Fuels, Refractory and Furnaces

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Lecture No. # 16

Furnace: Types and Classification

This lecture talks about the furnace. I will be telling you what is a furnace: type and classification.

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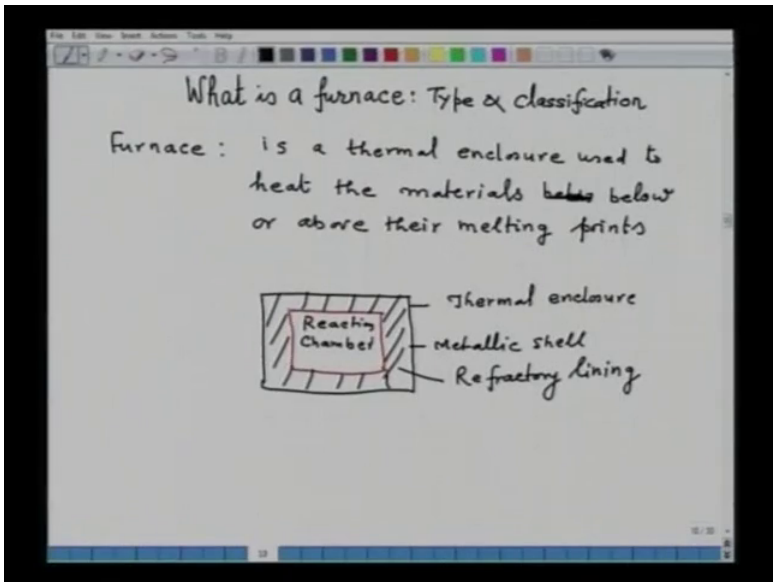

A furnace – we will be defining as – is a thermal enclosure used to heat the materials below or above their melting points for several purposes. In fact, if we try to make a diagram of a furnace, for example, this is a metallic phase, which is surrounded by refractory lining. And, in fact, this – let us call as a thermal enclosure; and, it consists of for example, this one is a metallic shell; and, this one is the refractory lining, because… When we talk of high temperature, then metallic shell, because of its high thermal conductivity and cost, it is not used directly; that means, this is being lined with the refractory material because of the conservation of heat purposes. The metallic shell have a very high thermal conductivity and whatever amount of heat that will be generated, it will be immediately lost. So, this is one, is the reaction chamber reaction chamber.

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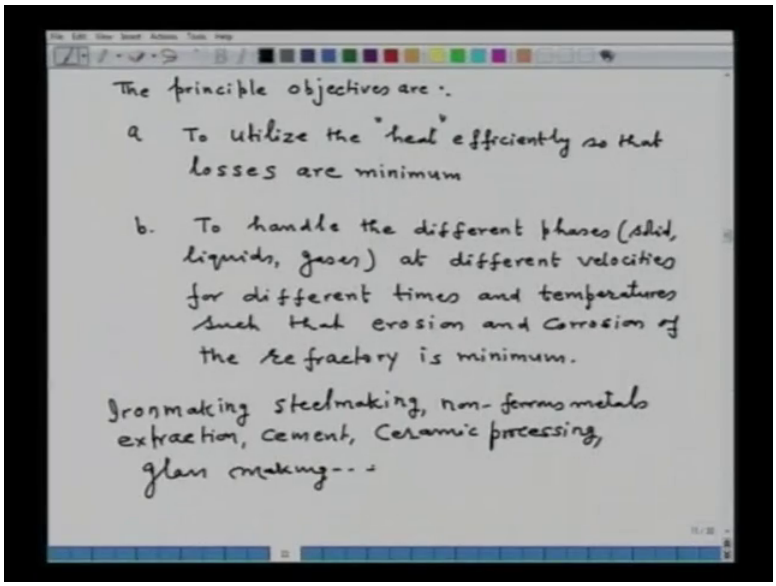

In this particular definition of furnace, which we call as a thermal enclosure, the principle objective objectives are: a – to utilize the heat efficiently, so that losses are minimum. Now, this is a very important objective particularly in view of the conservation of energy resources is concerned. We have to operate the furnace or we have to design the furnace, so that whatever amount of thermal energy is supplied by whatever way is used efficiently. And, at the same time, the losses are kept to a minimum value, because whatever will be the losses, the losses is also in terms of calorific value, which is directly the loss of fuel; we can also call this way also

