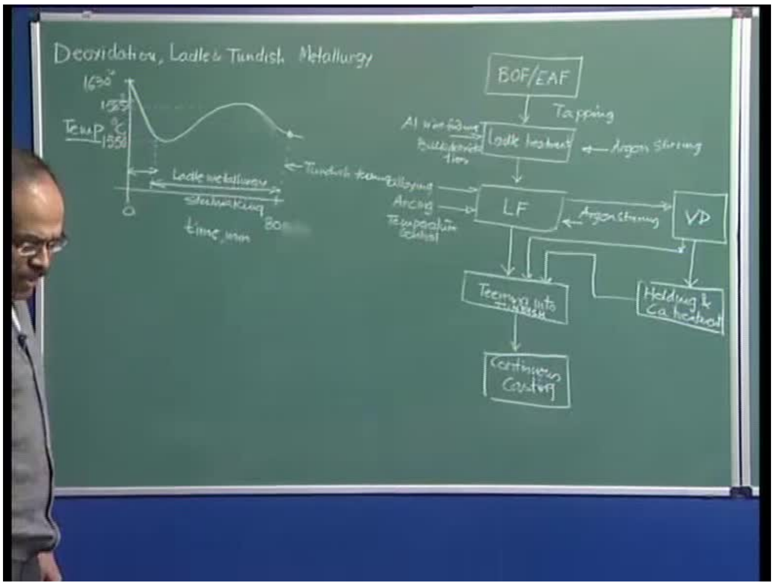
Steel Making
Prof. Deepak Mazumdar
Prof. S. C. Koria
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Module No. # 01
Lecture No. # 29
Deoxidation, Ladle and Tundish Metallurgy

So, having said so much about ladle processing. Let me now draw a full-fledged general ladle metallurgical circuitry as well as a specialized ladle treatment circuitry.

(Refer Slide Time: 00:30)



So, first we start with a BOF and an EAF. - Basic Oxygen Furnace or Electric Arc Furnace steelmaking - So, this is the primary steelmaking; followed by that, we have tapping operation, and this is tapping and we have ladle treatment, and basically in this ladle treatment, we are talking about argon stirring, and what we are doing in this ladle following tapping is nothing but deoxidation, may be we are doing aluminum wire feeding or bulk deoxidation.

So, once deoxidation is over, the next general treatment is the LF. So, in LF, we have argon rinsing or argon stirring, which is always there, and then, in LF, we have alloying; we have arcing and we have temperature control. Basically, we have just composition and control or enhance the melt temperature, and following this, we have teeming and this teeming is teeming into tundish. So, this is the most common ladle metallurgy steelmaking circuitry or the secondary steelmaking circuitry.

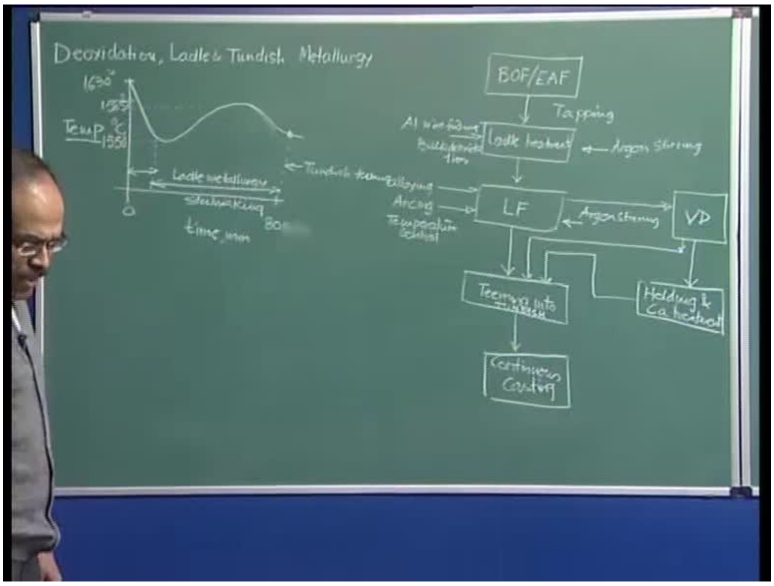
But we must understand that we have an option here; that means, after ladle metallurgy, ladle furnace, we need not go for teeming, we can have here. What is known as the VD operation? - Vacuum Degassing - and then, after VD, we can take the ladle either here or teeming or we can take it to holding as well as calcium treatment. So, that is also possible, and then, after this, we again go here, and then, finally, this is teeming into tundish and continuous casting.

So, these are optional treatments. We can have vacuum degassing as well as holding and calcium treatment. They are not for every grade of steel. So, therefore, I have left it on the right hand side and this is the straightforward ladle metallurgy circuitry, and these are the expensive or more exotic ladle metallurgy circuitry for enhanced composition and control of a steel.

Now, during this process, if I now wish to summarize that how does really the temperature of the melt changes, which is an important aspect of ladle metallurgy steelmaking operation. So, you will have time here, and as I said in the beginning that, the entire treatment operation can really go up, you know, from 0 which represents the tapping from the BOF and this could be something about 80, 90 or 100 minutes. So, I will write it like this 80, and so, this is a total span of ladle metallurgy steelmaking operation where we can take all these things into account.

So, we have temperature here, and if you tap, for example, the melt at 1630 degree centigrade by the time, the tapping is over, so, 15 minutes, or so, the temperatures drops down drastically and say about up to the value of 15. How much temperature can be dropped during the taping operation and initial period of holding of metal in the ladle filling? So, something around 80 to 90 degrees of drop in temperature can really takes place. So, if you start from 1630 degree centigrade, so, this essentially implies that we will get something like 1550 degree centigrade or something like that, which essentially tells us that there is about 80 degree drop in temperature.

(Refer Slide Time: 00:30)



And then, we have, as I have mentioned in the previous lecture, that we have various endothermic and exothermic processes, and also, we supply heat in the ladle furnace. Now, the temperature gradually goes up to compensate, and ultimately, as it is plot, so, something like I would say 1585, which may be our desired casting temperature. So, let us just mention it 1585; so, that is the temperature we are talking about here, and then, we are transporting the ladle basically to continuous casting or this is the period the ladle is in tundish, so, tundish teeming. So, this is the duration something like 10 to 15 minutes of time the tapping and holding in ladle, and then, this represents the duration of ladle metallurgy steelmaking including physical transport.

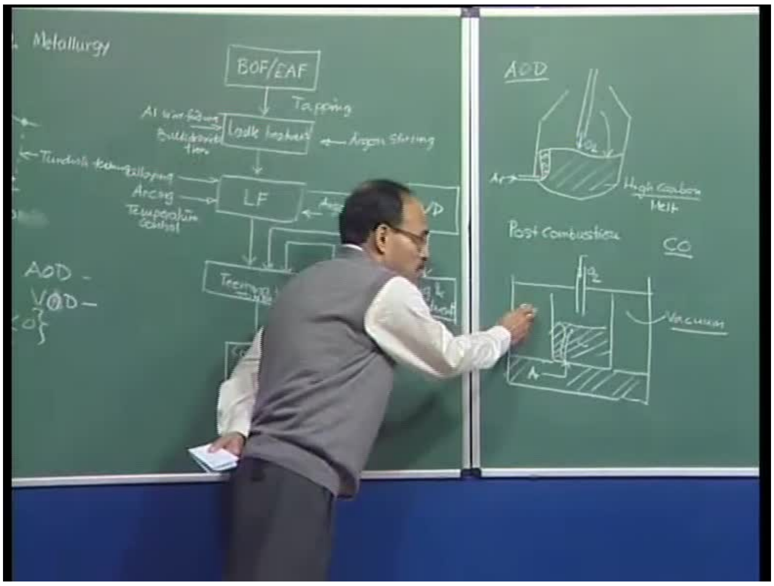
So, this is the desired temperature at which the molten steel is to be delivered into the continuous casting dish that is tundish. Although we have poured molten steel at 1600 degree centigrade and you have heated in between through ladle furnace, we see that by the time in about 80 minutes of time, the material is delivered not at 1630 degree centigrade but marginally higher than 1550, which may be about 1560-1570 degree centigrade as I have tried to indicate in this particular figure.

