

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

Module No. # 01

Lecture No. # 01

Introduction

So, I welcome you all to this course on steel making. This course, which comprises of nearly 40 lectures, will be delivered by myself Professor Deepak Mazumdar and Professor Sathish Chand Koria, both of us working at IIT Kanpur for a long time and specialize in steel making. And throughout this course, our objective has been to provide adequate knowledge on steelmaking to you, such that you can appreciate the reasons of this subject in present context, understand its wide knowledge base, and then, think that how developed the subject is and how difficult it is really to make further improvements.

Today, when we talk about steelmaking, we understand that it is know more than nearly 150 years old near perfect technology, enormous casting rates, enormous steel making in primary steel making vessels and highly **cleans** and sophisticated grades of steels. So, we have advanced remarkably and doing further improvements, steel making certainly is not as simple as in many new fields, which has emerged in recent years.

So, it is therefore necessary that you have adequate knowledge of the subject; you have adequate knowledge of the fundamentals, and it is with this adequate knowledge and fundamentals, we think that you will be eventually a better steel maker, a better steel making engineer or a steel making metallurgist as we say and will be able to contribute eventually in the field of steel making.

Now, as I have mentioned, we will deliver lectures about 40 hours; sometimes you will see me, sometimes you will see Professor Koria. We will deliver lectures on diverse topics, which will encompass primary steel making, secondary steel making, casting processes, electric arc furnace steel making, dual steel making, continuous casting, you name it and we will be delivering lecture on practically all aspects of steel making.

So, this being the first lecture, I will start the discussion with an overview of the subject, which is sort of general. I intend to give you a historical perspective first and followed by that, **will** I will give you an overview, which is a broad sketch of the steel making circuitry and examine in details, the issue of energy in steel making and finally, I will wrap up this two lectures section by making certain statements, regarding the future of steel making what was yesterday, what is today and what will be tomorrow like for all of us.

Now, as you are aware that steel is a very old material and known to mankind for a long long time. And today, you look at any area, be it automotive sector, railway sector, construction sector, everywhere you find steel is there and what is steel to us as a metallurgist? Steel is a solution of carbon in iron with certain amount of trace elements may be sometimes silicon, sometimes other alloying additions like manganese and occasionally, we have some impurities also present in steel, which we are unable to drive off completely.

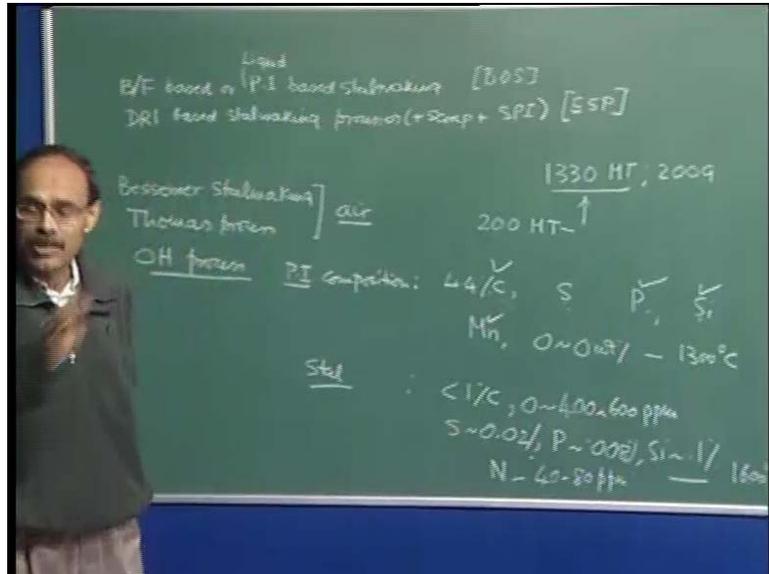
But from an engineer's point of view, steel is a material, which has diverse properties and these properties, which come to our use, almost we are talking about engineering properties and steel **has** as we know excellent toughness, good tensile strength. For strength, it has a good strength to weight ratio, it is basically I would say **a that withstand thermal** high thermal environment or high temperature environment, it is immense recycling potential. You imagine, you have iron ore from the mines and then, you make iron and eventually that iron becomes iron ore, it corrodes and it gets back into the soil so.

It has many qualities which has made it attractive, but most importantly is the wide range of mechanical properties and this mechanical properties, we have been able to reduce into steel by virtue of a proper melting circuit, a proper refining circuitry and finally, by you know, series of mechanical working processes for why we control the microstructure of steel and induce into steel a variety of properties.

Now, steel is made as you all know, **either from the blast furnace** blast furnace iron making, of course you must have done **so** at this particular course. So, molten steel molten iron, which we produce in blast furnace, which is known as the pig iron, so we

can have a pig iron based **on blast furnace, based iron making a steel making process**, alternatively we can have a DRI based steel making process also.

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So, blast furnace based steelmaking, I will write it like this; blast furnace based steelmaking based or pig iron based steel making and then, we have DRI, which is called direct reduced iron- DRI based.

DRI based steel making basically does not require, often do not require molten pig iron. So, it is supplemented with some amount of scrap, may be **sometimes** some amount of solid pig iron. And pig iron based or liquid pig iron based this I would say better liquid pig iron based, because some plants do use solid pig iron charge also and a DRI based steel making processes often uses this plus scrap plus solid pig iron.

So, liquid pig iron based steel making processes essentially is the oxygen steel making processes, which we say as basic of the steel making process. On the other hand, DRI based steel making processes are found with the electric steel making processes or electric. The furnace in which BOS is carried out is termed as the BOF basic oxygen furnace; the furnace in which electric steel making is carried out is at electric arc furnace, as we all know.

Once we produce steel, which is we called as the crude steel, which are the series of secondary defining operations and following the secondary refining operation today,

what you have is continuous casting. As you all must be knowing that, invert casting has been faced out, of course in certain specific areas we have ingot casting steel practice, but very in the middle school level.

You know more than 95 percent of the world steel produced today is cast to continuous casting process. Today a steel plant based on ingot casting with BOF steel making is not sustainable at all, because the rate at which the basic oxygen steel making process produce steel, it requires an equally fast process to convert molten steel into solid product.

So, ingot casting is a much slower process; the conversion rate from liquid to solid is much slower in ingot casting than in continuous casting. So, ingot casting is no match for BOS. So, BOS or BOF, we require what is, we will call as continuous casting is **made it**.

