Non-ferrous Extractive Metallurgy

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Module No. # 01

Lecture No. # 22

Extraction of Copper (Contd.)

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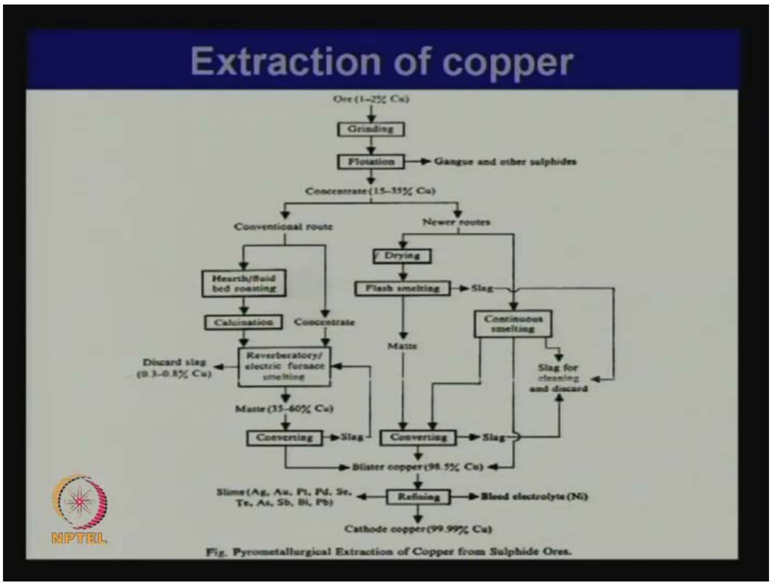

Extraction of copper

Fig. Pyrometallurgical Extraction of Copper from Sulphide Ores.

I have started delivering some lectures in module six of this course, which is about the extraction of metals, from sulphide ores. And we have already discussed copper extraction. Let me go back to the beginning once again, and make some general comments.

The reason, I am going back is, because sometimes you understand general statements better, if you know the specifics and sometimes, it is the other way around. For example, you understand the specific steps better, if you know the principles, and once you know the principles, you know the specific steps better. So, actually in learning, we have to keep on doing this; going back to principles and some general observations and go back to some specifics.

Let me give you an illustration of that. What you must have noticed is when we are discussing extraction of copper, is that not only our aim was to get copper out of copper ores, but many other elements as such. Now, remember what I mentioned in the beginning that sulphides are very good solvents, not only for each other, but also they dissolve other things like precious metals.

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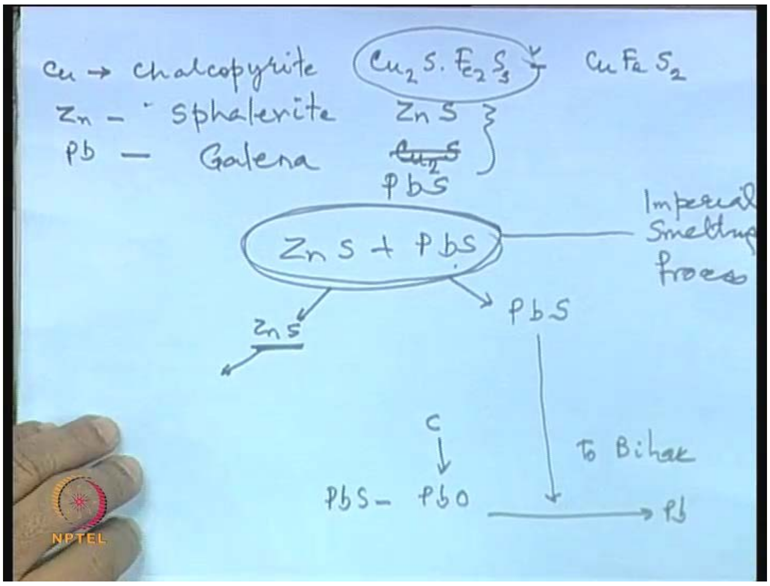

Now, we have talked about processing of chalcopyrite, which is sometimes, written as Cu 2 S. Fe 2 S 3 or as Cu Fe S 2. We can write it in either way. When we come to the extraction of zinc, which I will take little later, this is the ore of copper. For zinc we have ‘sphalerite’, as the main mineral, and for lead, the main mineral is ‘galena’. It so happens that many deposits have more than two of these, you can have a sulphide deposit with bit of this and this or all three of this. There are some sulphides which are called as mix sulphides, where all three are very much there together, along with many other things. But generally we find that zinc sulphide and copper sulphide, sorry this is PbS lead sulphide often go together.

We know that these sulphide deposits are mostly found in Rajasthan, and that is why we have the zinc plant in Udaipur. It so happens, that in these deposits, where we have both Zn S and Pb S (Refer Slide Time: 04:06), we can have a concentrate rich in Zn S by separating it out by differential floatation. This can be separated out by differential floatation means a zinc sulphide concentrate and a lead sulphide concentrate. This goes through the zinc plant in Udaipur, goes through the hydrometallurgical route. First, zinc sulphide is roasted into zinc oxide, then it is dissolved in acid like sulphuric acid, and from that acid solution, after proper purification, we electrolyze the solution to get zinc. This cannot be done for lead sulphide.

What is done now is this lead sulphide comes all the way to Tundo, a place in Bihar. This lead sulphide is to be roasted to Pb O, and then is reduced by coke, in a blast furnace in order to produce lead. So, see the interesting thing, we have zinc sulphide and lead sulphide, together in Rajasthan. Zinc sulphide will go for treatment nearby, whereas lead sulphide has come all the way to Bihar because we need coke. So, the question is either you take coke to Rajasthan or you bring lead sulphide to Bihar.

Lead is also produced in Vizag. Again, the concentrate comes from that place to Vizag, unless it is imported. Copper pyrites, which is also a kind of mixture of iron sulphide and copper sulphide, can be found as a rich concentrate, in Eastern India, that is why we have a copper smelting plant in Ghat Salem, but there are many deposits in India, where all three are together. I will come to that towards the end, and till now, we do not have a very successful, commercial process for exploitation of these. For various reasons like, may be due to their location, may be the extent to which they are there or the complications that one has to go through to handle three elements from them.

But, this is very successful. We have zinc sulphide and lead sulphide together. They can be separated out, by floatation and when separated, they go to their respective places for further processing. One goes in one way and the other goes way another way.

Now, there is also very important process called, ‘Imperial Smelting Process’, which I will discuss. In Rajasthan itself, there are blast furnaces, known as imperial smelting process, where a concentrate containing both of these can be treated. Lead will come out by carbothermic reduction. During this reduction, zinc also will come out as vapors from the top, and there is a way of recovering zinc from these vapors. We will discuss it, as it is a very modern process, for production of zinc and lead, from the same unit. In theory, if there is any copper, in that concentrate, that can also be recovered as a separate phase in imperial smelting process. Normally, it is not a very desirable thing.

