Steel Making
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Indian Institute of Technology, Kanpur
Module No. # 01
Lecture No. # 17
Modern Steelmaking II, Electric Arc Furnace

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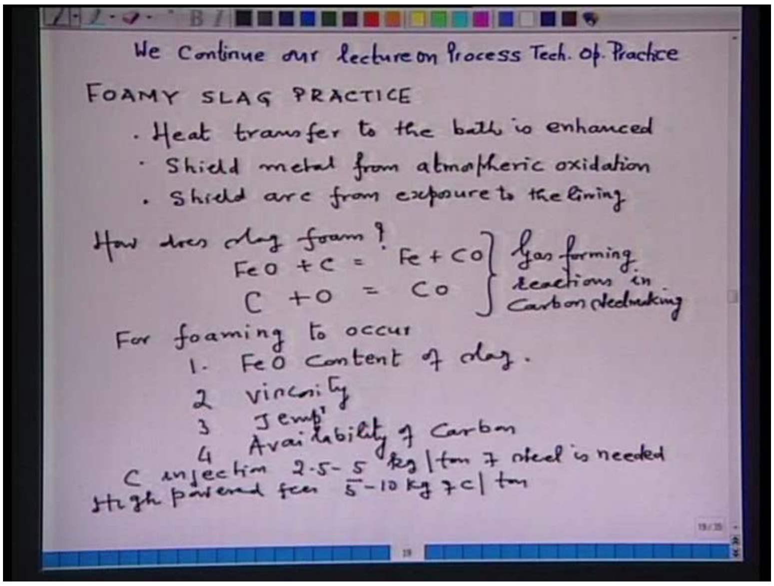

We Continue our lecture on Process Tech. op. Practice

FOAMY SLAG PRACTICE

- Heat transfer to the bath is enhanced
- Shield metal from atmospheric oxidation
- Shield arc from exposure to the lining

How does slag foam?

$$\left.\begin{array}{l} FeO + C = Fe + CO \\ C + O = CO \end{array}\right\} \text{Gas forming reactions in Carbon steelmaking}$$

For foaming to occur

1. FeO content of slag.
2. viscosity
3. Temp
4. Availability of Carbon

C injection 2.5-5 kg/ton of steel is needed

High powered fces 5-10 kg of C/ton

So, we continue our lecture on process technological operating practice. In that sequence, we will be discussing today foamy slag practice. As I have already explained, what is a foamy slag and how does it form in our lecture on slag making fundamentals. Now, the advantages of foamy slag practice are, for example, heat transfer to the bath is enhanced. How is it enhanced? Because, now, the arc will be submerged into the slag and on account of submergence of the arc into the slag, more heat will be transferred to the bath and less heat will be radiated to the wall.

Another advantage of foamy slag practice is, the foamy slag, it shields metal from atmospheric oxidation. Now, this is obvious, as a liquid metal is shielded by a foamy slag, so, no atmospheric air will come into contact with the hot metal. Third advantage is that, it shields arc from exposure to the lining. Now, you can imagine, in the absence of a foamy slag, the arc which is created by striking graphite electrode with the scrap, the arc will be radiating its heat directly to the wall. Now, if we submerge the arc into the foamy slag, what will happen? Then the heat will not be radiated to the lining of the wall and hence the lining life will also improve.

Now, the question is how does slag foam? For foaming of the slag, as already I have said, a gas forming reaction during the operation of the electric arc furnace should be there. So, the principal gas forming reaction is again the oxidation of carbon. Carbon plus oxygen, it forms carbon monoxide or carbon plus Fe O in the slag, it forms C O plus iron. So, the gas forming reaction is Fe O plus C that is equal to Fe plus CO or C plus O that is equal to CO. These are the gas forming reactions in carbon steelmaking.

In case of alloy and stainless steel making, the foaming slag mechanism is slightly different. We will deal at the time, when I will tell you the stainless steelmaking practice. During the melt down period, progressive melting of the scrap, it exposes arc to the lining of the side wall of the furnace. Now, for the foamy slag, it is required that carbon content of the bath should be sufficient and oxygen should also be available. So, that means for foaming to occur during the operation, what is required? One required Fe O content of slag, then, slag should have viscosity, I would not low viscosity, I will not also high viscosity, but, that viscosity, where, which allows the entrapment of the carbon monoxide bubble, temperature, and above all, the most important thing is availability of carbon.

Now, why I have written this thing, imagine, for example, 100 percent scrap melting practice. Hardly there is carbon over there. So, it is not possible to foam a practice which runs on 100 percent scrap. What to do? Then you have to inject carbon, if you want a slag foaming practice. Also, you have to inject oxygen also. If there is a proportion of a sponge iron or a hot metal, then carbon content of the bath is available and accordingly the carbon monoxide reaction will be there. So, what I wanted to say is that, that the availability of carbon has to be ensured.

Now, typically the carbon injection is just around 2.5 to 5 kg per ton of steel is required for adequate foaming during the operation. If they are high powered furnaces, they will be requiring around 5 to 10 kg of carbon per ton of steel would be adequate for slag to foaming. Now, obviously, radiation from the arc has decreased, more heat will be transferred to the bath because of the foamy slag practice or the arc is submerged into the foamy slag, the electrical efficiency will be high and accordingly the power consumption will be low.

