Engineering Thermodynamics

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Lecture - 50
Thermodynamics of Reacting Systems: Introduction to reacting systems and combustion.

This is the second module of Thermodynamics and we will now start the third sub topic which is Thermodynamics of Reacting Systems.

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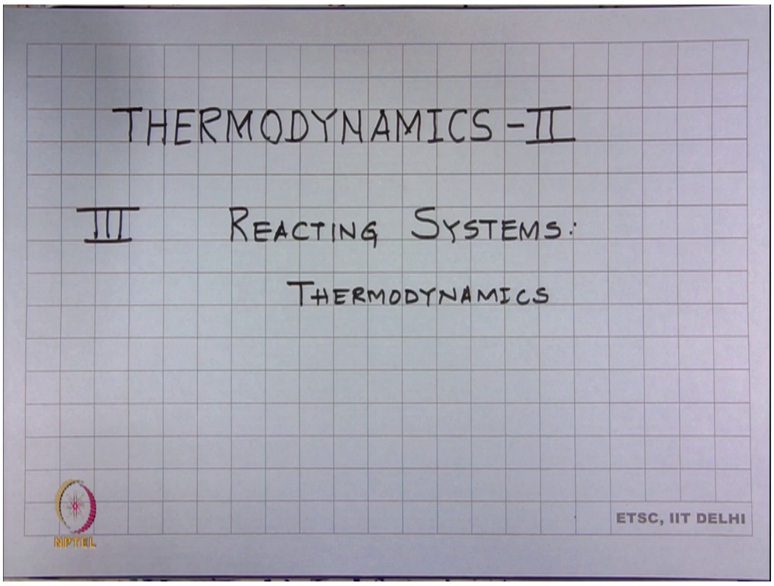

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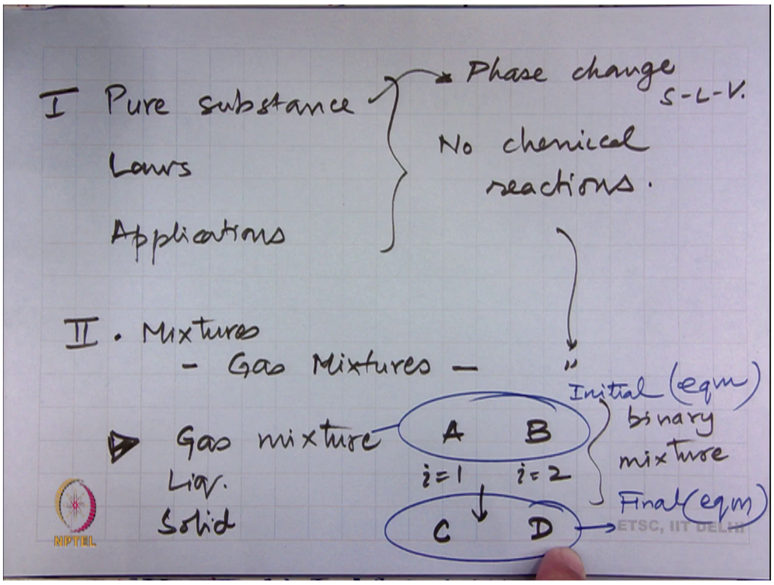

So, what do we mean by this? But so far, everything we have learnt in the first part of thermodynamics which was dealing with, pure substance, the laws and the applications. In all of these there were no chemical reactions; we had one type of a molecule.

And no matter what we did to that at the molecule level or at a macro level as a system; heating, cooling, work output-input heat transfer input-output that species remain the same. We then looked at in the second part, what we looked at was mixtures. And in that we said we shall focus on gas mixtures and we developed a general approach to say if there are two gases which are mixed how do we get the properties of that and then how do we use that in the laws to analyses them for heat and work transfer.

Again there also we said no chemical reactions, the only thing here we had though was that in some cases of a pure substance, we had phase change. So, solid, liquid, vapour phase change was there, but even phase change takes place, there is no chemical reaction taking place. It is same molecule that goes from one phase to the other phase. Now we are all saying that look we are going to look at mixtures, and we will particularly concentrate on gas mixtures although the theory we develop later on will be good for liquids and solids as well.

So, now we will say that we have a gas mixture, and later on we will look at liquid and solid. There the two constituents say A and constituent B. So, this was two component system i equal to 1, i equal to 2 binaries mixture. And now we say we will do something and let A and B react. So, there is a chemical reaction between A and B and it ends up producing an entirely different set of molecules, which we will call say C and D. So, what we had was we started off with a particular type of a mixture, we had a chemical reaction and we came up into a final state which is another set of molecules.

So, this was is the initial state, where we have two types of molecules and after the chemical reaction what we call as a final state we have two other types of molecules and maybe something else also. But the difference is this, that in both cases we are assuming that the initial state was a thermodynamic equilibrium, but during the reaction process there was no thermodynamic equilibrium.

The next thing that we have worried about is that when this thing happens there would be energy transfer. And that is what is of importance to us besides of course, the fact as to maybe the objective is to produce C or to produce D or to minimize something else. So, let us now define our scope of what we are going to do in reacting systems. And to do that, we will say that we are going to study this type of reaction that I just put out.

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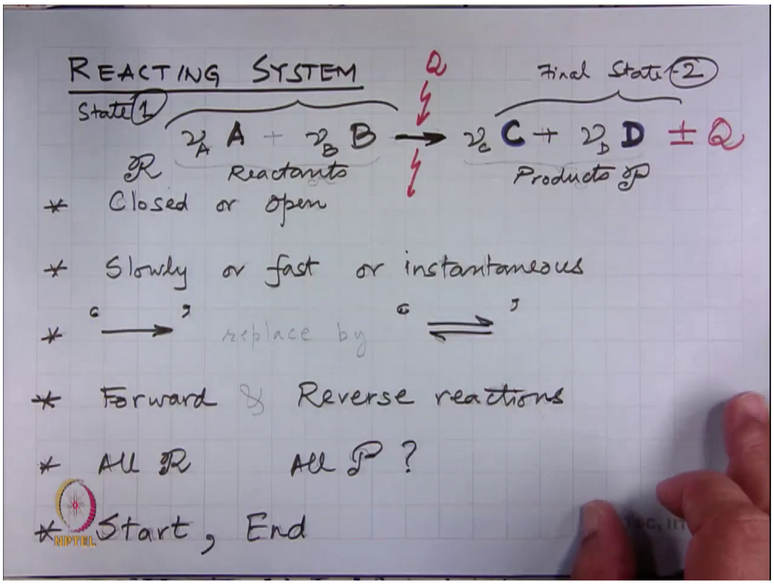

And we say that you have two different type of molecules; which you must have minimum two to make a reaction possible, we could have 3, 4, 5. And it will be minimum of two products that are coming out, without which you cannot complete the picture. So, we can say that products are C and D and reactants are A and B. So, we got two now categorizations taking place this b I just saw, this is the initial state or state 1 this is the final state which is state 2. And we are saying that A and B molecules react to produce C and D molecules and in what numbers they are there is what we put up here as the number of moles of each one of them nu A nu B and produce nu C and nu D.

