**Steel Making**

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**Module No.#01**

**Lecture No.#15**

So, today we will talk on electric arc furnace steel making. This is another modern steel making practice.Electric arc furnace steel making, once upon a time, it was focused on production of alloy and special steels,but, the recent years, it has become a preferred route for various engineering as well as special steels.

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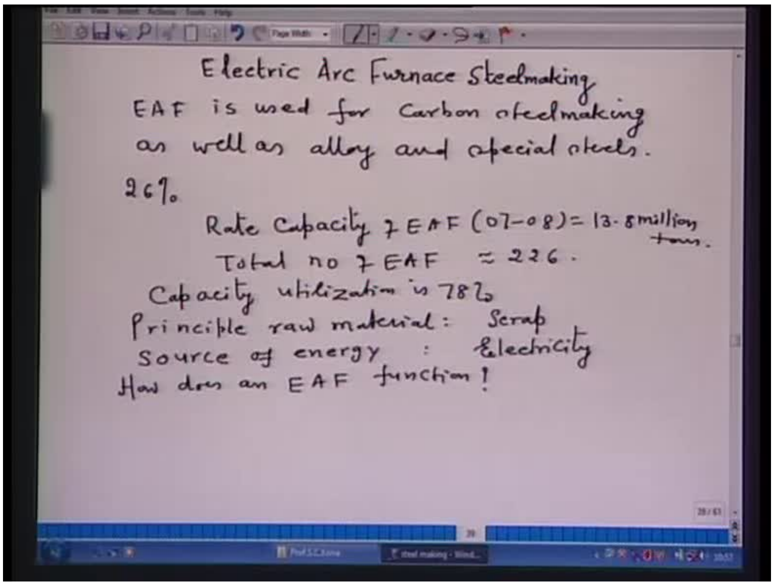


Mini steel plants have contributed to the growth of electric furnace steel immensely.Presently, electric arc furnace is usedfor carbon steel, for carbon steel making as well as alloy and special steel.Electric arc furnace is usedfor production of long products, but, nowadays, flat products are also being produced.

In India, according to one estimate,26 percent is the contribution from electric arc furnace in 2006-07, out of total of 50.9 million tons of crude steel.The rated capacity, rated capacity of electric arc furnace in 2007-2008, it was 13.8 million tons.Total number of EAF in the same year 2007-2008, was of the order of 226.Capacity utilization, capacity utilization is 78 percent in the year 2007-2008.Now, these all shows that electric arc furnace has become a majorsteel producing route in recent years.

Now, principal raw material is scrap, carbon steel scrap or alloy scrap.Major source of energy is electricity.

Earlier, this was the problem, that electric consumption was very high, that has hampered the growth of electric furnace steel industry.But now, alternative energy sources are also being used.So, with that reason, the electric arc furnace has become a preferred route.

Now, how does an electric arc furnace function?Electrical energy is used to produce an electric arc which heats the metal, either directly or through arc radiation.To produce an arc, a combination of electrodes are required.Two types of electric arc furnaces are now available presently.One, alternative current electric arc furnace and another, direct current electric arc furnace.

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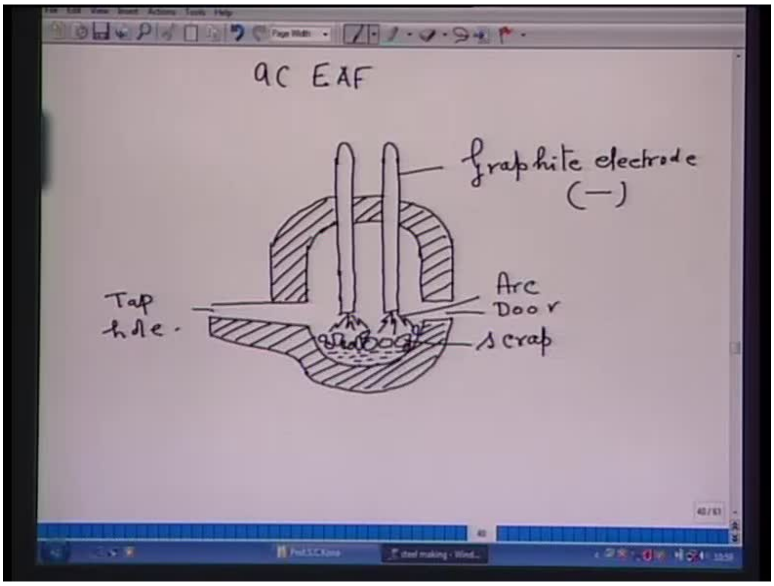


In alternative current electric arc furnace, the combination of electrode and cathode that looks as shown in the figure.So, this is a graphite electrode, which is negatively charged and this is,the scrap, which also acts as an anode.This is the arc, which is produced when graphite electrode hits the scrap.This is the door or charging.This is the tap hole.So, that is how the arrangement of electrode looks in AC EAF.

So, principally, what an alternative current electric arc furnace does, a graphiteelectrode destructs, there is scrap which acts as an anode, arc is being produced, with the radiation heat of the arc, the melting occurs.In alternative current furnace we use 3 electrodes.