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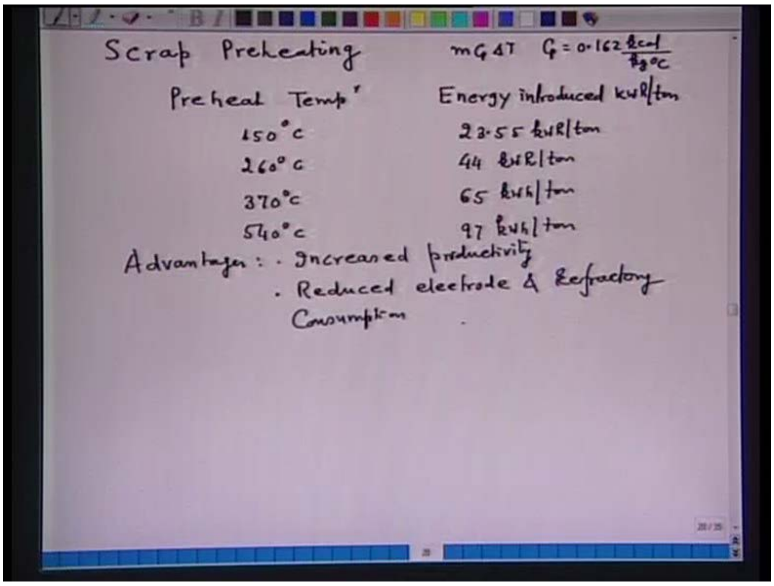

Scrap Preheating $mC_p\Delta T$ $C_p = 0.162 \frac{kcal}{kg\,°C}$

Preheat Temp'	Energy introduced kWh/ton
150°C	23.55 kWh/ton
260°C	44 kWh/ton
370°C	65 kWh/ton
540°C	97 kWh/ton

Advantages: · Increased productivity
· Reduced electrode & Refractory Consumption

Now, at least 0.3 percent carbon removal rate ensures good slag foaming, however, this is a figure which is obtained from some particular operation. Now, next is the scrap preheating. Now, as you are aware, a scrap which is charged at 25 degree Celsius and a scrap, if it is charged with temperature greater than 25 degree Celsius, if you charge a scrap with greater than 25 degree Celsius, that means preheated the scrap, you are adding additional amount of energy along with the preheated scraps.

So, naturally if a scrap is being preheated, the electrical consumption will be low, melt down period will be lower, electrode consumption will also be lower, because now, we have reduced the melt down period and accordingly the associated tap to tap time interval will also be low and electrical power consumption will also be low, since you are adding some amount of energy into the bath. The preheated scrap is a very important process technological operation in the electric arc furnace. The scrap is being heated by recovering the waste heat from the exit gases of the electric arc furnace.

Now, imagine, suppose if I take preheat temperature here and here I take energy introduced by preheating in kilo Watt hour per ton. Now, very simple, I can calculate it.

That is the energy is m C p into delta T, m, I take for example, 1000 kg, the C p of the steel, I can take for example, 0.162 kilocalorie per kg degree Celsius. And now, if I calculate, for example, my preheat temperature is 150 degree Celsius, then I will be adding around 23.55 kilo Watt hour per ton of energy into the bath. If I heat up to 260 degree Celsius, I will be adding around 44 kilo Watt hour per ton of energy. If I heat up to 370 degree Celsius, I will be adding around 65 kilo Watt hour per ton and if I heat up to 540 degree Celsius I will be adding around 97 kilo Watt hour per ton of energy. Naturally, more is the amount of, which is there with the preheated scrap, more amount of energy will be introduced, so, less amount of energy I will be required from electricity.

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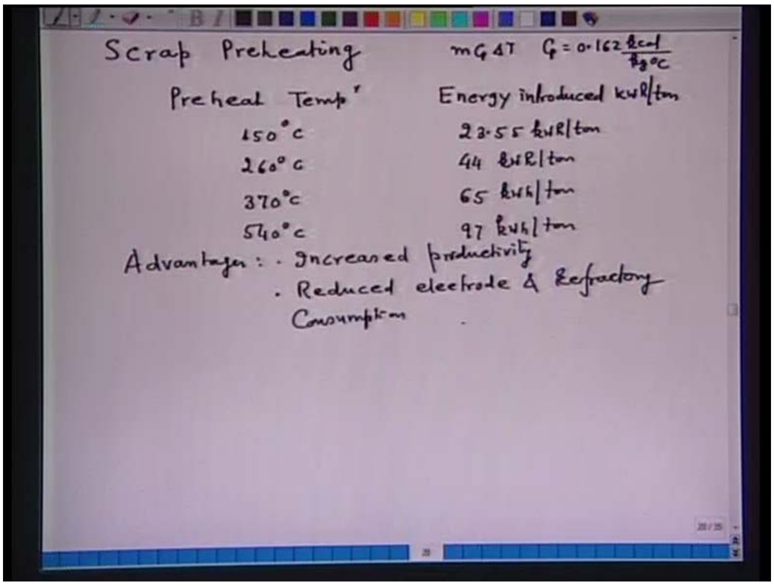

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Advantages : · Increased productivity
· Reduced electrode & Refractory Consumption

So, obvious advantages of preheating scrap, though it is obvious, but, still, to complete the lecture, I will like to write down the advantages. Increased productivity and I mean, these advantages you can derive from yourself by imagining that, now, you are introducing additional amount of energy. So, this additional amount of energy can melt more amount of a scrap, then per unit of electrical power consumption you will get more productivity, more amount of metal can be melted. Second advantage is that, reduced electrode and refractory consumption. Now, this advantage number 2, reduced electrode and refractory condition, they are the indirect advantages. Because, what you are doing, you are decreasing the melt down period, because you have added certain amount of extra energy by preheating the scrap. So, if you add extra amount of energy, you are decreasing the melt down period. If you decrease the melt down period, the total tap to tap time will also be decreasing. Less time will be used by the electrode for heating. Of course, the electrode consumption will be lower, because now, the time is less.

Now, for a particular heat is for less time in the electric arc furnace, so, obviously refractory consumption will also decrease. Now, the question comes, how to heat this amount of scrap? It is very easy to calculate. Say on the board or in the class room, I can always take a temperature equal to 600 degree Celsius or 800 degree preheated scrap temperature, I can calculate that amount of energy and claim that, so much amount of energy is there and hence I will be able to save the electricity. But the question comes, the extra investment. As I have said earlier, a technology requires ROI, return on investment as well as payback period. Payback period should be low and ROI, return on investment should be high. If you invest 100 rupees, your investment should be or profit should be more than 100 rupees, at least.