Second objective is to handle the different phases – with that I mean solid, liquids, gasses – the different phases at different velocities for different times and temperatures. Now, these are what we require such that erosion and corrosion of the refractory is minimum. Now, the second objective of the thermal enclosure is a very important objective, because we are handling different phases; it could be solid at different temperatures ranging from 700 to (( )) 1200 degree Celsius or even 1300 degree Celsius; liquids – the temperature may range from… Say if it is a liquid aluminum, around 700 or 800 degree Celsius; liquid copper – around 1100 degree Celsius; steel, which could be around 1600 degree Celsius; if it is a molten matte, the temperature is around 1200 or 1300 degree Celsius. So, their temperature will vary depending upon the molten alloy. Also, gases – that could be carbon monoxide, carbon dioxide, SO2, nitrogen; they are moving at different speeds at different velocities. For different times and temperature, the

temperature may be different; the time is also an important factor. Some of the thermal enclosures for certain processing operations may take an hour; some may take half an hour; some may take around two hours. So, that is where the times and temperatures.

The temperature may be varying across the reaction chamber as well as across the height of the reaction chamber. The temperature may vary, for example in steel – if you talk of liquid steel, you may have 1600 degree Celsius; and, the temperature may vary across the height of the reaction chamber; so, around 700 or 800 degree Celsius. So, that is where we have to treat for different times and different temperatures. Now, what is required in all these cases that the erosion and corrosion of the refractory should be minimum; that means, the phases should not be reactive with the refractory; the refractory should also be able to sustain that particular temperature, and so on. So, these are the principle objectives of designing of a thermal enclosure.

Now, just to give you an idea, the industries, for example say various industries like ironmaking, steelmaking, non-ferrous metals extraction, cement, ceramic processing, glass making and could be several others. These are the industries which uses the thermal enclosure for hitting the reactants in the thermal enclosure for various functions.

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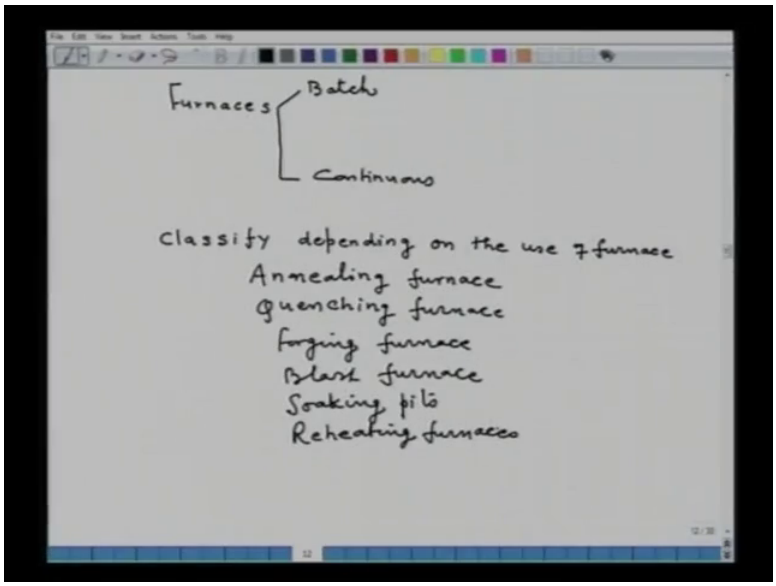

If we want to now classify the furnaces, the furnaces can be classified in several different ways. For example, if you want to classify say furnaces, it can be classified in several different ways: one way – easiest way could be batch furnace and continuous furnace. In

the batch furnace, at time t is equal to 0, the material is charged; and, at t is equal to some time, maybe an hour or two hours, depending on the type of treatment, the material is discharged. So, that is the typical of the batch furnaces. Another type of furnaces – they are the continuous furnaces here. At one end of the furnace, the material entered and at the other end of the furnace, the material exits the furnace. So, one can divide the furnaces or thermal enclosure which are operating in different industries, which I have just listed above; one can classify them; they are the batch furnace type of… they are the continuous type of furnace.

One can also classify depending upon the use of the furnace or thermal enclosure. With that I mean – suppose a furnace is used for heat treatment purposes, then we can call this as an annealing furnace as you must have heard; or, you have a quenching furnace; or, you can have forging furnace; or, you have blast furnace for example; or, you can have soaking pits; (( )) reheating furnaces. Now, in this classification, one does not bother whether it is a batch or whether it is a continuous. But, the name which is given to the furnace… The name is given as per its objective. So, if a furnace is used for the annealing treatment, which all of you know heating and cooling in the furnace, you call this as an annealing furnace.

If the furnace is used for forging purposes, then it is assigned a name something like forging furnaces. But, it is not as if the furnace does forging; no; what I mean, these names have been evolved according to the use of the furnace for a particular objective. you can have annealing furnace; you can have quenching furnace, forging furnace, blast furnace or soaking pits and reheating furnaces or a glass making furnaces or a regenerator or a… So, what I mean, this classification depends on the use of the furnace. So, here one does not bother whether it is a batch or it is a continuous; it can be a batch also; out of some, can be continuous also.

