Fuels, Refractory and Furnaces
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Lecture No. # 27
Principles of Burner Design

So, as introduced in the lecture 26 about the burner, objective of burner. And I have said over there that a burner is a most important component of the furnace. I have also said that the industrial furnaces they employ diffusion burner that is a burner which produces a diffusion flame.

Now, the idea of production of diffusion flame is that all the amount of Air is not mixed certain percentage of Air is mixed with the Fuel and rest of the Air is mixed in the furnace. So, today we will see what is the principle of burner design. In fact, a burner is a flow passage in which a mixture of Air and Fuel is passes through a flow passage whose cross sectional area it decreases in the direction of flow. So, as a result of flow of a mixture of Air and Fuel the burner will be able to produce a free jet. So, let us see how the design of burner is done so essentially let us see how a free jet looks.

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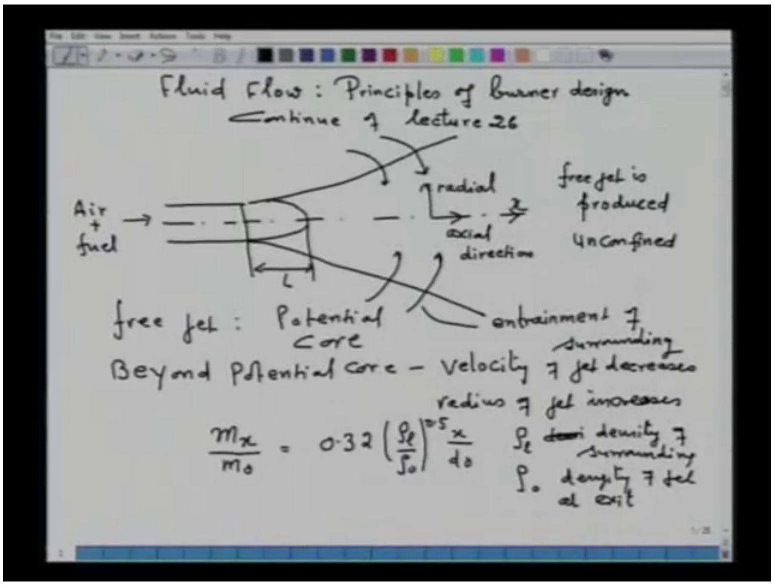

So, for example, if I take an axis symmetric nozzle of a burner, then this I will show as a burner this is outlet and as a mixture of Air plus Fuel is discharge is sort of a free jet is produced, that is a free jet is produced. You can also say it is an unconfined, it is produced in the atmosphere. So, as a mixture of Air and Fuel passes through this nozzle of a burner, a jet is produced. The velocity of the jet it interacts with the surrounding, the surrounding also sets in motion and because of the differences in the momentum flow rate of the jet and momentum flow rate of the surrounding. The surrounding enters into the jet and on account of that a jet is spreads as it is discharged into the surrounding.

So, here the entrainment of surrounding, this is the entrainment of surrounding as I have pointed out last time also and in the jet. So, a free jet is characterized by a potential core so, this is a sort of characterizes of potential core and in the potential core the entrainment of surrounding does not occur. The velocity in the potential core is same in the axial direction as well as in the radial direction. So, with this is the axial direction of the jet, this is the axial direction and this is the radial direction.

Now, beyond potential core, velocity decreases, velocity of jet decreases and radius of the jet increase. Why? Because of the entrainment of the surrounding now, the radius of the jet increases because mass of the jet increases. So, we can define, say for example, mass of jet at any point downstream the burner after the potential core that is m x is the mass at any distance x downstream the burner beyond the potential core. If I divide by mass of jet at the exit of the nozzle, then it has found to be equal to 0.32 row l upon row 0 to the power 0.5 x upon d 0, where row l is the density of surrounding and row 0 is the density of jet at exit of the nozzle

So, you see from this situation that as x increases so this is the direction x. As x increases row for a given row l upon row 0 and m 0 m x increases so that is what the spreading of free jet is, that is the jet spreads on account of entrainment of the surrounding.

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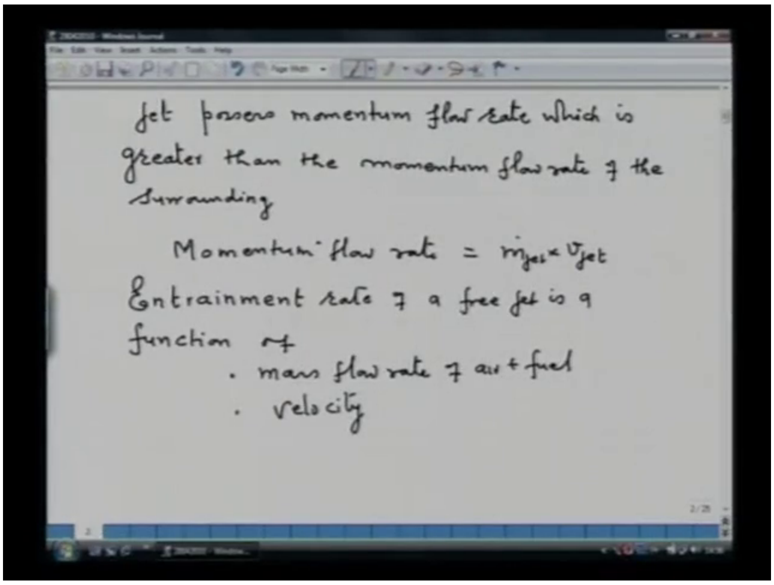