So, with basic oxygen steel making process and ESP or electric steel making process, we have a series of secondary steel making process, we will discuss this and as I said, a variety of secondary steel making processes and all the secondary steel making processes are not used to produce the given grade of steel; they are basically used depending on the requirement of the customer. This will be clear to you in a moment and following that, we will have continuous casting.

Now, what is the history of steel making **lines when was steel first made**? So, more than 150 years ago and the father of steel making is, Sir Henry Bessemer, a British engineer **who** first in a clear crucible, used a clay tube- fire clay tube-, **you** blow air, put molten pig iron and that is when steel making really started and since the days of Henry Bessemer, remarkable advances as you all know have been made.

So, we first started with what is the process known as the Bessemer process; we have the Thomas process; we have the open hearth process and gradually these processes, they were faced out by 1960s or 70s completely.

Today, basic Bessemer process of steel making is much be non-existent Bessemer process of steel making; similarly, Thomas process of steel making, which also involves blowing of air to molten pig iron has also be nearly faced out by 1970s. Open hearth steelmaking is remaining in one or two places all over the world. And today, bulk of the

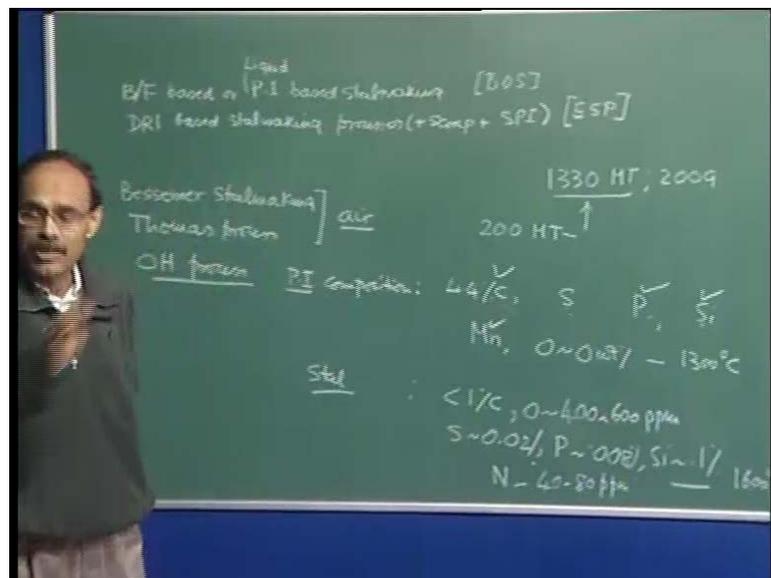
world steel is produced by two different roots, which is the basic oxygen furnace and electric arc furnace.

Now, the remarkable production of steel has been possible in last 50 years or 60 years, because of the advent of oxygen steel making process. And the first oxygen steel making process, which is known as the **healthy** steel making process started about in the year of **1950S** late 1950s in a place called **a linge places called** Linde and Donovick simultaneously, near Austria and since then the production of steel really has quite a bit.

And it is after the Second World War really, there is lot of scrap also available, then simultaneously how to convert that scrap into a meaningful value added product to the electric arc furnace also picked up momentum.

Today, if you look at the production of steel, you would say 60 percent of the world crude steel is produced through the basic oxygen steel making process; on the other hand, about 34 percent of the world steel is produced the electric arc furnace steel making process.

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Last year in 2008, for example, how much of steel was produced? Almost 1330 million ton in 2009, enormous amount of productivity, because everywhere **we the** whole world is developing. There are countries like India and China, where lot of construction has to take place and we have large population in these countries. So, the global demand for

world steel has increased remarkably over the years, particularly during the last few decades and so on.

So, if you look at the quantum of steel that we have been able to produce in the last 50-60 years, almost 5 to 6 times more steel has been produced today. So, if you talk of 1950-1960s, we were producing something like, you know say 200 million tons and today, we are at 1306 over, 6 fold increased in the last from 200 million tons around 1950-60 to about 1330 million ton in 2009, which essentially tells us that **as the** nearly you know **nearly** about 6 fold increased, 6 to 7 fold increase and that society needs now more and more steel, because development work has to go on, peoples lifestyle has increased. And actually, if you all know that the consumption of steel is an index of the wealthiness of a nation, I mean, because steel is used to produce automobiles; steel is used to produce refrigerator body; steel is a produced a used to make fans, air, conditioner bodies and so on.

So, in a high consumption of steel necessary tells that, people have lot of money in their pocket; they are able to buy all these kinds of gadgets for their comfort. Therefore, a society if it consumes more and more steel, we will certainly see that you know certainly that find that yes, the society is very developed society; people have lot of income and **they are going to** they can spend money in many items, the backbone of which essentially steel.

And indeed, another consumption of flat products; flat products means, as we will see later on, steel is produced in the form of say long products; long products is what? Railways, for example the rail track that you see many plants produced that, so we said it is a long product plant. Wire and rods, which are used in the houses these are all long products.

On the other hand, flat products are out of slabs and sheets and ultimately thin sheets or strips are produced by rolling and we say that if a plant produces, you may have seen huge trucks moving on the road with strips of steel in the form of a coil. So, how are they produced? They are produced from continuously cast slab and then, a continuously cast slab is rolled and then you produce thin steel.

So, this flat products, if a society consumes more flat products, that means, the society must be building in more automobiles; the society must be making more trains; the

society must be making more freezers; more household equipment, washing machine, household equipments and so on.

So, the consumption of flat products or still flats are again an index of the wealthiness of nation. So, severe remarkable increase as taken place in the arena of steel production and this has been possible because of widespread development application of knowledge and sub flow developments of newer technologies, new sensors and all these things have paved the way for enormous production of steel.

And today, if we look at the steel making circuitry, the way Bessemer made the steel and today, the way steel is being made, you know the number of **man** human hands required to produce such kind of steel, the level of automation, the level of process control, they are remarkably different that **one and** been practiced 100 years back or since the time of Bessemer.

