Steel Making

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Module No. # 01

Lecture No. # 16

Modern Steelmaking II, Electric Arc Furnace

So, we continue our lecture with flush slag practice. Flush slag practice means you flush the already prepared slag from the melt down stage, because, that slag was oxidizing in nature. If you want to remove sulphur from hot metal, then an oxidizing slag is of no use. So, it has to be removed, and instead, a fresh reducing slag is to be created. That is what flush slag practice means.

Why it is needed? Because sulphur and phosphorous, if they are to be removed from hot metal, then, because of the condition for removal of sulphur, you require a reducing slag, therefore, one requires a flush slag practice. How it is done? Oxidizing slag of the melt down stage is drained out, but is deoxidized with ferrosilicon or ferromanganese and eventually by Aluminium. Having done this deoxidization process, then pulverized coke and burnt lime are added into the bath.

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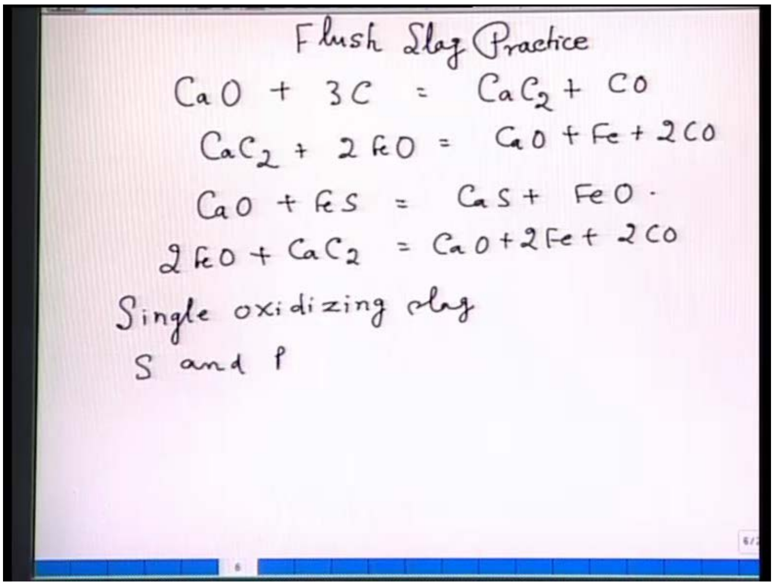

Now, this calcium oxide reacts with carbon, under the action of the arc, because arc has very high temperature and it produces calcium carbide plus carbon monoxide gas. Calcium carbide is a very strong desulphuriser. Now, this carbide in the slag, it reduces Fe O content. That means Ca C 2 plus 2 Fe O, that is equal to calcium oxide plus iron plus 2 carbon monoxide. Now, this calcium oxide, which is again being produced, it reacts with Fe S and forms Ca S plus Fe O and 2 Fe O plus Ca C 2 that is equal to Ca O plus 2 iron plus 2 carbon monoxide.

That is how the process of desulphurization of hot metal in electric arc furnace is being done. That means, a single oxidizing slag, single oxidizing slag is sufficient for removal of phosphorous. That means, if only phosphorous from hot metal is required to be removed, then, a single oxidizing slag is sufficient. If sulphur and phosphorous, both are to be required to be removed, then after removal of phosphorous, a reducing slag is to be created. So, that is how the refining and finishing operation is done in electric arc furnace. When this is over, then metal is tapped and cast and for further processing operation.

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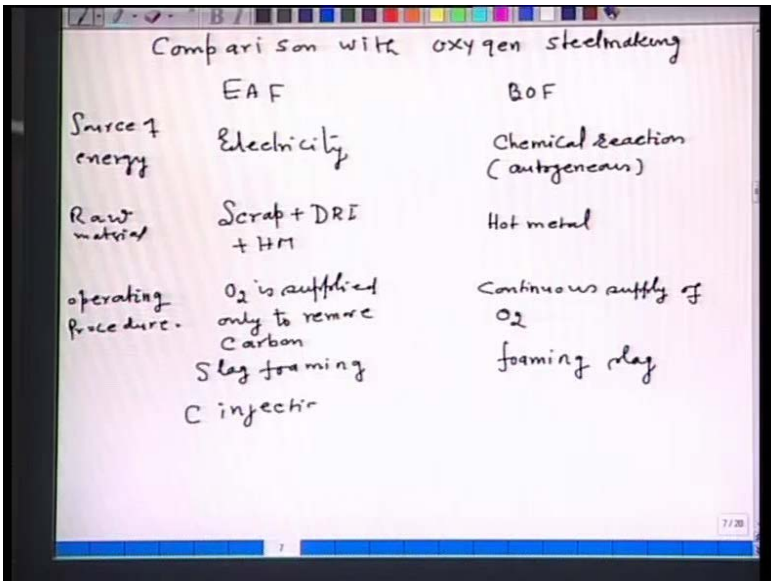

Now, a brief comparison with basic oxygen steel making, comparison with oxygen steel making, say here, I will put electric arc furnace. Here I will put BOF, that is basic oxygen furnace. Now, first differentiation is source of energy. In electric arc furnace, the principle source of energy is electricity, whereas, in basic oxygen furnace, this chemical reactions, they supply the required amount of heat to the process or another way you can call BOF is autogeneous.