So, what is required at this point of time or at this point to understand, a development of technology in order to preheat the scrap. So, here if you closely observe electric arc furnace, you will note, and as I have also drawn an energy balance diagram for electric arc furnace, there I have shown that 20 percent of the energy is carried away by the waste gases. Remember, the waste gases temperature is around 13 to 1400 degree Celsius. So, a technological person will think, why not to use this waste energy and develop a method for preheating. It is this particular idea that has led to the use of waste heat from the exit gases and to recover it by preheating the scrap and charging that preheated scrap in the electric arc furnace. Now, there are, several technologies are available, several ways are available. Now, here again, I will like to tell you that, an efficient and economical technology is to be developed utilizing the heat of waste gases.

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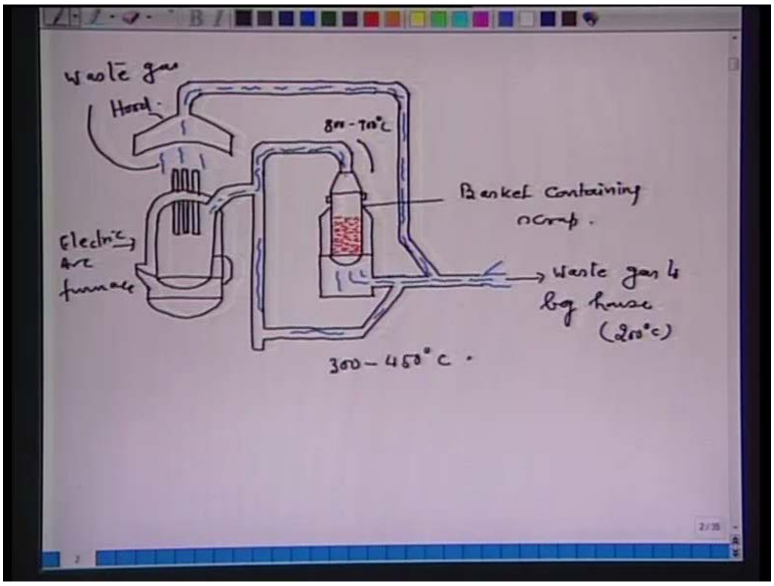

I will show you two such technologies. Now, for example, this is a technology which is being developed for heating the scrap. Now, here, this is the electric furnace; this is the electric arc furnace. This is the basket containing the charge. This is basket containing scrap. This blue line, they are the waste gas. This is of course,, hood. So, here the waste gases to bag house. Now, a portion of the waste gas is diverted to this particular loop and it rather enters into the basket, in that residence time in which the scrap is in contact with the flowing waste gas, the scrap will be heated up and the rest amount of gas is discharged into the bag house.

Now, here the waste gases may be entering around 800 to 900 degree Celsius. The waste gases we discharged to bag house is of the order of 200 degree Celsius. The scrap gets heated up to a temperature of 300 to 450 degree Celsius. I remember this method is a sort of discontinuous one, that means, every time you have to stop the process, you have to take the bucket out, take it to the electric arc furnace and charged the preheated scrap into the electric arc furnace, again bring the bucket and do a repeatedly that process. So, this is a discontinuous type of preheated scrap arrangement. But, even then, this has worked and this is working in some of the industry.

Now, by this the energy consumption will be reduced by a figure of 40 to 60 kilo Watt hour per ton and as regards the electrode consumption, that also be reduced, refractory consumption will also be reduced and tap to tap time will also be reduced. Now, to quote the figure, because that will vary from plant to plant. So, what I will like to tell you is that, because you are putting an extra amount of energy, so, it is obvious, the power consumption will be low, tap to tap time will also be low, refractory consumption will also be low.

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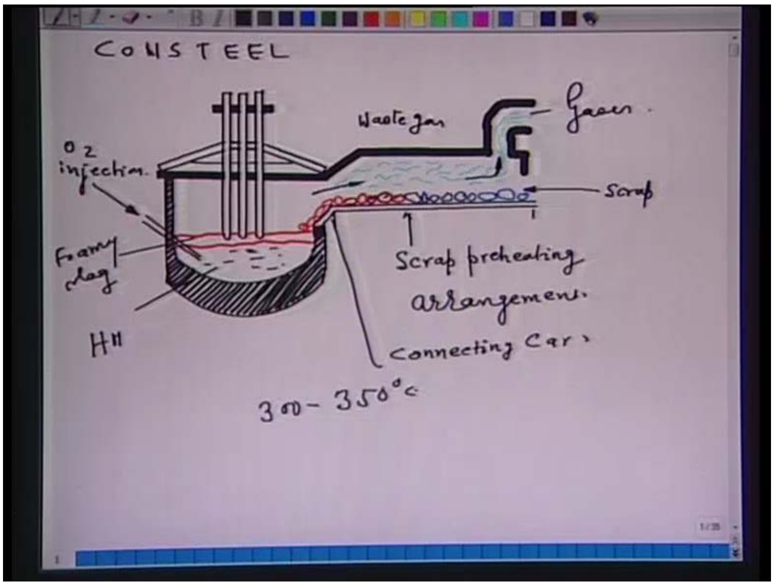

Now, another development for scrap preheating, which is also being working in some of the plant, is a continuous development. So, this development has been developed by Consteel. Here this is an oxygen injection. This is, we can call as a scrap preheater, a scrap preheating arrangement. These are the gases. This is hot metal. This is foamy slag and here the waste gases, directly from the electric arc furnace, they are introduced into the scrap preheating system. Now, somewhere here, this is a connecting car. The scrap is going in this direction. Somewhere 25 degree Celsius gets heated up, heated up and then it is charged into the melt.

So, a continuous process. This is the waste gas. Waste gas and the scrap, they are travelling counter current. Very effective mechanism of heat transfer, from the heat of the waste gas to the flowing or to the moving scrap. So, this is a sort of a continuous system for preheating of the scrap. Now, it looks very easy, but, there are several complications or several intricacies are involved. One of the main intricacy is that, you have to connect the electric arc furnace with the scrap preheating arrangement.

