Steel Making
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Module No. # 01
Lecture No. # 24
Steel Making, Additional Topics

Today, we will be discussing on process control and automation in steelmaking.

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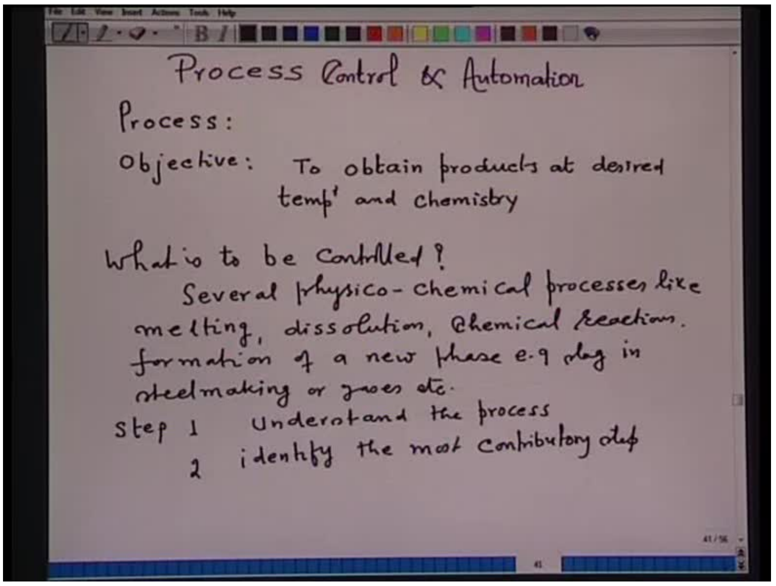

Let us say, in general, what is a process? A process converts reactants into products using thermal energy. Now, this thermal energy can be supplied externally or internally, that is, through exothermic reactions. What is the objective? Objective is to obtain products at desired temperature and chemistry at optimum consumption of energy. So, what we have to do for this? For that purpose, we have to control the process. Now, when we say we have to control the process, in general, what we mean? In fact, what is to be controlled? A high temperature process converts reactants into product through several physico-chemical processes. That means several physico-chemical processes like melting, dissolution, chemical reactions, formation of a new phase, for example, slag in steelmaking or gases, etcetera. All these physico-chemical processes are happening during the conversion of reactant into product for a particular process. So, in fact, we require to control, so that we get a product at desired temperature and of desired chemistry.

What are the steps required? Step number one: we have to understand the process; that is very important. Now, here we have to understand the process with reference to quantification of the process. Then, we should be able to identify the role of all the physical, chemical processes, which are responsible to convert reactant into product; that is very important; that is, understanding in terms of quantification of the physico-chemical processes. Second step that is important: we have to identify the most contributory step. That means out of several physico-chemical processes, there are few, which are in fact very largely responsible for the conversion of reactant in to product.

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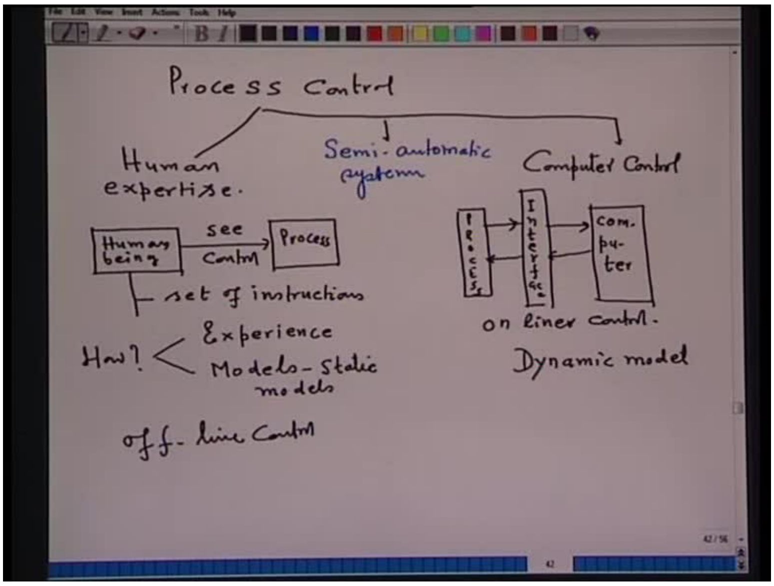

Once you understood that, then we can develop control strategy for that particular process and accordingly, the control models can be developed. Now, what is process control? Process control could be based on human expertise; with human expertise I mean; that means a human being is here or so-called an operator. He will see the process and exercise control. So, that is the process and the exercise they control. Now, in order to exercise the control, what human being needs? He needs certain set of instructions, which he can execute in order to control the process. Mind you: this is purely based on human expertise and whatever instructions that are given to him, he will execute at a particular time that all has to be set in advance, so that he can do during the process.