So, what we can say from here that is all this comes from the jet possesses momentum flow rate which is greater than the momentum flow rate. So, jet it possesses momentum flow rate which is greater than the momentum flow rate of the surrounding. And this difference in momentum flow rate is responsible for entrainment of the surrounding in the jet.

In fact, the momentum flow rate momentum flow rate is given by m dot jet into velocity of the jet. So, what we learnt from here what is the important message that I want to give from here is that the momentum flow rate within the jet it controls the entrainment of surrounding.

The surrounding will entrain till the momentum flow rate of the jet, it equals to momentum flow rate of the surrounding. So, as long as the jet possesses momentum flow rate when it is discharged into the surrounding, it will continue to entrain the surrounding till the jet momentum flow rate is equal to 0 so that is an important thing that we have to keep in mind, this is when the jet is unconfined. Unconfined means there are no boundaries that means a large amount of surrounding is available for entrainment.

But what happens, say an that means an unconfined jet can entrain as much as surrounding depending on the entrainment capacity of the jet. So, we can say from here that the entrainment rate of a free jet is a function of one mass flow rate of; for example, Air plus Fuel and second important is the velocity, these two things control the entrainment rate.

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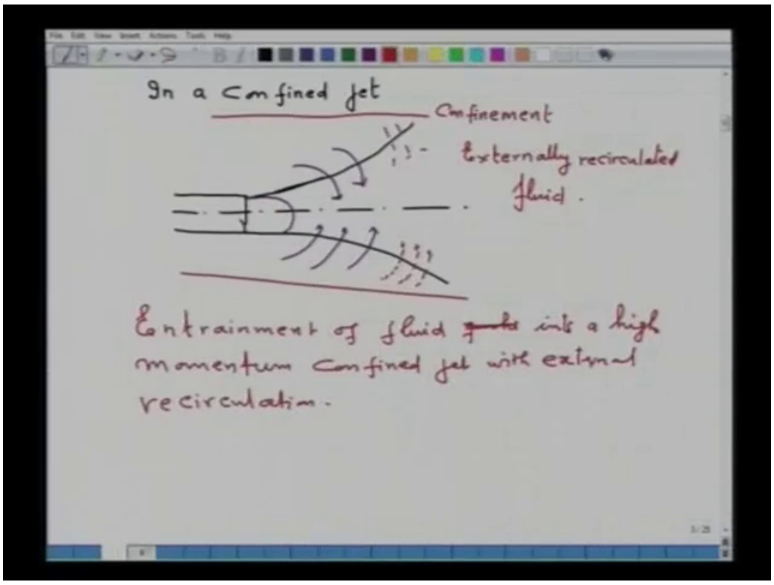

Now, in a confined jet, what happens? For example, in a confined jet, now, confined jet means the limited amount of surrounding is available. For example, an Air Fuel jet is discharged into the furnace where the surrounding is not unlimited so, a confined jet can occur. For example, in when the Air Fuel mixture is discharged into the furnace so, there the jet is confined. So, for example; in case of confined what happens? In case of confined jet what will happen? Say for example, again I take as; you see this is my burner and this is the jet and somewhere here I have the wall that is the jet is confined. This is the confinement; that means now there is a surrounding is limited.

So, when this is the case then what will happen? No doubt the entrainment process, well this is the potential core. The entrainment of surrounding will occur as long as the amount of surrounding is there. And when the momentum flow rate within the jet equals to that of the momentum flow rate of the surrounding then the entrainment will stop and the jet will suck the exhaust gases. So, from here one can say there will be this is what the externally re-circulated flue. So, this you can call it as an entrainment, this is the process of entrainment of fluid into a high momentum confined jet with external recirculation.

So, what I mean to say form here is very simple. In a confined jet the amount of surrounding is limited that means a limited amount of surrounding can be entrained into the main part of jet. So, the important thing for a confined jet is that the recirculation of the jet. So, in this particular case the jet will pull exhaust gases due to excess momentum. Now, applying this particular concept to the burner design, what it means? That means what we have seen there is a confined jet and there is a unconfined jet. In a unconfined jet, surrounding can be entrained as much as it is the capacity of the jet. In case of confined one there is a limited surrounding.