We are assuming that, the numbers here are such that all of A and B disappear and C and D appear. As we shall see later this need not always be the case, this mixture is what we will call reactants, and we denote it by the R and what you have here are the products; and this we will call P. And during this chemical reaction something else also happens which is Q. Energy release or energy absorption. So, during this process which is technically here, there could be energy input or output and this v is Q and in the way we write equations we put this Q on the product side and say plus minus Q.

So, this is what we want to study, and in general this is what is the reacting system where A and B could be anything. There are so many industrial processes where A and B could be very different types of molecules and the objective is to produce something else, that is in general this is the starting point of what we all do in chemical engineering. When this type of a system happens many questions will pop up.

So, we are going to list out some of those questions and first we say and we also get drawing on our knowledge of what you already learnt in thermodynamics. And the first question is was this a closed system or an open system; the equation by itself does not tell us anything so, we will have to factor that. The second is when this went here did this reaction happen very slowly or was it fast. Or a third case was it spontaneous or instantaneous, what we are meaning is that there could be a very slow chemical reaction or instantaneous could be there us something like an explosion that few microseconds the reaction is over.

Then we have put a arrows here, saying that everything is becoming like this, but technically is this correct that, if we do cause a reaction and finally, you come to an equilibrium state or there was a equilibrium here and a equilibrium there is it true that in this reacts reactants there were only two molecules and the product only these two molecules. Counter question is when this was in equilibrium was there some C and D in it or in the products when they were C and D were there any amounts of A and B in it?

And the answer is that yes this will always be the case and so, these reactions are always to be indicated by a two way reaction, that every time a reaction is going forward. There is also a backward reaction taking place we will later come to see how from kinetic theory of gases we can look at that and why even at equilibrium it does not means; the static equilibrium, but the dynamic equilibrium where all these reactions are still always taking place.

So, what we have here is a forward reaction and a reverse reaction. So, we have to worry about both reactions even you want to look at the complete picture. And that is the what we were question we were asking whether the reactants were all R only or the products were all P only or what they mix of C and D and maybe something else also. The second thing is we did not very we have somewhat clearly specified what is the starting state which is your initial state? State number 1 and the end state which is a final state which is state 2.

So, once you know that this is my initial state, this is the final state then we can begin to apply the laws of thermodynamics to do the calculations like we did for a single pure substance.

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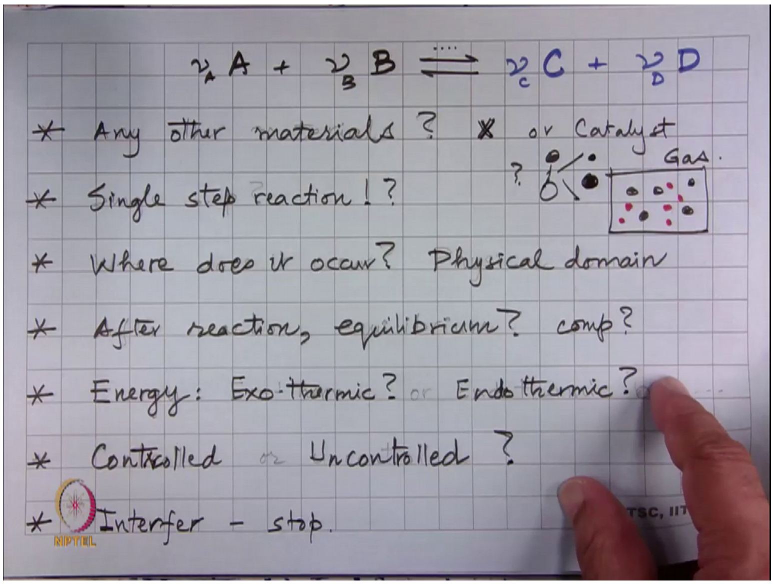

Then this reaction does not tell us, if there were any other materials there or substances for instance if we have this reaction that we have written nu A and nu B of B molecule on this side and on the other side, we have nu C of C plus nu D of D, and now we will say that this reaction went both ways well. Was there any other chemical here say some other chemical say X molecule, which was inert we did not react with did not participate in it, but maybe it affected the rate and way the chemical reaction took place. Or was there something else here like a catalyst that made it happen that also we have not said there.

Then we raise a very fundamental question about all reactions, what the way we write this? And the way we have been taught we have basically saying that if I put these two molecules in a control volume. So, this is one molecule and we put into this the second one then does it happen, that they just come do some collisions and straightaway the end product is this.

So, does it mean that one A molecule hits another B molecule and what we get is C and D does this happen in just one collision this happens. And this collision is we are talking because this is all in a gas phase or you call it a vapour phase. If this were to happen we would call this what is called single step reaction. Where in reality no chemical reaction is a single step reaction and we will see from this thing which is the kinetic theory of gases why that is the case. So, that is another aspect that this equation does not tell us.

Then we ask the question now, where and under what conditions does it happen? So, we are basically saying, what is the physical domain in which the chemical reaction takes place. So, you may have a big domain, but the reaction is confined to very small space within that domain what is that domain? And then we ask well after the reaction has happened and equilibrium is reached, at what point do we say that we have equilibrium do we wait for a long time? Does it happen very quickly? And in so once equilibrium has been reached, what is the composition at the end?

And then there is always the basic thing that we are all looking for with energy aspect of this reaction, where we have the most simple thing to ask is was this an exothermic reaction or was it endothermic? There are many types of reactions, which require heat to be supplied there are many others where heat is given out that is the exothermic reaction. And finally, yet another question we can ask is this a controlled reaction or is it uncontrolled?

But basically we are asking here, when we say it is controlled or uncontrolled? Is that did we design the reaction to happen in a particular way. So, we can control the parameters make it happen faster, slower increase the quantity decrease the quantity or what or is it uncontrolled? Where once it is starts there is nothing one can do it just goes its own way completely. And then there are other aspects we can add to it well can I interfere and stop this reaction. For example, I want to stop it and this is exactly what you would like to do when you have a fire and you want to stop it.

So, the fire is nothing, but again you got lot of chemical reactions taking place, I know you are asking the question what should I do to stop that chemical reaction? So, these are some of the questions that are coming up, by writing a very simple thing a reaction like this, which we have already come across many times. So, this it takes us to a very complex set of issues which are addressed in advanced courses in combustion. We will not go into many of these aspects here, but we will constrain ourselves to asking in one particular type of reactions which is combustion reactions and that to we will say what is the ka relation between properties of these molecules and the energy that is released.

So, we are only going to be taking a macroscopic approach to asking these very few questions of a particular type of a chemical reaction.

