Steel Making

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Module No. # 01
Lecture No. # 02
Introduction

So, we have discussed little bit about the oxygen steel making process. I am giving an overview of steelmaking in this very introductory lecture. So, let us now continue with our discussion on primary steelmaking; I will give you some idea about EAF, which is again a dominant steel making technology.

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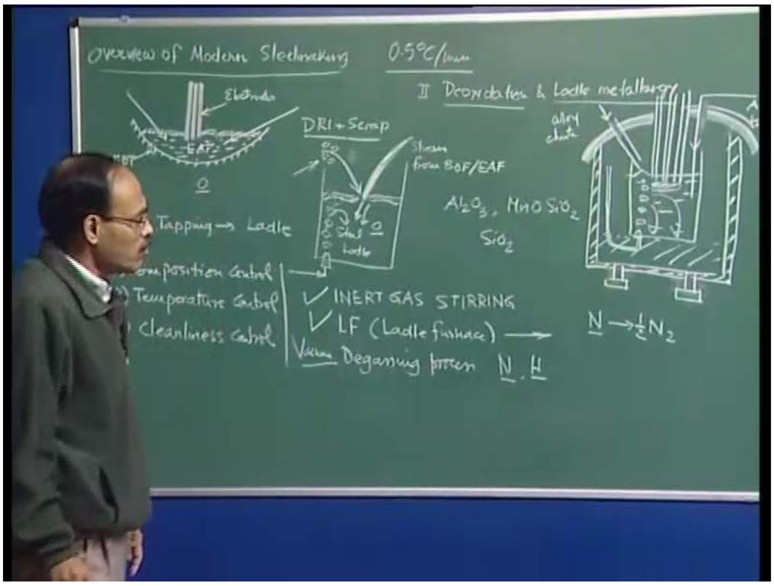

Now, this is a schematic view of an electric arc furnace and arc furnace. As I have mentioned, arc furnace steelmaking constitutes about 34 percent, which is the share of about 34 percent of the globally produced finished steel.

Now, three features in the electric arc furnace is important; this is an electrode; this an AC electrode arc furnace, basically in DC between DC and AC what is the distinction? The DC is the arc is stuck between the metal and the electrode, and here the arc is stuck between the electrodes itself, to have the arc furnace, the slag layer here, the electrodes here. And a modern day electric arc furnace is keep this what is known as EBT or in eccentric bottom taping. So, it is a cap hole basically, so the furnace is stilted little bit and then the material is tap a ladle.

What constitutes the feed of an electric arc furnace is primarily DRI plus scrap. So, plants which use electric arc furnace basically relay on scrap, which could be domestic scrap, because still plants produce lot of scrap. In house scrap or the scraps may be produced from the market, lot of scraps for about 7 to 10 days are typically in holding… there are huge scrap yards, scrap starting yards and so on.

The DRI is the typically brought or may be produced within the plant itself; most of the time the DRIs are procured from outside plan. So, the DRI and the scrap are basically the iron barring material in electric arc furnace.

Now, today, almost all electric arc furnaces have oxygen injection facility either through the Co jet technology, so this is not basically submerged jet; this is an impinging jet at an end of from all sides of the furnace and there are also came situations in which there are bottom stirring, of course through the bottom argon gases are introduced.

So, otherwise, if you do not have gas injection, there is basically not much source of agitation in the arc furnace and therefore, the arc furnace duration of the processing or making steel is far more there it is in the case of oxygen steelmaking. Oxygen steelmaking, there is intense amount of stirring, formation of slag metal, emulsion and so on. So, the rate of reaction is very fast.

On the other hand, in the absence of any significant oxygen stirring or oxygen injection, the duration is typically is expected to be typically much longer. And in any case, the rate of steel production in EAF is much lower than it is in the case of… Oxygen steel making process, the bath is shallow; the starting is not efficient and so on, but progressively, the duration of steel making is being continuously reduced by making innovations like, bottom gas injection as well as oxygen lancing from the topper employment of Co jet technology.

So, once you have charged DRI and scrap and then, the arc is stuck; heat is produced and melting goes on, oxygen is supplied and then, simultaneously lime is also added, in a slag is formed again; as I have mentioned EAF process is also run under basic conditions.

So that lining, refractory lining, is basically a basic material, and then, for about 60 to 70 minutes depending on the size of the heat, the refining goes on and at the end of the refining process what happened is, at the material is going to be tapped.

Now, whether you are producing steel in electric arc furnace or you are producing steel it through BOF, you must realize because of oxygen injection, the material or the metal now contains and this I have also indicated, lot of oxygen. And following the primary steelmaking, as I have discussed in the last lecture, the next step is the step two, which is de-oxidation and ladle metallurgy.

So, removal of dissolved oxygen, which can go up to 200, 400, 600 ppm depending on the duration as well as the rate of oxygen injection, the state of the metal and so on. We also should note that, when you tap the molten metal, so following steelmaking, we have the operation which is called tapping and tapping is done in a ladle, which is basically a cylindrical shaped, marginally tapered cylindrical vessel and the material from molten metal, from arc furnace or oxygen steelmaking furnace are going to be emptied into the steel ladle. So, this is stream from BOF or EAF. And I have also mentioned that, we do not want to carry out the oxidation here; even though carbon is now write, silicon has been removed.

I would like to also draw your attention to the fact that, because we are using pig iron, we are not using pig iron here; we are using DRI and scrap. So, the process cannot be autogenous. In BOF steelmaking, we have carbon, silicon, phosphorus and burning of or oxidation of carbon, silicon, phosphorus produces the necessary heat. In this case, we have very little amount of carbon present, DRI make on 10 some impurities it may contain primarily silica, alumina, etcetera.

So, very little amount to heat is going to be produced from the scrap or DRI or there is very little scope of oxidation of metal as here. So, as a result of which unlike BOF process, we do not produce heat in electric arc furnace. And that is why in electric arc furnace, we supplied external energy into the furnace and that is why a process here really is not autogenous and we need external and then, as the name suggests, the external source of heat is the electricity here.

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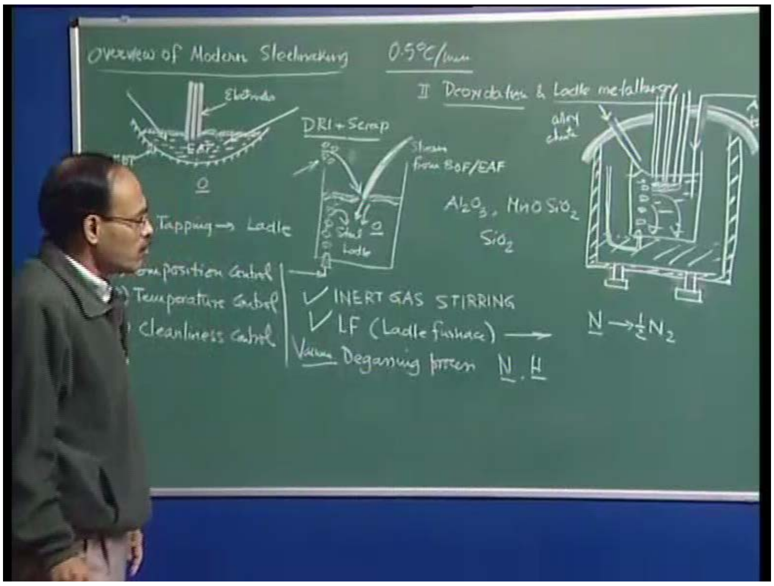

Well coming back again to the tapping is that, we will empty the furnace following steelmaking and empty the furnace into a vessel, which is a marginally tapers cylindrical vessel; this is again (( )) dolomitic lined vessel and we can empty with furnace with 5 minutes, 3 minutes something like that; the rate of taping could be about 16 tons, 20 tons per minute depending on the diameter of the nozzle. Beyond this process, we must also know that lot of the material contains lot of oxygen in the furnace.