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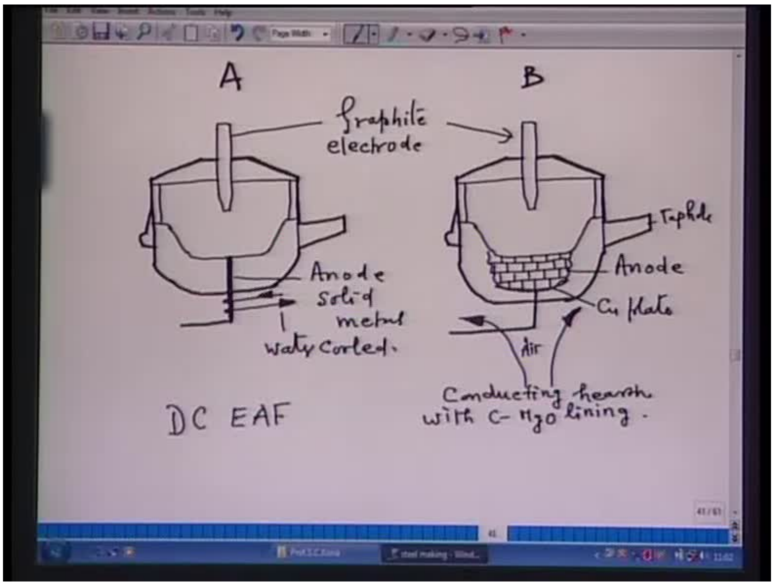


Now, anothercombination of electrode is DC electric arc furnace, which is shown in figure A and B.Now, in figure A and B, this is again the graphite electrode, this also a graphite electrode.

In DCEAF,1 electrode, that is,1 graphite electrode is used instead of 3 which are used in the ACEAF and another electrode is fixed at the bottom of the electric arc furnace.

So, as such, there are different ways of fixing an anode at the bottom of the electric arc furnace.Here, I have shown you, two ways here, in figure A and B.So, in figure A, you are seeing that, this anode, this is the anode which is solid metal.

Now of course,, this gets heated up.So, it is water cooled.This is one arrangement ofcathode and anode in DC EAF.Another arrangement, this is the anode and in this type of DCEAF, anode is a conducting hearth with carbon MgO lining.

Electric current is fed with copper plate which is installed at the bottom.So, this is in fact, the copper plate.Of course, this is the tap hole and so on.Here, this is the connections for electric current and here, again this anode is required to be cooled, because during heating a large amount of heat is being generated.So, anode also gets heated up and it has to be cooled.

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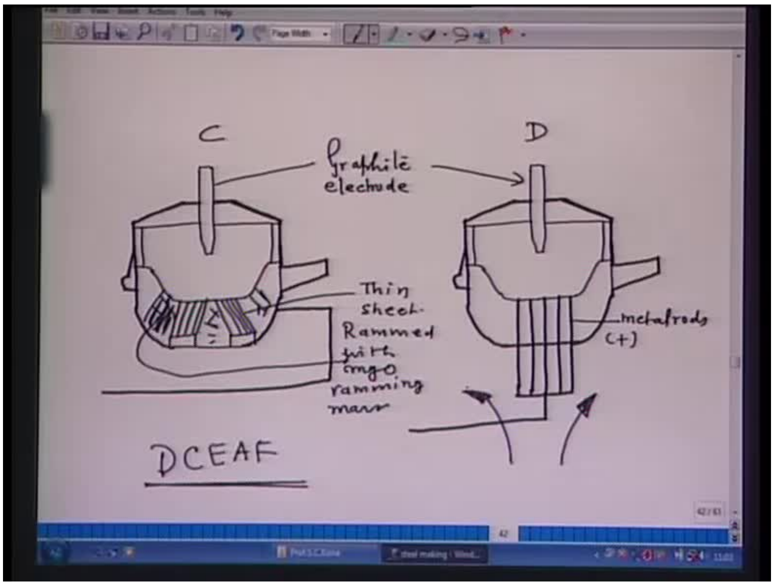


There are two further arrangements are available for fixing of the anode, which is shown in figure C and D.Again in C and D figure, this is the graphite electrode, but, the anode is different in both the cases.In C, the anode consist of thin sheet andthis is rammed with magnesia MgO ramming mass, that means, this is the bottomand this is the so called, ramming mass.

And, this is of course,, the electrical connection.In the fourth arrangement, which is shown at the D, these are the metal rods.This acts as a positive and they are embedded in C Mg OorMg O ramming mass.

So, what I wanted to say is that, in electric arc furnace, that, essentially two types of furnaces.AC EAF that uses 3 graphite electrodes,DC EAF use single graphite electrode, and anodes are embedded in the bottom of the electric arc furnace, and that different arrangements of embedding the anode in the bottom of the electric arc furnace.