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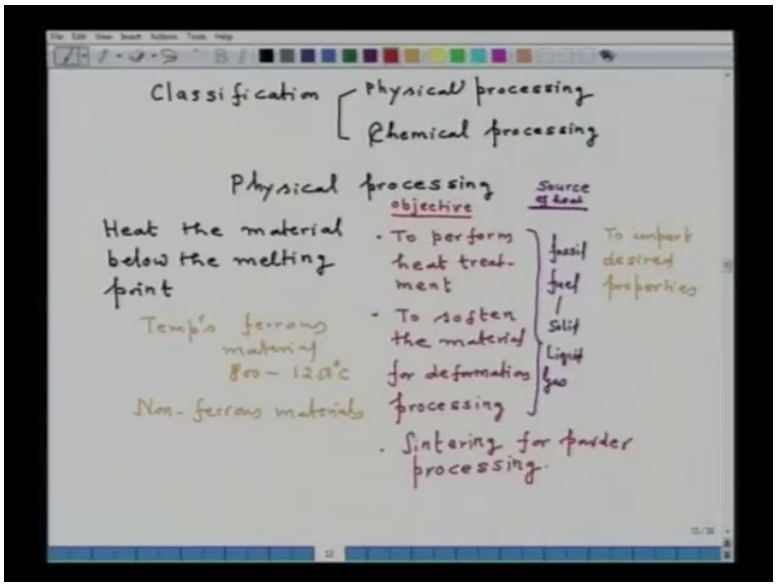

Now, another classification can be done based on the processing. So, one classification of furnaces can be done on the basis of physical processing; a broad classification – physical processing or chemical processing, because if you closely observe the industries which I have listed just before, you will note that there are furnaces, which are used for physical processing only. Physical processing means you are heating the material below their melting point. There are several processes among the industries, which are using for chemical processing also; that means, you are converting, you are caring out the chemical reaction for certain objective.

Let me elaborate little more on the physical processing, because this really gives an insight into what is a furnace and what is required in a furnace. For example, if I take classification based on physical processing – say in the physical processing, we heat the material below the melting point. Now, what is the objective? This objective: one objective is to perform heat treatment; another objective is to soften the material for deformation processing, because you want to shape the material. So, this is the objective.

Now, if I want to add here the source of heating, because we are equally concerned; when we talk of thermal energy, then you must know what the source of heat is. So, source of heating in both these type of objectives is fossil fuel, which could be solid, liquid or gas. And, the whole idea to perform the heat treatment or softening the material is to impart desired properties. Desired property means could be mechanical properties;

you may need high impact strength or high hardness or high ductility or what? All the properties. In order to get the property for a particular application, we use the so-called furnace for heating below the melting point of the material in one class. In another class, we heat the material to shape the product; there you have the billet, you have slab, you have bloom; you want to give the shape for the application. So, for that purpose, we have to soften it a 1200 or 1300 degree Celsius. And then, you roll it, forge it, extrusion heat metal working; or, whatever you want to do it you can do it.

Now, in all these, to heat the material below the melting point, the temperatures which are involved for all ferrous material – say for ferrous material, it could be anywhere between 800 to around 1200; also, 1250 degree Celsius. For all non-ferrous materials, the temperature will depend upon the melting point. For example, if it is aluminum, the aluminum copper alloy, then accordingly they are below the melting… There are several metals are involved. So, one cannot give a single melting point. But, what one can say, for non-ferrous materials also, it will be below the melting point of the respective alloy system or metal alloy system, which you have chosen.

Now, another objective for heating the material below the melting point; say in the powder processing, sintering for powder processing. Now, here also, the source of heat is the thermal energy derived from combustion of fossil fuel.

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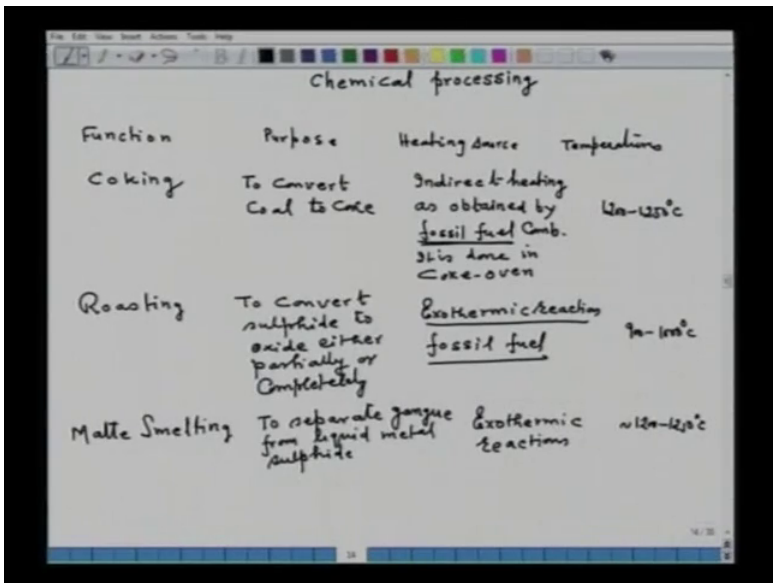

