Steel Making
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Module No. # 01
Lecture No. # 26
Deoxidation, Ladle and Tundish Metallurgy

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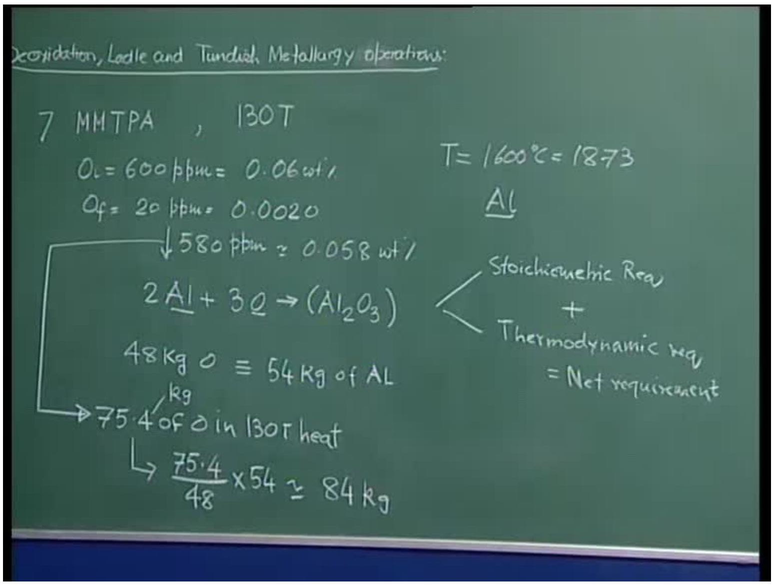

Is to carry out a simple approximate deoxidation calculation, and demonstrate that how one can really calculate the total amount deoxidizer which are needed, let us consider which has an annual production of about 7 million metric tons per annum and let us say that the size of a heat is about 130 tons. So, that implies that the size of the ladle or the vessel we are talking about 130.

Let us give some typical characteristics or assign some typical characteristic. The initial oxygen O i is about 600 ppm, and which if you convert to weight percentage, will come out to be 0.06 weight percentage, and then, let us assume that we want to take killed steel means much of oxygen in it, and let the final oxygen present in the steel be of the order of twenty ppm; that means which remove of 508 ppm of oxygen; that is what we are talking about.

The equivalent to about 0.058. The price that in every 100 kg of molten metal, there is about 0.58 kg of oxygen and oxygen that we are required removed. So, you can imagine with reference to 130 ton ladle, the amount is going to be really huge, and if you translate that amount in metric tonnes per annum steel production, the total amount of oxygen removed is going to be really enormous, which essentially imply that we will require lot of aluminum to deoxidize the bath.

Let us also say that the T that is about 1600 degree centigrade or 1873 Kelvin, and we are considering deoxidation by aluminum only. We are talking about a case of simple deoxidation. So, equation if you calculate, if you talk about reaction between aluminum oxygen, now, so, this is two tonnes of dissolved aluminum reacting with free atoms of dissolved oxygen which is producing Al 2 O 3, and as I mentioned to you that as reaction is concerned, total requirement will be detected by stoichiometry, stoichiometric reaction, requirement as well as thermodynamic requirement.

We have two components and we will add them up, and this together, we will give us a net requirement. Stoichiometric requirement essentially can be found out by looking at this particular equation. This tells us that, well, 27 into 2, that is 54 kg of oxygen, sorry, aluminum will be reacting with 3 into 1648 kg of oxygen. So, therefore, we have 48 kg of oxygen is equivalent to about 54 kg of aluminum.

This figure of 580 ppm or 0.058 weight percentage, this corresponds to about, let me just look at the figures, this corresponds to about 75.4 kg of oxygen in 130 ton heat. So, we are saying that in, we have to reduce. So, this amount it is actually, so, this much of oxygen really has to be eliminated; so many kg oxygen has to be eliminated, and if on the basis of this equation, we can therefore say that the corresponding amount of aluminum which is going to be needed is going to be 75.4 divided by 48 multiplied by 54 and this is going to be something like approximately 84 kg.

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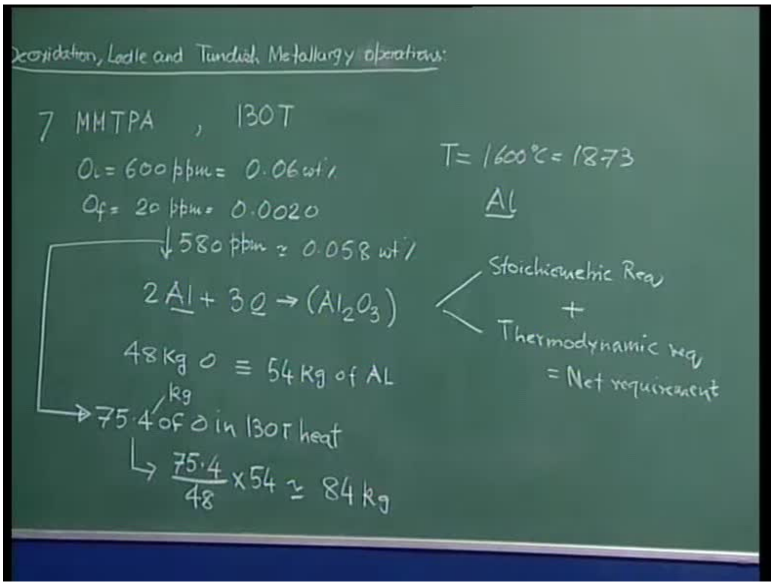

So, that means, the stoichiometry, on the basis of stoichiometry, we can say that 84 kg of aluminum is going to be, in order to purely to say that we want reduce the level of oxygen, you know, by 580 ppm. So, this much of oxygen is going to really correspond to this much of oxygen in terms of kg kilograms in a 130 ton heat. So, for every heat, the stoichiometry requirement is going to be 84 kg, but this is not going to be enough; so, this is 84 kg is actually comes here.

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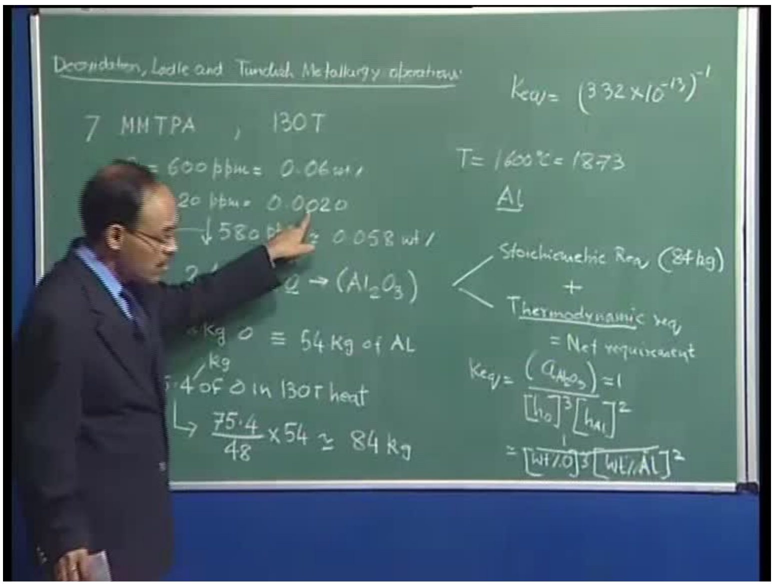

Now, we have to calculate the thermodynamic requirement and the thermodynamic requirement can be found out by look considering the equilibrium of this particular reaction, and if you write the equilibrium constant, the equilibrium constant, for example, we are going to say activity of the Al 2 O 3 induct side phase divided by if we assume Henrian activity of oxygen cube and activity of aluminum square.

We can assume here for the sake of simplicity that the activity of alumina is equal to Al 2 O 3 is actually equal to 1. So, this can be assigned to be 1, that is, you are considering a case of simple deoxidation, and now, we can make one more drastic assumption that well, the Henrian activity can be approximated in terms of a weight percentage scale. So, this is going to be really equal to weight percentage of oxygen cube multiplied by weight percentage of oxygen aluminum square. So, that is what is it is going to be.

Now, this K equilibrium which is directly related to the minus delta g naught divided by r t exponential can be known from thermodynamic data and the value that I have obtained is K equilibrium is equal to approximately 3.32 into 10 raise to the power minus 13 an inverse of it. So, I am writing the K equilibrium for the forward reaction. If I have to write for the backward reaction, the value of K equilibrium is going to be simply reverse. The inverse sign will vanish, and then, we will get the value of K equilibrium for the backward reaction.

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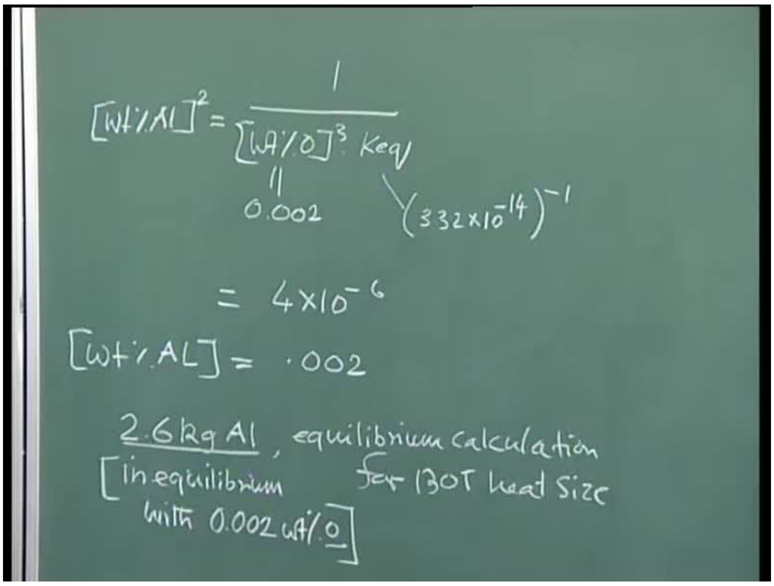

So, if I substitute the value of K equilibrium, what is the final level of oxygen? That is already given to us, which is equal to 0.002, and then, from this particular equation, we should be able to find out that what is weight percentage aluminum, and now, I go to other side, and from this by substituting the value, I can say that weight percentage of aluminum square is going to be equal to 1 inverse 1 by weight percentage of oxygen cube into K equilibrium.