So, the driving force for oxygen transport is not that much; so we have lot of oxygen here; we have some oxygen here; yes, oxygen do get transferred, but primarily nitrogen gets observed by the taping stream. So as a result of which, when the ladle becomes completely filled, it contains lot of the hydrogen as well as oxygen and these are to be eliminated. The first very step beyond the primary steelmaking is de-oxidation and then comes the ladle metallurgy or the secondary steelmaking and we must note here, that we do not want to carry out de-oxidation operation in the BOF or EAF, because we would like this furnace to be used not for de-oxidation, but for making of steel.

The economics of steelmaking demands that processes such as de-oxidation, etcetera be carried out in a vessel beyond the primary steelmaking reactor such as the BOF and EAF and that is why today, in most steel plant, we carry out de-oxidation in the primary steelmaking furnace, de-oxidations carried out.

So, during taping we also ensure that because we want to follow taping, since we want to eliminate oxygen; we would ensure that the carriers slag, which is high in oxygen potential, how much? As I mentioned, if you remember 20 to 25 percent, may be 30 percent also depending on the extent of oxygen blowing.

So, these slag, we really do not want to in the ladle, because we are going to deoxidize the bath and you may should be able to visualize, because if this slag contains lot of oxygen, because this contains 30 percent oxygen, if it is comes here in that the efficiency of deoxidizer utilization is going to be much less, because the deoxidizer is going to be heated by this slag itself.

So, we would like the deoxidizer to remove oxygen from the bath, which is dissolved in steel. So, therefore, the common practice is during taping operation, when the metal comes, we add; now I will remove this and I will said all deoxidizers additions and what are these deoxidizers? These deoxidizers are basically elements having greater affinity towards oxygen.

What are those elements? For example, I can say we know aluminum has very high efficiency or affinity towards oxygen, how do you know that? If you remember your thermodynamics, your Ellingham diagram load is the position of the line of a metal oxide, greater its stability and greater is its affinity towards oxygen.

So, you refer to the oxide Ellingham diagram and then, you can find out which are the element, which has greater affinity towards oxygen than iron, because oxygen is dissolved in iron, now you have to remove it. So you require an element which has greater affinity towards oxygen than iron has and in this context, aluminum, silicon, manganese, etcetera sulfides, and selenium also to some extent.

So, therefore, all those deoxidizer's additions in lump form, they are added into the ladle as the taping goes on. So, it is a simultaneous process; addition of deoxidizer as well as a taping. And already in the ladle before taping itself, lot of siliceous materials are added.

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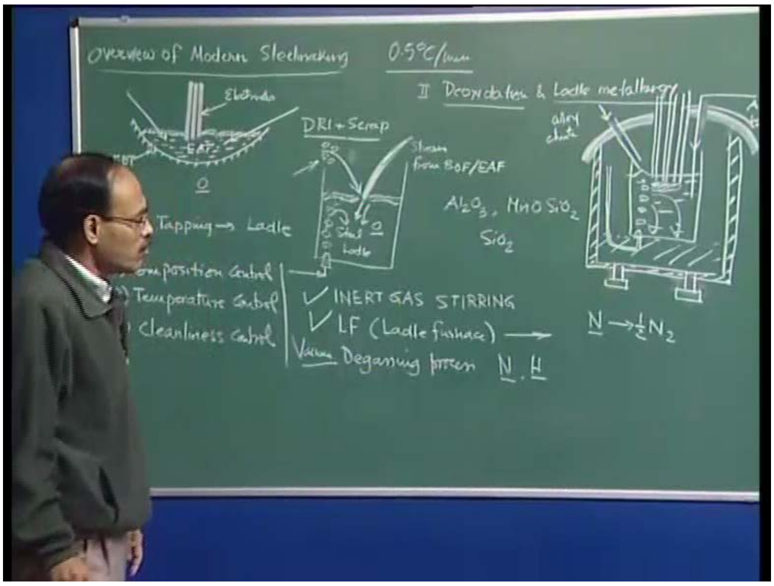

So, these materials deoxidizers will react with oxygen form some oxides; they will react with siliceous materials, par, etcetera and produce a slag layer basically silicates and that silicates are going to float at the free surface and prevent any preferential heat loss through the free surface, because the oxide layers here will provide some barrier for the escape of the heat to the surrounding; otherwise, the metal is going to get a really chill.

Now, these deoxidizer elements because they are lighter, there if you visit a steel plant, you will see they are projected in the vicinity of the jet impact zone, because it is here that the flow is downward and this try to downward flow try to catch the particles and take them down; as a result of which the deoxidizer elements very (( )) deep into the bath and then, reacted dissolve melt and react with dissolve oxygen. Otherwise, if they are projected in this particular region, they will immediately come up to the surface and here they will come in contact with atmospheric oxygen giving rise to very low yield or low efficiency of utilization of the deoxidizer.

So, one can do calculation and find out how much of deoxidizer elements typically has to be added in order to reduce the level of oxygen. So, we would like to have oxygen remove and oxide deoxidization products are may be manganese, silicate, you can have silicon, diasilica and all these de-oxidation products we will not like to get inside steel.

So, we would like to the de-oxidation products to float out. The de-oxidation products, if there interact in steel, if they remaining steel, we say they are inclusions. What type of inclusions? They are endogenous inclusions and we do not want any inclusions in the steel therefore, not only that oxygen has to be removed, but the resultant products of de-oxidation must also be eliminated. These products are lighter than steel therefore, they literally have a tendency to rise to the free surface, but note that if because de-oxidation these are new products, these are different phases.

So that means nucleation and growth mechanism is involved in the process of de-oxidation; aluminum will dissolved into molten steel, then oxygen react with dissolved oxygen form alumina and alumina is a separate solid phase, so here comes the issue of nucleation and growth. So, alumina can nucleate at various locations depending on where aluminum is reacting with oxygen. And we can have a wide range of sizes of alumina inclusions, alumina particles forming in the steel and these particles, if they are too small they are rise velocities very weak, because we know the raise velocity of your particle we can get some idea by using Stoke situation. So, if we use Stoke situation, we will find if the particles has 40 micron size, 80 micron size, they raise velocities of the order of millimeter per second.

