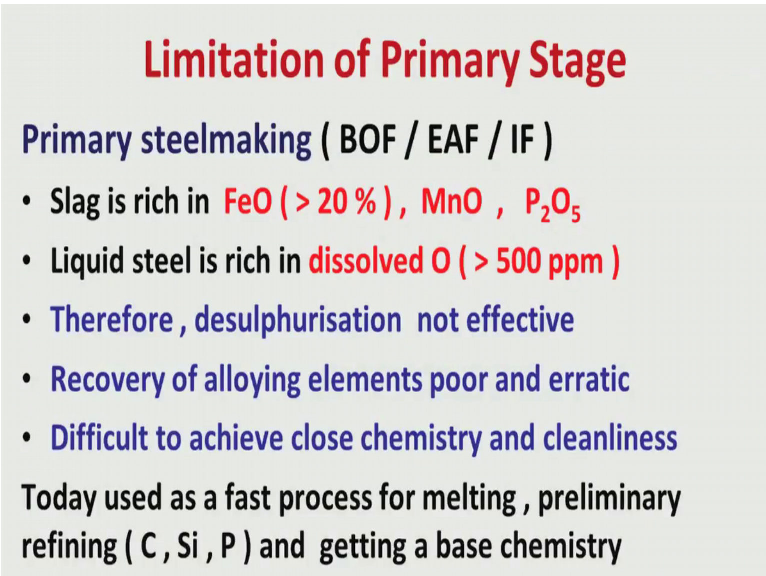
Steel Quality Role of Secondary Refining and Continuous Casting
Dr. Santanu Kr Ray
Department of Mechanical Engineering
Indian Institute of Technology, Madras

Module - 02
Lecture - 06
Limitation of Primary Steelmaking & Importance of secondary Refining

In earlier sessions I have talked about the different measures of quality. How you define quality, what are the ways - way to identify for different steel grades, what are the different criteria, which factors should we adhere to. Now I will be talking about what is the importance of secondary refining in achieving the desired level of quality, how do you achieve it, what are the different ways we can confirm to the application requirements of quality, one by one I will go in to all those issues.

So, as I have told you earlier secondary refining; that means, ladle metallurgy whatever you doing ladle for the final you know stages of quality improvement, that is very important secondary refining is an very important component of steelmaking.

(Refer Slide Time: 01:23)



So, I will be going ahead with secondary refining, now let me talk about why you know in the primary stage itself we cannot achieve quality. What are the limitations of primary stage while secondary refining or ladle metallurgy is essential for achieving quality? So, by primary steelmaking all of you know it can be either basic oxygen furnace BOF, electric arc furnace EAF or induction furnace. In induction furnace you basically melt the constituents the raw materials you can do very little refining. So, let us go ahead what are the limitations of primary stage what are the limitations of BOF EAF and induction furnace IF. The basic idea is the slag is rich in FeO; why it is the slag is rich in FeO iron oxide because all these are primary steel all this primary steelmaking stages are basically or in principle they are oxidizing process, you are putting oxygen in the furnace you want to oxidize some of the elements in the process the slag which is formed becomes very rich in iron oxide.

It has lot of amino it has phosphorous oxide as well because you know I have told you because in the primary stage you can take care of phosphorus because of the oxidizing environment. So, because of the oxidation reactions the slag is rich in iron oxide, is rich in manganese oxide, rich in phosphorous oxide. So, now, what are the problems? This liquid stream because of the oxidation process is very rich in dissolved oxygen that is why the slag is rich in iron oxide. The consequence is the liquid steel is rich in dissolved oxygen it is as high as more than 500 ppm it can go as high as 800 ppm. So, this is an issue to be thought about; that means we have to bring down this oxygen in subsequent stages in primary stage liquid steel is very rich in dissolve oxygen that is one important limitation.

Moreover since dissolved oxygen is very high in this primary stage desulphurization is not very effective, because I have told you earlier it will be very clear to you in subsequent stages that during desulphurization you need the liquid steel to have very small amount of dissolve oxygen, then only desulphurization will be very effective. So, since dissolve oxygen is very high in liquid steel in the primary stage, desulphurization is not at all effective then another important issue is the recovery of alloying elements poor and erratic.

