Non-ferrous Extractive Metallurgy

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Module No. # 01
Lecture No. # 20
Extraction of Ferro Alloys

I have been discussing extraction of ferro alloys and ferro alloying elements. Now do not be confused when I use them intermittently. Ferro alloying elements are those, which go into making ferroalloys. And I have been repeating that very often we need these alloying elements in steel, and it is easier to add these alloying elements as ferro alloys, but there are times when we want the ferro alloying element in elemental form for other uses. They are not always used for alloying there are other uses.

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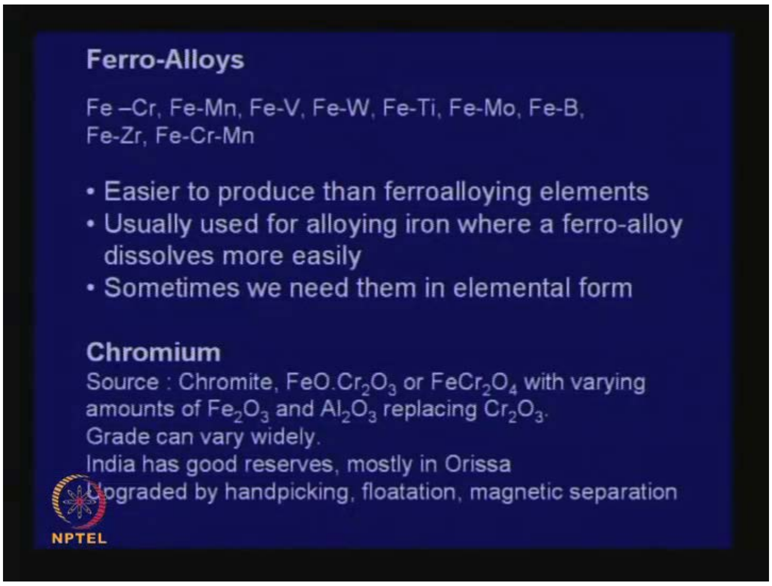

Ferro-Alloys

Fe –Cr, Fe-Mn, Fe-V, Fe-W, Fe-Ti, Fe-Mo, Fe-B,
Fe-Zr, Fe-Cr-Mn

- Easier to produce than ferroalloying elements
- Usually used for alloying iron where a ferro-alloy dissolves more easily
- Sometimes we need them in elemental form

Chromium

Source : Chromite, $FeO.Cr_2O_3$ or $FeCr_2O_4$ with varying amounts of Fe_2O_3 and Al_2O_3 replacing Cr_2O_3.
Grade can vary widely.
India has good reserves, mostly in Orissa
Upgraded by handpicking, floatation, magnetic separation

So, let us go back to a slide I had shown earlier. These are the common ferroalloys; ferrochromium, ferromanganese, ferrovanadium, ferrotungsten, ferromolybdenum, ferro boron, ferrozirconium, ferrochromium manganese, and I would repeat this, we want these ferro alloys because these elements called ferro alloying elements are required for alloying of steel.

It is easier to produce them in ferroalloy form and then add to steel. So, it is not only easier to produce they will mix very quickly and that is the advantage of why we are producing them as ferroalloys. But sometimes we need them in elemental form.

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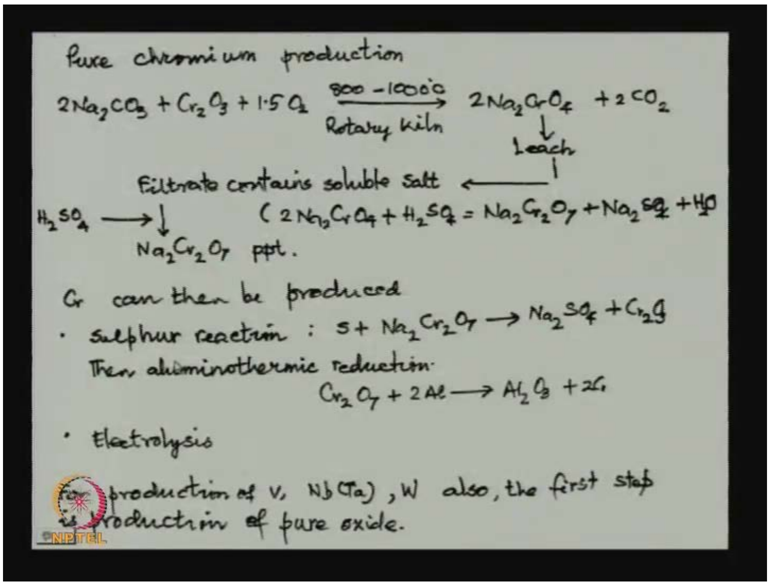

Pure chromium production

$$2Na_2CO_3 + Cr_2O_3 + 1{\cdot}5\,O_2 \xrightarrow[\text{Rotary kiln}]{800-1000^\circ C} 2Na_2CrO_4 + 2CO_2$$

$$\begin{tikzcd} & 2Na_2CrO_4 \arrow[d] \\ \text{Filtrate contains soluble salt} \arrow[d, "H_2SO_4"'] & \text{Leach} \arrow[l] \\ Na_2Cr_2O_7 \text{ ppt.} & \end{tikzcd}$$

$(2Na_2CrO_4 + H_2SO_4 = Na_2Cr_2O_7 + Na_2SO_4 + H_2O$

Cr can then be produced

- sulphur reaction : $S + Na_2Cr_2O_7 \rightarrow Na_2SO_4 + Cr_2O_3$

  Then aluminothermic reduction.

  $$Cr_2O_7 + 2Al \longrightarrow Al_2O_3 + 2Cr$$

- Electrolysis

For production of V, Nb (Ta), W also, the first step is production of pure oxide.

I have given you example of how chromium is produced from chromate by sodium carbonate roasting, getting making a chromate, and then treating that with sulphuric acid to produce N a 2 C r 2 o 7, and then from there we produce pure chromium oxide, which can go for electrolysis or aluminothermy reduction.

Now, there are many oxides in nature, which we which will go for ferro alloying elements, but we sometimes need them as pure metals also. And there are elaborate flow sheets for making of these elements by first always producing pure oxide.

