Steel Making
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Module No. # 01
Lecture No. # 28
Deoxidation, Ladle and Tundish Metallurgy

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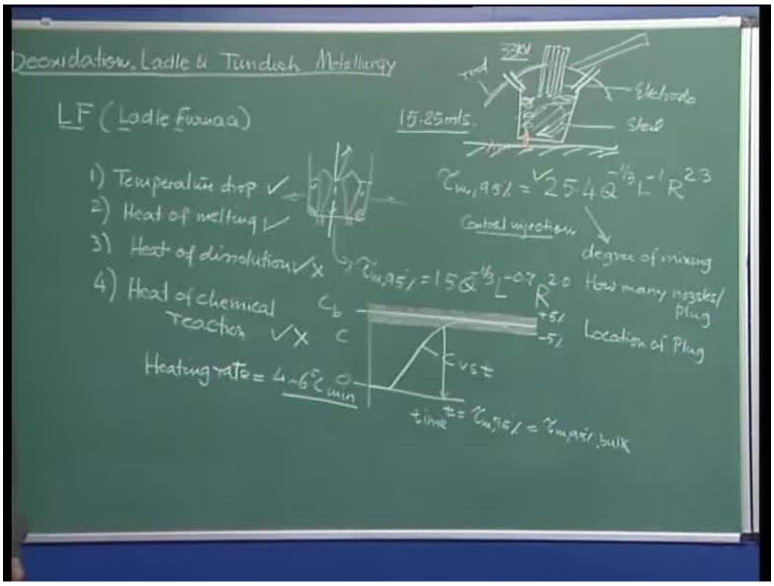

So, we are talking about mixing in ladles, and I have written correlations for mixing time in terms of operating variables, and I said that this correlation is valid for central injection, that is the next symmetric injection in a gas stirred ladle for certain range of gas flow rate, for certain range of vessel aspect ratio.

This constant, which is impercically fitted, this depends on degree of mixing. For example, if I say that it is 99 percentage mixing, in that case obviously this constant is not going to be the same, it is going to assume a much larger value.

It also depends on how many porous plugs or how many nozzles or plug; it also depends on the location of the plug. Actually, when we have, for example, a ladle with two different porous plugs, two different porous plugs, the correlation here for mixing a similar correlation assumes the value, which is very similar to the one that is shown in the above.

So, let me explore a little bit about the mixing time. So, suppose, when you add a species into the system on monitor a concentration, so, we have concentration versus time at the monitoring location which could be here, which could be here, which could be here anywhere in the system. (Refer Slide Time: 02:31)

Now, basically we talk about a reactor mixing time, which is important to us, because if mixing time depends on position, since at various location, the intensity of fluid flow and turbulence are not identical. So, the rate of mixing will vary from one location to another location in the system.

But, what we are interested from engineering sense is that we want a bulk or a reactor mixing time and that typically is characterized by the mixing of the slowest moving region, because by the time the slowest mixing region is mixed up to a degree of 95 percent, that we can say, rest of the system is going to be perfectly homogeneous. So, we have to identify that which is the slowest mixing region in the system, and accordingly, ascribe this mixing time with reference to the slowest mixing region and thereby say that the - that mixing time corresponds or represents the bulk mixing time or the reactor mixing time itself.

Now, basically when a tracer is added or an element is added into the ladle, it cannot go out of the system. At large amount of time, I will have a homogeneous concentration and that concentration may be this level of concentrations which I say as C b. Now, for example, if I have 1 ton of liquid here, and if I have added 1 kg, the uniform concentration is going to be 1 by 1000 multiplied by 100 in terms of percentage, and therefore, that is the uniform bulk concentration that I have represented, which is nothing but the mass fraction of the added element. The mass of the added element divided by the total mass of the fluid in the system, that is what we are talking about and that it is the final attainable concentration in the system.

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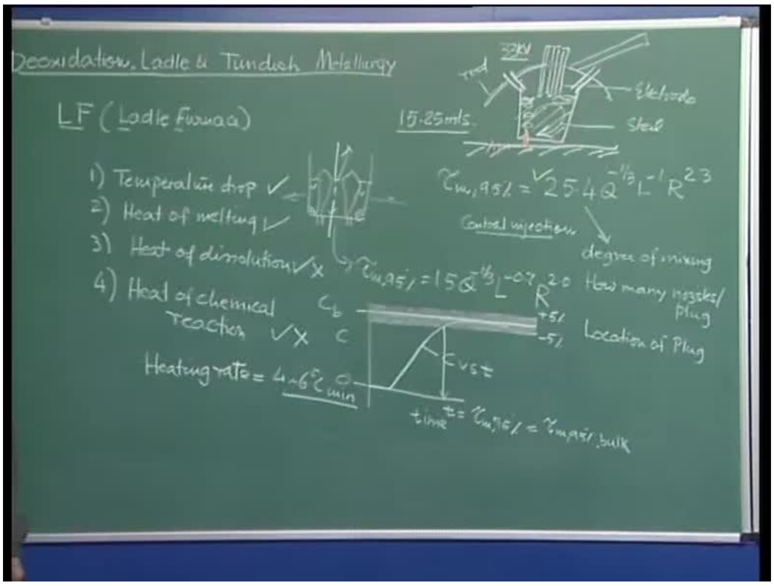

Now, following the additions dispersion at, for example, if I have added at certain point of time and there was no concentration of the species in the system. In that case, for example, say I add ferro niobium into steel and then I find that initial where steel have 0 ferro niobium concentration to the concentration is 0. So, and if I am monitoring at this particular point, I would say that for sometimes the concentration will be 0, and then, ultimately the concentration will build up and then eventually asymptotically approach the bulk concentration line.

So, C versus the concentration of niobium versus time, and then, we can say that, well, if I draw a band which is plus minus 5 percentage, so, this is minus 5 percentage, and this is plus 5 percentage of C b, in that case, I can say that, well, this is the time that corresponds to 95 percent mixing rate.

And this point where I am monitoring, if it is, if it corresponds to the characteristics of the slowest mixing region, in that case I can say that this mixing time indeed is equal to tau mixing 95 percent bulk, and this fitted constant here that I have shown is actually corresponding to bulk mixing time in a central gas injection where I have only one single porous plug, and I have the porous plug located at the geometrical central line of the system itself.

And for dual porous plug, as I have shown here, the correlation is essentially different. Although the exponents on Q L and R are similar at least in terms of their nature, because these are negative exponents on R, it is positive exponent which essentially is consistent with the theory of fluid flow in ladles.

Let us now look at the ladle furnace operation L F which is ladle furnace, write like this. I have mentioned that or we know that of the objective of ladle metallurgy steel making is to adjust the composition of steel, adjust its temperature, and improve its cleanliness.

We would be now talking about addition of following elements. Now, as we process molten steel for vacuum degassing or degassing operations or a inclusion flout out or injection metallurgy and even in holding period as I have mentioned that 0.5 degree centigrade of per minute of temperature drop. So, there is going to be considerable amount of temperature drop in molten steel contained in ladles.

As a result of which, we have to compensate for heating. It is not desirable that steel from primary steel making vessel should be taped at very high temperature to compensate for this temperature loss or the requirements of the secondary steel making, that is a very stupid way of doing things, because higher is the temperature in the primary steel making furnace, lower is going to be the life of the refractory’s there. So, it is not desirable to increase the temperature of molten steel beyond a certain level in the oxygen steel making furnace. Otherwise, it is going to impair the efficiency of steel making.

So, having tap the steel at the requisite temperature from the BOF, we have to have for the entire duration of secondary steel making. To sustain the entire duration of secondary steel making, we have to have at certain stage heating arrangements and that is facilitated by ladle furnace.

We may be adding, for example, so, first I would say that there is temperature drop, temperature, temperature drop because of heat loss through the, furnace, ladle walls from all sides in the pre surfaces, the heat is lose, and as a result of which temperature drop. We may be adding some alloying additions to adjust the composition of the steel.

Suppose, we may be adding some ferro niobium, some ferro titanium to adjust the composition and these are solid additions; their temperature has to be taken to 1600 degree and they have to melt or dissolve. So, heat of melting, we have to supply, melting it, and into endothermic process, so, we have to supplying the heat.

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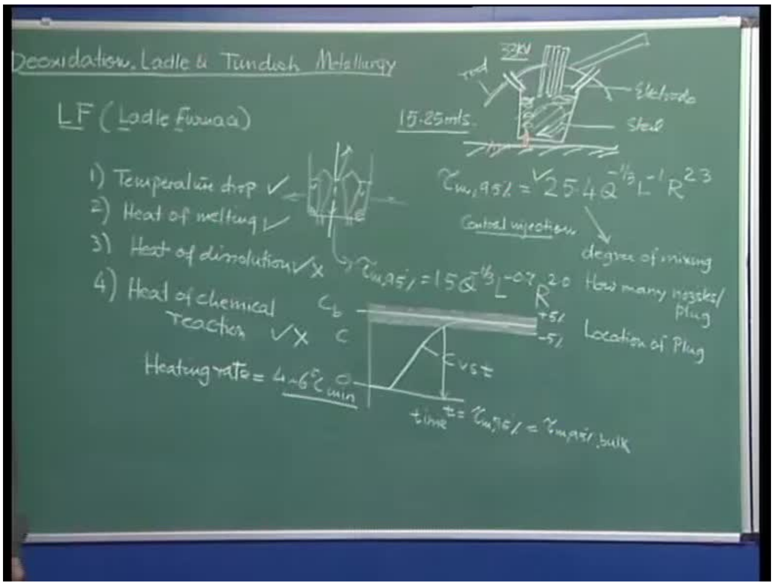

Number 3: once the allowing addition melts it is going to dissolve into molten steel, and then, I can say heat effect of dissolution this, of course, sometimes this could be positive, sometimes it could be negative, because some heat of dissolution will be exothermic in nature, some heat of dissolution will be endothermic in nature.