This is one and second, you have to optimize the length of this, scrap preheating, that is, this and this, such that the desired temperature of scrap could be attained, because the gases are moving continuously, and scrap is also moving continuously. So, it is the residence time of the waste gas in the preheated section, that will decide the temperature to which the scrap could be preheated. So, higher residence time larger temperature, lower residence time, smaller temperature. But, however, these are to be optimized and the, what is available is that, the maximum preheating temperature could be attained by this around 300 to 350 degree Celsius. So, that is what the preheating scrap and the technology associated with this. Again, once again, I will like to repeat that, this preheating scrap technology has to be developed. It has to be developed, keeping in view the parameters that are particular to a particular point.

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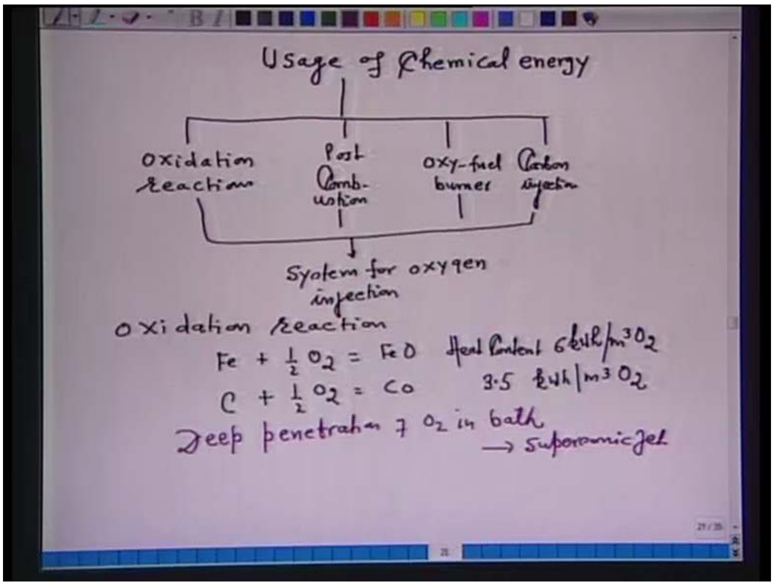

Usage of Chemical energy

Oxidation reaction

Post Combustion

oxy-fuel burner

Carbon injection

System for oxygen injection

Oxidation reaction

$Fe + \frac{1}{2} O_2 = FeO$ Heat Content 6 kWh/m³ O_2

$C + \frac{1}{2} O_2 = CO$ 3.5 kWh/m³ O_2

Deep penetration of O_2 in bath

→ Supersonic Jet

It is not there, that a technology which works in a x steel plant, the same technology will work in the y steel plant. It may work, it may not work. So, that is about the process operating technology.

The next development is usage of chemical energy. Now, usage of chemical energy, there are various ways in which this is being done. One is a oxidation reaction; another post combustion; third, oxy-fuel burner and fourth is carbon injection. Now, all these technologies, they require oxygen in order to derive the chemical energy. But, chemical energy means what, you carry out a chemical reaction and that chemical reaction must be exothermic in nature. When the reaction is exothermic, the amount of heat will be available to you. So, all these different facets of chemical energy, they require a system for oxygen injection. Now, let us see, what are the requirements. First, take say, oxidation reactions. Now, oxidation reactions for example, iron gets oxidized, carbon silicon and manganese gets oxidized.

Silicon and manganese, they are low in quantity. Iron and carbon are there. So, it is oxidation of iron and carbon, both are exothermic reaction and both provides energy to the bath. That means, the iron plus half O 2, it gives you Fe O and the heat content by oxidation of iron,that will be 6 kilo Watt hour per meter cube of oxygen. That much amount of heat will be available. If I allow carbon to proceed, it is a carbon oxidation, that is CO, then heat content will be 3.5 kilo Watt hour per meter cube oxygen. You may be tempted to carry out iron oxidation, because of the heat, but, well, it is a loss. So, normally, you do not allow iron oxidation to proceed. You allow carbon oxidation to proceed, so that, the energy is introduced into the bath.

Now, for carbon oxidation to proceed, you require a carbon content, at least greater than 0.3 percent or 0.4 percent of carbon. Below that iron oxidation will continue and any amount of energy you will be introducing by oxidation of iron, it may be compensated by the loss of productivity. So, there is no point in allowing oxidation of iron. So, in order to obtain chemical energy by oxidation reaction, it is the carbon reaction that must be preferentially allowed to occur, by having a carbon content at least greater than 0.3 to 0.4 percent carbon. So, therefore, in such cases, where this requirement is not met, that is carbon content of the bath is less than 0.3 percent, then an additional carbon injection facility has to be developed, if energy should be derived from oxidation reaction. So, remember, additional carbon injection facility is required.

Now, for carbon reaction to proceed, where carbon is in the bath, how the reaction will proceed? You have to allow oxygen to penetrate deep into the bath. That means, the condition for carbon oxidation to proceed is deep penetration of oxygen in the bath. That means, high velocity, that means, you require a sort of supersonic jet. Otherwise, it will not work.

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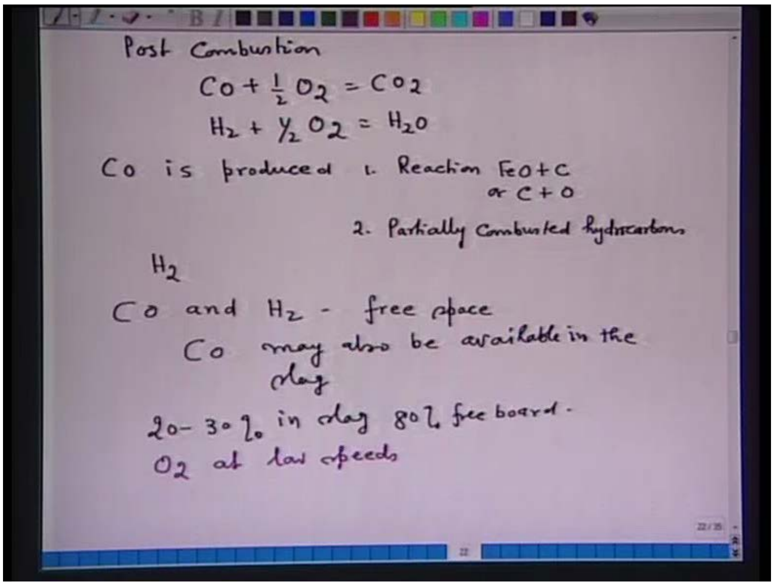

Post Combustion

$CO + \frac{1}{2} O_2 = CO_2$

$H_2 + \frac{1}{2} O_2 = H_2O$

CO is produced 1. Reaction FeO + C or C + O

2. Partially Combusted hydrocarbons

H_2

CO and H_2 - free space

CO may also be available in the slag

20- 30 % in slag 80 % free board.