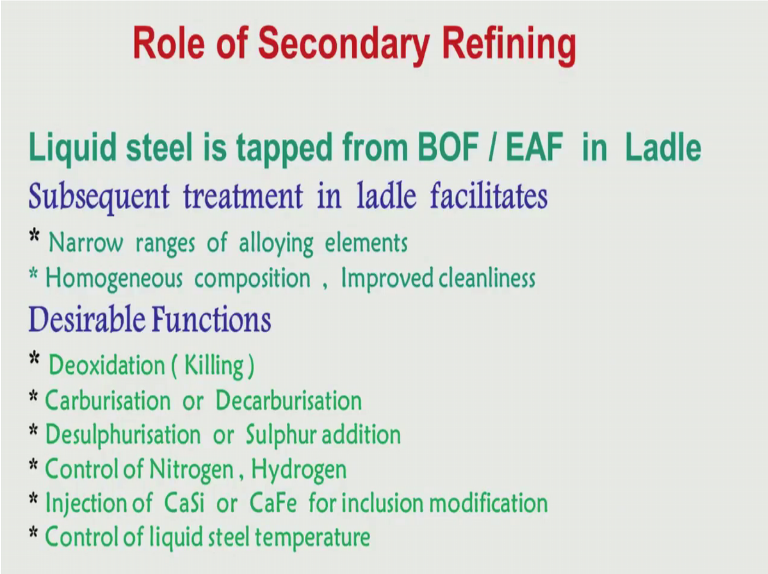
That means when we are adding some federalized like we want to adjust manganese we want to adjust silicon, we are we want to adjust some other adding elements like chromium, maybe we want to adjust you know some other elements like even nickel. So, the recovery of the alloying elements are poor; that means, recovered is not poor whatever federalize you are adding, whatever constituent of that particular aluminum, it is there in the federalize, but in the initial input materials finally, in the steel you get less than that it is sometimes maybe as low as 70 percent it may become 80 percent. So, it is recovery of the alloying element is less and it is erratic why it is it what do I mean by it is erratic? That means, maybe one hit you can get recovery of 70 percent another hit you may get 90 percent. So, you really do not know when you are making a steel in primary steelmaking state what will be the recovery of the alloying elements.

Why this is so? Again the culprit is more amount of dissolved oxygen steel, more amount of iron oxide in slag. So, the alloying elements which we are adding which we intend to add in the steel they become oxidized and part of it goes to the slag that is why the recovery is poor and you know erratic it is also erratic; that means, it is not very well defined how much we will get in the final analysis. So, therefore, it is difficult to achieve the close chemistry ranges. Today you should know that what I was alloy steel we are producing whatever steel chemistry we are producing the customer wants the chemistry should be very well defined it should be very close; that means, there should not be a variation of the alloying elements from heat to it. So, this is very difficult to achieve in the primary stage.

Moreover what is most important the cleanliness level good quality basically means the cleanliness level also should be high the residual element should be less the inclusions should be less it should be a clean steel. So, that also is difficult to achieve because you have very low amount of dissolve oxygen. So, total oxygen is high because of this you know the possibility of inclusion generation will also be high during subsequent stages if you if you want to you know cast a dissolve steel which is having very high dissolved oxygen from the primary stage you will have very high amount of inclusions oxides, you will be having very high amount of sulfides because the sulphur content is also very high. So, oxides and sulfides are more; that means, the cleanliness level is cleanliness level is poor. So, these are the difficulties at the end of the primary stage.

So, this primary stage today is used only as a process for faster melting and preliminary refining. What do I mean by preliminary refining? Basically we want to control some extent carbon to some extent sulphur and of course, phosphorous in the primary stage and the whole idea in principle is to get a base level of chemistry on which we can find you which can we find you in the subsequent secondary refining stages.

(Refer Slide Time: 08:40)



So, I have talked about what are the limitations in primary stage. Now what the secondary refining is supposed to do then all of us know that steel liquid steel from the primary stage; that means, either from electric arc furnace or basic oxygen furnace or in you know it does induction furnace this is stacked in a ladle it has to be stacked in a ladle, and then whatever treatments will be done those will be done in the ladle. So, what we want the secondary refining stages to do, we should be able to get very narrow ranges of alloying elements which was not possible in primary stage.