This is always a requirement, this is always a requirement, this can be a requirement, may not be a requirement. Similarly, we have temperature drop, heat of melting, heat of dissolution, and finally, we can say that heat effect of chemical. The alloying addition may dissolve, it may react with oxygen, for example, or any other elements present, and then, some amount of heat may be or absorbed, depending on whether it is a exothermic reaction or endothermic reaction.

So, there are lot of heat demand for the secondary steel making processes, and therefore, we have to have some arrangements for heating the ladle.

Now, how does a ladle furnace looks like? This ladle is converted into a ladle furnace just merely by we have basically a roof through which we have an arrangement like electrodes, so, these are my three electrodes and we have a roof here and this could be…

So, this roof may be the entire thing can be attach to an assembly and it goes like this. So, the roof is in this particular arm, the roof can be rotated; so, the roof remains with the electrode, remains like this normally, and if you go to a secondary steel making plant, you can see this arm, you can see the roof and you can see the electrodes hanging in open. Then the ladle is brought after taping to the ladle furnace station, and then, the arm rotates and puts the electrode as well as the cover over the ladle.

So, if this is the configuration, then I can see that, well, by, when I have a ladle inside, in that case what happened is the ladle goes something like this. So, this is my floor and then we have a porous plug here, through which gases are going to be evolve, and then this is the slag layer, this is the slag layer, and then, we have the metal layer sheets. This is the steel; this is the electrode; this is the roof, and roof and the electrode are the movable structures, or now you can see that this can be converted into what is known as a heating arrangement. Through the electrodes, arc can be established under high voltage, and we can have heating and heat can be supplied to the molten steel.

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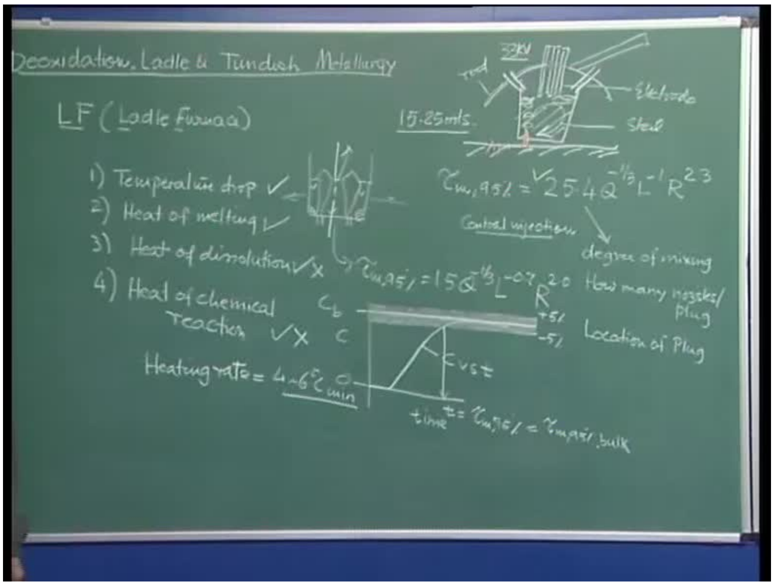

Deoxidation, Ladle & Tundish Metallurgy

LF (Ladle Furnace)

1) Temperature drop ✓
2) Heat of melting ✓
3) Heat of dissolution ✓ X
4) Heat of chemical reaction ✓ X

Heating rate = 4-6 °C/min

15.25 m/s

$\tau_{m,95\%} = 25.4\, Q^{-1/3} L^{-1} R^{2.3}$

Central injection

degree of mixing

How many nozzles/plug

Location of Plug

$\tau_{m,95\%} = 15\, Q^{-1/3} L^{-0.7} R^{2.0}$

$t = \tau_{m,95\%} = \tau_{m,95\%,\text{bulk}}$

So, this is the argon injection here, I can show it with a colored means chalk. So, this is the argon injection line, so, steel we have argon injection here. So, the bubbles raise here, so, there is going to be some amount of convection current and this convection is going to add the heat which is supplied by the electrode itself.

But at this, these are the arrangements for introduction of, say alloying additions, another arrangements for auxiliary additions into the system and these are our electrodes which are connected to the three phase circuits to a, may be 33 KV line and so on.

Now, where do you supply this? Convert the ladle into a ladle furnace, heat is being supplied. In that case, the heating rate is something like for some rating, typical rating about 4 to 6 degree centigrade per minute. How much of a duration we are talking about? We are talking about a ladle treatment the range of 15 to 25 minutes.

During this region, we may have aluminum wire feeding. If you have not carried out deoxidation earlier, we can have synthetic slag. One point which I have missed here is also that we may be forming some slag by addition of synthetic slag, because we have, if you have brought it immediately from the basic oxygen furnace, then there is no slag available here. So, we have to add some lime also, some spar also and form a fresh slag. So, the formation of a new slag may also, if it is involved, will consumes some amount of heat.

So, basically, the supply from transformer, I will coat some data to give you an idea, further say an 185 ton size ladle and the supply from transformers of the order of 33 megawatt, and this is from transformer, from transformer, and to the furnace, the power is roughly about two furnace. The power is set at the rate, if, 17 megawatt and this gives rise to a heating of at the rate of 4 to 6 degree centigrades per minute and the entire processing is done for 25 minutes, where we may have aluminium wire injection into the system for de-oxidation. We may be adding some amount of alloying additions to melt and adjust the composition of the alloying additions of bulk steel and so on.

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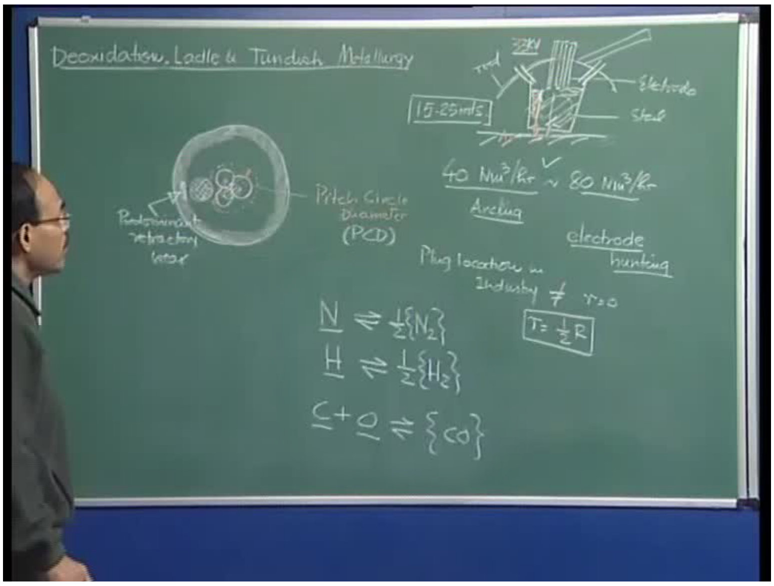

Now, it will be clear to you that why do you want alloy as the porous plug to be located at the center, before I go into that, I would say a typical arching flow rate could be something like a normal meter cube per hour to about 85 N m 3. That is the flow rate which is done in arching, but the objective is to compensate for temperature drop, and at the same time, expertise melting rate on supplied heat of chemical reaction and so on.

Now, if you look at the top, look from the top, then that, this, if you look like, this is the, this is the ladle for example, the top view of the ladle, let us say refractory line vessels I can draw a thick layer around it. There is a top view of ladle, and you are going to see now three electrodes in this particular way. These are our three electrodes.

So, there, this diameter at the center, if I, they can be encased in a circular per section, and this is called the pitch circle diameter, pitch circle diameter, or if you go visit shop floor, you will say people frequently talk about what is known as a PCD.

Now, when you injecting gas, if you inject the gas, for example, if I inject it at the center of the vessel, then this is going to come, the flume is going to surface through this particular region, the flume will be totally surfacing and straightening the electrodes directly.

On the other hand, if the flume porous plug is located, a little bit away towards the wall itself, in that case, I can see that the area in which the flume is going to be surfacing will be represented by this as days.

So, therefore, by displacing the porous plug towards the wall, it is possible to prevent direct contact of the surfacing flume with the electrode. Now, why it is so important? Because we know that in the flume region you have a high velocity. This bath does not contain carbon the electrodes are made of graphite. So, what happens is this graphite will tend to dissolve very fast, and this phenomenon is known in the industry or ladle furnace as what is called as an electrode hunting phenomenon, electrodes get hunted.