O_2 at low speeds

Now, let us see another… Post combustion, as we have seen in case of BOF steelmaking, it involves the oxidation of carbon monoxide or hydrogen, if they are present in the exit gases, in the free board of the furnace; so that, the heat which is created in the free board can be utilized for heating the scrap or slag or metal or whatever the case may be. So, the post combustion reactions are CO plus half O 2 that is equal to CO 2 and H 2 plus half O 2 that is equal to H 2 O. Now, for both these cases, or for both the reaction to occur CO and hydrogen should be available. Now, CO is produced, first by reaction between Fe O plus C or carbon plus O. These are the source of production of carbon monoxide. Then, partially combusted hydrocarbons entering with scrap, these are the two or three sources for carbon monoxide generation.

Now, hydrogen can be generated by the dissociation of the steam or the water vapour or the moisture that is present in the scrap. Now, CO and hydrogen, they can be available at the free space of the electric arc furnace. That means, above the slag. There CO and hydrogen would be available, but, carbon monoxide, it may also be available in the slag. So, that means, the post combustion of carbon monoxide and hydrogen, it can occur either at the free board or within the slag. So, typically 20 to 30 percent combustion or post combustion is attained in slag. 80 percent is attained in the free board.

Now, for post combustion to occur, what is required? Your oxygen injection system should inject oxygen at a lower speed. Why at lower speed, so the oxygen should distribute well with the exit gases. Oxygen should be there, where carbon monoxide is there. If you inject at a higher speed, then oxygen may go un-reacted and your job is not being done. So, the requirement for post combustion is just opposite to that of oxidation reaction. That means, now, what you require, you require inject oxygen at low speed. If you want to utilize the oxygen completely, then oxygen should disperse well in the free board or disperse well in the slag, if post combustion is carried out in the slag.

So, the next is oxy-fuel burner. An oxy-fuel burner uses natural gas or oil together with pure oxygen to produce high flame temperature. So, here the requirement of oxygen is different, that is, oxygen should mix with the natural gas produces a flame and that is being used in electric arc furnace. Now, the whole objective of using oxy-fuel burner is in the melt down period. After melt down period, you do not require oxy-fuel burner. In the melt down period, in order to accelerate the rate of heating, you supply an additional amount of energy through the flame. There are hard scrap is there, then flame is directed to the scrap, it cuts down the scrap and it melts, so, the melting is fast.

Now, you see, the requirement for oxy-fuel burner is different than your post combustion and oxidation reaction. You also do not require oxygen along with the fuel all the time. You just require in the melt down period and then you want to stop it. So, this is what the oxy-fuel burner requirement is.

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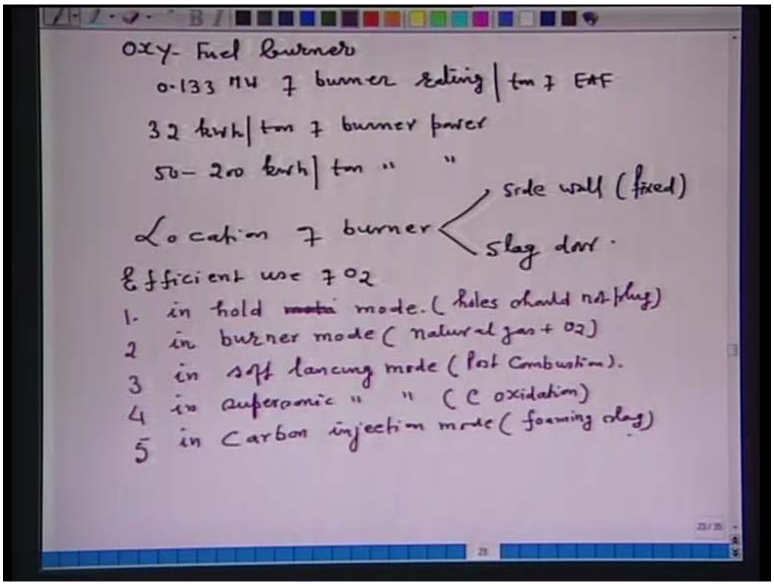

Oxy- Fuel Burners

0.133 MW of burner rating / ton of EAF

32 kwh / ton of burner power

50 – 200 kwh / ton " "

Location of burner — side wall (fixed), slag door.

Efficient use of O_2

1. in hold ~~mode~~ mode. (holes should not plug)
2. in burner mode (natural gas + O_2)
3. in soft lancing mode (Post Combustion).
4. in supersonic " " (C oxidation)
5. in Carbon injection mode (foaming slag)

Now, typically, industrial practice want around 0.133 mega Watt of burner rating should be supplied per ton of EAF capacity. Now, there are several other estimates, for example, somebody claims that around 32 kilo Watt hour per ton of burner power is required in, say high powered electric arc furnaces, where around 50 to 200 kilo Watt hour per ton of burner power is required in order to eliminate the cold spots during the heating. Cold spots means, where the electric arc is unable to reach.

Now, the fourth is the carbon injection. It is very simple. You require a pipe to inject the carbon, at the time when it is required. You know, the carbon injection may not be required all the time during the heat. We start from charging the scrap and then tapping around 2 hours, you do not require all the time, all the functions. So, you do not require all the time to inject oxygen at a supersonic speed. You do not require oxygen all the time to inject at a low speed. You do not required oxy-fuel burner all the time. You do not require carbon injection all the time.