ACEAF, that is, alternating current electric arc furnace has been used quite a long time where DC EAF is a recentphenomenon.As regardsthe construction of the main part of the electric arc furnace, is not very much different between AC EAF and DC EAF.Onlythe difference between the two, is in the arrangement of the electrodes and anodes.In AC EAF,3 graphite electrodes are used.In DC EAF, single graphite electrodes are used and anode are embedded in the bottom.In AC EAF, the anode is metal itself.

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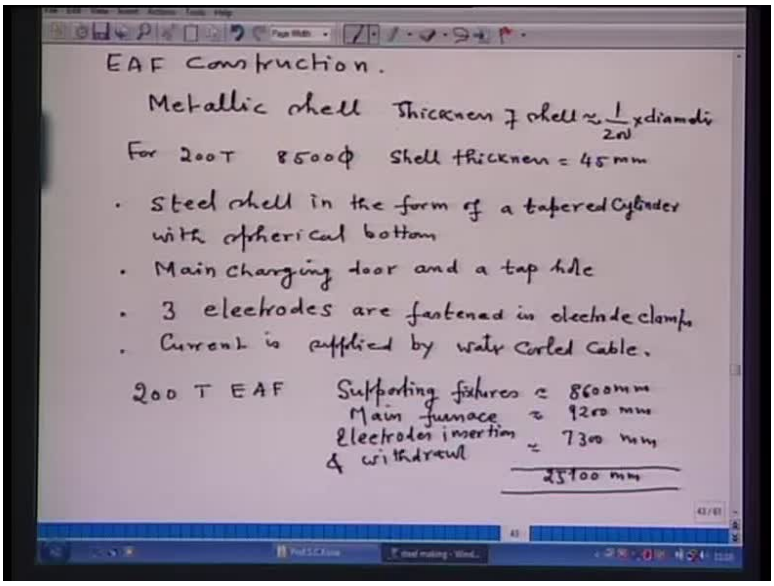


Now, with this, let us go to the electric arc furnace construction.Of course, metallic shell and thickness of shell isapproximately1 by 200 times diameter of the furnace.So,for example, if we have 200 ton electric furnace,8500 is the diameter of the shell, then the shell thickness is around 45 millimeter.

Now some important features, of the construction of an electric arc furnace.The steel shell - in the form of a tapered cylinder, which you have already seen in the earlier sketches, with spherical bottom, with spherical bottom.Now, a spherical bottom has slightly advantage, because the molten metal can be collected very easily over there.

Of course, shell has a refractory lining from inside.Second important thing, main charging door and a tap hole, as you have seen in the sketch of AC EAF.Then, AC EAF works with 3 electrodeswhereas, DC EAF works with 1 electrode or rather1 graphite electrode and 1 separate anode, which is built at the bottom of the electric arc furnace.AC EAF works with 3 graphite electrodes and they are fastened in electrode clamps.

The diameter of the graphite electrode is of the order of 400 to 700 millimeter, a quite heavy electrodes.Fourth, current is supplied, a current is supplied by water cooled cable.

Now, typically, a 200 ton electric arc furnace, supporting fixtures has a height approximately 8600 millimeter, main furnace has a height approximately 9200 millimeter, then, because the electrodes are to be lowered, they are to be raised, roof has to be removed.So, for that, an arrangement is required on the top of the electric arc furnace, so that a space exist, so that you can raise or lower the electrode.So, electrodes insertion and withdrawal, electrodes insertion and withdrawal mechanismapproximately, height is 7300 millimeter.

So, a EAF plant,for example, a 200 ton electric arc furnace capacity will have approximately height25100 millimeter.So, you can imagine, if you want to imagine the plant layout, that is, you need 25 meter of height to accommodate a furnace, supporting fixtures, electrodes withdrawal mechanism, then you require a crane, which holds the basket containing scrap, then you also require a place to tap the slag and molten metal, you require a ladle, so that metal can tapped into that and all such arrangements are required.

So, you can imagine, a layout of an electric arc furnace, what it will be consisting of.All these things are to be placed properly, so that, a smooth movement of the inflow and outflow material is guaranteed.That is the important thing over here.

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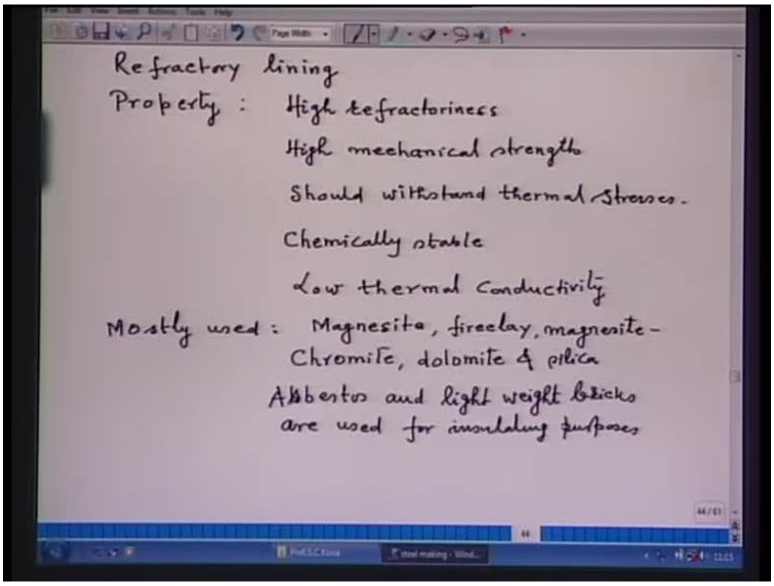


Now, say another important refractory lining, because refractory lining.A metallic shell, it cannot be use for production of the steel.All the heat will be lost.Metal and slag will react.So, you requirerefractory lining.Remember, refractory lining is the heart of steel production, particularly liquid steel production.