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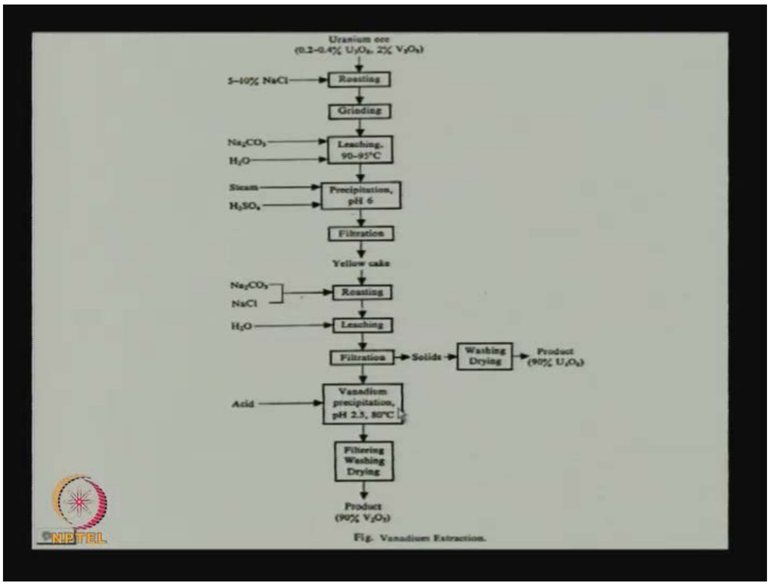

Uranium ore
(0.2–0.4% U_3O_8, 2% V_2O_5)
5–10% NaCl
Roasting
Grinding
Na_2CO_3
H_2O
Leaching, 90–95°C
Steam
H_2SO_4
Precipitation, pH 6
Filtration
Yellow cake
Na_2CO_3
NaCl
Roasting
H_2O
Leaching
Filtration
Solids
Washing
Drying
Product
(90% U_3O_8)
Acid
Vanadium precipitation, pH 2.5, 80°C
Filtering
Washing
Drying
Product
(90% V_2O_5)

Fig. Vanadium Extraction.

Like here is an example for vanadium oxide, which comes from a uranium ore that contains a 0.2 to 0.4 percent of U 2 O 8, 2 percent vanadium, B 2 O 5. The idea here is not we want make ferrovanadium. First we will try to; we are thinking to first try to produce pure F e 2 O 3, a pure V 2 O 3 and then worry [why/worry] what to do.

Now, it has to go through a many chemical steps. Some of the steps, you need not answer, but there is a very logic for all these things, why we do. Eventually why we try to get everything in a solution then by controlling PH or we get different precipitates. You can precipitate out uranium oxide. You can precipitate out vanadium as an oxide.

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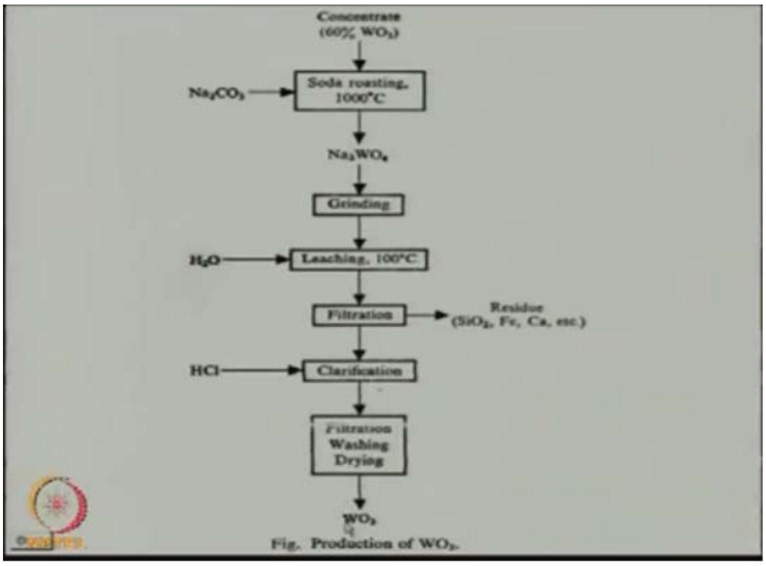

Fig. Production of WO_3.

Similarly, there are tungsten ores. Incidentally we do have some tungsten ores in Rajasthan, place called Degana, but very low grade. Because tungsten is very heavy, using gravity separation, we can get a concentrate going up to 60 percent of W O 3.

Again that goes for soda roasting, which is a very standard procedure to produce Na 2 W O 4. Grind, leach by water, filter it, you get rid of the residue and get a soluble compound of tungsten, then by hydrochloric acid treatment, we can precipitate W O 3. If you want pure tungsten then you have to start with W O 3.

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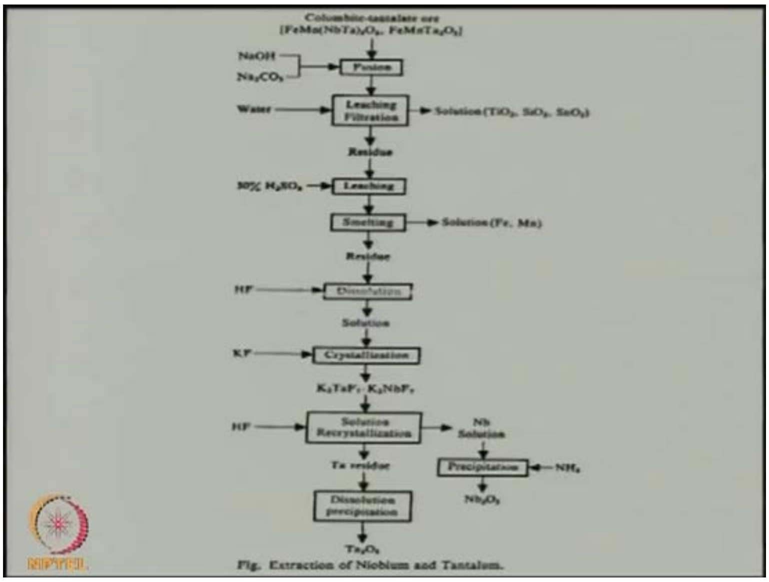

Fig. Extraction of Niobium and Tantalum.