Now, how we can do? For that, either he uses his experience and says that I have a long experience, I know what is happening at what time, I can exercise my experience and exercise the control accordingly; or, one has to develop models or for this, they are called the static models. In a static model, we have a input, we have a output; for a given output, we calculate the amount of input that is required; we pass on the instruction to the operator and tell him that these are the additions that have to be made at a time interval. For example, at t is equal to 0, this much has to be done; t is equal 5 minutes, that has to be done; or, whatever the timely instruction we have to be given, exercise that and we get an output.

Another type of process control that every technologist or engineer or a scientist dreams is computer control. That is a dream of every operator – he should sit in an air conditioned room and the output of a process is being controlled by a computer through set of instructions, which are given online and the information from the process is also received online. So, for computer control, what is required? We have a process over here – that is to be controlled; here, you have a computer, the man is sitting in the room or in air conditioned room or whatever; then a process, a computer – both should be able to talk to each other. That is, process should be able to talk to the computer that I have these problems and computer should be able to tell him that because you have these problems, this is the step that you have to execute.

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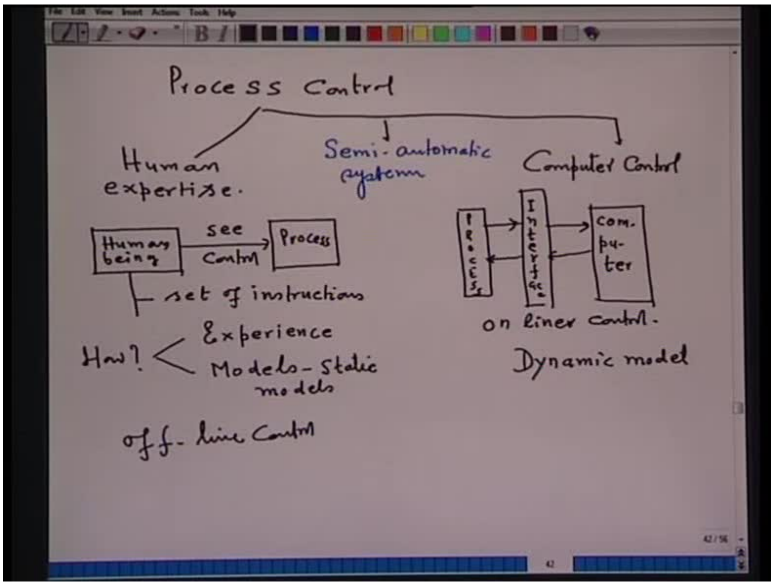

In fact, the process and computer – both should talk to each other. Both cannot talk in this way. So, what is to be done? For that purpose, an interface is to be developed and through this interface, the information is fed to the interface, which goes to the computer; computer again passes on the instruction to the interface; through the interface, these instructions come to a process and then the process can be controlled. So, that means via the interface, the exchange of information occurs between the process and the computer. This also is called the online control. Into this reference, this you can call offline control (Refer Slide Time: 11:43). Now, between the two extremes: offline control and online control, there is one more, which you can call semi-automatic system. That means part can be controlled by static; part can be controlled by computer model. That is how the semi-automatic system involves.

Now, in case of computer control, what is required? One has to describe the process; they have to quantify the process in terms of equation; then, these equations are converted in the form of a model and that model is fed into the computer. That is called a dynamic model. A dynamic model means a set of instructions are modeled by developing a model. Then, they are fed into the computer, so that on receiving a particular problem from the process, the model can process that information and can convert an instruction, which can be fed to the process back. That means what this computer control requires? The computer control requires continuous measurement of some variable as a function of time, so that it can be processed and then the instruction can be fed in the form of signal. So, that means there will always be an exchange of input and output signals. That is how the computer control works.

Now, given this introduction, let us see what happens in steelmaking? Now, say first we consider for example, BOF steel making. Let us now see the process control and automation in steelmaking. Now, we will start with the LD steelmaking. Steelmaking in BOF is very fast. Number 2: liquid steel at turndown results from several non-linear interconnected complex processes such as gas metal reaction as dependent on oxygen availability or slag metal reaction as dependent on slag formation, formation of three phase dispersion slag, gas bubble and metal, slag forming and so on.