Now, if I take another say chemical processing, furnace is an example for chemical processing. Now, in the chemical processing, what is done is that the reactants are heated below the melting point, above the melting point in order to carry out chemical reactions. So, here the carrying out of chemical reaction is an important issue; it could be below the melting point also; it could be above the melting point also. Now, here for example, if I give a function, then we may purpose the heating source and temperatures. For example, one of the functions could be coking. The purpose to convert coal to coke – you know already why this conversion is required; because the coal extract cannot be used in the blast furnace. Heating source is… Here in fact, it is an indirect heating as obtained by fossil fuel combustion; that means, here the reaction chamber is not directly heated, but indirectly heated and it is done in the coke oven. So, what is important is to note the heating source is here – fossil fuel. Temperatures involved of the order of 1200 to 1250 degrees Celsius. This is one particular function.

Another function we can have say roasting; roasting – to convert sulphide to oxide either partially or completely. As all of you know in the expression of metal from sulphide ore, the sulphides are converted to oxides and then for the further processing. So, you have heating source; one is the exothermic reactions. Exothermic reaction is one heating source; and, combustion of fossil fuel is another heating source. So, these are the two heating sources. And, the temperature say lay between 900 to (( )) 1000 degree Celsius; 1000 degree is a little bit higher limit; and, be around 900 degree Celsius. So, this is another function.

What function you can have? Matte smelting – now, in matte smelting, to separate gangue from liquid metal sulphide. So, here you note that in the matte smelting, the chemical processing is done in the liquid stage. Here a formation of slag and metal phases occur. So, here the source of thermal energy is exothermic reactions. You are handling now the phases like slag and metal as long as the gases also. So, the temperatures are involved of the order of 1200 to as high as 1250 degree Celsius.

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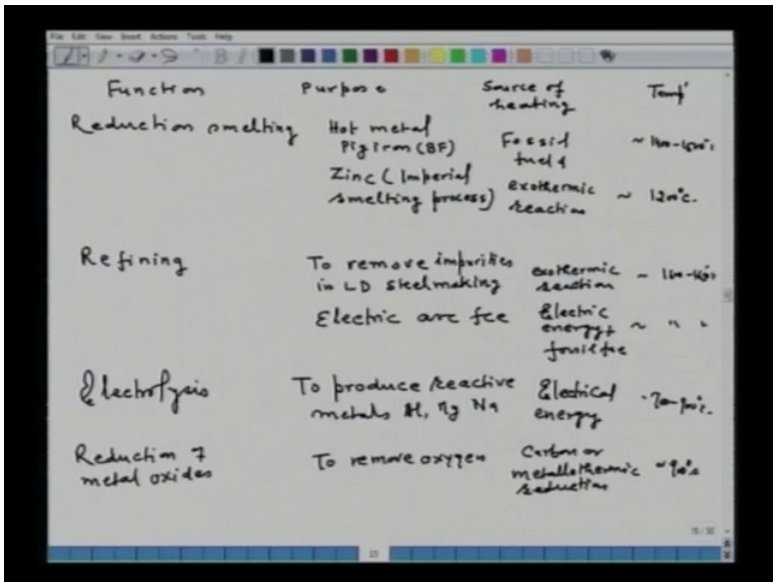

Now, let me put once again function, purpose, source of heating and involve temperatures. Another function could be reduction smelting. As all of you know, the purpose is to produce hot metal, which is called also pig iron. The process is a blast furnace. Also, reduction smelting is used to produce zinc in imperial smelting process. So, in the reduction smelting, the name – the blast furnace is the typical example of reduction smelting; then, zinc is another example. There could be another example; there could be several other examples. Also, you can list them.

Now, in both the cases, you see now the chemical processing is involved and the chemical processing results in the production of slag, metal and gaseous phase; source of heating – fossil fuel and exothermic reaction. In case of hot metal production, the temperatures involved of the order of 1400 (( )) high as 1500 degree Celsius; whereas, in case of zinc smelting, you may go around 1200 degree Celsius. Now, in zinc smelting, in additional phase like zinc vapor, that also comes into picture.