Similarly, tantalum, niobium; incidentally, the word columbite, there are two words for the element niobium; columbium, as well as niobium.

So, when we are saying columbite, is actually ore of niobium and tantalum. Now, here let me make small remark. You will find it is a columbite tantalite ore. There are these two elements are called twins; columbium and tantalum. No matter what you do, it is very difficult to separate them.

There is another twin like this called zirconium and hafnium. No matter what you do with zirconium there is always some hafnium associated and whatever happens to the zirconium compound will happen to the hafnium compound. But sometimes you do not want the twins together. We want them separated. Now this is a subject of a lot of studies in laboratories.

How you separate zirconium and hafnium? How do you separate niobium and tantalum? I, myself, have worked on zirconium and hafnium, separation for a long time, but that is not the subject of my discussion now.

Here there is a elaborate flow sheet (Refer Slide Time: 06:28). Here the aim is not only to treat these oxides to come to a pure oxide, the concentrate, but also to separate niobium and tantalum. And you see what a complicated flow sheet one has to adopt, and at stages one has to use hydrofluoric acid, which is a very dangerous reagent, and that there is no simple way of separating tantalum and niobium. But there is a process where we separate tantalum and niobium. These two are separate.

So, what I am saying is there are many oxides in nature from where we first produce a pure oxide and then try to produce the metal. In many cases, many such oxides will be taken into a halide form by chlorination, and then from the halide it will be easier to produce the metal, either through electrolysis or through an aluminothermic reduction, Thus, I will discuss in the next module, when I discuss actually next to next, when I discuss metals from halides.

Anyway, I will stop talking about production of ferro alloying elements in elemental form. Now I will go back to ferro alloys because that is the main subject of our discussion. Why do we need ferro alloys? I said they are very important there are some uses mentioned here, but I will discuss the uses little more in detail little later (Refer Slide Time: 08:00).

We need ferroalloys for alloying that is well accepted; that you know steel properties have to be modified by if you want to have a stainless steel; you have to add nickel and chromium. You will not add pure nickel metal or pure chromium. You will adjust a composition by adding ferronickel and ferrochromium, but apart from that we also need ferroalloys for many other things. We need them for deoxidation of steel and other gases too.

When there is… In after steelmaking is a process of oxidation and look at the way, ferrous metallurgy works. You have iron ore, oxygen level very high, in the blast furnace we have a reducing atmosphere, we produce pig iron, and under reducing conditions oxygen level is low. Now, we remove impurities from pig iron by an oxidation process either in a say from bottom blown or top blown converter whatever you blow oxygen. So, initially we remove the oxygen then we again add oxygen, so when we get steel the oxygen level is high, we need to remove that again and we have to use a deoxidizer.

And very often this ferro alloys are used as deoxidizers because the ferro alloying elements form very stable oxides. They also form stable nitrides. So, they are used for removing both oxygen as well as nitrogen.

Titanium and this is zirconium (Refer Slide Time: 10:00) not zinc, they form stable nitrides, whereas ferrosilicon, ferromanganese, ferrotitanium, are usually used as deoxidizers. So, if you want to add nitrogen we go for ferrotitanium, ferrozirconium also. Then ferrosilicon, ferronickel, is also added to control graphite morphology in cast irons. And ferroalloys, I mentioned can be produced by aluminothermic reduction. Then you get a ferroalloy which has no carbon. They can also be produced by carbon smelting in arc furnaces, in that case you will have carbides in the ferroalloys and you have to find a way of removing the carbon from the ferroalloys.

To remove excess carbon one has to introduce an element which reduces solubility of carbon. During carbon reduction, impurities are removed by oxidizing slag’s, controlled oxidation of carbon or finally, oxidation of carbon under vacuum. These are the three standard techniques of removing carbon from high carbon ferroalloys. I will discuss that little later, but first of all, let me spend some time on uses of ferroalloys, and what kind of resources we have in our country as regards the sources are concerned.

Now, unfortunately I haven’t made a slide out of this. So, I will have to read out something about ferroalloys, and their uses. Ferrochrome, both high and medium carbon ferrochrome, carbon can be 2 to 8 percent or chromium 78 to 68 to 71 percent.

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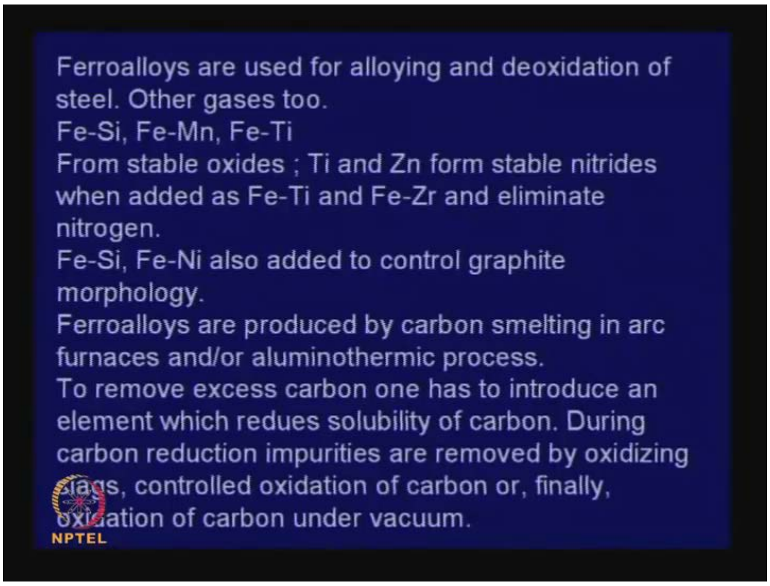

Ferroalloys are used for alloying and deoxidation of steel. Other gases too.
Fe-Si, Fe-Mn, Fe-Ti
From stable oxides ; Ti and Zn form stable nitrides when added as Fe-Ti and Fe-Zr and eliminate nitrogen.
Fe-Si, Fe-Ni also added to control graphite morphology.
Ferroalloys are produced by carbon smelting in arc furnaces and/or aluminothermic process.
To remove excess carbon one has to introduce an element which redues solubility of carbon. During carbon reduction impurities are removed by oxidizing slags, controlled oxidation of carbon or, finally, oxidation of carbon under vacuum.