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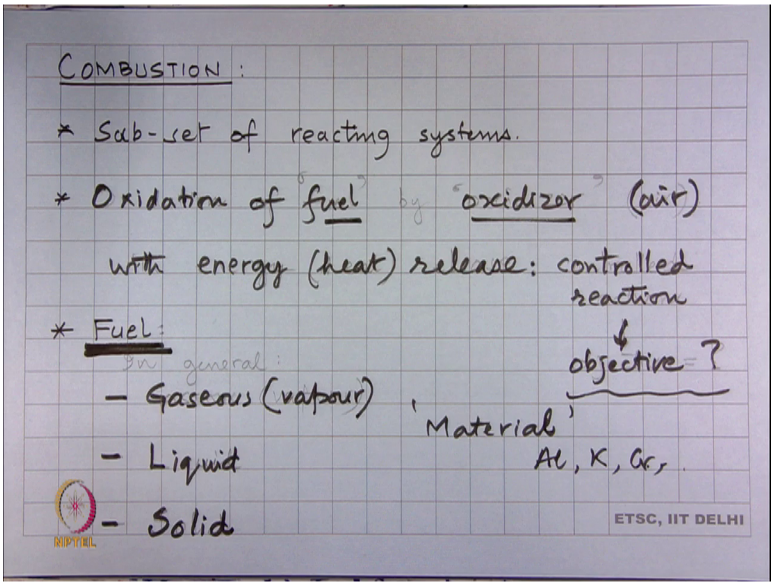

So, our focus is going to be on combustion; what it is? It is a subset of a reacting system and it is characterized by the fact that there is an oxidant or it is a oxidation of a fuel, by an oxidizer; which could be usually air, but could be something else as well. In an exothermic reaction, so we can say along with energy or heat release. This is what we are saying is combustion and this could be when we easily say this is combustion we usually imply that this is a controlled reaction.

So, we are actively designing a system to make some reactions happen in a particular way in a particular space at a particular speed. So, that is what tells us that what is it that we want to know about these type of a system. So, in the study of combustion we have to first begin by looking at two things; one is fuel and the other is oxidizer. And we say that in general if you look at the state, the fuels could be gaseous or we can even say that this is a vapour or they could be in liquid phase or in solid phase any of these can be there. And the question is what do we mean by saying? That there is something called a fuel. So, what is this fundamental idea, what is fuel?

So, implication is that we have saying that this is any material, which when burnt will release heat. So, is there any restriction on what do we mean by the word material or a substance? Well, technically anything and everything will burn or which means that will get oxidized if you have all the right conditions. For example, the common fuels like say gas oils and say wood and coal those are quite understandable, but the fact is that yes even metals like say aluminium or things like say potassium chromium, at the right state they also burn; and they are used in many applications, an example of this is your firecrackers and pyrotechnics that we see.

So, all the colours that we get it is coming out because there is a combustion reaction taking place with different elements and each element gives out a particular type of a colour. So, we are saying that in general fuel is anything that can be burnt in air or oxygen or in some other case. So, the other part is this was the fuel well what about the oxidizer?

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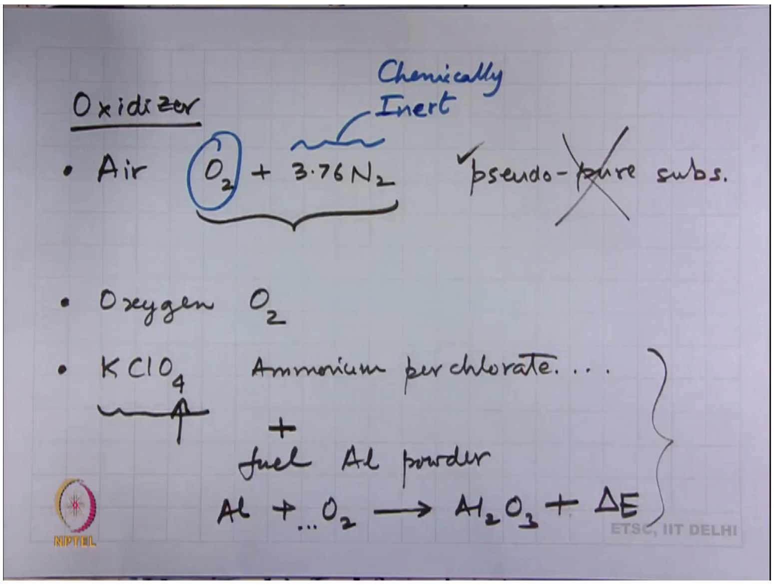

The most common oxidizer is what we have around is air; and air as we have already seen is O 2 plus 3.76 N 2 and the important thing now is that we do not treat air as a pseudo pure substance. So, in the first part of thermodynamics which was properties of a pure substance, we say that this is a pseudo pure substance even when we were looking at mixtures of air which is dry air and water vapour again we treated air as a pseudo pure substance. Now, when we are looking at reacting systems we will no longer treat air as a pseudo pure substance and treat it as a mixture of O 2 plus 3.76 N 2. So, this is one major change that we are now making from what we have learned so far.

The other oxidant that it you quite often's seen is pure oxygen O 2, and this is we used in many cases like say welding, where you have a fuel and oxygen being burnt to produce a temperature and then we burn that. And then there are very special applications where fuels could be something else like, Potassium perchlorate or Ammonium perchlorate or it could be even some other molecules. And these are characterized by the fact that in a molecule like this there are four atoms of oxygen. So, which means that if you can somehow get this oxygen out this becomes a fuel.

So, things like this when mixed with some sort of a fuel which could be say very fine aluminium powder; and then when ignited could burn. And so you have a chemical reaction of AL plus O 2 and you can balance this basically producing AL 2 O 3 plus a large amount of energy is released. So, aluminium becomes the fuel, but the oxidizer although it was oxygen came from a chemical like this one.

And the reason I cited this is, that that is what you would see in solid rocket motors of as a launch vehicles and missiles. So, that is the place where we get the oxygen and the oxidizer from. So, even in air when we talk of combustion with air it is actually the active part of air which takes part in the chemical reaction is this O 2 and in this course for now we will treat N 2 as inert, but inert in the sense that it is chemically inert. But when it comes to energy it does participate and we will look at; we will see that as we go along in these lectures.

So, now before going into the thermodynamics of it; Let us look at some applications and try to figure out what is it? That is actually happening and how, we can pick out the system that we have looking at and apply the thermodynamics that we are learning here. At the same time we will also see what are the limits of what we are learning? So, let us start by looking at the gaseous fuels and the process of combustion or burning of a gaseous fuel.