There are two other processes which are of course directly not relevant in the context of discussion of secondary steelmaking, but they are very important and similar process like the ladle metallurgy steelmaking although used in some different context. For example, in stainless steelmaking which you will be doing separately, we have processes like AOD and VAD. These processes resemble very similarly with the ladle metallurgy steelmaking operation. So, I thought that maybe I should discuss them here and they are not absolutely out of context.

So, AOD essentially represents Argon, Oxygen, Decarburization and VAD essentially represents, this is not VAD, sorry, this is VOD. - Vacuum Oxygen Decarburization – So, this process is not carried out under vacuum; this process is carried out under vacuum. (Refer Slide Time: 08:47) In both the processes, oxygen are supplied and the processes are essentially de-essentially implies decarburization processes.

And as I have mentioned that we have carbon oxygen reaction and this carbon oxygen reaction can be shifted; the equilibrium can be shifted to the right provided. We can increase the oxygen partial pressure, and also, if we decrease the pressure of C O, in that case, the reaction will be moving in the forward direction or we can drive the reaction preferentially in the forward direction.

(Refer Slide Time: 09:33)



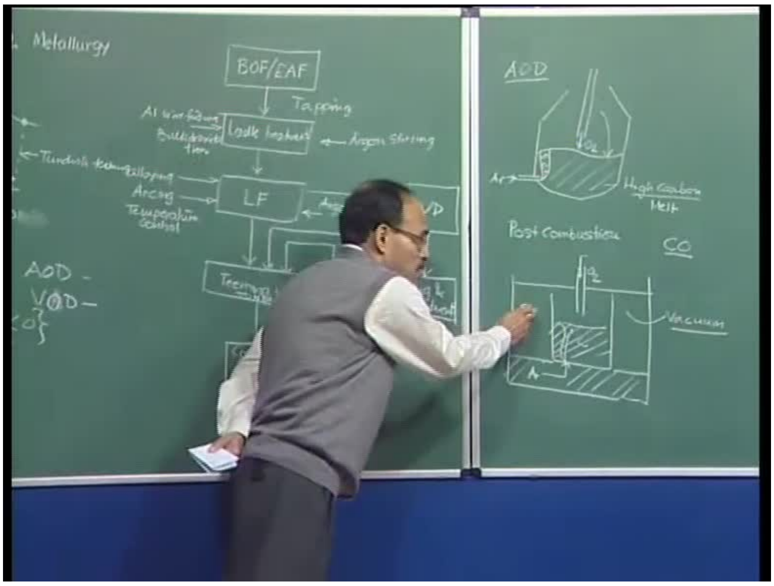
So, in the vacuum oxygen decarburization process let me now draw quickly the figure. So, argon, if we look at argon oxygen decarburization process, it is again carried out in a vessel, which is similar to our oxygen steelmaking vessel. Only difference this that we have a side blown nozzle through which argon gases is going to be supplied. So, we have a side blown nozzle and we have a supersonic lance and where the metal here, and through this, the oxygen argon bubble rises, produces stirring, and through this, the oxygen is supplied, and as a result of which, what happens is this melt which contains relatively high carbon, the carbon oxygen reaction takes place and that is how the oxygen gets into the melt and removes carbon; so, the carbon oxygen reaction takes place.

So, it is a high carbon melt basically. High carbon melt is initially subjected in the converter to oxygen and combination of argon. Initially, In initial versions of AOD, both argon and oxygen are introduced through the side blown lance, but today, oxygen is introduced from a separate lance. Initially at a supersonic speed, when there are lot of carbon present in the bath, but finally, towards the end of the process, when the carbon concentration drops down as more and more carbon monoxide forms; the flow rate of oxygen is gradually decreased.

Now, in stainless steel making, may be you know already that we require a very high temperature in order to produce a low carbon melt. So, therefore, we want that the excess heat is to be evolved. So, the supersonic oxygen gas which also does some amount post combustion. So, one sort of, one heat is that carbon will initially oxidize. Under steelmaking condition, we know that in the melt particularly, we can form carbon, oxygen preferentially carbon monoxide. Carbon dioxide is not thermodynamically stable, but towards when the gas rises upward because of its thermal buoyancy, what happens is towards the mouth the temperature gets smaller, and if you have a high partial pressure of oxygen, we can oxidize some of the carbon monoxide to carbon dioxide and some additional heat or chemical heat contained in carbon monoxide can be released within the furnace.

If that heat can be directed to the melt, in that case, the melt temperature can be increased substantially high, which will be conducive to making of low carbon grade of steel, and low carbon means we are talking about stainless steel which has an extremely small content of carbon, because carbon is not tolerated in the presence of high chromium, because chromium carbide forms and it leads to grain boundary deposition and grain boundary crank.

(Refer Slide Time: 09:33)



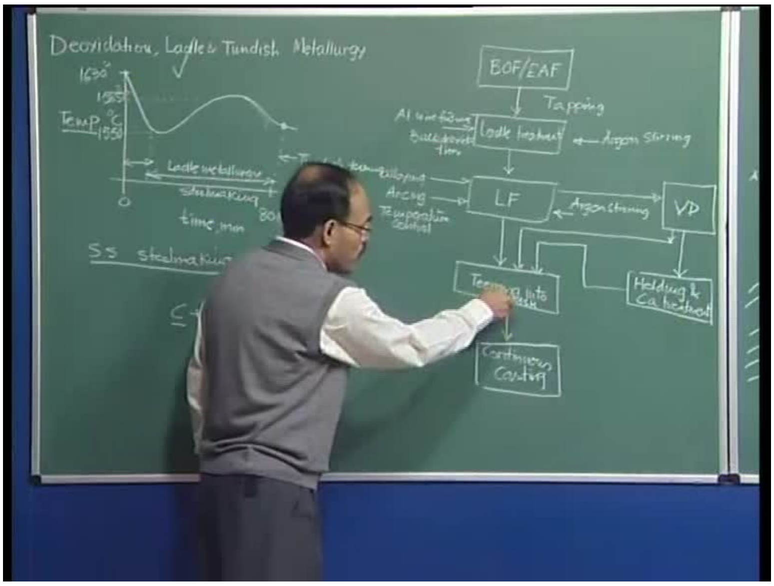
So, coming back to this particular issue that if we blow in large oxygen from the top, in that case, there is excess of oxygen particularly during the blowing period and this excess oxygen may combine with carbon monoxide releasing additional heat and this phenomena in EAF as well as in BOF as also in AOD converters is basically to harness the chemical heat of carbon monoxide so that the poisonous carbon monoxide is not released outside and also the chemical heat of carbon monoxide is released within the vessel and thereby which is called post combustion, and thereby, somehow direct the heat towards the melt; the melt temperature can be substantially increased.

You must understand that post combustion is going to be meaningful towards the initial part of the blowing when there are lot of carbon monoxide evolution and the carbon concentration is very large. VOD process is similar to, we have a ladle here, so, we draw a ladle, and then, we have oxygen from the top and then we have a melt here. We introduce argon from the bottom and then the entire thing is going to be sitting on a platform here, and this is the oxygen. Then, the entire thing is under vacuum.

So, basically, the same process we have metal here. We have argon gas which is injected from the bottom as usual, because the gas has to dissolve into the metal and this dissolution is a mass transfer control process, and oxygen, the dissolved oxygen has to go everywhere to find out carbon.

So, thereby, for you require some stirring, top lances as you must be knowing that it is not conducive to producing extensive amount of stirring here. Bottom blowing of gas is far more effective for producing good amount of stirring. So, therefore, argon is introduced here, which produces lot of stirring. Oxygen gas preferentially dissolved and this bath contains carbon or a high carbon melt and then the carbon oxygen reaction takes place, and because this is entire container is under vacuum; it is under sealed environment that this reaction goes on.