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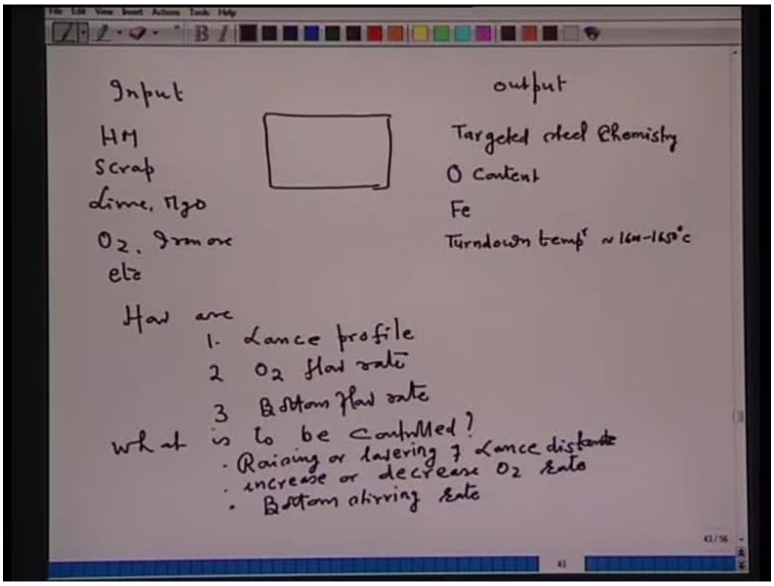

Control of these non-linear complex interconnected processes – what it requires? It requires, for example, if we have a box, here we have an input, here we have an output. So, input, for example, consists of hot metal, scrap, lime, M g O, oxygen or iron ore and etcetera; whatever the input you have that you must know. What is required in the output? We require output targeted steel chemistry. With that, I mean that the composition of steel.

We also want – oxygen content in liquid steel should be very low. We also want – at the output, iron content of the slag should also be very low. We also want that turndown temperature of steel should be around 1600 to 1650 degree Celsius. All these four things are important; particularly, the last one, there is the turndown temperature requirement essentially because no heat is supplied in the converter; from outside, it is the efficient utilization of the heat of exothermic reaction that has to do all these functions.

Now, given this input and output and given the various processes that are taking place inside the converter – gas metal reaction, slag metal reaction, slag formation, slag forming, three phase dispersion – all these are taking place as a function of time. So, we are getting the output. Now, in order to control all these processes; how are the processes controlled? First, they are controlled by lance profile; then by oxygen flow rate; then bottom flow rate. So, these are the three controlling parameters through which the various processes inside the converter are controlled in order to get the output, which I have listed over here. Now, what is to be controlled? We are talking of process control in automation in LD steelmaking. Now, what we have to control? We have to control raising or lowering of lance distance; that is, when the lance distance to be raised and when the lance distance is to be lowered, that is the one that we are looking for the control. Second, whether we should increase or decrease oxygen rate. Third, bottom stirring rate. So, we can control these three parameters that are in our hand in order to get the output.

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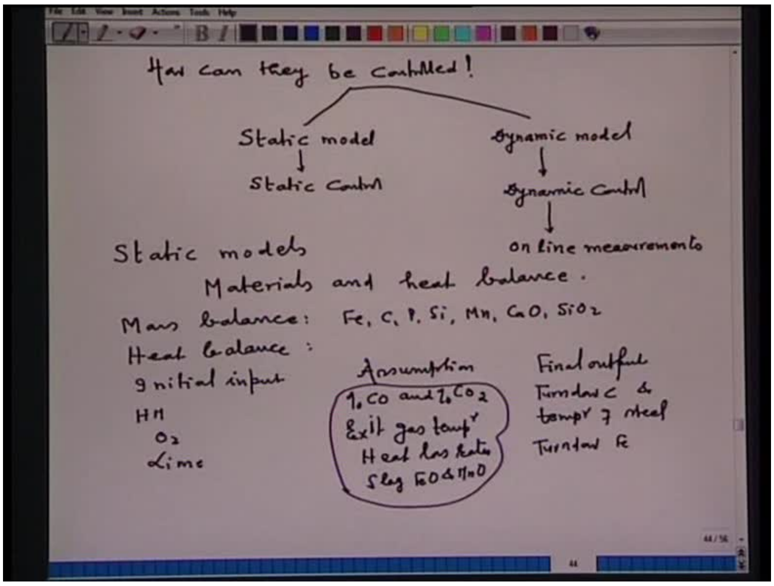

Now, how can they be controlled? Just the three that I have listed; the lance distance; how will you control the bottom flow rate and the oxygen flow rate? They are controlled by developing static model. A control based on the static model is called the static control; or, they can be controlled by developing dynamic model. A control based on the use of dynamic model is called dynamic control. The dynamic control is based on online measurement. The essential difference between static control and dynamic control is that of the time. In the static model or in the static control, the corrections cannot be taken online; in the dynamic model or in a dynamic control, one can process the information as a function of time and one can exercise the control as a function of time also. Now, for that purpose, one has to require to do online measurement. That means during the process, one should be able to measure something that should be fed into the computer and then a signal will be actuated.

Now, let us see first of all, a static model. Now, the static models are based on materials and heat balance by considering initial and final states of the system. That means for a given output, that input is required and all the inputs are to be given or one should tell right in the beginning that to give this input at t is equal to 0, this input at t is equal to for example, 2 minutes or 3 minute; that is the end of it. Then, after a certain time, you tape the steel and that is the output.