No heat is supplied from outside to run basic oxygen furnace for steelmaking. Another, raw material. The principal raw material in electric arc furnace is scrap. Though, now, directly reduced iron plus hot metal, they are also used in a small proportion, but the principal source of steel production in electric arc furnace is scrap. Here, in basic oxygen furnace, the principal raw material is hot metal. Plus, well, 20-30 percent of the scrap is ok, but the principal raw material is hot metal. In the operating procedure, in electric arc furnace, oxygen is supplied only to remove carbon. During melt down stage, sometimes you do require oxygen supply, but essentially, you require oxygen in case of electric arc furnace, when you require to remove the carbon.

Whereas in basic oxygen furnace, continuous supply of oxygen is to be carried out. In electric arc furnace, slag foaming, slag foaming is purposely induced. Why, in order to shield the arc, so that the arc does not radiate its heat to the lining. Another objective of foaming slag is, that most of the heat will be directed to heat the metal or scrap and less heat will be directed to the wall. So, the foaming slag is a part of electric arc furnace. If the slag does not foam in an electric arc furnace, then conditions are created so that the slag foams.

The whole objective of foaming slag is to submerged the arc, so that the heat of the arc which is very high does not radiate to the lining of the wall. So, this is one of the main objective of foaming slag in electric arc furnace. Whereas, in basic oxygen furnace, the foaming slag does not have that objective as that of EAF, the foaming slag, it enhances the rate of carbon and phosphorous removal reaction.

Another difference in the operating procedure is that of carbon injection. Carbon injection is purposely done in order to create foaming. How it is done, because for the foaming, one require a gas forming reaction that is C plus O is equal to C O. In electric arc furnace, operating with 100 percent scrap, hardly you have any amount of carbon which will give you carbon monoxide gas. So, for submergence of the arc in the foam, extra amount of carbon is being injected, oxygen is also injected, so that carbon monoxide evolves and the slag foams. So, what I mean to say is that, for foaming slag, when the gas forming reaction is not sufficient in electric arc furnace, then it is necessary to inject carbon in the bath. So, these are the, some of the essential differences between basic oxygen furnace and electric arc furnace.

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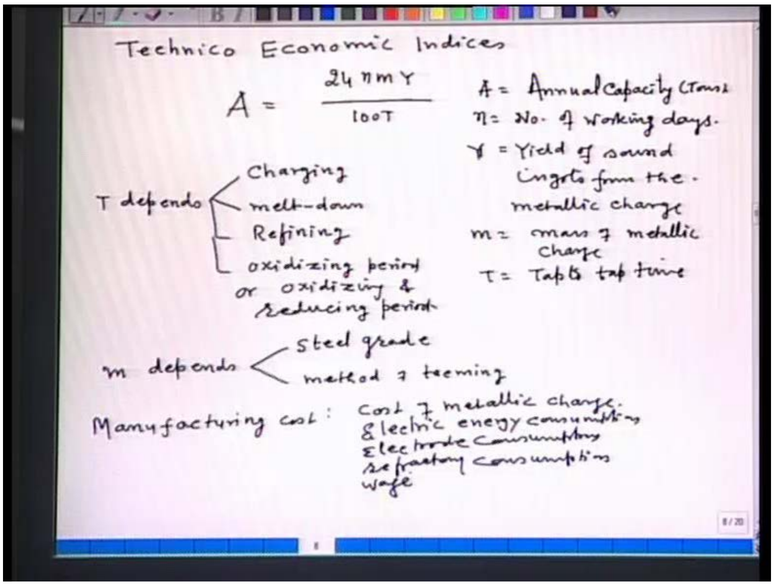

Now, let us see the techno economic indices. Say, A you write that is equal to 24 n m y upon 100 T, where A is annual capacity in tons, n is number of working days and Y, that is yield of sound ingots from the metallic charge, m mass of metallic charge and T is tap to tap time. Now, naturally, if m increases, annual capacity increases, n number of working days increases, capacity increases and above all, tap to tap time decreases, annual capacity also increases.

Now, in fact, tap to tap time T, it depends upon some factors like charging, how much time you take for charging, what is the time for melt down, then, how much refining is required and whether we require oxidizing period or one requires oxidizing and reducing period. If the melt down period is longer, naturally tap to tap time will be higher and accordingly, it will affect the annual capacity of the electric arc furnace. Now, this m, which is the mass of the metallic charge, it depends upon what steel grade is to be manufactured, it depends upon steel grade. Accordingly, you have to see what proportion of a scrap, DRI and so on are to be mixed and then it will also depend upon method of teeming. Because, once the steel is finished, then steel is to be teemed. Now, manufacturing cost of steel from electric arc furnace, cost of metallic charge, cost of metallic charge, then electrical energy consumption, electric energy consumption, kilo Watt hour per ton, then electrode consumption, electrode consumption, refractory consumption, then what are the wages…

So, all these, they include the cost of electric steel production. Among them, the cost of metallic charge is also very high and followed by the electrical energy. So, wherever electrical energy is cheap, the cost of the steel production will also be cheap.