(Refer Slide Time: 15:50)

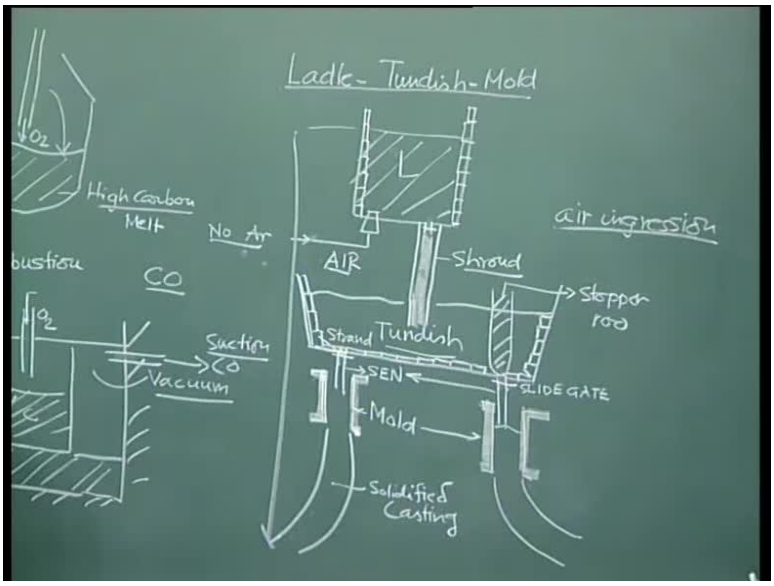


Therefore, this equation which I have written here under reduced carbon monoxide partial pressure or reduced pressure within the system, because whatever carbon monoxide is forming, may be you can draw here a line that through this or suction is going to be applied and all carbon monoxide is going to be taken out, and as a result of which, this is maintained at a very low pressure, and under low pressure, this equation will be driven towards the forward reaction.

So, this much for ladle metallurgy, we will now move on to the tundish metallurgy, the continuous casting, and teeming into the tundish is what we are going to discuss continuous casting will be discussed later on. So, having done all sorts of operations in terms composition adjustment, in terms cleanliness adjustment through injection metallurgy, in terms of gas control through vacuum degassing techniques, we are now set to cast the molten steel through continuous casting. Today as you all know, ingot casting has been phased out because of techno-economic significance. We all know that the rate at which BOF will be turning out hot metal; it cannot be matched by ingot casting.

So, we require a downstream process which can match with the higher rate of production of BOF. Here, we are talking of 2 kg of decarburization per second and this is an enormous rate of steel production. So, we must be having a very quick method of casting of molten metal and that is why continuous casting has become very popular; it can really match the productivity of the BOF and ingot casting is no match here.

(Refer Slide Time: 16:54)



Now, let me first draw a ladle tundish mold assembly which is the essence ladle tundish mold assembly. I will introduce make a small drawing and then introduce some of the terminology. So, the ladle, which contains now molten metal. At this particular stage, when we take the molten metal ladle for continuous casting, although the porous plug is still attached to the ladle, we must indicate that at this particular stage, there is no argon injection. So, argon injection is stopped. When we take the ladle to the continuous casting web, the plug is nearly the connection here pours is disconnected from the plug. As you know, we repair the ladle or take the ladle after all these operations to the continuous casting bay.

So, there is no argon rinsing now. The material is sitting steel is here in the ladle itself, and then, as I have mentioned to you that we have a slide gate arrangement here, and through this slide gate arrangement, I am going to explain that slide gate little later, and through this slide gate, we have what is known as is the shroud which is typically attached and this shroud basically protects the stream of molten metal that flows out of the ladle.

So, from the ladle, the material now flows into tundish which typically you can assume that it is like a distributor of molten metal and we have strands here, and this is continuous casting mold. So, the molten metal enters here and then the continuous casting product is drawn like this.

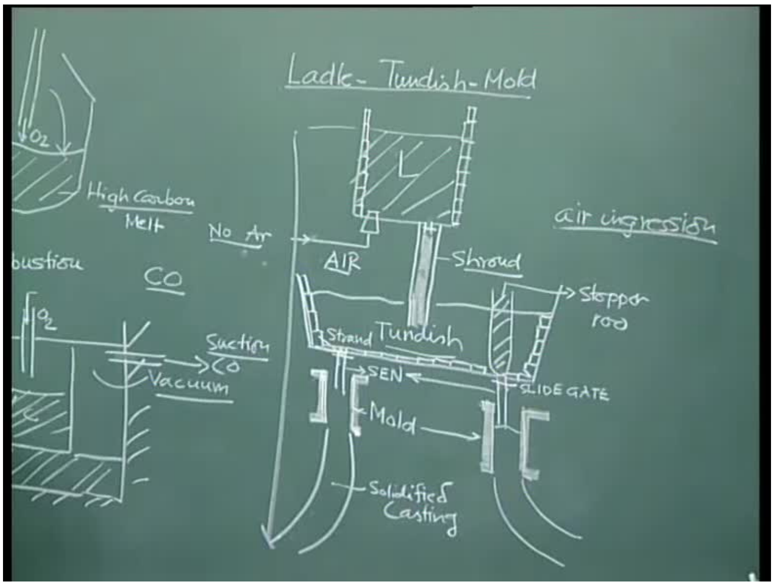
So, this is the water cooled mold, I will draw like this. Then you can better understand it is the water cooled copper mold. This is the solidified casting; this is the tundish, and as you can see that metal which is there in the ladle, it first comes into the tundish and this is the shroud, and what is the purpose of shroud? The purpose of shroud is to protect the molten stream. Otherwise, what is going to happen? This molten stream, if it remains exposed, there is no shroud; this is going to interact with my surroundings. I have oxygen and nitrogen and there is going to be continuous transfer of oxygen and nitrogen.

So, the shroud is going to be submerged up to a certain depth in order to ensure that molten steel has no chance to come in contact with the surrounding here. So, we have to prevent; this is the transfer operation. Whatever we have been talking here, in the ladle metallurgy steelmaking, the material was always sitting in the tundish. So, this is a chemical processing operation, a physical processing operation to some extent also inclusion removal, etcetera.

But now, we are talking about transfer operation, teeming operations, tapping operations are transfer operations, and these transfer operations are extremely important in steel making circuitry. We would like to see that the quality of steel which we have achieved during the processing steps must not be compromised or deteriorated during the subsequent transfer operation. They are extremely critical as far as the quality of steel is concerned.

We must understand there is a phenomenon which you will come across and is called an air ingression. If there are leakages, when the shroud is going to be attached to the bottom of the ladle, in that case, there may be some pours and holes here through which air maybe drawn into and that phenomena is termed as the air ingression which drastically reduces the quality of steel.

(Refer Slide Time: 16:54)



Now, what is there within the shroud? And the shroud is filled up with inert gases basically. So, this tube which is attached to the bottom of the ladle, so thus, through the slide gate the slide gates can be moved like this way and the openings maybe made bigger or smaller, and thereby, the flow rate can be controlled and the flow rate is typically is not controlled in the industry. Manually it is basically done through a control algorithm which takes into account the melt depth and the diameter how much is this to be opened in order to pump in molten metal into the tundish at a constant rate.

In the tundish, these are called the strand of the tundish. Again, we have a slide gates are here and we do not have shrouds here. What enters here is called the SEN - Submerged Entry Nozzle. So, these are the submerged entry nozzle and this is my slide gate, and the purpose of slide gate is to regulate the flow. In many tundishes, you have seen steel plants; you may have visited steel plants. It is not necessary all steel plants will have slide gate, but it is a modern technology necessitates that good quality of steel can be made with slide gate arrangements, but there is another arrangement also which is called a stopper rod arrangement. This is the stopper rod; this also does the flow regulation.

And this stopper rod if it is raised, in that case, this opening is going to be bigger; more metal is going to flow out of the tundish, and this, but it is kept down in contact with the surface, then this strand is closed and this strand is closed, and therefore, no material flows out. So, by controlling the movement of the stopper rod up and down, we will be able to control the flow of material into the mold itself.

So, ladle tundish mold this is the arrangement and we are talking of a height of three floors. The ladle is sitting something around 15 to 20 meters above the ground level. This billets are going to be discharge or the slag is going to be discharged at the floor level. So, above the continuous casting machine and this is a curved mold. So, you require an enormous amount of space. The mold may be sitting you know about 6 to 7 meters or 8 meters high, and then, the billet comes out, it bends and it is discharged horizontally. So, from this point onwards to this point, we are talking about more than 20-30 meters of height. It looks like a three storey building; actually it is a steel plant.

Now, the tundish is a refractory lined vessel. We are storing molten metal here which is understood that we have to have refractory line. The tundish will also perform just like the ladle for a some amount of heats only. This one tundish will not work forever; it can take about 16 or 17 ladles, maybe 20 ladles, sometimes maybe 8 ladles depending on the condition of the plant that we are talking about.