What I am trying to say is that these sulphides, are often mixed together, and by differential floatation, we can have concentrates that are rich in either one of them or both. Generally, we will like concentrates, which is only rich in one main metal. So, that there is a well-defined process, but, imperial smelting process can handle a concentrate containing both zinc sulphide and lead sulphide.

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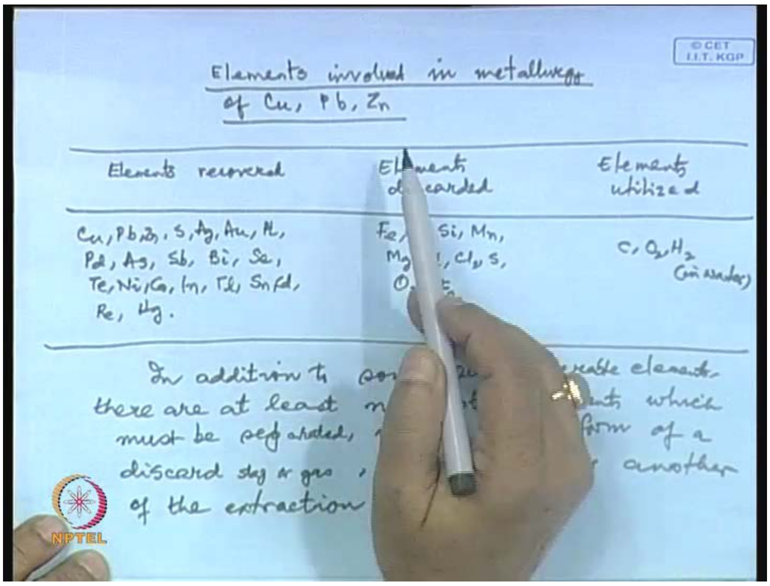

Elements involved in metallurgy of Cu, Pb, Zn

Elements recovered	Elements discarded	Elements utilized
Cu, Pb, Zn, S, Ag, Au, Pt, Pd, As, Sb, Bi, Se, Te, Ni, Co, In, Tl, Sn, Cd, Re, Hg.	Fe, [illegible] Si, Mn, Mg, [illegible], Cl, S, O, [illegible]	C, O_2, H_2 (in water)

In addition to [illegible] recoverable elements there are at least [illegible] elements which must be separated, [illegible] form of a discard slag or gas, [illegible] another of the extraction [illegible]

Now, you will appreciate with what is happening in sulphide metallurgy. In sulphide metallurgy, the main elements involved are copper, lead and zinc. Apart from that, we recover 20 elements more during their processing. Copper, lead, zinc of course, depending on the main element, then sulphur, silver, gold, platinum, palladium, arsenic, antimony, bismuth selenium, tellurium, nickel, cobalt, indium, tin, rhenium, mercury; all these are recoverable and they are recovered.

You recall the flow sheets, which I have shown, for copper refining; many of these are coming out of that. Now, these elements are also there, but they would be discarded because they would not have commercial value, even if discarded one were these. Therefore, we say that in addition to these 20 recoverable elements, there are at least 9 other elements, which must be separated, usually in the form of a discard slag or gas at one stage or the other of the processing stage. Very interestingly, the main elements that we are utilizing in the processing of copper, lead and zinc are carbon, oxygen and hydrogen. Hydrogen in used in the form of water.

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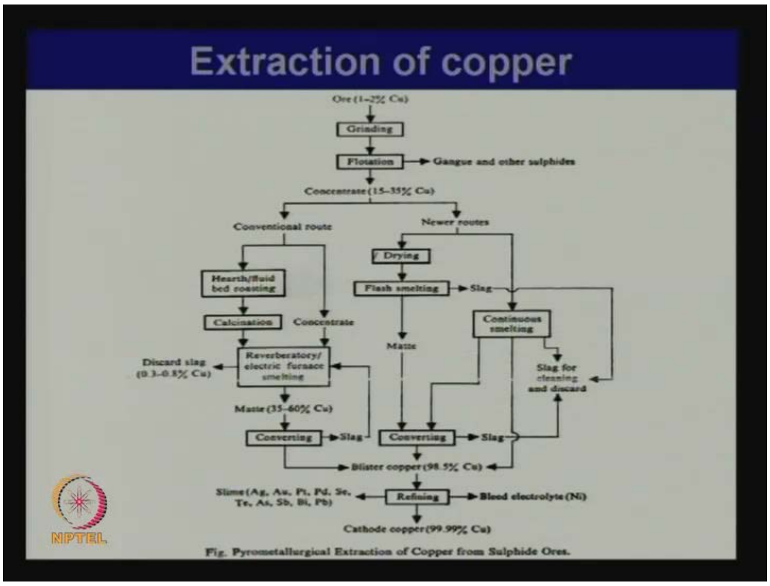
Extraction of copper

Fig. Pyrometallurgical Extraction of Copper from Sulphide Ores.

Now, we will go back to copper again, and see the relevance of the statement, which we have made. We have seen that as far as copper metallurgy is concerned. We start with an ore, which consists one to two percent of copper. It has to be first grounded to fine size. Then floatation upgrades it to 15 to 35 percent copper. Then the conventional root has three main steps: one is roasting, then reverberatory smelting, and converting, to finally, get an intermediate product called blister copper, which on refining will produce cathode copper very pure and whole lot of by products in this line recovered.

Now, there is another minor step sometimes called calcination, which is not a very important step, and we can ignore that for now. The first step of roasting, which can be in a hearth roaster or in a fluid based roaster, you should understand by now, there the main point is to heat the concentrates without fusion in the solid state. The main idea is to oxidize the concentrate so that most of the iron sulphide is taken to the Fe O stage and preferably not beyond. Because, if it goes beyond Fe O then subsequently we will find it difficult to remove them through slagging, so to ensure that it does not get over oxidized, we have to leave a lot of iron sulphide unoxidized. Now, this is an oxidizing step (Refer Slide Time: 12:18). You need oxygen to oxidize the concentrate. Next main case is reverberatory or electric furnace smelting, where a liquid phases are formed. We add fluxes so that we have a slag. In that slag we will take the Fe O that was created here, and some more of the iron sulphide that was left behind, would also be oxidized, taking to a Fe O state, and we will try to remove as much of iron as possible, in the slag here.

Essentially, we will be left with a matte, which is a mixtures of copper sulphides and iron sulphides, with very little of oxygen left, very little of Fe O left.

Now, during the converting, whatever that Fe O, iron sulphide is remaining in the matte will be oxidized, taking in to a slag phase. The slag phase will go back here, because there could be some copper coming out, so we have to recover that. So, finally, a stage comes where all iron sulphide has been oxidized and that process of oxidation provides heat during converting, which becomes its autogenous process. We are left with what is called white metal, which is all Cu 2 S.