So, some of the properties that are required for a refractory.First, you require high refractoriness.Naturally, refractory should be able to sustain that high temperature, which is created, particularly in the arc, because the walls of the furnace, roof of the furnace, they will be heated by the radiation from the arc and in arc has a very high temperature and on account of that heat, the refractory lining should be able to sustain that particular temperature.

Also, you should require, high mechanical strength.That is, to, resistance to compression.Then, it should also withstand thermal stresses.Another very important property that is requiredfor refractory lining material is, that the lining material should be chemically stable and non-reactive to slag metal and gases.

Another important property, the lining should have low thermal conductivity, low thermal conductivity.Now, low thermal conductivity ensures that, the heat losses will be minimum.Now, mostly used refractories are Magnesite, fireclay, then,Magnesite-Chromite, dolomite and silica to line different parts of the electric arc furnace.The parts consist of bottom, tap hole, side wall, roof of the furnace, door.So, they have the different requirement and the different requirements are being met by different type of refractive material, because the cost of the refractive material is also an important issue.You cannot put a very expensive refractory where it is not required.

So, depending on the requirement, the particular type of refractory is put in the lining of the electric arc furnace.Asbestos and light weight bricksare used for insulating purposes.

That is, imagine, close to the shell, where the requirements are not that stringent, one can put the lighter reflective material, because their objective is to block the heat, is to avoid the thermal losses,whereas, the refractory which faces the metal slag, there you should have a very high quality refractory.The refractory should be able to sustain the chemicalattack of slag metal and gases.So, depending on the requirement, thisrefractory can be used.

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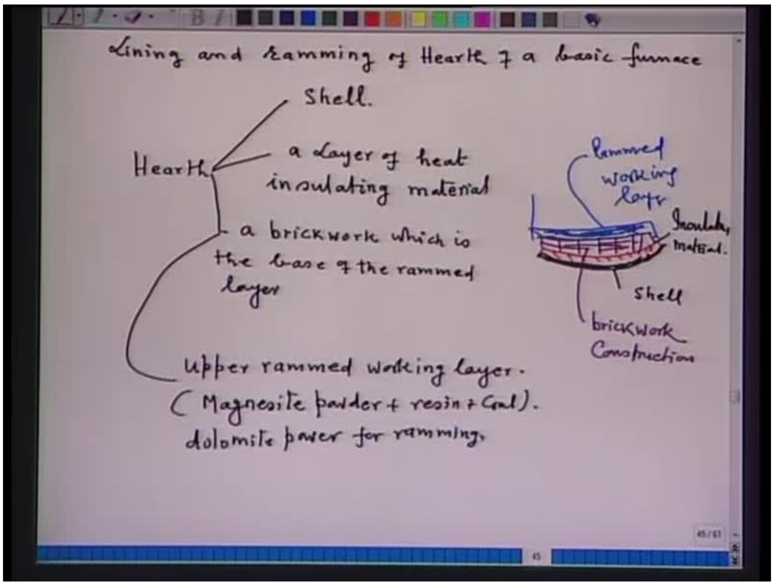


Now, say lining and ramming of lining and ramming of hearth of a basic furnace.Now, here again, I can tell you that, there are acid furnaces or there are basic furnaces.Acid electric arc furnace can be used only for melting purposes, but, in the basicEAF, one can do refining also.The main difference between the two is in the refractory lining.

Nowadays, because electric arc furnace is used for carbon steel making, their refining is also required.So, basic electric arc furnaces are widely employed, because there refining can also be done.Refining means particularly, removal of sulphur and phosphorus, which is not at all possible in the acid electrical arc furnace.

Why it is not possible, because lining is acid.For removal of sulphur and phosphorous, you require basic lining.So, basic electric arc furnace is widely used because of the production of carbon steel, which requires refining also.

So, a hearth consists of the following layers.You have, first of all, a shell.On the top of the shell, a layer of heat insulating material, that is, if I show, then here… So, this is the shell.This is the insulating material.This is the insulating material.

On the top of the insulating material, a brick work construction is done, which forms the base of the ramming layer.So, a brick work, which is the base of the rammed layer, that is, this is a sort of brick work construction. Then, they provide upper rammed working layer and this upper rammed working layer consists of magnesite powder plus resin plus coal or some practice use dolomite powderfor ramming.That is, this particular layer, which is on the top of the brick work lining, is the rammed working layer andhere you have the walls and so on.