So, therefore, they will take even still long time to rise. Therefore, what we want? We want that de-oxidation products should not be solid; they should be liquid such that two liquid particles can coagulate, form a bigger mass and that bigger mass may have a higher rise velocity and as a result of which they can get to the slag metal interface; you know very rapidly.

So, why we have added deoxidizer elements directed them to the correct place and as a result of which as the ladle is being filled, de-oxidation goes on, slag is formed, inclusion float is on takes place and as the ladle is completely filled by the time that de-oxidation is complete and the level of oxygen in the furnace in the ladle is very low.

Note that right from the stage of taping, we have argon is injected into the ladle. So, you have argon bubbles raising and this basically gives raise to some kind of a argon bubbles, raises it is a gas injection through the liquid steel, thus the argon bubbles raises, then what happens? Because of the buoyancy of the argon bubble, liquid also tends to rise and then recirculates in the system.

So, therefore, we want to stir the contents of the ladle, of course there is a stirring, because of this, jet is coming with a very high velocity so there is a relevant stirring, but after really the ladle is filled, there is no jet. So, the current will now die down, but we do not want that to happen; we want always some amount of stirring for thermal and material homogenization.

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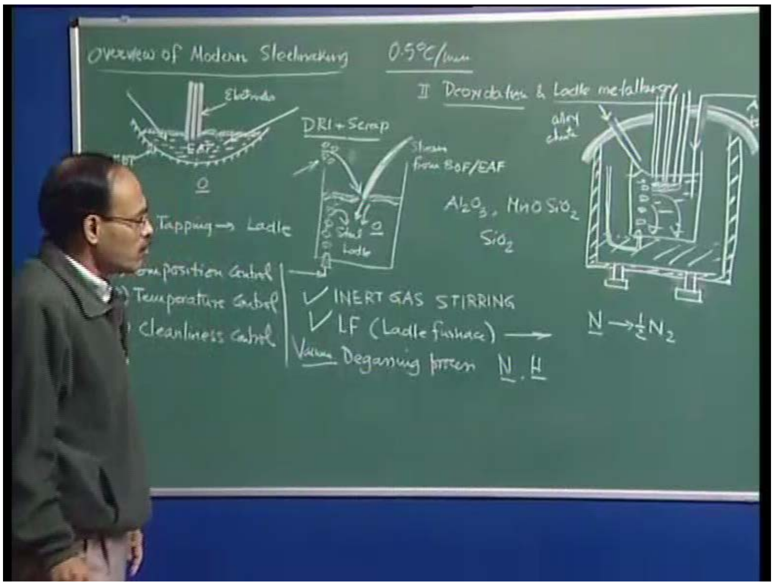

So, we use a porous plug through which we inject some amount of argon and this argon is deliberately introduced right from the begging of the taping, because otherwise what happens is molten metal can solidified around this and as a result of which it may become difficult to inject argon gases.

So, right from the beginning of taping argon can be introduced at a smaller rate. The essential objective is for all subsequent processes of secondary steelmaking, we will require inert gas or argon stirring gas it is going to be here.

So, at this particular stage, the ladle is being furnaces taped into the ladle, ladle filling is complete; de-oxidation is carried out and the ladle is now move to the secondary steelmaking.

So, if you visit a steel plant, you will see that at that particular point as the ladle is moved or the ladle is lifted from the taping area, you will see that the ladle is the bottom of the ladle is connected through a host pipe and that pipe basically is the argon feeding pipe through the porous plug.

Now, we talk about ladle metallurgy. So, the objective of ladle metallurgy is composition adjustment, composition control, temperature control and cleanliness control, these are the three primary objectives of ladle metallurgy steelmaking.

Now, the steel that we have here as I have mentioned or as we have seen it, may contain lot of alumina particles still within the melt itself; not that each and every alumina particle has floated up; it may contain lot of dissolved nitrogen; it may contain some amount of sulphur, which is not acceptable to the customize.

So, therefore, the composition at this particular stage as ladle is being lifted from the taping area is not right; we cannot cost this steel, remember we have deoxidized steel, but the composition is not right we have to have further composition adjustment and of course, when you are making an alloyed steel, obviously different rates of steel has been made in steel plants, so you have to make some allowing additions and so on. So, we will have to adjust now the composition of the steel as per the requirement of the customer.

In the process of cost composition control, we must be knowing that, if we want to add allowing additions, we will add cold additions. So, with the cold additions, there is going to be some drop in temperature, because of the melting; there may be some heat of mixing, heat may be produced.

So, at thermal readjustment may be necessary. So, there may be a temperature drop in most of the cases and therefore, we have to over-win that loss in temperature somehow, such that as the material following, ladle metallurgy as the material goes to the continuous casting or the casting bay, we have the correct temperature.

So, the final stage of steelmaking which is the continuous casting today, and when the ladle brought to the turret, turret means, which is the place, where the ladle is kept about the tundish and where from material is fed into the tundish and from the tundish into the mole.

So, when you bring that ladle in or place the ladle on the turret, there is no scope for any further adjustment of composition; there is no scope for any further adjustment of temperature; there is no scope for any further adjustment of temperature cleanliness; cleanliness means, we are talking of inclusion control.

So, in the during the ladle metallurgy steelmaking itself, we will not only you know do composition adjustment; we will not only do get to the right temperature, but we will also control the inclusion counts in the material such that, when steel is brought to the turret, it has absolutely no question regarding either of the or any of the three issues. And that is why it so important for us to control the secondary steelmaking or ladle metallurgy steelmaking processes.

So, effectively that we can deliver material with composition because for example, if you cannot mid composition correctly, then what is going to happen?

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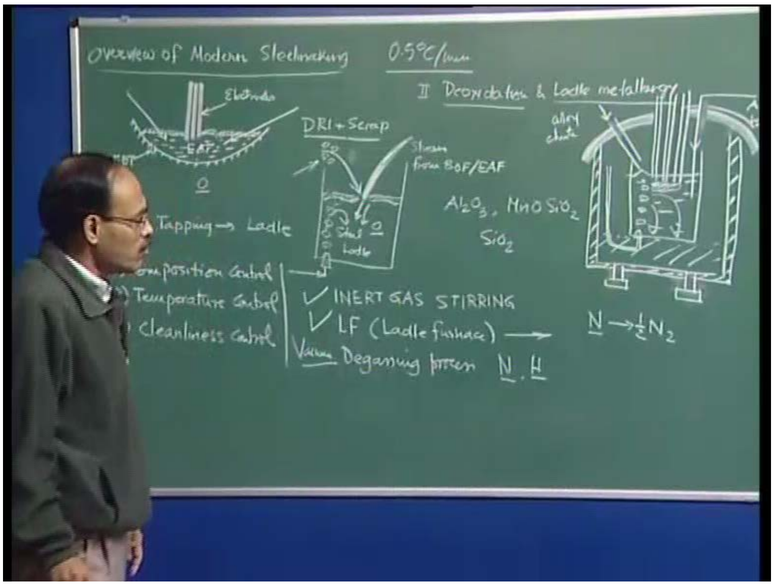

We are going to produces steel, the customer is not going buy, because he is going to say that look, I ask for this composition, your composition is different from mine and it is too much of hydrogen, too much of nitrogen, I am not going to buy it. So, the material gets rejected. If your temperature control is not correct, that means, you have not been able to bring the ladle and the turret at the right temperature, you may have many operational problems. You make your If your temperature is low, you have a cold heat and cold heat means, you have to premature your freezing, everything stops. If you have two larger temperature or two larger super heat, you have problems with the cost structure; you have problems with the mold super heat.