Now, the Cu 2 S starts getting oxidized, starts forming Cu 2 O, and when we have twice as much Cu 2 O as Cu 2 S, they react mutually and starts forming copper. Copper will settle to the bottom, because its settling to the bottom, we cannot have bottom blown converter. So, the converter is side blown. And finally, we have to find a time, when all that copper sulphide has been converted to copper. And mind you there is no reducing agent involved. You are simply oxidizing copper sulphide to form Cu 2 O, then Cu 2 O and Cu 2 S is reacting to give copper; it will form blister copper.

Now obviously, we have an oxidizing atmosphere here. In the reverberatory furnace, we do not need such as from oxidizing atmosphere, because mainly we are removing the Fe O in the slag state. But, we want a stronger oxidizing atmosphere during converting. So, there are three stages with different Pa O 2 requirements. Now, the advancements in copper metallurgy, aims at combining these steps. Why do we want to combine? To understand that look at this slide.

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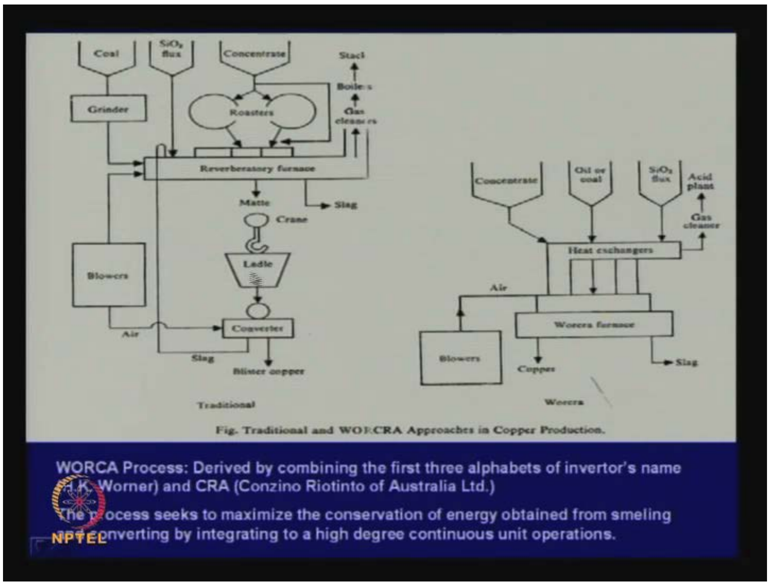

Fig. Traditional and WORCRA Approaches in Copper Production.

WORCA Process: Derived by combining the first three alphabets of invertor's name (H.K. Worner) and CRA (Conzino Riotinto of Australia Ltd.)

The process seeks to maximize the conservation of energy obtained from smeling and converting by integrating to a high degree continuous unit operations.

So, this is a conventional root. We have the concentrate goes to roasters. Now, after you have roasted the material, it has to be taken out, transport at to a reverberatory furnace, where you are making a matte, after you have made the matte, the matte has to be transported through ladles into a converter to form blister copper.

So, these are transportation operations involved between roasting to reverberatory furnace, reverberatory furnace to ladle. So, you have three steps, and during these intermediate gaps, you lose a lot of heat. You just take out hot material from here; we charge here, we are losing heat there. You take out hot material from here in ladles. Not only you are adding operation of steps, you are also incurring lot of heat losses.

So, the attempts have been made to combine these steps. Now first step, in that direction was the flash smelting. That after we have got the concentrate, they are dried, and then there is no separate roasting and smelting. It is all done together in a flash smelter, where in suspension all the reactions take place, in one stage you produce matte, and that goes for converting. So, you are producing in one step, matte. Now, the third generation wanted even to combine these two into one. So, that we start from concentrate, and in one reactor go straight to blister copper. This is called the continuous smelting route, and many developments have taken place in that direction.

The idea will be to take the concentrate and in one reactor, it will be continuously smelted, means it would undergo, roasting, smelting, converting, and straight away it will produce blister copper. Now, there is we cannot think about process, which will combine refining also in all this and produce a refined copper. That is not possible, because these are pyrometallurgical processes where this refining combines pyrometallurgy and finally, electrometallurgy.

But one, two and three steps can be made into two steps in flash smelters, and all three can be combined into one reactor, in continuous smelting operations. What will be the advantage? Is that you will get rid of the going for one steps to the other, transporting material from one to the other, having heat losses. And once you have one reactor, where everything takes place and things can be faster or speedier, heat losses would be low. But things will be more difficult. Why they will be more difficult? Because here is a reactor where the condition can be uniform same Pa O 2 will prevail in the roaster, is roasting.

One Pa O 2 will prevail in the reverberatory furnace, and during converting we are injecting oxygen, there is certain oxidizing environment, in the converter. If you want to convert these three into a single reactor, then a reactor must be so designed that its partial pressure of oxygen varies from one region to another. So, it is not a reactor, where the gaseous atmosphere is uniform. It is not possible. So then go from concentrate to matte to blister copper and so the reactors have to be designed with notionally separate regions and they are connected all right.

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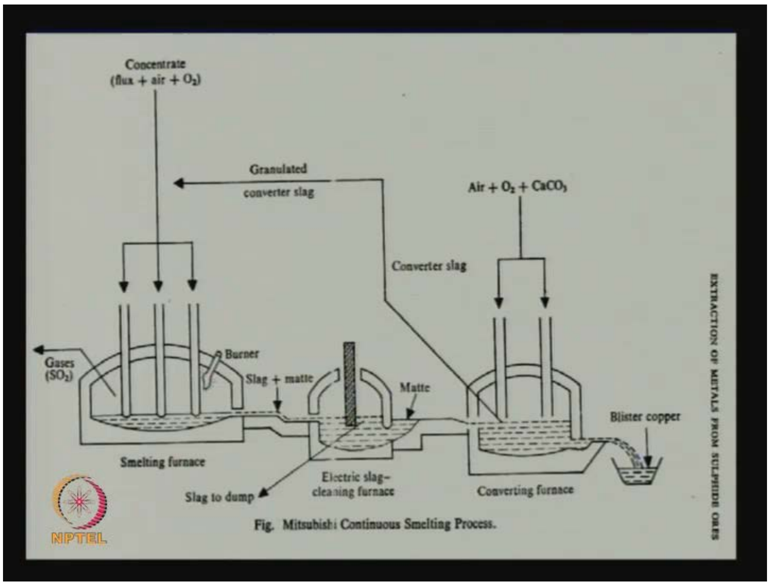

Fig. Mitsubishi Continuous Smelting Process.

But they are separate regions, where roasting, smelting, sometimes roasting smelting can be combined as in the flash melting, but definitely smelting and converting are two different operations all together. Now, a simple way of doing this was done by the Japanese. The Japanese proposed a smelting process called the Mitsubishi Continuous Smelting Process, which actually was a continuous process, but not necessarily one reactor. Now, they had three reactors, but the interesting concept was that there is a smelting furnace, where flux, air and oxygen as you see injected, combine roasting and smelting in one step. That can be combined roasting and smelting in one step, then the slag and matte they flow out, because the next reactor is put at a lower level.