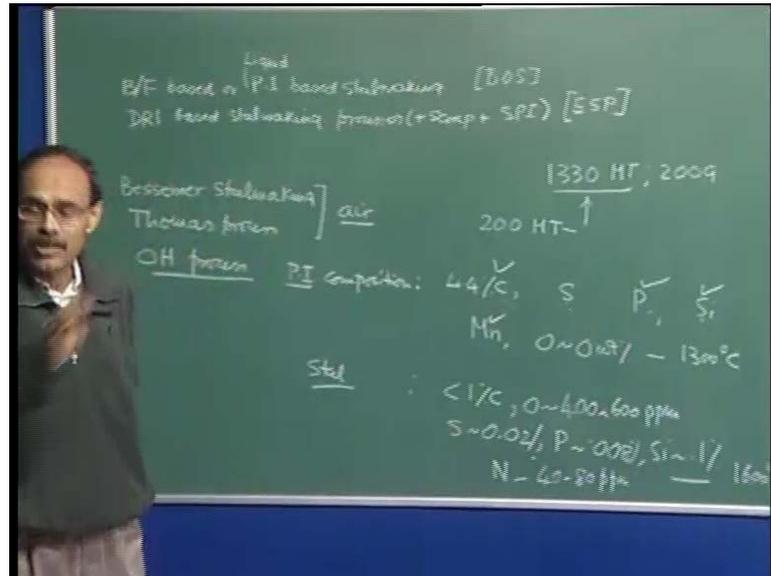
So, steel making now, since the days of Bessemer, for example, I have mentioned about Bessemer steel making, Thomas process, then you have open hearth process, which face now extension.

Now, this process **are open Bessemer and** Thomas processes is used **here** as the oxidizing agents. Because in those days, there was no means to obtain pure oxygen; Bessemer did not recognized that it is not correct to blow air, it is in fact we knew that perhaps, it is better to blow oxygen, but in those days, there was no source of cheap availability of oxygen, a big issue and there is no commercial processes is available, so he had no option, but to blowing.

And today, we know that nobody would because some oxygen is available so using of air as an oxidizing agent is not really desirable.

Now, if you look at pig iron composition, the pig iron contains, for example approximately 4.4 weight percentage carbon; **it can contain various types of** it will contain some sulphur; it will contain some phosphorous; it will contain some silicon; it will contain some manganese; it may contain other elements and oxygen virtually is 0 weight percentage less than 1 ppm, because **blast furnace is** blast furnace has an extremely reducing environment.

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Now, the level of sulphur, the level of phosphorous, the level of silicon and manganese, which is there in the pig iron, which flows out of from the blast furnace depends on the raw materials used in the blast furnace and operating conditions in the blast furnace.

For example, you have this, that if the blast furnace is operated, blast furnace hearth temperature is very high, in that case I would expect that the level of silicon contamination in pig iron is going to be there should be large. Similarly, if I say that well, a blast furnace can necessity is not optimum, in that case sulphur level can be very relatively large.

So, depending on the raw material composition, depending on the blast furnace operating conditions, the level of sulphur, phosphorous, silicon and manganese can vary significantly.

For example, silicon could be of the order of 1 weight percentage; manganese could be of the order of 1.5 weight percentage; sulphur could be of the order of 0.15 to 1.2 and in blast furnace we have no phosphorous removal; so the phosphorous could be about 0.15 and so on.

Now, we will talk about crude steel. In this crude steel, which flows out of primary steelmaking we can have carbon less than 0.1 percentage; we can have lot of oxygen now, because it is an oxidizing steel making process and so the level of oxygen

contamination could be as high as 400 600 800 depending on again the process. If you have pumping in too much of oxygen, note that the solubility of the oxygen in molten pig iron at 1600 degree centigrade is about 0.2 weight percentage, which means about 2000 ppm of oxygen can go really inside steel.

But it does not happen; so this level of contamination can be 400 600 and the operator can control it. So, we can have to say 400 to 600 ppm oxygen and as I have said, this is no sacrosanct value; this will depend on your the operating conditions. Now, sulphur and phosphorus can be get down 0.02; in the primary steel making process in the phosphorus also, we can get down to 008; silicon can be 0.1 weight percentage and so on.

If you take secondary steelmaking, it is possible to reduce oxygen level; you can have nitrogen also and nitrogen could be 40 to 80 ppm, perform the nitrogen comes; nitrogen is absorbed during trapping operation. So if will empty the furnace, the molten steel comes from the furnace and falls into the ladle it interacts with the ambient atmosphere and thereby oxygen passes nitrogen passes into.

Sometimes if you have moisture in the environment also raw materials are hydroscopic you can have some hydrogen pickup also and the level of hydrogen could be 2 to 5 ppm depending on the plant conditions.

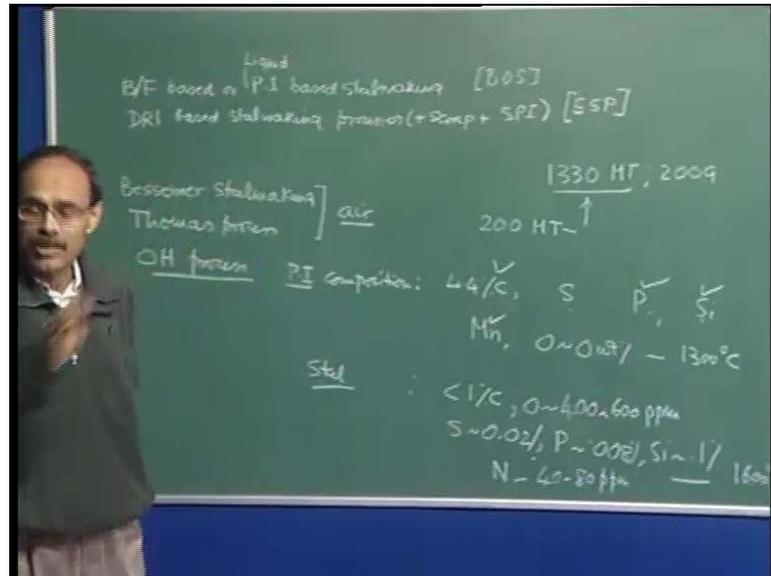
So, to immense as you see phosphorus, silicon, manganese, carbon, so removal of this, you will study this in detail. In the principles of steelmaking, they have higher affinity towards oxygen. We will also in the element diagram that we will discuss when I talk about the science base of steelmaking under the section of thermodynamics.

You see these are the elements carbon, phosphorus, silicon, manganese, they have great affinity for oxygen and that is why when pump in molten pump through molten pig iron, oxygen what happens is these elements reacts with oxygen and gets oxidized.

