# Steel Making

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## Lecture No. # 12
## Modern Steelmaking I, Oxygen Steelmaking

After studying steelmaking fundamentals now we can straight away go through steelmaking practice. So, now, onwards the lecture will comprise of modern steelmaking practice.

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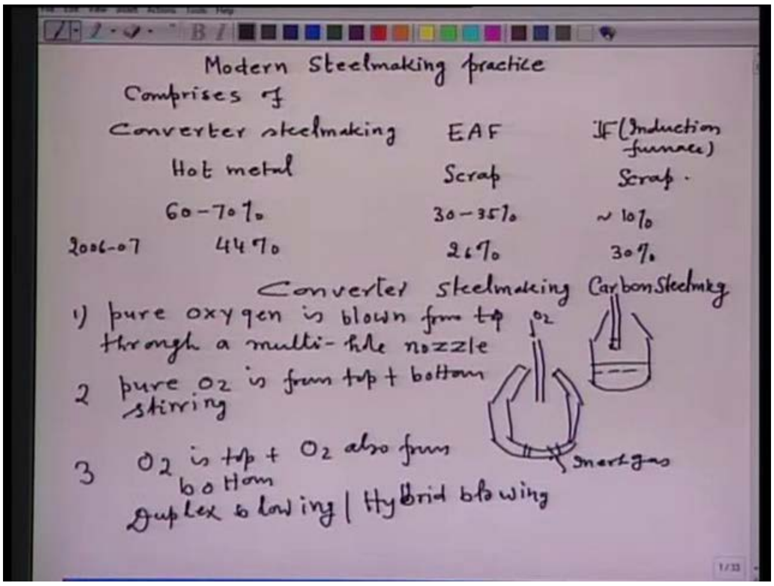


Now, modern steelmaking practice it comprises of say converter steelmaking then electric arc furnace steelmaking and small portion of a steel is also made in the so, called IF that is the induction furnaces I will put it induction furnaces.

The principle raw material in converter steelmaking is hot metal, the principle raw material in electric arc furnace is scrap the principle raw material in induction furnace is also is scrap.

The proportion of crude steel production from converter steelmaking it comprises of the order of 60 to 70 percent around the world 30 to 35 percent from electric arc furnace and 10 around say 10 percent from induction furnace.

In India, however, the proportion is slightly different in the year 2006 2007 the proportion of converter steelmaking in total crude steel production was 44 percent the proportion of electric arc furnace was 26 percent, however, the proportion of induction furnace in total crude steel production was very high of the order of 30 percent anyway this is just a data which I have given you.

So, let us take first of all converter steelmaking at the movement we are talking of carbon steelmaking carbon steelmaking.

Now in the converter steelmaking pure oxygen is blown from top through a multi-hole nozzle through shape is something like this..

This is a vessel this a metal and here centrally placed vertical lance bottom is fitted with the multi-hole nozzles this is number one number two in another version pure oxygen is blown from top and through bottom some inert gas is also injected and that is called bottom stirring.

So, here if I can show it this is lance which blows pure oxygen well this is a refractory lined vessel and through the bottom inert gas is injected in still another version of converter steelmaking oxygen is blown from top plus oxygen also from bottom.

Both versions that is two and three they are called duplex blowing or the hybrid blowing and some also called top blowing oxygen and bottom insert processes and top and bottom blowing processes is still some another version pure oxygen is blowing through the bottom.

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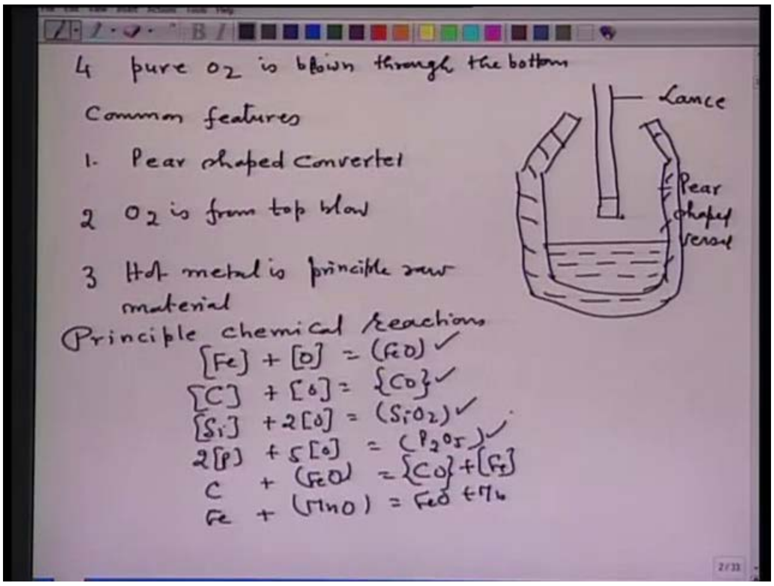


Now, this particular which is called bottom blowing steelmaking is hardly used any in any part of the world it is just a modified version of basic bessemer process where air was injected in 1878 instead of air in the modification oxygen was introduced through the bottom, but, as a bottom blowing steelmaking pure bottom blowing steelmaking is not practiced to my knowledge.