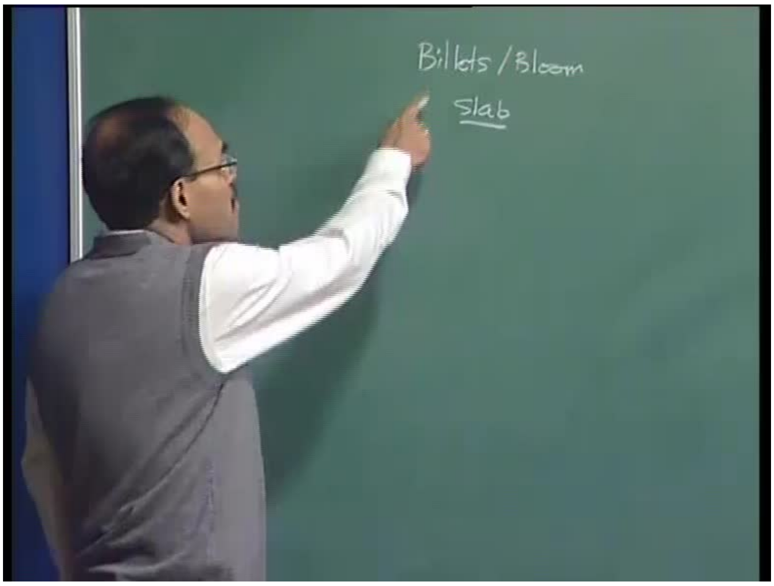
The ladle is, one ladle is brought here, and then, as soon as this ladle is emptied, the fresh ladle comes maybe with the same composition or different composition, but the tundish can still go on. So, we can go on ladle after ladle and the tundish can work for about 16 or 17 ladles or 20 ladles as I have mentioned depending on the quality of construction and the refractory bricks with which the tundish is made.

So, it is a steel lined vessel. Basically same type of refractory’s which are there in ladles are used, and the thickness of the lining is also almost same like the thickness of lining in the ladle; so, there is not much. Holding and transfer vessels have similar types of characteristics. Magnesia bricks, basically magnesite, magnesia, tar dolomite lined bricks, they are basically used in ladles and tundishes.

As you can see here that, we have one shroud entering the tundish, but the shroud distributes the molten metal into two different molds. Therefore, traditionally we visualize tundish as a distributor of molten metal into continuous casting molds. I have shown only two molds; it is not necessary that we have only two molds. There are to be multiple number of molds actually. Let me draw a figure and then explain it in the contest of billet or bloom casting. This is a drawing. Two strands I have shown here basically, essentially. This is a slab casting arrangement, but if you have billet and bloom casting arrangements, we can have multiple or more number of strands as I may explain.

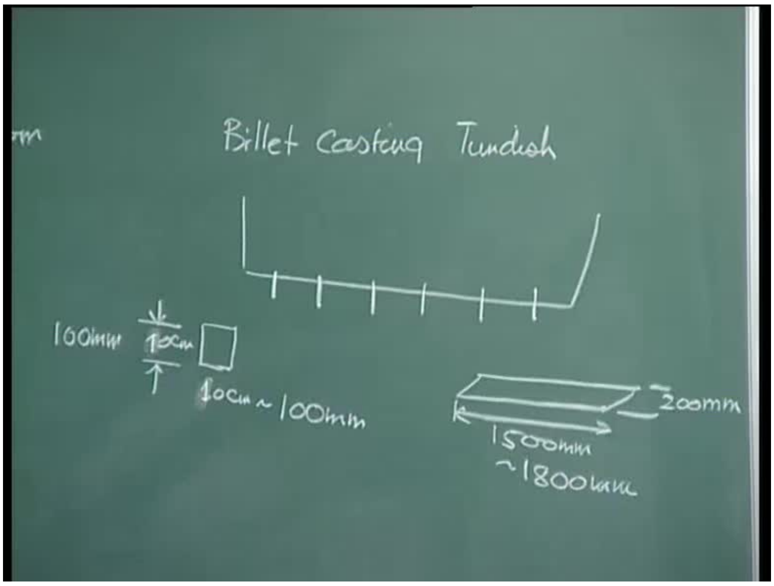
So, as we know that steel plants produces what is known as long products or flat products. Long products basically are your rails, beam blanks which are used in buildings, wires and rods, and on the other hand, flats products are basically slabs and strips.

(Refer Slide Time: 26:54)



Now, we can have long products are basically billets or blooms, as we all know, billets and blooms, while the flat product is slab. Now, the slabs have massive cross sectional area, the size, how much we can be talking about 30 centimeter or 20 centimeter thick slab with the width of the slab maybe 1.5 to 1.8 meters. On the another hand, billets could be 8 inch by 8 inch; blooms could be something like 20 inch by 20 inch.

(Refer Slide Time: 27:40)

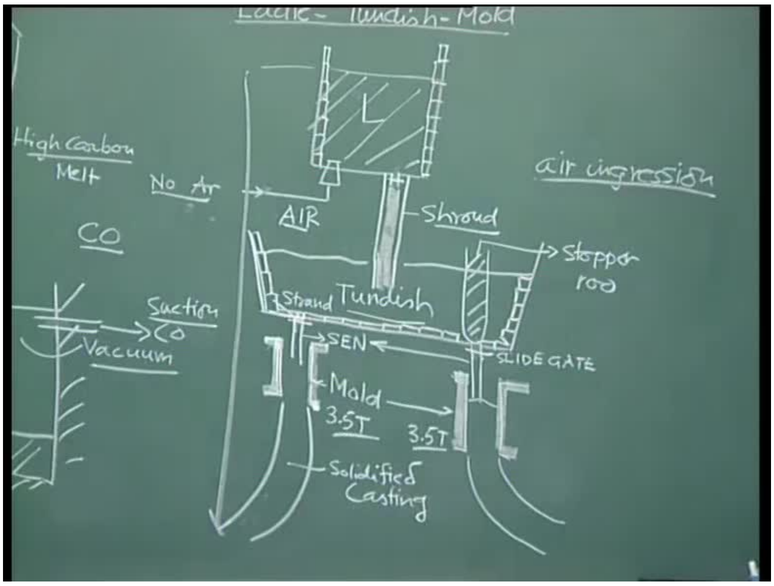


So, therefore, it is understood that if we are talking of a casting rate, that plant demands that we have a casting rate of about through one continuous casting 8 tonnes per minute for example. In that case, it is understood that if you have a billet cast at tundish, if the tundish is producing billet or casting billet, billet casting tundish, you will have more number of strands.

So, we can have one strand here, second strand, third strand, forth strand, fifth strand, sixth strand, because billets, billet cross section as I have mentioned, billet cross section could be about 8.5 to 8.5 inches something like this. On the other hand, we can say that if you convert it, say 20 centimeter into 20 centimeter, maybe I will say 10 centimeter is a better size 10 into 10 centimeter. That is the cross sectional area of a billet. On the other hand, if you talk of slab, for example, the slab could have thickness of about 200 mm and this could be about 1500 to 1800 mm.

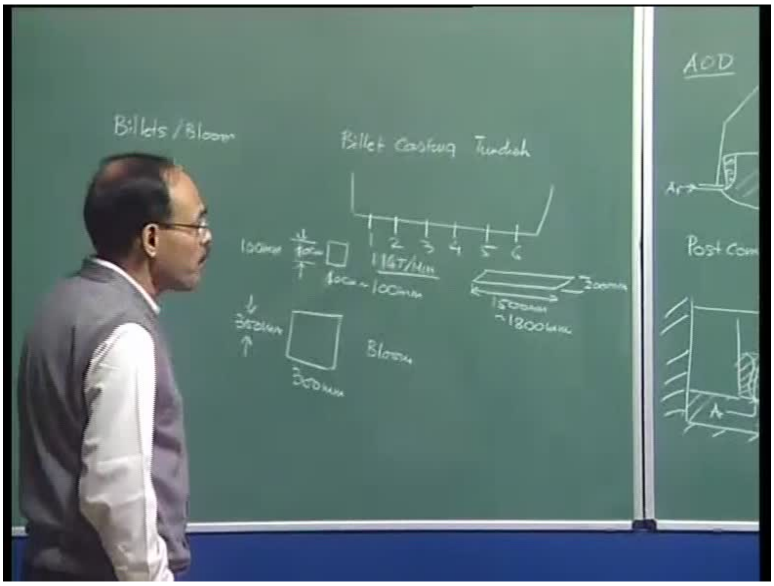
So, here, I am saying this is equal to 100 mm and this is also equal to 100 mm. So, the flow rate for a given casting speed, the flow of amount of molten metal in a slab caster tundish is going to be enormous.