They are use to supply chromium for stainless steel making and to produce alloy steels for mining and milling operations. So, we need ferrochrome in many applications. I am mentioning here that it is for adding chromium to steel and also for making various kinds of alloys that will be required for mining and milling applications.

We need low carbon ferrochrome where carbon should be as low as 0 to 2 percent for finishing additions in stainless steel making. There are some requirements in stainless steel making where carbon cannot be tolerated. There it has to be low carbon ferrochrome. Ferrosilicon is mainly used as a deoxidizer in a steel industry that you have an oxidized bath add ferrosilicon; silicon will react with oxygen, oxygen remove as silica.

Ferrosilicon promotes formation of graphite as I had mentioned and by decomposition of Fe 3 C. So, it also used to produce malleable iron containing nodular graphite. Limited additions of silicon to low carbon steel improves tensile strength, yield strength, and impact strength, and Fe Si carbon alloys silicon up to 4.5 percent are suitable for magnetic material with high resistivity and permeability with reduced core losses; so, all kinds of application.

Why do we need ferrotungsten? Ferrotungsten is for manufacturing of tungsten steels. You know tungsten imparts hardness. So, for high speed steel, such as steels having ability to retain hardness at high temperatures and therefore, used as machine tools we need tungsten steels. So, we have to use them as ferrotungsten. A typical composition will be tungsten 18 percent, chromium 4 percent, vanadium and cobalt. We can we also have precipitation hardening tungsten alloys and iron vanadium, ferrovanadium is used for imparting fine grain size to steels that improves mechanical properties.

Ferromanganese, of course, without ferromanganese the steel industry will be dead. Ferromanganese is of vital importance. It required for deoxidation of steel, desulphurization of steel. For every ton of steel that we are producing we need 5 to 6 k g of manganese. So, as we expand the steel industry, ferromanganese production also has to increase. Alloy steels containing almost 14 percent of manganese are used in manufacturing of jaw crushers, railway equipment like tracks, points, crossings and switches. Without manganese in steel, it is unthinkable and the manganese added as ferromanganese.

High carbon ferromanganese is generally used for additions to carbon steels where carbon is tolerated in steel. You can add high carbon ferromanganese, but low carbon variety will be used only of alloy steels where it is necessary to have low carbon levels. Ferrozirconium is sometimes used for deoxidizing, sometime for scavenging, and then zirconium treatment improves shock resistance properties and therefore, steels are treated or steels thus treated are used for tools like rock drills.

And lastly ferrotitanium, it is also used for deoxidation, it is also used for alloying, it is a strong carbide stabilizer, and titanium is used in austenitic stainless steels to prevent intergranular corrosion. Its addition also improves hardening characteristics of plane chromium steel. So, variety of applications of this ferro alloys and we need them for steel industry or it cannot survive without the ferro alloy industry.

What about India's situation as regards the ferro alloys? We are very fortunate in having good deposits of chromium and as I mentioned there are most of it is in Orissa. It is estimated there are about 3.5 million tons with one million ton of chromium content higher than 48 percent; they are available. Manganese, total deposits about 180 million tons, about 120 million tons, with manganese content higher than 46 percent. So, India is rich so far as chromium and manganese deposits are concerned. Tungsten has very limited deposits. It comes in the form of wolframite with tungsten content, it can be very high, but the ores are of very low grade.

For Titanium, India has huge deposits of titanium, extensive deposits, estimated at about 250 million tons. Ilmenite, which is Fe O. Ti O 2 or rutile, only Ti O 2, they are found, mixed with beach sands. All along our eastern coasts, as well as, western coasts and vanadium also we have total deposits about 20 to 25 million tons with vanadium content only 0.2 to 2.5 percent.

So, these are the resources we have. A very common thing that we need is ferronickel that has to come from nickel sources that is very limited in India. We do not have nickel resources as such, but we do have nickel as chromite overburden. You see the chromite mines in the top layer about 0.6 to 0.8 percent, nickel is available, it has been known for a long time.

So, before chromite mining, the top layers are separated out and they have been kept there for many years now and they have made mountains in Sukinda valley of Orissa, you see big hills. Those hills have this chromite overburden containing say 0.5, 0.6 or 0.8 percent nickel. On the whole, a huge amount of nickel is there, but we still have not got a process for extracting that nickel, we are working on it.

I will come to this in a later thing where we talk about metals from sulphides. Nickel also comes from sulphides, and nickel also comes from oxide sources. Maybe I will take it up in this lecture also, but in India good nickel reserves are not there, but nickel is associated with chromate reserves; low grade nickel reserves are there.

So, this India has all the reason to go for a vibrant ferro alloying, ferro alloy industry and its happening also. There are many ferro alloying plants. Now, I will now not discuss aluminothermic reduction. I have given an example of aluminothermic reduction; say in the case of manganese, you can produce the metal, if you want to produce ferroalloy then all you need is iron addition.

But generally for large scale production of say ferrochromium, ferronickel, ferrotitanium etcetera, we need to go for a carbon reduction, which will give carbon in the product, then finally, you have to find a way of removing the carbon, and as I mentioned there are three standard techniques for getting rid of the carbon in the ferroalloy.

First will be having produced that ferroalloy, which has carbon, it has to be treated by an oxidizing slag. The oxidizing slag will oxidize the carbon and remove it. The other thing could be remove the carbon by oxidation through oxygen injection. Now, this may sound very interesting that suppose you have a ferroalloy like ferrochrome, at high temperature it has carbon, and I say you can remove the carbon by injecting at high temperature, oxygen into the bath.

You may think this is going to oxidize chromium or oxidize the ferroalloy; this does not happen, because if you go back to the Ellingham diagrams you will find at very high temperatures carbon monoxide is becoming more stable as compared to the metal oxides. So, if we inject oxygen into the bath, you have an exothermic heat heating the bath and if the bath temperature increases, oxygen will react with carbon, in preference to chromium or manganese or iron.