So, now if you note all these variations or all these versions of converter steelmaking there some features are common. So, the common features in all versions first is pear shaped converter is used that is second common feature is that oxygen is blown from top through a lance which is fitted with multi-hole nozzles.

So, this is the lance this is a pear shaped vessel of course,, it is refractory lined and third common feature is hot metal is the principle raw material..

So, whether we have pure top blown steelmaking or we have top and bottom blowing also called hybrid blowing or duplex blowing processes these three features they are the common features in all the 3 processes.

Now, let us see now the principle chemical reactions are F e plus O that is equal to F e O then carbon plus O that is equal to C O S I plus 2 O that is equal S i O 2 then 2 P plus 5 O that is equal to P 2 O 5 carbon plus F e O that is equal to C O plus F e F e plus M n O that is equal to F e O plus M n.

Now, note all these reactions say reaction this iron oxidation carbon oxidation silicon oxidation phosphor oxidation they are all exothermic in nature and you must note that in all variations of converter steelmaking no heat is supplied from outside.

After noting these essential features all these processes are called basic oxygen furnace processes B O F or basic oxygen steelmaking B O S these are the various names that you will find in different books.

Now, in recent years pretreatment of hot metal has become in some plants a standard practice the pretreatment of hot metal means the hot metal which is trapped from the blast furnace it is treated for silicon sulphur and phosphorous content and this practice of pretreatment is used whenever it is required to produce high quality steels.

For example steels which require good surface finish steel which require free from internal cracks and in certain applications when sulphur and phosphorous content requirement is less than 0.01 percent.

So, when on certain applications the chemical composition. So, much restricted then naturally the pretreatment of hot metal that is control of silicon sulphur and phosphorous before hot metal is charged into the converter steelmaking is required to be done.

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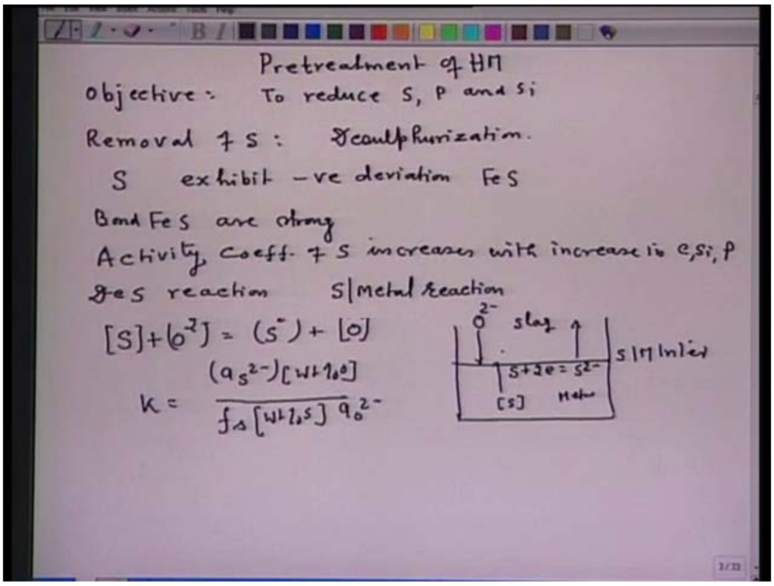

So, as such before we go with the details of modern steelmaking practice I would like to give you a little information about the pretreatment of hot metal it means in various practices hot metal from blast furnace directly charge into the converter.

Now, the objective of pretreatment is really clear to reduce sulphur phosphorous and silicon as regards the thermodynamic condition for the removal of phosphorous and silicon we have already seen earlier while dealing with the steelmaking fundamentals.

What we have not seen over there is a thermodynamic condition for removal of sulphur because we have said there that steelmaking is done under oxidizing condition and sulphur removal under oxidizing condition is very very minimum at that point of time we have not considered the sulphur removal.

But now when we are considering pretreatment of hot metal as a separate step then to appreciate the requirement for sulphur removal it has become necessary to understand how sulphur is removed.

Now, first of all removal of sulphur this is called desulphurization called desulphurization now certain important characteristic features of sulphur that is sulphur it exhibits negative deviation from henry's law what does it mean negative deviation means the sulphur has a strong tendency to form a compound like F e S. The bonds between F e S it is bonds are very strong and hence it is not easy to remove sulphur from hot metal unless some conditions are created. Number three the activity coefficient of sulphur increases with increase in carbon silicon and phosphorous.

Now, let us see what is a desulphurization reaction I will put d e s as a desulphurization. So, a desulphurization reaction. Now, first of all desulphurization reaction is a slag metal reaction is a slag metal reaction in a metal sulphur is present in the elemental form where as a slag sulphur is present in ionic form, that means, transfer of sulphur from metal to slag requires the following steps.

First sulphur should be transported to the metal slag interface there it should received two electrons. So, that it gets transfer to S 2 minus ions in order to maintain electro-neutrality at the slag metal interface a reverse transfer of ions should occur from the slag side to the metal two electrons will be generated at the slag metal interface and then sulphur will be converted to S 2 minus it will go into the slag and the ionic affinity which gives ions for example, O 2 minus then O will transfer into the metal.