(Refer Slide Time: 29:13)



So, for example, in industry, we can see that we can have 3.5 tonnes per minute. That is the rate of casting in a conventional steel plant or steel mill.

(Refer Slide Time: 29:29)

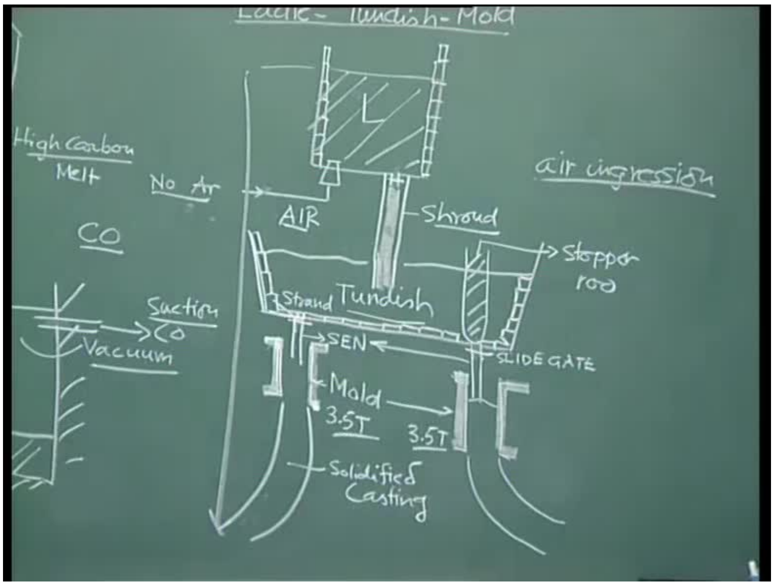


So, we are casting through two strands about 7 tons, and a same plant producing billet now would be using strand number 1 2 3 4 5 6, and in each of which, maybe we will have casting something like 1.33 ton per minute. So, 6 multiplied by 1.33 tonnes is roughly about 1.16. I would say this becomes equal to 7 ton per minute and this is going to be equivalent to 3.5 tons per minute.

So, therefore, if you are producing small cross section jobs like billets, we have to have a multiple strand tundish; so, it is not necessary that we have always two strand tundish. It will depend on what kind of a plant. We are talking about billet casters will have, for example, 6 or 8 strand tundishes, multiple number of strands are there. In bloom, which could be about 300 by 300 mm, 300 by 300 mm. So, that is a bloom cast, and in bloom, we can basically have not 6, but about 3 strands, sometimes about 2 strand also it is possible for smaller mills such that the cross section is bigger. So, as the cross section becomes bigger, the number of strand decreases. That is the thumb rule you can apply.

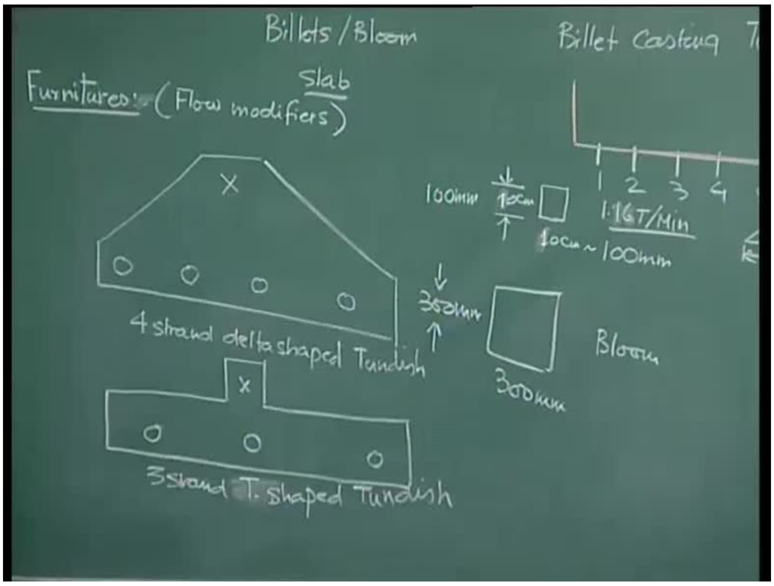
So, in continuous casting therefore, tundish is going to feed. A number of molds and how many numbers of molds are going to there. That will dictated by what sort of a product. We are talking about billet bloom slab and so on. The tundish basically has lot of furnitures in it, and what are the furnitures in tundish or these are also called flow modifiers.

(Refer Slide Time: 29:13)



I have drawn a tundish which is a bare tundish. There is nothing inside the tundish. The material is coming from the ladle; it is flowing out. So, that is how the materials goes and flows out of the strand. This is not desirable in tundish as I am going to explain to you. So, therefore, inside of tundish will contains some furnitures and this will also vary from one tundish to another.

(Refer Slide Time: 32:04)



Also I have drawn a tundish which basically looks like a rectangular shaped tundish. If you look at the cross section and the cross section for the top view of the tundish will look something like this. So, it is a rectangular shaped tundish, but it is not necessary that all the tundishes are going to be always rectangular cross section.

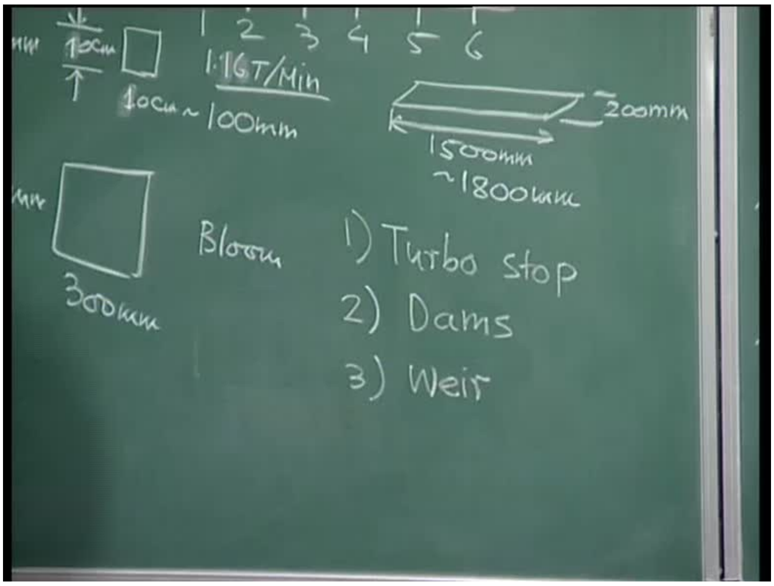
So, we have various shapes of tundishes; we have many numbers of strands. We have different kinds of geometries and this gives us lot of possible combinations to play with in order to regulate the fluid flow in the tundish itself. How the material comes and how the material flows out of the tundish into the mold that can be governed by various types of flow control devices or flow modifiers as well as tundish geometry and so on.

I can show that beyond rectangular tundish, we can have what is known as a delta shaped tundish. A delta shaped tundish will look something like this. And this is the region where the cross essentially tells us that where the shroud enters the tundish. So, that is the region where shroud enters, and this is the 0 are nothing but strands. So, this shows a 4-strand delta shaped tundish. We can have T shaped tundish also. This is a 3-strand T shaped tundish.

So, most of the industries either uses T delta or a rectangular shaped tundish, of course, some minor variations could be there, but in general, these are the three types of tundishes which are commonly seen in steel industries. So, 3 strand T- shaped tundish.

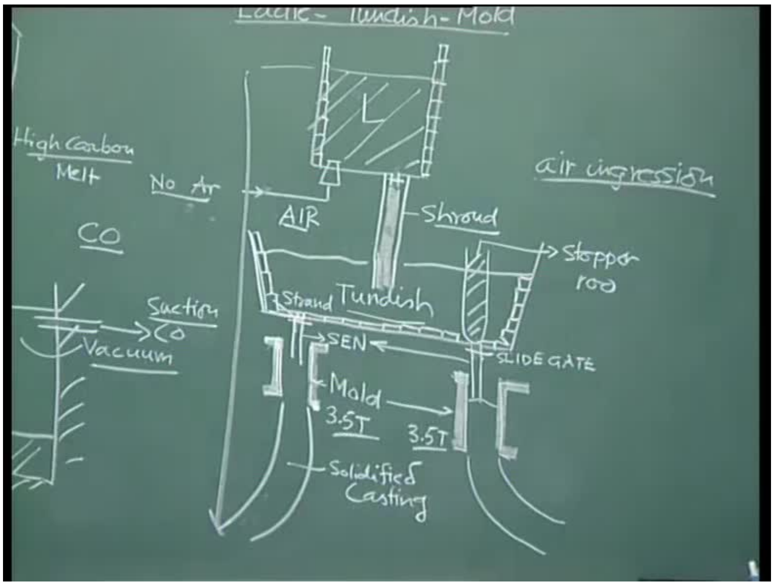
What are the furnitures that we are talking about in tundish? Various kinds of furnitures are possible. I am going to explain and show, place them in the tundish and then you will be able to understand.