So, now, I substitute the value of K equilibrium is equal to this specific expression. I substitute this is equal to 0.002. That is what is the final level of oxygen. We are talking about K equilibrium. We are talking about 3.32 into 10 raise to the power minus 14. This is actually 14, I stand corrected here, and this is inverse, and then, I should be able to calculate weight percentage of aluminum, and this, I think comes out to be equal to 4 into 10 to the power minus 6 which gives the weight percentage aluminum. In the melt, in equilibrium with 0.002 weight percentage oxygen is equal to 0.002 and these terms out. This tells me that, well, the thermodynamically about 2.6 kg of aluminum is needed as far as equilibrium calculation for 130 ton heat size.

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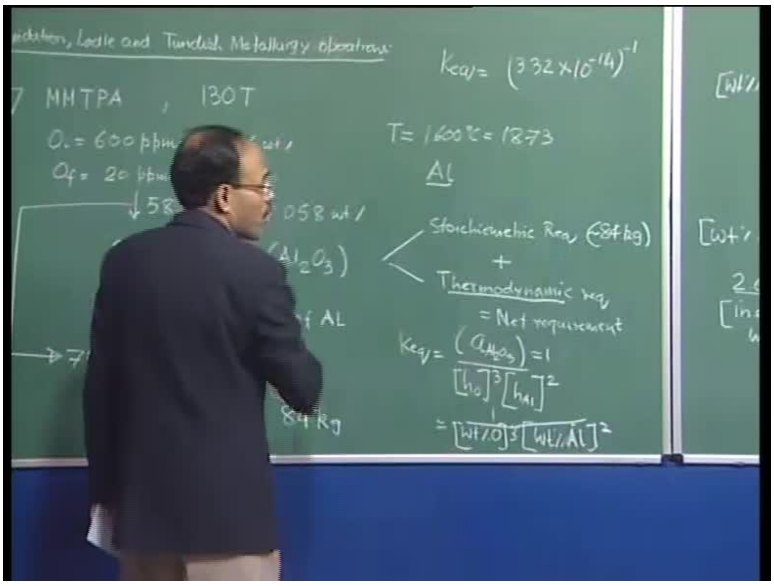

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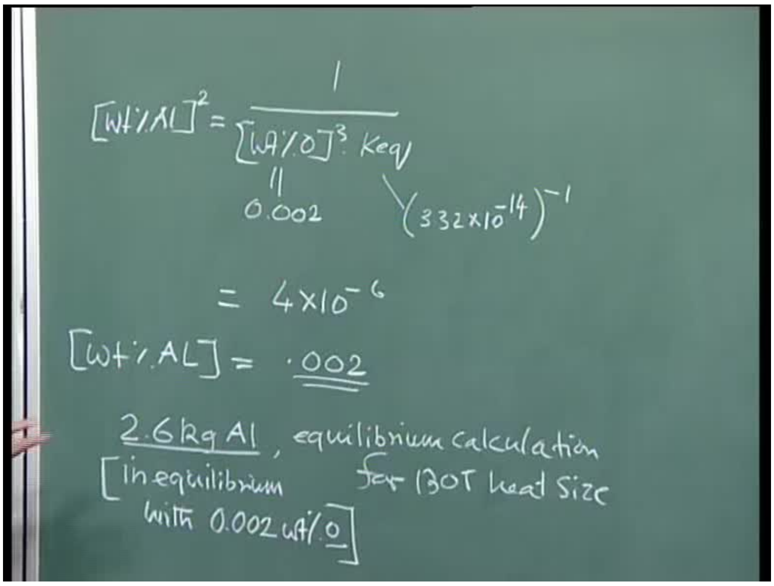

And this is 230 kg of aluminum in equilibrium with 0.002 weight percentage oxygen. So, I come back here; I have already obtained 84 kg approximately; 84 kg to be the thermodynamic stoichiometric requirement on the basis of this calculation. So, this figure weight percentage of aluminum is this much; so, I can translate it very easily that in 100 kg, I have 0.002 kg of aluminum.

So, therefore, in a 130 ton heat size or 13 into 10 to the power 4 kg, how much of oxygen is going to be there? And that oxygen turns out to be is equal to some value that aluminum is going to come out to be 2.6 kg of aluminum. So, this value incidentally turns out to be same as the value that we have; it is just mere coincidence, nothing beyond that. So, 0.002 percent weight percentage of aluminum is there in the bath in equilibrium with the same amount of oxygen, and this once translated to 130 ton ladle size, we find out that the thermodynamic requirement is actually 2.6 kg of aluminum.

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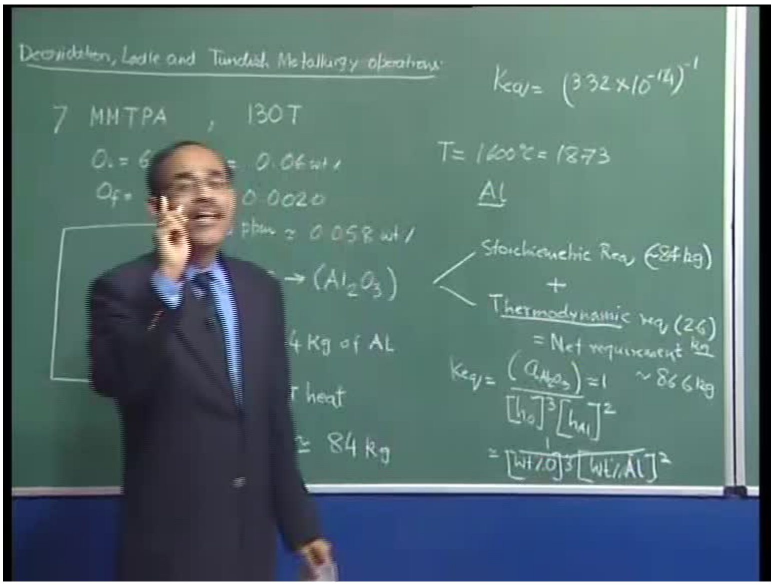

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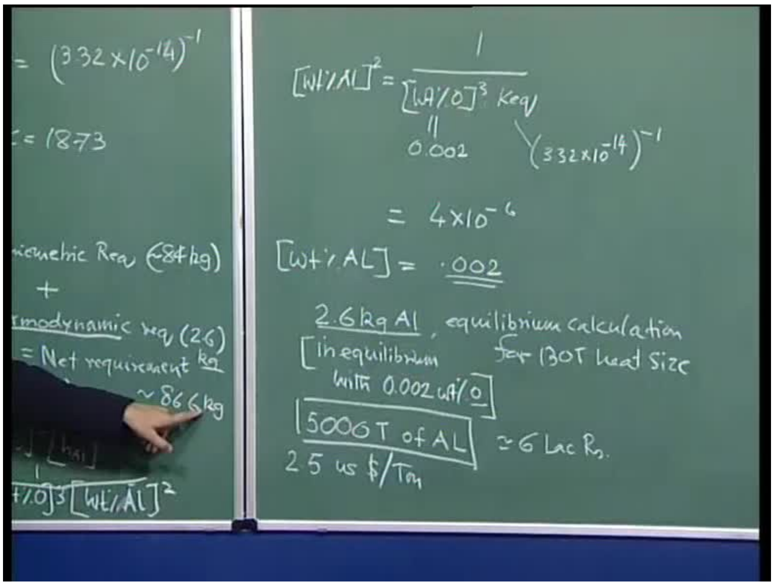

Now, we can sum this to up, and then, tell us that, well, the net requirement is going to be approximately 86.6 kg. So, for every 130 ton heat size, we are going to require. Now, 86.6 kg of aluminum which is to be added, and now, if I translate it to 7 million tonnes of steel, you can imagine that value and it is going to come out to be something like, I think 5,00,000, approx 5,000 tonnes of aluminum.

So, this is the total requirement for the 7 million tones. For 130 tonnes of heat, we will require 86 kg. So, for 7 million tonnes of plant production, how much of aluminum is going to be needed which is equal to 5,000, approximately 5,000 tons of aluminum, and taking that aluminum is about 2.5 US dollar per ton. This comes out to be approximately 6 lakh rupees in Indian currency.

So, this much of oxygen, this much of aluminum – 5,000 tons of aluminum will be needed by the seven million ton steel plant and this 5,000 tonnes of aluminum at the current rate of production consist about 6 lakh rupees or in Indian currency. Now, it is important to know that this assumes that we are adding. If we add 5,000 tonnes of aluminum or in a given heat, if we add 86.6 kg of aluminum, that much aluminum is going to be utilized for stoichiometric and thermodynamic requirement.