So, steel making basically is an oxidizing refining process; you introduce oxygen and thereby, you refine the impurities, which are present in or elements which are present in pig iron itself.

Now, if you introduce oxygen here, for example, you can understand that this air is going to have nitrogen in it; 79 percent nitrogen 21 percent oxygen. So, therefore, the contamination of steel produced with nitrogen is going to be very large.

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Also we must know that this blast furnace iron making, it depends on a fuel, because we have to meet the thermal requirements of many endothermic reactions, which takes place in the blast furnace; you know oxide reduction reactions are all are endothermic reactions. So, from where the heat is going to come? The heat comes through combustion of coke into carbon monoxide and that melts and reduces iron ore and helps to melt solid pig iron or sponge pig iron in the liquid state or bring it into the liquid state.

So, we have in the blast furnace, external heat source which is of the burning of the fossil fuel, which provides the necessary heat. On the other hand, in steelmaking we do not require any external heat source; steel making is an autogenous process, which means the oxidation itself produces so much of heat that it is enough to bring steel at a temperature of about required temperature over 1580, 1590 or around 1600 degree centigrade.

So, a threshold amount of carbon, a threshold amount of silicon is necessary to produce that desired level of heat. Because in this steelmaking reaction also, we have to supply heat for many jobs, for example, lime dissolution, slack formation, these will necessarily recover heat. Where from the heat is going to come?

The pig iron, what kind of a temperature it is tapped? It is taken out of the blast furnace may be about 1300 degree centigrade, again this may vary 1350 or so. On the other hand, we have steelmaking at 1600 degree centigrade.

So, after we have supplied heat for all endothermic processes, the entire mass we are going to take; checkup the temperature by 1600 degree centigrade. Therefore, it is understood that if it is an autogenous process, the heat liberated in steel making is, because of the oxidation of carbon, because of the oxidation of silicon, because of the oxidation of phosphorus and manganese. We have to have some critical amount of this elements present in the pig iron; otherwise it will be very difficult to bring it to 1600 degree centigrade.

Often in steelmaking, we will see that the level of contamination is such that the temperature gets even more than 1600 degree centigrade and that is why when such a scenario is, you know we experienced; we had coolant into steel, which is nothing but the plant generated solid scrap and that solid scrap when you put into the steel making reactor the temperature goes down. So, coolants are normally used, but what is important for us to know is that steel is an autogenous process.

Now, when you use air, we are pumping in more amount of air, because they are **contains...** you require some threshold amount of oxygen to get into that, to get that **terms** oxygen comes into molten metal, molten steel; you have to pump in more amount of air, because they contain only 21 percentage of oxygen.

So, therefore, it is understood that more volume of air is going to be introduced; more volume of air if it is introduced, that means, more heat is going to be consumed by the cold layer and then, we are introducing more amount of nitrogen because of that and this nitrogen is without doing anything goes out of the steel converter therefore, it is going to take away heat.

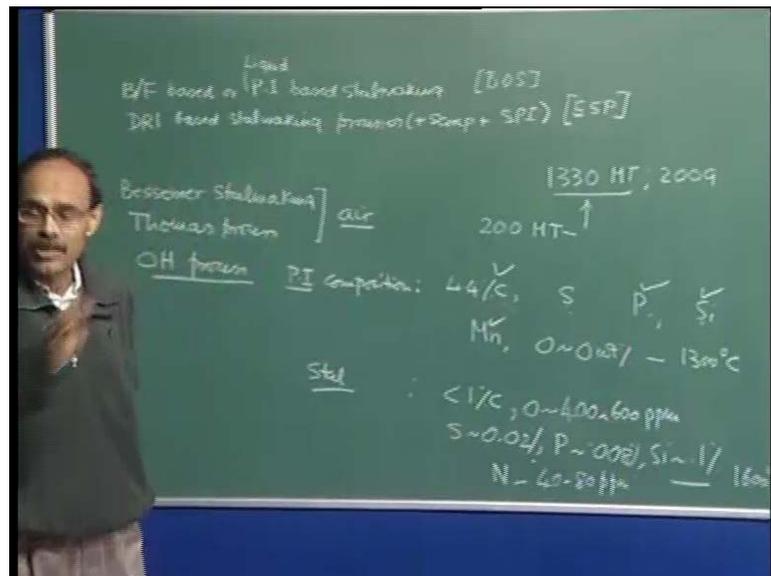
So, in the Bessemer's steelmaking process because of these thermal requirements, you know you require a critical amount of phosphorus, a critical amount of silicon such that this critical amount of silicon and phosphorus may upset the requirement or **may fulfill**, I would say fulfill the thermal requirement of the process.

Otherwise, if you do not have a critical amount of phosphorus and silicon, in that case so much of heat is going to be lost because of the high volume of air injected, that the steel may not be at the desirable temperature.

And that is why, you know even though people knew that air is not a good oxidizing agent, you cannot produce that soft steel of a very low level of carbon and the steel with air. So, therefore, there is **always steel makers, always** wanted in the beginning to produce or to make steel through an oxygen steel making route, which was not possible since late 1950s, when the Henry steel making process was encountered.

Open hearth process- this is a pneumatic steel making processes. Now, steelmaking process as you all known can be classified into acid steelmaking process and basic steel making process.

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In acid steel making process, for example, the slag is acidic, that means, acidic means the basicity is less than 1. You already know the definition of basicity; so basicity is less than 1. So, the pig iron having more silicon and therefore, less phosphorus **and you can** because removal of phosphorus as we will see, will require high basic slags; removal of silicon may not require, you know phosphorus is not there we can make silica's oxidized silicon to silicon dioxide, fix into iron oxide produce the ferrous silicate slag and that we will be calling as acid steelmaking process.