(Refer Slide Time: 34:42)



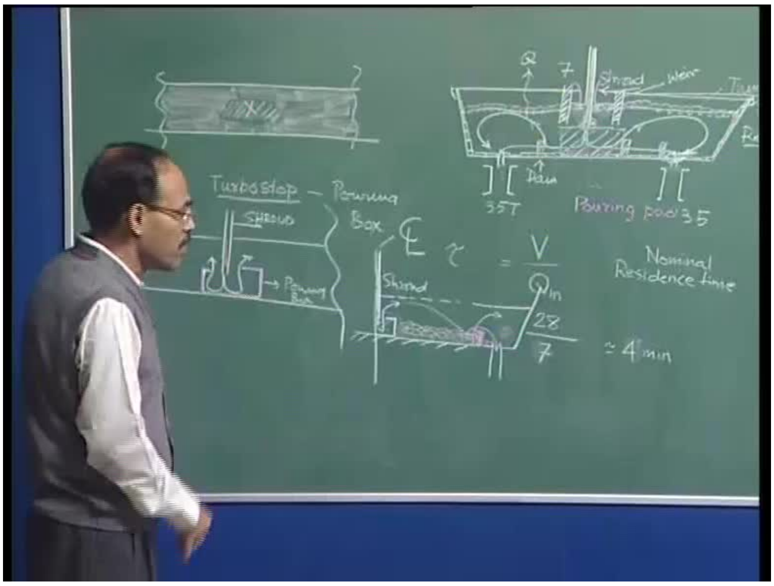
Number 1 is Turbo stop this is common number 2 Dams and number 3. These are the 3 essential or the basic types of furnitures which are normally introduced in the tundish. What is the objective of introducing such furnitures in the tundish?

(Refer Slide Time: 29:13)



Let me just explain this to you. For example, if you imagine that the material coming from the ladle, it is falling through a great height; so, it is coming into the tundish with an enormous velocity. If it is coming with an enormous velocity, it comes and strikes at the bottom. Typically, at the bottom where we may have always what is known as an impact pad, because here, otherwise, the refractive wear is going to be maximum.

(Refer Slide Time: 35:40)



So, if you look at this figure, it is that once clear that this material which is coming at a very high rate. The velocity with which it impinges on the tundish is also extremely high 8 meters per second, 7 meter per second, so on depending on the rate of casting. So, we have to have in order to prolong the life of the tundish, because at no point, the refractory can get weaker and this is the region object impacts the material from ladle comes in. So, we require what is known as a pouring pad. So, this is nothing but a reinforcement by refractory so that the wear of tundish refractory is not significant.

Now the fluid comes or the molten steel comes impinges on the surface, and then, it spreads radially and it comes here and flows out through this. If it happens like this, then what happens is that we call that it is going to be short circuiting. The flow is coming impinging on the pouring pad and straight forward getting into the mold or through the strand without spending much time in the tundish itself.

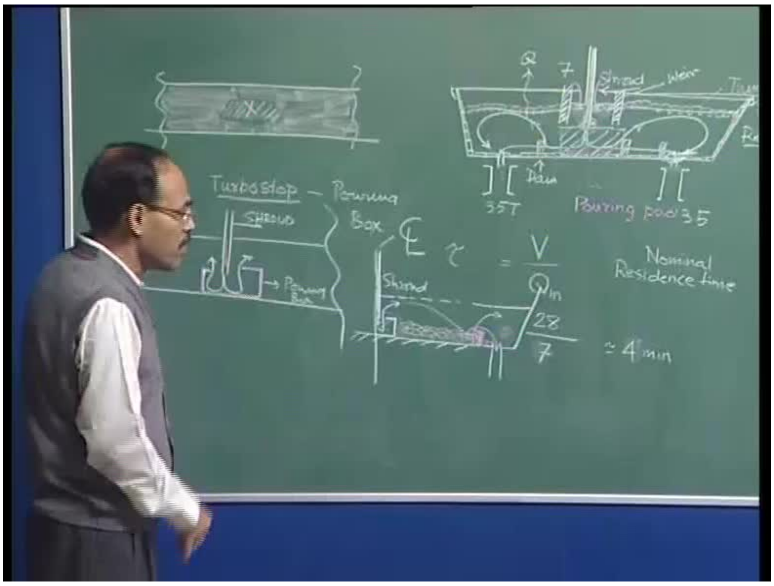
Now, for example, we are casting at a constant rate. The tundish as I will demonstrate to you except for the initial period of filling, when the ladle is opened for the first time or towards the final stage when there is no more ladle sitting at the top the level of the tundish really changes, but otherwise, the tundish is continuously operated at a constant height and this height ensures that we have a constant casting rate. Therefore, the flow rate of metal which comes from the ladle is exactly equal to the flow rate of the metal which leaves out of tundish. So, Q 1 plus Q 2 is equal to Q input. That condition is met under steady state casting condition or throughout the casting region except for the initial period of tundish filling and the final stages of tundish draining.

So, if you look at this, the volume of the tundish to which it is going to be filled up. Finally, the steady state volume, and if you divided it by the volumetric flow rate, then this gives us a times scale. So, volume divided by volumetric flow rate, the dimension of this is going to be time and this time is known as tau, which is nothing but the residence time and this residence time is called the Nominal Residence time.

So, the material which comes in here has a potential to spend so much of time depending on how much of volume we can have at the volumetric flow rate. So, for example, we may be casting at 7 tons per minute and this tundish may have volume of 28 tons or volume corresponding to 28 tons. So, I can say that for a 28 ton tundish and 3 tons per minute, we are talking about something like 9 minutes.

So, you can take because the density is same in both the expressions. So, 3 tonnes is the mass flow rate and 28 ton is the capacity. So, therefore, the residence time in terms of the masses can also be found out; 28 ton is the volume of the tundish; 3 ton is the volumetric flow rate into the tundish or if you make it say 3.5, 3.5, then I can say it to be 7. So, let us say this is 3.5 tonnes we are drawing through here; 3.5 tonnes we are drawing through here. Therefore, 7 tonnes per minute is the material is inlet flow rate. Therefore, we can say that it is not 9; in this particular case, its value is 4 minutes.

(Refer Slide Time: 35:40)



So, the reactors has a potential to hold molten material at least for 4 minutes of time. Now, if the material comes here and then it is goes out like this, it is spending virtually no time in the tundish itself. So, therefore we say it is short circuiting, it is by passing the tundish volume, and tundish processing as I have mentioned, the tundish need not be today looked as solely as a distributor of molten metal. Particularly when we are talking of quality improvement, we are talking about inclusions removal the enhancement of steel quality as well as minor adjustment of composition and control of temperature also in the tundish itself. So, tundish should not be looked like an ideal reactor; it is a very vital processing reactor, but the quality of steel can be significantly influenced.

But if such a thing happens in tundish that the material comes without spending much time, it goes into the mold, then you have no scope to maneuver with the quality of molten metal in the tundish itself. So, as a result of which, what we say? We want material to spend longer amount of time; therefore, we apply flow modifiers.

For example, if I put a dam here, just hypothetically speaking, on this particular side, in that case, you can see that this stream is not going to come directly, because the dam would not allow it to come. The dam will direct it to flow upward, and in that case, what happens? The fluid will flow something like this and then come back in this particular fashion so that the residence time of the material… So, in the in the absence of this dam, there would have been short circuit, but placing the dam, I have been able to eliminate short circuiting completely, allowing material to spend longer amount of time, and within this time, now I can adjust the, I can do something. I have some time available in my hand and I could do some modifications. I can improve certain aspects of steel composition and quality by taking advantage of this particular characteristics of the flow itself.