So, this is what I am going to illustrate over a diagram for example, if I take this is a slag metal interface let us see sulphur is sitting somewhere here then it will transfer over here then the sulphur it must have two electrons to be transported to S 2 minus then and then S 2 minus can be transferred into the slag. So, this I will put as a slag and this as a metal.

So, here there should be O 2 minus ions and this O 2 minus ions they are transport into slag interface on the slag side that the transfer of transfer of sulphur from metal to slag is accompanied by the transfer of oxygen from slag to metal.

So, the same reaction I am going to write down now S plus O 2 minus that is equal to S 2 minus plus O this is in the metal this is in the slag this is in the metal and this is in the slag. So, if I write down the value of K K will be equal to activity a S 2 minus to weight percent O weight percent O upon F s weight percent sulphur into activity of O 2 minus.

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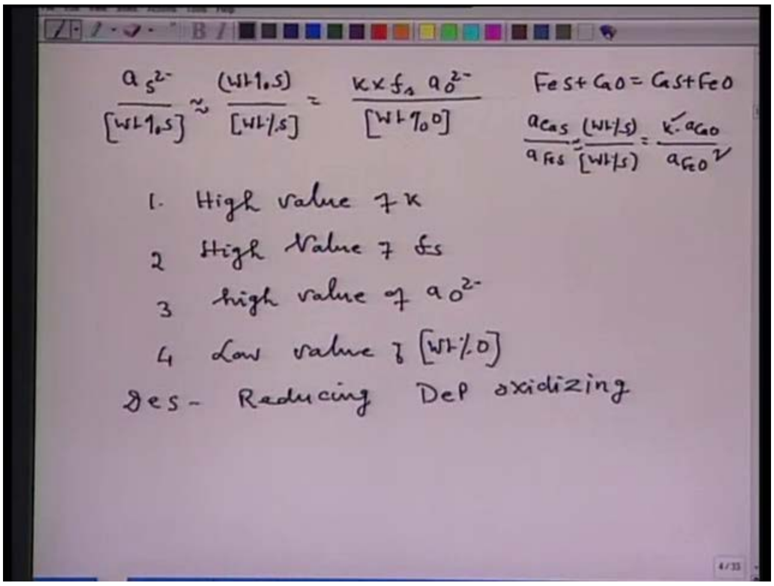


Now, a rearrangement of this equation in the form of the desulphurization ratio we can put it say a s 2 minus upon weight percent sulpur that is approximately equal to weight percent sulphur in slag upon weight percent sulphur in metal that will be equal to K into f s into activity of o 2 minus upon weight percent O.

Now, the same reaction you can also put it for in a molecular form F e S plus C a O that is equal to C a S plus F e O you can write down the value of K you can arrange the variable such that you get on the left hand side a desulphurization for example, like activity of C a S upon activity of F e S that is approximately proportional to weight percent sulphur in slag upon weight percent sulphur in metal that will be equal to K into activity of C a O upon activity of F e O this is what it can also be done like this.

Now, what we can derive from this equation the information for efficient desulphurization first of all the left hand side of the equation that is weight percent sulphur in slag upon weight percent sulphur in metal should be high if it is high then weight percent sulphur in metal will be low.

So, in order this ratio should be high in order the ratio of weight percent sulphur in slag upon weight percent sulphur to be high K must be high I write down the constant high value of K high value of equilibrium constant again high value of F s then high value of activity of O 2 minus ions in slag and low value of weight percent o in metal.

Similar information you can obtain from the molecules picture also high value of K high value of activity of C a O in slag low activity of F e O in metal any way. Let us concentration this 1 2 3 4 point high value of K depends on temperature and accordingly temperature can be adjusted.

High value of F s how high value of F s can be obtained initially I have said that the presence of carbon phosphorous and silicon increases the activity coefficient of sulphur and therefore, the presence of the carbon silicon and phosphorous they enhance the desulphurization. So, third point is high value of activity of O 2 minus ions what does it mean high value activity of oxygen ions means you should have a highly basic slag. Now, you recall the definition of basicity on the basis of oxygen ion there we said it is a free oxygen ion that are important and that and that contributes to the basicity of slag.

Fourth point is that low value of weight percent oxygen in metal, that means, the highly reducing conditions are required for desulphurization you also notice from the sulphur transfer equation that the sulphur transfer from metal to slag is accompanied by oxygen transfer from slag to metal and that oxygen which is been transferred from slag to metal it must be removed that is why you require the reducing conditions also.

About the removal of silicon and phosphorous we have already done. So, desulphurization just summarizing it require reducing condition, dephosphorization oxidizing condition and. So, is silicon also.

Now, given this particular information we know about the removal of sulphur we know about the removal of silicon we know about the removal of phosphorous now this pretreatment of hot metal now consist of treating the hot metal in the transfer vessel.