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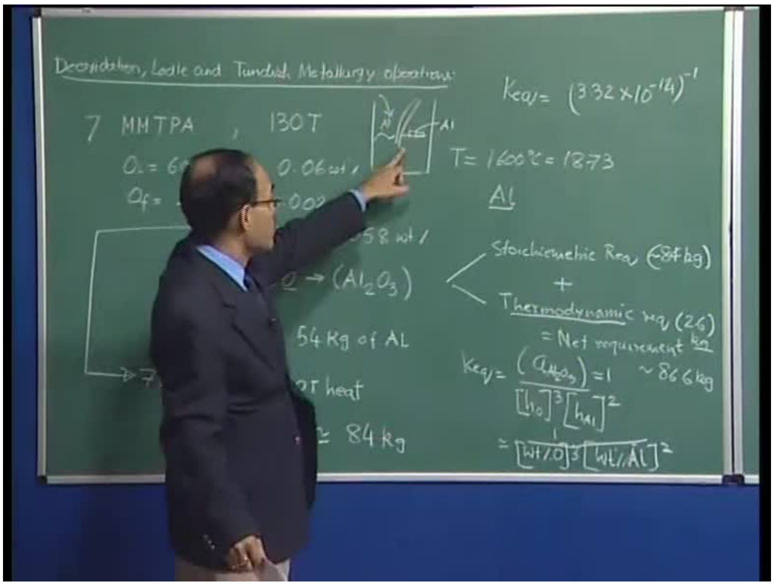

So, we are not considering any loss of aluminum, but in reality, what happens is that we have to add more amount of aluminum much more than 86.6 kg, because some of the aluminum added is going to be reacting with the atmosphere. What did I say? I said earlier that, well, we have a ladle here, and that, in this particular ladle, we have stream coming in and we are adding aluminum in this way and all the aluminum will be floating here. So, these are going to be my aluminum.

So, the aluminum, deoxidizer aluminum which is added through the shoot into the melt is going to come to the free surface because of its lesser density, and as a result of which, this aluminum a part of heat is going to be reacting with the atmosphere as it reacts with, as its melts and dissolves into the molten steel bar in order react some oxygen.

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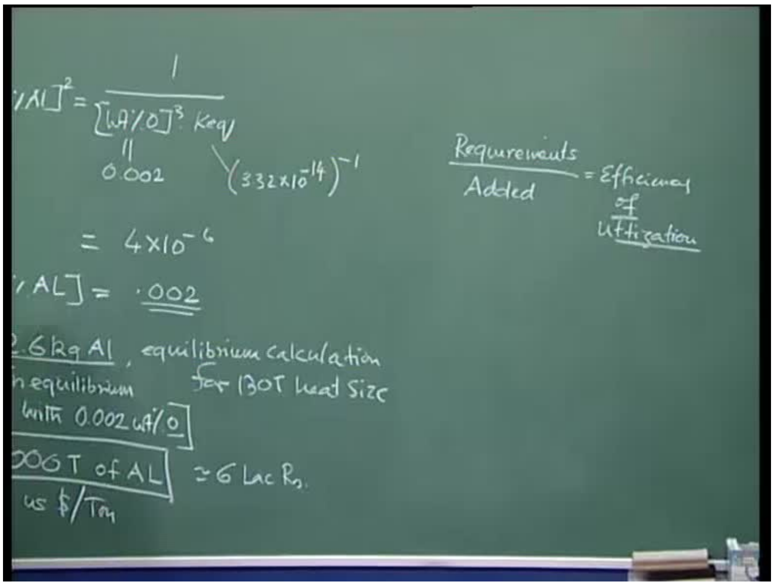

So, therefore, it is understood that we have to add more amount of aluminum in its dictated. This is the requirement of the process. So, this requirement now I can say that, well, requirements, and what is added? Divided by what is added determines the efficiency of utilization, efficiency of utilization, and so, requirement is how much? Requirement is 86.6 kg, but we are going to add more than 86.6 kg, and as a result of which, the efficiency of utilization is going to be less than or equal to 1.

Now, for buoyant additions like aluminum, etcetera, the recovery rate or the efficiency of utilization is significantly smaller than one; it is about 60 to 70 percent in general processes. As a result of which, you can enhance these values by about 30 percent, or so, the 6 lakhs of money that I am showing here could translate to something about 10 lakhs, 12 lakhs of rupees per annum.

So, the calculation has indicated that large tonnage of aluminum is required in steel plants when we are going to produce low oxygen steel or killed steel, and we have also noted that huge expenses, they are involved as a result of a large tonnage of aluminum, and therefore, there is considerable interest in the industry to minimize the wastage of aluminum.

I have also mentioned that the efficiency of utilization which is also turn in the industry as recovery. The recovery of aluminum because of its wastage, its reaction with the ambient and other sometimes Fe O in the processes gives us a small value much lower than one. So, quite a bit of aluminum is going to be wastage, which will not take part into the deoxidation reaction at all.

So, industrialist have been concerned for improving the recovery rate of aluminum, and in much older times, many other processes like bullet shooting methods, etcetera, where devised. As I have indicated earlier, the typically bulk of the aluminum additions will be made through a shoot. It is going to be dropped through a shoot pointing to the region, where the stream from the furnaces entering into the ladle or the impart zone such that the aluminum can be ambient some surface.

So, the scientists knew that we have to somehow deep the aluminum submerged, and then only, we can improve the recovery of aluminum. We have to stop the contact of aluminum with the slag or with the ambient and aluminum has to come in contact directly with the metal. So, therefore, it has to remains some surface.

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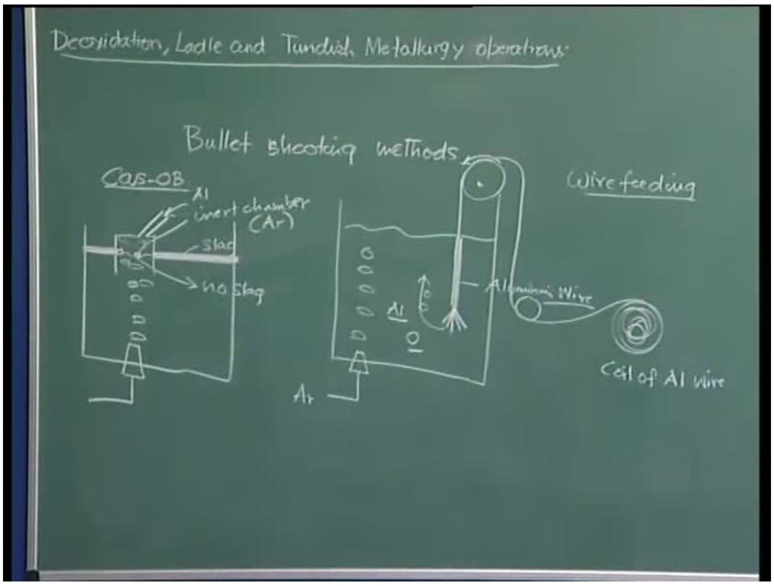

And earlier, many time years back, people use to introduce a method which esthetically called which of course is absolute. Now, there are better methods. I am going to tell you bullet shooting methods and this basically where device in which you have a big gun, through which, huge aluminum bullets point, which is like cylinder conical shapes, they are going to be injected into the or pumped into the molten metal or molten steel, and people use to think that if you can shoot the bullet of aluminum with a very high speed, it has a potential to penetrate deep inside the bath. As a result of which, the recovery of aluminum can be increased, because it can really go inside the some surface.

Today, apart from bulk alloy additions of aluminum, we have wire feeding of aluminum which is very popular and this is basically done in order to improve the recovery or efficiency of utilization of aluminum. For example, the aluminum wires, if you have a melt in ladle, so, you have a porous plug here, porous plug here, through which argon is going to been injected, and once you have a coil here, through which, the aluminum wire comes and it is, so, this is basically a role which rotates and this is the aluminum wire.

So, you have a huge coil from which through pulling, the aluminum wire is drawn something like this. Say this is the coil of aluminum wire. These are basically essentially coated aluminum wire; so, it is going to be fed into the bath at a very high speed. Now, as I mentioned earlier, that is a solid one, solid object which is being entering into the molten metal. So, therefore, a solid crust is going to be formed around the wire as it enters. So, these are solidified crust and then the crust melts back, and at this particular moment, may be you can think that jet of aluminum is going to be shoot, and this jet of aluminum, because of its buoyancy, is going to rise up, and this droplets of aluminum are then going to dissolve into the bath, whereby they can react with dissolved oxygen producing aluminum.

So, the efficiency of utilization is more reproducible and the efficiency of utilization or the recovery is also significantly more than the bulk addition. That is typically practiced and that I have been talking about all along this lecture. There is another process also which is known as the cas-OB process and this process is again another portion of the argon stirred ladle. So, the material has been poured into the ladle from the furnace, and now, what happens is - if you look at the process, it goes something like this. So, we have a snorkel here and we have the porous plug somewhere here. So, from the porous plug, you have bubbles which are going out and this is the melt here. So, we have basically the slag layer which is contained outside this snorkel.