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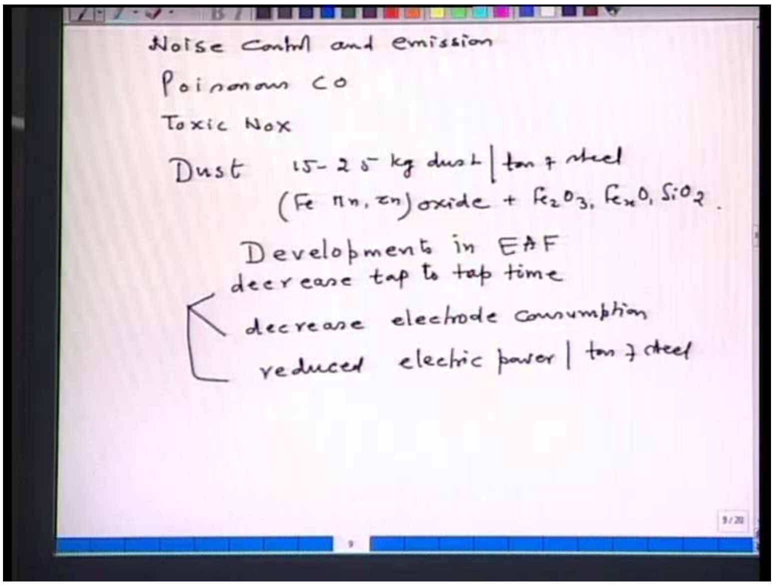

Now, a little bit about noise control and emissions, noise control and emissions. Now, if you happened to see an electric arc furnace plant, that is a mini steel plant, and if you happened to be there during the melt down stage, then you will understand the sound and the noise that is created by the production of the arc, that is, when the electrodes are lowered, a very large amount of sound is being produced because of the arc and so on.

So, one of the most important considerations, in case of electric arc furnace, is control to the noise. Another, you have poisonous carbon monoxide. One has to take sufficient measure. Then toxic NOX, because under the action of the arc, there is some infiltrate (( )) air is there, then nitrogen can decompose to N and it may be react with N O, so, that may form the NOX and that is very poisonous gas. Now, in this particular case, possibly foaming slag practice will be very good, because then, the arc will be submerged in the foaming slag and whatever air, which is being infiltrated into the electric arc furnace, that will not come into the contact with the arc.

Around 15 to 25 kg dust produced per ton of a steel. Now, this dust contains iron oxide, manganese oxide and zinc oxide. From where the zinc is coming, zinc is coming from the automotive scrap. Because, if the galvanized steels, their scrap is being used, then a large amount of zinc will also be joining the dust which is coming out of the electric arc furnace. Plus, it also contain Fe 2 O 3, which is highly oxidized state of iron. Also, it contain Fe x O, and also contain S i O 2, because all these things are generated, because of the very high temperature coming in the electric arc furnace.

So, having seen the operation of the electric arc furnace, this operation for carbon steel making and for alloy steel making will not be very different. The difference will be, for example, in carbon steelmaking you may charging either 100 percent scrap or 70 percent scrap and plus other raw material. In alloy steel scrap or in alloy steel production, you may be using only alloy steel scrap except otherwise the operation is more or less similar. Now, having understood the operation, let us look into the developments in EAF technology, developments in electric arc furnace technology. Now, in the last two decades, several developments in electric arc furnace technology took place. Particularly because of the concept of mini steel plants. Most of the mini steel plants, they work with the electric arc furnace. The steel production from electric arc furnace has to be competitive with data basic oxygen furnace.

In order to make the electric arc furnace steel competitive with data basic oxygen furnace, it has become imperative that the developments that are introduced into the electric arc furnace technology, so that the cost becomes comparable to data basic oxygen furnace. The main development that took place in order to decrease tap to tap time, to decrease electrode consumption and to reduce electric power per ton of steel. These 3 factors, they constitute the cost component of the production of steel. In conventional EAF without any development, the tap to tap time was the order of 2 and half to 3 hours. It is a too longer time and it is not comparative with data of the basic oxygen furnace, where tap to tap time of 400 tons of steel is around an hour. Electrode consumption is also an important part of the cost of the steel that is being produced from the electric arc furnace. Electric power is the main cost for production of steel.

So, concerning these three points, a significant development have been taken place in the last two decades. Particularly, because, the mini steel plants have gone. All mini steel plants have electric arc furnaces and just to give you a figure, already, I gave you earlier, but here, I think, let me repeat the figure. The contribution from electric arc furnace to the total steel production or rather total crude steel production under Indian condition in the year 2007 2008 was 26 percent, wherein, that year, 7-8, India has produced 50.3 million tons of steel, there wasthe significant contribution from electric arc furnace.

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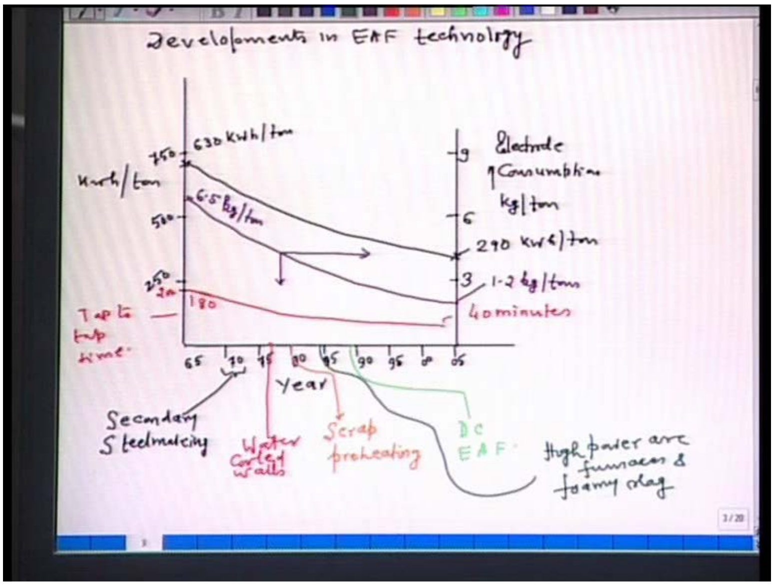

Till that period, around 226 electric arc furnaces were there in the country. So, developments were essential and now, let me show, on this particular graph, I am showing the developments in electric arc furnace, the developments in EAF technology. Now, before I tell this particular, we have one thing which is very important, that I should tell you, is that these are all technological developments. The technological development, they are associated with the investment also. Now, that technology will diffuse into the market that has ROI, that return on investment is high and as well as their payback period is very low.