So, in the industry very often carbon is removed by oxygen injection, and that is not oxidizing ferroalloy, it is removing carbon, because that carbon monoxide is now thermodynamically more feasible, more stable. The third will be something very obvious. If you apply vacuum and then C O would get eliminated, because carbon monoxide will form in the gaseous form, so the reaction of formation under oxidizing conditions, carbon will form carbon monoxide and by vacuum treatment we can remove. These are the standard techniques.

If I discuss one particular process, like say for ferrochrome, this will become clearer. Now, let us proceed. In this book that I have referred to many times, my book on non-ferrous metals production, many pages have been devoted to production of individual ferroalloys.

Whatever has been written is still very sketchy, because there can be a course on ferroalloy production, which will run for one whole semester, but you do not have to go know all about ferro alloying making; you need to know the principle.

So, just whatever I am saying now and little bit from the book should do.

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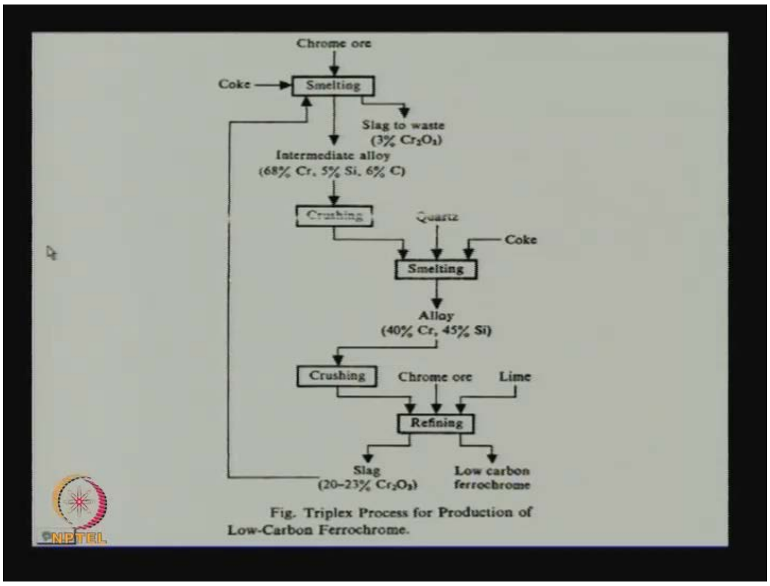

Fig. Triplex Process for Production of Low-Carbon Ferrochrome.

Let us talk about production of low carbon ferrochrome alloy. Now, generally how do you produce ferroalloy by carbothermic reduction? You will have an electric furnace. You will take the concentrate, say chromite, manganese ore, whatever. You bring in carbon, you reduce, and you get the metal because there is always iron oxide or you add the iron ore and you get iron as an element and you also get carbon because the ferro alloying and even it will form carbon.

And then you find a way of refining that as I said by various processes such as treatment with oxidizing slags or by raising it to high temperature oxygen induction or by vacuum. Now here is a method called Triplex process for production of low carbon ferrochrome (Refer Slide Time: 25:40). How do you go here? We will start with chrome ore. It will be smelted using by reducing agent coke; of course, you will also add fluxes like quartz, lime.

So that you produce a slag, that slag will go to wasted, it will only have 3 percent Cr 2 O 3. The alloy we will produce by smelting would have 68 percent chromium; around it will have some silicon because from quartz some silicon will come. It will have some carbon. So, here is the carbon that we would like to remove (Refer Slide Time: 26:26). We will crush; we will smelt again adding quartz and coke, we will produce an alloy which will now have more of silicon. We crush chrome ore lime refines; we can produce a slag that has 20 to 23percent Cr 2 O 3. It will go back to smelting and it will produce low carbon ferrochrome.

There are many flow sheets about different kind of ferroalloys. Now, one ferroalloy that attracts us is something that I would like to mention here and that is ferronickel. Now little while ago I told you that India does not have nickel resources, but India does have nickel in the chromite overburden.

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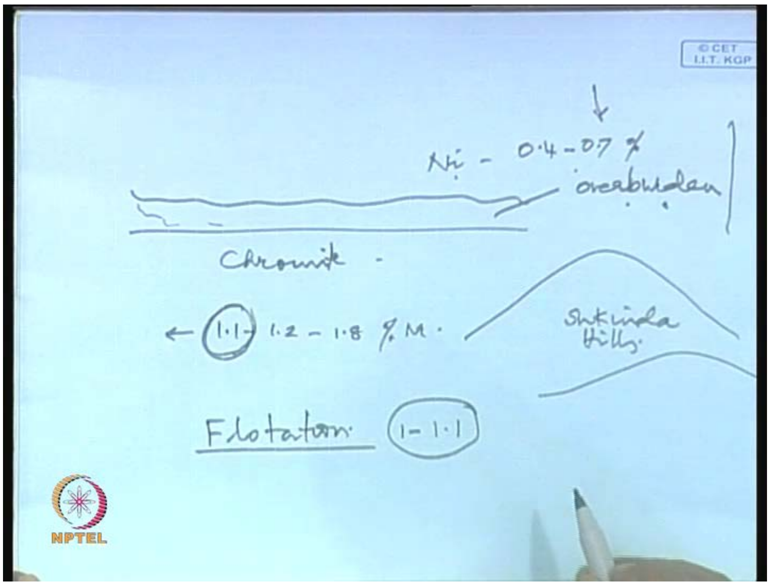

So, let me discuss a possible way of getting nickel from that chromite overburden. Now again what is chromite overburden? We have chromite in chromite mines. In the top layer is what we call overburden. This layer contains nickel to the extent of say 0.4 to 0.7 percent and in the chromite mines of Orissa they have been all removed before mining. They have stock piled in big hills in a place called Sukinda hills.

There are millions of tons there now. So, if you consider this percentage of nickel in them, we already have a reserve of thousands of tons of nickel staying there, without serving any purpose. So, a lot of effort has gone into finding a process of extracting nickel from this chromite overburden, and the laboratory with which we were I was associated regional research laboratory at Bhubaneswar. Now it is called institute of minerals and materials technology.

It took up this problem on a priority basis. We are not the first to do that. National and metallurgical laboratory also studied this problem some 30 years ago and the essential approach for treating similar overburdens is very well known. All over the world people extract nickel from sources where nickel can be 1.1, 1.2, may be maximum 1.8 percent nickel, and for that standard pyrometallurgical techniques are available.