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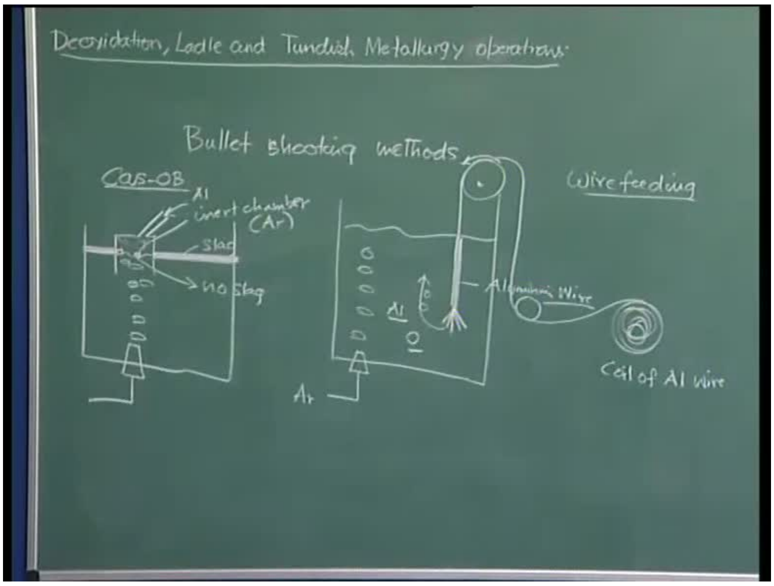

So, this is an inert chamber basically and we have the melt surface here, and this region, this is slag, and here, there is no slag as you would note here. Therefore, the bubbles rise here within the central part; there is large velocity there, because the gas is rising through the snorkel. There is an inert atmosphere here; there is no oxygen, because the argon bubbles or argon gas is going to be there and through this shoot alloys like aluminum, etcetera, are going to be introduced into the melt.

Now, once you introduce aluminum through this, you must understand looking at the figure that aluminum will have more chance to come in contact with the slag, and also, alumina even though it might float on the free surface, you may see that the aluminum blocks are here really, but if the cause, I do not have oxygen in that atmosphere, this environment is really filled up with inert gas or argon gas. So, therefore, what we will see that the buoyant additions which are going to be introduced into the cas-OB process will have a greater potential to react with the molten metal dissolve into the molten metal, then reacting with oxygen as it happen in a typical conventional furnace tapping operation.

So, cas-OB process, it is now well known in the industry that it gives rise to much more better recovery rate of aluminum even when people are adding sometimes recarburization of steel. So, to get the maximum utilization of graphite, this a technique which normally people uses. This is a very efficient method for introduction of buoyant alloying regions.

So, I will stop about deoxidation at this particular moment, and now, I am going to go into the second topic which is the ladle metallurgy, but before I start ladle metallurgy, I would like to bring to your notice the significance of ladle metallurgy for example. Now, I have been talking about, you know also the primary steelmaking, we produce crude steel which contains lot of impurities, and the duration of primary steelmaking of course, will vary depending on the capacity of the converter 30 minutes, 28 minutes, 50 minutes, something like that.

On the other hand, secondary steelmaking or ladle metallurgy involves a variety of processes; there is not that one process steel is been treated. Once the ladle is filled by molten metal from the furnace, then the secondary steelmaking or ladle metallurgy operation starts.

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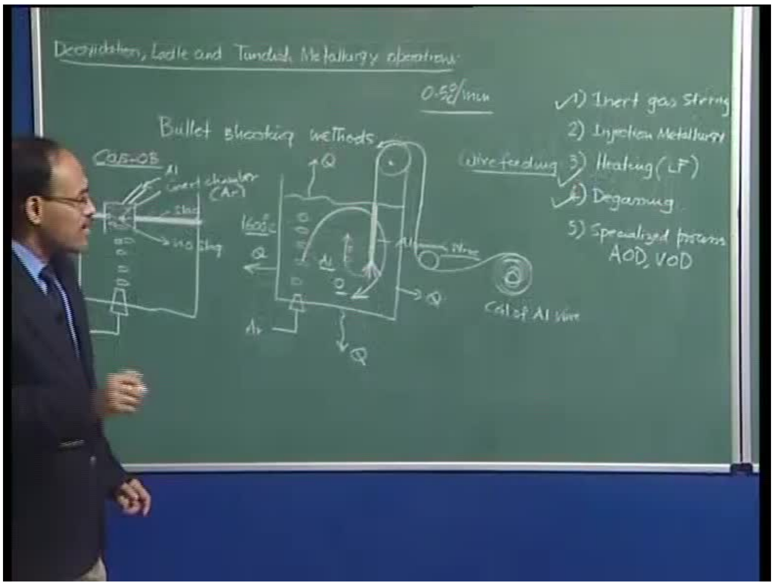

And the objective of ladle metallurgy or various ladle metallurgy operations can be several one, we say the commonly is inert gas stirring. This is one aspect. I will explain to you what is the necessity of this. Then, we have injection metallurgy, you may inject something. We may have heating and we may have degassing basically and also we have various specialized processes, special processes like AOD and VOD, which is termed as argon oxygen decarburization and vacuum oxygen decarburization.

As you all know that stainless steel, for example, contains very little amount of carbon. We do not want carbon, because if you have carbon, then chromium carbide segregates in the quality of stainless steel is deteriorate significantly, deteriorate significantly. So, we require low carbon, and when you produce stainless steel in a specialize techniques to decarburize the bath and these are the two techniques.

So, variety of processes are really fall within the domain of ladle metallurgy and the duration of all this put together can be much longer than the duration of primary steelmaking operation. We must understand that if we try to introduce or treat steel through all this processes, the cost of steel is going to be extremely large.

Now, therefore, for every grade of steel produced, all these treatments are not going to be justified. We may just do inert gas stirring and heating for a common grade of steel, but for a specialized grade of rail steel, which does not tolerate too much of hydrogen, for example, in that case, on the top of this two, we may be interested to carry out degassing processes, because degassing is a process to drive out dissolved gassing from molten metal.

So, the more and more secondary steelmaking processes are going to be incorporated in the steel making circuitry. We will see that the duration of production is going to be longer steel production, is going to be longer. As a result of which, the productivity of the plant is going to go down and it is compensated by obviously raising the price of steel.

So, therefore, and a steel produced by simply inert gas stirring and ladle heating is going to be less price. Then steel treated by inert gas stirring with heating and degassing combined itself, and as it is to be noted that for every grade of steel, all this treatments are not justified. We have to understand or we have to know the specification of the customer what the customer wants, and based on that, we are going to select that whatever the processes which are necessary to be encompass in the domain ladle metallurgy operation.

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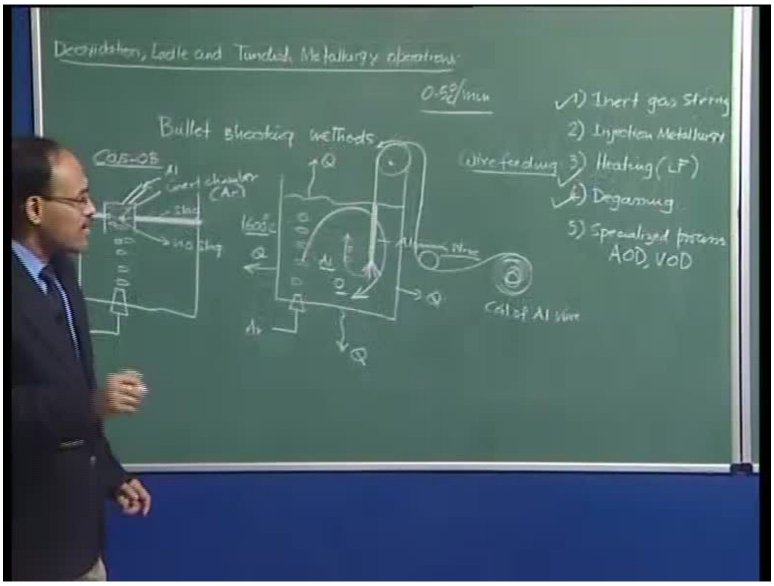

Inert gas stirring that we briefly introduce this terms essentially tells about introduction of argon gas into molten steel. Why we use argon? Because we must understand that we are now continuously refining steel. We are producing; we have removed decarburization. We used crude steel; we have removed oxygen; we are going to take out subsequent operation.

So, at this particular stage, we really do not want to contaminate. We cannot, we do not need oxygen. For example, there is nothing to bond there, no silicon oxidation or phosphorous oxidation as necessary. If we introduce nitrogen to stir the contents of the ladle, in that case, what happens? Steel is going to be reach in nitrogen; that is also not desirable.

So, basically, we are going to introduce argon into the ladle. So, during the ladle metallurgy treatment all along this process, the material in the vessel needs to be continuously stir. We require stirring here; without stirring, the rate of the metallurgical processes are going to be or the chemical processes are going to be very small, because we know that steelmaking reactions are basically mass transport control reactions and mass transport control reactions have a tremendous influence of the fluid dynamics of the reactor.

So, therefore, in the absence of any stirring, we will not see much rate of the chemical reactions or noticeable rates of the chemical reactions. That is why we need stirring, and gas stirring as I have already mentioned is the cheapest mode of stirring, and we require inert gas stirring, because the inert gas is not going to contaminate molten metal. At every stage from now onwards, we are going to ensure the steel does not get contaminated either from the environment or with the refractory or with introduction of foreign materials and so on.

So, inert gas stirring is an essential part of ladle metallurgy. The objective is to continuously stir the contents of the bath such that thermal homogenization, material homogenization, chemically reactions, inclusion floatation, these can all operate with its maximum efficiency.

Next comes injection metallurgy. Injection metallurgy talks about injecting some powder through an auxiliary lance into the molten steel. What is the objective of injection metallurgy? For example, we may use some reagents to control the morphology of inclusion. We may use some powder material also into the molten metal to say increase the rate of desulphurization.

So, there are many objectives, and injection metallurgy is very popular which essentially tells of injection of solids in the powder form into molten metal. Powder form we use because then the surface area is more, which is essentially implies that the rate of reaction is going to be, and injection metallurgy very popular in the context of inclusion morphology change, in the contest of a desulphurization and so on.