Another function where thermal enclosure required is a refining. Typical example is to remove impurities. Now, here again, the typical example is that of LD steelmaking and electric arc furnace. To remove impurities for example, in LD steel making, where source of heat is exothermic reaction; and, the temperatures involved of the order of 1600 to as high as 1650 degree Celsius. Another is an electric arc furnace. Here source of heat is

electric energy plus some account fossil fuel; the temperature again of the same order of magnitude.

Then, still another function where thermal enclosure is needed is the electrolysis. Now, in the electrolysis, the purpose is to produce reactive metals, such as aluminum, magnesium or sodium; and, source of heat is mainly electrical energy. Now, here the temperature could be as high as 700 to 900 degree Celsius. Also, you can have reduction of metal oxides. Reduction of metal oxides – the purpose is to remove oxygen. Now, here again carbon or metallothermic reduction; source of energy is again indirect heating; and, the temperature involve is of the order of 900 degree Celsius. What I mean, one can further list down. For example, in cement industry, the calcination is done again in the solid state in order to produce calcium oxide. You can have ceramic industry, is the glass making industry; everywhere these furnaces are in fact used.

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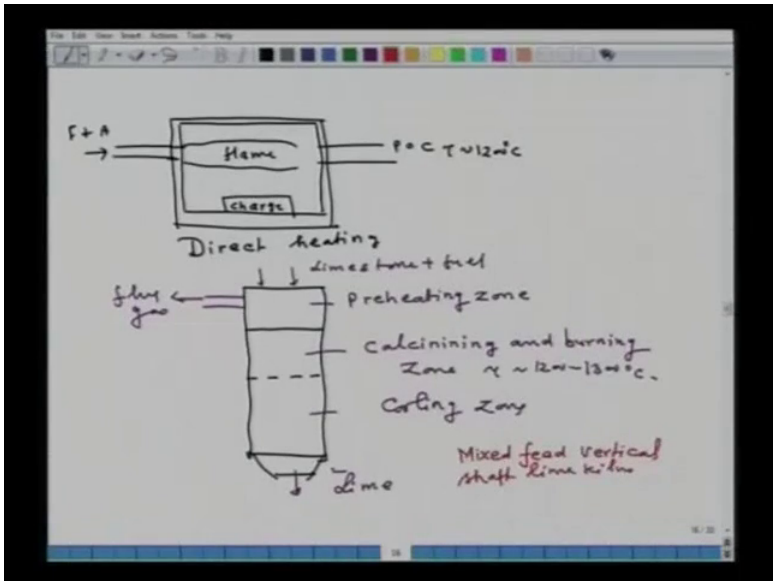

If I want to show you some of the say type of say furnaces just as a few sketches, then you will note… For example, you have – this is an enclosure and here we are passing fuel plus air; this is a flame; this is a charge; this is a flame. And, here you have the products of combustion; the temperature depends upon the temperature of the combustion chamber, which could be around 1200 degree Celsius or it may vary depending on the case. So, this is called the direct heating. Example of direct heating of flame is directly heating the charge.

Another example – say we can have a sort of in a vertical shaft lime kiln; say what happens, we have say this is a lime kiln; there are various zones also. So, here lime stone plus fuel is charged; the exit is somewhere here; where the exit is here is the flue gas. This is a preheating zone. This one is a calcining and burning zone (Refer Slide Time: 33:33). And, here the temperature could be of the order of 1200 to as high as 1300 degree Celsius; and, this is the cooling zone. And, from here the lime is discharged. So, this is the typical mixed feed vertical shaft lime kiln. So, here you can see the requirement of thermal enclosure is quite different; the temperature also varies from bottom to the top. A lime stone and fuel enters on the top; that is preheated. Further, it comes down, temperature is high. This is another type of furnace.

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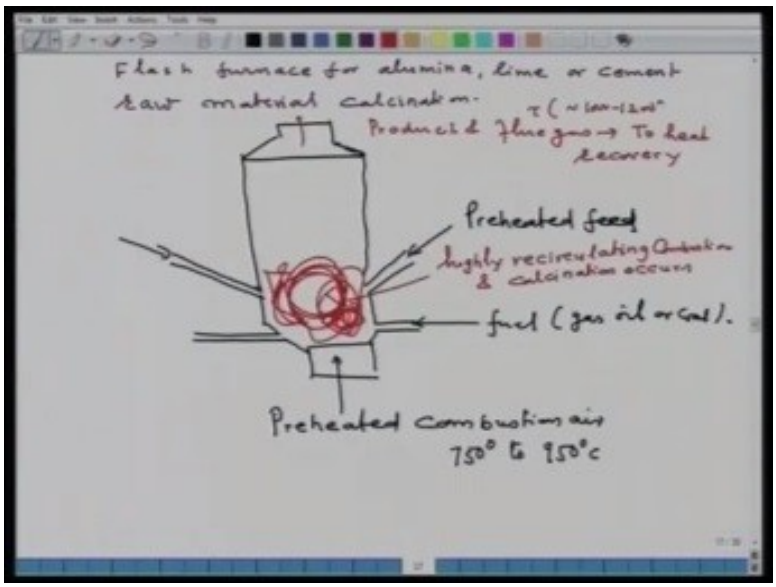