So, therefore, by displacing the porous plug towards the wall, we are able to minimize the hunting of the electrode or dissolution of the graphite electrodes into the melt. Of course, we must understand that where you displace the plug towards the wall, although we can save the electrodes from the direct interaction with the surfacing porous plug or surfacing argon liquid steel flume. This surfacing flume becomes very close to the refractory line wall. Therefore, you will see predominance, predominant refractory wear in the vicinity where I have the predominant refractory.

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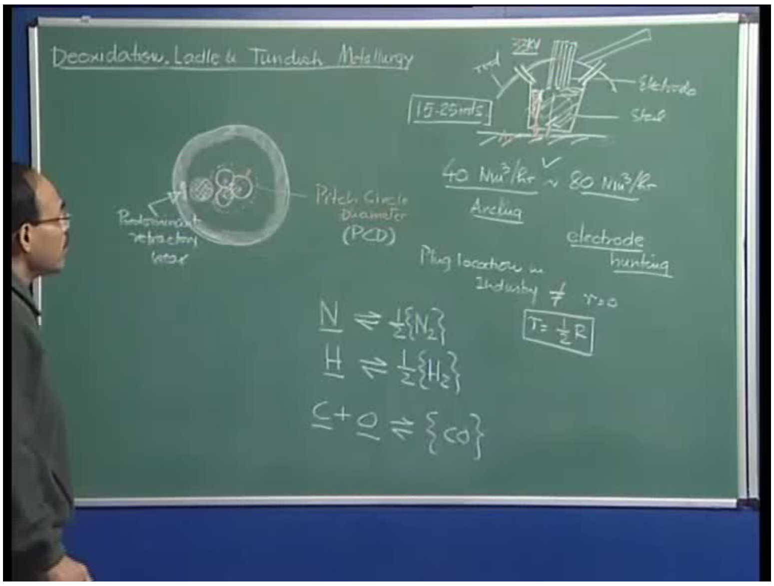

So, this is the region where you are going to experience, you are going to see that there is going to be considerable amount of refractory wear. Why it is so? Because the bubbles arising here, the high velocity regions are located here; so, it is a very high downward velocity which comes close to the wall, and as a result of which, because of this high downward velocity which is shown by a red error here, the hydrodynamic erosion of the refractory beams are very significant.

So, typical location, therefore, the location of the porous plug basically is at the mid bath radius position. So, the plug is displaced, plug location in industry, location industry is not at r is equal to 0, but it is at basically r is equal to mid bath radius position. So, we will always do that.

I think having said this much. Let us now go to the other section of ladle metallurgy. The next important topic for us is degassing. So, the drop in temperature in tapping, the drop in temperature because of holding, the drop in temperature (( )) the melting and dissolution processes are going to be compensated about through ladle furnace or through treatment in ladle furnace.

So, when you get the material out of ladle furnace, it has little bit more temperature, then is desired at the concentration. Its composition is correct in terms of solutes but it may still contain nitrogen which may have been absorbed during taping of the furnace itself. Hydrogen, which may have been absorbed because of some wet material like, for example, the lime that I have added or we have added to make the slag, the lime may be hygroscopic in nature. The hygroscopic in nature can contain lot of moisture.

So, carbon silicon manganese are sulphur phosphorus and another alloying additions niobium, titanium, etcetera, may be right, but at this particular stage, the material may still contain some dissolved gases, and once we element dissolved gases, that means the composition of the steel in the ladle is going to be perfect. Its temperature is going to nearly right, and at the same time, we have to now only ensure towards the later part of ladle treatment is that what is the level of ladle invest in the melt, and once that point, we have been able to address, we can go forward and cost the steel through a steel making tundish ladle more simply.

So, having fulfill the objective of the material in through ladle furnace treatments, so, the next objective would be that, if you want very sophisticated grade of steel, arctic pipeline grade steel, rail steels, for example, which has very little tolerance for high nitrogen and hydrogen. Hydrogen and nitrogen, we all know that hydrogen causes the brittleness, nitrogen impairs toughness of the steel very drastically and also, you know, if you are talking of making a deep drawing steel, in that case the significant amount of nitrogen is not tolerated.

So, at this particular stage, even beyond ladle metallurgy, we have beyond ladle furnace. We may have some nitrogen and hydrogen and which you can have to be eliminated. The technique that are used are the commonly called the degassing technique and these are basically the vacuum degassing technique. Degassing will be facilitated under vacuum, and once I tell you the principle briefly, you will understand that pipe vacuum facilitates dissolution.

For example, if you take nitrogen, which is dissolved in steel, we can underscore, and then if you consider the equilibrium of this reaction, and this nitrogen, it is driven out of the melt and it goes into the gas phase. at

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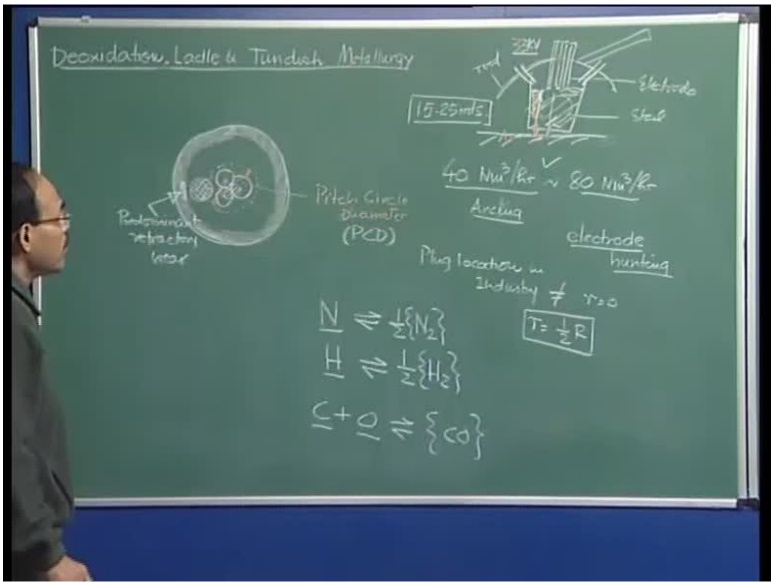

Similarly, if you have hydrogen in the melt, and then, we have equilibrium of this reaction is half of H 2. Similarly, under vacuum, the carbon oxygen reaction can also shift. We have studied in primary steel making reaction C plus O is equal to CO at one atmospheric pressure, and that curve, that is drawn for percentage C against percentage O, that line will shift depending on what the pressure is. So, whatever carbon and oxygen are there in the melt, under the application of vacuum, the curve is going to be shifted. So, the equilibrium CO equilibrium will also shift another backup.

It is at once clear that smaller is the partial pressure of nitrogen in the gas phase, more will be the tendency of this reaction to go from the left to the right. This is the simple principle of solubility product. On contrary, we can say that higher is the concentration of nitrogen in the product phase. This is the product; this is the reactant; (Refer Slide Time: 23:59) so, higher is the concentration of nitrogen, more will be the tendency or to go in this direction or less will be the tendency.

So, by continuously removing, by continuously removing nitrogen from the system, we will be able to facilitate this reaction to move in the forward direction by continuously removing hydrogen from the system, we will be able to facilitate metal to loose hydrogen and same is true also with carbon monoxide.

So, therefore, all this gas forming reactions as I have enumerated here, - the three reactions - they are going to have a greater tendency to move in the forward directions from left to right under the application of reduce pressure and that is why we apply carry out the degassing operation in steel making under reduce pressure.

And what sort of a pressure we are talking about? We are talking about 1 millie watt pressure is an extremely a low pressure, and at that pressure, we are going to help the steel for some amount of time, and of course, to obtain that kind of a pressure, we have to have pressure like chambers as well.

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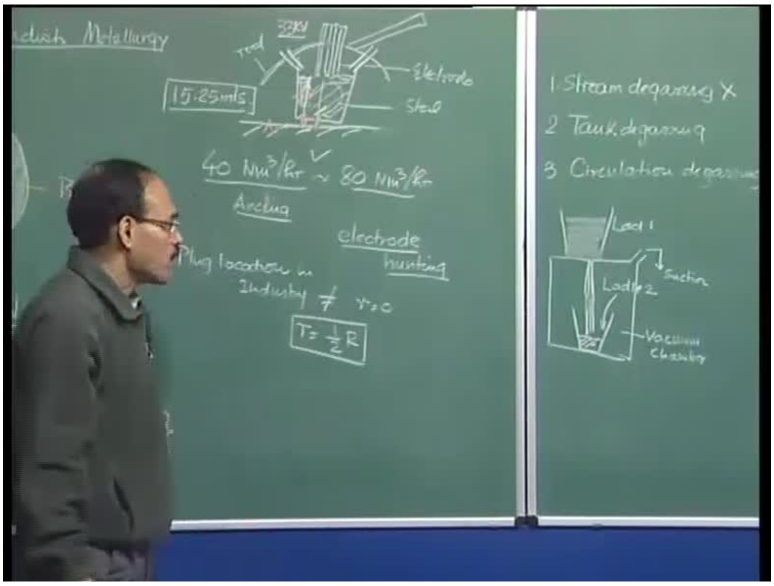

And there are various kinds of degassing processes which are there in industry. Now, typically three different types of processes are known - one is called stream degassing which of course has become oxalate stream degassing, the second one is called tank degassing and the third one is called circulation degassing.