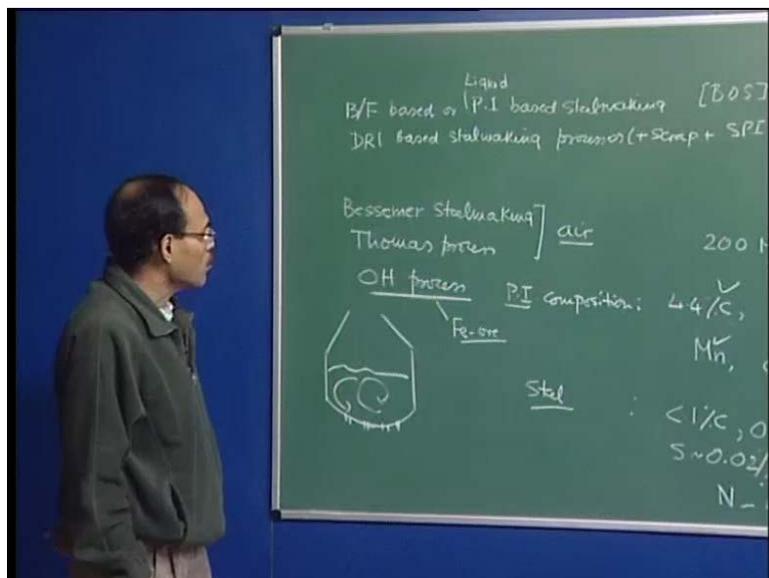
Basic steel making process, the converter lining is going to be acidic also, because if your slag is acidic, in that case if the lining is basic, then the slag is going to heat up that line and the vessel will require frequently lined which is not desirable.

So, in the case of basic steel making process, basic steel making process is going to be used when charge contains more phosphorus and less silicon, particularly in the context of basic Bessemer process.

So, in basic steel making processes you have slag basicity more than 1, so you can afford to have a lining of the reactor also as basic; if we make the lining acidic then the slag is again going to heat up the...

Today acid steel making process nobody practices; steel making process are all basic, whether it is electric arc furnace steel making process ESP or whether it is BOS, it is always basic oxygen steel making process, because by making a slag with high basicity more than 2, 2.5, 2.8, etcetera it is possible to simultaneously eliminate both phosphorus and silicon when we particularly inject oxygen to the system.

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So, coming back to the history of the steel making, so air has problem; acid steel making is not practiced; acid steel making process is Bessemer steel making basically faced out; the basic Bessemer process you know has also been faced out; now and the open hearth process is not a pneumatic process; so these are in a bottom blowing converters. So,

through the bottom of the converter, you know in a vessel converter is nothing but the pear shaped vessel in which steel is made. So, we have set of (()) to which air was introduced, so these are pneumatic steel making processes. So, the air, we have a molten metal here and as the air is introduced, then there is going to be complex convection current here and this expedites the rate of reaction, which has essential of the steel making process itself.

Open hearth steel making process, on the other hand as the name suggests the hearth, you have the a big hearth, wide hearth and that hearth is opened; it is basically there is no oxygen injection in the original version of open hearth furnace, then how was the pig iron going to be oxidized? Pig iron is going to be oxidized in open hearth process; the oxidizing agent is the iron ore.

This is very little agitation in the open hearth parts and as a result of which what happens? The rate of the reaction steel making reaction carbon plus oxygen, sulphur plus calcium oxide, phosphorus plus oxygen, silicon plus oxygen all these reaction as we will see later on when we talk about the fundamentals, these are mass transfer control processes; they depend on the level of education.

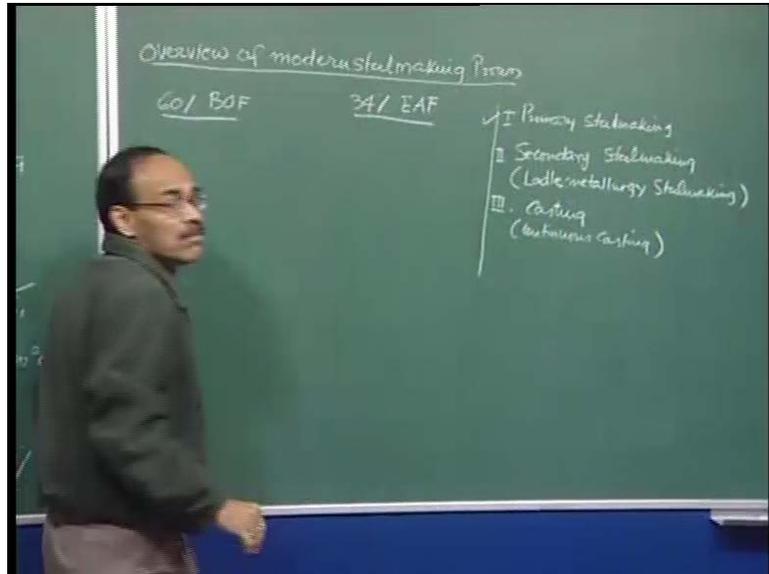
So, in the open hearth process because you do not have much education, because we have no oxygen pumping to the open hearth furnace; you have oxygen is supplied from the iron ore and that oxygen which is present in the iron ore will reacts with phosphorus to silicon, then become phosphorus pent oxide and silicon dioxide and then, they will react with lime in the slag and forms calcium silicate calcium phosphate and so on.

But that is the level of hesitation in the open hearth process is small; the rate of steel production is extremely weak. So, greater the slow rate of open hearth process is responsible for its look loosing of the clarity and therefore, laser harshness of open hearth processes involve some kind of an oxygen glancing also. But today, certainly with oxygen steel making processes we have better off; so we really do not have the confident all these things,

So, these processes have certain many demerits with regard to the present day steelmaking technology, which is oxygen based and as I discuss, give you an overview of the oxygen steel making; you will be able to understand that how does these processes

compared **these or these** and the productivity, the wide range of quality that have today possible to oxidizing making processes.

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Now, let me give you an overview of the modern, so this is overview of the modern steel making process. I think if you are interested to know about the subjects of you know there is greater details, there are text books available, you can refer to and in the present context perhaps beyond this is not important for us to go beyond this depth.

Now, where you talk of modern steelmaking process, we are talking of the era of oxygen steel making that means we are talking of the post 1950 years and we are talking of steelmaking that is mostly oxygen steel making processes.

Now, as I have mentioned today, we have 60 percent of steel through basic oxygen furnace and 34 percentage of steel through electric arc furnace. And I do not right basic arc furnace, because steelmaking today for say it is basic steelmaking. So, you have a lime **which** slag was there; now remaining 6 percentages what is there? These could be **(())** industries like induction furnaces, open hearth furnaces a few of them, which are available; so you know rest other processes, induction open hearth, etcetera filling the gap and make it 100 percent.