So, one is to look the various development that have taken place in electric arc furnace steelmaking, from the angle of ROI and payback period. ROI means return on investment and payback period. That development or that technological development will be accepted by the market, when it is payback period is low and the return on investment will be high. So, that is an important thing. So, in this particular graph, this is here kilo Watt hour per ton, y axis is kilo Watt hour per ton and here is the year, on this side, this is the electrode consumption in kg per ton.

Now, here, say a small, this I will put as 200 and this small scale is the tap to tap time, tap to tap time. Now, tap to tap time is decreased from 65, around when it was 180 minutes. Today the electric arc furnace, you can find as per the literature, it can take even in 40 minutes. Has also, continuously decreased the electrode consumption you have to read, this is the year wise and this side is the electrode consumption, starting it was around 6.5 kg per ton. It has continuously decreased to a figure of 1.2 kg per ton with the successive development that took place over the years. As regards power consumption, which was here, it around 630 kilo Watt hour per ton, you can imagine the used power consumption in 60s or 70s, it has continuously decreased to a value of around 290 kilo Watt hour per ton.

Now, say around 70 secondary steel making have come in to picture. Secondary steel making was developed and with the introduction of secondary steel making, it has become possible that some of the refining and finishing operation could be done in the, could be done outside the electric arc furnace and hence the power consumption will be reducing.

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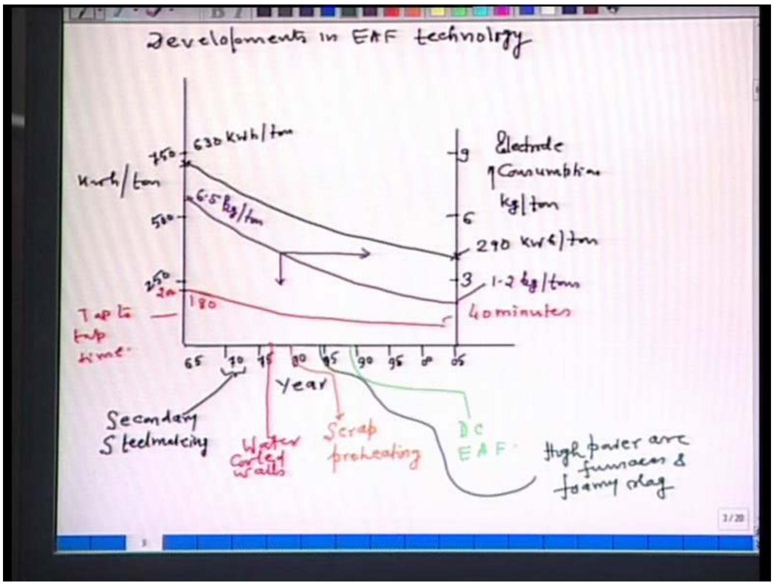

Around 75 this year, water cooled walls were introduced. Water cooled walls, side walls and the roof, they were introduced and that also contributed to decrease in tap to tap time, decrease in power consumption as well as the electrode consumption also. In around 80s, scrap preheating technology was introduced. Preheat this scrap, you are introducing certain amount of energy into the furnace, naturally, the power consumption will also be decreasing.

In around 90s are here, somewhere here, DC electric arc furnaces has been introduced. In around 85, which I had forgotten, I have to tell you, around 85 or 80-85 period, the high power arc furnaces and foamy slag practice was introduced. For your information, these years which I have shown, they are approximate they can vary from here and here and there, but what I wanted to emphasize over the fact, continuously development in the electric arc furnace technology made possible to decrease a power consumption, to decrease the electrode consumption and to decrease the tap to tap time, with the result, refractory consumption will also decrease, because now the electric arc furnace vessel is handling liquid steel for a small amount of time.

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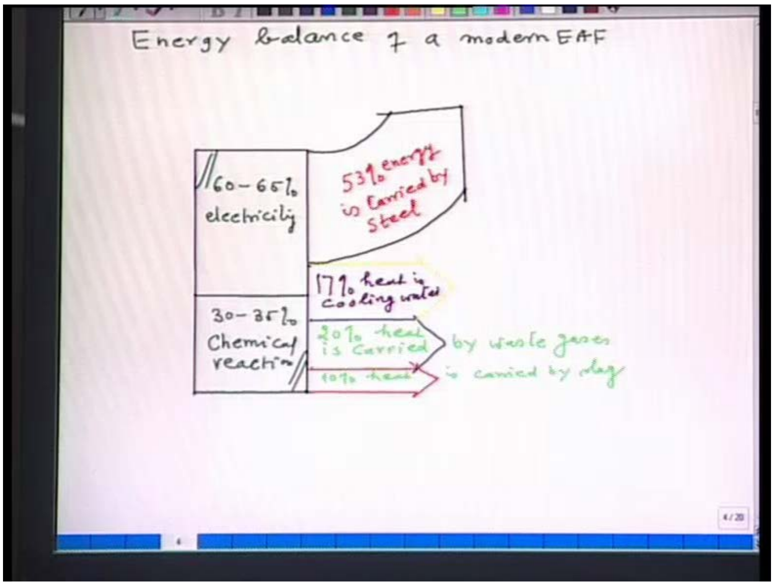

The energy balance of a modern electric arc furnace. Let us see energy balance of a modern electric arc furnace. Now, 60 to 65 percent of energy is introduced by electricity. 30 to 35percent of energy is introduced by the chemical reaction. So, this side, this side to this side, these are the energy input. On the right hand side, around 53 percent of energy is carried by steel, because you are tapping the steel at around 1600 or plus 1600 and 50, so, it will also carry a very large amount of heat.