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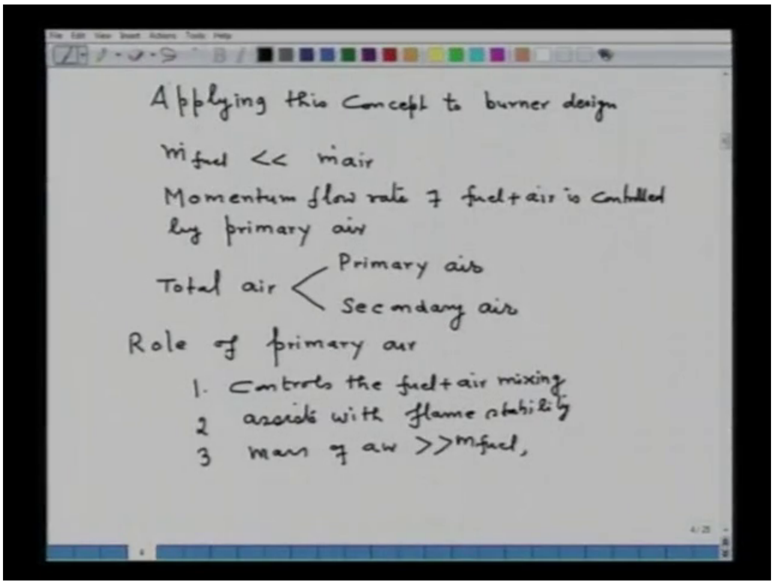

So, what we learn when we apply this to the concept of burner design, then we learn the following; that means applying this concept to burner design; that means, now the first of all we have to agree that m dot Fuel is much much smaller than m dot air. In calculation, I have said that for one kilogram of the fuel, you require around 13-14 kilogram of the air. So, one should be very clear that the momentum flow rate of the mixture of air, Fuel jet will be largely controlled by the amount of Air rather than amount of fuel.

Now, this is especially true when we are going to design burner to produce diffusion flame. That means the momentum flow rate of Air Fuel jet is controlled by primary air. So, what we deduct from here that momentum flow rate of Fuel plus Air is controlled by primary air. That means you have to decide what percentage of the Air we will be mixing with Fuel and rest percentage of Air we have to supply in the furnace itself. So, accordingly, for the burner which are based on diffusion flame the total Air total Air is divided one in the primary air; that means, the Air which is mixed with the fuel, normally, it is 30 percent of the Air which is mixed with the Fuel rest 70 percent of the Air is supplied into the furnace utilizing the concept of entrainment of the surrounding in the furnace so another part is the secondary Air.

Now, depending on the core of supply of the rest amount of Air one can even have tertiary Air also that will depend upon the burner design. So, the primary, the role of primary Air is very crucial. Role of primary Air is important, first of all, primary Air it controls the Fuel Air mixing, the Fuel plus Air mixing. Say higher is the momentum flow rate more amount of surrounding will be entrained into the jet. But then one should be careful that only you require to entrain the rest percentage of Air from the furnace because some percentage you already mixed with the Fuel so that it design is an important case.

Second, the primary Air it assists with flame stability. Because for stability of the flame it is necessary that the right amount of Air is available in the flame. Now, third, as I have already said since mass of Air is far far greater than mass of fuel, so, momentum of a mixture of Air Fuel jet is largely controlled by the primary amount of Air and hence the percentage primary Air is an important consideration. Now, remember we are talking about the confined jet by the furnace wall, so, here a degree of recirculation is an important issue.

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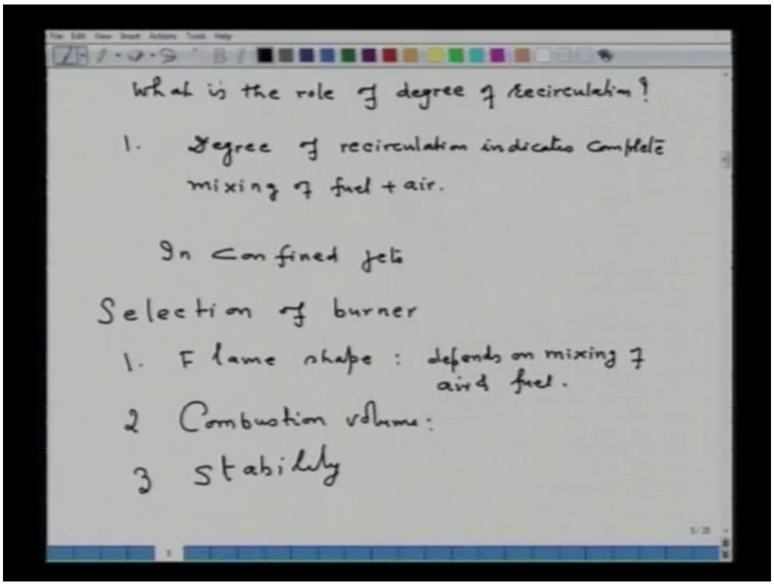