So, I said that this is not there, but it is good to know a little bit about stream degassing, what does that mean? That means we have a chamber, a ladle, so, this is a small little ladle which is sitting here, which contains molten metal, and then, we have molten metal falling in another ladle which is contained in a big chamber. So, this is ladle 1, this is ladle 2, and this is the vacuum chamber, and this is the suction. (Refer Slide Time: 26:21)

So, when the metal falls from here to this place, what happens is the steam is not coherent. You can, we have seen that if you open a tap, the stream, the water stream from the tap is highly non coherent; it does not fall like a cylindrical shape at one, so, there are droplets. So, there is a large formation of droplets because of the application of high pressure as the material falls there.

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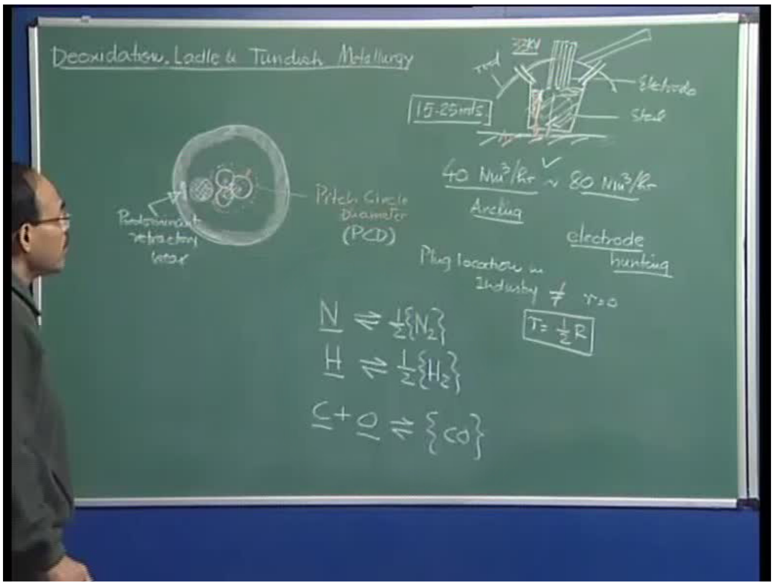

Large surface areas are created, and large surface area essentially implies, because these reactions are occurring at phase boundary. You must realize that this is, in the metal, this is in the gas phase. So, this chemical reaction must be occurring at the phase boundary. These are heterogeneous chemical reaction. Therefore, the rate of the chemical reactions is going to be related to the surface area.

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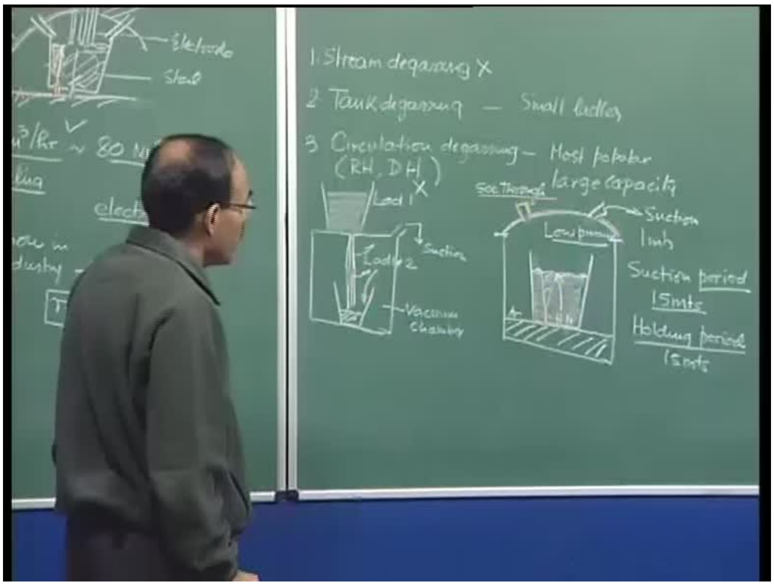

So, as a result of, exposure of the stream to vacuum in the form of tiny droplets or high length. What we are basically doing is we are enhancing the surface area through which this sort of a reactions or which of course, there is low pressure system here. So, you have increased the area and we have low pressure system. As a result of which, lot of hydrogen and nitrogen from the metal will go to the gas phase and they will ultimately drawn out. It is enough, a very efficient process and that is why it is become very very… We cannot reach very extremely low hydrogen and nitrogen through this technique and that is why it is become oxygen.

Tank degassing on the other hand is an improved version of this. Tank degassing is basically adopted for small ladles, small ladle means how much? We are talking about 50 ton ladle, 60 ton ladle, 70 ton ladle of that particular size. Circulation degassing is most popular and this is for most popular and this is for large capacity ladle, large capacity ladle.

The principle everywhere is same; increase surface area, increase subject to low pressure system and that is how you are going to eliminate the gas phase itself.

The efficiency of circulation degassing is the highest and that is why it is become more popular and it is widely accepted for larger capacity ladles and because the capital investment in circulation degassing is very very heavy. Circulation degassing again has two different types - one is RH and one is DH, and this DH circulation degassing has become virtually absolute today, it is RH degassing process which is universally some versions of RH regassing, of course, is available, but the essence of this, I am going to describe the RH regassing is being applied in most of the large capacity steel plants in a routine basis.

So, coming to tank degassing. Tank degassing essentially means that we have a tank, and in this tank, we have a ladle and this is the ladle which contains molten metal and this molt there is argon injection here, it is argon injection and the entire thing here is subjected to… We may have some windows also, through which one can see through that what is a state, and then, we have suction here, argon is injected here, we have slag here, and the flume is generated, and this produces low pressure system, and as a result of which, fresh materials are going to be exposed to the low pressure, and there, this is particular reaction is going to facilitate.

We must understand that without argon, what is the scenario that we are going to have? We are going to have molten metal covered with it completely by slag. So, we have one to bring molten metal in contact with vacuum or the atmosphere, and as a result of which, what happened is we have to blow in other.

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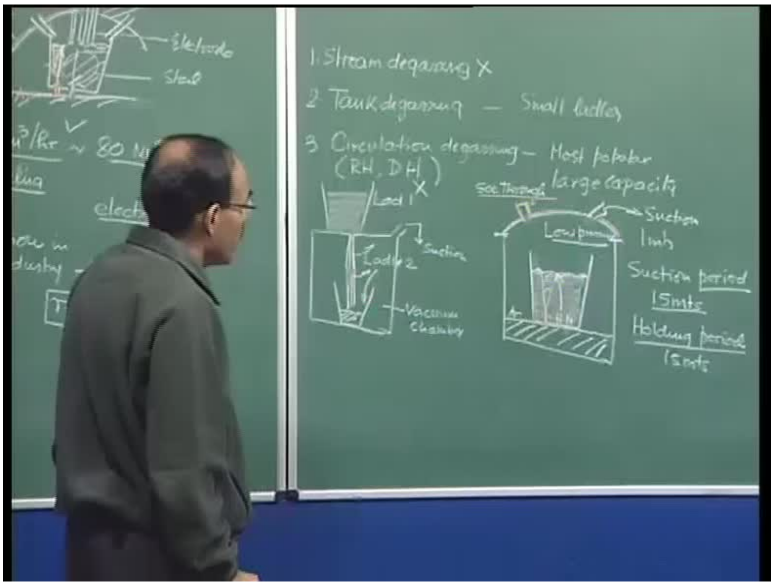

Also you must understand that the hydrogen or nitrogen which is sitting here has to move to the free surface and then only the interfacial chemical reactions can take place at the gas or a bulk metal interface. So, therefore, we understand that the injection of gases during vacuum argon gas, during vacuum degassing process is extremely important as it facilitates to bring in fresh material towards the slag metal interface or towards the metal ambient interface, and as a result of which, fresh metals containing hydrogen and nitrogen are exposed to vacuum, and where, this particular chemical reactions take place producing alter low nitrogen and hydrogen steel.

Now, there we can have initially what is known as a suction period. So, basically, we have this tank which is there in the degassing area. So, if within this tank, this particular ladle which contains the metal is lifted with rover head crane and then it is brought and kept inside the tank.

So, that is arrangement and then an additional cover is brought and that cover is put over the tank and this is this particular cover I am talking about. So, once this cover is brought, it is made air tight and then the suction starts, and one can monitor through this particular window, which is, which I say as a seat through window, this is the one and see the progress of degassing process itself.

So, the tank is an enormous structure. It could be, you know, if the diameter of the ladle is 3 meters, this tank could be about 9 meters to 10 meters in diameter. The huge tanks are available and these tanks are made of extremely thick steel plates. Suction period typically could be, it depends on the size of the ladle basically, I am talking with respect to a 15 ton ladle, but the suction period is 15 minutes and holding period - holding period means depressurizing period holding period - is about 15 minutes.