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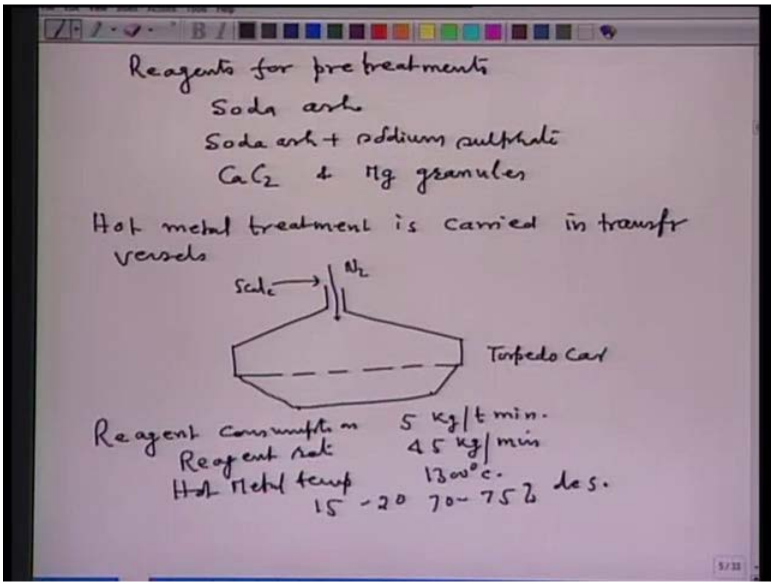


Now, the reagents for pretreatment soda ash then soda ash plus sodium sulphate calcium carbide and magnesium granules now for your information magnesium is a very strong desulphurizer. Now, this reagents can be added or they can be injected now hot metal pretreatment is done is carried out in transfer vessels now you know that when hot metal is carried over to l d shop then it is carried over in a torpedo ladle.

Now, a torpedo ladle it look something this way. So, in a torpedo ladle (( )) here for example, nitrogen injection along with the reagents sometimes scale is added to create an oxidizing atmosphere. So, this is the torpedo car. Now, this torpedo car their capacity can be as high as hundred or three hundred tons capacity in the torpedo ladle the pretreatment is carried out another place could be when the metal is state from the blast furnace the runner of the blast furnace and metal flows from the (( )) of the blast furnace to the ladle and there is a long runner and in that runner also the pretreatment can be done.

Ah now the reagent consumption 5 kg here approximate figure per ton minute reagent rate that is injection rate could be 45 kg per minute. Hot metal temperature be around 1300 degree celsius and it takes around 15 to 20 minutes to attain for example, 70 to 75 percent desulphurization simultaneous removal of sulphur and phosphorous is also being adopted in certain practice.

Now, having seen a short account of hot metal pretreatment now we can come back and to our modern steelmaking practice which we are dealing with the converter steelmaking. So, in the converter steelmaking either one can charge hot metal or pretreated hot metal.

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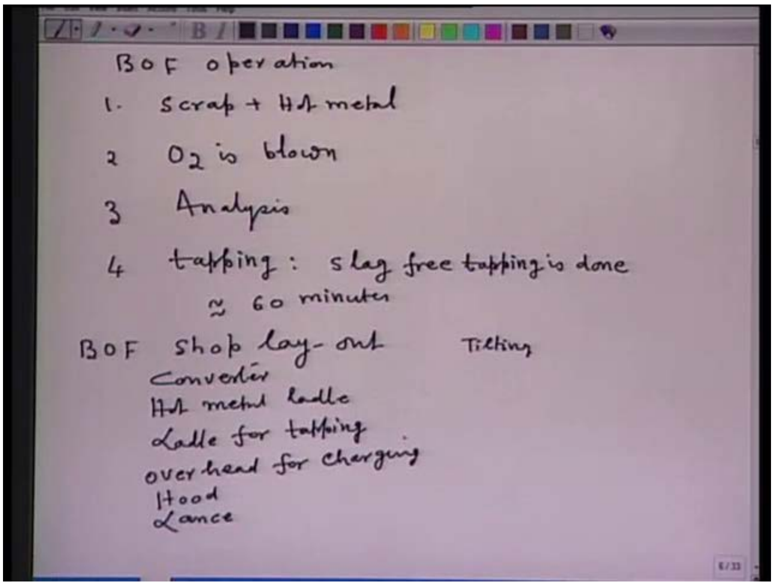


So, B O F operation it first of all consists of a scrap plus hot metal, that means, we charge scrap top operative charge hot metal, but, the principle feet is the hot metal which is 60 to 70 percent depending on the heat balance and rest could be scrap takes around two to three minutes for charging.

After charging scrap and hot metal lance is brought into the position and oxygen is blown then oxygen is blown through a lance with multi-hole nozzles.

Now, the blowing continues for ten to fifteen minutes and once the blowing is over sample is taken for analysis then the third point is analysis and when the analysis confirms to the specified chemistry of the steel that is required to be produced.

Then, the fourth step is automatically tapping and here caution is exercise that as far as possible slag free tapping is done. So, in all these B O F operations right from charging to tapping it takes around approximately sixty minutes that could be fifty minutes or maximum time is sixty minutes.

Now, remember this particular time of charging to tapping is independent of converter capacity that is whether we have fifty tons of converter or we have four hundred tons of converter the tap to tap time is approximately of this order of magnitude and this is the beauty of converter steelmaking.

Now, let us shortly see B O F shop layout now typically what is required for the B O F shop layout we require converter it is place for hot metal ladle for charging then you require one ladle or two ladle for tapping then you require overhead for charging then we require hood for the transport of the exit gases and naturally we require the most important component that is the lance.