So, why I have shown here, because hearth is a very important part of the electric arc furnace and the rammed working layer, that is directly in contact with the metal and that is why it should have a very high quality.

Now, say total thickness of the hearth lining is approximately that of the bath height.So, the bath height is 1 meter or 1.2 meter approximately, the height of thehearth is of that order of magnitude.

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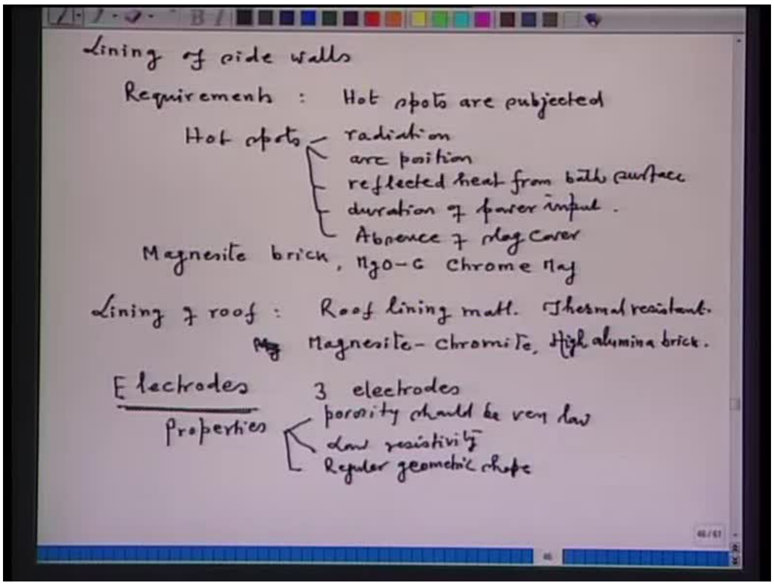


Then, let us see lining of sidewalls.Now, the shell is first covered with asbestos sheet, fireclay bricks ((being then)) and then rammed with the working layer.Same as what you have done for the hearth, first the shell will have the asbestos sheet, for insulation purposes, followed by the fireclay and followed by the ramming mass, because that, that ramming mass will be in contact with the slag metal and gases.

Now, some of the lining requirement of side wall, requirement of refractory for sidewall, because, the electrodes they produce the arc and the radiation of the arc…You have 3 electrodes,3 spots could be formed on the walls of the furnace.

So, the hot spots requirement could be, hot spots are subjected to severe conditions.Hot spots means, they have very high temperature andhot spots are formed, radiation from the arc.Then arc position, because, either the electrodes are too near thewall or away from the wall, then reflected heat from bath surface, duration of power input and absence of slag cover.

So, accordingly what I mean to say, these are all radiation, arc position, reflected heat from bath surface and all these which are listed, theyare all present there.So, accordingly, the selection of refractory is very important for the sidewall.

Normally, say, Magnesite brick lining or Magnesite carbon brick lining, the facing the reaction chamber, chrome magnesite, they are used for the lining material, which is facing the slag metal and gases.Now, say, lining of the roof, you know, roof is movable.Charging of scrap is done from the top.So, you have to remove the roof.So, lining of the roof is also very important case.Now, lining of the roof, it will depend on the heat load.

Now, heat load is very high in the melting period, because in the melting period maximum amount of power is supplied to melt the scrap from 25 degree Celsius to as high as 15 or 1600 degree Celsius.The melt is not covered by slag.So, the heat from the arc is reflected to the roof of the furnace and accordingly the material of roof is very important.

But, well, in the reducing period, once melting is over, then, the heat load is lower.But, well, once you design the roof, you cannot change it.Whether if it is low or if it is high, what I want to say is that, the refractory material has to be selected, considering the highest possible heat load that is there, in electric arc furnace operation and the highest possible load is in the melting period.

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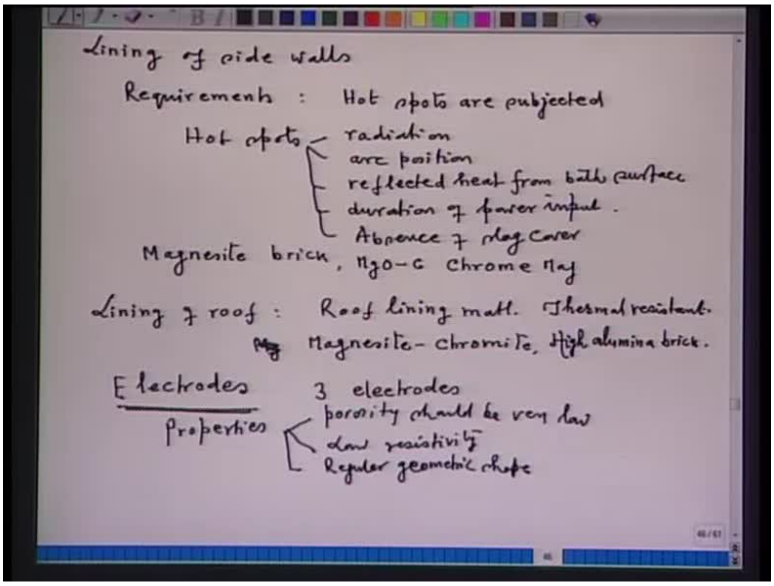


So, the roof lining material, as such, should be thermal resistant.So, roof lining material should be thermal resistant.That is, one of the very important property.Preferred roof material, they are Magnesite, Chromite or high alumina brick.