Actually we have gone and seen many plants in other countries, but nobody has worked with any starting material with less than 1.1 or 1.2 nickel. Then our first thing was to see can we do something to this fairly loaded overburden and bring it up to something like 1.1 percent nickel. We found it is possible. We found a way of using a flotation process to upgrade nickel to almost 1.1 or 1 to 1.1 by using a flotation process, and the idea was simply to take out the gangue material of floatation, and we found that the nickel is mostly associated with iron, after what is rest. Rest is silica, iron etcetera with a mineral called goethite which is there.

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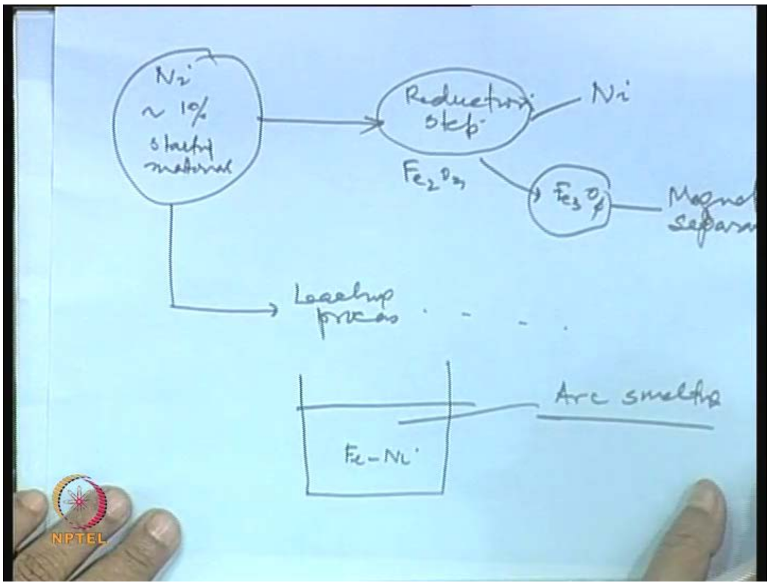

Then the standard technique all over the world is this that you have nickel, say roughly one percent as starting material. It will be; it will go through an open earth or rhetorical reduction process. It has to go through a reduction step. Now, in the reduction step, nickel is very easily reduced to the metallic form and if you have the Fe 2 O 3, and other things, you can reduce to something like Fe 2 O 4. This we can magnetically separate or we can take this, try to find the leaching process and selectively take out nickel. So, many such approaches have been tried out to get a starting material, where nickel percentage will be high. Then, attempts have been made to produce ferronickel by arc smelting.

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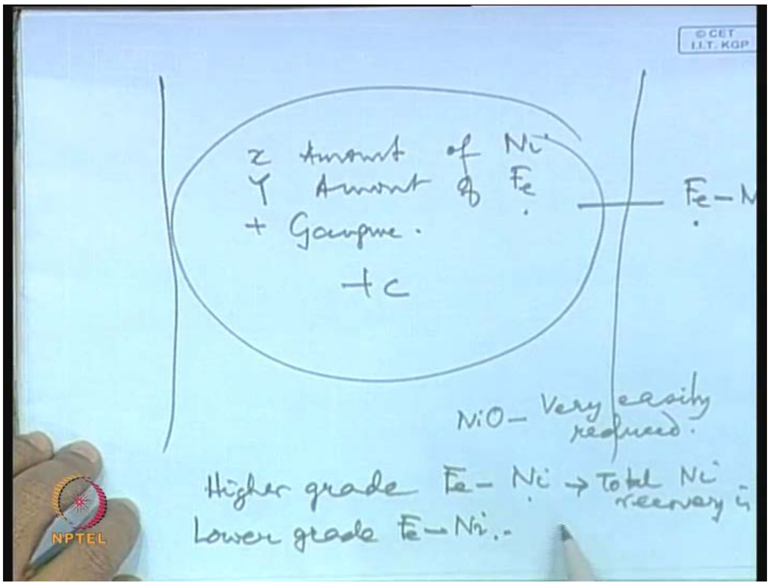

Now, say hypothetically we have a starting material with x amount of nickel and y amount of iron plus gangue. Gangue means silica etcetera. You want to reduce it by carbon. You go to high temperature. Now, you should know that nickel oxide is very easily reduced. It does not need much partial pressure of C O; it is very easily reduced. So, if you have a starting material which has some nickel and it has some iron oxides, it is very easy to produce nickel, but the now the question comes is balancing between. What will it produce? It will produce ferronickel because iron will also be reduced, nickel will also get reduced.

Now, if you continue reduction for a long time then you will get more nickel out, but you will also get more iron out. If you do it for a small time, you will get initially very pure nickel, very high grade ferronickel, but recovery of nickel will not be enough. So, we have a contradiction here. If you want higher grade ferronickel means nickel percentage is lower then total nickel recovery is low. Now, if you settle for lower grade ferronickel means nickel content is lower, then total nickel recovery can be high. Try to understand the dilemma. I have a starting material which say has 1 percent, 2 percent nickel oxide or whatever. You put everything in an electric arc furnace reduce by carbon. It also has iron oxides. So, carbon will very easily reduce nickel initially, but nickel oxide reduction would take time. You have to balance between the grades of ferronickel we want and the total nickel recovery, if you want to take out every amount of nickel that is there in the ore then we will continue the reduction process for a long time. In that process you will end up with lot of iron also, in ferronickel.

If you do not continue for a long time you will get something which has higher percentages of nickel, but total recovery of nickel from the initial charge would be low. So, these balancing acts one has to try out look at the economics. Lot of work is going on in India on this, but we have in those Sukinda overburden, huge amounts of nickel there. And remember India needs may be 20000 to 30000 tons of nickel per year or even more for alloying purposes, all that nickel is being imported.

Nickel is a strategy metal without that we cannot do. We have the resources, but they are low grade resources, they are not high grade resources, and we have to develop our own technology. Internationally, there is no technology suitable for these low grade resources. But we are almost there, we can do it, but then there are many problems why although something looks ok on paper in the laboratory, the technology is there can be commercial process, but there are many reasons why it does not go and make an industry. So, I think with that I will conclude a module five about production of metals from oxides. Before I end, I would introduce the next module, which would be module five.