Now, the next question which I pose, now, so what is the role of degree of recirculation? Now, as I have already said the jet begins to pull the exhaust gases, once it is excess momentum becomes equal to 0, then it pulls the exhaust gases once; let me repeat once again, the jet pulls the exhaust gases when it possesses an excess momentum. And this is possible when we have a confined jet and that is due to the limited surrounding. Because of the limited surrounding or limited amount of surrounding the jet will possess excess momentum and when the surrounding exhaust then the excess momentum of the jet it pulls the exhaust gases into the main part of the jet.

So, the degree of recirculation indicates complete mixing of Fuel plus air. How does it do it? That means, we have added say 30 percent of the primary Air and 70 percent secondary Air in the furnace and when the moment that the jet begins to pull the exhaust gases that means the mixing of total Air is complete. So, the degree of recirculation is important. Now this degree of recirculation which indicates complete mixing of Fuel and Air this also gives us that the mixing is complete and that is an important thing here. In case of confined jet, absence of recirculation in it is a tendency for the flame to extend until it impinges onto the furnace wall or load. That means if you have a confined jet if there is no recirculation or no cooling of the exhaust gases, what will happen? It will result in the spreading of the flame and the flame may hit the walls of refractory and as such it may destroy the refractory lining.

So, in general we can say, a high momentum re-circulating jet will also produce a stable flame which is controllable. Now, this is what the principles of burner design, in that one has to control the proportion of primary Air such that the momentum flow rate within the jet it is able to entrain the surrounding and also the entrain the exhaust gases. Now, with this let us pass on to the selection of burner.

Now, there are various important issues that one has to consider for selection of a burner one flame shape, shape of the flame and this shape of the flame depends upon, depends on mixing of Air and fuel. Second, important point is combustion volume. Now, normally, this gas burners are designed to release heat as high as 110 into 10 to the power kilo calorie metre square of combustion volume. So, what is important here how much amount of combustion volume is available in the furnace and accordingly one has to select whether you go for light oil burners or heavy oil burners or gaseous Fuel burners. Third important point of course, is stability, stability is also an important thing.

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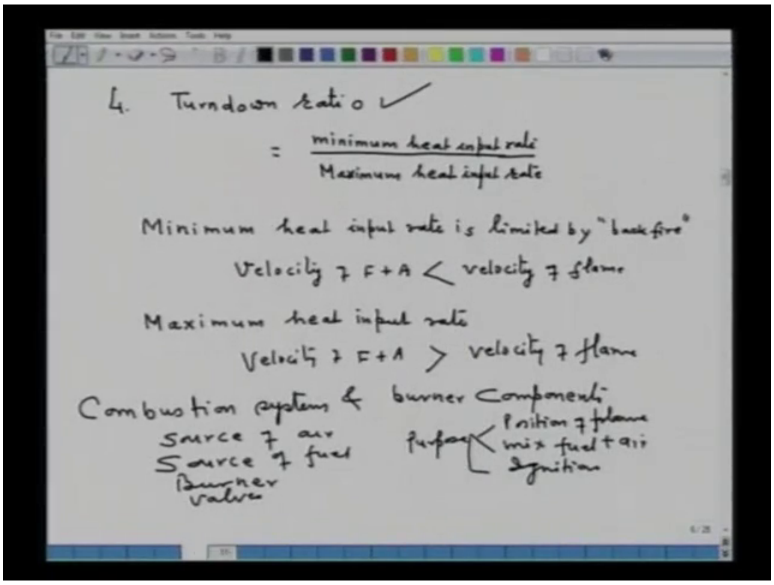

Now, fourth, is the most important point is the turn down ration and turn down ratio is equal to say minimum heat input rate divide by maximum heat input rate. Now, you know this turn down ratio is very important and provides a large flexibility to the operator. That is in times when you require a minimum heat input then you should be able to dossal the amount of Fuel and at times you require maximum heat input then you should be able to increase the amount of Fuel and your burner should have a wide turn down ratio. That means, the operating limit should be high between minimum and maximum so that an operator can adjust it is in self during the operation of the furnace.

Now, the minimum heat input rate, say, minimum heat input rate is limited by fire, what does it mean? That means you have say velocity of you have velocity of Fuel plus Air and you have velocity of flame, that with which the Fuel and Air mixture is burning. So, if velocity of Fuel and Air is smaller than velocity of flame and flame will backfire into the burner. Why it will be smaller? Because in the case of minimum heat input you want to dossal the amount of Fuel so, when you want to decrease the amount of Fuel the velocity of Fuel and Air that will be lower than the velocity of the flame. And in that case the flame will backfire into the burner so that is the minimum heat input. Now, the maximum heat input rate, what you have to do for maximum heat input? You have to increase the velocity of Fuel and Air for amount of Fuel and air. So, if you increase the velocity of flame Air that is the velocity of Fuel plus Air this is greater than the velocity of flame, then what will happen in this case? You are discharging more amount of Fuel and Air into the flame then it is combustion capacity then the flame will extinguish.