So, that means, you have to have a burner, which can do all the functions simultaneously, without plugging the holes. Because, if you have the burner you will be installing it in the furnace, and at different point of time, different functions are to be done by their burner. So, the location of burner is very important. So, location of burner, you can have either in the side wall or slag door. Side wall burners are the fixed mounting type of burner and this slag door burner, you just take a submersible lance, go through the door and inject it and again take it out.

So, the removal and injection is easier for a slag door, but, whereas, when the burners is mounted, fixed on the side wall, then a burner is required where all the four requirements of oxygen can be met. So, typically a burner that rather works in a burner mode as well as oxygen injection mode throughout the melt cycle. Burner mode means, we are using oxy-fuel burner or you are injecting fuel. Once the melt down period is over, then you go in the oxygen injection mode, depending on the requirement of oxygen.

So, now, to summarize efficient use of oxygen require what? Efficient use of oxygen, it requires to have a burner which can work in hold mode. I am listing now, the requirement of a burner, which is to be designed to carry out all the functions simultaneously, when it is mounted, fixed on the side wall. First thing is that, the burner should be able to work in hold mode. That means what? The holes should not plug, that is important. Second, in burner mode. That means, I should be able to inject natural gas plus oxygen to create a flame during the melt down period. Third, in soft lancing mode. Soft lancing mode, means, if I want to carryout post combustion, as I have said, low speed. So, this will be when I require post combustion. Fourth, in supersonic lancing mode and that is, when I want to carryout carbon oxidation. Because, then the jet should be penetrating into the bath, so, I require a high velocity.

A burner should also be able to work in carbon injection mode. And that is, when I require a foaming slag. That is, what I mean to say from here, that I require a singular device, not 5 devices, I require a singular device which can do all my functions. And at the same time, the function which is not being performed and a hole which is being provided for that function, it should not be plugging. That is the requirement.

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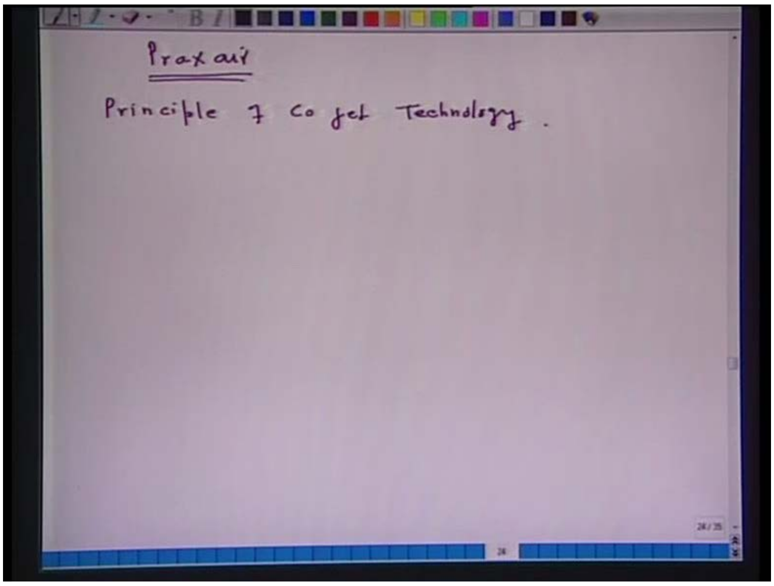

Praxair

Principle of Co jet Technology.

So, such innovative design has been developed by company called Praxair. They developed a design which can work in all the different modes, depending on the time which is required. However, the design for this burner is not available, because it is a proprietary item, but, in summarizing, I can say that these burners, they are installed on the side wall of the electric arc furnace. And these Praxair burners, they are working in several electric arc furnaces satisfactorily and the whole idea of this burner is that, they can inject in the mode in which, during the operation and electric arc furnace requires.

As I foresee, this particular injection system must have a combustion burner, where oxygen and natural gas is burned, a flame is being introduced and depending on the requirement, natural gas can be taken off or if you want to inject a carbon injection, then a carbon injection pipe can be easily inserted and so on and so forth . Not more than this design is available in the literature. But what is being done, in this particular burner is that, they employ a concept of co-jet technology. So, principle of co-jet technology.

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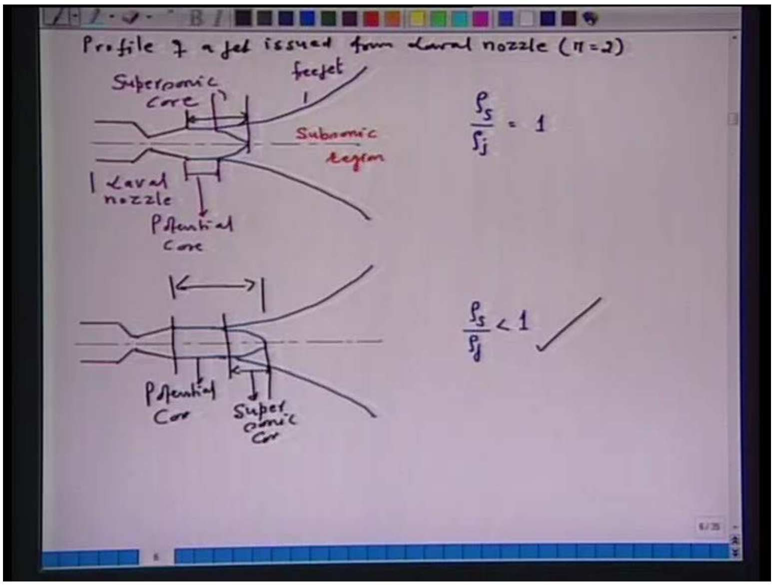

Now, a co-jet means, a jet of oxygen is coming from a nozzle at a very high speed and also it is surrounded by a flame. Now, let me illustrate what is meant by a co-jet. Now, before that, let us see, how the jet issues from a Laval nozzle or how it looks, when it is issued from the Laval nozzle. What I have shown is a profile of jet, profile of a jet issued from Laval nozzle at Mac 2. Mac 2 is, that means, a twice the velocity of sound and velocity of sound, of oxygen is around 329 meter per second at 298 Kelvin.