Next comes heating which is also called as LF operations. In this case, the ladle is going to be, as I will show you later, the ladle is going to be converted into a ladle furnace, whereby just take the way we heat molten metal in an electric or scrap in an electric arc furnace. See, in the same manner, electrodes are going to be submerged into the stop slag layer and it is basically an arc heating process. That is essential for the heating purpose.

Now, why do you need heating? We must understand that we have tapped the molten metal at1600 degree centigrade for example. Now, having tapped the material at 1600 degree centigrade, lot of heat is going to be lost through the wall, through this wall, through this wall, (Refer Slide Time: 29:13) and possibly significant amount of heat will be lost to the top surface, because the top surface is the slag cover; these are all refractory cover. As a result of which, we will see tremendous amount of heat is going to be lost.

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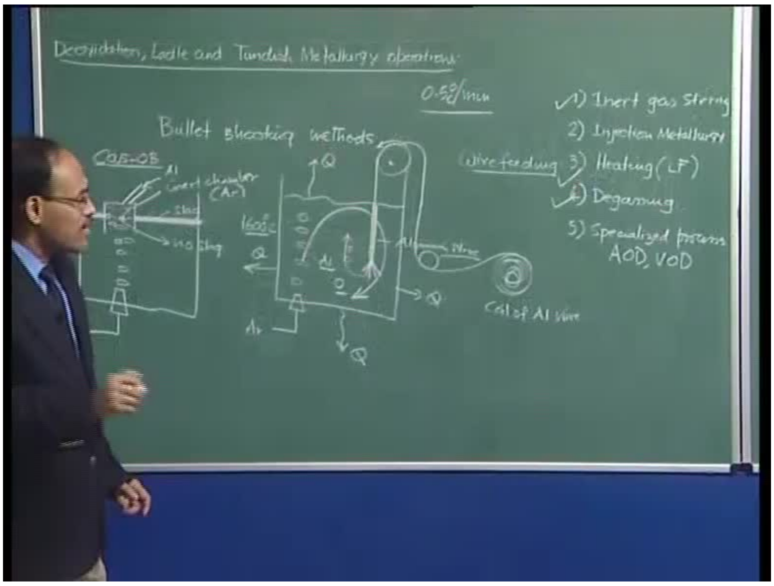

Now, if heat is going to be loss, so and that the duration of secondary steelmaking or ladle metallurgy is substantially more. So, we can encompass, we can envisage that the total dropping temperature because of such heat loss during the process are going to be really consider will be high.

Now, typically during the holding period of a ladle, it is known that about 0.5 degrees per minute. This is the rate 5 degree centigrade per minute. This is the rate at which the temperature drops during the holding period. Also we must understand that in the secondary steel making or ladle metallurgy operations, we maybe using different solid reactants; we may be forming slags; we may be injecting some solid spices or we may be adding some alloying additions to adjust the composition of the steel.

These alloying additions, the dissolution of lime for making fresh slag, etcetera, are going to consume heat. These are all in the thermic processes, and where from the heat is going to come, the heat is going to be taken away from the metal, and as a result of which, the metal temperature will drop significantly.

But remember, that the downstream process is the continuous casting process, where we require a fixed temperature. So, we have tapped the molten metal at 1600 degree centigrade. If you do not do heating and carryout all this operations, by the time the material goes to continuous casting. There it is going to be considerably chill, may be prematurely solidify as well.

So, somewhere in between the circuitry of ladle metallurgy, we do require that a heating operation is done and this heating operation basically compensates for heat loss as well as heat required for many endothermic processes, which are carried out under ladle metallurgy simple condition, and as I said the electrode heating, the same principle as arc heating. An electric arc furnace is been applied, and I am going to show you later this, you know, a nice drawing of a ladle furnace.

How do you convert this ladle into ladle furnace? That will be very clear. When you show you the electrode, etcetera, and there you will come to know that why this porous plug is really located of the center and not immediately below from the center line? It is shifted either towards the left or it is off set basically why it. So, that will be clear when you talk about that ladle furnace.

Following heating, we have degassing process and degassing basically is removal of gasses. We have, as I mentioned to you, now the molten metal might contain lot of nitrogen, where from nitrogen has come, nitrogen has basically come during the taping, entering of the taping stream into the ladle. So, the furnace, in the furnace, we are using basic oxygen furnace; we are using oxygen.

And now, that when you are tilting the furnace and we are filling up the ladle, that during that process, what happens is the molten steel draws, falling molten steel stream draws, lot of storming here which contains lot of nitrogen. As a result of which, the material contained in ladle will contain lot of nitrogen. Also depending on the quality of the raw material use lime, etcetera, contains lot of moisture and also there are lot of leakages in the mini plants also as you can see.

So, there are sporadic contacts, you know, with water vapour, and so, which gives rise to significant amount of hydrogen, sometimes even 3 ppm, 4 ppm. So, nitrogen and hydrogen which are there in the steel can be driven out by degassing, and as I will show later on, the degassing is most effective under vacuum or under reduced pressure condition.

So, to produce quality steel, that does not contain much of dissolved gases. Oxygen we have removed by deoxidation, and whatever little nitrogen and hydrogen are there in the melt, that can be removed by the vacuum treatment of steel, and specialized processes as I said the names are here argon, oxygen, decarburization, because when you decarburize the bath, we have, we inject argon and oxygen together and this argon and oxygen helps with a decarburization of the bath.

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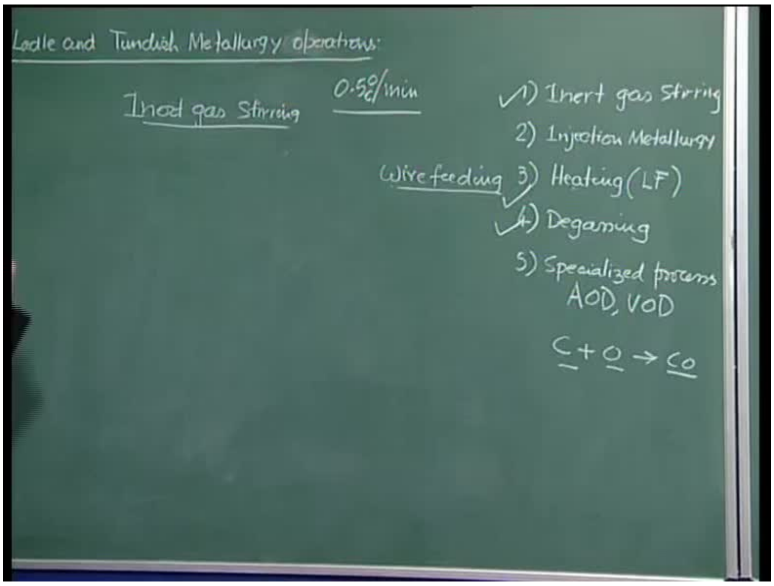

The oxygen injected reacts with carbon produces some heat and also carbon monoxide and this is again vacuum oxygen decarburization, because you have the reaction dissolved oxygen and dissolved carbon, and we know that smaller is the partial pressure of carbon, larger is the tendency of the reaction to go from left to right.

So, we will be able to produce low carbon steel, extremely low carbon steel if you are operating at a low pressure, and this is the essence of vacuum oxygen decarburization. Now, I am going to discuss about inert gas stirring in detail, and since the steel is now sitting in the ladle, we will talk first about the construction of the ladle which is very important for us to understand.

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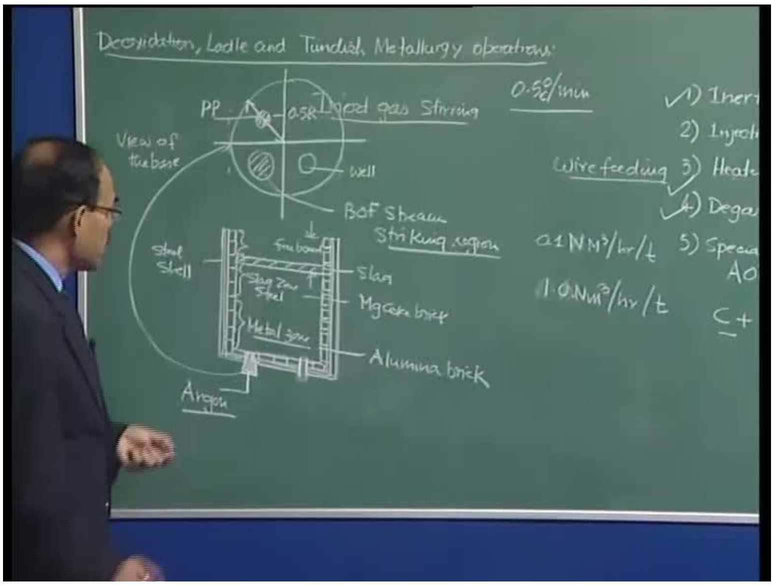

So, if you look at the ladle, it really looks like a cylindrical shaped vessel. So, this is the longitudinal sectional value and I draw. So, let us say that this is the view of the base. Basically, this ladle is contained in a steel shell; this outer shell is steel, and then, we have lot of refractory materials, for example, we can have refractory tiles here; we can have papers here, lot of riming materials here which constitute the permanent lining, and then, we have finally, the layer of this is going to be the refractory bricks, and there are different kinds of bricks with which this is really we have steel plates; we have refractory tiles; we have refractory papers, and then, we have, so, these are the bricks.

Now, the bricks are lot of uniform type here; that means there is a gradation of bricks depending on the requirements. We can see that if we take the longitudinal cross section, may be there is, this is where we have the porous plug which is located, and then, we have to drain molten metal out and we have the well also at the bottom. Now, this is steel shell. Typically, we will see that the ladle is going to be filled up with some steel with this particular height, and then, we may have a slag layer which is there. So, this is going to be called as the free board of the ladle; so, this distance is free board.

