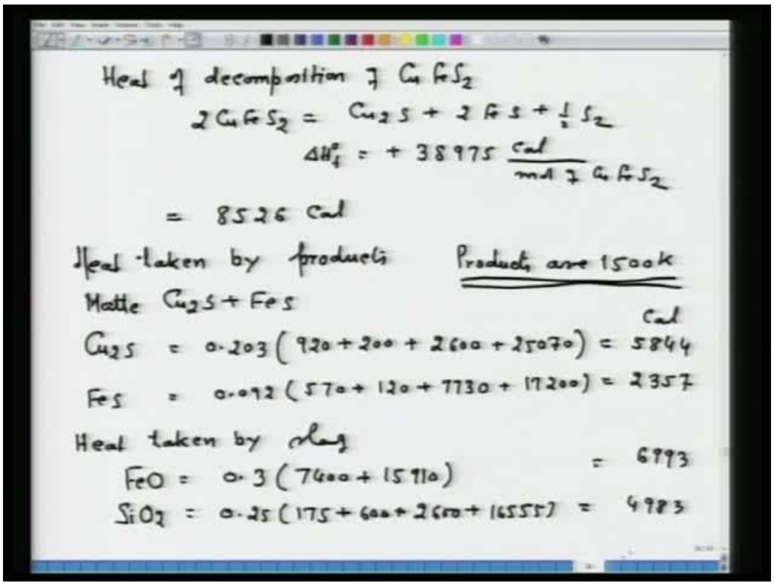
Now in the analysis if you sum total the analysis it is not becoming 100 percent. So you do not bother, consider the rest 2.5 percent as inert, that means they are not taking part in the reaction.

Now the third product is the gases and the gases consist of SO 2 which will be 0.548, I am writing in gram moles, and nitrogen that is 2.616. So this is the material balance.

Now you have to perform heat balance. So for heat balance you have to first calculate heat liberated. Now heat is being liberated in this reaction- S plus O 2 that is equal to SO 2 and Fe plus half O 2, that is equal to Fe O.

Here delta H naught f is equal to minus 70940 calorie per mole. Here it is minus 64300 calorie per mole. I know the moles of Fe O and the moles of SO 2 and there is no other source from where heat is liberated. So, total heat liberated is equal to 58196 calorie. This is the amount of heat that is liberated during this melting process.

(Refer Slide Time: 35:52)



Heat of decomposition of $CuFeS_2$

$$2CuFeS_2 = Cu_2S + 2FeS + \frac{1}{2}S_2$$

$$\Delta H^\circ_f = +38975 \frac{\text{cal}}{\text{mol of } CuFeS_2}$$

$$= 8526 \text{ cal}$$

Heat taken by products

Products are 1500 K

Matte $Cu_2S + FeS$

cal

$Cu_2S = 0.203(920 + 200 + 2600 + 25070) = 5844$

$FeS = 0.092(570 + 120 + 7730 + 17200) = 2357$

Heat taken by slag

$FeO = 0.3(7400 + 15910) = 6993$

$SiO_2 = 0.25(175 + 600 + 2600 + 16555) = 4983$

Now first we have to calculate, Because all the copper is present at Cu Fe S 2 some amount of heat will be taken by the decomposition of Cu Fe S 2- that is, heat absorbed. Heat of decomposition of Cu Fe S 2 is equal to, say we write down the reactions at 2 Cu Fe S 2 that is equal to, Cu 2 S plus 2 Fe S plus half S 2. And here delta H naught f for the decomposition of Cu Fe S 2 is equal to plus, remember plus, 38975 calorie per mole of Cu Fe S 2.

If I calculate heat of decomposition now, this heat of decomposition will be 8526 calorie. You have to calculate Cu Fe S 2 and then you can calculate this one.

Now this is the heat absorbed. You can also call it as a heat output or whichever way you want to call. That much of heat will be subtracted from the heat input. Now heat taken by the products: say one product is matte.

Matte is Cu 2 S Fe S. You have to calculate for example, for Cu 2 S the temperature which we are considering, at which the products are discharged- say all the products are discharged at 1500 kelvin, that is one thing that is important.

The products are discharged at 1500 kelvin; so, while calculating the heat taken by matte which can say for example Cu 2 F so you have to heat it from 298 to 1500 kelvin. So first you have to add the heat of transformation, then latent heat of fusion and then the heat or sensible heat in raising its temperature from 298 to 1500 kelvin.