So, you are seeing 53 percent of the total energy input into the electric arc furnace is being carried away by the steel. Of course, you cannot do much. 17 percent of the heat is lost by the cooling water. That means, large amount of water circulates and you have to, the panel and the walls, it takes around 17 percent of the total heat. 20 percent of the heat is carried by the waste gases. Remember, the waste gases contains carbon monoxide, as well as they are being discharged at 13-1400 degree Celsius. So, what percentage of energy, it is shown here, that is 20 percentage energy is taken by the waste gases, is only the sensible heat.

Remember, carbon monoxide has also potential energy. So, its combustion will also generate a large amount of energy and 10 percent heat is carried by slag. Now, you notice from this energy balanced diagram of a modern electric arc furnace, in the absence of any energy other than electrical energy, the electric arc furnace works on 100 percent electrical energy. The developments which took place over the years, they have allowed other source of energy to be introduced into the basket, into the electric arc furnace and that has tremendously decreased the electrical energy required per ton of a steel. You are looking in the energy balance diagram around 30 to 35 percent energy is coming from chemical reaction. Also, the heat carried by the waste gases has attracted the attention of technologists and they also thought, why not to use this waste heat energy.

So, the developments in EAF is mainly concentrated on the use of waste gases and how to supply additional amount of energy or how to supply an alternative energy in the electric arc furnace.

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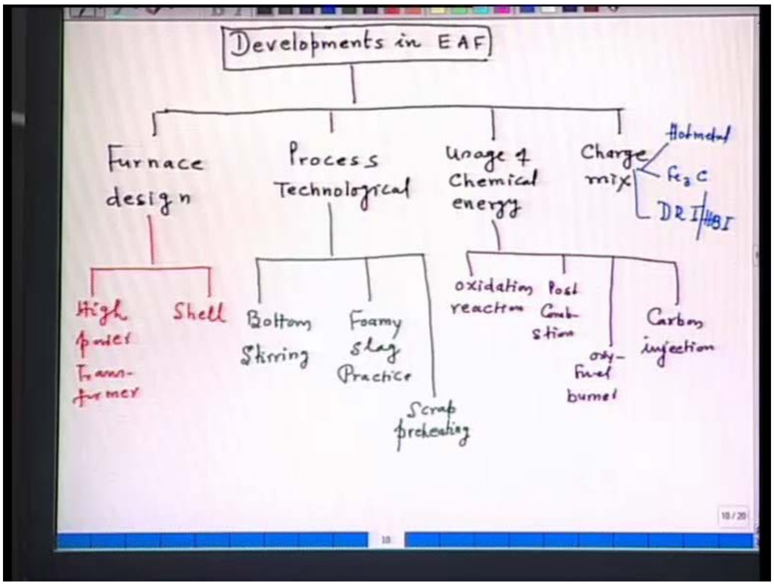

Now, what I am going to do, I will now classify the developments in the electric arc furnace. I will make a diagram for you, the developments in electric arc furnace. So, developments in electric arc furnace has taken place principally, say one, in the furnace design. Another development took place, process, technological process technological operating devices. Third, uses of chemical energy. Fourth, development took place in the area of charge mix. In the furnace design, two developments are to be noted. One is the use of high power transformer and second is in the development of shell. In the process technological parameters, some developments which took place, one is employment of bottom stirring, foamy slag practice and third, scrap preheating,

In the uses of chemical energy, the developments went on is oxidization reaction, oxidation reaction, post combustion, use of oxy-fuel burner and carbon injection. For charge mix also, considerable development took place in the charge mix. Hot metal, Fe 3 C and the important development is in the use of directly reduced iron, which is also called HBI, hot bricketed iron. So, this is a chart for development which took place over the years in electric arc furnace.

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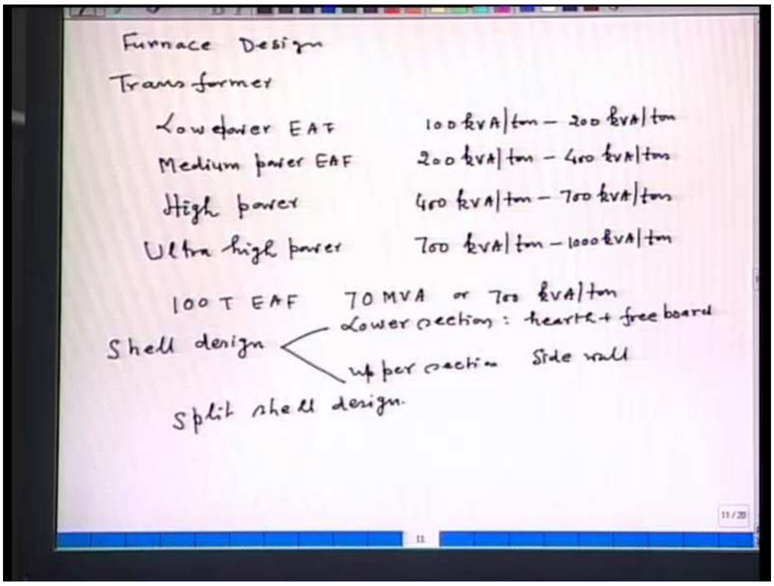

Now, I will take one by one. Now, let us go first of all, the furnace design, transformers. You know, current trend is to have electric arc furnace with higher capacities and high power transformer, because the productivity of electric arc furnace, among other factors, it depends on the capacity of the transformer power. So, the current trend is to go for high power transformers. So, I will like to classify this transformer, the low power electric arc furnace. They have a transformer rated capacity varies from 100 kilovolt ampere per ton to 200 kilovolt ampere per ton. These electric arc furnace equipped with these transformer, they are, they are known as low power electric arc furnaces.