So, these between these two limits they turn down ratio is rather decided. Now, so these are the important factors for selection of the burner among which the turn down ratio appears to me as the most important factor, because this gives a wide flexibility to the operator to adjust the flow rate at the time of operation. Now, combustion system and burner components, say you have, you should have source of Air and source of fuel, burner, valves for controlling and purpose and purpose could be, for example, position of flame. What is the purpose of this burner? Position of flame that is an important, then mix Fuel with Air Fuel plus Air then ignition. So, these are the some of the important components.

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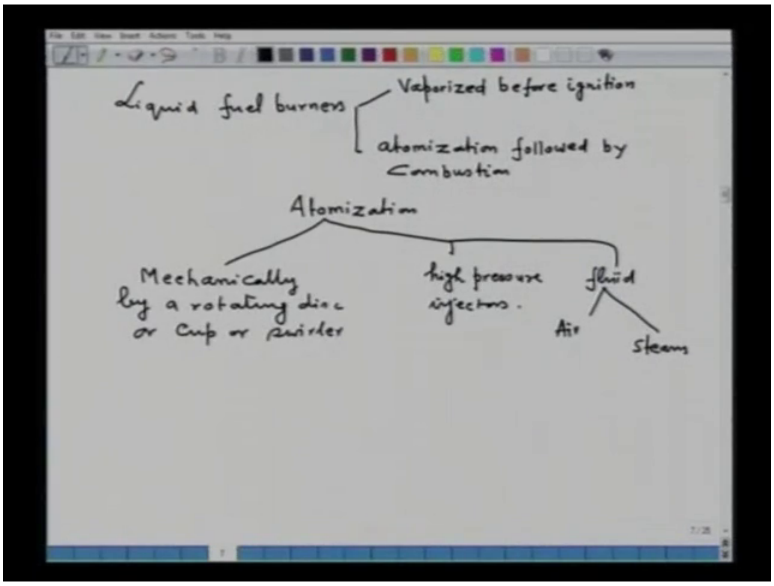

Now, let us see little bit about the liquid Fuel burners. Now, in the liquid Fuel they are not like gaseous Fuel burner, because the gas and Air can be mixed. Where incase of liquid Fuel burners, you have to atomize the liquid fuel. So, there are two types of burner, one is the vaporized; the oil is vaporized before ignition these are the one type of burner, but these type of burner they are not in common use. In another type of say atomization followed by combustion; well, this particular type of burner they are in common use. Now, here the most important is the atomization of liquid oil.

Now, the atomization that is atomization disintegration of oil into the droplets so, naturally, finer the droplets faster will be combustion coarser will be droplets slower will be the combustion rate. So, what is important in atomization, one has to choose the velocity of oil and velocity of combustion medium such that the fine droplets are produced. So, the atomization can be done mechanically, say mechanically by a rotating disc or cup or a swirler. What is important? You should impart some type of force into the oil so that it can atomize. Another way is high pressure injectors that is you inject the oil at a high pressure and third is that the fluid is used as a atomization source and fluid could be Air or it could be steam. So, these are the ways so depending on the method of atomization, the burners are designed accordingly.

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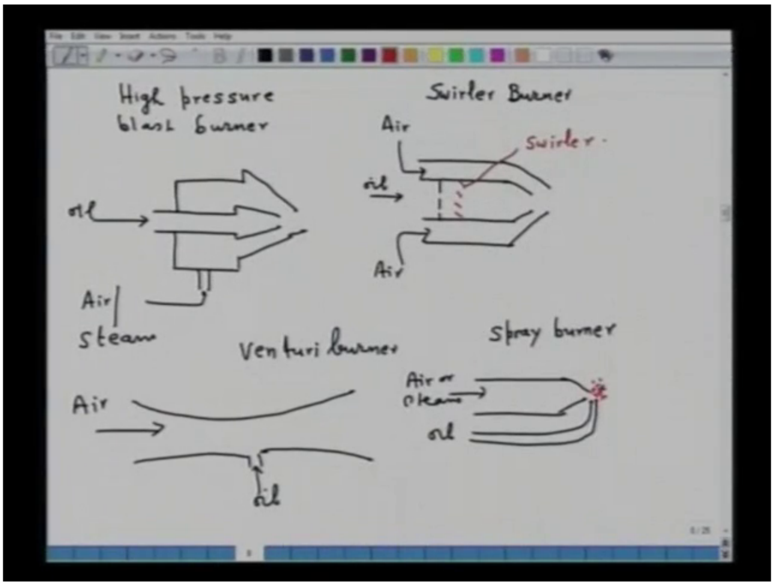

So, I will show you some of the some of the sketch of the some typical burner say, for example, the one type of burner that is the high pressure blaster burner, though this is for example, I have this is the oil supply of oil this is where the oil is supplied. Now, oil is normally, it is heated to 60-80 degree so that it is flow able so that it is viscosity decreases and from here (No audio from 32:43 to 32:54) so, here atomizing fluid like Air or a steam it can be supplied.