So, you require very tight temperature control in order to cost molten material steel through continuous casting in a seamless manner. And finally, cleanliness also a customer governed issue. The customer will demand most of the time that the steel be clean and unless, you have been able to produce clean steel and nobody is going to buy our steel so that will also cause significant amount of rejection of steel. So that is why the entire secondary steelmaking, over surround these three issues and there were variety of secondary steelmaking processes, which are today practiced in order to achieve either of any of these three objectives or fulfill any of these three objectives.

Now, the first thing to note about secondary steelmaking or ladle metallurgy steelmaking is that the duration of ladle metallurgy steelmaking could often be more than the duration of primary steelmaking.

The size of the ladle is same as the capacity of the electric arc furnace or capacity of the BOF. So, one heat is stepped into one ladle itself; so the furnace capacity is 130 ton; the ladle capacity will also be 130 ton.

Now, this ladle is going to be kept with a gas injection, which is a common feature of ladle metallurgy steelmaking. All ladle metallurgy throughout the ladle metallurgy steelmaking process, will have argon gas injection to the melt and you will see later on, when you talk about the fundamentals of steelmaking, that steelmaking processes are mostly mass transport control heat and mass transport control and therefore, we require some convection current in the system and therefore, to generate that convection, gas is introduced and the stirring is actually buoyancy driven.

So, the convection current that we generate is because of the buoyancy of the gas itself; gas injection by the by ensures the cheapest mode of stirring in such system and because we are talking of high temperature system 1600 degree centigrade. So, this is a very efficient technique of introducing stirring in the system in steelmaking vessels.

Now, we have secondary ladle metallurgy steelmaking and three objectives are to be fulfilled. And as I have mentioned that a variety of processes are there and we have inert gas stirring; this is common to all ladle metallurgy steelmaking techniques.

Now, following that, we have LF or ladle furnace, this is again sort of an arc furnace type scenario. So, what happens? The ladle, is as the gas is being injected, because as I mentioned gas is continuously being injected; so the ladle is lifted may be or brought to the LF station, which is called the ladle furnace station and what it basically does?

So, we have a ladle here; so the ladle is brought or lifted or sometimes it may be kept in a bigger container also; it will be immediately clear to you and this container may be at basically on wheels, so I should think write it; show it like this; so wheel section should be… So, the entire thing is on rails and the ladle is moving and of course, I have the tube here, which goes and introduces gas into system.

So, as the ladle which is filled with molten metal is brought to the LF station, then LF station basically, that if you go to an LF station you would not see much apart from a big transformer and the reflex structure and you can see that the electrodes are hanging from that.

So, the roof is attached to an arm and as the ladle is brought in that container, the arm moves and the cover comes and the ladle is now covered and through this, the electrodes are lowered; so it is again an arc heating basically. So, this is the cover; this is the ladle cover; so this the entire roof with the electrodes are attached to an arm, which is going to bring over the container and then, once it is shield here, we have arcing started, the high voltage is fed in to the electrodes or power is started and then, arcing starts and trough this arcing the material gradually mix up heating.

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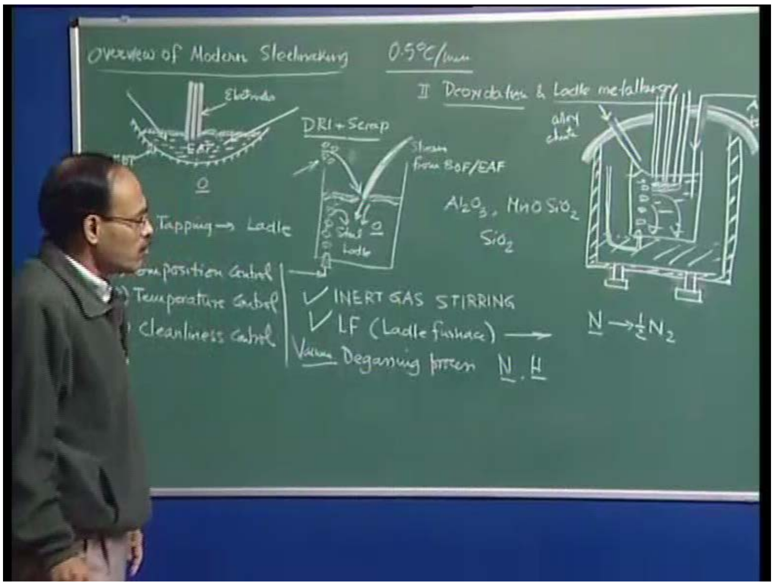

Now, during arching, because we want significant amount of temperature can be dropped 40 to 45 to 50 degree centigrade during the taping operation itself. Now, we are going to adjust the composition; we are going to, may be add allowing additions; we may add…

some times what happens is, we may do carry out further de-oxidation also; we can have aluminum wire feeding also into the ladle for de-oxidation purposes.

So, therefore, also we can have; this could be an alloy chute through which all allowing additions are going to be introduced and as I have mentioned, melting chemical reaction, melting of the allowing additions, these are all going to consume heat.

So, beyond this temperature drop of 45 to 50 degree during taping, may be depending on the duration of your taping this could be even 80 degree centigrade. So, I am just talking with respect to a typically a small scale steel pants, small size ladle in the 50-60 term size heat that the temperature drop is about 45-50 degree centigrade, where material is drained at about 15 tons per minute or so.

Now, beyond that temperature drop because of these cold additions, we are going to have temperature also temperature drop and so we want to change the chemistry composition and at the same time, we want to pick up the material also and that is what is being facilitated in the ladle furnace itself, which is shown here.

So, we put in power and what does this gas stirring do? The gas distributes, induces velocity filled in the system, stirring in the system and as a result of which, the heat which is produced in this particular localized and this heat is going to be removed and distributed all over the system.

So, the gas stirring essentially enhances the temperature and composition homogeneity, it enhances mixing in the system itself. So, this is all the time in most of the steel plants, in ladle metallurgy, this is a common process which is going to be used in ladle metallurgy steelmaking process. Now, this is the essential component inert gas stirring and then, ladle furnace, after this ladle furnace you can continue to put in the gas, then you can lift the ladle and take it to the turret.

Now, depending on what is the specification of the customer, you can have a variety of other processes. Now, if you think that well, look I have that too much of nitrogen; may be customer is not fussy about nitrogen and hydrogen. So, if I have mostly you know, the allowing additions and oxygen the level correct, I can sell the market.

So, beyond this, once the correct temperature is achieved, once the composition is adjusted, you can take it to the turret and begin the casting process. On the other hand, if you say, now my customer is very fussy about the level of sulphur; the customer is very fussy about the level of hydrogen, nitrogen, then a series of subsequent process is going to come.