So these automatically flow out, and this intermediate chamber is called an Electric Slag Cleaning Furnace, means you have got the slag and the matte. But, the slag can be treated at to get the right temperature, under right Pa O 2, to recover all the, if there is any C O loses. And there is a baffle here we see, which dips into the liquid, which means only the matte can go from the bottom to the other end. But, the slag gets struck here, slag cannot, slag floats on top. The slag cannot go that way, there is a port hole through which slag would come out and to for dumping.

So, this intermediate state is to ensure that copper loses, in the slag are minimized, and the slag is not allowed to flow to the next chamber, because of a baffle is taken out. Only the matte can go under the baffle, and flow into the next reactor, which is again at a lower level. So, these three go from one level to a lower level to the lowest level and so the matte will flow from here into this slag. If there any copper, that copper would be recover that matte will go here and then this is a converter where air, oxygen, calcium carbonate are there, and you get blister copper and the converter slag, will be granulated and it will go back here. Just in case there were some copper loses.

Now this is a kind of continuous process, in the sense that continuously concentrate is being fed, continuously blister copper is coming out. But, the whole thing is not a single reactor. But this is easier to operate, because you can maintain a very high oxygen partial pressure here. The oxygen partial pressure here required is low, and here it is a conditioning compartment where you have the Pa O 2 as you need, in order to recover copper. So, this is the Japanese process, but this is not the ideal solution.

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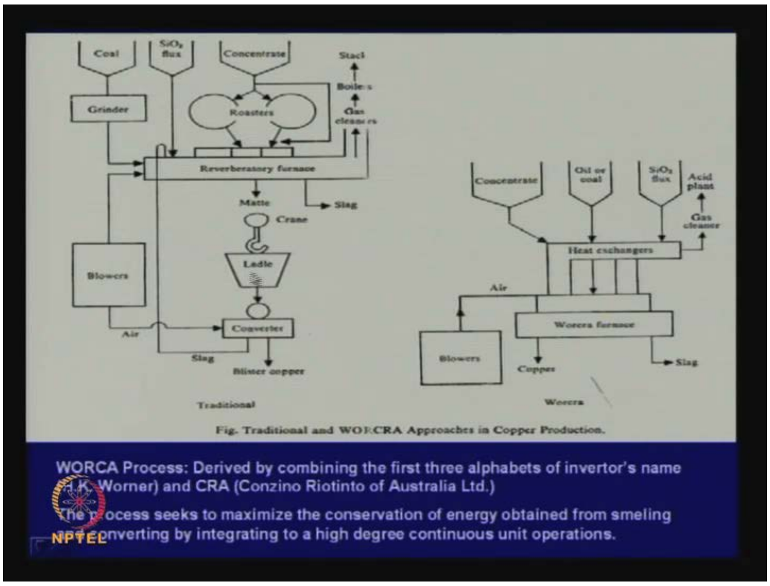

Fig. Traditional and WORCRA Approaches in Copper Production.

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The process seeks to maximize the conservation of energy obtained from smeling and converting by integrating to a high degree continuous unit operations.

The one of the first answer to this question, of combining all the steps, was provided by a man called Worner and the process is named after him, is called WORCRA process. This is derived by combining the first three alphabets of the inventors' name Worner with C R A, which is Consignor Riotinto of Australia limited. It is an Australian company where Worner was working.

So, he conceived the idea. There are many others who were conceiving the idea, but he finally, developed a process which was workable. The process seeks to maximize the conservation of energy obtained from smelting and converting by integrating to a high degree of continuous operations. Now, I have mentioned earlier that all the reactions that are happening during sulphide processing or oxidizing, whenever sulphides get oxidized they produced heat. But, if you have different stages then much of the heat generated in one step will not go into the next step, because in between you lose that heat, especially when you are transporting material or if you have too many units, from the surfaces of which heat get lost.

If you put them all in one reactor then heat loses will be minimized and you will make better use of the heat being generated in the smelting and converting operations. Now, this is the scheme this is a Worner WORCRA furnace (Refer Slide Time: 25:47), where Pa O 2 will not be uniformed all through. We will tell you how. And schematically it has to have air injection. Whatever heat will come out will go through heat exchanges for recovery of heat. The gases that are S O 2 that will come out will go to acid plant to make sulphuric acid.

This is flux Si O 2 concentrates. These are going into here. Oil or coal, this is for supplying heat. Now one of the very interesting concepts to be used in a continuous furnace is that the partial pressure of oxygen cannot be uniform also. This, another interesting concept, which need some engineering; that is that matte and slag phase must flow in opposite directions. You cannot have matte and slag flowing together and coming out at the same end. In all this reactors we will find matte is coming out on one side, slag is flowing out from the other side. Why this is so?

The two basic principles of a continuous operation will be that one in the reactor partial pressure of oxygen will not be uniform all throughout and the other is there must be counter current flow of matte and slag.

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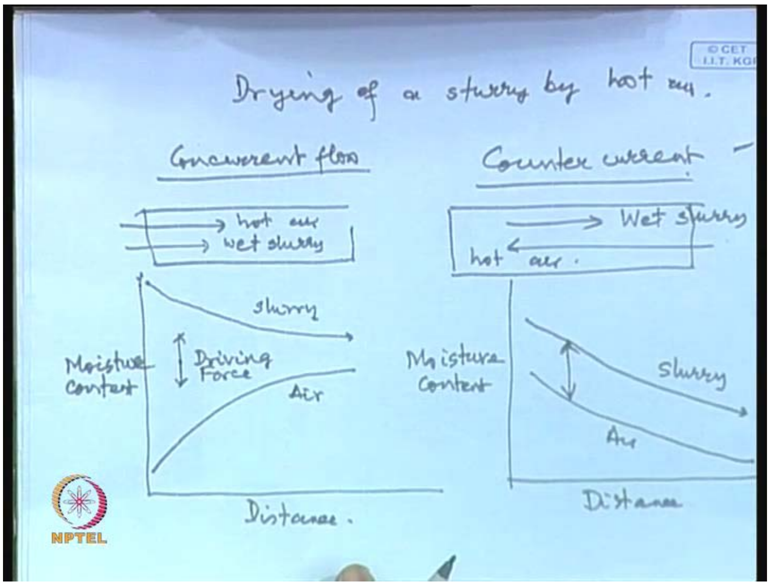

Now, what is the advantage of counter current flow? For that, consider the drying of slurry by air, hot air. Now, in concurrent flow which means where the slurry and the hot air are going in the same direction, schematically it is like this; hot air and wet slurry. If you plot the moisture content as a function of distance, the air is initially very dry. So, it is going to pick up moisture as it moves along, whereas, the moisture content is very high and it will gradually, this slurry will gradually lose moisture content.