We should be able to get a homogenous composition; that means, there should not be a variation from one area of the liquid steel to the another, we should have improved cleanliness very important requirement as I am mentioning repeatedly. So, these are the important requirements. So, now, if we get into the exact details what are the desirable functions of secondary refining, what do you expect what do you intend to do during the secondary stages, let us go one by one. First and important is deoxidation which is known as killing also from practical point of view, some people call it killing of steel. So, deoxidation is necessary because the dissolved oxygen in liquid steel after primary steelmaking is very high more than 500-600 ppm, this must be brought down to very low level, otherwise it will be difficult to cause the material, otherwise you know the cleanliness level will be poor. So, this is the first and most important requirement most important desirable function during secondary refining.

Next is the carburization or decarburization. As I have told you after primary steelmaking stage we have a very best level of chemistry may be the carbon content may be 05, may be 06, may be 04 now the final carbon level in the heat we which want to process which want to produce the grade which one to produce may be having either lower carbon than this or higher carbon than this. If you want higher carbon than that; that means, we have to carburize we have to increase the carbon level again if you want to decarburize the steel; that means, we want a carbon level of say 02 or say 015 or say 025 so; that means, we want to decarburize the liquid state. So, this also can be done during secondary refining stages.

Next most important or I must tell one of the important requirements for having a good qualities desulphurization; that means, the sulfur content of steel liquid steel has to be brought down at this stage. I have also told you that in most of the steel applications we need low sulfur, but there is one application requirement specifically it is called machinable steel wherein we want to have a very good machine ability in steel, here intentionally we may add some sulfur in the steel to get good machinability good cheap formation during machining.

So, there are some sulfur addition may be necessary that is of course, a very you know one of requirement, but most of the steel we want desulphurization; that means, sulfur should be brought down. So, this can be done during secondary refining; another important requirement is control of nitrogen and hydrogen these two are gaseous elements, these two are present in liquid steel depending on the process of primary steelmaking, what are the process parameters we may have some high amount of nitrogen and hydrogen in steel. So, this must be brought down for having good quality of steel.

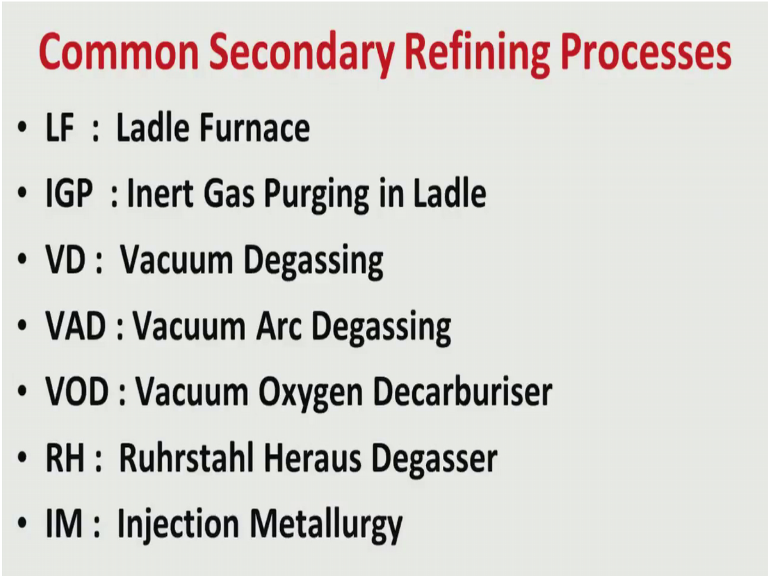
So, control of these gaseous elements nitrogen and hydrogen is possible in secondary refining stage, then inclusion modification as I have told you earlier during deoxidation what is happening is I will come to this in greater detail subsequently, but just let me talk about it talk about this that inclusion formation during deoxidation if you kill with aluminum which is a very efficient you know deoxidant. What we are forming is alumina this alumina inclusions are solid, because the melting point of alumina is higher compared to the melting point of liquid steel. So, therefore, these are solid particles of alumina in steel after deoxidation. Similarly we might have silica if you deoxidize with silicon. Now particularly for alumina which has a very high melting point which is solid if you want to modify the inclusions; that means, if you want to change the shape of the inclusion or we want to control the melting part of the inclusion and make it liquid during at during the time of steelmaking what is the way out.