For 30 minutes of processing time, for about 50 tons of steel, and during the suction period, the pressure here, in the chamber, continuously drops, and then, once 1 millie watt pressure is this at that particular time give about 15 minutes of holding, and during this particular duration with argon gas injection, you know, this reactions are driven towards the forward direction, and as a result of which, we produce low nitrogen and low hydrogen state.

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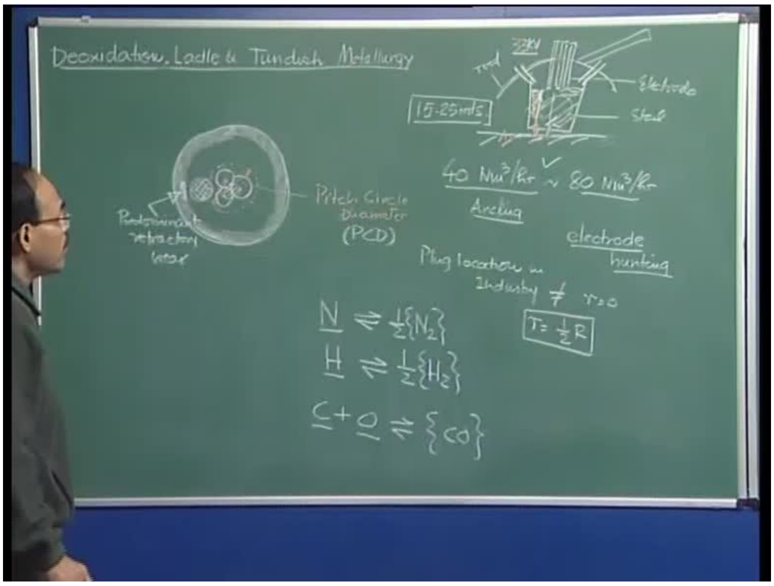

Now, in degassing process, there could be significant drop in temperature also. So, therefore, the material that is brought here actually is a overheated to some extent in order to compensate for the degassing process, because L F is before degassing process, so, to compensate for the temperature which is going to be loss during the degassing process and what we are going to see? We are going to notice that there is a temperature drop because the degassing and this temperature drop has to be compensated by the LF station, therefore, the material which comes from the L F is at a higher temperature, then is required by the continuous casting way in order to compensate for the temperature drop in the vacuum process itself.

We must understand here that because the pressure is extremely low, the bubbles are subjected to just the ferrostatic head. So, the bubbles really grow enormously in the system. So, as a result of which, the same gas injection which will produce say x amount of stirring in this system; in under vacuum, it is going to produce significantly higher amount of stirring because of the increase in the gas volume, because as pressure goes down, the volume of the gas increases.

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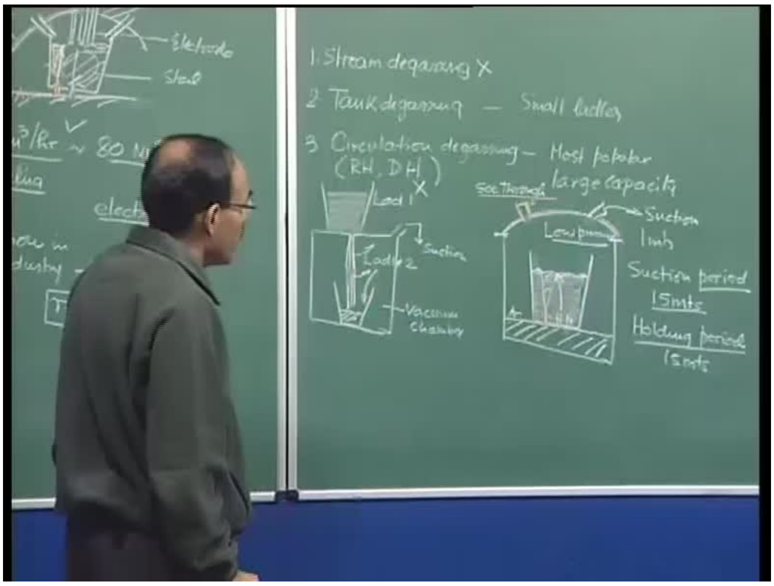

So, the volume of the gas for in the same gas flow rate is going to be higher here, then it is here; the size of the bubbles are going to be higher here, then it is here, and as a result of which, even a small little flow rate is going to cause considerable amount of stirring in the system itself. This stirring produces the slag high area and brakes the slag; this is the slag; this is the slag, and this is where the metal directly comes in contact with the atmosphere environment. (Refer Slide Time: 35:51)

It is not here, there is no contact with the metal and the atmosphere here because it is covered with slag. There is no contact here, it is only through this surface that the metal comes in contact with the unbind atmosphere. Now, we have a circulation time concept and that circulation time basically is 3 times the mixing time.

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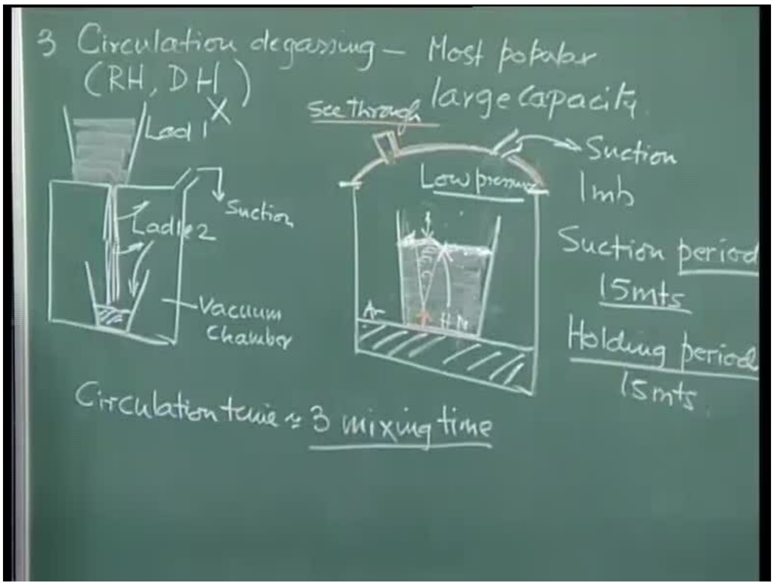

So, I can find out that what is the mixing time of the ladle. Suppose, if I have a correlation like the one I have shown mixing time is equal to 25.4 into Q raise to the power 1 by 3, etcetera, etcetera. So, if I know the mixing time, so, I can substitute the parameters, the gas flow rate, depth of the liquid, the radius of the vessel, I can calculate the mixing time, and then, 3 times the mixing time you roughly give me what is known as a circulation time, and that means, that one time to circulate the steel in the system, we can have, you know, which could be about 3 times longer, then the mixing, time and we may be 9 or 8 circulation, or 13 or 14 circulation, depending on the level of final attainable hydrogen and nitrogen, and accordingly we can knowing a mixing time, we should be able to find out. That what is the processing time.

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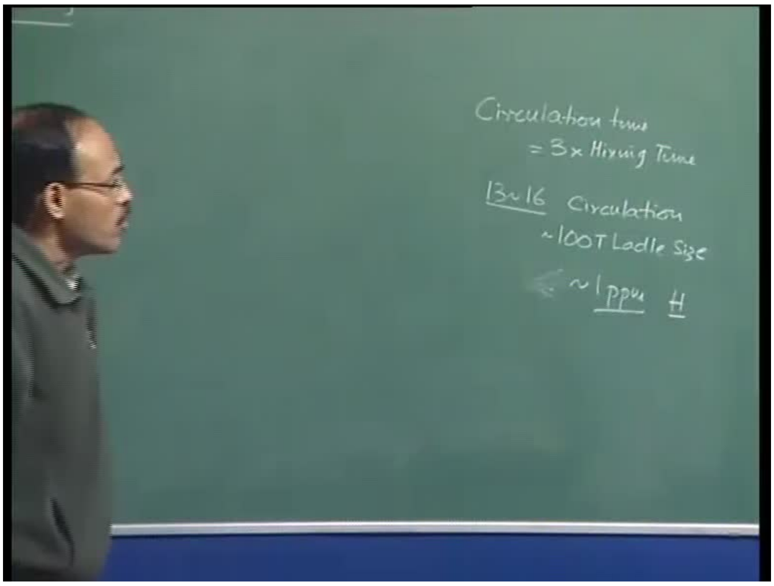

The number of circulation actually necessary could depend on the size of the ladle and just for us, for the sake of getting an idea that for a 100 ton ladle size about 13 to 16 circulation may be necessary and each circulation time corresponds to about 3 times of the mixing duration. So, that gives you an idea, you know, and this is needed to get a hydrogen approximately about, say approximately 1 ppm hydrogen in order to attain, dissolved hydrogen system, you require about 13 to 16 circulation.

So, this will depend basically on the size of the ladle how many circulations are necessary and the final composition of the desired.