Now, one such process is the degassing process. We have various types of degassing processes, which will study in detail when you talk about secondary steelmaking or you know ladle metallurgy techniques.

Now, this degassing process - the basic objective of the degassing process is that we want the dissolved gasses like nitrogen, hydrogen to be removed. And we know that this sort of a reaction- the degassing reaction- are going to be facilitated under lower pressure, because lower is going to be the pressure, more will be the tendency to go in the forward direction. Therefore, the degassing process is carried out under vacuum and therefore, most often we say that these are vacuum degassing process.

Note that, if I require vacuum degassing process beyond ladle furnace, then I am going to spend some more money, some more time. So, therefore, as more and more treatments are going to be given to steel, the cost of steel is also going to be produced or increased. So, if I take steel from LF furnace to cost and or then LF subsequently degassing and then, take this steel for casting the degas steel is going to be far more expensive than the LF treated steel. Because the simple fact that I have spent more money, more resources so I would require more money or demand more money from the customer itself and also the specification is far more stringent and the quality of steel is far more better.

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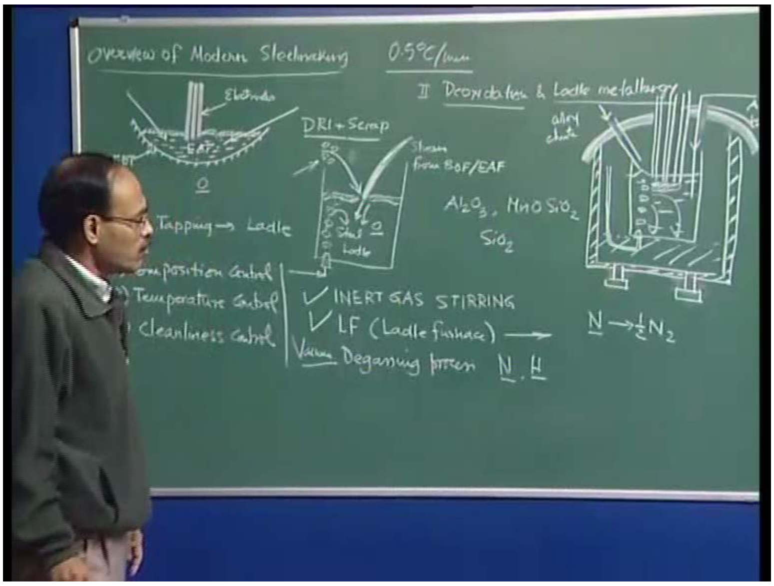

So, therefore, more and more treatments we had; this is always common; this is always common; these are the two essential components of inert gas ladle metallurgy technique, but the subsequent treatments are optional; they are market driven that depend on what the customer has demanded from you.

So, we are going to take subjects steel and that is why, this is as I said why I have drawn this in a container box, which is moving in way? Because now, after the ladle treatment, the temperature of the steel, we must also remember here one thing that, after following ladle treatment, LF treatment, the making of steel is not always complete; we may not take the steel for casting.

So, there may be subsequent operations. Degassing process, for example, there may be injection metallurgy processes for another 20 minutes; degassing processes could be about 30 minutes and again in this 30 minutes and subsequent 20 minutes of injection process, the temperature has to be will be dropped because of radiation losses.

And then finally, once degassing vacuum degassing is over; once injection metallurgy is over; you would transport the ladle physically to the turret, the ladle sits there in the turret itself and all this can take again 15 to 20 minutes of time and during that time also, the temperature of the material can drop and it can drop often if the ladle is covered about 0.5 degree centigrade per minute.

So, all this calculation one has to do, that how much of temperature actually is going to be dropped and then, we can say that well, I will do the heating and bring the temperature in such a way that with subsequent processes, whatever heat is lost and in transportation of the ladle to the turret and holding period, whatever temperature is dropped you know, the temperature here is taken to such a way well that it will compensate for the drop and come up with the right level, which is required by the casting operator or the costar operator.

So, therefore, some engineering calculations are necessary that to what extent we can take the temperature? Here for example, we just go to the casting bay immediately from the LF, we would say may be 5 degrees more than what is required by the custom operator?

If it has to go through by vacuum degassing process, if it has to go through injection metallurgy processes, then I would say may be 30 degree is more or may be after vacuum degassing processes, we have to bring it that to the LF, because there may be significant amount of temperature drop itself.

So, to and fro moment may also be there and all these are going to consume time and that is why I have mentioned, that ladle metallurgy techniques can actually take more than the duration of the primary steel making process.

So, we have circulation degassing, tank degassing processes; this we will do later on in greater detail. But vacuum facilitates removal of gases and that is why we treats steel under vacuum and the removal of gasses is facilitated under vacuum and that is why the degassing techniques in steelmaking are known as the vacuum degassing techniques.

So, it is clear now, that I can bring move this entire thing on the container, because this is the container that I am talking about in which the ladle is there. So, I can once the LF treatment is over, the roof is lifted up; the ladle is still sitting in that bit vessel and the vessel is moved from on to the rail and it is taken to the vacuum degassing station.

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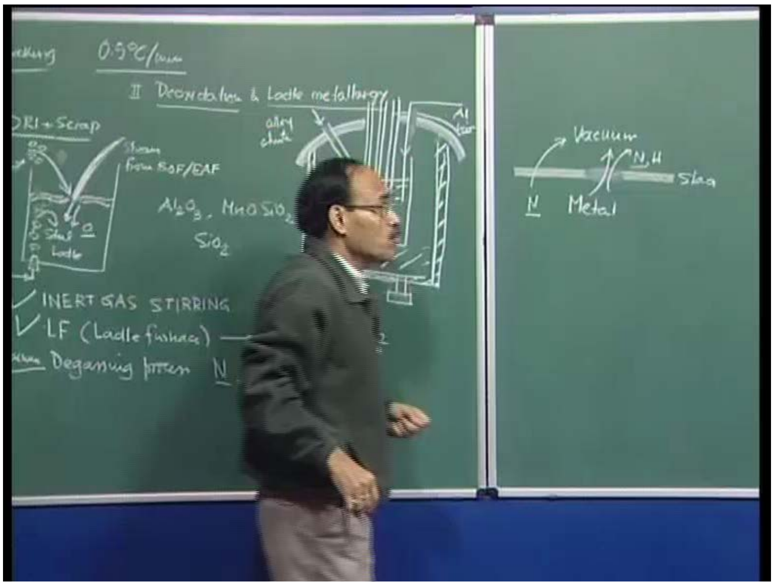

And in the degassing station what happens is, that a fresh cover now the ladle from the top is empty; so fresh cover - air tight cover - is brought and the suction started and as a result of which you know, the vessel becomes depressurized and you continue to inject argon and you must remember that, we have a slag layer here and the metal is here and the vacuum is here and we want nitrogen from here to go to nitrogen here.

So, we want some opening here; I do not want the slag and what creates this opening? This opening is created by the gas injection or the inert gas stirring. So, the argon gas rises; it pushes the slag and brings the molten metal in contact with the vacuum and it is through this, that nitrogen, hydrogen will go into the gas phase.