Now, mass balance or material balance, whichever way it is done, of all elements, for example, iron, carbon, phosphorus, silicon, manganese, calcium oxide, S i O 2 and whatever the oxide, which are present, then heat balance is also done. All heat producing reactions are considered. The amount of heat, which is generated and the amount of heat, which is used; a balance has to be made, so that the required heat output can be obtained. Here certain set of assumptions are required to make it. For example, it takes an initial input, underlying assumptions and final output. Say initial input could be hot metal, oxygen and lime. You have to make certain assumptions, for example, the percentage C O and percentage C O 2; what is exit gas temperature that we have to feed for static model? then, heat loss rates; then, what is excepted slag, F e O and M n O, a turndown as a function of calcium oxide or S i O 2? These assumptions, which I have listed over here, can be made or from the several heats, a data file is being generated and from the data file, some average value of these assumptions can be determined. Final output – we want turndown carbon and temperature of a steel, and turndown iron content of slag and oxygen content of steel.

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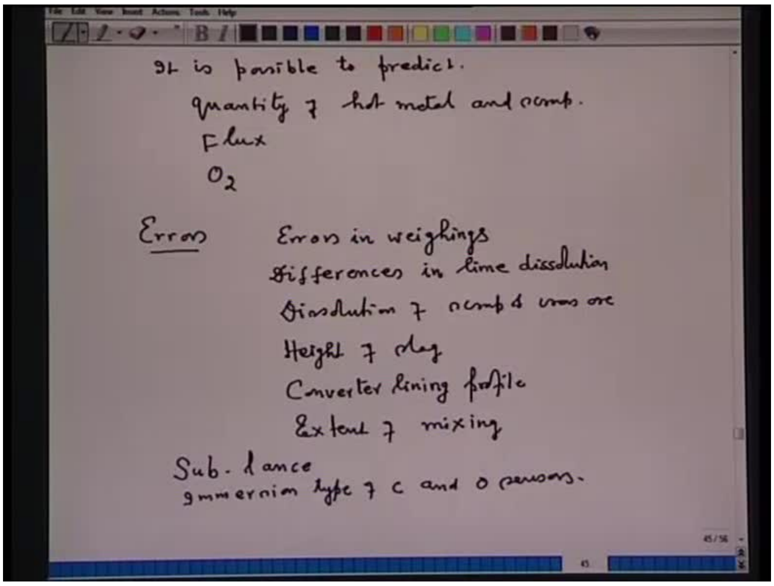

Now, with this static model, it is possible to predict say quantity of hot metal and scrap, then flux and iron ore additions, and total quantity of oxygen that is to be blown. Now, the predictions that depend on the data and tuning the output; such predictions may have uncertainties because of the assumptions that are entering into the formulation of the model. However, the reliability of predictions can be made by utilizing the data from several earlier heats and we come to an average value of the assumptions.

Since BOF steelmaking is a static process; that means what? No two heats may have the similar type of physico-chemical process; I am talking in terms of quantification. For the same input and for the same output, it may be possible that the heat may vary from one to another. This is because the process is highly turbulent in nature; you are supplying an oxygen that of very high velocity, lot of droplets are being formed, refectory way, so on; so many things are there. This can make the predictions unreliable.

Some of errors that may result in prediction; first is error in weighings; second, differences in lime dissolution; if from one heat to another heat there is a time lag between the dissolution of lime, then accordingly, prediction will be affected. Then, dissolution of a scrap and iron ore – size of the scrap; where they are put? Because of the turbulent condition, how the scrap dissolution is going on? Let may vary from heat to heat. Then, height of slag and entrain metal droplets – that may vary from heat to heat also or within even a heat from as a function of time also. Then, converter lining profile, extent of mixing. These above errors – some errors can occur by the human beings; some errors may occur because of the stochastic nature of the process. So, these errors can be minimized or the predictions by static model can be improved by having measurement through a sub-lance. What does it means?

A sub-lance is an extra lance other than the oxygen injecting lance that is immersed from the top, a sample is taken and temperature and carbon content is determined. That is a sub-lance measurement. Then, one can also have the immersion type of carbon and oxygen sensors. The data, which are collected by the sub-lance are fed into the computer, which compares with the model prediction and to suggest the corrective measures. So this type of control, where we have exercised the data from the sub-lance and then partly, we use the computer, is called as a semi dynamic control. We have seen that the static model has limitation. Therefore, we go for the so-called semi dynamic control model. In a semi dynamic control model, we mix both; it is part of the information we utilize from the static model and some of the information we utilize through the online measurement.