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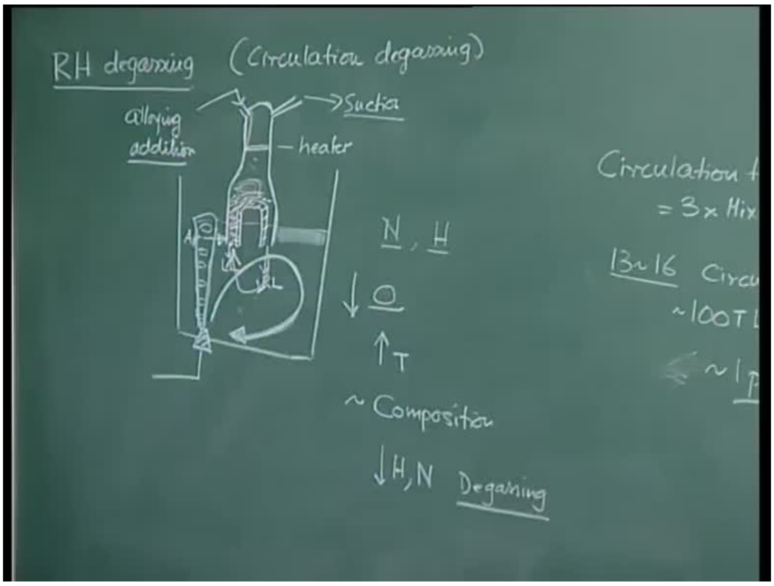

Now, the last and the most important type of degassing is the RH degassing process and this is, this is called a circulation degassing. The generic name of the process is circulation degassing and it will be clear to you in 1 minute that for doing in y.

Now, the ladle is here. The porous plug through which argon is inject here, and then, we have basically, then we have argon again here. So, this argon may be because of stirring and we have argon which is being injected through. This is the apparatus actually, the circulation RH degasser and this degasser is brought and it is going to immersed into molten steel.

It has two lags as you can see, this is called the left lag, left leg and this is the right lag. So, when we immerse this degasser into molten steel and then introduce a lift gas argon here, so, the argon gas, because of its buoyancy is going to raise up practically, and as the argon gases is going to raise up, molten metal will also raise along with it.

So, I have molten steel. This is the argon bubble here for bulk stirring. This may be there may not be there; so, it is causing some stirring here in order to take material from here to the left lag, and then, because of this lift gases which raises through the lift through the left lag, it draws molten metal along with it.

Now, as it draws the molten metal, low pressure system is going to be applied here, and as a result of which, what happens is the material will flow from here to here. So, some argon gas bubble is going to be introduced here; the bubbles are going to raise, along with it the molten metal also going to raise into the degasser, and then, it is here, and we apply suction, so, the molten material here is all exposed to vacuum, and this is the plate which is may be acting as a heater to supply heat to the molten metal because I said that there is going to be significant amount of temperature drop.

So, the bubbles injected here is going to enhance or increase in size because of the application of the vacuum, and as this big bubbles raise with extreme evaporated, they are been drawn from the high pressure at a very fast rate. So, there is going to be lot of molten material drawn into the upward lag, and as a as the material is drawn into upward lag, from some hydro material has to come, and as a result of which, some circulation is going to.

And this argon gas through the injector, through the porous plug, this is now going to bring in more and more fresh material into the lag, and as a result of which, a circulation that is established here is going to expose all the material content in this system under vacuum, and as a result of which, the material will be effectively degassed. We can also have certain stream composition adjustment alloying additions and it is a highly efficient degassing process.

So, this is the general conjunction current generated because of the porous plug and this is the flume or as if this flume causes a overall bulk circulation, on the other hand this argon which is I have shown being introduced into the left lag is termed as the lift gas.

And this lift gas actually draws the material into the vacuum chamber, exposes it to vacuum, and as a result of which, we have metal vacuum or metal embed interaction here; so, we have the heterogeneous chemical reaction or the degassing reactions taking place, not here, not here, but it is taking place really here to got the material or the metal is going to be exposed to the combined medium, but this circulations are also equally important, this lift gas also is important in order to expose fresher and fresher material at every instant of time to vacuum itself.

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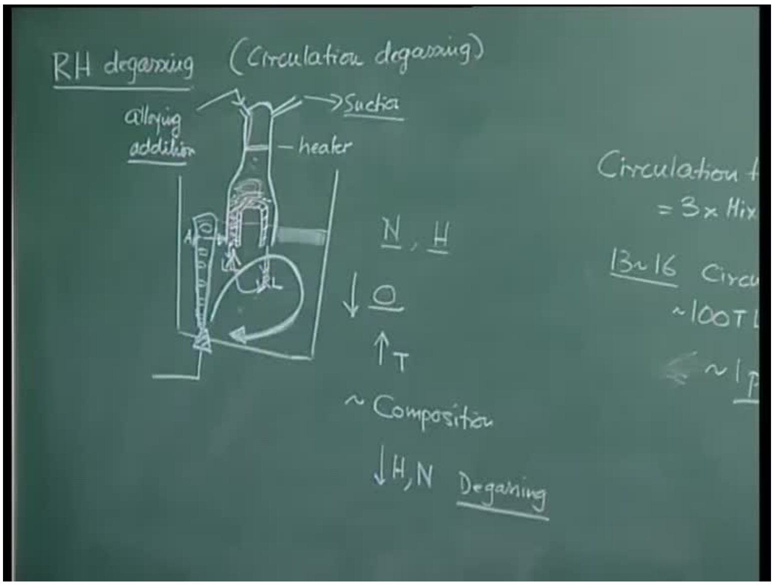

So, these are called the sparkle; this is called the sparkle. This left lag and right lag and there thing what is being immersed into molten metal is snorkel and this snorkel as arrangement for suction, and we can apply the same pressure. One maintain 1 millie watt pressure or even lower and then we can make certain alloying addition. The entire chamber is filled and is operated in such a way that we can monitor temperature also by starting sensors. Without breaking the vacuum, all these alloying additions temperature measurements, etcetera can be carried out by breaking a vacuum itself.

And it is important that the lags are submerged to a certain depth. Below the slag layer, because I am going to, we are going to have some slag here, so, they have to go really below the slag layer, such that it is not slag. What is drawn inside? It is the molten metal. Some amount of submergences of the lag inside the metal is very very important, and as molten metal is subjected to the degassing technique, the nitrogen and hydrogen level in a molten metal can be significantly.

So, at the end of inert gas stirring, or if you look at from furnace taping operation, we have furnace taping and then deoxidation operation, then ladle metallurgy operation, and then, finally, degassing operation. What we have been able to achieve is that we have been able to reduce oxygen content of the melt through degassing. We have to increase temperature of the melt, and through L F operations, we have been able to adjust composition correctly in the L F itself. We have been able to remove hydrogen and nitrogen through degassing.

So, composition is correct; less amount of hydrogen and nitrogen temperature is up; oxygen is down. So, whatever were the demerits, or you know the problems associated with the primary steel making that the material contains lot of oxygen because of oxidation refining reactions. It had - the composition was not right, only the carbon content what was right, and that during tapping your transfer operations, we had lot of pick of hydrogen and nitrogen. All these have been regulated or controlled effectively through inert gas stirring through ladle furnace through random circulation degassing and process.

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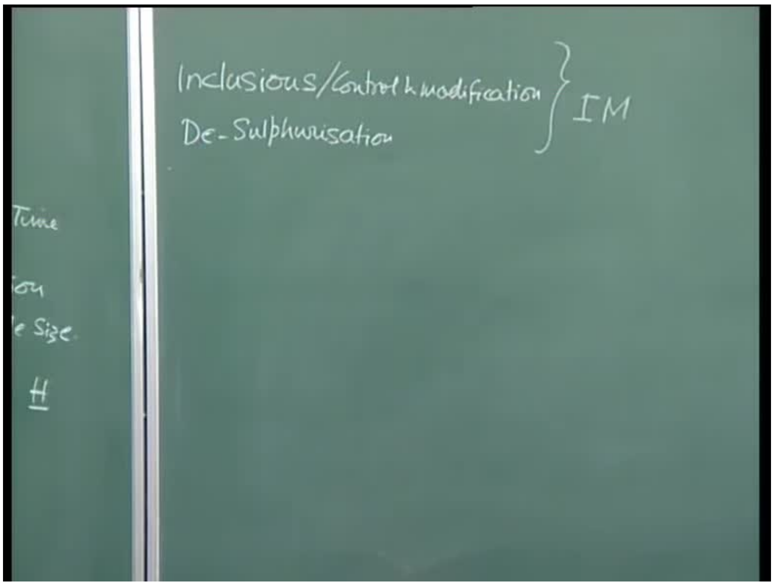

So, the final front here of this is now, we may still have some issues regarding inclusions, and also in some specific cases, we may be concerned, which what is known as desulphorisation, and inclusion control and inclusion modification as well as inclusion control modification, these come under the jurisdiction what is known as injection metallurgy shortly IM.