We add something which will react with alumina and the melting point will come down we know that c i o when it combines with l 3 o 3 is the possibility of bringing down the melting temperature through eutectic reaction. So, it is necessary to control the melting point of inclusions through injection of either CaSi; that means calcium silicide or CaFe; that means calcium iron. The whole idea is to use calcium to modify the inclusion to make it liquid to make it spherical at the time of steelmaking.

Now, another important requirement during secondary refining desirable function you can tell is control of liquid steel temperature. You know when we are doing continuous casting or when you are doing even inward casting is typical temperature range is necessary; that means, that particular super heat is necessary every steel composition has a liquidus temperature. Normally the temperature of the liquid steel when it is taken the casting bay it is slightly more than the liquidus temperature it is called the super heat. Now we must cast at a particular range of super heat it cannot be very high then the structure will be bad the solidification structure will be poor it should not be very low, then there is a problem there may be a interruption in casting there may be premature solidification and likewise there may be difficulties in during casting.

So, control of liquid steel temperature is very important. So, these are the desirable functions in secondary refining; deoxidation or killing, carburization or decarburization, desulphurization mostly control of nitrogen and hydrogen injection of calcium where injection it is called for inclusion modification and then of course, control of liquid steel temperature these are the desirable functions of secondary refining.

(Refer Slide Time: 16:54)



Now, let me just go through what are the very common secondary refining processes which are used in modern steelmaking practices. First is called ladle furnace which is known as LF, another is inert gas purging in ladle. I have told you that from primary steel vessel; that means, b o a for you know EAF steel is captain ladle; now that ladle then is taken to different you know stages of defining secondary refining. So, it may be taken inside a ladle furnace or it may not be taken in a ladle furnace, but you may pass inert gas from the bottom that is called inert gas purging in ladle; that means, the ladle should have facility for purging of inert gas from the bottom. It might be possible to you know blow inert gas from the top as well, but mostly ladles are having facilities of inert gas purging from the bottom. So, this is called IGP inert gas purging.

Then as I have told you the degassing; that means, control of nitrogen and hydrogen in steel is very important. So, there might be a necessity of vacuum degassing; that means, you create some vacuum you take the ladle inside a vacuum chamber, you create a vacuum and that will help in the degasing process. So, that may be VD vacuum degassing. Now you we may have to require to increase the temperature. So, there may be a necessity of some arcing facility for increasing the temperature because during the process of secondary refining, due to the process of transporting the liquid steel from one vessel to another and during transportation from one way to another temperature is coming down. So, there may be necessity of increasing the request till temperature. So, some arcing may be necessary. So, vacuum arc degassing has the facility of vacuum as well as arcing. So, the temperature can be increased in vacuum itself then vacuum oxygen decarburizor VOD this is another important secondary refining process.

Here we have vacuum facility as well as we have facility to push argon sorry push oxygen. So, oxygen is going to decarburize; that means, oxygen will react with carbon for decarburization. So, VOD uses vacuum as well as oxygen in gas to control decarburization then there is an RH process is known as ruhrstahl heraus degasser; it was developed in Germany rule is a ruhr is a very important area industrial area of Germany, stahl is the German you know name of steel in German in dosh language steel is known as stahl. So, this process ruhrstahl heraus degasser this was developed and patented in Germany. So, this RH process is also very important degassing process.

Then another important is in the injection metallurgy, I have told you that sometimes it is necessary to control the inclusion shape the inclusion melting point through injection of were injection of CaSi or CaFe calcium silicide or calcium iron. So, it is done through injection metallurgy. So, injection metallurgy is another secondary refining process. So, I have talked about LF, IGP, VD, VAD, VOD, RH IM there are several other secondary refining processes, but these are very common that is why I want to highlight these processes. Now earlier one I have told what are the desirable functions deoxidation carburization or decarburization desulphurization control of nitrogen hydrogen that is (Refer Time: 21:17) then injection of CaSi or CaFe, then control of liquid steel temperature and then I have talked about what are the secondary refining processes.