Another, the medium power electric arc furnaces. They have the transformer capacity 200 kilovolt ampere per ton varies to 400 kilovolt ampere per ton. Now, high power EAF, high power electric arc furnace, they have from 400 kilovolt ampere per ton to as high as 700 kilovolt ampere per ton. Ultra-high power electric arc furnace, they have 700 kilovolt ampere per ton and it goes up to 1000 kilovolt ampere per ton. So, these furnaces are called ultra-high power furnaces.

Now, the current trend, wherever it is possible, is to go for ultra-high power furnaces. Now, for example, if you want to have 100 ton electric arc furnace, then if this furnace is to be equipped with ultra-high power transformer, then the transformer capacity should have 70 megavolt ampere or 700 kilovolt ampere per ton for ultra-high power transformer capacity. Then, second is about the furnace shell design. Second development took place in the area of shell design. So, I will put it now as, lower section and upper section. Lower section includes, that is hearth plus free board. Upper section, rest, that is side wall and roof and soon.

Now, with dividing these two it means, there is a concept of split shell design. Now, in this split shell design, you have lower section and upper section and they are connected, so that no air leaks. The only advantage of the split shell design is that, at the time of repairing or at the time of refractory lining, suppose lower section require, for upper section require, then accordingly the time required for refractive lining is saved. Because, depending upon which part has gone bad, that part can be removed and that part can be refractory lined.

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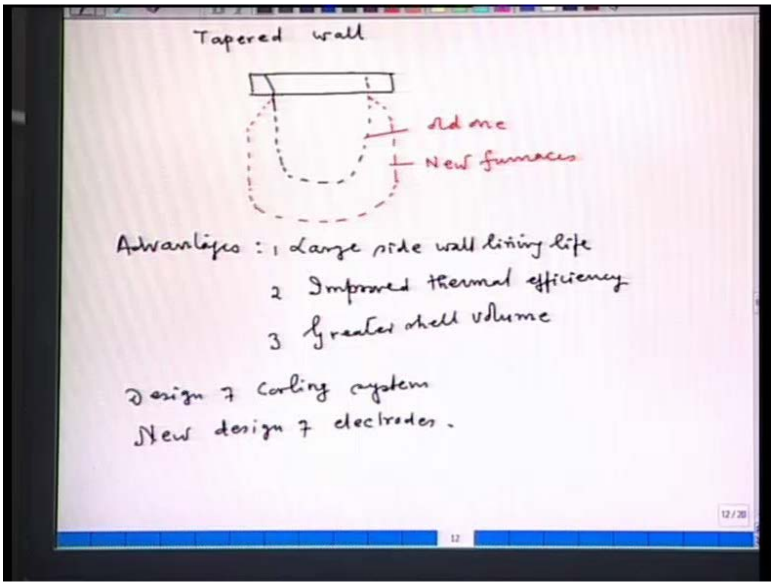

Now, another, for increasing the capacity what has been done now, is a tapered wall concept is being used, tapered wall is being adopted. In a tapered wall if this is the furnace wall, earlier we have this sort of electric arc furnace. Now, the trend is evolve a tapered wall, so that, these are the new furnaces and these are the old ones. And now, the whole thing is that, you have made the tapered wall is dia of the hearth and lower side section of the shell are of larger diameter than the top opening.

Now, the advantage of this new design is, some advantages of new design, for example, larger side wall lining life. Now, since the distance from the electrode to the lining to the side wall of the lining is increased, so, longer side wall lining life and then as, on account of this, you have improved thermal efficiency and third, you have greater shell volume, you have greater shell volume. Because the diameter has become little larger, so, greater shell volume, improved thermal efficiency and the most important advantage is that, the lining life could be increased because, the distance between the electrode and the side wall now is increased.

Another important development, in case of shell, is design of cooling system for roof and side wall. That means side wall and the roof, they have the pipes where the water flows, so that, the amount of heat which goes out, it decreases. Third development is new design of electrodes. Water cooled electrodes, argon injection through hollow electrodes, they are all the practices that have cut down the reduction in electrode consumption.

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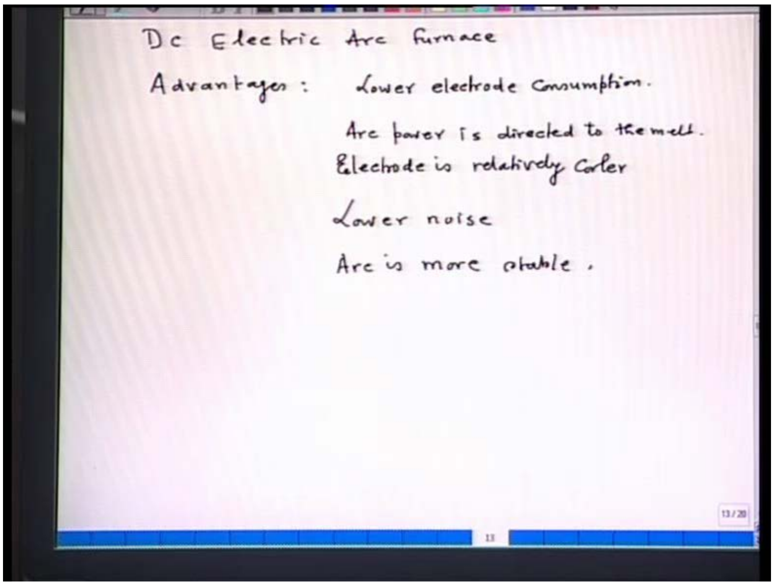