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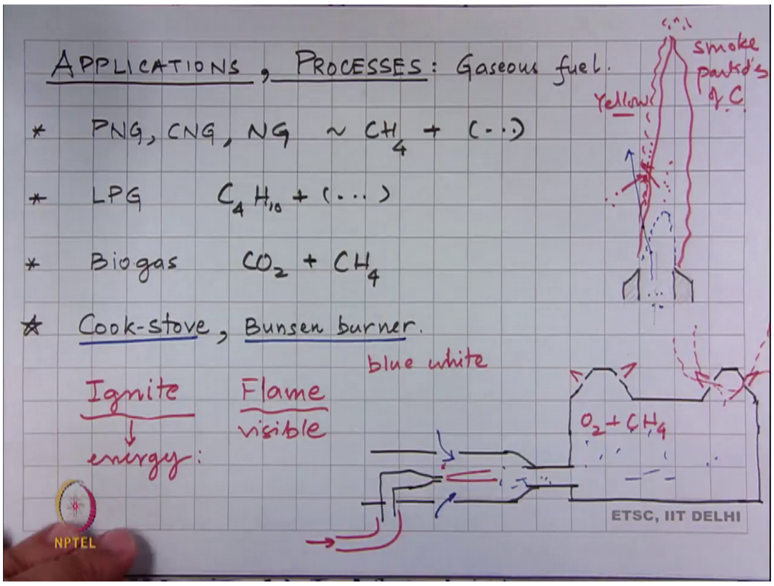

So, what we have? Is some examples here this could be pipe natural gas or compressed natural gas or one can even call this N G which is largely well over 95 percent is methane.

The next other are fuel that we have what is burnt in the web gaseous phase is LPG which predominantly is C 4 H 10, but actually this is both of these they are obtained from crude oil after a bunch of process and so they are never 100 percent pure substances, but they have smaller amounts of many other chemicals with them. For our purpose we will just say this is methane and LPG is butane. Then there is biogas which is the gas that you get when you do digestion of waste and this is nothing but 50 percent CO 2 plus 50 percent C H 4. So, it is a very large amount of carbon dioxide unit and the methane that is coming out, this becomes the fuel part of it CO 2 of course, is chemically not participating, but yes in the energy balance it does coming.

So, let us take an example some examples and see what happens. The first example I have cited here is a cook stove or you can even look at the Bunsen burner, where the gas being burnt is either methane or here it could be LPG. So, here is a sketch of what is happening in our domestic LPG stoves; the fuel is injected from here this is the tube into which the fuel comes and it does not matter whether it is LPG or whether it is C H 4. The fuel comes out here with a high velocity, creates a low pressure which in turn sucks in surrounding air; forms a mixture of the fuel and air it comes into this bottom chamber and through small holes in this ring they many of them in a circular manner we see that a flame sits over there.

But remember that if we just put it on and do nothing there is no flame. So, we have a lighter or a matchstick that we put to it and that sets up a flame. So, that is something we did; that by itself the reaction did not start we had to do something to ignite it. Basically ignition means, that you have to give certain energy to initiate the chemical reaction; once the reactions stabilizes it is self sustaining then you do not need to give ignition again and again.

And it is an issue in terms of safety also that if we try to ignite it and it does not ignite, and the gas still continues to flow; gas air mixture continues to flow, then you could have a potentially dangerous situation, where if at some point there is a ignition taking place you could have this whole thing burning very fast causing an explosion. So, what is happening here is that this mixture went in and if there was no flame there this mixture would have just gone out and flown out like that. In the particular case methane is lighter than air it goes up if it were LPG it would slowly start coming and settling down towards the floor its heavier than air.

Now, that there is a flame the same thing is happening, that the reactants are going in they go through the flame and they come out. So, what you have is a thing which is called the flame, which is that part of the domain where the chemical reactions are taking place that is what the part. And usually we associate that with the visual visible part of it, is a visible flame and then there is an invisible part of the flame; visible flame is where you get light which is where the chemical reaction is taking place.

So, this is what is happening and what we see typically in this case, is mostly you get a blue and whitish type of a flame, and when we put vessels on it we do not see any deposit happening; that means, there was no smoke being produced which smoke is nothing, but carbon particles. So, if the holes are open this is what will happen, but if somehow this holes get clogged or completely shut, air is not coming in then it comes in then you start seeing yellowish colours coming in. And this is something we can do in the Bunsen burner where at the base of the burner there is an opening and that opening is if the opening is open, air is coming in you have a me what you are coming into this is methane plus air which is got the oxygen.

And so it forms a small flame bluish white in colour and that is where the combustion is taking place these gases come get go through this in the process the temperature of this gas goes up its composition changes, and that is where the energy came from the release. Now, if the air port were to be closed, something else happens you would have seen that this flame becomes very big, it becomes much bigger and it is changes its colour from a small bluish white flame to becoming a yellowish flame and you can see at the top smoke that is coming out which is particles of various carbon.

So, here we have come across two new things; one when it was a small flame here and here which was bluish, white this was produced when oxygen and the fuel they were together, this is called a pre mixed flame. And the second case when only the fuel came then it because there was inside there is all fuels no air outside it is all air no fuel no reactions take place there, it forms region there, where mixing was taking place and because of that there is a chemical reaction taking place over there it forms a yellowish flame and. So, here air has to diffuse into the fuel or the fuel has to diffuse into air and this is what is called diffusion thing.

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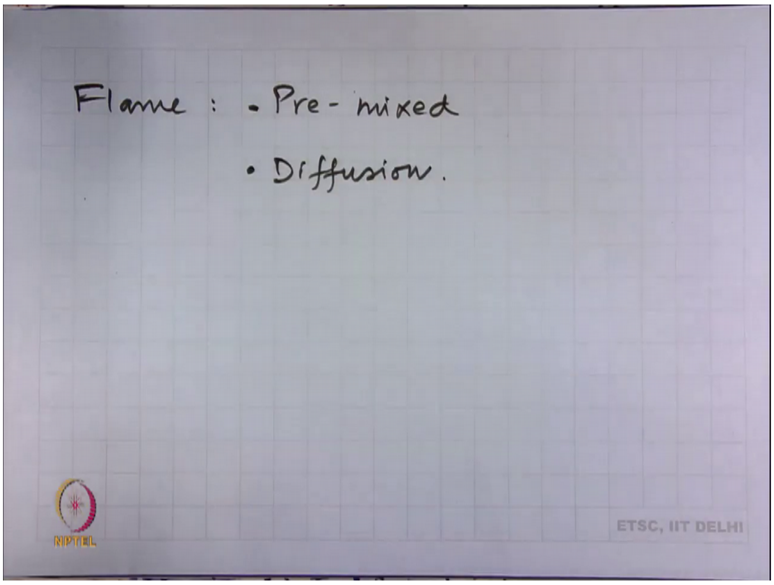

So, we have introduced two new things, but one what is the type of the flame? What is called pre mixed and the other one is a diffusion flame. So, this is one important thing that has come out. Now let us see some other ways in which we can burn a gaseous fuel. So, what happens in a furnace or in an oven?