Now, initially, the driving force for drying is very high, because there is a big difference between the moisture level in the slurry and the moisture level in air. But, after sometime the driving force comes down and therefore, the process is not very effective any longer. Whereas, in the counter current flow, the wet slurry is moving in one direction, the hot air is moving in another direction and there the picture would be something like this. Moisture content versus the distance; the hot air is going to pick up moisture whereas, slurry is going to lose moisture with distance. Now, here the driving force will remain almost uniform for a long distance.

So, if you allow it to flow, counter current flow is very effective in bringing one phase from one layer to the other layer. This is the basic principle also in the case of counter current flow of slag and matte. Because we want matte and slag to react and ensure that any copper in this slag phase goes into the matte phase. How will it go? One of the ways as I have mentioned is Fe S will react with any Cu 2 O in slag, form Fe O in slag, and copper will be recovered and it will go to the matte phase.

So, we need a counter current flow of metal and slag and for that some simple engineering techniques are employed. I will now come to some configurations that are applied in WORCA furnace design (Refer Slide Time: 31:31). There are many kinds of designs available, and let me also mention WORCA, rather Worner was one of the first to suggest a continuous operation and we call that plant as WORCA, but subsequently many other continuous operating plant designs have been proposed and some are working successfully.

Of course Australia is a leader and there is a process called as, ‘Out smelting’ for continuous operation of copper, but there are also many others. All of them make use of two basic principles; Pa O 2 will be different in different regions in the same reactor and slag and matte must flow opposite each other in contact with each other. So that finally, when the slag is discarded, it has been minimum amount of copper in it and the matte that is recovered as the maximum copper recovery.

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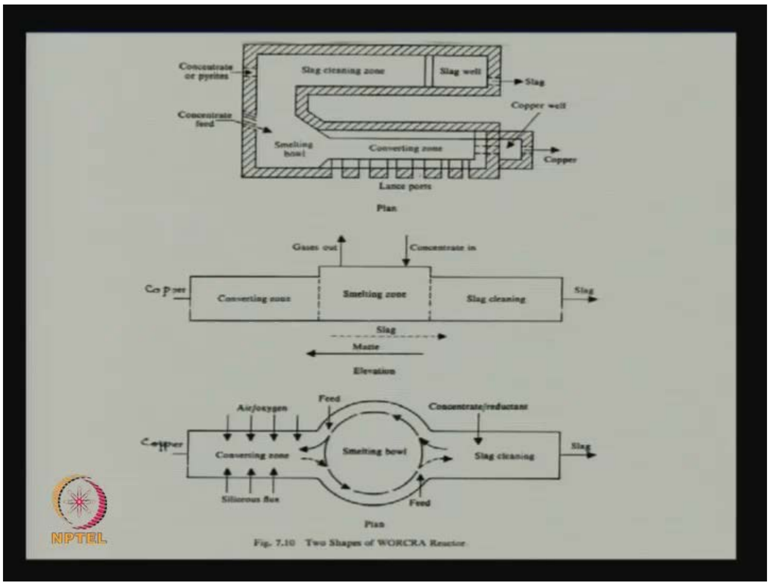

Fig. 7.10 Two Shapes of WORCRA Reactor

Let us go, look at one or two designs. Here are two designs of WORCRA furnace. One is a U-shaped design; the other is a straight design. Now, in this design basically, there is a smelting bowl. This smelting bowl is where we are combining roasting and smelting of the concentrate and the matte that is being produced is moving in this direction. How it is made to move? I will come to that.

And the slag is made to move to that direction. Now here some more concentrate is coding to ensure complete copper removal, because if the slag is carrying some copper, reaction with concentrate will recover that copper to produce matte; matte will again come back here. Finally, there is a slag cleaning zone to ensure that it is cleaned of any residual copper and slag goes to a well, matte will go to… This area where there is converting, very high Pa O 2, here there is less Pa O 2, something intermediate here.

And this is a straight design. You have converting zone in one side, smelting zone here, slag cleaning zone here, slag is moving that way and copper is moving that way. This is the elevation; this is the plant. In the elevation you see concentrate in, gases out; smelting zone slag goes this way, matte goes that way. This copper comes here and slag comes out here. We are getting blister copper, mind you. Now this is the plan view, they are. This is the way the thing is made to circulate continuously. Air, oxygen will be blown in the converting zone. These are the fluxes going in. This is the slag cleaning zone where again we will put some concentrate if necessary some reductant.

If there is some Cu 2 O you must get that copper out by reduction of the Cu 2 O. So, here the Pa O 2 level has to be very low. Here, it is very high, it is the highest here and it is intermediate here.

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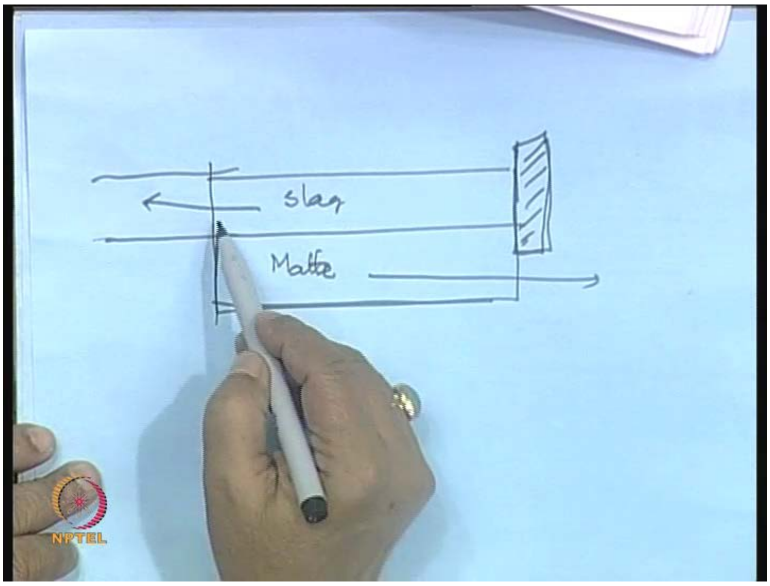

Now, how do we ensure that copper and slag move in other direction? The simple technique for that is the following we know that slag is lighter and matte is heavier. So, in a reactor if we put a baffle like this, means slag cannot flow that way, it has to flow this way, and matte will go that way. So, matte will go this way and we do not have this, slag will flow that way. So, whenever we have the slag and matte, slag layer is building up and we do not allow it to go to this side where matte is going by simply have a baffle which dips into the matte. The matte will always can run through. But the slag cannot penetrate this. The slag is made to flow that way. We can even make it easier by providing a gradient here. So, the matte flows more easily. Slag has to flow to the other side. This is the very simple engineering thing which you will find in one of the designs.