Now, we can also see how… Another furnace for example, flash furnace for alumina, lime or cement; I will try to sketch for you raw material calcination. Now, here say this is the say entry of the preheated heat; this is how a flash furnace looks. Now, here from this, a preheated combustion air is supplied. And, the air is preheated to a temperature of 750 degree C to 950 degree C. You can note down from here the adverse requirement or the very different requirement for design of the thermal enclosure. Here fuel is entering. Fuel – it could be gas, oil or coal. Here a preheated feed. So, in this zone, highly recirculating combustion and calcination occurs. The reaction rate is very fast, because both are in suspension; the kinetics are very fast.

And, here on the top you have the (Refer Slide Time: 38:04) product and flue gas. And, this goes to heat recovery. Now, the temperature of the flue gas – it will of course depend upon the temperature inside the reactor, which could be anywhere between 1000 to 1200 degree Celsius. So, you can see now, the heat recovery is also a very important component of all the furnaces or of all the thermal enclosures in which the gases discharge at a very high temperature.

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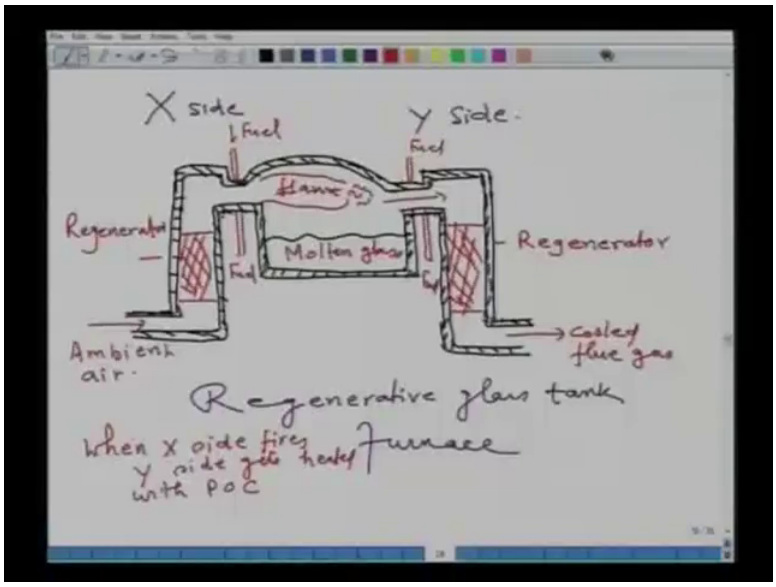

This is what I discuss for you is a regenerative glass tank furnace. Now, this regenerative glass tank furnace – here is the entry of fuel, fuel, fuel and fuel. Now, this regenerative glass tank furnace – the furnace is attached with the regenerators. Here ambient air; here the cooled flue gases. So, this is a portion, is also a regenerator; this is also regenerator. Now, note there are two regenerators attached to the furnace. Here this is a molten glass. As a result of air and fuel, it mixes over here; a flame is created. And, products of combustion – they flows down the regenerator and…

What I wanted to say is that a furnace – it is also integrated with the heat recovery devices. In this particular case, you see that two regenerators are at each. So, the two regenerators work in intervals. Say for example, when x side fires, that means it fires a preheated air; y side gets heated with POC or products of combustion or flue gas. It reverses. When y side fires, x side gets heated up. So, this is typically a glass making

furnace looks, which is attached with the so-called regenerative or the heat recovery devices.

Similarly, one can have the furnaces, some examples of the physical processes. In the physical processing, the continuous furnaces for heating of the slab, bloom, billet – they are very long furnaces. The length may vary of the order of 25 to 30 meter, treating a billet for example, 58 or 50 tons per hour as the billet discharge capacity of those furnaces. They are very long furnaces. The flue gas – they are discharged at around 800 to 900 degree Celsius, because all these continuous furnaces. Some portion of their length also acts as a recuperator; that means, some of the heat is recovered in the furnace itself, so that the flue gas discharge the furnace at a lower temperature, then the soaking temperature of a furnace, which is 900 degree Celsius. In batch furnaces for physical processing, the temperature of course will be the temperature of a furnace; maybe around 12 or 1300 degree Celsius, because there is no choice. There the furnace does not recuperate the heat.