Another important development, as I have said, is the DC electric arc furnace. As already I have given in the introduction, the current passes from graphite electrode to the anode, which is embedded in the bottom. You use only single graphite electrode. And on account of which, certain advantages that are plain for DC electric arc furnace. Certain advantages which are claimed for DC electric arc furnace. You have lower electrode consumption. Now, first of all, you have only one electrode, instead of three, that is they are in the AC electric arc furnace. So, on account of it, you have a lower electrode consumption, because you have only one electrode which is exposed. Second advantage is that, arc power is directed to the melt. Electrode is relatively cooler, relatively with reference to the AC electric arc furnace.

Now, how arc power is directed to the melt? When we compare to the ACEF, an ACEF generates an electric arc because scrap acts as an anode. So, the heat transfer occurs from the arc to the melt. In case of DC EAF, you know, one anode that is embedded at the bottom and one graphite electrode on the top, so, the current flows in the metal because of the cathode and anode. So, arc power is better directed to the melt as compared that of AC EAF. Therefore, the electricity utilization is much better in case of DC EAF. The only problem in case of DC EAF is arrangement of anode at the bottom of the electric arc furnace. Because, that, there lies the whole technological details, how the electrodes are embedded in the bottom of the anode.

So, a DC arc furnace, they create lower noise. Why lower noise, because they only know one electrode. Then arc is also more stable. So, these are the, certain advantages of DC EAF, but the electrode technology limits diameter to a maximum of 700 millimeter, allowing a DC current of 100 kilo ampere and power of 70 mega volt ampere for single electrode furnace. Because you have only one electrode, if you want to increase the diameter of the electrode, in order to increase the current, then you have to go for 1000 or 1200 millimeter electrode, but at the time, at this point of time the electrode technology does not allow to produce an electrode of larger diameter. That means, with this, the furnace size is limited to around 200 tons. That is the maximum size, as far as the literature says.

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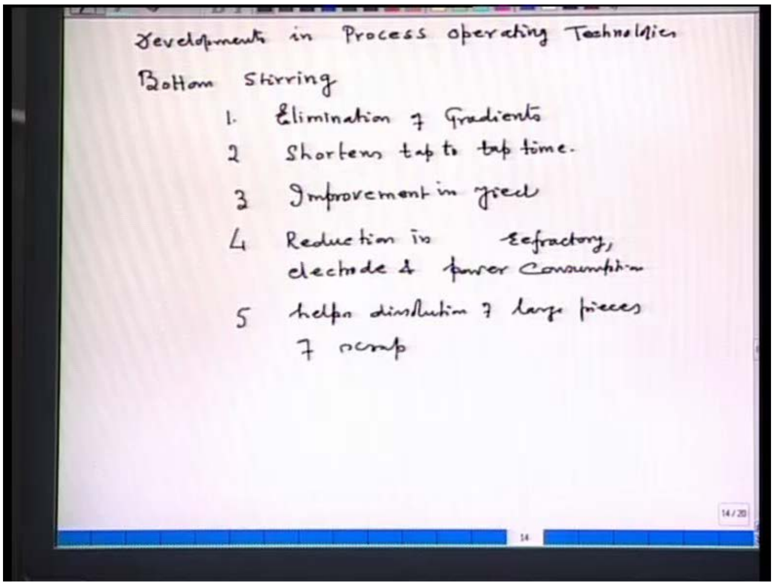

Now, another development, in case of development in process operating technologies. One is, for example, bottom stirring. When you stir anything, the temperature and the concentration gradient will be eliminated and therefore, the refining reactions are faster. So, one can write down the advantages, first advantage would be elimination of gradients. Second advantage shortens tap to tap time, shortens tap to tap time. Third, improvement in yield. Fourth, reduction in refractory electrode and power consumption.

Now, this advantage is coming because of shortening of tap to tap time. When you shorten the tap to tap time, naturally the electrodes are exposed for a lesser amount of time. The one particular heat is expose also, for a short time with the refractory and hence all these things will follow. Another important advantage for bottom stirring, it helps dissolution of large pieces of scrap, because, now the stirring conditions are good. So, the scrap can be dissolved little bit faster. Now, very important thing that comes, where this bottom stirring plugs are being introduced. For stirring purposes, one uses the inert gas like argon or nitrogen. If the steel can accept nitrogen, then nitrogen stirring, if the steel cannot accept nitrogen, then argon stirring.