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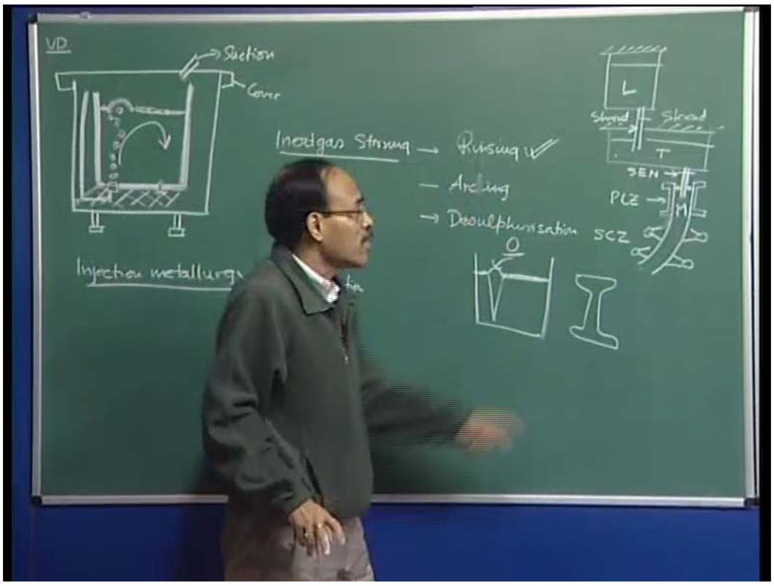

So, this is the same ladle I have shown here; so this is the rail; this is the wheeler the container and now, we see there is a physical cover; the suction is applied; we have a low pressure system and we have inert gas stirring continuing and as a result of which what happens, through this port area - slag high area - what happens, the material comes directly in contact with the vacuum and then, the removal of gasses is facilitated.

So, basically we have a suction period; so we depressurize the system for some time and then we hold it, so holding period another 15 minutes, so may be 30 minutes for 100 ton ladle or something like that. So, time degassing this is basically a time degassing process. You will know about circulation degassing later on, but the essential feature here is that we continue to start the ladle as we depressurize it for 15 minutes, we depressurize the container, bring the pressure down at what pressure? May be 1 mille bar or even less than that and then, we vigorously purge argon and more argon we purge in, more bigger area is going to be created; more efficient surface area is very important here, because it is a hydrogenous reaction. We have nitrogen dissolved in the metal and nitrogen going to the vacuum so this is going to take place, the reaction at the interface. You will know more about hydrogenous reactions later on when you talk about the fundamentals and hydrogenous rate of hydrogenous (( )) reactions are controlled by the interfacial area.

So, more is the argon flow rate, more bigger is the opening; better is the contact or the melt with the ambient atmosphere and therefore, more is the transfer of the dissolved gases from the melt into the (( ))

So, we have inert gas stirring and in inert gas stirring, we have a… Our objective is only to mix the material, suppose we have added and composition adjustment, everything is done. The final stage, now we want to take it to the casting bay what we do is, rinsing and the flow rate at rinsing is very small; we do arching also with inert gas stirring; we will be do arching and we can do desulfurization also; we can add gas stirring by controlling the flow rate.

So, before VD also when we were doing arching, followed by arching we can carry out some desulfurization, blow, add some line blow lot of argon, intermix slag and metal and thereby facilitating desulphurization also.

So, following VD, after VD, we can have injection metallurgy and the purpose of injection metallurgy would be to control the inclusion morphologies, to control to fine-tune the chemical composition, calcium injection is very popular Ca injection. So, this is actually a code wire injections; calcium in the form of code wire is injected deep inside the melt and this calcium becomes gas under steelmaking conditions; it is a low vaporizing temperature.

So, therefore, the calcium vapor dissolves into steel and molten calcium may react with oxygen; it can react with sulphur; then it can form complex compounds with alumina inclusions and so on and thereby, help, produce a liquid inclusions, change the composition of the inclusions, clean steel in terms of its chemical compositions particularly sulphur, etcetera and so on.

So, these are various techniques, which one would use. Calcium injection again is a very expensive affair; calcium is a very expensive element to add into steel, so this also going to add cost of steel on a part term basis to a significant extent.

So, we have inert gas stirring; we have LF practice; we have we have LF ladle furnace treatment; we have injection; we have vacuum degassing and we have injection metallurgy. A series of operations can be carried out and the entire objective as I have mentioned of ladle metallurgy is to control the composition, is to control the temperature is to control in the cleanliness. And once all these things are over, the final stage could still be before I take the ladle in to the turret is the rinsing operation. Because now, I want to finally homogenize the steel, there should not be any particulate gradient; here is larger concentration, smaller concentration, no, we do not want that kind of a scenario; larger temperature, smaller temperature no, we want a new form temperature and new form concentration.

So, therefore, we would like to gently start the system and when you gently start the system, we do not want any slag high area, because if you have slag high area, then the ladle is no more, it is opened.

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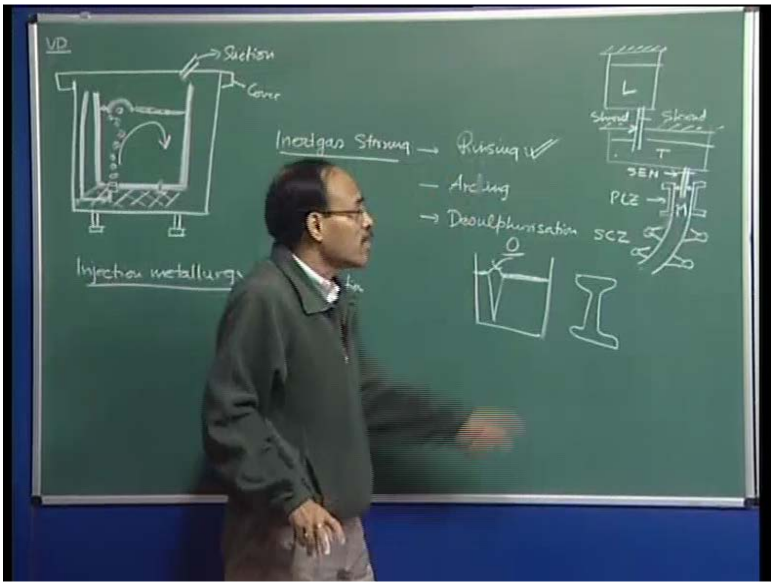

So, we have oxygen here in the atmosphere. So, if you create an opening here, this is a slag cover; we will have re-oxidation. So, a very mild stirring is necessary in order to remove that temperature and composition in compositional homogeneities and that is call the final rinsing operation as the ladle is being taken to the continuous casting bay.

So, at that particular time, the final rinsing operation is completed; the ladle is placed on the turret and before that, we disconnect this host and now, you know there is, of course I have not drawn it here; there is a well here, through which molten metal will flow out.

So, porous plug is disconnected the host is disconnected from the porous plug and then, the ladle is sitting on the turret and another slide, gate is opened and through this well, the material goes into the tundish and to the mold. As I would like to show you here through a simple sketch.