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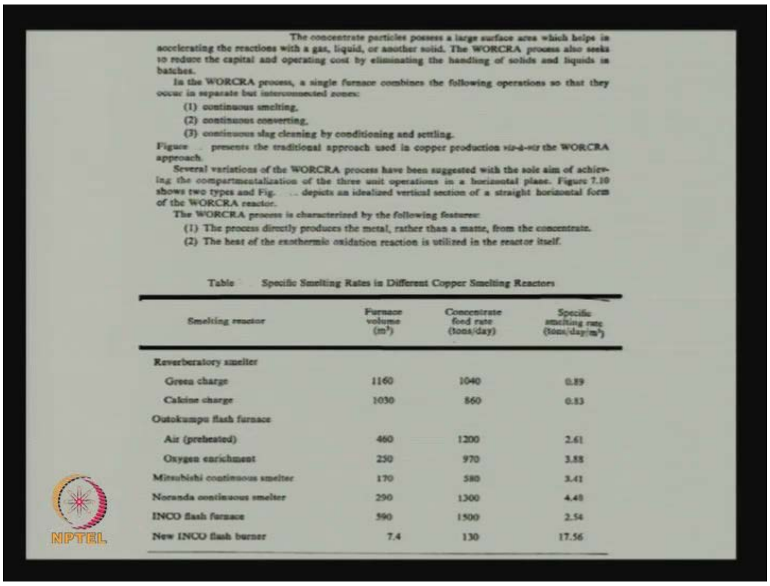

The concentrate particles possess a large surface area which helps in accelerating the reactions with a gas, liquid, or another solid. The WORCRA process also seeks to reduce the capital and operating cost by eliminating the handling of solids and liquids in batches.

In the WORCRA process, a single furnace combines the following operations so that they occur in separate but interconnected zones:

(1) continuous smelting,
(2) continuous converting,
(3) continuous slag cleaning by conditioning and settling.

Figure … presents the traditional approach used in copper production *vis-à-vis* the WORCRA approach.

Several variations of the WORCRA process have been suggested with the sole aim of achieving the compartmentalization of the three unit operations in a horizontal plane. Figure 7.10 shows two types and Fig. … depicts an idealized vertical section of a straight horizontal form of the WORCRA reactor.

The WORCRA process is characterized by the following features:

(1) The process directly produces the metal, rather than a matte, from the concentrate.
(2) The heat of the exothermic oxidation reaction is utilized in the reactor itself.

Table Specific Smelting Rates in Different Copper Smelting Reactors

Smelting reactor	Furnace volume (m^3)	Concentrate feed rate (tons/day)	Specific smelting rate (tons/day/m^3)
Reverberatory smelter			
Green charge	1160	1040	0.89
Calcine charge	1030	860	0.83
Outokumpu flash furnace			
Air (preheated)	460	1200	2.61
Oxygen enrichment	250	970	3.88
Mitsubishi continuous smelter	170	580	3.41
Noranda continuous smelter	290	1300	4.48
INCO flash furnace	590	1500	2.54
New INCO flash burner	7.4	130	17.56

Now, let me read out one or two things here. The concentrate particles posses a large surface area, which helps in accelerating reactions with a gas, liquid or another solid. The WORCRA process all seeks to reduce the capital and operating cost by eliminating handling of solids and liquids in batches. A single furnace combines the following operations. They occur in separate, but interconnected zones in the same reactor, continuous smelting, continuous converting, continuous slag cleaning by conditioning and settling. I have compared the traditional approach and the WORCRA approach.

Now, there are several variations of WORCRA the sole aim in each is achievement of compartmentalization of three unit operations. It could be in a horizontal plane, it has to be done and we have shown it two, one new shaped and the other is a linear version. Again the main characteristics are that the process directly produces a metal rather than a matte from the concentrate. The heat of the exothermic oxidation reaction is utilized in the reaction itself. Now, many such continuous smelters have been proposed and in my book, I have given a comparison of the smelting rates in different coppers smelting reactors. This is difficult to make a direct comparison because you know reactor shapes, sizes etcetera are different.

But, one way would be to compare smelts specific melting rate, which is tons per day per meter cube. There are some reverberatory furnaces where the green charge is put means without drawing the concentrates, is introduced and in some it is first calcined, is dried and then introduced.

Obviously, the specific melting rate would be more if you have calcined charge furnace volume. They are more or less the same. Actually in green charge specific melting rate is a bit higher, because I think some others are heat generated. Now in the flash smelter like one Outakompu flash smelter, one can have pre heated air or oxygen enrichment in the reactor environment; obviously, there is oxygen environment specific reaction rate would be a smelting rate, it will be much more. See it is about four times that of the conventional reverberatory furnace. In Mitsubishi continuous smelting, it will be about 3.41, but in other kinds of continuous smelters there is one called Noranda, which I will show you, it can be a much higher.

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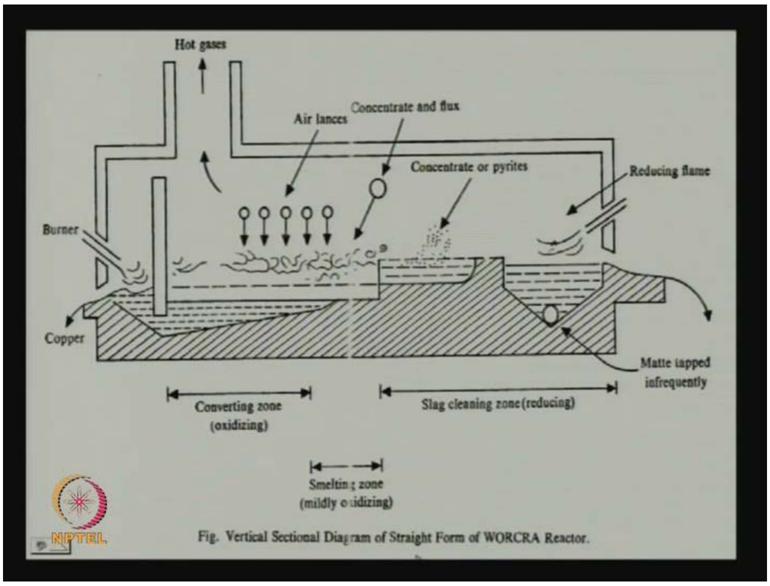

Fig. Vertical Sectional Diagram of Straight Form of WORCRA Reactor.

And now there are also other reactors where these operations are much faster. Let us consider one. This is the vertical sectional diagram from one kind of WORCRA reactor, which again I will show you that engineering principle that there is a baffle here, which will not allow the slag to come that way.

But matte converted copper, blister copper can come under the baffle and come out this way whereas, the slag can flow to that side and the slag can be taken out. There was a process called Noranda process, which was developed in Canada. Again, similar in concept, you will find that matte is coming this way; slag is coming from that side. Again there is this baffle going into the matte like phase, so that the slag cannot go to that side.