Now, there could be several designs I mean it is not that one which I have drawn that is the one, but there are several designs are available; all that is important you should have an inlet for atomizing fluid and an inlet for oil. The atomizing fluid should be distributed uniformly so that it can disintegrate the requirement is only this. The requirement is downstream the burner, you should have a fine spray because then it will combust faster that is the important.

Another you can name for example, swirler burner. In the swirler burner what is done they this is again the source of supply of the oil, so, this is the oil and here supply the Air somewhere here the swirlers, this is the swirler, here and here, Air and Air is passed. The whole idea of this; this is all the whole idea provides the swirling action to the flow of oil and hence it further disintegrates along with this. This is another design you can have is sort of a Venturi burner. In a Venturi burner say this is the design of venturi burner, here fast Air and here oil is supplied, now, the advantage of Venturi burner that very high velocity of Air can be produced. Another type you can have spray burner. In the spray burner say you have this is the so called fast Air or steam and here this is the oil and here say a spray is then produced so this is the spray burner. So, another type of burner is the self recuperative burner.

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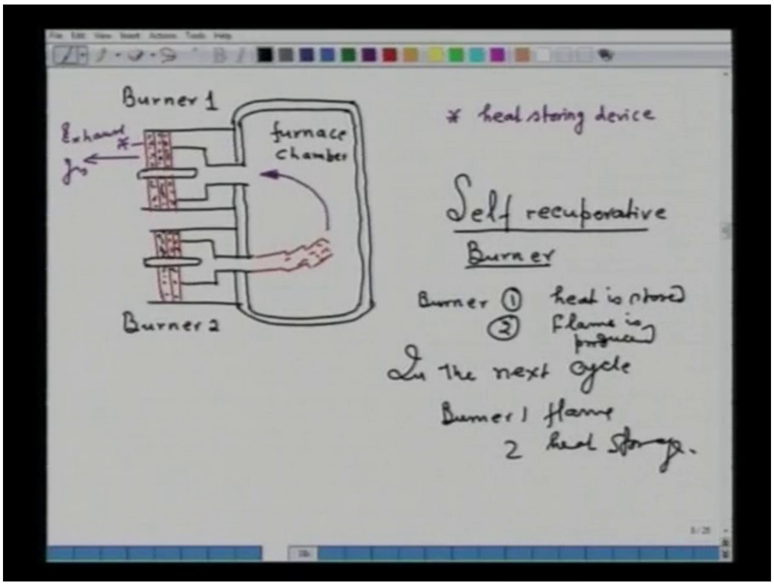

Now, this is very interesting this self recuperative burner in that the burner is self equipped with the heat storing devices. So, as such this is the furnace chamber, and as you note the furnace chamber is equipped with two burners, burner one and burner two. So, in this case burner two is producing flame the exhaust gases are re-circulated into the heat storing device of burner one, where heat is stored and then in the next cycle burner one produces flame and burner two is on the heat reclaiming devices.

So, this type of self recuperative burner is a very recent innovation and it is very helpful in conserving the heat. Because now, you are conserving the waste heat through the burner itself, that internally you are conserving the waste heat to heat, the preheated air. Similarly, you can have self regenerative burner also, in the self regenerative burner the burner is equipped with the device for heat storage and also there are used in true burners are used that is one heat storing second flame producing and in another cycle the reverse is being done. So, this is a very important I thought I will just mention about the modern usage of the burner.

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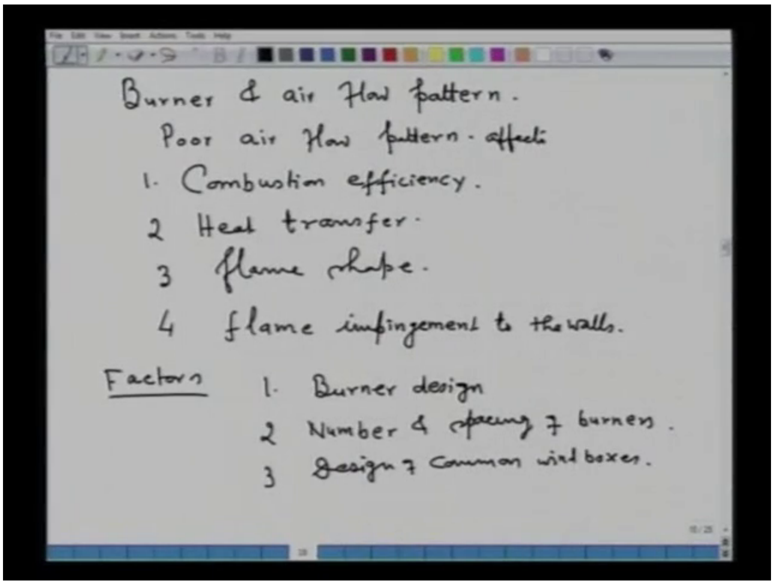