(Refer Slide Time: 21:27)

Secondary Refining Processes and Capabilities

Capability	VD	VAD	LF	VOD	IM	IGP
Deoxidation	Yes	Yes	Yes	Yes	Yes	Yes
Desulphurisation	Yes	Yes	Yes	Yes	Yes	Minor
Decarburisation	No	No	No	Yes	No	No
Heating	No	Yes	Yes	Yes (chemical)	No	No
Degassing	Yes	Yes	No	Yes	No	No
Inclusion Modification	No	Yes	Yes	No	Yes	Minor

Now, let me show to you that which process is capable of doing which function. In one you know transference I am trying to show I am trying to highlight what are the capability of the different secondary refining processes. At the left if you look at the you know this transparency you will find or look at this slide you will find first requirement is deoxidation as I have told you, now what are the different processes which can do deoxidation. All these secondary refining processes can do deoxidation this is because this is the most important and fundamental requirement during secondary refining oxygen or in liquid steel has to be brought down. So, deoxidation is essential and all degassing rather all the second refining processes whether it is VD vacuum degassing ,whether it is VAD, whether it is LF, whether it is VOD, whether it is injection metallurgy, whether it is you know inert gas purging all processes are capable of doing deoxidation.

Next comes desulphurization now one of the processes which can do desulphurization; again we will find most of these processes are capable of doing desulphurization VD yes VAD yes, LF yes, VOD yes, injection metallurgy of course, yes because you are putting calcium calcium can do lot of this good desulphurization. IGP inert gas purging you can do a minor amount of desulphurization provided you can add some calcium oxide in the process it is possible to get some amount of desulphurization. So, again you have found that oxygen control and sulfur control are two most important functions of secondary refining and most of the secondary refining processes are capable of doing these two functions.

Next let us come to decarburization; now you will see that basically decarburization can be done only by VOD. VOD is I as I have talked to you vacuum oxygen decarburization, the details I will come to later how it is done you are putting oxygen that will react with carbon in steel and finally, carbon monoxide will form and this will come out of the steel. So, the vacuum will enhance this decarburization process. So, VOD is capable right doing decarburization now I have told you that sometimes it is required to increase the liquid steel temperature; that means, some heating facility is sometimes required during the process of secondary refining. Now let us see which secondary refining process are capable of heating the liquid steel. As I have talked to you that VD is vacuum basically vacuum degassing it has no heating facility.

So, it cannot do any heating VAD vacuum arc degassing; that means, there is a possibility of arcing that there is a facility of arcing in this process. So, heating is possible. LF ladle furnace again this is possible because you have some arcing facility in this process as well. VOD heating has to be done there is no arcing facility, but through chemical heating; that means, you can add some aluminum here and you know aluminum to alumina reaction; that means, aluminum reacting with oxygen to get alumina this is a highly exothermic reaction. So, it is called chemical heating in this process some heating is possible.

Injection metallurgy there is no heating facility, you know inert gas purging IGP in the ladle again it does not have any heating facility. So, heating facility is possible in VAD in LF. Basically these are two processes where there is a possibility of arcing and you can increase the temperature whenever there is a necessity. So, we should remember that for all other processes whatever liquid steel temperature is there we have to live with it; that means, there is no possibility to increase the temperature. So, the temperature management becomes a bit critical in all other stages, but except in VAD in LF where there is a possibility of increasing the temperature in possibility of heating through arcing. So, it is easier to get a good amount of you know temperature management better temperature management while you are using VAD and IF.

Then let us come to degassing; that means, control of the gaseous constituents in steel k c s elements in steel which are hydrogen and nitrogen. So, what of the processes whenever there is a vacuum in the process it is possible to do the gassing? So, VD vacuum degassing it is possible, VAD definitely it is possible, then VOD again there is vacuum; that means, it is possible LF there is no vacuum in ladle furnace it is not possible injection metallurgy again no vacuum. So, it is not possible IGP inert gas purging there is no vacuum. So, degassing is not possible

Only the minor extent of because of you are pushing lot of inert gases argon. So, it might be possible to you know take out to certain extent to small extent the gaseous elements which area present in liquid steel, but it is a minor. So, basically there has to be a vacuum in the process. So, VD, VAD, VOD these are the processes where you can do lot of degassing. So, as I was talking of the different you know secondary refining processes and the capabilities, I was talking about the inclusion modification which is one important requirement.

So, it is possible in VAD it is possible in ladle furnace possible in of course, in induction injection metallurgy because the whole purpose of injection metallurgy is to modify the inclusions. To some extent to a minor extent is IGP, but not possible in VD because there is no you know it is basically vacuum degassing, but not much of possibility of inclusion modification neither in VOD. So, I have talked about what are the different secondary refining processes what are their capabilities.