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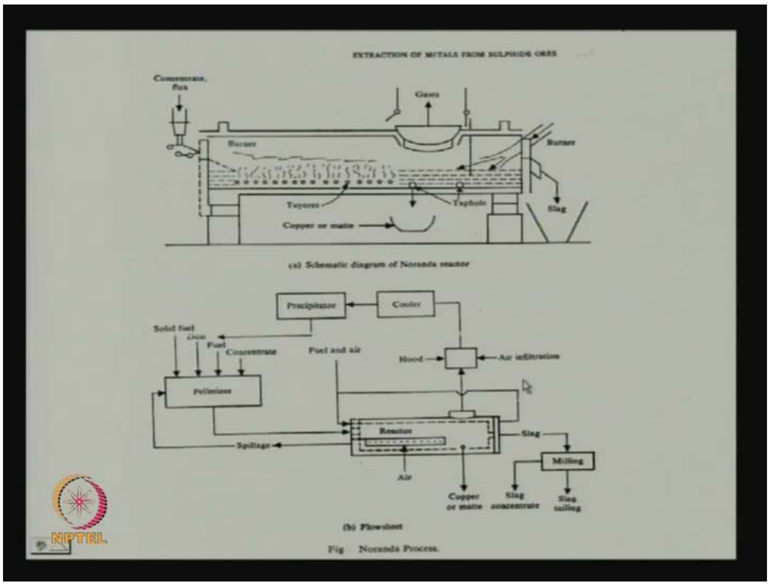

Here, also there is a tuyeres zone. This is where the converting operation takes place. This is where we will have the smelting operation. It is clearer here. This is the reactor. Copper or matte is coming from one side; slag is being taken out here and some of the other details not necessary.

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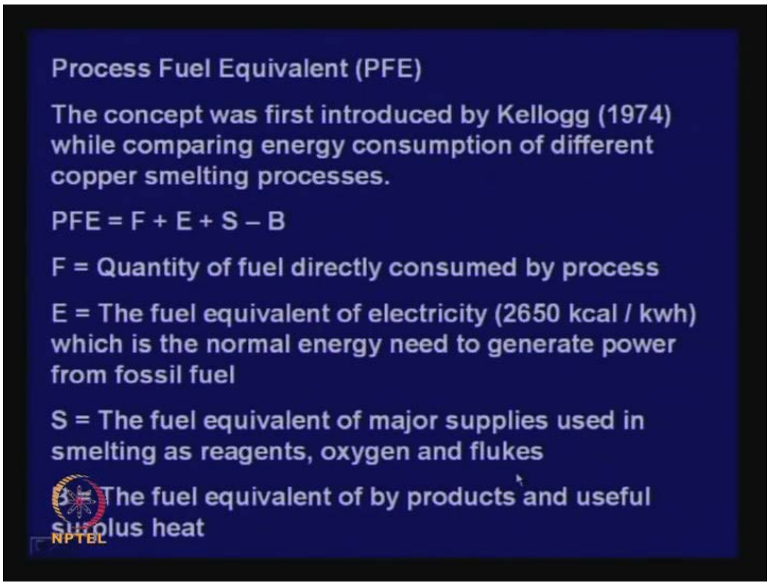

Process Fuel Equivalent (PFE)

The concept was first introduced by Kellogg (1974) while comparing energy consumption of different copper smelting processes.

PFE = F + E + S – B

F = Quantity of fuel directly consumed by process

E = The fuel equivalent of electricity (2650 kcal / kwh) which is the normal energy need to generate power from fossil fuel

S = The fuel equivalent of major supplies used in smelting as reagents, oxygen and flukes

B = The fuel equivalent of by products and useful surplus heat

Now, there are so many processes for copper smelting and next I will also come to the hydrometallurgy of copper. And people would like to know which process will require more energy. How do we analyze the energy requirements? For that Kellogg gave a very interesting concept. He proposed that we use a thing call Process Fuel Equivalent to compare energy requirements. Initially, he did it for only the copper metallurgy, but now it has become of general use in many extraction processes.

So, the concept introduced by Kellogg says this that we should consider a term process fuel equivalent which is a summation of four terms; F, E, S, B. F is quantity of fuel directly consumed by the process. Are you using coal or are you using fuel oil? And what is the heat value of the fuel we were using that is what you are consuming. Are you consuming electricity? If you are consuming an electricity then E, what is the fuel equivalent of the electricity? And further, there is a well known conversion that this 2650 kilo calories per kilo watt hour, which is the normal energy need to generate power from fossil fuels.

So, the energy input into this system in terms of solid or liquid fuel or electricity, you first calculate. Then we calculate S. S is the fuel equivalent of major supplies used in smelting as reagents, oxygen and fluxes. This is something that one usually forgets that in a process you have brought in some raw materials, but the raw materials have not come out of nothing, they have come out of something, and they have needed energy for their processing. So, you have to find out how much of energy was required to produce the raw materials that you are using. For example, you are starting with the copper ore. You are grinding the copper ore. So, you need to know how much of energy you have required in grinding; you find the fuel equivalent.

Then you are doing floatation. For floatation, you are blowing bubbles. You are using pumping. There are the liquids, have to may go from here to there, the slurry has to move from here to there. How much of energy is required in that? Remember, in the very first lecture, I had said that initially when we are under graduate students, we were told that if you reduce an oxide by aluminum, the alumina thermal reduction is highly exothermic. You do not have to supply any heat. You simply ignite and everything would automatically like the oxide will get reduce to metal.

What we were not told at that time is that it is not really a process which is very friendly from the energy point of view. In that step it is fine, but then you have needed energy to produce that aluminum to start with; you cannot ignore that. That is why we cannot always say that a raw material is a zero energy source. Consider steel making, in steel making you can produce from iron ore to steel, you need energy. Suppose you find scrap steel lying around, which is nobody is using, you take the scrap, you produce steel. You will need less energy. Because the scrap is already impure metal, but then, it is not being used. It is a zero energy source.

But suppose you are not getting scrap and as a scrap substitute you produced sponge iron, in sponge iron plants take (( )). If you have produced sponge iron which can go for electrics furnace smelting, but sponge iron is not a zero energy source. It has needed lot of energy for processing of iron ore, reduced by coal to produce sponge iron. So, if you want you analyze the energy production for steel making, electric furnace steel using sponge iron, you have to take into account the heat that has gone into making of sponge iron to start with.

Similarly, in copper smelting, we have to find out the energy required in the production of raw materials that are using. It could be copper concentrate, the fluxes; if you are using oxygen then you have required energy to produce that oxygen. When you are injecting that oxygen you need power to inject that oxygen that will come later. That comes under the fuel requirement in the process.