So these values, I did them, will be equal to 0.203, 920 plus 200- they are the heat for transformation, 2600 is a latent heat of fusion and 25070 is the heat required to raise 298 to 1500 kelvin. So this becomes 5844 calorie.

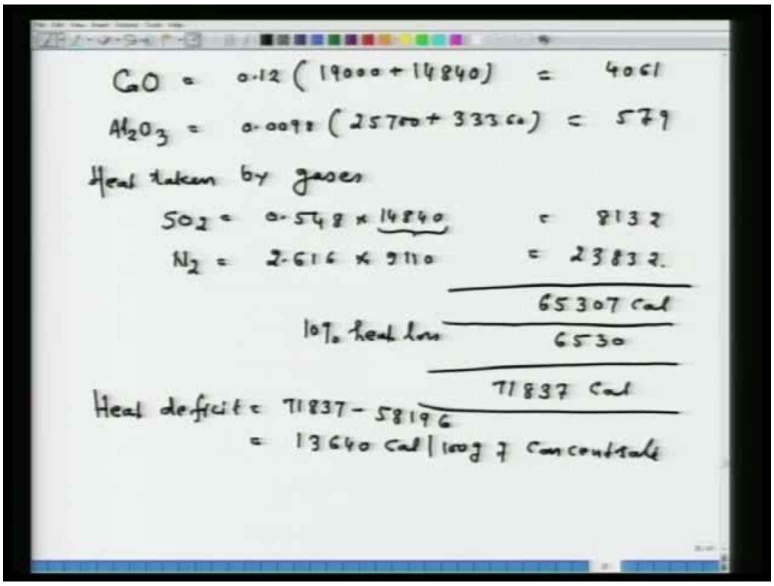
Similarly, it is taken by Fe S- that is equal to 0.092. You have to do the same thing, 570 plus 120 they are the transformation, plus it has to have latent heat- that much you have to supply, plus that is the heat or sensible heat possessed by Fe S that will be equal to 2357- this is about the matte.

Now heat taken by slag- they are forming slag from 298 to 1500, so again you have to incorporate transformation, phase transformation, latent heat of fusion and sensible heat.

For example, for Fe O we have 0.3, 7400 is a latent heat of fusion, there are no transformations involved, plus 15910, that is a sensible heat in heating from 298 to 1500 kelvin and this is equal to 6993 kelvin.

Now about SiO 2. You know SiO 2 exist in two phases- crystalite and tridymite. So accordingly, heat of transformation 175, plus 600, plus latent heat of fusion, plus 16555 and that makes 4983 calorie.

(Refer Slide Time: 40:08)



CaO = 0.12 (19000 + 14840) = 4061

Al_2O_3 = 0.0098 (25700 + 33360) = 579

Heat taken by gases

SO_2 = 0.548 × 14840 = 8132

N_2 = 2.616 × 9110 = 23832

65307 cal

10% heat loss 6530

71837 cal

Heat deficit = 71837 − 58196

= 13640 cal / 100 g of concentrate

Then calcium oxide that is equal to 0.12, 19000 plus 14840, that is equal to 4061 calorie.

Similarly Al 2 O 3 that will be equal to 0.0098 into, 25700 plus 33360, that is equal to 579.

So what I mean you have to while calculating the heat taken by the product you are reaching from 298 to that particular temperature. So you have to add all heat which is required: heat of transformation, latent heat of fusion, phase change and then the sensible heat. And now, heat taken by gases- so SO 2 that is 0.548, they are the moles, and that is 14840.

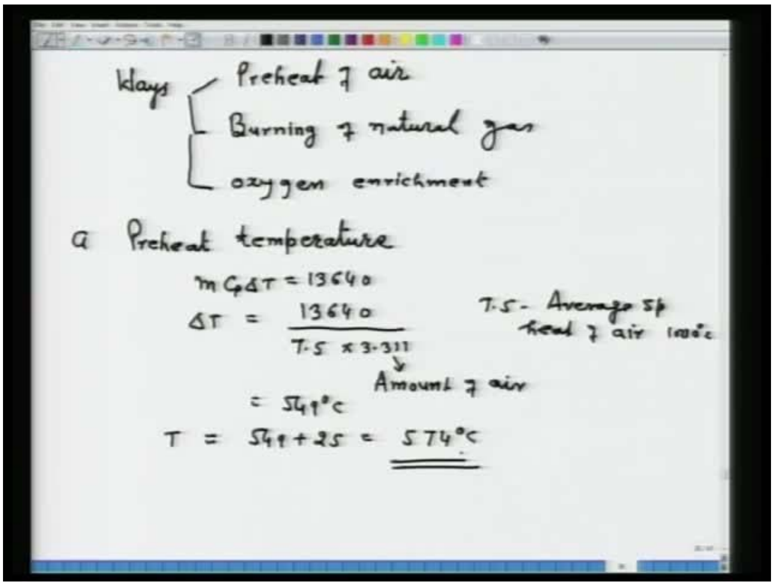
Now this 14840 is the sensible heat in raising the temperature of SO 2 from 298 to 1500 kelvin. That is, this is the value of H 1500 minus H 298. That is equal to 8132, that of nitrogen, that is equal to 2.616 into 9110 that is equal to 23832.