Nowadays, use of water cooled element, they are also used, because they increase the lining life.Because the maximum amount of heat is transferred to the roof,if you have the water cooling arrangement, the life of the roof also increases.Now, let us see the electrodes.Electrodes are used to supply electrical current.3 electrodes are used in AC EAF.3 electrodes or rather 3 graphite electrodes are used in alternative current electric arc furnace.Mind you,1 graphite electrode is used in direct current electric arc furnace. Please remember.

The material of the electrode could be carbon or graphite, but, the graphite electrode is a preferred material, because it is better, because it can be machined easily as compared to carbon is brittle as compared to graphite.So, graphite electrodes are commonly used.

One of the required property of the graphite electrode is, it should not be porous.The properties, that is required of the electrodes,one of the property, electrode should not be porous.Porosity should be very very low.

Why it should be very low, because oxidation will occur.Then low resistivity, what does it mean, to minimize electric losses.Then, regular geometric shape.It should be able to possess regular geometric shape, so that, the contact is ensured.

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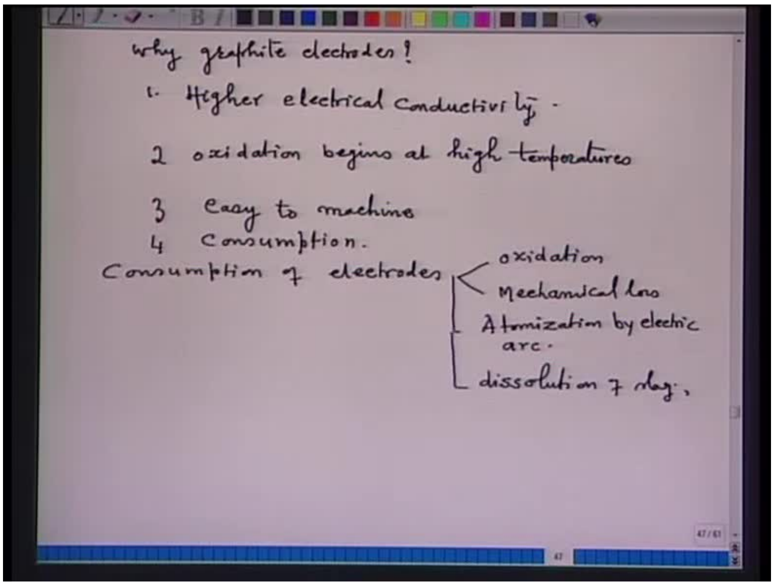


Now, why graphite electrodes are preferred than carbon electrodes?Because, graphite electrodes have higher electrical conductivity. Higher electrical conductivity means higher current density is possible and lower electric losses will be there.Ultimately, you will be supplying electricity and the losses are more, well, you have to supply more amount of electricity.

Second, oxidation begins at higher temperature.Third important property, easy to machine.Because, you have to prepare or you to have an electrode which can be machinable.Because, whatever the shape of the material you are getting, you have to prepare a round shape.

Shape is important, because they are to be clamped in a graphite holder.If the clamp is loose, then losses of electricity will be there. So,therefore,a material which can be machined is very good.So, in that aspect, graphite is easy to machine.

Fourth important point is, consumption is less than carbon electrode.Now, consumption of electrode, it depends upon oxidation, mechanical loss, because of the movement.Then, it also depends upon atomization by electric arc and dissolution by slag.

Now, electrodes in a 3 phase arc furnace are positioned at the apexes of an equilateral triangle.Now, electrode spacing diameter is very important.If the electrode is spaced near the wall, then the lining will be affected, but, you are occupying the larger area of the path and hence meltingwill be faster and that is not good.So, the lining will beaffected.

If the electrodes are too near to the, I mean too away from the wall, then they will confine a very small area for the heating and hence melting rate will be low.

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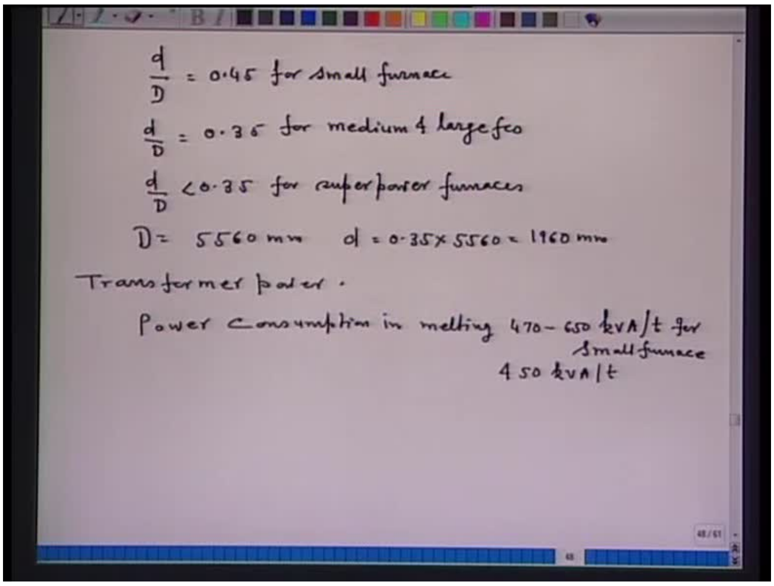