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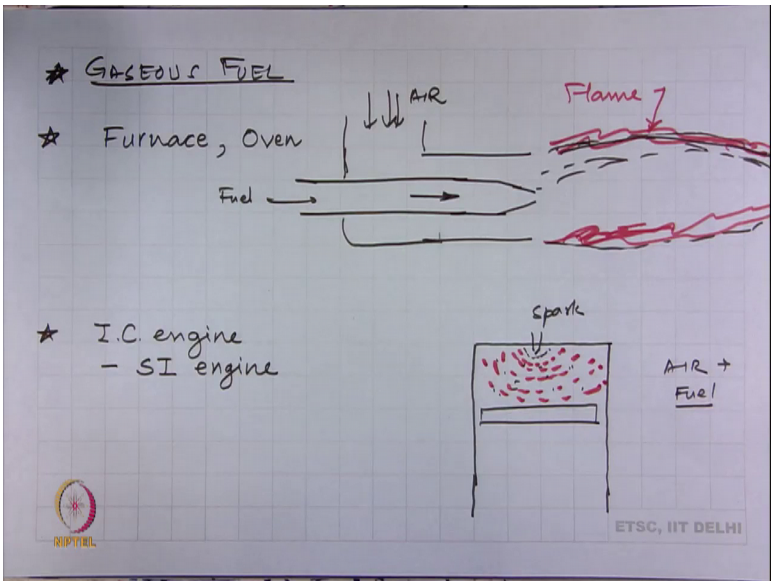

So, what one does there is that we have a supply of the fuel coming in, which is say this pipe and separately they run the supply of air; and this is the fuel and this is a steady process we are continuously throwing into it and what happens is this whole thing mixes and it ends up forming a flame.

So, what we have done is that we have mixed it, try to get as good a mixing as possible and produce pre mixed flame or else you will end up having producing a diffusion flame. A third application is the internal combustion engine, particularly a spark ignition engine where what we have done is say the piston is at the end of the compression stroke, inside this what we have is a mixture of air plus the fuel is in gas or vapours phase. And then with a spark plug we do the ignition and what we have is combustion taking place.

So, what it does is that, because we release the energy here the reaction first starts here and then it produces more energy this causes the reaction to now be there and this keeps going forward. And you have a situation, where the flame is moving forward behind the flame are the products ahead of the flame are the reactants. So, that is what happens you know in a spark ignition engine.

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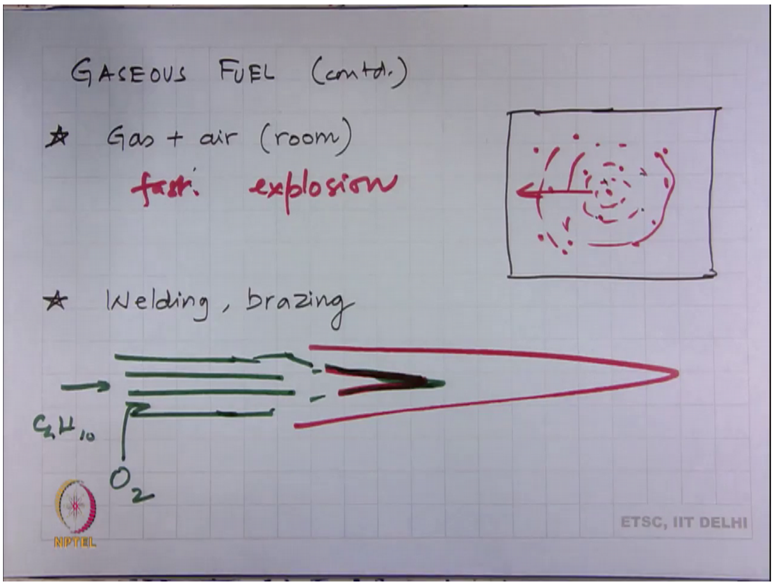

What could either be other possibilities of burning it; and one is that if we have a room in which say the gas has been leaking for some time and there was air. And at this point there is an ignition source here then again the same thing happens what you saw happening with the engine, where this part took place immediately the flame spreads like this, the rate at which this flame goes is very fast and what you have is an explosion.

So, this was uncontrolled explosion, which we did not want that is why we call it uncontrolled. In spark ignition engine we were controlling that explosion and in the other cases like a LPG burner we do not want an explosion. Another example is a welding and brazing where what one does is that we have the same idea, that you have gas fuel coming in which is typically C 4 H 10.

And around that we are putting in typically pure oxygen and then we produce various types of flames, that you could have seen in your workshops, that you could have a small flame and oxidizing flame, a reducing flame, a big flame all these are possible by adjusting the ratio of these two. The important thing here to note is that oxidizer is pure oxygen and so this flame is much hotter. So, qualitatively we say that if O 2 was there we got a hotter flame air is there we did not get; so, hotter flame why we will look at in this course.

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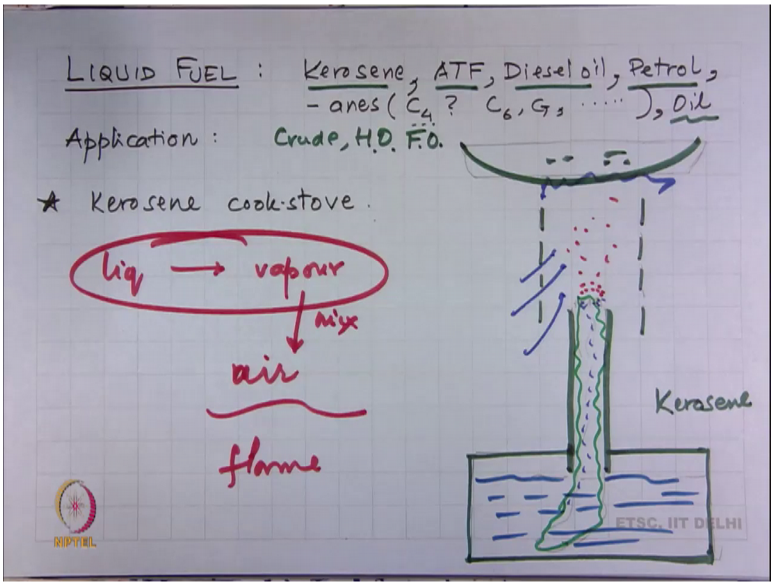

Now, let us look at liquid fuels. And what we mean by liquid fuels? With the whole variety of things look like kerosene, then ATF aviation turbine fuel which is the fuel that is used in aircraft engines, whether it is civilian or military does not matter. Then there is various grades of diesel oil, high speed diesel like diesel oil like that and then we have petrol and we can even say that there is crude oil or heavy oil or it is also called fuel oil or furnace oil which is a pretty much like crude oil but slightly cleaner.

And most of and then there could be other types of oils, including say things like vegetable oils. We can approximate these by much heavier hydrocarbons typically starting with C 4, say butane then there could be hexane, heptanes octane’s, decane and dodecane and heavier and heavier hydrocarbons. So, these hydrocarbons are the ones that exist in the liquid phase, in the ambient pressure and temperature conditions.