But, the oxygen as the raw material also has an energy equivalent. So, these are the energy inputs. Now B is the fuel equivalent of byproducts and useful surplus heat. If there is exothermicity; exothermic heat that will come there, if there are hot gases coming out from which you can recover heat, if there are hot materials coming out there is a fuel equivalent that has to be taken out, that is a thing of an advantage. These are disadvantages. So, process fuel equivalent has to; P F E, have to take in to account the fuel inputs directly, indirectly to raw materials and the energy that you are getting from the heat of reaction and from the heat value of the hot products.

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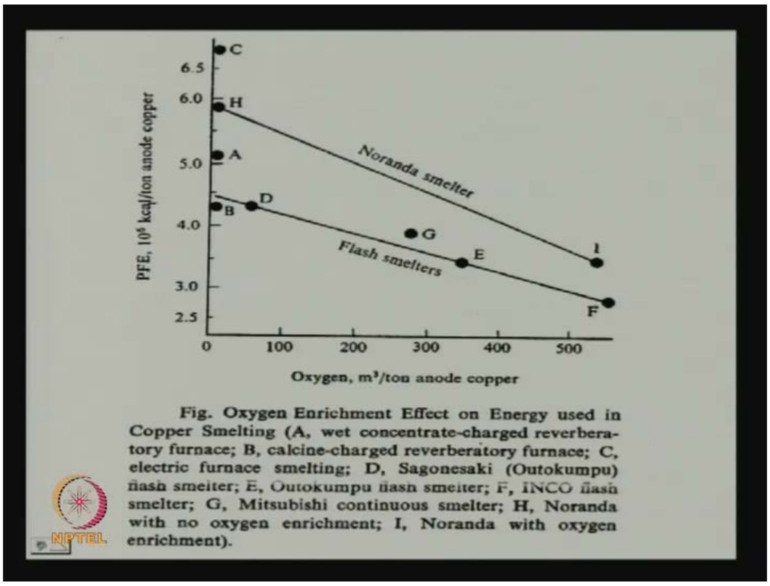

Fig. Oxygen Enrichment Effect on Energy used in Copper Smelting (A, wet concentrate-charged reverberatory furnace; B, calcine-charged reverberatory furnace; C, electric furnace smelting; D, Sagonesaki (Outokumpu) flash smelter; E, Outokumpu flash smelter; F, INCO flash smelter; G, Mitsubishi continuous smelter; H, Noranda with no oxygen enrichment; I, Noranda with oxygen enrichment).

Now, a very interesting thing has been found that you are using in converting air or oxygen and in the process, in many places, whether during roasting or smelting you are maintain an oxidizing atmosphere. People have made a general analysis of what role does oxygen play in terms of P F E; it has been found that oxygen enrichment effect on energy used in copper smelting is the more oxygen is used per ton of anode copper in the final step, the less is the P F E value. What does it mean? Means as far as possible one should use oxygen enriched air or oxygen then, the total energy requirement becomes less. From common sense we can tell why because when you use air you are heating up a lot of nitrogen which has no role in the process. It takes a lot of heat then goes out as hot nitrogen with whatever air is escaping.

If you eliminate that that nitrogen part; enrich air with oxygen, your heat efficiency becomes better. Now, here the comparisons have been made between wet concentrate-charged reverberatory furnace; calcine-charged reverberatory furnace; electric furnace smelting, then Mitsubishi continuous smelter, Noranda with no oxygen enrichment. So, we have put all kinds of things and generally, it is found that if you have oxygen enrichment the process will be better from energy point of view.

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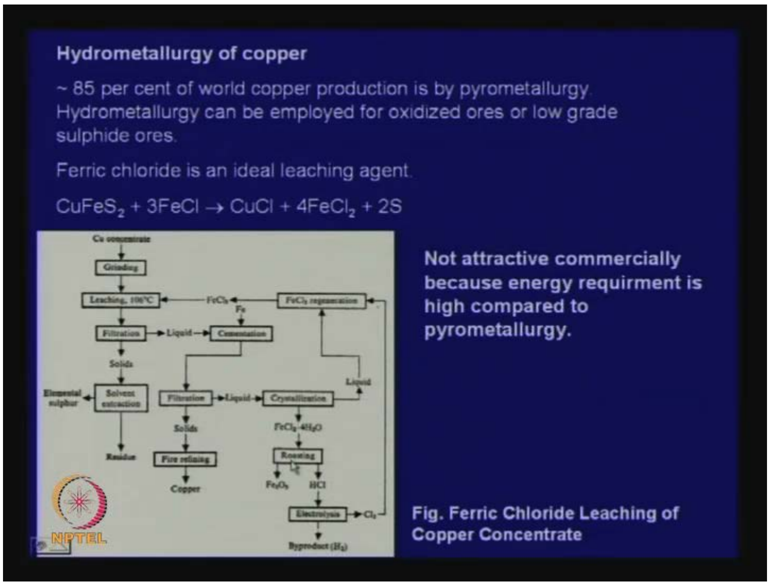

Hydrometallurgy of copper

~ 85 per cent of world copper production is by pyrometallurgy.
Hydrometallurgy can be employed for oxidized ores or low grade sulphide ores.

Ferric chloride is an ideal leaching agent.

$CuFeS_2 + 3FeCl \rightarrow CuCl + 4FeCl_2 + 2S$

Not attractive commercially because energy requirment is high compared to pyrometallurgy.

Fig. Ferric Chloride Leaching of Copper Concentrate

Now, this is all about the pyrometallurgy of copper. Now, 85 percent of worlds copper production is by pyrometallurgy. And of that I think the most is by the conventional route. Of course, using flash smelters and it is now become the middle stage, is now more common. Nobody now uses reverberatory furnace and that means roaster reverberatory furnace and converters. The first two are having been combined in many places including the copper plant in Ghat Salem. But, continuous copper production still not that common, because it needs more control obviously. You need sensors; you need computerization, because you need that an input material must always remain in the same composition little bit, because if there is any variation then the entire chain of operations will suffer.

But, 85 percent is still from one or other kind of pyrometallurgy, but then hydrometallurgy can also be employed in extraction of copper, and for that, the common process is ferric chloride leaching of copper pyrites, to take copper into solution and then with that will become our starting point.

I will come to that in a next lecture, but in passing, I will just mention one thing that in the copper mines, it was found sometimes that when you have taken out the pyrites; mine is abundant, after many months or years they find that when rain water is accumulated it has turned blue. Apparently, it has leached the residual copper sulphate that was abundant in the mines. And then people discovered there are some natural bacterial reactions which cause this. This is called bacterial leaching of copper ores.

And found accidently, now it is also being employed in so many places, but this is a slow process, particularly suited for low grade copper ores where there is certain kind of bacteria, if they are introduced; they are called Ferrobacillus, Ferro side. There are other bacteria whose job is to convert the minerals into soluble sulphates. I will not discuss that, but in my book there is a reference to bacterial leaching of copper ores or bio leaching of copper ores. They are also applicable in case of uranium ores, but they are of course, not commercially as important as other processes as the ferric chloride leaching process that will discuss in the next lecture.

Thank you.