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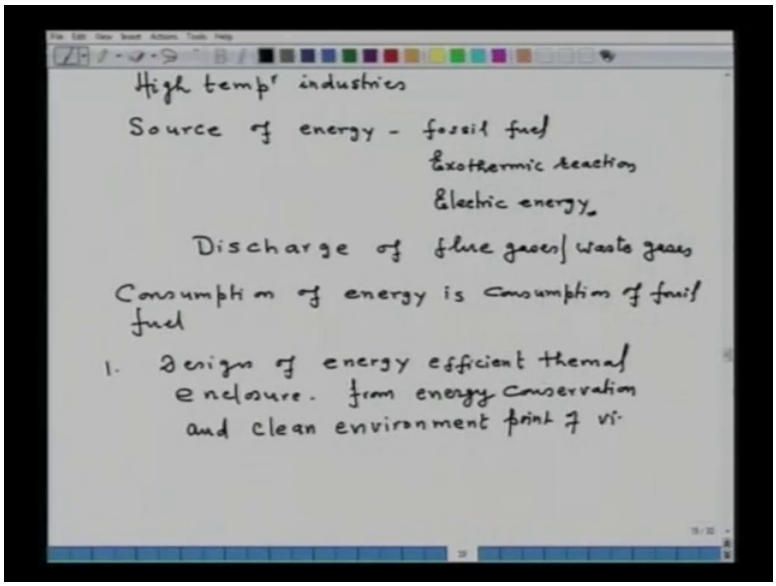

So, in some substance, what I wanted to say is that in high temperature industries – could be iron-steel making, cement, glass, ceramic processing and so on. So, summarize its source of energy. Source of energy is fossil fuel, also exothermic reactions, also electric energy. But, electrical energy is also an example of fossil fuels. We consume electrical energy if it is generated by the combustion of fossil fuel. Then, equally, we can say a

source of energy though it is electrical energy which is visible to us, but it is in fact the fossil fuel.

Also, another important feature of the furnaces that we see is the discharge of flue gases, waste gasses or whatever name you will like to call. They are at a very high temperature. In most of the furnaces, they are the temperature of the order 900 to as high as 12 or 1300 degree Celsius. And, it possesses a large amount of energy. So, while designing or while considering furnaces, the consumption of energy is consumption of fossil fuel. Of course, where exothermic reactions are being used, it may not be that case. But, in majority of the cases where thermal energy is derived from the fossil fuel combustion, then this is the case.

So, several things are important from here. One – design of energy efficient thermal enclosure, is the very important point. Now, this design of energy efficient thermal enclosure – this is particularly very important from energy conservation and clean environment point of view. You can also say to secure the energy resources and to have the sustainable environment, it is very important that the thermal enclosures derive their energy from combustion of fossil fuel or design for very efficient; that is, they should be very energy efficient.

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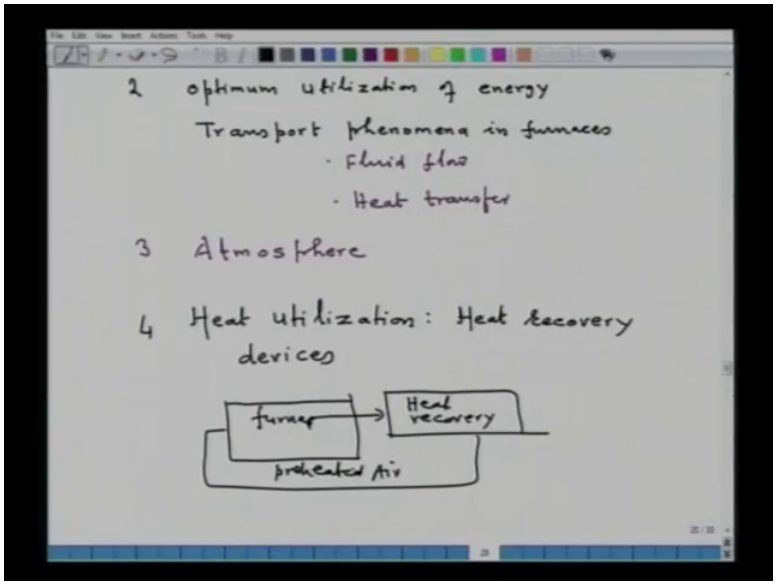

In this connection, second important point is the optimum utilization of energy. In this connection, it is equally important the transport phenomena in furnaces. Under the

transport phenomena, this is the fluid flow and heat transfer. If we want to understand the furnaces, then the transport phenomena in furnaces assumes a very important, how the flue – flue means the gases and the liquid – they are flowing; how the heat is being transferred and so on, so forth. Third important thing is atmosphere. In certain furnaces, we can use for heat treatment purposes; the atmosphere is also a very important. You may have reducing atmosphere, oxidizing atmosphere or neutral atmosphere. So, equally important part of the furnace design is also the atmosphere.