So, there are many applications where this is used and we start by looking at the kerosene cook-stove. So, what happens in this? Is there is the wick type of kerosene cook stove; there is the tube which carries in it a wick, which is dipped at the bottom in a kerosene tank. So, we have here at the bottom you have a kerosene tank, in which the fuel is put there. So, the fuel is here the wick is nothing but a sort of a fabric artificial or manmade; which is porous.

And because of that this fuel is sucked up by capillary action into this; and if you do nothing then this kerosene will keep evaporating from there and nothing will happen. But if we light it up with a matchstick and the construction of the stove is such that outside there is a cage, through which air can come in, then at the top one can see a nice stable flame being produced by this. And if this is clean and lot of air is coming in, these three pretty much a blue flame that is produced by this type of a wick stove. And on top of that we put all our pans and parts and that is where the cooking takes place.

So, what is happening here? Is that we got the liquid coming up and then at the tip of the wick this thing kept getting energy from the flame which was already there it vaporized. So, the liquid fuel first became a vapour, this vapour then mixed with air; and then we had the flame being produced. To the additional thing that has happened in the case of a liquid fuel is this part of the process the liquid becoming a vapour. So, that is what is the basic idea; so this is what is the kerosene type of the kerosene cook stoves. Now let us look at something else which is an oil lamp.

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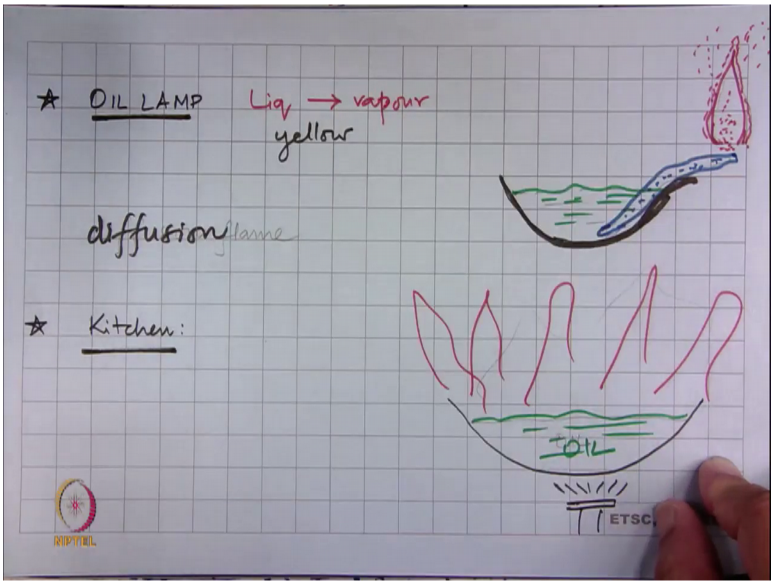

So, what you have done is, we are taking a small pool of oil and this is where we can say that this oil, and with the same thing like the kerosene stove and what we put there was a wick. So, this is the wick sitting here, this could be made of cotton or something else again this is there because it is porous.

This gets soaked with oil, oil comes up to here then we put a match stick to it ignite it and then what we see happening is you see a flame coming there. Same thing happened this oil vaporized came here and by boil see because it was hot it started rising and because then we have put a flame to it started mixing with air. So, there is a zone in which it mixed and then, somewhere in that zone the chemical reaction started it burnt and the products kept leaving the flame.

So, the same idea is coming up here that first the liquid became a vapour, but the difference from the earlier application was that this vapour came only at one point and the only way it could get air was by mixing with the ambient air by diffusion. And so when this thing particularly it burns you always end up seeing a yellow flame; and the yellow flame is because the combustion has got the oil, it is not going to the full extent like we did earlier. It is formed some very small soot particles which became hot and because of that it was emitting a colour which is radiation the both infrared and visible where there will be lot of yellow wavelengths in it.

So, that is why this flames which is the diffusion flames, whether it was gas or with oil these are yellow flames. So, this is the idea that we saw is diffusion flame. So, that was the oil lamp and then, something that we often see happening as a mishap in the kitchen that if you are doing some deep frying and you put all the oil into a pan or a [FL]; and you are heating it. And if by chance, it allow it is get allowed to be very hot and the flame is also very big around it then, there could be a possibility that this oil itself will catch fire.

So, what is happening here? Again is that oil is vaporizing mixing with the air and burning and because this is too big. It cannot have a stable small flame like this it burns in many places at different times, because very time dependent and a transient type of a flame. So, there is something we do not want to do and as the safety things this the last thing that you want to do on this is throw water on it. Water is will come on this it is heavier than oil it will go down, it gets hot oils are well over 100 degrees Celsius, the oil will be the water will become a vapour. The expansion of thousand times in volume it will splash this oil out of this and come on to your hands. So, never throw water on an oil fire.

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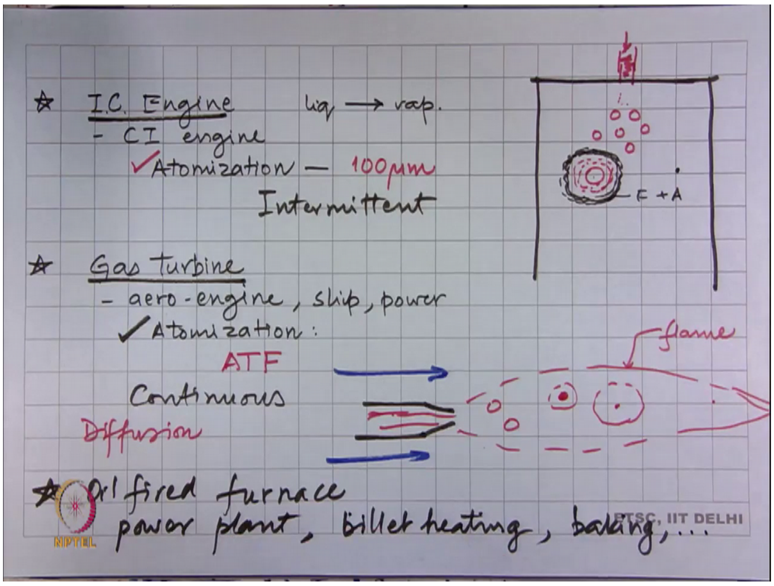

Now let us see what happens, another important application of liquid fuel combustion. This is the internal combustion engine which is a compression ignition change in type. So, what is happening here? Is that we have the cylinder and at some point we started injecting the fuel. So, when you say that injecting a fuel basically what we are saying is that we have a small opening in, which there is the liquid fuel which we are injecting at a very high pressure; and because of that when it comes out after a while it becomes a mist of droplets of the fuel. So, this is atomization and typical diameters of this in engine says like 100 micrometers; so you are looking at that fine a mist of fuel.