So, in this diagram, this is a Laval nozzle and this is the free jet. Now, this free jet is characterized by the density of surrounding divided by density of jet. That means the behaviour of the free jet is decided by the ratio of the densities of surrounding as well as jet. That means a jet issuing from the nozzle, it spreads into the surrounding and the rate of spreading depends upon what is the density of the surrounding. Typically a supersonic jet, because when you say M is equal to 2, it is a supersonic jet. Its velocity of jet is more than velocity of sound. A supersonic jet is characterized by, this is called the potential core. From here to here, this is called supersonic core and then, this is the subsonic region.

So, I am giving here, a relative behaviour when the ratio of density of surrounding to density of jet is changing. For example, if this ratio is equal to 1, this is my basis of comparison, then, this will be the length of potential core, from here to here is the length of the supersonic core. In the potential core, whatever velocity at the exit, that will be maintained throughout the potential core. In the supersonic core, the end point of the supersonic core will be where, in the jet, the velocity has attained to the sonic velocity. So, in fact supersonic core will extend from here to here. This is the total length of the supersonic core. Beyond this is a subsonic region. Now, if the ratio is equal to 1 then I have shown here, whatever the length is, potential core is this, length of supersonic core. Beyond potential core is, from here to here and total length of supersonic core varies from here to here.

Now, suppose if the ratio is less than 1, density of surrounding is less than the density of the jet. Jet is denser, so, jet will be able to diffuse much higher in the surrounding as compared to when its density ratio is equal to 1. So, accordingly, if this is my exit of the nozzle, so, you see, this is the length of the potential core, this is the potential core length and this is the supersonic core, beyond potential core and this total, we can call as a supersonic core. So, the length of potential core as well as length of supersonic core, they are larger as compared to when the exit ratio is equal to 1. That means, if my surrounding is lighter than the jet, then the rate of the spreading of the jet in the surrounding is delayed. That means, rate of the spreading is low, so, on account of which the exit velocity of the gas is maintained over a longer distance as compared to when the ratio is equal to 1.

Now, let us see what happens. So, imagine a jet of oxygen is being issued through a nozzle and if the jet is surrounded by a flame, what will happen? What is the surrounding of the jet? The surrounding of the jet is of very low density. The density ratio is far less than 1. What will happen? That will lead to a jet which will spread very very little as the jet exits the nozzle. So, now, if I create a nozzle, where in the center I allow oxygen to pass, in the annular space I let a natural gas to flow, I unite the mixture. So, the jet from this nozzle, it discharges as the oxygen jet which is surrounded by a flame, as a result of the explanation which I have given you for rho s upon the rho j is equal to less than 1, what will happen for that jet. That means, that length of the jet or the potential core length of the jet will be much longer as compared to what I have shown in the density ratio less than 1.

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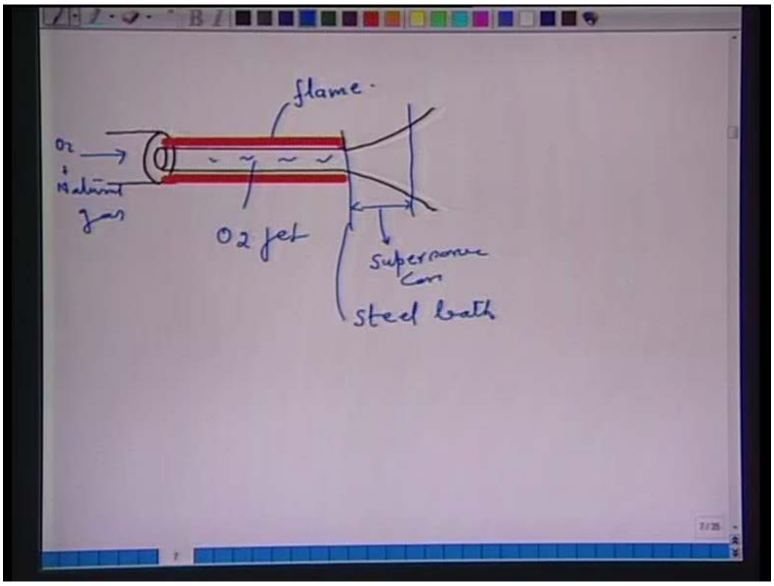

This is what I have illustrated in the next figure. Now, in the next figure, you see that, this is a sort of oxygen jet, is oxygen is discharging and this is a flame. Here, a mixture of oxygen plus natural gas. So, if this oxygen jet is surrounded by a flame, the density of the surrounding is very much low. So, you see, the length of potential core, not the supersonic core, length of potential core is very large or very high as compared to the other two previous cases. Since length of the potential core is great or large, then length of supersonic core will also be large. So, length of supersonic core will be, if I say, somewhere here, this is the end of potential core and this will be your supersonic core length, beyond potential core.

So, total length of the supersonic core is potential core plus supersonic core. So, that means, if now, I put my steel bath somewhere here, that means, I heat the steel bath with this particular jet, then what will happen? The jet will penetrate deep into the bath. On account of that, I can carry out carbon oxidation. If I do not want this highly penetrating jet, I remove the natural gas. So, the jet will behave in a similar way as that in the previous cases. So, what I have illustrated from here, that a jet surrounded by a flame, it has a higher potential core and such a high potential core penetrates deep into the bath and it can meet the requirement of oxidation reaction.