Now, in the next module, we are going to discuss production of metals from sulphide sources, and what will be the metals, they are the metals of ancient times; copper, lead, zinc. These sulphides are often found in nature all mixed together because the sulphides intermix very well. Another peculiar thing about sulphides is they are very good solvents for precious metals. Now, we think of silver, gold, platinum, etcetera, we do not find them lying around in earth’s crust. Of course, there is something like Subarnarekha where gold particle are flowing down the river.

They were chunks of gold available in the new world when the Spanish conquerors came to South America they were amazed to hear stories of cities paved with gold. It was not exactly true, but it was almost true because huge amounts of gold were there with the original inhabitants who were later called Red Indians. There huge amounts of gold’s in them. That is what drew more and more people from Europe who massacred them, left right and center, at that time may be native gold was available in plenty. But now gold will be found as grains embedded in rocks or in sand and everything. But gold, platinum silver, etcetera are also there in supplied deposits, because millions of years ago when earth formed and the you know your oxides and sulphides, and all kinds of things, the sulphides dissolved these.

So, we will find the supplied metallurgy will not only give us the metals of ancient times they would also give us as byproducts, a very valuable byproducts of precious metal, and very often many processing steps, the cost of processing step, will be met by the value of the byproducts that will come in sulphide metallurgy.

Now, sulphide metallurgy should be obvious to you, is a very old thing, and people have been working on sulphides for centuries. So, many things that are done today, have come from ancient times, and only now people understand why those things are done they wealthy at that.

Basically, I was concerned with general principles of extraction and refining. You have seen that you may have two oxides or three oxides which look similar, but the way the metals are extracted from them may be quite different, and even if a method is similar they are all intricacies which are very different. The time now has come to move on from oxides to another kind of starting material and they are sulphides.

I was mentioning that sulphides are very good solvents. They mix amongst themselves, they also dissolve precious metals, but there are no sulphide deposits which are very rich. Now that is another problem, like in oxides can be very rich deposits such as deposits of aluminum, deposits of iron, deposits of magnesium, calcium; they can be very high in the metal content. For sulphides that is not true, but ancient someone had found out how to start with this very low grade materials also.

Now, I would not go back to the ancient processes that I had discussed in the very beginning and it is not right to go into discussion of those things, but let me start with this problem today that what you do with a sulphide mineral where the metal content copper or zinc is only about one percent or even less. There is no other source of that metal which is richer in terms of the metal content. Now, fortunately somebody found out and very exciting process called Flotation for enriching such ores.

Now, it is because of such discoveries, which can be accidental or which could be results of trial and error that many metallurgical processes have evolved. In flotation, the whole idea is very similar to the way we clean our clothes. Now when our clothes are dirty and why they are dirty because dirt particles are sticking to the textile.

Now, if you shake it, they would not go. If you put it in water and rinse, some will go, the rest will not go, but if we put our clothes in soap solution and you rinse the soap bubbles that come out they take out the particles of dirt with them. Why do the particles of dirt move up with the soap bubbles? It is because of some surface tension phenomena that the dirt particles are attracted more to the surface of the soap bubble than to the surface of the of the cotton textile.

So, as the soap bubbles rise they take the dirt with them and they float up, and if you take out the froth, you will find it is very dirty. All the dirt is in that. There is a similar process in the case of sulphides. I do not know who discovered it. Exactly same process it is called, ‘Froth Flotation’.

You create a froth using a frothing agent, and the whole idea would be when these bubbles raise, the particles of sulphide minerals stick together. They will rise whereas, the gangue the dirt, silica, alumina, soil, etcetera, they will not rise.

Now, this also means that you have to make the particles very fine otherwise soap bubbles will not be able to carry them up with them. So, froth flotation will necessarily require also fine grinding. So, if we have an ore, a sulphide ore in which we have the metal sulphides, it has to be ground very fine so that sulphide minerals are in a very fine form, then they will be treated to forth flotation. There are various reagents which create this froth and the bubbles when they rise they will take the sulphide minerals with them to come to the surface.

So, if the surface is cleaned off, we get a concentrate which can have 25 to 30 percent of the sulphide ore. So, in one jump we go from one percent or less to 25 to 30 percent metal. Once you have that you got a starting; you can start. So, in all sulphide metallurgy the first step will be concentration with the froth flotation.

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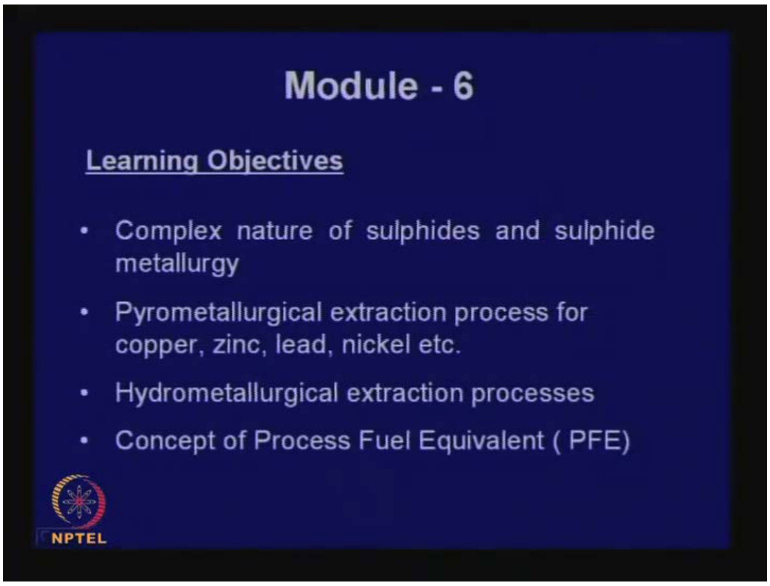

Module - 6

Learning Objectives

- Complex nature of sulphides and sulphide metallurgy
- Pyrometallurgical extraction process for copper, zinc, lead, nickel etc.
- Hydrometallurgical extraction processes
- Concept of Process Fuel Equivalent (PFE)

To introduce module six, which I am about to start now, the learning objectives would be the complex nature of sulphides and sulphide metallurgy. Then, we will go to discuss pyrometallurgical extraction process, individual for copper, zinc, lead, nickel, etcetera because nickel is also found as sulphides in many places.