So, to control or to alter the flow field or flow of liquid in the tundish or melt in the tundish, favorably various flow modifiers are introduced. We must say also note here that the tundish is going to be always covered with a slag, which is known as the tundish slag. So, this is the tundish slag, and basically, this is based on rice-husk; this serves as a source for absorption of the inclusions.

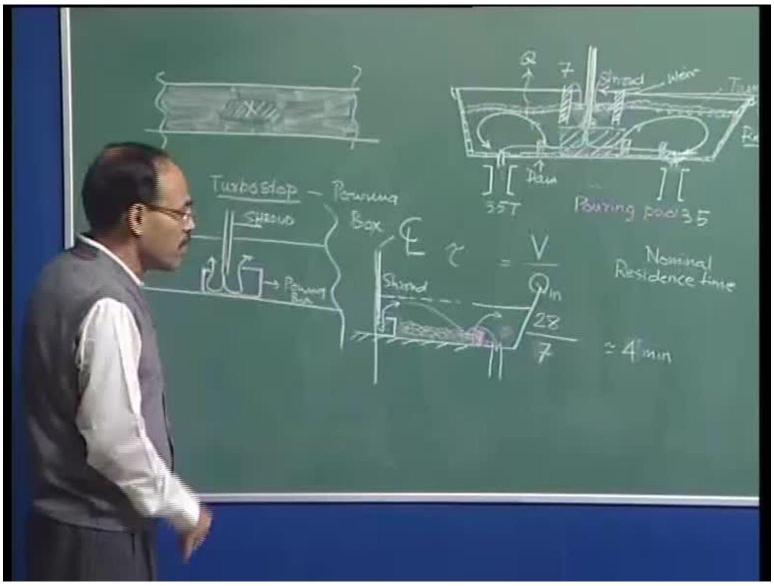
So, if we can create, if we can spend liquid allow, force liquid steel to spend some more time in the tundish itself, so, that particular time lighter inclusions will tend to float, and once they float, they can be absorbed by this slag which is always there. So, the slag is freshly prepared, it is not the ladle slag, but the tundish slag is made out of rice-husk and different chemicals in order to create a conducive environment for the absorption of the harmful not metallic inclusion.

Tundishes are also going to be covered with the refectory, because tundish, if we are talking of slab casting tundishes, what would be the length of this tundish? We are talking about 6 to 7 meters long. So, we can imagine that the surface area is going to be enormous, and if the surface area is enormous, there is going to be tremendous amount of heat loss from the tundish itself.

We also have seen that why do not you have the strands so close to each other, because if we have close to each other, in that case, they will not be spending much time; bulk of the reactor will remain idle, material will enter through this and then flow out through the strands if they are located here. So, the strands are to be placed far away and this necessitates that the exposed surface area of tundish is going to be therefore very large. Tundish is a shallow but long reactor.

So, what tundish if you would note has come from stables where horses are used to be fed. If you have seen that there are 6 or 7 horses and there is a tundish shaped vessel, where you know food materials are kept and all the horses then pick up their food with their mouth from the tundish itself.

(Refer Slide Time: 35:40)



So, the shape of their food bowl in stables are similar to the shape of tundish and that is why I think that the name tundish has come in the steelmaking literature because of resemblance with the platter that the horses use in stable. So, there because of this large surface area, we have to have tundish covers also and this tundish covers really prevents lot of heat. So, not much heat can go out of the tundish, the wall reflects the heat back, and as a result of which, even though the surface area may be very large, the drop in temperature of the molten metal at this particular location and at this particular location is barely 5 to 7 degrees of centigrade.

So, if it is 1660 here, it could be 1653 here, 1654 here, and if you are operating with tundish cover, in that case, that will be much more pronounced temperature drop. I would like to also mention that ladles; in many steel plants, ladles are also, in all ladle metallurgy operation, ladles are also operated with physical covers and this physical cover really cuts the radiative heat losses from the surface of the melt.

So, now, we are very conscious about energy because of cost of reduction of specific energy consumption, because where from the energy comes eventually? They come from the fossil fuels and which has tremendous influence on the environment. So, we have to be very careful not to waste energy but to minimize the consumption of energy, and therefore, operating ladles and tundish with cover has assumed all the more importance in the current scenario.

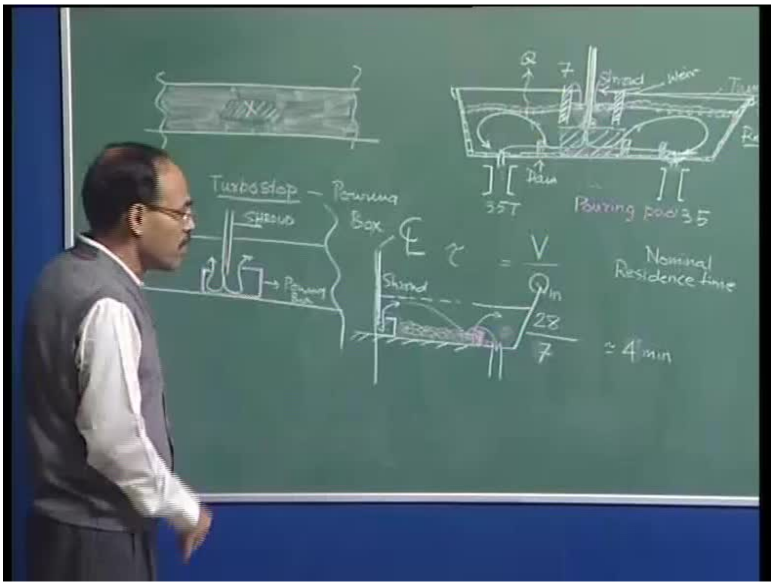
The material comes from the ladle into the tundish at a very high speed. So, we can except that significant amount of turbulence is going to be prevalent in this particular region. So, this is the region in the tundish where we are going to except lot of turbulence, and why lot of turbulence? Because the velocity is large; the size of the reactor is big, and as I have mentioned that the kinematic viscosity of steel is very, steel is a very flowable liquid just like water. Water and steel have the same kinematic viscosity; so, the flow is going to be extremely turbulent here.

And turbulence is no good as far as removal of inclusion is concerned. So, we want that the turbulence is to be reduced with significant extent. We also want that the flow need not be going downward, because inclusions travel in which direction, inclusions will travel towards the upward direction. So, I should create a flow which itself is directed upward; so, thereby, helping the inclusions, you guys go head, you know. I am giving you some assistance with the upwardly directed flow, and as a result of which, the inclusions will have a greater tendency to move towards the upper surface.

So, for example, this dam would be very good in comparison to no dam situation, because the dam is deflecting the flow and directing it in a direction which is directed towards the where? These are slags it is directed towards the slag, and therefore, this sort of a dam, placement of a dam is going to create a surface directed flow, which will be very good for inclusion float up also.

So, turbulence is not very good here and we must also know that we have lot of slag here. So, if we have lot of turbulence activities here, what is going to be happened? This area is going to blow opened up because of the tremendous amount of turbulence present. So, therefore, we can see that this lot of reoxidation, we are always worried about reoxidation in ladle in tundish, and reoxidation I have categorically mentioned that it spoils the quality of steel. So, the slag layer need not be broken at any stage and it is here that immediately above the impinging jet from the ladle. We have a possibility for breaking of the slag layer by atmospheric oxygen and nitrogen can go into melt.

(Refer Slide Time: 35:40)



So, the submergence of the shroud into the melt, the geometry of this particular, you know, the promo defects in this particular regions are very important in order to control turbulence in order to prevent any extensive rupture of the slag layer or even as such slag metal interaction. If too much of an activity here, then what is going to happen? We have slag here and that slag particles maybe entrained into the melt, and as a result of which, what happens? This area from the top will look open.

So, if you draw the cross sectional top view, for example, the top view will then look like, I will just draw a section of it to give you an idea. So, we have, this is the shroud region and we have everywhere slag, and basically, that is what I am talking about that this region is going to be exposed; there is no slag here, and because of high flow rate of molten steel, because of no way to damp the turbulence itself. The slag may be, there may be lot of activity as the slag droplets maybe entrained. These droplets may be entrained here, and these droplets, if there are no dams, etcetera, maybe entrained also.

So, slag emulsification can take place because of the turbulence, we can have rupture of the slag layer, whereby reoxidation can take place, and therefore, it is necessary today to restrict turbulence here and that is why we have structures which are placed or furnitures which are placed below the nozzle, which are known as turbo stop or this is also known as pouring box.