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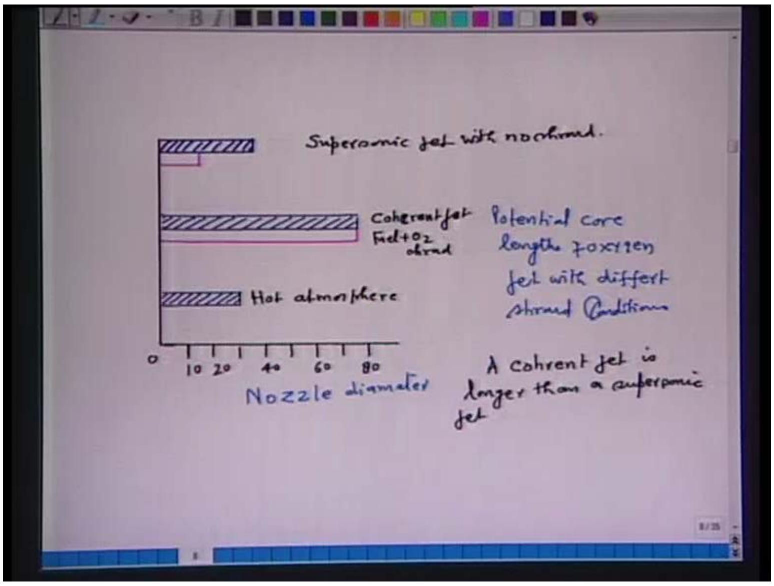

Potential core length of oxygen jet with differt shroud Conditions

A cohrent jet is longer than a supersonic jet

So, now, if I can show here, for example, these are the nozzle diameters. That means, I want to show, now, the potential core lengths, I want to show now, potential core lengths of oxygen jet with different shroud conditions. So, what you see from here, this is a jet which is discharged in a hot atmosphere. This is supersonic jet with oxygen shroud only. So, length of the potential core is somewhere at 20-25 or something. Now, here this is a coherent jet, as I explained just in the previous figure. This is a coherent jet, that is fuel plus oxygen shroud. So, you see, the length of the potential core is very very long as compared to when the jet is discharged only in the hot atmosphere.

Now, again, this is a supersonic jet with no shroud. So, what is being illustrated over here is that, a jet surrounded by the flame, that is called the co-jet. A co-jet has the capability of greater potential core, then, it will penetrating deep into the bath and it can do the job of carbon oxidation. So, these type of burners, using co-jet injection have been used by the Praxair to perform all the functions simultaneously.

Now, some of the advantages of co-jet is that, a coherent jet or a co-jet is longer than a supersonic jet, because, its ambient is a flame. These coherent jet injectors can be installed above the bath or in the side wall of the furnace to carryout effective bath lancing. So, what is being important is that, these type of coherent jet technology and its translation into the design of the burner have allowed to perform all the functions, which I have listed, for example, oxidation reaction, post combustion, oxy-fuel burner and carbon injection. Through this type of design of the burner all the functions can be made simultaneously.

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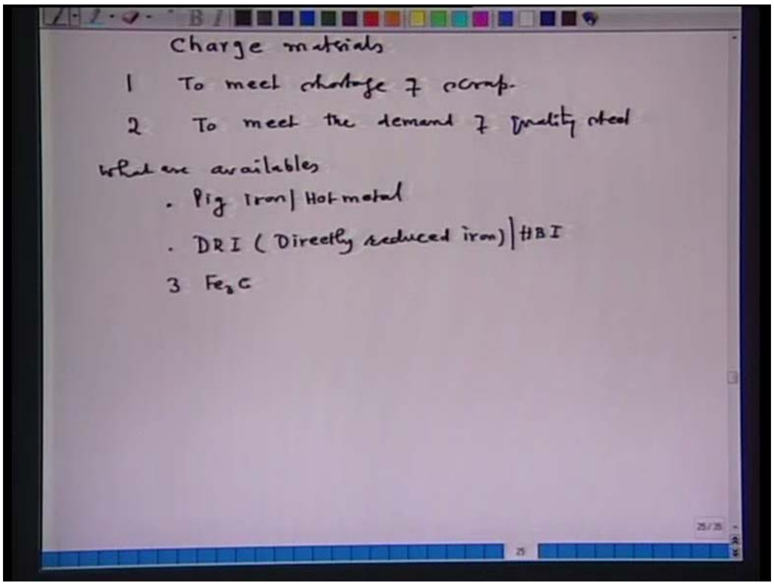

Charge materials

1 To meet shortage of scrap.

2 To meet the demand of quality steel

What are availables

- Pig Iron | Hot metal
- DRI (Directly reduced iron) | HBI

3 Fe_3C

Next is, development is the use of charge material. Electric arc furnace is started with the scrap. Today, all grades of steel are being produced by electric arc furnace. There are certain problem with this scrap, that means, availability of the scrap of high quality. So, in order to meet the high quality scrap, when it is not available, then alternatively charge material are to be developed. Now, the reason for development of alternative charge material is, one, to meet shortage of scrap and to meet the demand of quality steels.

What does it mean? That means, scraps, they contain tramp elements and as such it is very difficult to remove tramp elements, all the tramp element enter into the steel. So, those quality of a steel which require no tramp element, there you have to find scrap with a low value of the tramp element, that is very high quality scrap is required. Now, in order to combat this particular problem, alternative charge materials are developed. What are the alternative charge materials? What are available? One is pig iron or you call, if it is in the vicinity of the blast furnace, the hot metal availability.

Now, you know, hot metal contains 4 percent carbon, silicon and so on. So, now, the electric arc furnace must be able to refine, if the scrap is to be substituted by pig iron.

Second alternative charge material is DRI, directly reduced iron. Directly reduced iron, when it is produced from coal or HBI, that is, hot bricketed iron when it is produced from natural gas and then it is bricketed. Third is iron carbide Fe 3 C. Use of pig iron, now, the maximum is a limit. You cannot use more than certain percentage of pig iron. Why, traditionally electric arc furnace was developed to melt the scrap only.

No refining was envisaged. If at all refining was envisaged, for a very little amount. Now, with the increasing content of pig iron, you increase the impurities also, as carbon, silicon, manganese and so on. So, now, you have to refine it. So, if the refining time gets long, then your productivity will be affected. So, the maximum percentage of pig iron that can be tolerated is of the order of 30 percent, not more than 30 percent. Hot metal, it gives benefit in terms of productivity, tap to tap time and so on.

Now, as regards the directly reduced iron, this particular aspect, we will take tomorrow in our lecture.