So, we have the well here and through the well and this is the tundish and though the tundish, we have this is a continuous casting mold; this is schematic drawing.

So, we have a flow control device here; we have we have to have a physical cover here; this is the physical cover of the ladle; so there is similarly, a physical cover of the tundish and this is as I have mentioned, we have processing and transfer operation, this is again a transfer operation from ladle to tundish; from tundish to one and these transfer operations we must control; we must ensure that the quality of steel is maintained, it does not come and contact with the surrounding atmosphere and that is why we want to minimize the temperature laws, that is why this is a physical cover. We want to minimize the contact of molten metal with combined atmosphere, so we have a physical cover and the ladle in the mold.

This is the shroud; shroud means you have a stream, which is following into the tundish and around which we put a pipe or a tube and in that tube, argon gas is circulated. This is an externally fitted tube at the base of the ladle; this is an ACN submerge entry nozzle. So, we have a melt here- melt level; so this sub CAN, which is attached to the base of the tundish, what is tundish? You will study later on, but this basically, is a distributor of molten metal between ladle and the mold.

So, we can have the tundish can fit one mold or it can fit a variety of molds and this will be clear to you, when we study a ladle metallurgy as well as tundish metallurgy later, but for the time being, it is sufficient for you to note that tundish two tundish will be able to feed one or many molds simultaneously.

So, it is basically a distributor of molten metal, but apart from that, it has important metallurgical function such as inclusion, flotation, temperature, controller, etcetera which will be discussing later on.

So, the ladle is sitting in the turret; the slide gate is opened here and through the shroud, molten material is fed into the tundish and from the tundish, it goes into the melt. So, this is the ACN submerge entry nozzle and this is the shroud and what is shown here is the prime is the continuous casting.

Now, depending on the plant, we can produce bullet, bloom or slag. If you have a bullet cost, bullets are small 4 inch by 4 inch cross section square cross section; blooms could be 10 inch or 12 inch by 12 inch; blooms could be round also, 1 feet diameter huge cylindrical shape you know rods, I would not say rods, but cylindrical shaped cost products coming out and then, we have slabs, which could be 200 mm thick or 20 centimeter thick and this could be about 1800 mm wide.

So, we can produce many such devices also; we can produce I Beams also, which is an Neon net shape casting process something like this; these are used in structures. So, all these products can be made to continuous casting and we have a copper cold mold here and then, we have secondary cooling zone or the spray cooling zone, we will study extensively the continuous casting techniques.

So, the mold is water cooled; so some materials solidifies here and then, the solidification is completed in the secondary cooling zone. This is secondary cooling zone and this is called the primary cooling zone that is the mold. And in the secondary cooling zone, we have spray of water, which is injected on the surface of the solidifying steel wheeler or the slab and as the result of which steel becomes completely solidified and as it comes down, as it drawn at some point through a sharing machine, the bullet or the slag disrupt of into sizes and then, it subsequently take into rate furnace or (( )) for further mechanical treatment and final operations.

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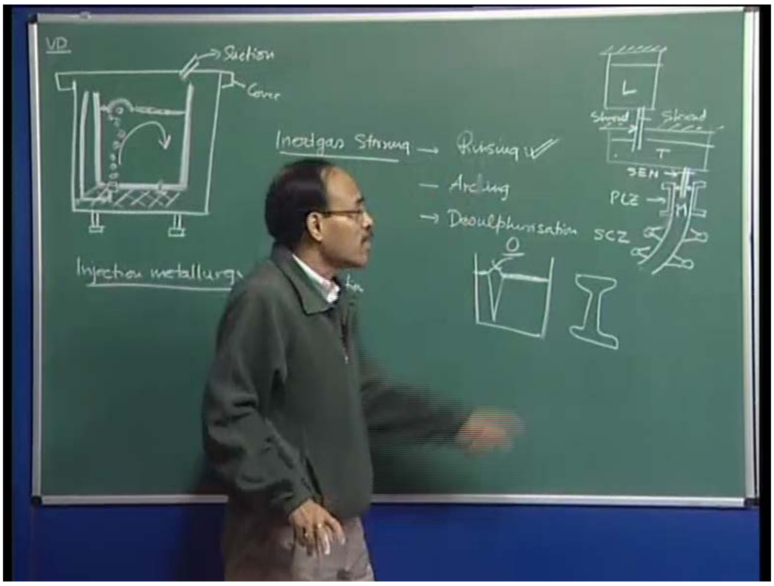

So, continuous casting machines perform vital roles in the sense, the machines do reciprocating movements, because that this need not be the solidifying bullet or the slab need not attached to the mold wall; this is the copper by the way, the mold is mold material is copper so the copper is very soft. So, therefore, there is a tendency for the steel to get attached to the wall of the mold and the mold is much slightly also tapered to facilitate the withdrawal. We must understand that the mold will expand, because of heat; the product is going to contract, because of solidification, there is going to be some gap actually, between the strength surface or the solidifying products surface in the mold wall and through this gap what flows out is known as the mold powder, which is a very important material and you will know lot about mold powder when continuous casting is discussed in a procure sections.

So, the melt is covered with mold powder; this mold powder finds continuous entry into the space between the solidifying strength and the mold wall, and you will if you visit a continuous casting plant, you will see that solidified mold powders are coming here; so this mold powders need to be continuous replenished.

So, you will see, you know people or machines are there which are putting in mold powders on the surface of the continuous casting and you know, melt at the continuous casting mold. So, typically we have this distance could be about 10 meters long from the meniscus to the point, where the solidification is completed which is call the metallurgical cooling, then some solidification is done in the primary cooling zone because of water circulation; the cooling water takes away heat how much heat? Most is the super heat is removed here and final solidification is takes place in the secondary cooling zone or the spray cooling zone.

So, this is here water place, which are impinging on the surface and which as you know water you have very large heat capacity, so water is able to withdraw lot of heat through the surface, extract lot of heat through the surface and bring the bullet at the slag. So complete solidification within a short distance.

There are lot of defects, it is it look so easy to produce, you know continuously cost products as if through continuous casting, but you know to produce defect free product to continuous casting on a sustain basis is a very big challenge and almost every time, we find that you know the products has either corner cracks or in the mid phase cracks, it has segregation or some defects called (( )) for example, the mold material if it soft, then the mold will undergo distortion and as a result of which you wanted to produce a square cross section product, but the for such products shape has become you know has certain element of (( )) because the distortion of the mold itself.

So, there are lot of defects, which can actually show in the final product, if you are not able to control the process properly; most important here are the rate of heat extraction, the characteristics of the mold powder, the design of the CAN, these are very important parameters apart from you know the composition, casting, speed, etcetera.

Now, I will say so much about steelmaking; I do not wish to go further, because we will be doing lot of, you know these subjects in great detail in the subsequent sections. I would like to mention for the next few minutes that today, the way steel is made as changed remarkably since the days of sir Henry Bessemer during the last 50 years, particularly also the simplistic LD process, which was there in 1960s, it has undergone so much of transformation with new kind of devices, process control and so on.