Now, next important thing that comes say burner and Air flow patterns, say Air flow patterns that is the way in which the Air flows in the furnace, it is very important that is a poor Air flow pattern, what it does? It will affect naturally combustion efficiency. Because for combustion efficiency mixing of Air is important with the fuel, it will also affect heat transfer, flame shape, and a poor flow pattern may cause flame impingement to the walls.

Now, for that purpose the Air flow pattern is important. Now, Air flow pattern is primarily determined by the as you recall as you recall in the principle of burner design, it is the momentum of the jet that is the how much amount of primary Air is mixed. Now, the factors which affect burner, Air flow pattern; factors that affect Air flow pattern first is burner design, how the burner is designed, how much amount of primary Air is taken and so on. Second, important thing, the number and spacing of burners, and then third the design of common wind boxes.

Now, in some furnaces use single burner then probably it is the amount of primary Air that is important, but the several furnaces for example, the heat treating furnaces they use burner more than one burner. So, in that case, number and spacing of burner is important the supply of Air is also important in case of number and in case of burners where more than one burners are used so, these are the say important things. Now, most of the say some furnaces which use single burner system say for example, rotary kiln for used for alumina cement chromo chrome oxide and so on, they are used; they are using for example, single burner system. And in the single burner system they supplier has a control only for 30 percent primary because rest of the Air it is method of design or it is method of entry has to be done by the plant itself.

What I mean to say is that when a single burner is used, the manufacturer of the burner has only control over thirty percent of the primary air, because then we can design corresponding to 30 percent of the primary air. Rest 70 percent of the Air the way it is supplied in the furnace the number of ports, number of places, velocity all this will be decided not by the burner manufacturer, but by the plant itself. So, in case of single burner, the burner supply has control only up to 30 percent primary air. Now, rest amount the 70 percent of the Air their way to supply velocity that is called secondary Air has to be designed at the furnace itself.

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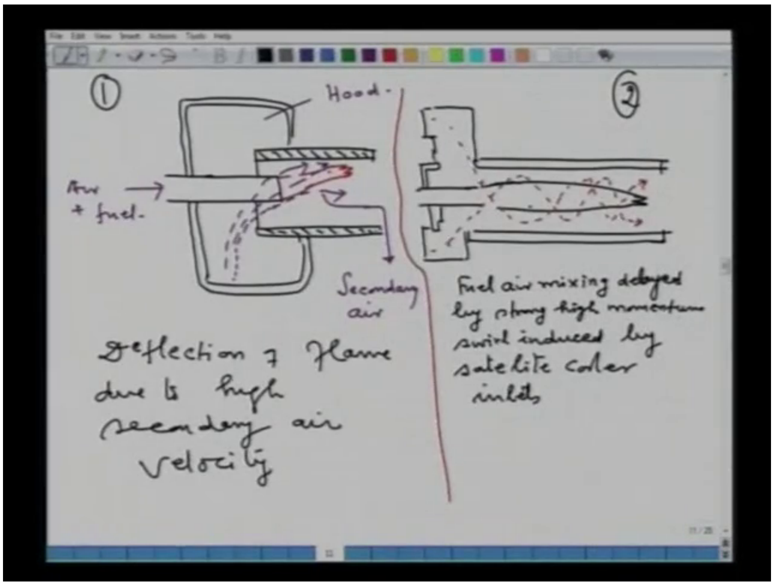

So what can happen, for example, if you see in case of this one where if this is the red color stone this is the flame then the high secondary Air velocity it can deflect the flame. So, it is very important that the design of ports for supply of secondary Air is designed properly. Now, in case of two, what can happen you can see here, the Fuel Air mixing can be delayed by strong high momentum Fuel that is induced by satellite cooler inlets. That is what is important, that I want to say over here is very simple and for the primary for the single burner user it is important that the design of secondary Air inlets should be properly done so that a proper mixing can occur. Now just to end this particular lecture I would like to give you few self assessment questions.