So if I sum total all, that is: heat absorbed by Cu Fe S 2, heat taken by matte, heat taken by slag and heat taken by the gases, it comes to 65307 calorie. I want to add here 10 percent heat loss of the heat output, so that will be 6530. The total heat out required is 71837 calorie.

Now my objective is to illustrate what to do when there is a heat deficit. So you are seeing now, heat deficit in this particular problem is equal to 71837 minus 58196. The heat deficit is around 13640 calorie per 100 gram of concentrate.

I want to illustrate what could be done in order to meet this deficit- there are several ways.

(Refer Slide Time: 42:58)



Ways
- Preheat of air
- Burning of natural gas
- oxygen enrichment

a Preheat temperature

$m C_p \Delta T = 13640$

$\Delta T = \frac{13640}{7.5 \times 3.311}$

7.5 - Average sp heat of air 1000°c

3.311 → Amount of air

$= 549°c$

$T = 549 + 25 = \underline{\underline{574°c}}$

One way is preheating the air. Naturally, the question comes- to what temperature should we preheat?

Second, burning of natural gas. You burn extra amount of natural gas, provide extra calorie and the third way is oxygen investment. My objective of this problem is to illustrate these three mechanisms, which can be used to supply the additional amount of heat.

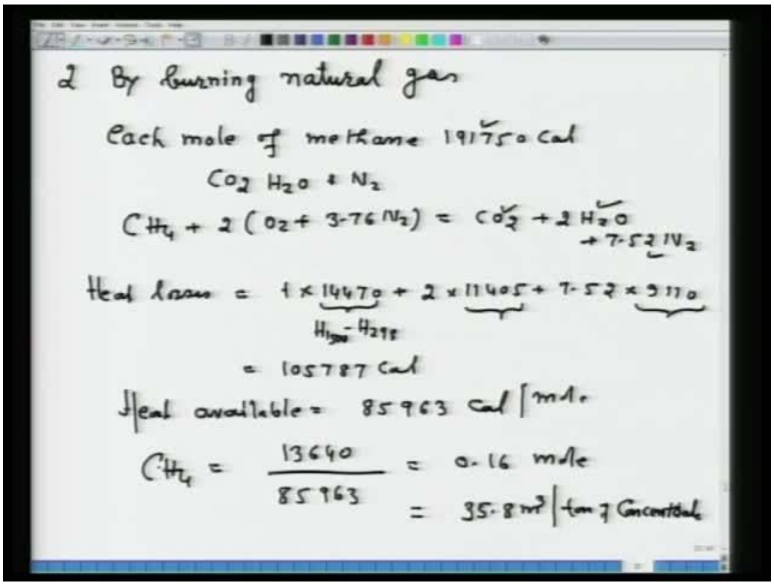
Now seeing the preheating of air, the important things is how much temperature, at what temperature, you will preheat the air. So, a - required is preheat temperature. How will you calculate preheat temperature now? This is often an industrial problem. Well you can suggest you preheat the air, the manager will ask you what is the temperature that I should keep it at.

So straight away, m C p delta T is equal to 13640- that is the heat deficit. So I know now delta T, that is equal to 13640 upon I am telling you what is 7.5 into 3.311- 3.311 is the amount of air. Because you know the amount of nitrogen in air is 2.616 divide by 0.79. That will give you the amount of air and 7.5 I have taken- this is the average specific heat of air in calorie per gram mole. That is what the specific heat of air within temperature range thousand degrees Celsius.

So for accuracy you can take this C p of oxygen, C p of nitrogen. This delta T value that is equal to 549 degree Celsius, then T- preheat temperature will be 549 plus 25, so that will be 574 degree Celsius.

So that makes the suggestion with a quantification of the value of the temperature that is required.