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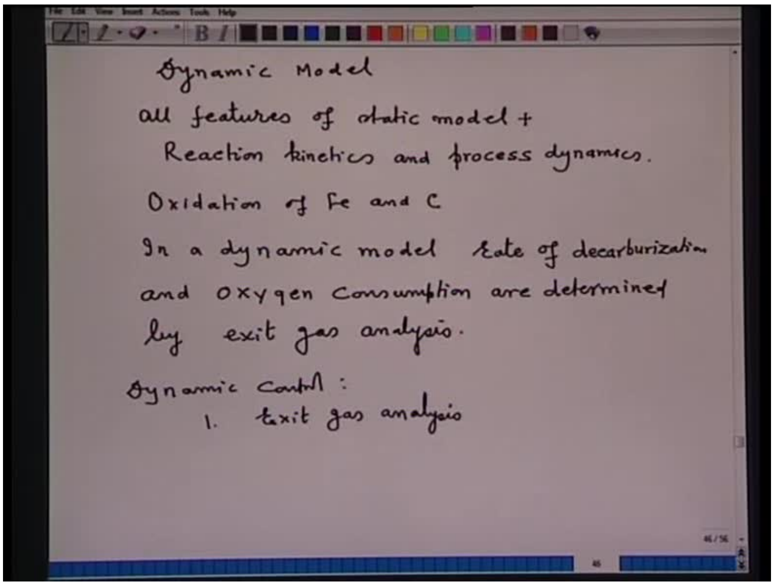

Now, the online measurement as I said, consists of the sub-lance. Now, in the sub-lance, a metal sample is taken, and the temperature and carbon content is determined, because you know – in the production of steel from the raw material, besides other elements, carbon content is the most important. Carbon – you have start from the 4 percent carbon; it decreases to whatever value and then at the end, we have the final specification. About silicon, manganese and phosphorus – though they are important, but the measurement of carbon suffices to exercise the control of the process.

Now, with these, let us see what a dynamic model is. In fact, the static models do not calculate the variation of blowing parameters as a function of time. That is what we require. We just give instructions in the beginning and the human operator executes the instructions. However, if we want the variation of blowing parameter there is a function of time, then it is not possible by a static model. Then, we have to develop dynamic model. A dynamic model contains all features of static model plus it contains the information from reaction kinetics and process dynamics.

Now, when we say we consider reaction kinetics, then automatically we have introduced a time factor. As a function of time, we can control the rate of a reaction, which is important for a process or which contributes significantly to the product, we develop the rate equation. Now, this rate equation already has a function of time. Now, as a function of time, I measure some parameter during the process, I feed into the computer. The computer calculates by the rate equation, which is already inbuilt. It gives an information, which is then fed back to the process. So, that is how this reaction kinetics and process dynamics have to be incorporated in order to build a dynamic model.

Now, if we consider, for example, the reaction kinetics point of view, then essentially measure oxidation reaction. Remember: I said in the beginning that you have to identify the major contributory physico-chemical process that result into the product. However, several processes are going on, but one if you can identify that, it is very good. In case of a steelmaking, it is the oxidation of iron and carbon – are the major oxidation reactions. In a dynamic model, rate of decarburization and oxygen consumption are determined by exit gas analysis. How? At the exit, you have to put a sensor, which can take the sample of the gas, fed it to the online analyzer and from the analysis, one can find out the rate of decarburization. That is, we know the percentage C O and the percentage C O 2 in the exit gas. Knowing the amount of gas that is produced, one can calculate the amount of C O and the amount of C O 2, and hence the amount of carbon, which is going out in the form of gases. As a function of time, one can integrate over the time period and then knows that what is the rate of…, what the total carbon that has been removed is. Through these measurements, one can exercise the so-called dynamic control.

What dynamic control requires? The first requirement for dynamic control is to measure continuously and the corrections continuously in blowing parameter. That is what the fundamental of dynamic control. You measure some parameter continuously and exercise control continuously. That is what the feature of dynamic control. In fact, you are leading to the so-called automation. Now, for that, we have to look upon what parameter can be measured? That parameter should be measurable. How to measure it? The technology is to be developed because the processes are occurring at high temperature; you have to see what is available for measure. So, in converter in steelmaking or even to that extent electric arc furnace steelmaking, what is available is to measure exit gas analysis. So, for dynamic control, exit gas analysis and composition can be measured. So, exit gas is analyzed by taking a probe and also, measurement of temperature is done.