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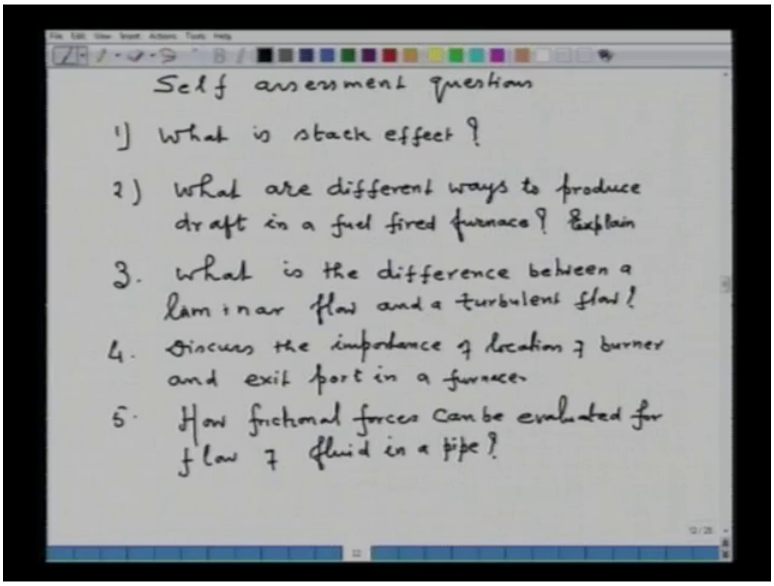

And in general, they have the questions from say lecture 21 or till 27 lecture, I have already given the numerical problems in lecture 21 to 26. Now, certain additional certain theoretical problems I can give you so that you can think first answer what is the stake effect. what is stake effect? I have discussed it we have solved the problem also; just find out what is stake effect. Second, what are the different ways to produce draft to in a Fuel fired furnace, I also discussed this in detail say balance draft, sports draft, induced draft, natural draft, you have to see and answer this particular question.

Third, what is the difference between laminar and turbulent flow? I have also said and we have discussed this in our lecture and find out and make the answer. Then the discuss the importance of location of burner and exit port in a furnace. We have also discussed, try to learn fifth, how frictional forces can be evaluated for flow of fluid in a pipe, This is related to the mechanical energy balance.

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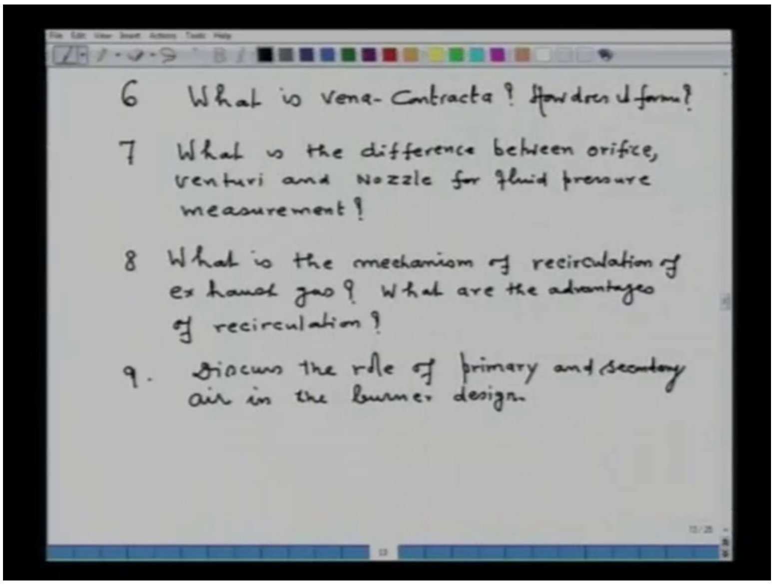

Now, sixth what is Vena-contracta? I have discussed this in detail, how does it form? As you have discussed it again relates to the contraction of the flow lines as the fluid passes through an orifice, try to learn and get a feel of Vena-contracta that is the most important in the design of the orifice.

Seventh, what is the difference between Orifice Venturi and Nozzle for fluid pressure measurement? This is again I have discussed, you sketch all these three and discuss how they are designed number one, discuss also what happens when the fluid flows, in a Orifice there is a concept of permanent pressure drop because of the formation of jet because of the formation of aides and so on that you can discuss and understand these things.

Now eighth say what is the mechanism of recirculation of exhaust gas? This is also I have discussed the mechanism of recirculation of exhaust gas is that a jet should have excess momentum, this excess momentum will induce the exhaust gases into the jet. So, this all I have discussed and you can again bring here and right now. Also what are the advantages of recirculation? You know one of the biggest advantage of recirculation that is when the jet pulls exhaust gases into the flame then the flame temperature is decreases and the decrease of flame temperature also help in reduction of the Knox formation that is important, try to learn.

Nine, discuss the role of primary and secondary Air in the design of burner, in the burner design. So, these are some of the questions that I thought you must learn. And in addition the several problems I have solved in the lectures on transport phenomenon in furnaces. The unsolved problems I have also mentioned please solve that. So, our next lecture, will comprise of transport phenomenon in furnaces heat transfer.