Otherwise, if you do not have free board, then what happens? If you translate the ladle, because the ladle is to be moved from one place to another, what happens? The molten steel is going to go out of the ladle. So, significant some amount of free board 60 centimeter, 70 centimeter, it varies from plant to plant is necessary.

So, molten steel is there. On top of molten steel, we have slag layer, and this slag as I repeat again is not the oxidizing slag of the furnace, This slag has been prepared a fresh. It is by the addition of lime as well as spa materials silica in the ladle during the filling operation, and also, now, it contains lot of alumina also, because we have added aluminum to deoxidize the bath. So, alumina Cao Si O 2, this is basically the decomposition of the slag.

Now, this lining which is there on the free board is not critical for us, because this is not subjected too much of hydrodynamic erosion. Mostly the chemical and hydrodynamic erosions are going to be there over these surfaces. These are the surface which are going to be attack severely by molten metal and slag, and this zone basically, we can divide roughly this is the free board zone, and then, we can say that there is the slag zone and then we have this metal zone.

The slag attacks refractory vigorously depending on the composition of the slag, and if you particularly have little bit of iron oxide, that is detrimental for the slag, because iron oxide is impregnates into the refractory way. So, the corrosive is, to minimize the corrosive attack of brick refractory on the brick, the slag zone material is basically is a math coke, Mg coke, math coke brick. On the other hand, this part is going to be basically primarily alumina brick.

If you look at the cross section, then what happens is - we see at the base, we have this is the well here and this is the porous plug here. So, this is porous plug and this is the well, and below this, we may have a slide gate. I am going to maybe you know or I am going to talk about it later. The slide get controls the flow out of the ladle.

This ladle is going to be taken into continuous casting. It is going to feed a tundish, and therefore, we have to take up molten. So, through this porous plug, as you introduce gas, it is through this well, we are going to be taking out molten metal. Typically during the process, this remains closed by using some refractory or ramming material and so on.

And somewhere here, we must understand this is the region which you should plan that when the molten steel stream from the furnace enters the ladle, it is here that the stream really impinges. If the steel impinges here or here, there is going to be significant damaged to the ladle. We do not want porous plug or the well region to come directly under the falling stream. The stream is going to be falling on this.

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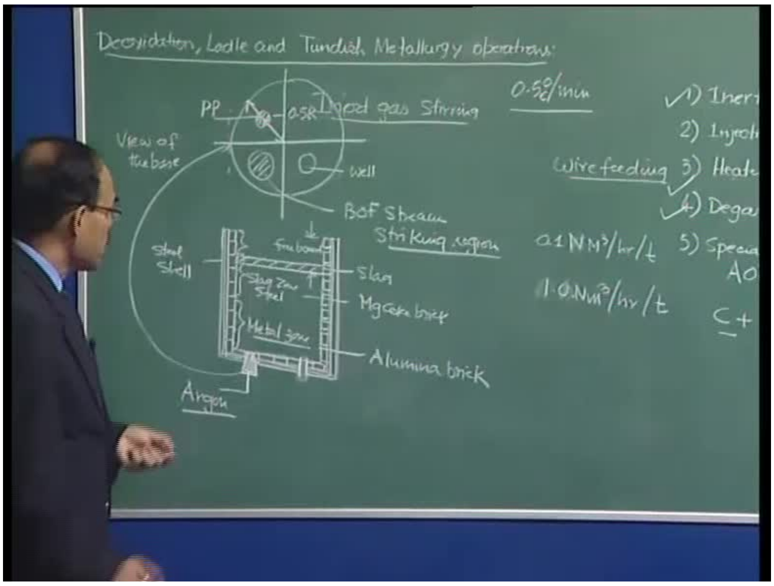

So, there is going to be a different kind of a refractory material in this particular region, because the impact of the stream is going to be really severe. So, extremely large hydrodynamic erosion can be expected in this particular region where the stream is falling. So, this is the BOF stream striking region and this region needs to be reinforce properly with the refractory area.

Now, the plug as I have shown here, this plug is typically located as if you look at this, if this represents the r value, this is located roughly about 0.5. So, 50 percent of the bath radius position or I would be say that the porous plug is located typically at mid bath radius position.

The number of porous plugs, for example, may be one or two depending on the size of the ladle, in many ladles of bigger capacity like 200 tons, 250 tons and so on. We can have two in porous plugs, and in this case, the porous plugs could be located diametrically opposite or they could be displaced located in the adjacent quadrant and the whole arrangement has to be restructured. When you have two porous plugs, then what I have located in this particular figure?

Now, argon is going to be injected through the porous plug, and as I mentioned to you that the flow rate of the argon will determine the extent of hesitation. Now, we have a diverse range of argon flow rate and the typical argon flow rate can go from 0.1 normal meter cube per hour per ton of steel to about 0. or 10 times more, so, 1 normal meter cube, let say n normal meter cube per hour per ton. So, this is the range of ladle metallurgy steelmaking argon flow rates and this flow rates has you would note is significantly smaller than the flow rates in an oxygen steelmaking process.

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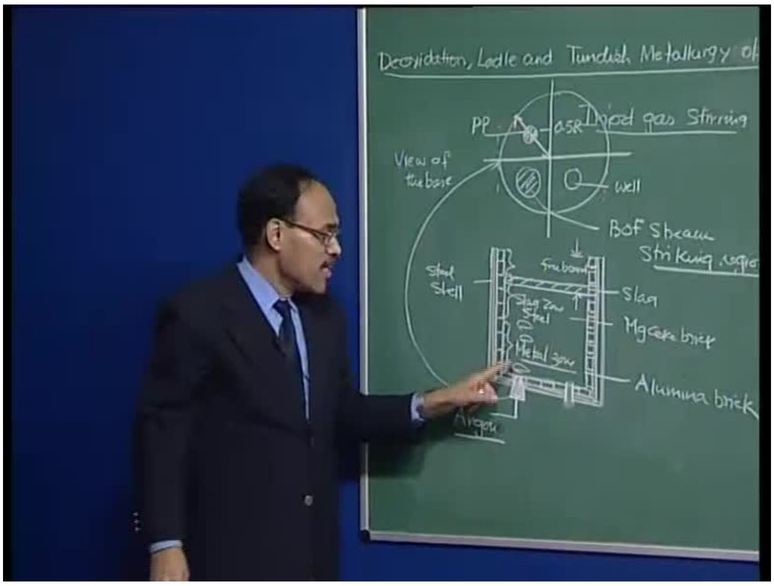

Now, let us look at when you introduce gases, what happens? So, when you introduce gas, argon gas through the bottom, this argon gas rises, because the gas has buoyancy just like the way you would see that you have a long. If you go to the thermal power plant for example, you will see big the long chimney, and through the chimney, the smoke comes and that is called the smoke plume which rises vertically upwards, because it is lighter; it is at higher temperature. In this case, the gas is lighter than that of steel. So, as a result of which, the gas rises through the molten steel because of its buoyancy, and this region, we say that it is a argon liquid steel plume region.

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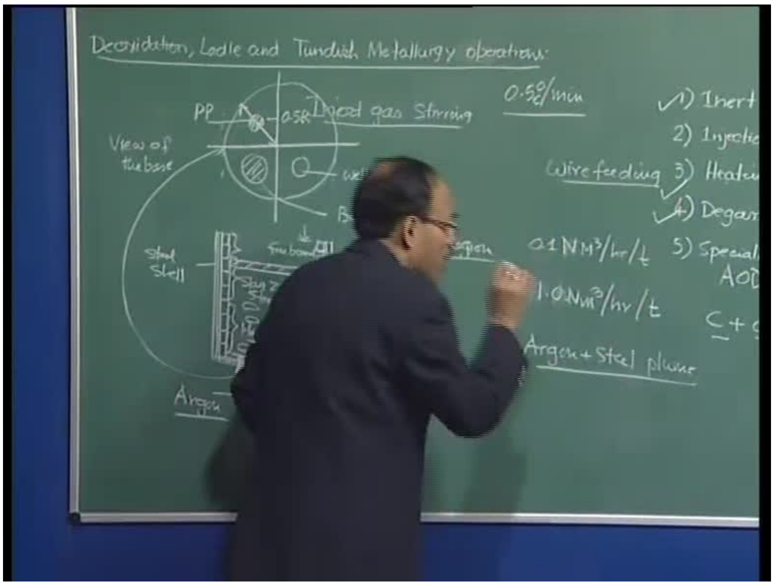

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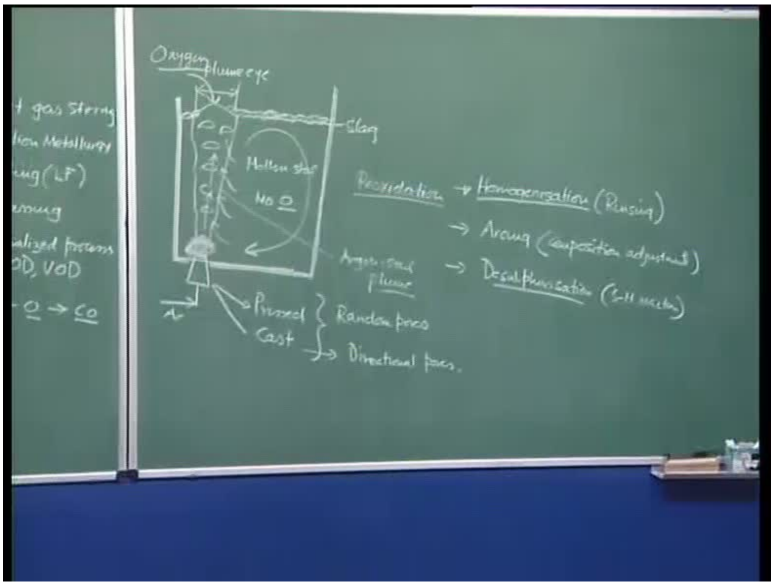

So, argon plus steel, let me give you a clarified picture. Now, having given you the design on the refractory features, let us now draw about it. So, I have the ladle here; I have the porous plug here. I inject argon and what I see is a region here through which bubbles, this is the slag layer. So, this is slag and this is my refractory lined ladle and this is molten metal, molten steel and this is what I am talking about.