That perhaps, when LD steelmaking was introduced, if somebody compares the LD steelmaking today and 50 years back, one may find my God there is so much of difference. And these journey in the last 50 years, which was contributed to immense development in the area of steelmaking has been largely, because of in which our knowledge base as continuously improved. We have been able to develop many sensors; there have been tight process control; we have been able to do extensive amount of modeling and all this, I will eventually led to the remarkable success of a steelmaking technology as we see today.

Now, we will for example, in the future, we have to, of course produce steel, where a yield and quality of steel is going to be a foremost important. We would like to have higher yield, but apart from that, you know issue of yield and quality, we have to also understand that our specific energy consumption is not quite favorable.

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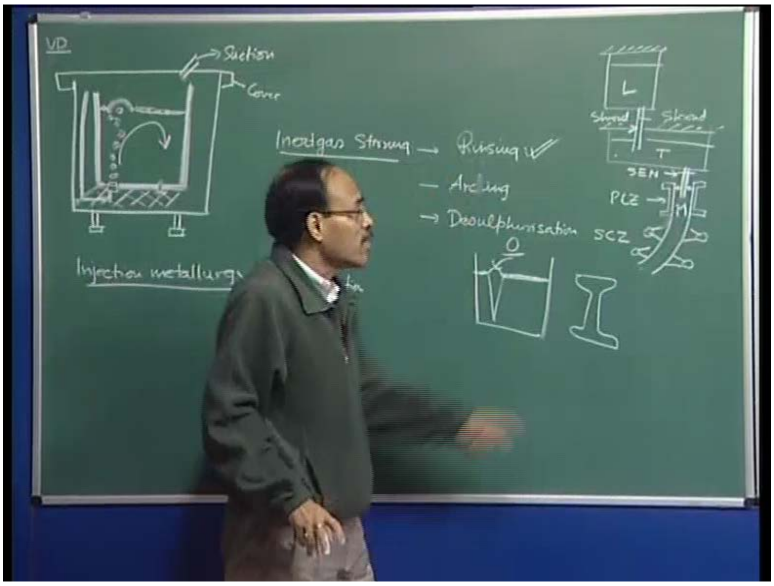

If you have to compete with other steelmaking industries or other materials, our specific energy consumption as to go down and also, we produce lot of dust through the oxygen steelmaking or the electric arc furnace processes. So, these dusts, you know we have to have good de-dusting system and the gases, which come out from the steelmaking furnace have lot of potential; we have to use them to recover energy and make the process more environmental friendly. And look at the hazards in steelmaking industries, you know it is a high temperature; I have gone to many steel plants and I found that you know people going below a 150 ton ladle and physically fix in the shroud, we require an extensive amount of automation also in the steel industries.

So, there are many issue before us today and particularly, in the next 2 decades or so we will see that beyond the issue of quality and beyond the issue of productivity, more trust will be there in terms of, for example, another issue which I should mention is there is cycling potential.

Now, we have lot of slag is being produced, for example, but slag disposal and recycling is a very important aspect. So, to visualize these in their entirety, I would say that specific energy consumption is going to be a very big issue for us in the future steelmaking technology and you know all this for example, if take it to ladle furnace, then bring it to vacuum degassing and then, again there is a necessity for taking it to ladle furnace to Jacob the temperature further.

The thermal audit and temperature managements are very important; we cannot afford to lose heat, because waste heat in the industry as I have seen, for example, you know many a times, I found that there is no synchronization and the plant the furnace is emptied.

If the material is put into the ladle and then, the ladle is waiting somewhere for a long duration or prime there are no takers and for 20 odd minutes the ladle which contains 1600 material with 1600 hundred degree centigrade, you know its losing heat and possibly today we cannot afford to do that you know we have to have better synchronization.

Now, continuously cost product we have phase product, which comes out and which is stopped into (( )) as I have in indicated to you slabs or bullets or so on, it set a high temperature, but typically what happens is, it is made to cool down in the ad-joint areas and then, after some period of time, it is taken into that the heat furnace or to the (( )) and then to the rolling mill.

Why not take if this hot bullet itself you know to the rolling mill or the slag to the rolling mill and a produce final product. And indeed now, technologies may call endless strip production technology has come, where we have electric arc furnace, continuous casting and strip casting all are in one line, you know molten steel comes, then it goes to a secondary steelmaking; then it goes to the your strip casting process, which is again a newer version of continuous casting. We have this is a conventional slab casting; you have thin slab casting; we have strip casting strip; casting means we are casting 5 millimeter thick strip in the continuous fashion.

So, at one end you have electric arc furnace; at other end we have (( )) and it is coming out continuously without the any necessity of substantial reheating and so on. So, it is an endless strip production. Technology these has come recently and driving force for such development has been and that we want to reduce the specific energy consumption.

So, specific energy consumption is a very big issue for us; we have emission is a very big issue; dust, how to ladle furnace, then your electric arc furnace and BOF, which produces tremendous amount of gas, how to regulate those, how to get a clean gas, which has lot of a calorific value or you know potential usage, how to take care of it. We have issues they are like recycling; finally, we have issues like automation and so on.

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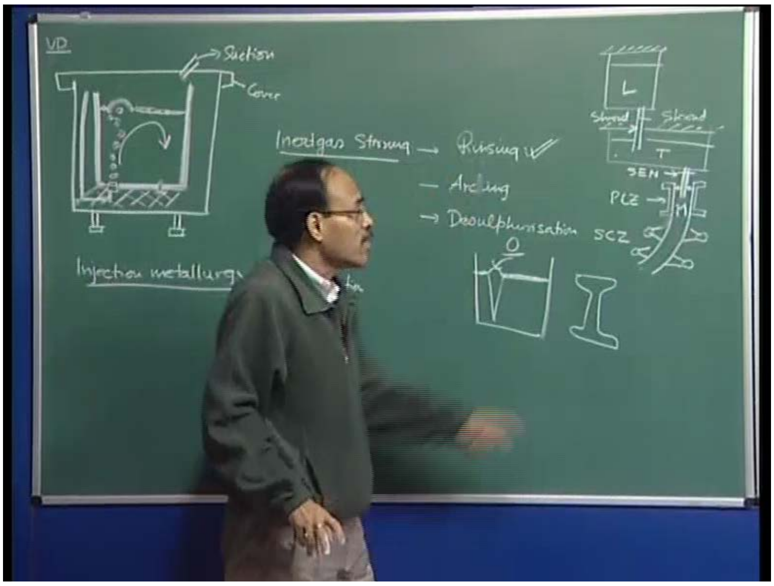

We require also better process controlled, better sensors, etcetera. So, these are some areas and to me, it appears that in the forcible future or may be even in your life time possibly BOF and EAF will continue to with dominating routes of steelmaking.

So, as for as the main trust of steelmaking is concerned, this will continue, but you will see lot of peripheral developments as for as these four points, which I have just now mention and also in terms of sensor development, in terms of robotisation, in terms of automation and so on. I think so much is enough for an over view of steelmaking and the future of steelmaking. So, we will now, in the lecture continue with the science base fundamentals of steelmaking.