This pouring box is going to be placed immediately below the shroud and the objective of the pouring box is to dampen turbulence or restrict the turbulence within this particular region itself, do not let it go to the other side, because you would like to have very weak (( )) kind of a flow here which will be conducive. We do not want any significant amount of turbulence or high velocity. In the bulk of the tundish, it has to be restricted in this part of the tundish, and therefore, we say, we can apply a pouring box here.

A dam is what I have shown here, then we can have weir also here, and somewhere, you can say that weir is something like this, and as a result of which, what happened is we have, for example, the flow which comes like this, which, you know, goes like this there is no scope for the slag to be entrained here. So, the presence of a weir actually prevents very little amount of slag entrainment. So, this is the dam and this is the weir.

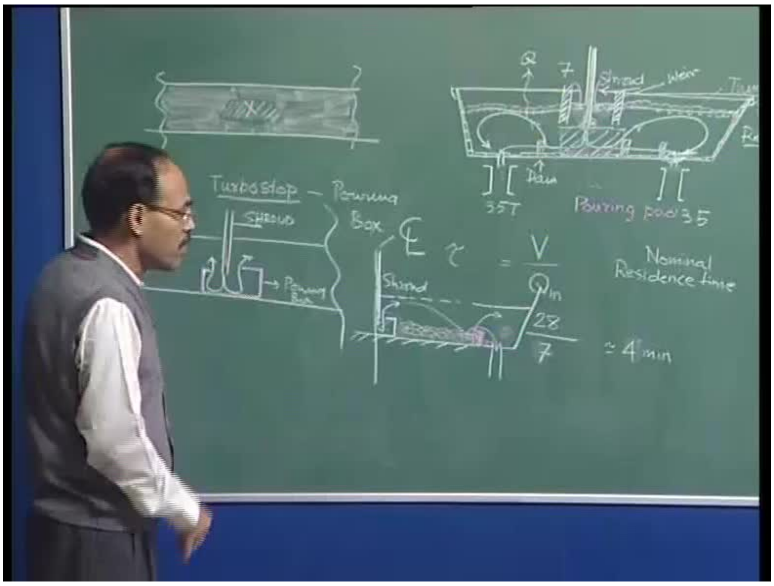
So, dam and weir are typically applied in combination and the objective of dam is to produce a surface directed flow. The objective of weir is to not allow any slag material to be moving along with the melt. The slag will not be moving with this fluid or melt and that is why this dam and the weir are applied in conjunction.

Now, many times today, as I said that, all these things are not going to be applied in conjunction. If I have a turbo stop or a pouring box here below stream, in that case, the dam and the weir may not be necessary, because turbo stop is going to restrict turbulence, and thereby, there will be as such no slag entrainment and the turbo stop will also create a vertically directed flow.

For example, a geometry of, you can imagine that is with the base of the tundish is like this, a turbo stop will look something like this. That is the way the turbo stop really looks like. So, it is a section; so, this is the shroud. This is the pouring box or the turbo stop, and now, this is a refractory line; this is actually made out of castables, very strong structures. So, this is the box. So, the material is now discharged not within the tundish but within the box, and the material comes here and then it goes out something like this;

it goes out something like this and it also creates some amount of vertically, you know, upwardly directed fluid motion and which is created by the dam itself.

(Refer Slide Time: 35:40)



So, the turbo stop, actually the placement of a turbo stop can create surface directed flow. It can prevent also entrainment of the slag, because the flow, you know the upward direction flow here, the flow is moving up; the flow is moving down here. So, the flow can be significantly reduced, and as a result of which, the entrainment of slag can also be or the mixing of the slag or opening of this area can also be substantially eliminated.

So, when you have a turbo stop, it is not necessary to have dam and the weir, but we must understand that if we do not have, for example, a near strand dam in most of the cases. Let me draw a separate figure; illustrate this concept. So, this is the central line and this is half of the turbo stop. I am showing you this is the turbo stop and this is my strand here and this is the shroud and this is my center line. So, the material, this is my free surface. The material goes like this and we have often in here strand dam.

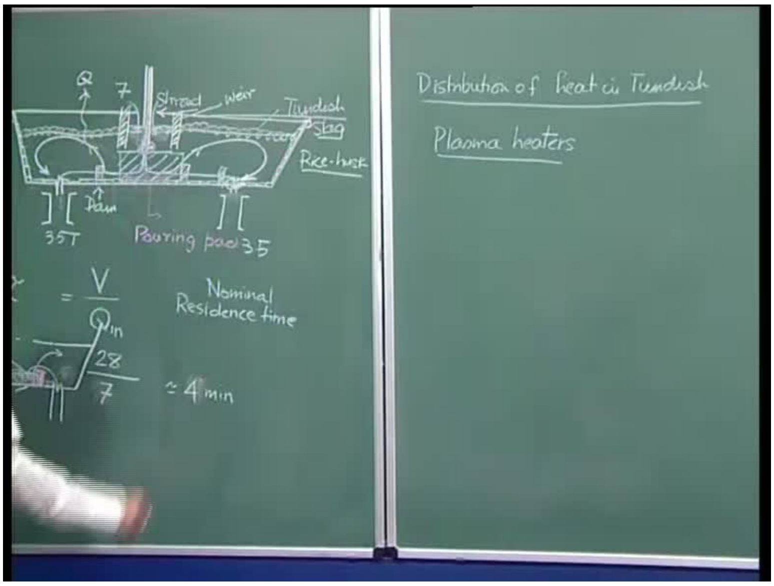
The objective of this dam again is to prolong the residence time. You see the material come here and it will not be able to flow through. Even that is going to approach like this, it cannot go. Then, again, it will going to rebound striking the dam, but the most important function of the dam in industrial tundish is to prevent strand freezing.

Because when the first metal comes in from the ladle, this metal is not very hot, because it is sitting at the bottom of the tundish and through where the heat losses taking place. So, it is relatively cold, and then, as the material in the core of the ladle will flow out that metal, is really much more hotter. So, this material as it comes and as it fills up this cavity and then it flows, trickles here the first metal. So, the metal trickles and gradually flows here; so, the first metal is going to be subjected to a very high level of radiation losses. So, by the time it really reaches here, what can happen is that material can freeze and block this nozzle.

So, we would like some material to pile up here. If this dam is there, in that case, material will not flow but the material will keep on piling here lot of material and there will be no freezing, and then, at one point of time, the material will start to flow. This is the initial stage of tundish filling; that is what I am trying to say.

So, the near strand dam has no function once the tundish starts to work. This has a function only in the initial stages when we do not want any strand freezing because of substantial amount of heat loss from the initial amount of metal, which enters the tundish.

(Refer Slide Time: 57:10)



We can now talk about the distribution of temperature a little bit; distribution of heat in tundish. It is often required that if the temperature drop of this material is significant, suppose if you are operating with not a thick slag, if you are operating with no tundish cover, in that case, there can be significant amount of heat loss, and in that case, in tundish, it may be necessary that the temperature of the metal is heated up. So, in that particular case, how to heat the molten metal? How to supply heat to molten metal?

We have plasma heaters for example, and through these plasma heaters, there can be one plasma heater here, second plasma heater here, third plasma heater here and fourth plasma heater here, and these plasma heaters from the top are going to supply heat to molten metal, and thereby, the material in the tundish can be heated up.

We must understand that if you want to remove inclusions from the tundish, we require a very quiescent flow; we require a upwardly directed flow, we do not want too much of turbulence. On the other hand, if you want that we have to supply heat and that heat is distributed all through the molten metal uniformly, in that case, there has to be a good amount of mixing in the system or not a weak flow or not a surface directed flow but, you know, a very well mixed kind of a flow has to be there, which will take the heat from this surface to the bulk of the liquid and distribute it there.

So, the conditions, therefore, we learned from this that the conditions which are conducive to inclusion floatation. The fluid flow conditions which are conducive to inclusion floatation are not same as the conditions which are required to improve or enhance the temperature of molten steel. So, enhancement of temperature or enhancement of material mixing, if you are adding some alloying additions to distribute it in the system itself, then we will require a high velocity; we will require high mixing conditions prevalent.

On the other hand, if you want to separate out or remove inclusions, we do not want that high mixing flow. We require what is known as a flock flow or a very weak kind of a flow which will be conducive to inclusion floatation. Indeed if you have flock flow and surface directed flow, that tundish is ideal as far as removal of inclusion is concerned.