So, all these thing for example, converter then on the top of it you have the additional you have the over head for charging ladle or hot metal ladle for tapping of a steel lance it comes through the hood to the converter and these are all arranged vertically and a total height of the shop you can imagine could be around twenty to twenty five meter high.

And say tilting because for tapping you have tilt the converter it is done by electric motors the typical mass of the converter though it depends on the capacity you can think of mass of the converter means mass of the converter plus mass of the refractory lining plus mass of the metal it may go to eight to twelve hundred tons depending of the capacity of the converter. So, it is a very. So, it is a really a shop worthwhile to look and visit the plant.

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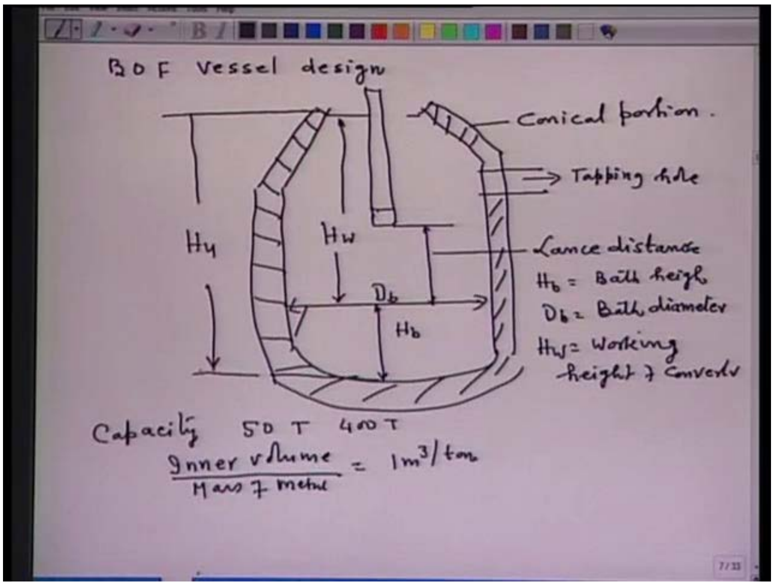


Now, let us go to the B O F vessel design now typically B O F vessel it look something this way this one. This is a refractory lined vessel this is this height is called H b this dimension is diameter of the path this is the top lance fitted with nozzles and this distance from here to the metal height is called lance distance.

We will be using this lance distance very frequently. So, this is the lance distance H b that is the bath height D b that is the bath diameter and from here to here this is H w and H w is the working height of the converter this is the refractory lining to which I will just come in detail. Somewhere here tapping hole is provided this is the tapping hole to tap the liquid steel because you have to tilt it and for tapping. So, this particular portion is the conical portion and the height from here to here that is the useful height. So, these are the typical dimensions of the converter.

Now, the capacity of this converter capacity it varies from let us say fifty tons to as high as four hundred tons or even five hundred tons I do not know, but, I think 500 tons is also there.

Inner volume upon mass of metal that is equal one meter cube per ton then all converters the bath height over bath diameter which is called aspect ratio of the bath it varies between 0.25 to 0.3, that means, converter steelmaking baths are shallow.

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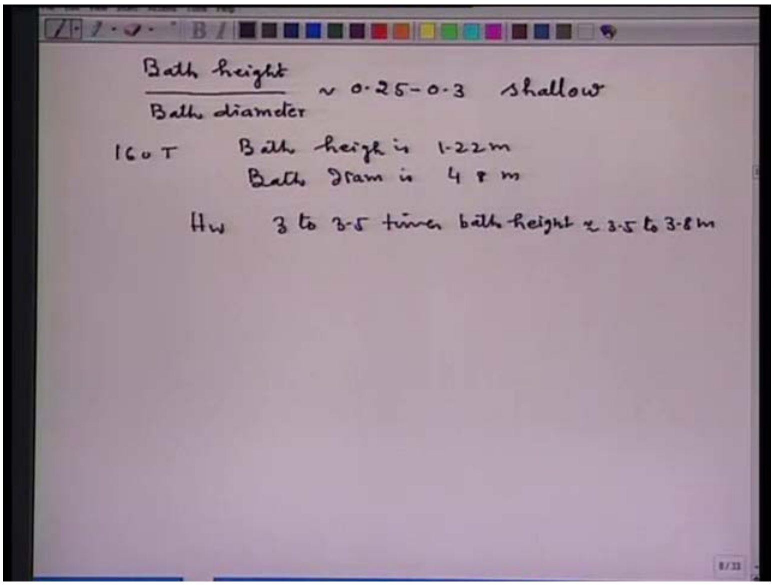


That means the capacity of the converter increased by increasing the diameter rather than the height because if you increasing the height then the shop becomes very tall because you have to charge everything from the top. So, the capacity of the converter is increased by increasing the diameter of the bath rather than the height.

Now, this point is very important particularly when we consider top and bottom blowing I will suggest that you please keep in mind I may use this at that particular time. So, shallow bath.