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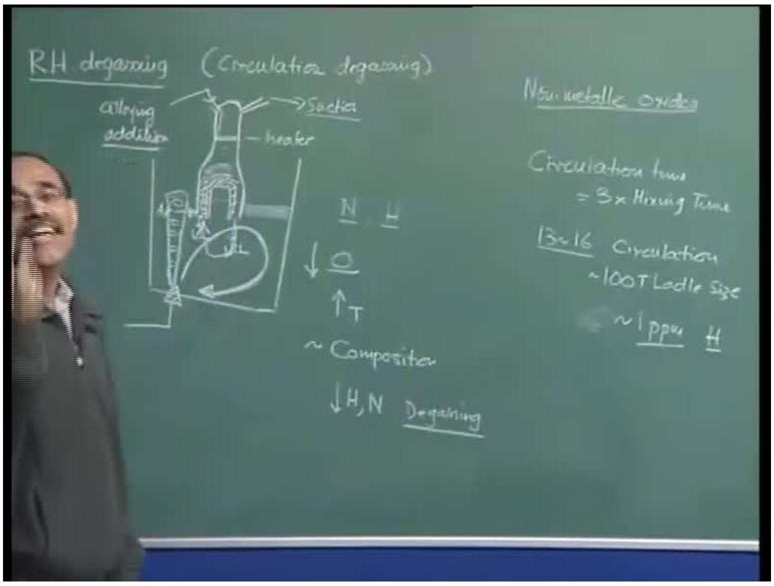

Desulphorisation, we all know that blast furnace is the ideal place for removal of sulphur because blast furnace provides as with a relatively basic slag. It has extremely low oxygen potential or highly reducing environment and also we have relatively high temperature which are thermodynamically correct for desulphorisation.

Now, that the slag is not really very basic and sometimes that would cannot have too high which is in the blast furnace because it will may have that too high a temperature, one to make the slag fluid, one to drive the desulphorisation reactions from left to right. In that case, what we feel is that we have too much of a silicon in the metal because the silicon deduction reaction will take place at the elevated temperature because there is lot of coke in blast furnace, and as a result of which, the pig iron is going to conflict lot of silicon and that silicon is going to drastically effect the performance of the oxygen steel making processes, because more silica means more temperature, more silica means more slag volume, more silica means more line.

So, therefore, if we cannot eliminate lot of sulphur in blast furnaces, sulphur removal cannot be achieved to a significant extent in basic oxygen steel making furnace, because the conditions thermodynamically are not favorable there. We have a high oxygen potential and we all know that sulphur removal is not facilitated under oxidizing evolve.

So, therefore, even beyond primary steel making, even beyond L F and vacuum degassing processes, we may have the sulphur content of the steel depending on what kind of a raw material we use relatively high, and there, we may be required to produce an ultra low sulphur steel.

Also we may have generated lot of inclusions in the steel. We will talk about inclusion later on in this course, but let me first tell you that inclusions basically are unwanted and foreign materials steel. For if the sources of inclusion, the inclusion sources of inclusions are basically due to entrapment of the deoxidation products or entrapment of the slag in the melt, for example, I may have some slag particle, I have an inter stirring and that slag particle may be interrupt and it may never get floated up from the molten steel system. So, final steel cost will show that, yes, indeed slag particles have been interrupt at certain stages of steel processing.

Similarly, I may have deoxidation products which may not have adequately floated and this deoxidation product actually takes such a long time to float that the manifest in the final cost steel. So, I thought extraction of the steel and I felt, well, you know, there is lot of manganese silicate there and it can immediately say, well, I deoxidize the bath with manganese silica manganese and that is why manganese silicate has come. So, the inclusion are basically of deoxidation products in this particular cases.

Also we may have refractory from the wall in out and that refractory please may get also interrupt. So, various kinds of foreign materials and these are inclusions when you are talking of inclusions; these are nonmetallic oxides. That is the basic nature of this. When you do continuous costing, you will see that the mold powder can get into molten steel and the mold powder can manifest in the solidified bilateral blooms or slabs and they also form some, they are also called inclusions, but inclusions depending on their origin where from they have come. In this, add that they are either endogenous inclusions or exogenous inclusions. Endogenous inclusion are basically deoxidation product, interrupt slag, interrupt refractory particles are basically exogenous, no matter what they are they are not wanted because they are the mechanical properties of steel.

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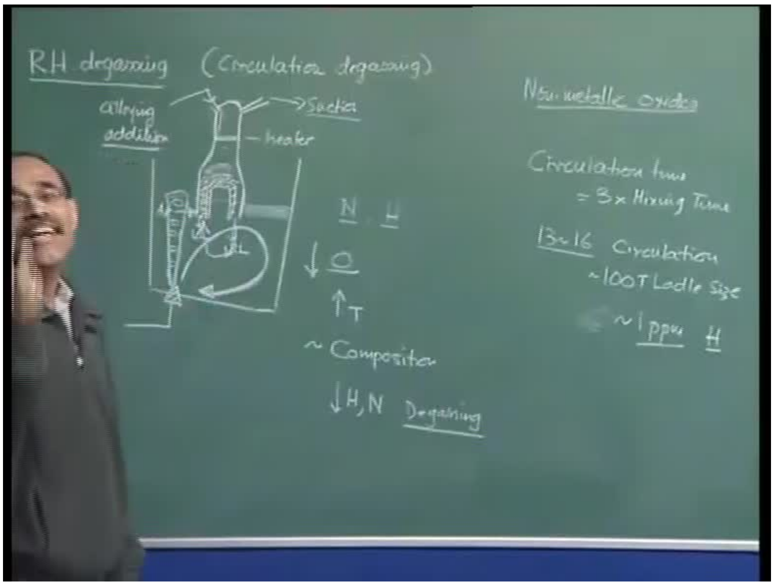

So, it may be necessary in certain cases that well, since the inclusions are there, they may be solid inclusions we can inject certain species into the system, and as a result of which, we can convert the nature of the inclusion, for example, if you inject calcium into steel, in that case, we can form, for example, calcium aluminate, if I have already alumina inclusions, and then, I can form calcium aluminate inclusions and which may have, you know, some complex with silica, etcetera, for actually give raise to a liquid phase inclusions and which has a greater tendency to come in contact with each other liquids have a greater tendency to formulate or quells, and if they can become bigger, they can really rise up to the slag metal interface very easily.

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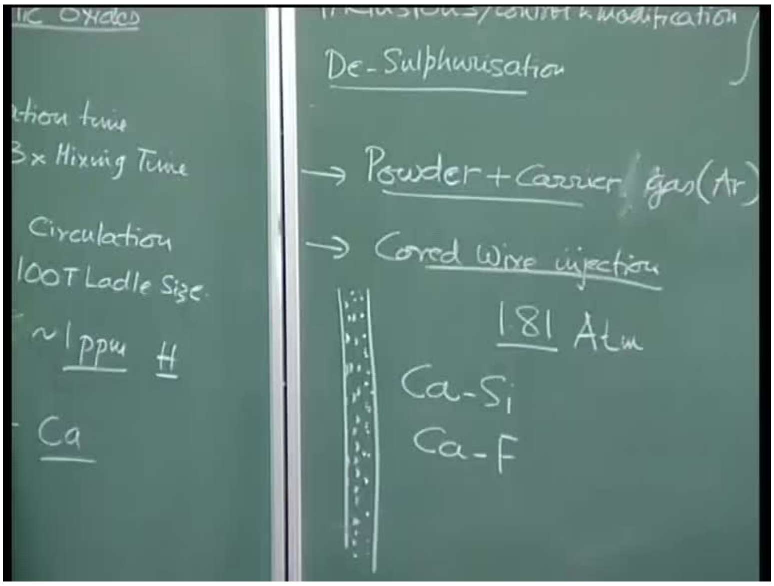

So, modifications of inclusion and desulphorisation may be necessary in some processes beyond and these are basically beyond the ladle metallurgy treatments, conventional ladle furnace vacuum degassing technique, and there, we say that we have a host of techniques particularly injection metallurgy. What we inject certain material and what do inject really? We can inject powder and that powder will be injected with a carrier gas. For example, a carrier gas could be argon; I do not want to use nitrogen here, because I have just now subjected the steel to tank degassing process or circulation degassing process, spend so much of money and effort to remove nitrogen. So, the carrier gas there has to be such that it does not contaminant molten steel.

So, argon is an obvious choice, and how do you use powder? Again, we are talking about multiphase reactions, reactions between various stages hydrogenous reactions where we are talking about reactions are the phase boundary, so, we know the rate of the heterogeneous reaction is directly proportional to the surface area. So, therefore, the powders, when they are injected into molten steel, they have extremely high reactivity and this is basically pneumatic injection of powders with a carrier gas. We can do this or we can have a cored wire injection also.

Cored wire injection essentially implies that we have a cylindrical wire, and in this, we have really powders are encased, that is what it is. So, there is a coating and within this so as the coating melts, and this wire is going to be injected, cored wire is going to be injected into steel. This surface is going to melt, and once this surface melts, this solid particles are going to be released in the system itself, you know, providing large surface area large reaction rate and so on.

So, if you have sulphur for example in steel, in that case, the sulphur can be taken care of by injecting of calcium, calcium sulphide may form, and we can also say that if you have inclusions like alumina, etcetera, and if you inject calcium, in that case, we will be able to told inclusion morphology as well as inclusion shape and characteristics.

One important objective or problem, sorry, with calcium injection is the calcium under steel making condition is gaseous in nature as 1600 degree centigrade calcium can stay as vapour. So, whatever calcium, you inject either in the form of powder or in the form of a cored wire, that calcium, when it will come to a contact with molten steel, it is going to immediately become vaporized.