(Refer Slide Time: 45:39)



2 By burning natural gas

Each mole of methane 191750 cal

CO_2 H_2O & N_2

$CH_4 + 2(O_2 + 3.76 N_2) = CO_2 + 2 H_2O + 7.52 N_2$

$$\text{Heat loss} = 1 \times \underbrace{14470}_{H_{1300} - H_{298}} + 2 \times \underbrace{11405} + 7.52 \times \underbrace{9110}$$

$$= 105787 \text{ cal}$$

Heat available = 85963 cal / mole

$$CH_4 = \frac{13640}{85963} = 0.16 \text{ mole}$$

$$= 35.8 \text{ m}^3 / \text{ton of Concentrate}$$

Now another option that I have said, is by burning natural gas.

Suppose I take methane. Now methane, it liberates heat. Each mole of methane librates 191750 calorie heat. But you also lose heat because on combustion of methane you are producing CO 2, H 2 O and nitrogen- they will be heated up.

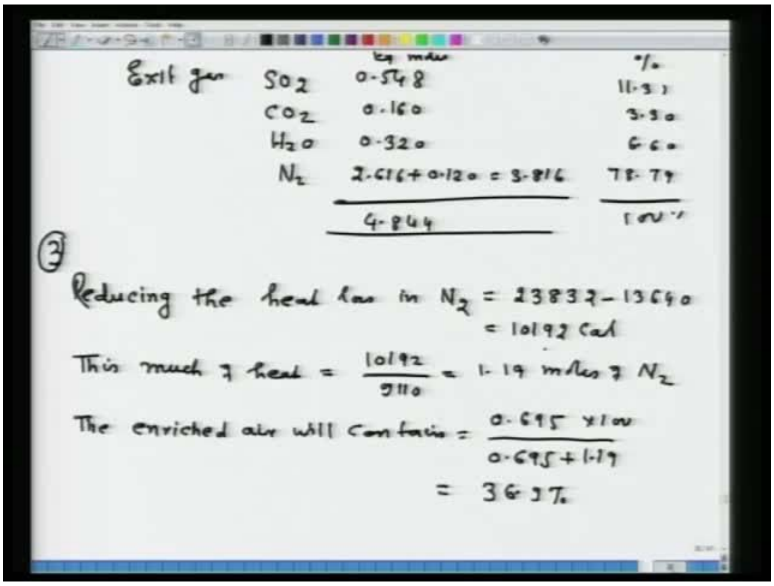
So the reaction which we will write down: CH 4 plus 2, O 2 plus 3.76 N 2, that will be equal to CO 2 plus 2 H 2 O plus 7.52 N 2.

Now I will say the heat loss is because the heat will be carried by this, this and this. That will not be available to meet the deficit. So the heat losses will be CO 2 - 1 into 14470 plus 2 into 11405, plus 7.52 into 9110.

Now this 14470 is the H 1500 minus H 298 for CO 2. This is for CO 2, this is for H 2 O and this is for nitrogen as you have used earlier. So total amount of heat which these products will take that will be equal to 105787 calorie.

So heat available would be- if you subtract this heat from this heat, 85963 calorie per mole. Now what is required? So how much methane will be required? 13640 is the heat deficit, available is 85963 when you combust one mole of CH 4, then we require 0.16 mole CH 4 to meet the deficit. That will be equal to 35.8 meter cube- remember per ton of concentrate. Now you know you have the second option. If you have no option to preheat the air you try the natural gas and approximately you will need around 35.8 meter cube per ton concentrate.

(Refer Slide Time: 49:06)



Exit gas		kg mole	%
	SO_2	0.548	11.31
	CO_2	0.160	3.30
	H_2O	0.320	6.60
	N_2	2.616 + 0.120 = 3.816	78.79
		4.844	100%

③

Reducing the heat loss in N_2 = 23832 − 13640
= 10192 Cal

This much of heat = $\frac{10192}{9110}$ = 1.19 moles of N_2

The enriched air will contain = $\frac{0.695 \times 100}{0.695 + 1.19}$
= 36.87%

Now my dear friend, remember, you have the gases that will not be comprised of SO 2 and N 2 but it will comprise CO 2 and some additional amount of N 2 because you are using methane along with the air. So you have to recalculate the composition to see that your process runs. The exit gas now will comprise of SO 2, CO 2, H 2 O and additional H 2 O to that which we have calculated earlier.

So, SO 2 there is no change, CO 2, yes it will be added- 0.160, H 2 O will be 0.30 and nitrogen will be 2.616 from earlier plus 0.120 you are adding now. That becomes 3.816 and now the total moles of gas are 4.844, mind you, per 100 gram of concentrate.