Now, say total height. So, total height of the converter for example, 150 tons converter it may vary around nine meter or 9.1 meter from conical to the bottom now say typically for example, the capacity is one hundred sixty ton bath height is 1.22 meter I mean this dimensions are approximate, but, you should know that these are the order of magnitude. Bath diameter is 4.8 meter working height of the converter is approximately 3 to 3.5 times bath height which in this case is approximately equal to 3.5 to 3 8 meter.

Now, the concept of working height is to provide a sufficient height to carry out the metallurgical work during refining of hot metal to steel shell diameter around say six meter or well it depends upon the converter capacity also.

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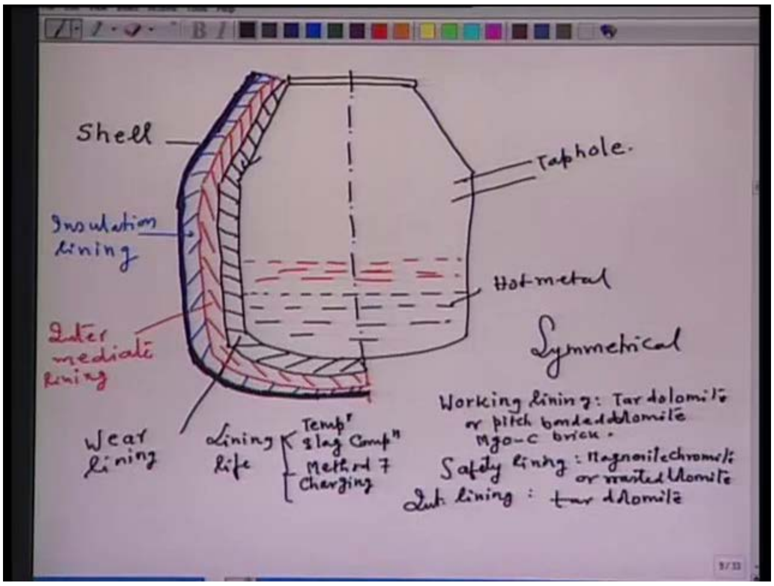


Now as regard the refractory lining that is shown in this particular figure the outside one you have the shell and first you have the insulation lining which is backed by the intermediate lining and then you have the wear lining.

That is here in the wear lining here you have the metal bath this is say hot metal this is slag. So, the wear lining is the most important part of the lining because this is the lining which is subjected to wear corrosion action and. So, on and so forth.

Now, typically working lining now I have show here only one half of the converter because it is symmetrical. So, other half has the same type of refractory with the same dimension. So, working lining consist of tar dolomite or pitch bonded dolomite some plants also using M g O C brick they are very good brick. About safety lining about safety lining which is also called insulation lining we have used magnosite chromites or roasted dolomite then the intermediate lining that is consists of tar dolomite tar dolomite.

Now, among this the most important part of the lining is the wear lining that is this particular lining this must be resistance to corrosion for hot metal and slag it should not be porous it should be able to sustain high temperature thermal shocks and. So, on the very important part of the converter steelmaking is the wear lining.

That is a lining which is directly exposed to the action of slag and metal and repair is done after every for example, thousand heats the refractory consumption could be depending on the practice 1.5 to 2 kg per ton the lining life depends upon temperature slag composition then method of charging are the small small factors, but, cumulative they make around 2 k g per ton consumption of lining then formation of skull at the conical portion of the converter. So, these are all the So, called the refractory part of it.

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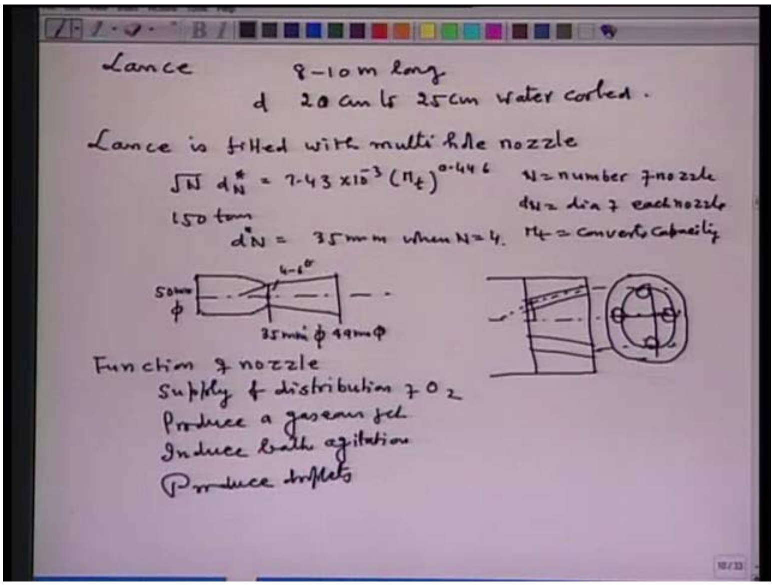


Now, let us see the lance .Lance in fact, is a heart of converting steelmaking it is 8 to 10 meter long the diameter of the lance is varies from 20 centimeter to as high as 25 centimeter and it is water cooled it is water cooled. Water cooling at the rate of 50 to 70 meter cube per hour at 5 or to 6 kilogram per centimeter square pressure the lance is fitted with multi-hole nozzles.