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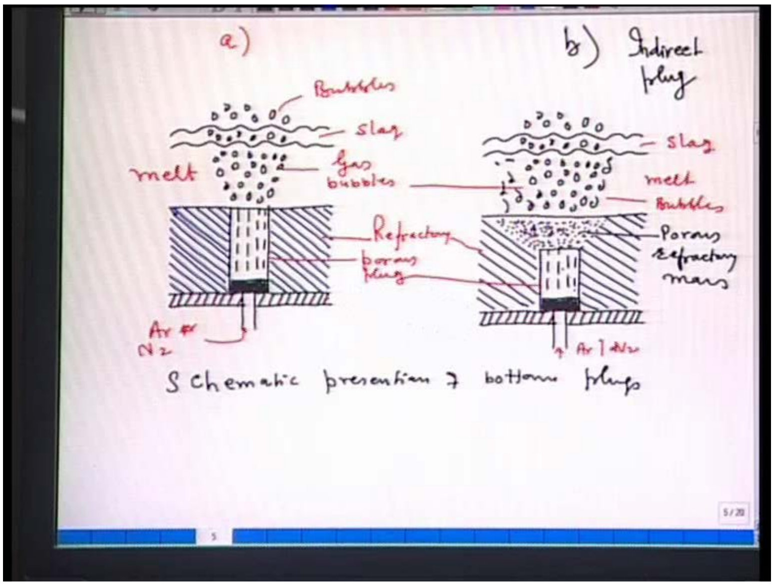

Now, common sense says, if you have three electrodes, then the position of three electrodes with respect to bath is clear. Then the stirring plug should be put in between the electrodes. Now, another important thing, the development of bottom plugs. Now, these bottom plugs, they look of this particular way. These are the schematic representation of two types of bottom plugs. Now, remember, the stirring of the gas through the bottom of the converter, it does not involve any science. It requires a technology. One has to design the plug, so that, it can inject argon or nitrogen through the bottom of the electric arc furnace continuously, uninterruptedly and without plugging. Where is the science here? Here, it involves purely a technological issue.

I could get two designs of the plug from the literature, but there could be many more. You may think of some other design. Because, ultimately, it has to work at place. Now, in one design, this is the refractory lining and this is the porous plug. Here you put argon or nitrogen. These are the gas bubbles, this is slag and naturally, these are the bubbles that are going out. So, here the stirring plug is a sort of a very straight pipes. I mean, this straight, this stirring plug has to be designed and has to be made. In this particular case, which I will put as a, what you are doing, the stirring plug is directly in contact with the melt. So, this is the melt. What does it mean? You have to blow continuously and constantly a certain amount of gas, so that the bottom plug does not plug. If they plug it, no gas will flow and the advantage of bottom stirring will not be there.

In another design, this is again the porous plug. From here argon or nitrogen… This is the refractory lining. These are the gas bubbles. This is the melt. This is the slag and these are the bubbles. Now, what has been done in this design? The refractive plug is shorter and the distance between the bottom of the melt and the plug is rammed by a porous refractory mass. So, in fact, this thing which is being shown over here, this is a porous refractory mass. So, what happens in this particular design, the porous plug does not have contact with the melt. The refractive mass of the hearth, it is in contact with the melt. Of course, the design of the porous refractory mass is an important feature here, because, now how the gas will flow. Now, the gas will flow through the plug, through the porous refractory and then ultimately to the melt.

So, here a larger surface area of the melt will be covered as compared to in the design a. So, if I put this is design b. So, here I mean, little more area because everywhere the gas will come and so, little larger area will be covered by the injection of the gas as compared to that of the a design. So, this a, if it is called direct plug, so, b is called indirect plug. The difference between the two, which is a very important difference. In a type of design, the plug is directly in contact with the melt. So, you can imagine the operational difficulties that could be there. A continuous amount of gas has to be injected through the plug. Otherwise, the melt will penetrate and the some of the holes of the plug will be blocked and then it has to go for repair.

In the design b, which is indirect plug, no doubt, the plug is not directly in contact with the melt. Melt is in contact with the porous refractory that is between the bottom of the melt and the top of the plug, a porous refractory mass is rammed. Gas is injected through the plug. It discharges through the porous refractory mass and it is injected into the melt.

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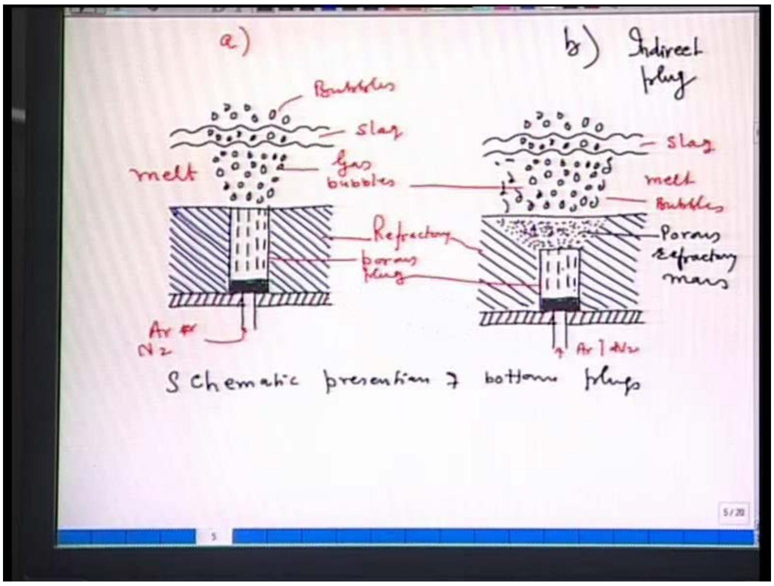

Obviously, advantages of the indirect type of plug is, a large surface area of the bath will be covered. The stirring will be better, but then one has to also design, fabricate and manufacture the porous refractory mass, so that, it allows the gas injection. So, these are the, one of the important differences between the two types of plug. However, there could be another designs also. So, further developments in electric arc furnace will be covered in the next lecture. Thank you.