So, a ratio between the pit circle diameter, the electrode and diameter of the bath is of the order of magnitude, which I am giving you here, if d is the pit circle diameter of the electrode, where all the 3 electrodes are arranged at the apex of an equilateral triangle and D is the bath diameter, then this is approximately equal to 0.45 for small furnaces, d by Dis equal to 0.35 for medium and large furnaces and d by D less than 0.35 is preferred for super power furnaces.

For example, if diameter of the bath is say 5560 millimeter, then pit circle diameter of the electrodes would be 0.35 into 5560, that is equal to 1960 millimeter is the pit circle diameter.

Another important issue is, transformer power.Among other factors, the transformer power depends upon whether oxidizing period is longer or reducing period is longer.Power required during oxidizing period is much larger as compared to reducing period.

For high alloy steels mostly require reducing period,so, the power requirement will be low.For carbon steel, where oxidizing requirement is required for refining and for melting, so, power requirement is higher.That means power requirement for plain carbon steel is relatively higher than power requirement for alloy and special steel.

So, power consumption in meltingis of the order of 470 to 650 kilo volt Ampere per ton for small furnaces.Now, these are just a roundabout figure.You may have a different figure.It may be lie in between this range.For bigger furnaces, the power requirement is 450 kilo volt ampere per ton for bigger furnaces.

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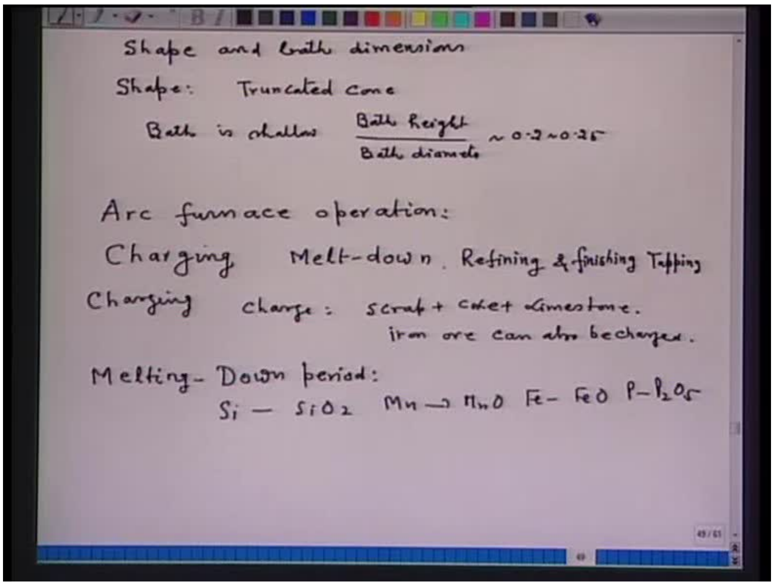


Of the shape and dimensions of bath.Shape of the bath is atruncated cone with a smaller base at the bottom, combined with a spherical segment, as I have said earlier also, it is easier and faster to collecta liquid metal pool in the spherical bottom.

Bath is shallow, that means bath height upon bath diameter is in the range of 0.2 to 0.25.That means, electric arc furnace steel bath are shallow in nature.

Now, havingstudiedthese various featuresof electric arc furnace, now let us quickly go through arc furnace operation.Arc furnace operation consists of charging, then melt down stage,refining and finishing and last is,of course,, when everything has been done, we have to tap it for further processing.

So, in the charging, what is done?Electrodes are raised, roof is swung away and a basketwhich contains scrap is filled with and is lowered in the furnace.

So, in the charging, the charge may consist of scrap plus coke plus limestone.In some of the small furnaces, door charging is also being done, but, in bigger furnaces door charging is not possible.So, a heavy baskets, a very high capacity, they are filled with the scrap, baskets are raised through crane and dropped from the top of the furnace into the hearth of the furnace.So, the arrangement of scrap in the basket is important.

In this, first, light scrap is put and on the top of the light scrap, heavy scrap is put.This is obvious, because heavy scrap, that takes a long time for melting.So, if heavy scrap comes in contact with the hearth, it get melt first, light scrap will melt easier.So, that is what, a small important thing.

In the charging mode, besides scrap, coke, limestone, iron ore can also be charged.And sometimes, if you want to charge refractory alloying element,for example, to prepare alloy steel, then the refractory alloying elements are directly charged into the arc crater region, because there is a temperature is very high.So, there the refractory material have a very high melting point.Therefore, if they are not charged in the arc crater region they will not melt.