Now, number of nozzles and the diameter where a relationship with the converter capacity and. In fact, the relation is root N where n is a number of nozzles into throat diameter that is equal to 7.43 into 10 to the power minus 3 converter capacity raise to the power 0.446. Where N number of nozzle d N diameter of nozzle diameter of each nozzle M t is the converter capacity. Now, for example, if I take 150 tons capacity then d N from this equation it comes out to be equal to 35 millimeter when N is equal to 4.

So, the nozzles are laval type of nozzle and the nozzle look something this way they are the laval nozzles. So, this diameter is called the d star N I put d star N and this diameter is 35 millimeter and they are designed and the exit diameter is around 49 millimeter the angle of this divergence is around 4 to 6 degree.

This dimension this diameter is around 50 millimeter diameter this is 49 millimeter diameter this is 35 millimeter diameter. So, this is how a laval nozzle looks.

Now, the four hole lance it looks something like this for example, if this is the lance tip this is the centre point. So, this is on the right side I have shown you a four hole nozzle which is fitted at the bottom of the lance now this 1 2 3 4 they are symmetrically placed nozzle and the angle of inclination of each nozzle with the excess of the lance is around 10 to 12 degree and the idea of that particular angle is to provide a jet which is non-coalescing in nature downstream the lance.

Now, the function of the nozzle is for example, supply and distribution of oxygen supply and distribution of oxygen produce a gaseous jet to iinduce bath agitation and to produce droplets and produce droplets.

So, that is why the nozzles are fitted at the bottom of the lance to inject oxygen at a very very high pressure another important feature of the lance is that these lances are water cooled and the bottom of the lance which is fitted with the nozzle is having the copper tip and the water is cooled up to the copper tip if not then the tip will melt. So, there is very strong water cooling is necessary for this type of lances.

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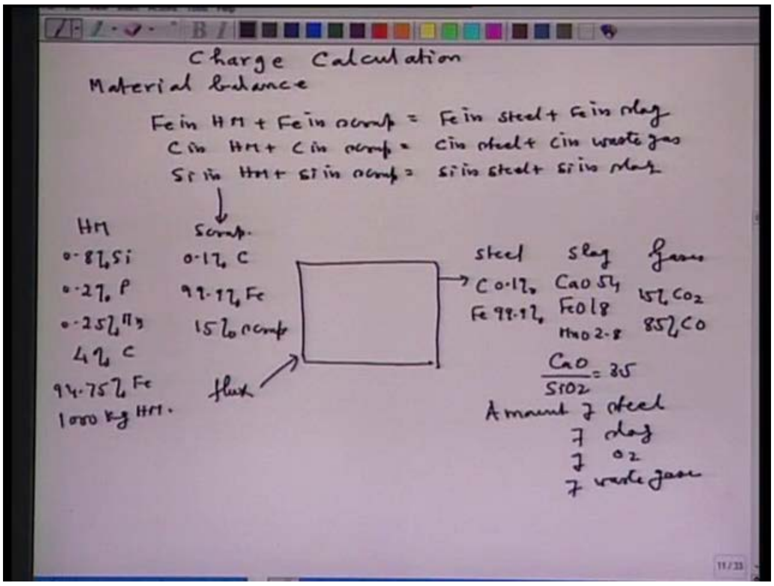


Now, let me go to the charge calculation. In fact, for charge calculation one has to do material balance and material balance input must be equal to output.

So, all inputs are collected on one side and all outputs are connected or other collected on the other side then the balance of various elements are made for example, say iron in hot metal plus iron in scrap that is equal to iron in steel plus iron in slag then carbon in hot metal plus carbon in scrap that is equal carbon in steel plus carbon in waste gases.

Similarly, silicon in hot metal plus silicon in scrap if it is there that is silicon in steel plus silicon in slag and. So, on you can make the balances of each element and these balances can be solved for knowing the quantity of the each input and output.

Now, let me illustrate by a simple example, I take this is the box where I am putting my input now say input consist of hot metal and the hot metal is say having 0.8 percent silicon 0.2 percent phosphorous 0.25 percent manganese and 4 percent carbon and 94.75 percent iron.

I am adding here scrap which is 0.1 percent carbon and 99.9 percent iron and I am adding around 15 percent of scrap I am producing a steel with the composition say carbon 0.1 percent and rest iron which is 99.9 percent.

I am producing slag which is having Ca O 54 percent F e O 18 percent M n O 2.8 percent and the basicity ratio C a O upon Si O 2 of course,, on weight percent that is equal to 3.5 and the gasses which I am producing they are having 15 percent CO 2 and 8 5 percent carbon monoxide now I am using 1000 kg hot metal.

Of course I am adding flux also. So, now, let us calculate amount of a steel amount of slag amount of oxygen and amount of waste gases amount of flux can also be calculated if the composition of the flux is given then for example, most of the time lime is added. So, lime in flux it enter lime in slag and from that balance amount of flux can also be calculated. Now, let me illustrate by this say for calculation of the amount of steel for example, I do the iron balance 1000 kg hot metal 150 kg of scrap if I do the iron balance then what I do it now let me put it say x is amount of steel and Y is amount of slag if I do the iron balance.