So, we can expect that as the gas is issued from the porous plug. We will have the gases rises, and as the gases rises, what happens is - it draws along with it molten step metal, and as a result of which, it creates an intense kind of a flow within the system. Also the gas to leave to the surrounding or go back to the surroundings and this is typically called the slag eye or the plume eye. Through this, the argon bubbles really escape to the surrounding. Now, you see, there is a very interesting aspect of argon stirring operation is that we have oxygen here and this metal contains no oxygen, no dissolved oxygen, we have taken away all the oxygen by the addition of deoxidize elements.

Now, as the slag eye is been created, what happens here? We have molten metal, which comes in direct contact with atmospheric oxygen. So, as a result of which, oxygen gets dissolved, because oxygen has extreme solubility in molten steel weight affinitive of oxygen with iron, and as a result of which, at this high temperature, lot of oxygen passes into the molten steel, and this oxygen, once it gets into molten steel, what happens is it starts reacting with aluminum which is dissolved in steel and the aluminum feeding starts, and as a result of which, the slag becomes progressively richer in iron oxide.

And this is a very important aspect which you call as a reoxidation of steel. So, if we, at looking for quality steel, this reoxidation must be prevented to the extent possible particularly towards the later stage of ladle metallurgy steelmaking operation. So, porous plug are basically refractory materials, because a part of which is in contact with molten metal as I have tried to indicate in this figure. So, they can be either pressed or they can be cast; both the ways, they can be produce. They can have random pores and they can have directional or directed pores. Some of them have slots also, by which, gases are delivered into the molten metal.

Now, the precise nature in the argon stirring operation, argon injection operation, the precise nature of the pores, etcetera, really does not influence much about the flow field which is generated in the system, because the size of the bubbles which are generated in the system is dictated by thermo physical properties, because the flow rate is small.

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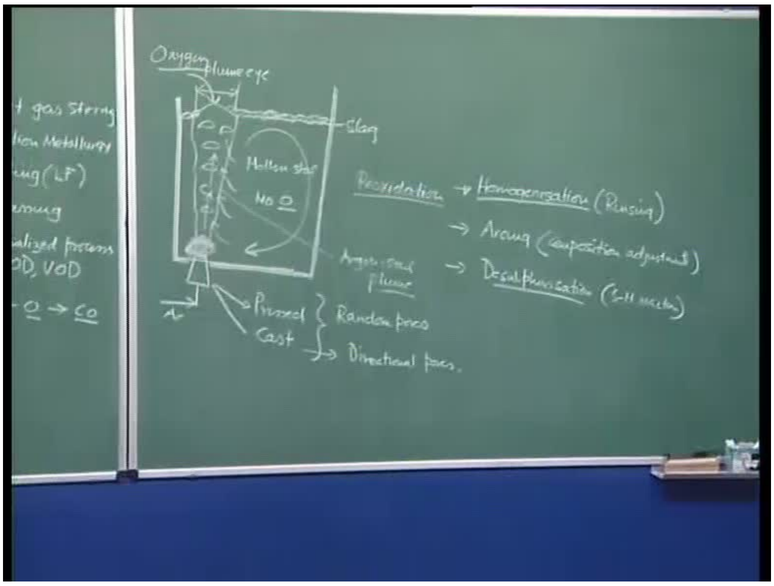

Typically a big gas envelope forms here and this gas shutters into a number of bubbles and these bubble rise. The size of this bubbles are dictated by the thermo physical properties of the melt rather than by that details of the pores and whether the directional or random. So, this has partially no role to play. And flow recirculation or the intensity of flow which is produced here depends on the flow rate rather than the characteristics of gas injection; so, that means, if you are injecting gas for the sake of the statement, I am making instead of a porous plug, if I would introduce the same amount of gas through a say tuyere, it is going to produce the same amount of more or less the same amount of recirculation.

So, therefore, the details of the nozzle design for argon injection into ladle is not much critical. It is only important for us to know that we require is refractive material, which needs can sustain for a long time. We cannot afford to replace this pores plug every heat. So, it has sustain heat, heats, 10 heats, 12 heats, depending on the requirement and we have various techniques. They have different performances as far as argon injection is considered. So, we can have two plugs. We can have 1 plug; 1 plug would be used for typically 50 ton, 100 ton, 130 tonnes eyes ladle; 2 plugs would be used when we are about 300 tonnes or 500 tonnes ladle size and so on. And we are using a variety of range of gas flow rates. This depends on the objective of argon stirring operation, and the objective of argon stirring operation, I would say could be one is homogenization and homogenization means we are talking about mixing.

So, if we add a spoon of sugar into a cup of tea, in that case, you got to stir it and this is called the material homogenization. You are, otherwise, what is going to happen? If you do not stir it, you will sip the tea, and see, the first sip does not contain much sugar, whereas the last tea that you are going to drink will contain lot of sugar and that is because of the in homogeneities of sugar distribution in the cup of tea.

So, argon rinsing basically is carried out to homogenize the bath in terms of its temperature, in terms of its composition. So, we would have as a result of homogenization and argon rinsing, same amount of oxygen or same amount of nitrogen or same amount of silicon, everywhere, we are going to have same temperature also more or less in the system, not much difference. So, thermally and materially, it can be homogenized by argon injection.

So, second objective of argon injection, so, this is basically homogenization, which is called in industry or shop floor as a rinsing operation. Then we have in heating operation, we can have arcing or a flow rate during composition adjustment, so, and we can have desulphurization also slag metal reaction. When you are talking of rinsing, basically this is the final stage of argon rinsing; that means all treatments are over. We are going to now give some kind of a little gentle stirring into it and we require a very small flow rate so that the eyes becomes small and there is not much scope of deoxidation of the metal.

Arcing which is the heating operation basically we are talking about. At that particular moment, we are going to add lot of alloying additions which has to dissolve the flow rate is going to be little bit higher, and for desulphurization, we will require extensive amount of slag metal mixing in the system which is carried out during the beginning of the argon rinsing operation immediately following deoxidation. In that case, the flow rate would be very high.

So, the flow rate that I have coated were one normal meter cube per hour per ton basically corresponds to about desulphurization process in ladle. From the other hand, 0.1 normal meter cube per hour per ton corresponds to the rinsing operation, and somewhere around 0.4 to 0.5 normal meter cube per hour per ton would correspond to the alloy dissolution or making the chemistry during the ladle arcing operations such that material and heat at distributed evenly that in system.

So, all ladle techniques have one thing in common. They in one way or other, uses the argon which is injected from the bottom of the ladle. The objective of argon injection, it took stir the contests of the ladle which can add in thermal homogenization, material homogenization, chemistry adjustment, inclusion floatation and many other lied aspects of steelmaking.

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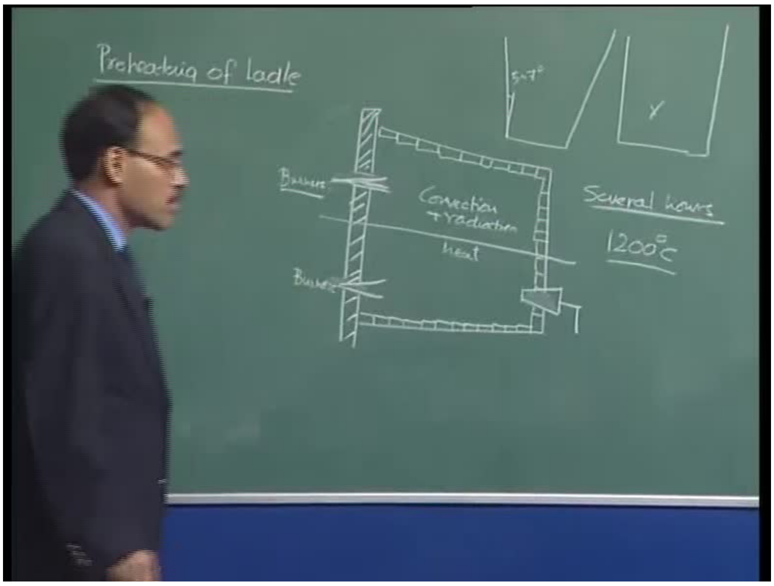

Now, before I proceed further, I would like to talk about little bit about the initial part of ladle pretreatment; that means, when we bring the ladle below the basic oxygen furnace to tap the contents of the furnace into the ladle, the ladle requires to be preheated and the preheating is basically carried out in gas fired furnace preheating of ladle.

So, you can imagine if you look at the ladle is, I have drawn the ladle so far as a perfect cylinder, but please note that the ladles are rarely perfectly cylinder. They are about marginally tapered. My drawing may not be that good, but this tapering we are talking about in ladle is about 5 to 7 degrees. So, the refractory lined ladle is put in this particular position, and then, it is sealed with a cover, and in this cover, we have holes and there are burners. So, these are burners, and as a result of which, there is convection and radiation of heat in this chamber.