So, we have primary way steelmaking. In a steelmaking, today we divided into three different categories; we will say we have primary steelmaking, the secondary

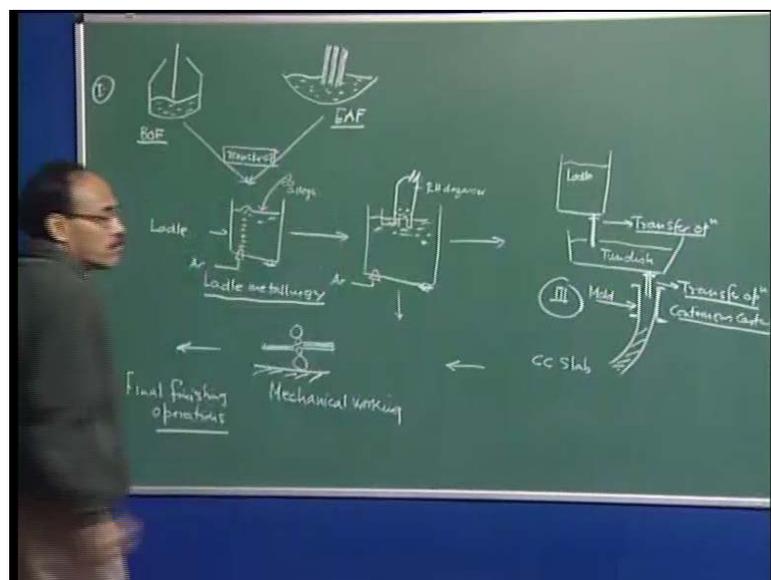
steelmaking I myself do not like the name of secondary steelmaking as if it is secondary it is not so important, but **we will** seeing this course that secondary steelmaking today is the heart of steel making.

It is here that the finest quality of steel is going to be produced; it is here we are going to ensure, you know the first kind of a future product still solidifies steel product we are going to deliver to the customer. So, this is far say the most important part of the modern day steel making.

So, I do not wish to say secondary steelmaking, although this terminology is very common in industry. So, I we will call it as a ladle metallurgy steel making that will be my terminology ladle metallurgy steel making and finally, we will say casting and when you talk about casting, we talk about primarily continuous casting.

So, this is basically the components of the modern day steelmaking circuitry and we will talk of primary steelmaking. We have two predominant routes of primary steelmaking this is number 1, which is 60 percent BOF and 30 percent EAF.

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So, let me now schematically draw this; so we have this is the basic oxygen furnace and this is schematic representation of a healthy converter that of plants here. Similarly, we have a schematic representation of an EAF, we show that well, we have three different electrodes here and this is an EAF process.

So, we can produce steel with this and then, common to this primary steelmaking process is our secondary steel making and this is **what is known as...** we have finally, subsequently so this is number 1, what I shown here is primary steelmaking; this is secondary steel making or the ladle metallurgy steelmaking. So, we have here transfer operation.

We know variety of secondary steelmaking or metallurgy steel making process may be I can show that is all to have a process. If it is necessary from the gradient steel should be produced, then we can have and we have here like this; this is an RH degasser. We will study this later on; the purpose of this is to eliminate other; we can keep on eliminate gases and we can still have **arc** a variety of processes we will discuss.

Following this, so this is the vessel, which is a ladle, the material will be transferred from the BOF to the ladle or from the EAF to the ladle and there is the **(())**. And then, we have, so this is ladle; this is tundish and this is continuous casting; these are slide gates, which controls the flow. So, from the ladle, the material gets transferred into tundish; from the tundish its gets transferred into continuous casting and this is the slab, which has been produced continuously cast slab.

And subsequent to this, so this is the third stage, which is the continuous casting and again you see between the second and the third stage what you have? We have transfer operations.

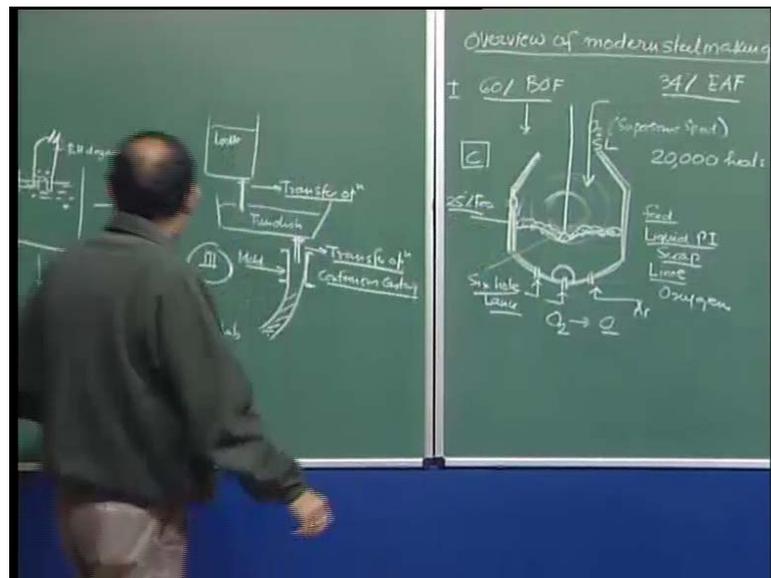
So, steel making parse, we can say it comprises of variety of processing operations; you are processing, you are doing chemical treatments as well as transfer operations and as we will see in this course, we ensure correct quality of steel; it is important that we have adequate understanding of the processing operation as well as the transfer operation.

We cannot ignore the transfer operations; do not ever think the transfer operations are not important; they are equally important in order to ensure and then, comes the final stages, which are the mechanical working process.

So, we have you know rolling mills; we have **they have so** mechanical working and we can have continuously cast slabs, then the total delegate furnaces can be put into soaking kits, can be rolled, can be galvanized; we **can we are** say final finishing operation. So, this is the overall broad view and this is 1, 2 and 3.

Now, let me give you some idea about, of course you are going to deal about basic oxygen steel making processes. So, BOF, EAF, ladle metallurgy and continuous casting, let me explain this circuitry during the next 1 hour or so that we will get an eye overview of the subject of modern steel making.

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So, what constitutes feed to the BOF? So, this is a pear shaped vessel and it is refractory lined and as I mentioned to you that the refractory has to be basic, because the slag that is going to form here is going to be basic; you want to remove both phosphorus and silicon in the process.

So, therefore, the lining is basic; it is a steel shell, the vessel can be rotated like this, while we on tap it, there is a tap hole somewhere located here; we will do the details of this contrasts later on also.

What constitutes the feed of this? Feed here mostly liquid pig iron scrap, then we have and oxygen. So, we have water cold lance here, this lance basically is a vertical tube and under vertical tube, we have attachments which deliver molten metal and oxygen to molten metal in certain fashion.