Now, if calcium becomes vaporized and its vapour pressure at under steel making condition is roughly about 1.81 atmosphere at 1600 degree centigrade. So, these implies that immediately often contact with molten steel calcium is going to be in vapour phase.

Now, if it is vapour phase, in that case what happens is the vapours being lighter. They will immediately try to come out from the melt itself, and if they come out from the metal, the contact time between calcium and molten steel is going to be extremely small, and as a result of which, you will not be able to dissolve significant part of calcium.

Because if sulphur is sitting in the melt in the dissolved form, you want calcium to react with this sulphur, the calcium from the cored powder has to get into the state of dissolution. The calcium powder has to melt and dissolve, if it becomes gas also, it has to dissolve, the calcium powder has to dissolve into steel, get into this stage, and then only this sulphur atom which is going to be accessible to it.

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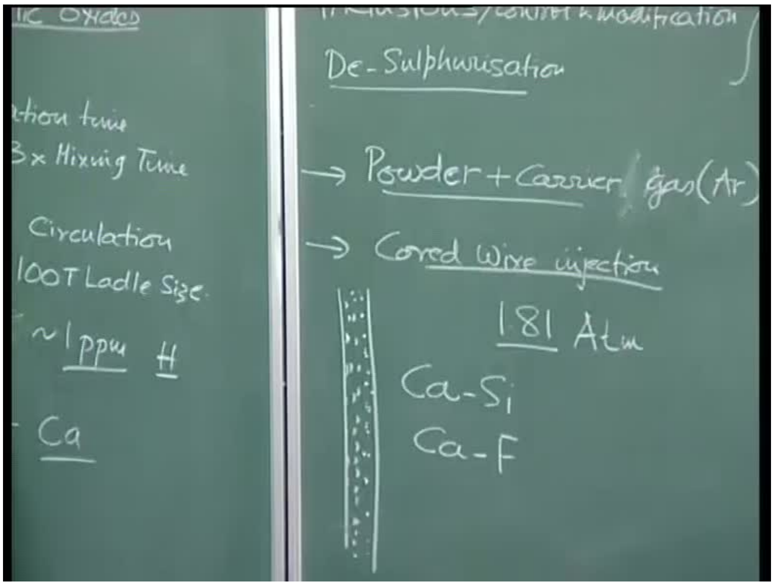

But this dissolution will depend on how much of contact time is there. If the calcium, injected calcium does not stay there for long amount of time and it immediately surfaces in the form of big gas and well up spare bubbles. We can understand that there is virtually from to a little scope for calcium to get dissolve, and in deep, this is a very important issue in calcium injection that the recovery of calcium is extremely small, and also, even if the, if you can increase the contact time, the solubility of calcium in steel is roughly about 0.0250 weight percentage.

So, as a result of which, under steel making condition although injection of calcium has may advantageous in terms of inclusion morphology control and modification. It is going to be highly expensive affair because the solubility is less to lot of calcium that we are going to use, we are going to inject into the melt. Actually not do any useful work rather than they are going to go and as take to the surrounding.

So, this is a very important point and that is why calcium treated steel are extremely a expensive. So, we can have, they say Ca-Si way, calcium silicide injection and calcium fluoride Ca-F way, so, both the ways they are injected to the powders could be calcium silicide or calcium fluoride and not in pure form though and that is the way they are injected into steel.

How do carry out desulphurisation? So, by coming back to this particular issue before we start the desulphurisation, I would say that by injecting calcium into molten metal by either powder with a carrier gas or in the form of a cored wire, just like they way we do alumina wire injection which I have demonstrated. It will be able to pumping calcium into molten steel and whatever calcium is going to dissolve, that calcium is going to react with alumina inclusions and it can add in formation of complex inclusion compositions, whereby, it can control the shape as well as nature shape, composition and nature of the inclusion itself.

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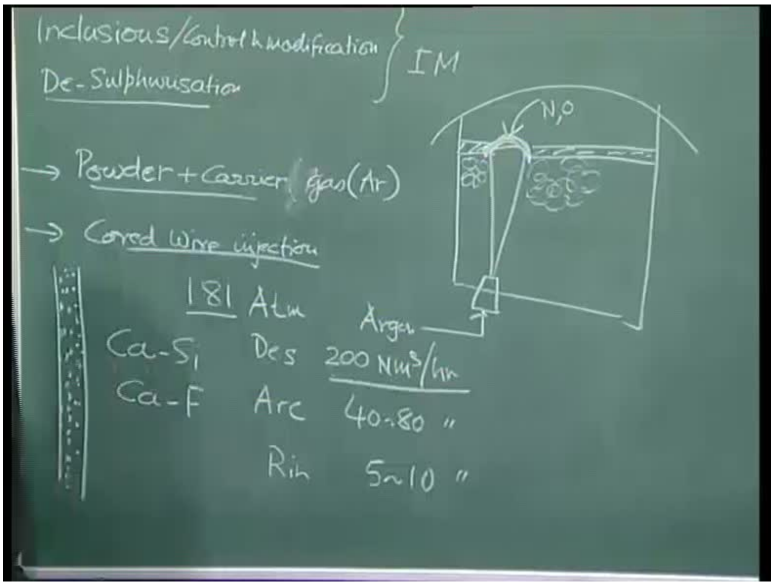

As well as desulphurisation is concerned: desulphurisation basically is carried out at relatively high argon flow rate in the ladle. Now, we have, for example, you have this ladle and then porous plug here and then we have the slag layer, so, the slag layer is here. So, you make fresh slag with lot of calcium because now you want to desulphurize the bath, and as a result which, as a result, what you require is that a highly basic slag should be there, so, we prepare more line, you had more line, dissolve more line and make a highly basic slag.

And desulphurisation as we all know is a slag metal reaction. So, the larger is the contact area between slag and the metal, you are going to have more effective desulphurisation. So, you can pump in basically more argon, relatively more argon rate, I have told you that 40 normal meter cube of argon per hour will be blown through the porous plug, so in we are doing arching. When you are doing rinsing, may be 5 to 8 normal meter cube per hour, but when we would be carrying out desulphurisation, this could be about 200 normal meter cube per hour. That is the flow rate that we are going to be.

So, this is for desulphurisation. Arching we are going to say 40 to 80 normal meter cube per hour and this is arching, and rinsing, you are going to say 5 to 10 normal meter cube per hour and that is the kind.

So, significantly higher flow rate is used to desulphurize the bath and as you all know that desulphurisation is slag metal reaction, so, there is going to be, the surface area is going to be very very important. So, when you blow gas at a very high rate, what is going to happen? There is going to be expensive amount of stag droplets which will be entrained in the vicinity of the flume.

Because the surface in flume will go up, it is going to go down, and there will going to be tremendous amount of circulation, and as a result of which, what happened is lot of slag material emulsion and slag droplets are going to be entrained and which is drastically increase the surface area and adding in desulphurisation reaction which is basically a slag metal reaction.

And of course, we must understand that when you do this, we have a tremendous fluid dynamic activates in the flume region because the flow rate is very very large, and as a result of which, we can have lot of droplet formation, lot of reoxidation, so, it is perhaps desirable that the entire thing is covered up and carried out.

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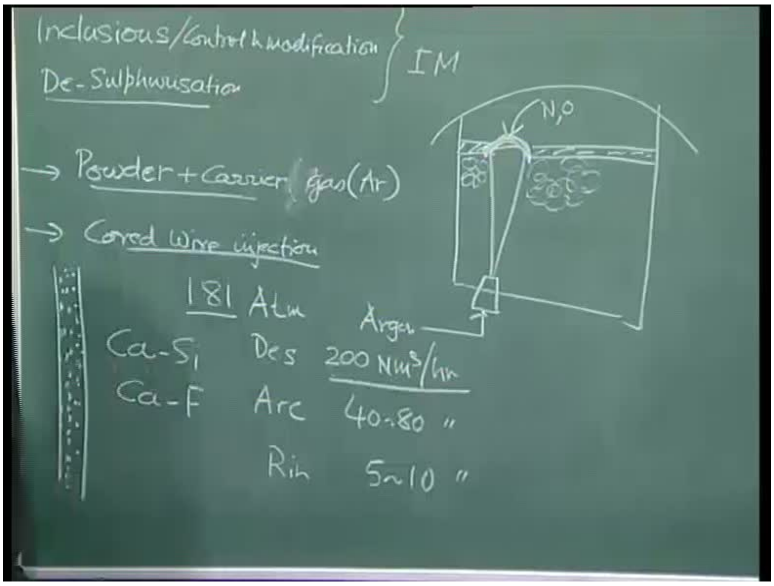

This operation can also be done in tank degassing operation, for example, desulphurisation can be carried out where it is facilitated under vacuum. So, there is at least no scope for oxygen absorption or nitrogen absorption from.

So, if you do it in an uncovered ladle, if you use very high flow rate of 200 normal meter cube per hour, and have no cover there, in that case lot of nitrogen and oxygen can really get into molten steel jeopardizing, and the quality which we have been trying to meet to ladle metallurgy steel making operation.