So, before we take the ladle through for a tapping operation, the ladle is going to be preheated and this is basically this is the cover, really refractory cover, and there are holes and we burn gases. This is gas fired burners, and as a result of this burning of the gases here, we generate enormous of amount of heat and the heat is going to be converted and radiatively distributed all over, and as a result of which, the ladle is going to be preheated.

Now, typical preheating tangents can go from several for several hours depending on the size of the ladle. By the by, what could be the size of the ladle? I have myself seen plants like, you know, 30ton size ladle, where they have small little electric arc furnace. I have also seen plants which are about 500 ton BOF. So, the ladle sizes can very enormous; 30 ton size, you can imagine about 1 meter diameter to about a 500 ton size ladle, which could be about 4 meter diameter. So, it is an enormous difference in size.

And accordingly, the amount of refractory which is use into significantly different. Amount of the duration of the reheating or preheating is going to be also significantly different several hours will be needed to preheat, and basically, we go up to 1200, 1100 to 1200 degree centigrade, and once it is done, the ladle is ready and then the tapping operation can initiate.

Because otherwise, you take a cold ladle and pour the hot metal from the blast, from the BOF, what is going to happen? There is going to be enormous impact on the loss of temperature or loss of heat, and as a result of which, we will form solidified skulls bulk much of will be solidify over the refractory line. So, never ever steel is going to be poured in a molten in a unheated ladle. So, this is porous plug and this gives us accompany.

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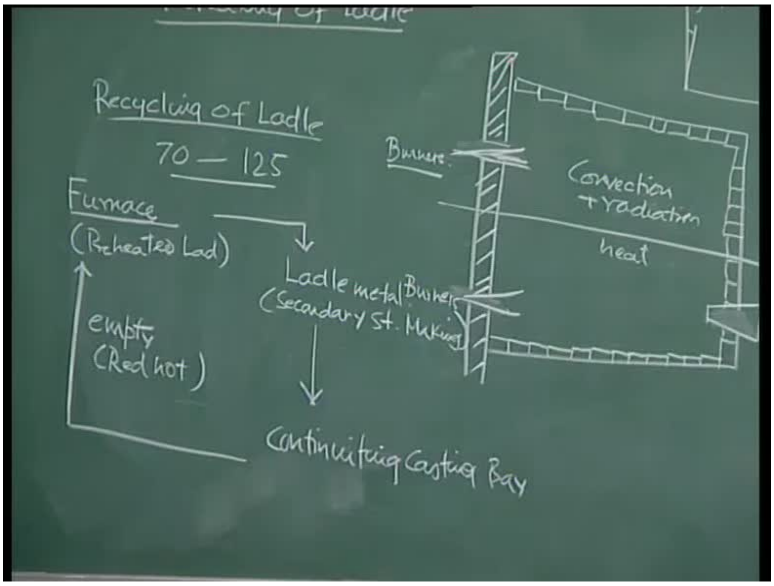

Now, there is another term which I want introduce which is called the recycling of ladle, which I have briefly mentioned recycling of ladle. I want to give some figure. The recycle of ladle implies that we have, from the furnace, we have a preheated ladle. It goes to ladle metallurgy or we say secondary steelmaking. From there, so, the tapping operation can be, if you are casting tapping may be about 8 tonnes 7 tonnes per minute or something like that, in that case, you can fill up the ladle in less than 10 minutes if it is a 50 ton size.

So, we are talking about 5 to 10, 10 to 15 minutes time duration here for the tapping operation. Furnace could be about again 30 40 minutes, and then, ladle metallurgy duration here could be about 60 70 minutes, and once all the secondary steelmaking operations are over, assuming that we required degassing LF operations - ladle furnace operations - or heating operation, injection metallurgy, everything. Then, we go to the continuous casting. The same ladle travels to continuous casting bay, and then, empty ladle is brought here empty, but it is a red hot ladle, red hot, because it was containing, so, this is actually called the cycling of the ladle.

How many times the ladle can move in this cycle? It depends on may be 70 heats, it can go up to 125 heats. That is are the figures that I have from my own experiences with particularly an Indian steel industry.

So, after say 125 heats or 70 heats, the life is, we say that the life of the ladle is now over, because there has been tremendous amount of erosion of lining, tremendous amount of skull formation, and therefore, the ladle necessitates some kind of a relining exercise, in that case, what happens? This, the working lining is going to be replaced and new bricks are going to be put depending on the requirements of specific regions as I have mentioned earlier.

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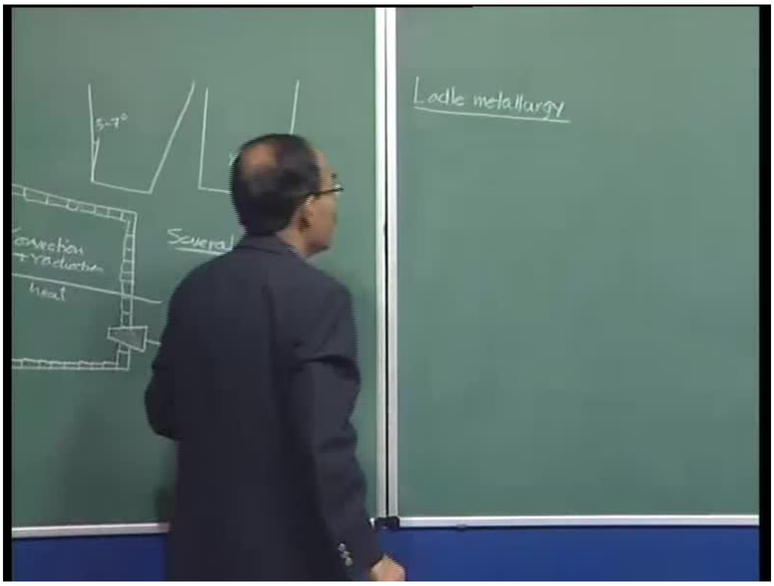

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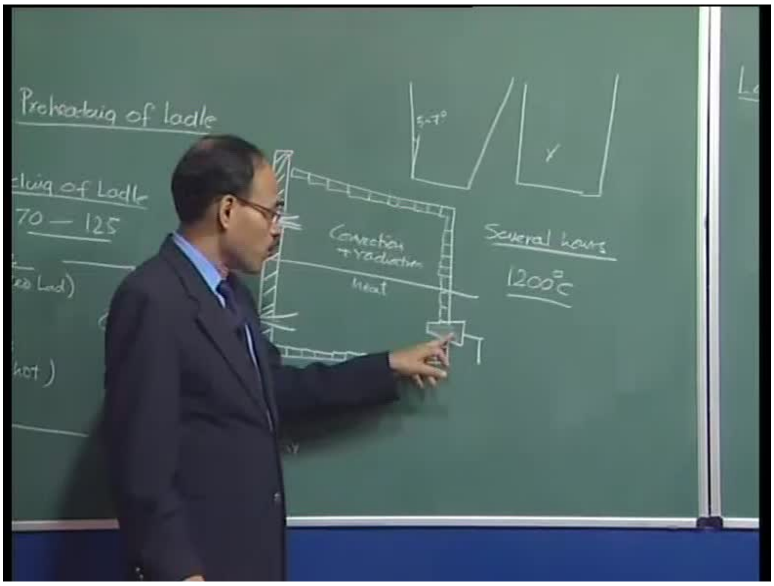

So, to sum up now, I will, in ladle metallurgy, we are going to introduce lot of argon through the porous plug; the argon will stir the contents. The objective of ladle metallurgy is to enhance the composition and cleanliness of steel.

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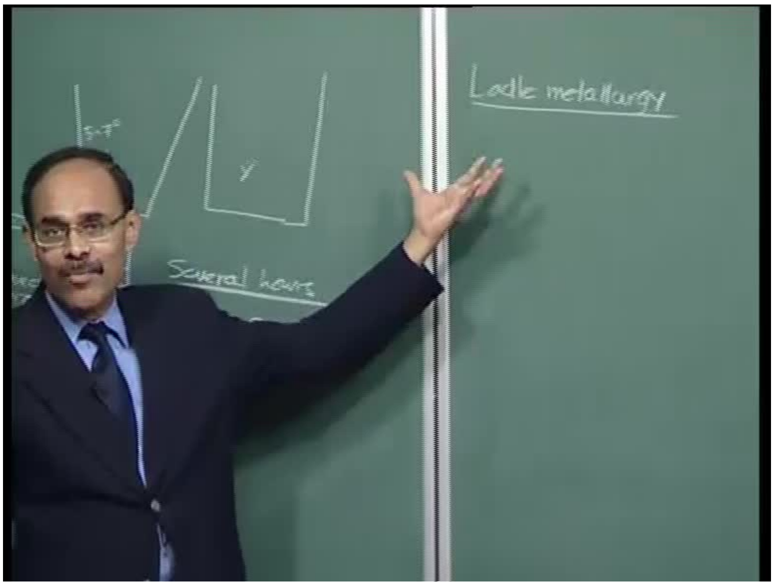

Cleanliness is a very important parameter which I have not so far talked about in this course. So, you will come across this term repeatedly towards the later part and divert of inclusions, removal of inclusions, modification of inclusions, these are extremely important. So, the objective, it is really the value addition goes in secondary steelmaking or in ladle metallurgy operations.

It is the heart of today’s steel plant activities, because this is where the quality of steel is hardness to the maximum possible extent; we have partially known. When you talk about the high grade automotive steel, high grade pipeline steels, these are the steels which have no impurities, very tight compositions with no casting defects and so on, and their foundation is led in this ladle metallurgy area itself.