So, typically we have 6 hole lance; we will study the lance design later on. For greater interaction of oxygen and liquid, because we want oxygen is there in the gas feeds, the oxygen has to dissolve in molten metal and there only in the molten metal it can see the

carbon which stays in the dissolved form it can see the silicon, it can see the phosphorus and interact with them.

So, the dissolution and these reactions are essentially important for the production of heat, because more is the carbon oxygen reaction, more is the phosphorus oxygen reaction, more is going to the heat evaluation. So, therefore, the rapidity which hit the slag is going to be formed will depend on how much of heat is going to be available and this will react with the related to the dissolution of oxygen process.

The multi hole lance distributes oxygen and ensures that oxygen, phosphorus from the gas space to the molten metal is highly efficient. So, we have cavity depression; this as I will discuss in the next or section. This is an impinging gas jet; the gas jet is impinging on the surface and oxygen is introduced in supersonic speed that means the Mach number is greater than 1.

So, once you introduced oxygen at a supersonic speed, tremendous amount of... what happens, you can imagine take, for example, a bucket full of water and then you tried to use a blower on the surface of water, you will see there is going to be a lot of droplets of water, which has going to be ejected and whether ejecting at a supersonic speed, you can imagine that you will create an enormous number of metal droplets are suspended in the system.

So, you create here a mixture of gas slag and metal droplets and you increase the surface area and as I have mentioned and you will also know in greater details, that steelmaking reactions are mostly mass transport control, hydrogenous chemical reactions must transfer control so they depend on interfacial area. So, finite the droplets of metal is created, because where is the carbon sitting, where is the sulphur sitting, where is the phosphorus sitting they are all in the metal.

So, if you can create larger surface area, you will have a better possibility of the chemical to expedite the chemical reaction. Therefore, when you eject oxygen, it is supersonic speed, you create a large number of droplets and that droplets will produce larger surface area; so the decarburization, dephosphorisation rates are very high.

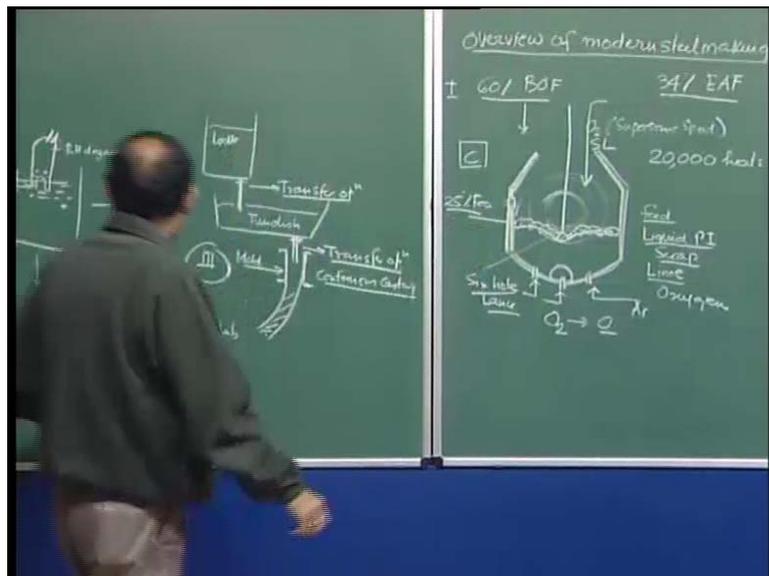
As a result of this, you can now imagine that the rate of steelmaking in such vessel is going to be extremely large; carbon has good affinity for oxygen, so the carbon oxygen

reaction will be expedited. And we can have steelmaking, you know huge tonnage of steel can be produced within, you know 30 minutes to 1 hour duration.

What is the average **can if it** decarburization weights we are talking about? We are talking about no mass of the order of tons kg of carbon per second that is the rate of decarburization we are talking about.

Now, these vessels can be of different sizes depending on the size of the plant; in some cases, we can find 130 tons vessel, but today there are plants, which are 500 tons vessels uses 500 ton ladle and water. Now, it is a highly expensive vessel; the relining, **the bricks** fire bricks that we used here, basic bricks are highly expensive. So, we would like to **you know** take this vessel not for frequent lining, once you line the vessel, our objective will be to use as many blows as possible.

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So, therefore, we want a very good or prolonged lining life and therefore, today what happens is, the economics of steel making is such in demands that we should consider only decarburization in primary steelmaking vessel, forget about other adjustments like desiliconization, silicon of course get removed dephosphorisation and desulphurization to a significant extent.

Carbon will be eliminated, phosphorus can also be eliminated or we will not bother too much about the level of oxygen or level of sulphur we can remove that. So, our major

thrust in today's primary steelmaking vessel is to eliminate decarburization. As soon as the carbon is eliminated, we say that well, now you take the steel we bring it to these processes ladle metallurgy steelmaking and there we adjust other composition phosphorus, sulphur, etcetera and so on.

Now, to expedite the rate of reactions here, further we have combination blowing steelmaking processes also which is a version of the oxygen steel making process. In many steel plants, they use the combinational blowing steel making process; these does not mean that we use oxygen from the bottom; we use argon, a small amount of argon is used and that argon produces, you know adequate amount of stirring, which expedite the process.

We have also processes which are called **modern** blowing steel making processes or tube off process, where we do not have a lance, but we inject oxygen from the bottom itself. And there what you do you? **We use coaxial spheres through one you have to a 2 cylindrical cylinder shape it hallow cylinders which are used as spheres.** So, we have an inner cylinder and then an outer cylinder, through the inner cylinder oxygen is produced; oxygen is introduced; to the outer cylinder, hydro carbon is introduced; oxygen is produced. If oxygen is introduced through the sphere, in that case enormous amount of heat is going to be produced here, because of the oxidation reaction and as a result of which the life of the sphere can be significantly reduced.

So, hydrocarbon acts as the coolant how? The carbon cracks and the **crack** cracking is an endothermic reaction. So, if you introduce hydrocarbon, of course injection of hydrocarbon contaminates the bath with carbon; this is true, but to prolong the **life** sphere life, because if the sphere life is less in that case, the fined furnace will lead frequent lined relining and that will you know jeopardize our principles objectives of using this **converter for...**

For how many heats? Today 20000 to 30000 heats, heats converter can sustain in progressive modern steel plants.