Now, what happens is how does it burn? So, what is happening is that, these fuel drops will come out this surrounded by hot air, because it got compressed this fuel will keep vaporizing and form a cloud of vapour around the drop; this will keep moving into the air and at some point you will start seeing mixing taking place, and we start seeing a mixture a zone where you have a mixture of fuel plus air. And it is in this thing that because the high temperature it will ignite itself, and it will end up forming a flame, which is sitting somewhere around this drop. With that heat coming back to the drop will keep on evaporating this flame will be there it will gradually change its shape. And finally, when all the fuel is consumed it will form some little particle of impurities or some charge at the end and the flame will die out.

So, each drop goes through this, and there are millions and millions of these drops every time it does it and that is how it is burning, but the point is that here also first it was the liquid fuel which became a vapour which mixed with the air and then burning took place, but the way it is burning is very different. So, this is a very simple idealization of how a single drop of a liquid fuel when atomized how it will burn. Another important application of where combustion takes place is a gas turbine, aircraft engines not just for powering aeroplanes, but also for powering ships and for generating electric power.

In all the cases the process is the same that you atomize it, but the difference is that in an engine you inject it and then you stop and then nothing is there; and then again the next cycle again you inject it and then it stops. So, this is an intermittent process whereas, in gas turbines this is continuous. So, you have a injector through which the fuel is coming out, the liquid fuel is there aviation turbine fuel which is typically that is what it is called, it is some sort of a very light version of kerosene; it comes out the drops come out here they gradually go out and become small and they have a vapour cloud around them.

And then they become smaller and the vapour cloud is burning away and at some point the combustion is complete and because of the fact that it is a diffusion flame. These flames will be yellowish and overall all the millions of drops which are doing this will give the appearance of a space which is called the flame; this is a continuous process. So, you are continuously injecting this and also continuously supplying air and to the flame is produced over there.

So, that is the difference between the droplet mode of combustion in an internal combustion engine and in an aircraft engine. Or for that matter the same thing also happens in any industrial application where oil is being burned. So, you could have an oil fired furnace, this could be a power plant which is normally burns coal, but at low loads it also burns oil or for the ignition you use oil or it could be a billet heating furnace; which is used for heating metal before you do forging or it could be that you are firing base for baking and many other applications.

So, the main idea was that in a liquid fuel you first have to vaporize it, mix it with air and only then it will burn, but the reaction that we wrote in the beginning it did not tell whether it was solid or liquid or vapour we just said you know it happens. And now we are seeing much more complicated than that.

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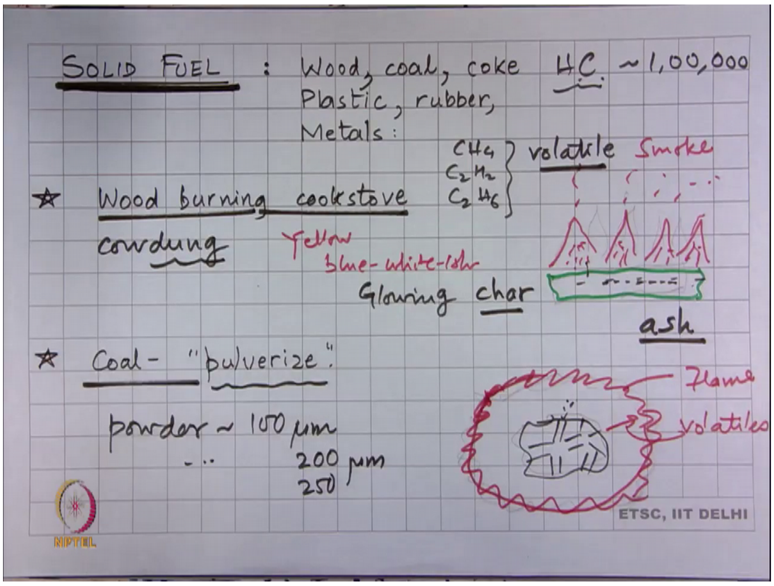

The third type of fuel we are going to be looking at is solid fuel. And this is examples of this is wood, coal, coke or a plastic rubber and even metals.

So, we take the example of the wood burning stove. So, we took the example of the gas burning stove which is used by about 15 percent of the households in our country, then we looked at the kerosene stove which is after about 30-50 percent of the households used kerosene for cooking. And then the remaining large section of households still use wood or maybe cow dung or just dung cakes.

So, what is happening here is that you have fuel say a wood which is cut into a piece. And we know that if we try to put a matchstick to it does not burn, if it is a very very thin piece of wood then yes it might catch fire, but it will not sustain it will die very quickly, but then when you make it big it needs a lot more heating before it catches fire. And once it catches fire what we are seeing is going to happen is we start seeing flame, that are sitting on top of it and you can clearly see that there is the distance between the two and that this is the fuel vapours coming out and then, they mix with air and from this flame.

So, this is a very mixed type of a thing, largely a yellow type of a flame, but in some places it could even be blue whitish and there will be a lot of smoke. Basically saying that your burning process was not very good in the sense that everything did not become carbon dioxide and H 2 O, but became something else. So, what is happening is that we needed to give a lot of energy to the wood before it could start burning.

But what that energy was doing was it was heating up the wood and wood or for that matter coal everything is now we are looking at very heavy and big hydrocarbons. Gas was like methane or ethane very light very small hydrocarbon molecular weight wise. Then we looked at liquid fuels which was C 4, C 8, C 10, C 15 type of things. And now we are looking at hydrocarbons which are much bigger whose molecular weight could reach something like 100000.

So, a very long complicated hydrocarbon which do not have a fixed formula and so it is very difficult to write what chemical reaction is taking place. But heating this hydrocarbon what it does? It breaks it up and it first releases some very lighter fractions of the hydrocarbons. So, there might be C 4, C 2, H 2 may be C 2, H 6 this type of things will come out after breaking this molecule and they are the ones which are burning. Then finally, when all of this is burnt out you can see that this flame is gone.

But this then it is glowing, which means that now all the lighter hydrocarbons have been knocked out their heavier hydrocarbons which are there which cannot be converted into vapour phase. They just sit there and they wait for air molecules to come to them knock it out and then there is a reaction taking place. So, this is what it gives out is what is called volatiles and what is finally, left behind and burning is called char burning and finally, what is left behind after everything has been burnt which cannot be burnt anymore, we just call it ash which is nothing but various types of mineral matter which is there in the solid.

So, the whole process is now lot more complicated and to get stable combustion we needed to give a lot more energy to this and this is what makes its burning very very difficult. Same thing happens with coal and then in the power station or in industrial scale to make it burn we do something else. So, that it burns and burns faster which is that we pulverize it; that means, we make coal powder again of the order of means size of 100 microns ranging from very small to maybe 200 to 250 micron particles.

So, the mixture of particles of different sizes, this is fired into the furnace and what each particle does? Is that you have a particles there coal is not solid or homogeneous it has got lots of passages in it and the heating that it takes place again, it releases volatiles they come out they form a mixture around the coal particle and this is where then finally, you get a flame and until all the volatile.