We will talk about hydrometallurgical extraction processes because many of these metals particularly zinc can be extracted by pyrometallurgy, as well as by hydrometallurgy. Then, we will talk about something called, ‘Process Fuel Equivalent’, that how do we analyze or compare processes from the point of view of energy consumption, for that we will need a criterion called, ‘Process Fuel Equivalent’.

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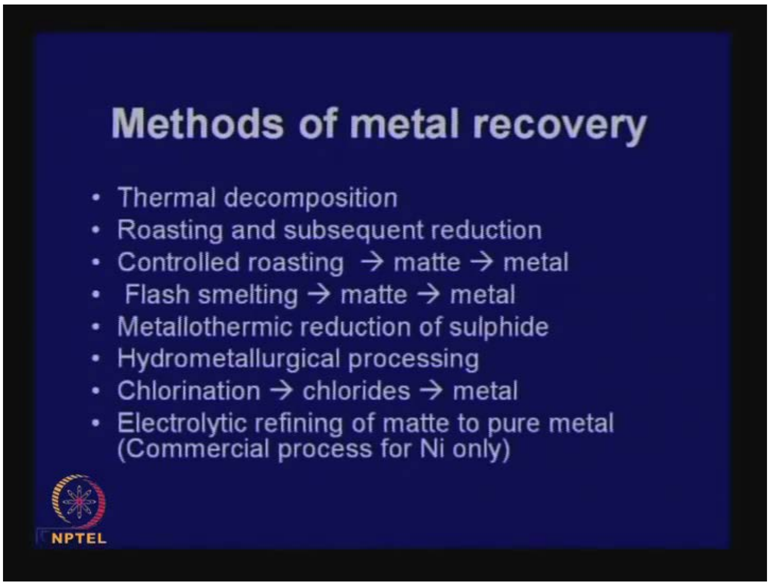

Methods of metal recovery

- Thermal decomposition
- Roasting and subsequent reduction
- Controlled roasting → matte → metal
- Flash smelting → matte → metal
- Metallothermic reduction of sulphide
- Hydrometallurgical processing
- Chlorination → chlorides → metal
- Electrolytic refining of matte to pure metal (Commercial process for Ni only)

Now, before I proceed further, you should know, what are the general methods of getting metal from a metal sulphide? There are some very standard approaches. One is thermal decomposition. There are many sulphides which simply decompose on heating; example is mercury sulphide, Hg S.

All one has to do is to heat it, it will give mercury and sulphide, but it is an exception. It does not happen in all cases of sulphide. In other cases we can go for roasting and subsequent reduction, means from the sulphide, you produce an oxide by roasting then you reduce by carbon that is very obvious.

The third method is very interesting and it is relevant for copper that you start with a sulphide concentrate, you roast not to produce an oxide of copper, but only an oxide of the impurity element iron, and then that iron oxide is taken away in the slag, you are left with a sulphide of copper and iron; that is called matte.

So, in copper, we will not produce copper oxide for reduction. We will produce what is known as matte. We take the sulphide. We will roast it not completely, but incompletely so that the iron sulphide and copper sulphide are getting roasted. Iron sulphide is incompletely roasted; most of it is forms oxide and is taken away, copper sulphide remains intact. And we get a product of copper sulphide and iron sulphide, which is called matte. That matte goes for smelting and that smelting is also of different kind. You do not have to reduce by carbon. We will see simply by controlled oxidation from the sulphide mixture you can get copper straight away. So, that is the third route.

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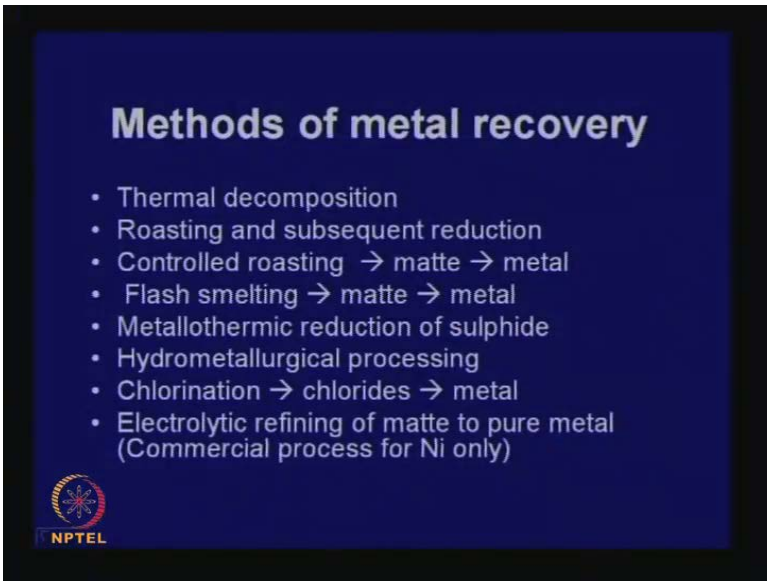

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Flash smelting is an improved step, improved process of combining roasting and matte smelting. Then if we can produce a pure metal sulphide, you can always go for metallothermic reduction also, because there are some metals like calcium which can produce very stable sulphide and so these base metal sulphides can be reduced.

Then there are hydrometallurgical processsing where the sulphide concentrate can be roasted to make oxide, and leached taken into solution and that from the solution by chemical treatment, solvent extraction, ion exchange, precipitation will produce finally get a pure solution to neutralize or whatever, so that will be hydrometallurgical processing, or we can take the sulphide, from there you can get a chloride, and from the chlorides you produce the metal. And there is electrolytic refining of matte directly to pure metal; that also have to try. So, there is a variety of options and that is what makes sulphide metallurgy very complex.

In some cases there are two or three ways it can be done and what we choose depends on economics, depends on the kind of circumstances, in which you are, and depends on the expertise you have. So, we will discuss these things in module six in detail, starting from the next lecture. Thank you.