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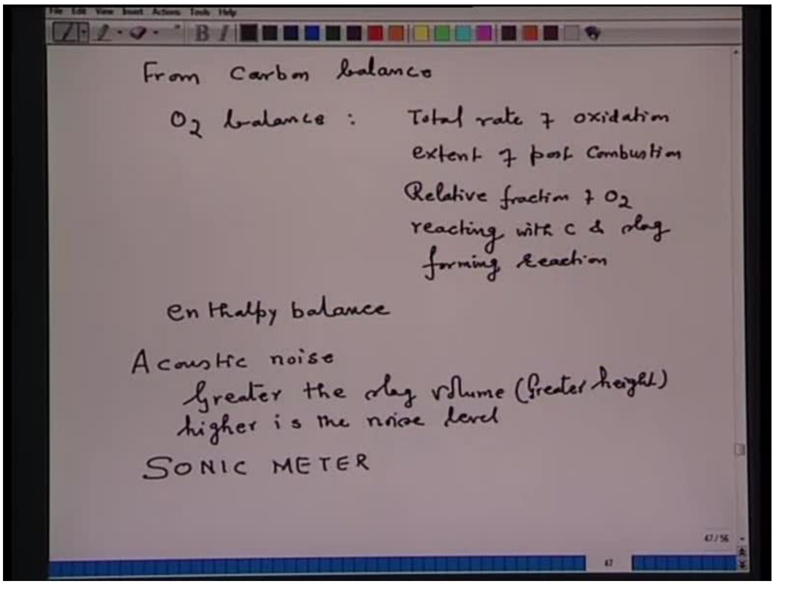

Now, this gas composition, which has been determined by an analyzer and the temperature are used to calculate in real time, carbon, oxygen and enthalpy balance of the gas phase. Now, from carbon balance; for carbon balance, decarburization is determined, because C O and C O 2; from that, one can determine the decarburization rate. Then, from oxygen balance; that gives us the information about total rate of oxidation. It also gives an idea of extent of post combustion and relative fraction of oxygen reacting with carbon and slag forming reactions. Now, these balances are done online by the computer. Then, we get a time bound information or time bound control strategy, which can be exercised.

Then, the enthalpy balance; it gives you the energy leaving the system. By doing the energy balance, one can find out what is the heat utilization or energy utilization. Now, another online measurement that can be done is the acoustic noise. In LD steelmaking, the acoustic noise results from slag volume and emulsion in the slag; emulsion is the dispersion of metal droplets in the slag. The greater the slag volume, the high will be the acoustic sound. So, from the acoustic sound or from the level of the acoustic sound, one can exercise the control. That means the greater the slag volume – that means greater height, higher is the noise level. So, by measuring the noise level, if the noise level is too high, that indicates that height of the slag is very high in the vessel. So, these noise levels are measured by the so-called sonic meter. What a sonic meter does? A sonic meter measures the sound intensity level continuously during the blow. This information is used online to control the emulsions, so that the slag does not slow. So, these two online exit gas analysis and measurement of acoustic noise by the use of sonic meter, is the tool to exercise a dynamic control of LD steelmaking and it is being done.

What is required to develop online process control? By the very nature of the requirement of dynamic control or automation that something you should be able to measure online. Computer should process and the information should be fed right at the time to the converter so that corrective measure can be taken again online. That means you require the sensors, which can measure the output continuously; we also require sensor, which can control lance distance, oxygen flow rate and bottom stirring, because everything you want online. So, these are the important things.

Now, here the very important is development of sensor, because to measure exit gas analysis, you require a very rugged sensor. Why? Because the exit gas temperature will be 1400 degree Celsius and that too it may contain entrained solid particles. So, a sensor has to work under very adverse condition. Similarly, if you want to measure for example, the acoustic noise, then you have to have a sonic meter, you should have a probe, you have to dip and the converter in steel making is highly turbulent in nature. So, what is required is to develop a sensor, which is robust in nature.

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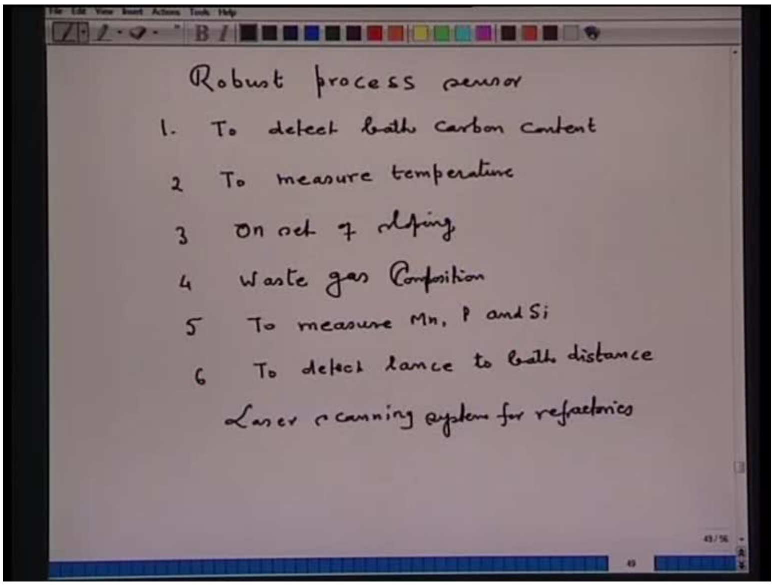

What is required for automatic control or dynamic control is the development of – I will put the word – Robust process sensor. This will require several types of sensors. For example, one – to detect bath carbon content; that means the sensor should dip right from the mouth to the bath through the slag. So, we require a very Robust type of sensor. Second, to measure temperature; for that, you have to dip into the metal bath or slag bath, wherever. Require a sensor to know onset of slopping to control the height of the slag. Waste gas composition.