The percentage- they are in kg moles. Now percent would be 11.31, 3.30, 6.60 and 78.79 and that makes 100 percent. That is about the second option.

Now third option as I said, enriching the air with oxygen. When you enrich the air with oxygen that means you are reducing the amount of nitrogen. So what do we have to do? Reducing option number three: oxygen enrichment, how much that is question will be asked.

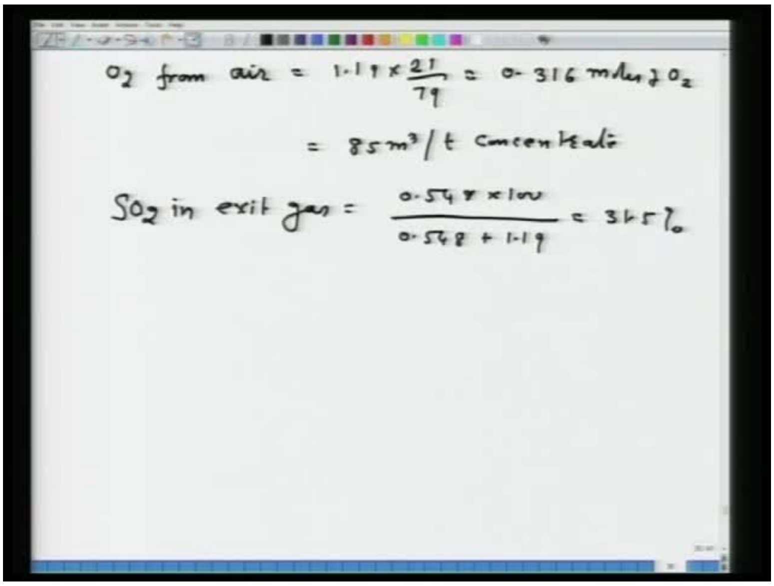
So reducing the heat loss in nitrogen- because nitrogen was carrying certain amount of heat and the heat that was carried away by nitrogen was 23832- if you see my earlier calculation. If I subtract from here heat deficit, that is, 13640 then I am required to reduce the heat by 10192 calorie. That means I will reduce the nitrogen and increase the oxygen.

So now how much amount of nitrogen will be required if I want the nitrogen to carry this much amount of heat? This much amount of heat will be contained in 10192 upon 9110 that is, 1.19 moles of nitrogen- 1.19 moles of nitrogen now would be required as compared to earlier when I was not using oxygen enrichment. I required 2.616, remember the earlier calculation.

Now if I use 1.19 moles of nitrogen I will be meeting the deficit. Now in order to do that what will I have to do?

The enriched air will contain-- now corresponding to 2.616 I have to calculate the amount of oxygen-- 0.695 upon 0.695 plus 1.19 into 100, so the oxygen enrichment will be thirty six point nine percent.

(Refer Slide Time: 52:32)



O_2 from air $= 1.19 \times \frac{21}{79} = 0.316$ moles of O_2

$= 85\ m^3/t$ concentrate

SO_2 in exit gas $= \frac{0.548 \times 100}{0.548 + 1.19} = 31.5\%$

So now I will be requiring oxygen from air that will be equal to 1.19 into 21 upon 79- that will be 0.316 moles of oxygen, that will be equal to 85 meter cube per ton of concentrate. This will be pattern of concentrate.

Now I can calculate SO 2 in the exit gas- that will definitely be less. That will be equal to 0.548 into 100 upon 0.548 plus 1.19- that is equal to 31.5 percent and rest will be nitrogen.

So what I have done in this particular problem is that I have suggested that these are the three options from where you can meet the heat deficit: preheating of the air, oxygen enrichment and use of fuel. These are the three options which are available to you for meeting the heat deficit and I have illustrated that each of the option has this particular requirement and now what is to be done.

Now here comes the management, here comes the availability of the facilities- that also you have to keep in mind. If you are able to preheat there up to the temperature you can install a preheater, well then you can do that. Because all that is required- they are the three independent technologies.

Now which technology will be able to defuse into your plant economically will be decided by several factors. One of the factors is: what will the return on investment be that you are going to boot. Because each technology requires investment. The important thing is that you can suggest any of them. But ultimately that technology which will defuse into the plant is one which has a lower payback period and higher return on investment. That is the basic philosophy of economics for diffusion of the technology into the market.

Thank you gentlemen.