So, if you are talking of thirty heats a day, in that case you can imagine that for 1000 days, the converter can last and 1000 this casting means that you will require a converter to be relined only after 3 years of time.

Once you reline it, for 3 years we have to forget about it. Techniques like today slacks fleshing techniques to prolong further the life of the lining of the converter. So, coming back to the bottom blown oxygen process, we have hydrocarbon injection that hydrocarbon cracks and produces locally endothermic reaction and that endothermic reaction actually protects the sphere.

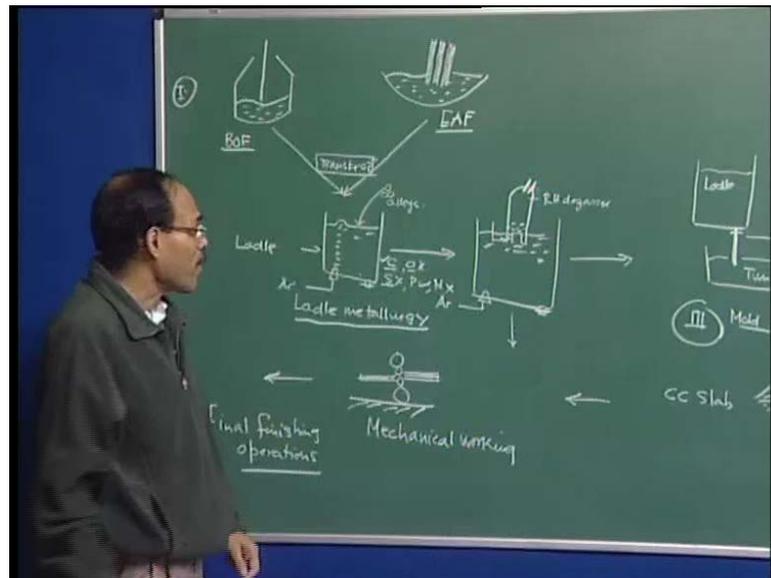
So, here various versions of the steelmaking process mostly **be healthy** and combinational blowing steel making processes are being used and these are very fast processes and main task here is to decarburize the bath.

And once you decarburize the bath, we say that steel is made and we must understand that along with steel as you refine the steel to produce also, lot of slag here, which has high percentage of iron oxide; it is a highly oxidizing slag, because when you oxidize carbon, when you oxidize silicon, when you oxidize phosphorus, because iron is abundant some amount of iron also oxidizes and whatever oxidizes is goes to the slack phase that all you have known.

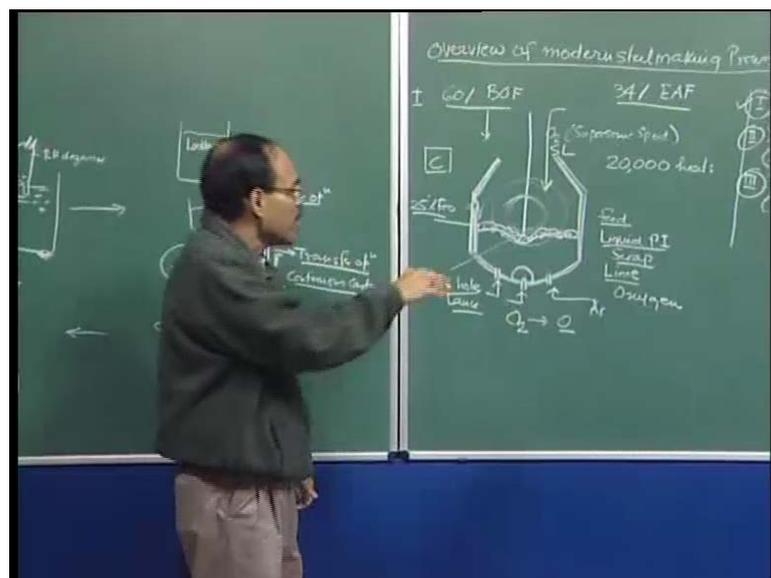
So, slag is basically comprised of various oxides; we have added calcium oxide to fix silica, phosphorus, etcetera it is a basic slag. So, silica, phosphorus, silicon dioxide, phosphorus pentoxide, manganese oxide, calcium oxide, FeO they are all comprised constitute the steelmaking slag, which has a very high oxidizing form.

And say it have so after steelmaking, blowing, you initially introduced oxygen and then after some time, we take sample to find out that how much of carbon is there, how much of and then controlled the end blow period based on that simple analysis.

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You have also sublance and through this sublance, the sublance is immersed into molten metal and sublance sample is collected and we know that how much of heat is there and what is the level of carbon comes in, carbon comes in carbon present and based on that we adjust our final stage of the blower, fine tube, the final stages of blow into the little bit amount of oxygen and then, get the final composition of the melt in terms of very well in terms of carbon and once that is done, you empty that vessel and where you empty the vessel you have a transfer operations here; you tilt the vessel and will pour it

in the ladle as you tilt the vessel; you must ensure that the slag does not get into the ladle, but you will require some amount of slag here to serve as a protective cover.

So, we will firstly make a slag; we will not want any oxidizing slag, which is the carry over slag and carry over slag is a very detrimental as we will see as you advanced in the course.

Now, following recap, as recap finished starting then the furnace is made vertical again the operator inspects if there are any cracks or the lining heat, which add or not at the particular point we can have slag fleshing also and after that this the preparation for the second heat and blowing starts further in the preparation of blowing is done next blowing is done for the subsequent heats.

Now, following that, we will have this, we will know much more details about the oxidized steel making process, you know about the details for this much background is good enough as for as this overviews comes on and we can also have electric arc furnace to which we will going to produced steel.

So, the material which comes out of here is going into the ladle; now carbon is right, oxygen is not right, sulphur may not be also right, phosphorus may be ok, carbon is ok, so which will require further amount of treatment? Because we have to get oxygen right, we have to get sulphur right, may be nitrogen is also not right, because in the transfer operation nitrogen has picked up.

So, the steel which is comed out is not in the final steel that we want, this is the proved steel; it will require a variety of refining processes, some gaseous species have to be removed, some further refining has to be done; oxygen has to be removed and so and so a variety of ladle metallurgy processes would be necessary.

Now, I am going to talk about the electric furnace steel making and we will also see what is the essence of an electric arc furnace steelmaking process