We also require sensor to measure manganese, phosphorus and silicon, because for the controlled chemistry, the concentration of these elements are also important; particularly phosphorus, because at the turndown, you have to provide or give a message that well now, the steel has been finished and it can be turndown, so that taping can be done. for that purpose, the phosphorus content of a steel is very important besides carbon; you cannot tape at higher carbon or higher phosphorus; so, you must tape at a right carbon and right phosphorus; otherwise, reblowing of the heat has to be done. So, these sensors also play an important role to develop the dynamic control strategy. Also, you require a sensor to detect lance to bath distance. As I have already said in my lecture on the behavior of gas jets that the importance of gas jet, and the importance of the distance between the lance and the metal bath; if we can detect or we can find out a sensor or we can develop a sensor, which can detect online – what is the distance between lance and the bath, then it will help to develop a dynamic control of the process.

Another thing is that we also require laser scanning system for refectory, because refectories are also during more (( )) during the process; 0.5 or to 1 millimeter per heat – that is their effective here. You should also be able to record online what the refectory of air is. Similar type of control can also be exercised, for example, in electric arc furnace. In electric arc furnace, again you can have the online gas analysis. In fact, using the online gas analysis, the dynamic control model has been developed and they are in use.

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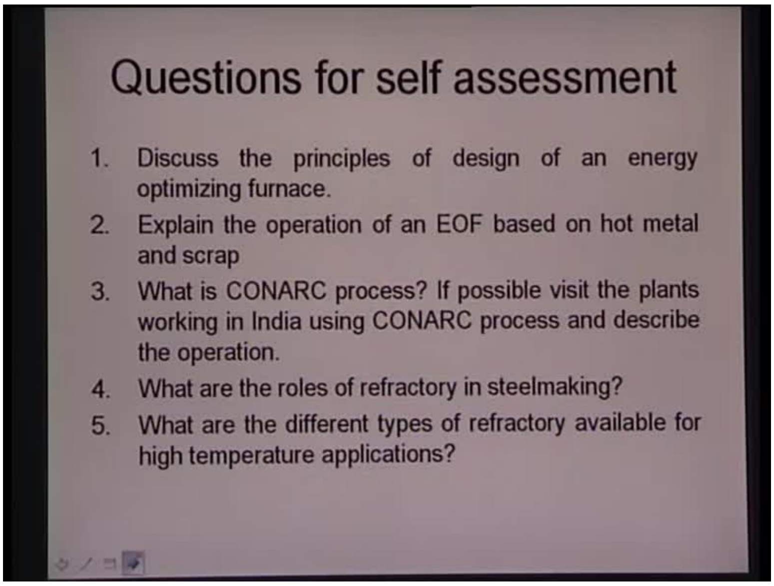

Regards the 6 lectures that I have given to you, here are the questions for self-assessment. Number 1: discuss the principles of design of an energy optimizing furnace; I have said an energy optimizing furnace is three independent inter connected reactors, and I have also discussed the various design features of each and every independent reactor. You can read and you can make the answer.

Explain the operation of an EOF based on hot metal and scrap. Now, the only important – if you want to have EOF process for 100 percent scrap, then the liquid heal is to be provided. I have discussed and you can also make the answer over here.

What is CONARC process? CONARC is a combination of converter steelmaking and electric arc furnace; it is in fact, a twin shell concept. This is just a suggestion – if possible, visit the plants working in India; I already said that there are 2 or 3 plants working in India under the CONARC process; please visit those plants if opportunity exist; or, if there is a possibility, you will learn more, because CONARC may be a future of steelmaking. Describe the operation. What are the roles of refractory in steelmaking? Already I have said. What are the different types of refractory materials available for high temperature applications?