Fourth important point in the case of furnace design is heat utilization. Heat utilization – how the heat, which is being produced; how it is utilized for a particular objective. Whether it can be done with the low amount of energy or not, also, heat utilization is coupled with in total, the amount of heat, which is being supplied and the amount of heat, which is lost. If the amount of heat is supplied is x and the amount of heat which is lost is y, then y should be as minimum as possible. With this, what I wanted to say here, as you have seen also in the lecture, the flue gasses and waste gases discharge at a very high temperature. So, in the heat utilization, the most important part is the design of heat recovery devices.

Now, not only is the design is important, but it is also important their integration with the furnace unit. Now, for example, if we have a continuous furnace, where continuously flue gasses are exiting – here if we integrate for example, a heat recovery device and this is our furnace, then the supply of preheated air must also be there as a function of time, because it is a continuously operated furnace. What I mean to say is that in the design of the thermal enclosure of the furnace, the heat recovery and its integration with the furnace is a very important technique. Particularly in view of the conservation of energy resources and environmental cleanliness, heat recovery is very important.

Now, one has to assess whether the heat, which is being recovered can be used continuously in the furnace or heat which is being recovered can be used for some another function. For example, one can produce a steam out of it in the boiler. So, this is also an important issue in case of design of thermal enclosure; that is, heat recovery devices whether you want to have a recuperator or a regenerator or a steam boiler or a waste steam boiler, it has to be integrated. Now, as you have seen, in case of glass making tank or glass making furnace, the furnace is integrated with the regenerator. The

blast furnace – they are integrated with the blast furnace stoves. So, these are some of the say important part for design of the furnace.

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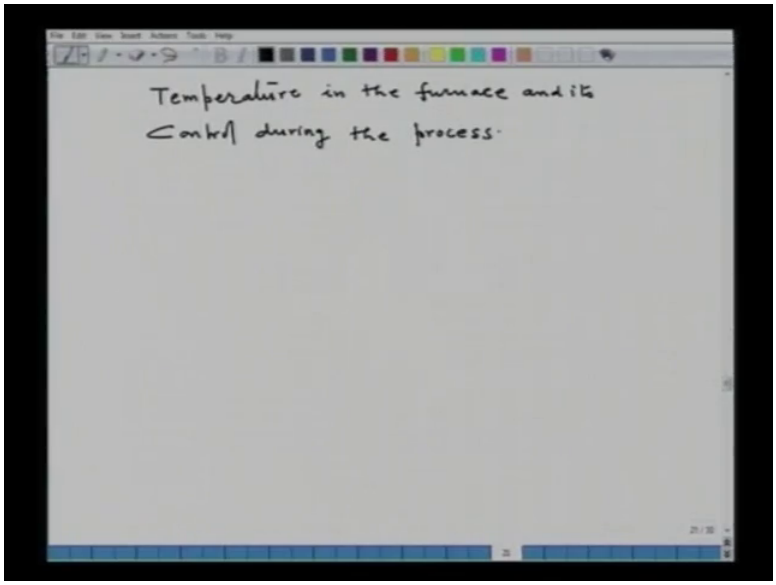

Now, another equally important feature is the temperature in the furnaces and its control during the process, because for certain processing, it is important that you should have created a particular temperature. Temperature measurement is an important exercise. How you are going to measure the temperature? The atmosphere is very adverse. The gasses are moving at high speeds, maybe reactive. With the turbulence in the gasses, liquid phases are moving – reactive liquid phases. So, there the temperature measurement – because control of temperature is also important, it is not required that some part of the furnace is over heated; that means wastage of energy; or, some part of the furnace may be under heated; that is also wastage of energy. So, to surprise this particular lecture, what I wanted to say is that the furnace in all pyrometallurgical processes or in manufacturing industries plays a very important role. Also, in the cement industry, glass making industry, ceramic industry, wherever the furnace, which I defined as a thermal enclosure, they are used, the furnaces plays a very every important role.

Also, one has to note the exit of the flue gases, which is at a very high temperature – it also contains the pollutants. So, from the environment and energy consideration, the recovery of the heat and discharge of the gases to the environment are also important issue. So, in the subsequent lecture, I will be starting with the heat utilization in furnaces.