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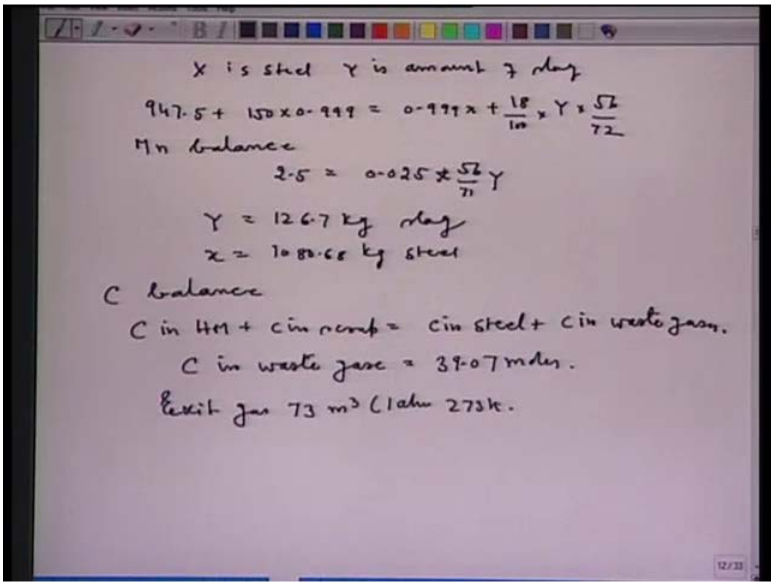


So, iron balance will give me 947.5 plus 150 into 0.999 that is equal to 0.999 x plus 18 by 100 into y into 56 upon 72. Now, I do manganese balance now if I do manganese balance then immediately I get 2.5 that is equal to 0.025 into 56 upon 71 Y I solve both the equation I get Y is equal to 126.7 kg which is the amount of slag that will be produced and amount of a steel that will come 1080.68 kg steel will be produce that is how you will be solving the material balance or charge calculation then now in order to calculate the amount of exit gas what I do I do the carbon balance.

So, if I do the carbon balance a carbon in hot metal plus carbon in scrap that is equal to carbon in a steel plus carbon is waste gases I write for you carbon in hot metal plus carbon in scrap that is equal carbon in steel plus carbon in waste gases.

So, if you do all these balances then you can find out the carbon which is gone in waste gases that will come 39.07 moles from here the percentage of CO and CO 2 is given. So, we can find out the amount of CO 2 and CO. So, the exit gas you can simple calculate will come out to be 73 meter cube at one atmosphere and 273 kelvin.

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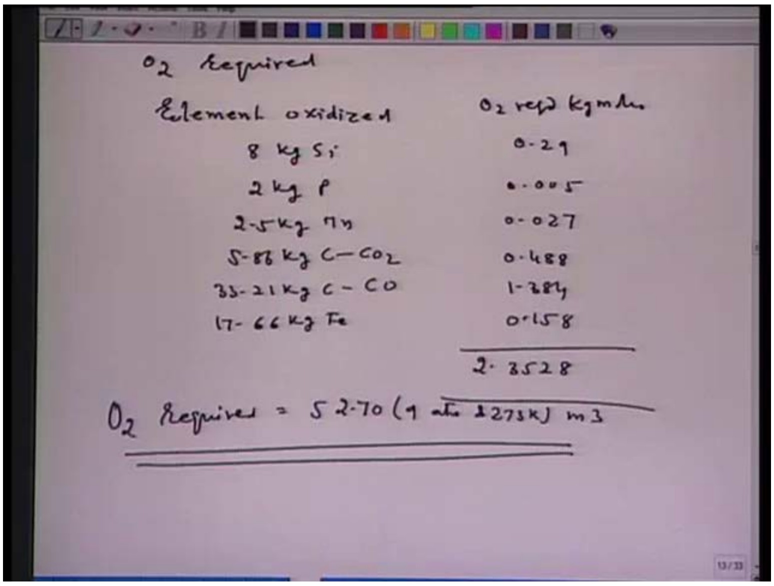


Now, we can calculate now the amount of oxygen required the oxygen required silicon to Si O 2 carbon to CO 2 carbon to CO M n to M n O and all these oxidation reactions they are to be written and accordingly you find out the amount of oxygen that is required how much amount of element is being oxidized. So, if I write immediately say element oxidized and then oxygen required in kg moles.

Say I oxidize 8 kg silicon 2 kg phosphorous 2.5 kg manganese 5.86 kg carbon goes to CO 2 and 33.21 kg carbon goes to CO and 17.66 kg iron goes to FeO. Now, the oxygen required will be here 0.29 here it will be 0.0058 here it will be 0.027 here it will be 0.488 here it will be 1.384 here it will be 0.158 if I sum total it I will get 2.3528 kg moles of oxygen. Now, 1 kg mole is 224 meter cube at one atmosphere in 273 kelvin. So, oxygen required you can simply get by multiplying 2.3528 by 22.4. So, you will be getting around 2.70 at one atmosphere and 273 kelvin meter cube this is the oxygen required in order to convert one ton of hot metal to a steel.