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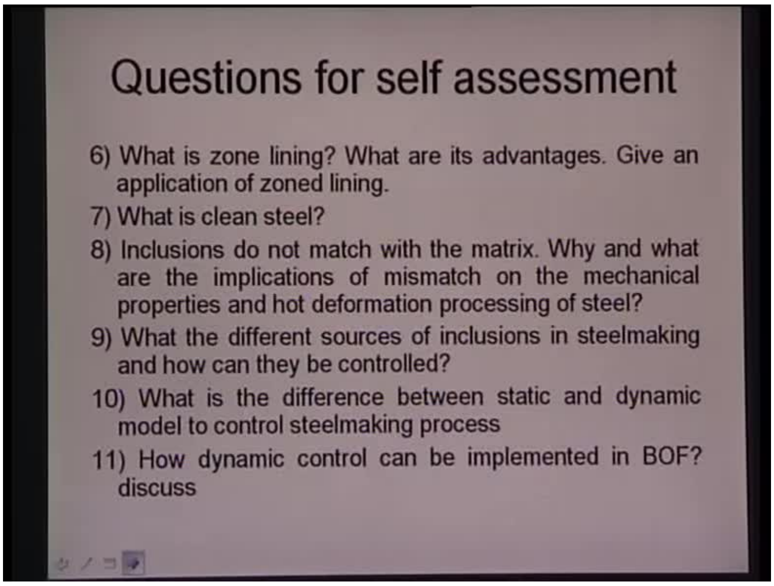

What is zone lining? I have explained by taking two important: corporate vessel and LD converter steelmaking; you can also take another example, for example, ladle or continuous casting tundish – there also, zone finding is done. What are the advantages? Give an application of zone lining. I will here request – you take the example other than what I have given in my lecture; you may take the example of ladle or you may take the example of continuous casting tundish, or whatever you feel appropriate and put it here, and extend your knowledge.

8th – Inclusions do not match with the matrix because of the difference in physical property. Why and what are the implications of mismatch of the mechanical property and hot deformation processing of a steel? In hot deformation, you apply the load, you deform; so, if the inclusion is vital, then it will break; if the inclusion is ductile, then it will role or along with the load. So, accordingly, you have to find out what is the implications about the property of inclusion with the hot deformation. What is the difference between static and dynamic model to control steel making process? I have just now finished with the lecture. How dynamic control can be implemented in B O F process?

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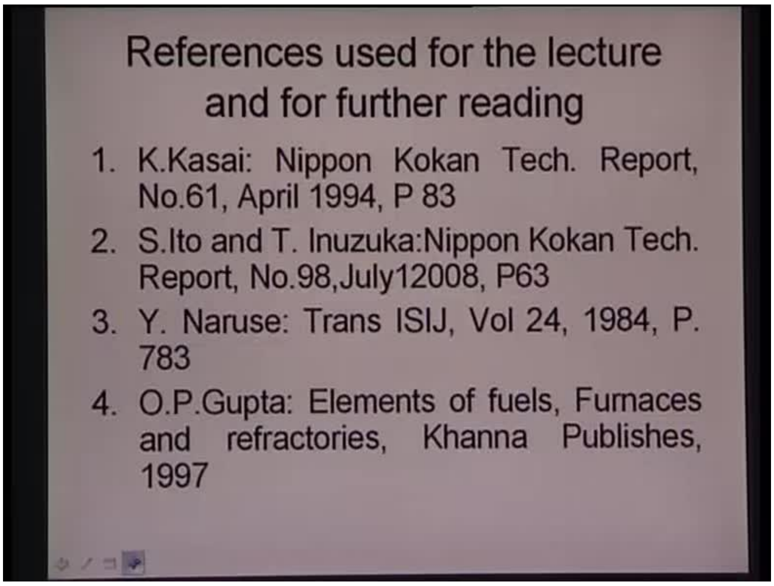

Now, here are the references, which I have used for preparing the lectures.

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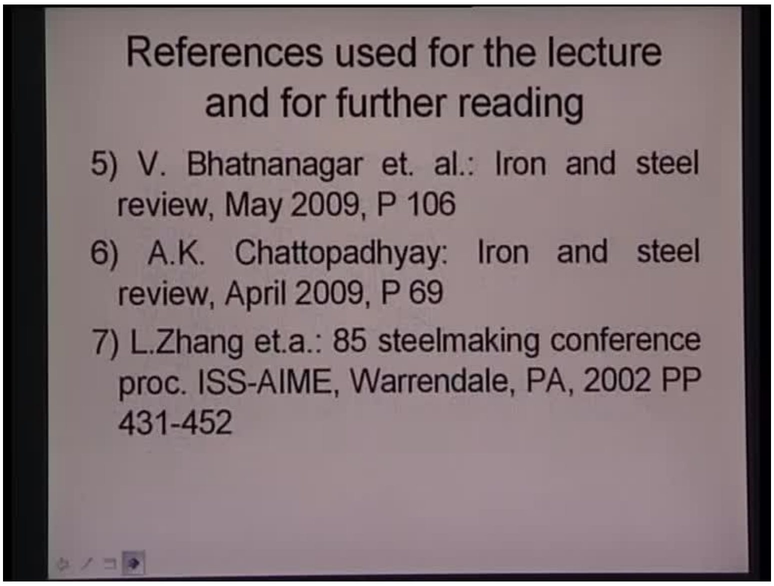

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