So, what is burning out? Now are the volatiles and after all the volatiles are gone this flame will disappear the charge will sit back and this is heavier hydrocarbons and carbon then they will keep burning. So, it is got more complicated to make solid fuels burn. So, now, let us summarize and say well what have we learnt in all of these things.

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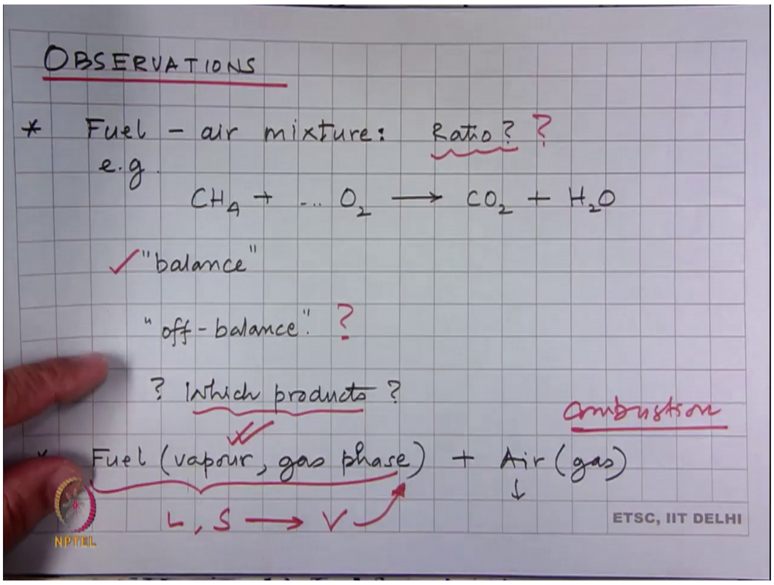

So if what or the observation? That first we need a fuel and air; but we have not yet answered the question; in what ratio if it goes completely from this to this. So, for example, you say that we have a balanced reaction, if it is not then what? Practically this also happens and so then we say in both cases you know which are the products that will be there, the next thing and the most important thing we saw just now is that all chemical reactions are combustion takes place in the fuel in the vapour phase.

So, all combustion is that the fuel first has to come into the vapour or the gas phase mixed with air and then burn or burn while mixing both are possible. So, but this is important whether it is a liquid or a solid first we have to convert it to a vapour, then only we can look at the combustion process.

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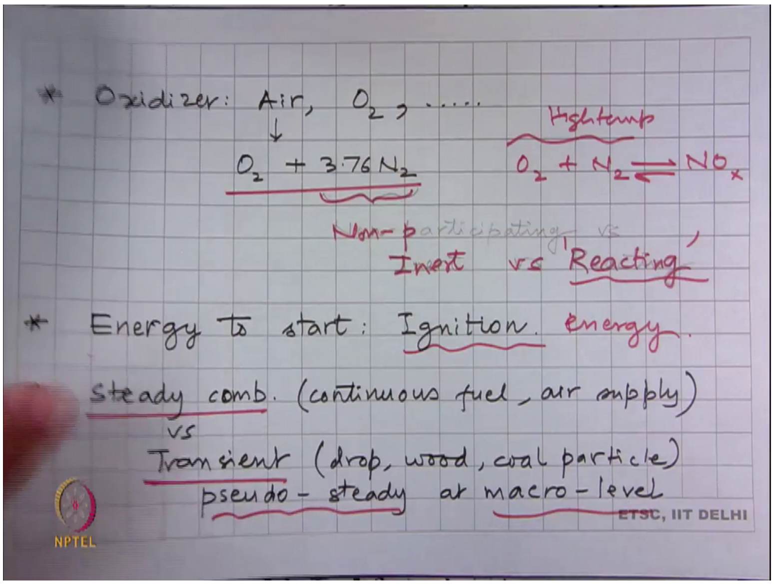

Then we saw what are the oxidizer, it is air which is O 2 plus 3.76 N 2; N 2 as we have said this is not participating or you can say that this is some inert, but at certain temperatures to certain extent it will also participate in a chemical reaction need not necessarily be a exothermic reaction or the one that we are actually looking for, why? Because, if you have this thing burning a mixture of O 2 and N 2 and this is at a high temperature then, the reactions will start and we will start getting various forms of nitrous oxides.

So, although we will not look at this aspect in this course; in fact, is that this is a reason for the pollution that and all these combustion process will throughout. We then saw that to start any of these in all these cases we needed ignition which is a certain amount of energy. Gases required less liquid required a little more solid requires lot more energy to start, then we looked at one some applications which where there was a steady combustion like what you saw inside the gas turbine or the furnace all those which were transient, where it would burn. And then, the fuel would disappear then come somewhere else the burning of a drop or the burning of wood and coal. So, this we can then analyse as some sort of a pseudo steady state burning at the macro level.

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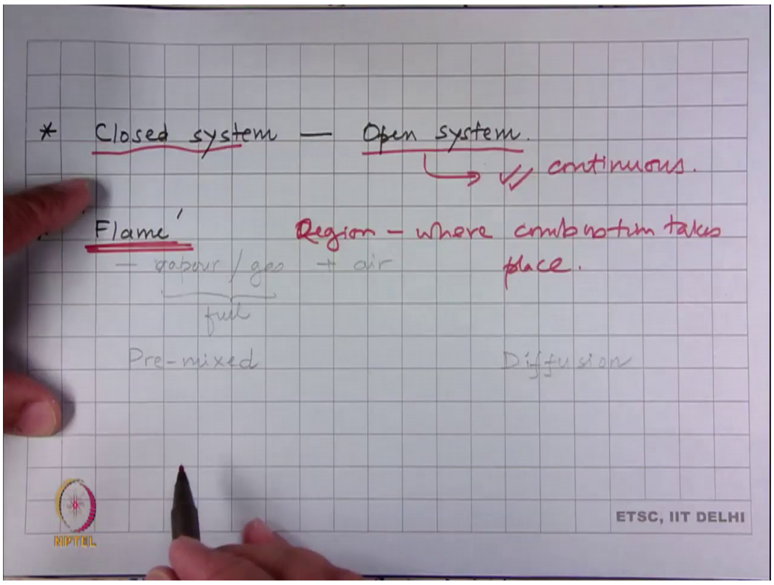

And finally, we also say that well what was the did happen in a closed system and open system in almost all these cases where we needed something to happen continuously we had to have an open system; so this is gives us a continuous output. And then we came across the idea that there is something called a flame which is a region where the chemical reaction happens, where the combustion takes place.

So, this is what we will now look at, the thermodynamics is now coming to the point where this is important to us; we are going to ignore all the other aspects that we came across in all these applications. There is fluid mechanics issues, there are heat transfer related issues that we will not worry about, we are only going to say we will look at the flame see what is happening in the flame and try to get some answers to that. So, in the next lecture we will go back and look at the flame in detail and try to make a simple model to achieve our objective. So, with that we will conclude this lecture.

Thank you.