Certain alloying elements, they can be charged along with the scrap also.Once charging is over, roof is brought back to the position, then electrodes are lowered and an arc is struck and thereby begins the melting down period.

Now, in the meltingdown period, first of all an arc, which is cut, the metal melts or the scrap begins to melt and collects on the hearth of the furnace.

So,as the melting progresses, the electrodes are gradually lowered, so that, a stable arc is present during the entire melt down operation.Remember, in the entire electric arc furnace steel making, it is the meltdown period that consumes a very large amount of power and if shorter is the melt down period, less power will be requiredand longer is the melt down period, more power will be required.

So, melt down period is the period where power consumption is maximum.Now, during melt down period silicon oxidizes to SiO 2, manganese oxidizes to MnO, iron also oxidizes to FeO and phosphorous also oxidizes to P 2 O 5.

Now, remember, that you have also added there, iron ore, which creates oxidizing condition,you have added lime, you have added limestone, so, lime will also be available.So, in the melting period itself, the slag will form and the phosphorous will also be able to remove, because removal of phosphorous, as you learnt earlier, required oxidizing and basic and lime slag.So, during the melt down stage the dephosphorization is also achieved.

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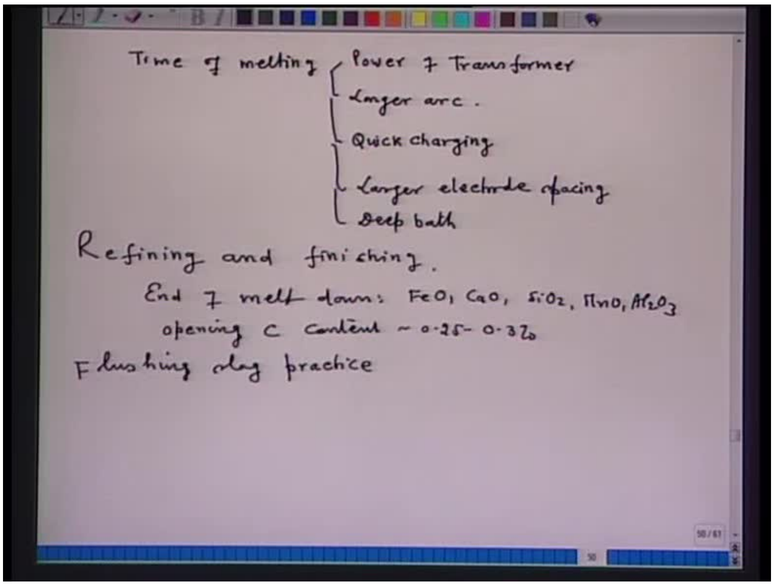


Now, the time of melting, it depends on the following factors, it depends,first of all, on power of the transformer, power of transformer.

It also depend upon, whether the arc is long or short, say longer arc, they need lower current, lower will be the heat losses and higher will be the electrical efficiency, that means melting will be faster.

Also, long arcs are covered by the solid charge, because smaller arc, it may not be covered by the solid charge.If the arc is long, it will be covered by solid charge and what is the effect, less heat losses will be there.Also, quick charging shortens the melt down time, because every time you charge,for example, big furnaces which are 2 or 3 times and every time you have to start the process, open the roof, heat loss will be there.So, quick charging, it helps to reduce the meltdown time.

Now, larger electrode spacing, larger electrode spacing, it decreases the melt down period, because it encompasses, or the arc encompasses the larger scrap area, but, well, too large spacing, then we will be too near the walls and the accordingly,or the walls of the furnace will be affected.So, an optimum has to be struck.

Deep bath and relatively narrow shell, it also shortens the meltdown time.So, what we have achieved in the melt down time?We can also get some refining, as I have said already, dephosphorization can be done and when all the metal has been molten, then the reducing period or refining and finishing period begins.So, the end of the melt down stage is that, when all these scrap has been molten and that end of the melt down period is called, that the operator has attained the flat path condition.

Now, in the refining and finishing, at the end of meltdown, we have a slag which contains FeO, CaO, SiO 2, MnO and Al 2 O 3, which is coming from iron ore, some calcium chloride is also added for slag fluidity.Now, the important point in the refining and finishing operation, that the opening carbon content should be around 0.25 to 0.3 percent higher than required for thechemistry of the steel, which is being produced.

If the carbon is less than this, then certain amount of ((recarburides)) are also added along with this scrap.Now, this is required in order to facilitate the carbon boil, because the carbon boil helpsto remove the gasesas well as it also helps for the inclusion flotation.This is called a flushing slag practice.

Now, whether flushing slag practice will be used or not, it depends upon whether desulphurization is required or not, because the slag which we have produced, is highly oxidizing in nature, because it is required for phosphorous removal.

Now, if you want to produce a low sulphur steel or if you want to carry out the desulphurization, then what we have to do, we have to remove the oxidizing slag and we have to make the, first, we have to make a reducing slag and for making of the reducing slag, calcium oxide, burnt lime, pulverized coke, they are added.This part of the lecture I will carry on in the next lecture.