Fundamentals of Combustion

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Lecture – 02
Fuel and Their Properties – Part 2 Gaseous and Liquid Fuels

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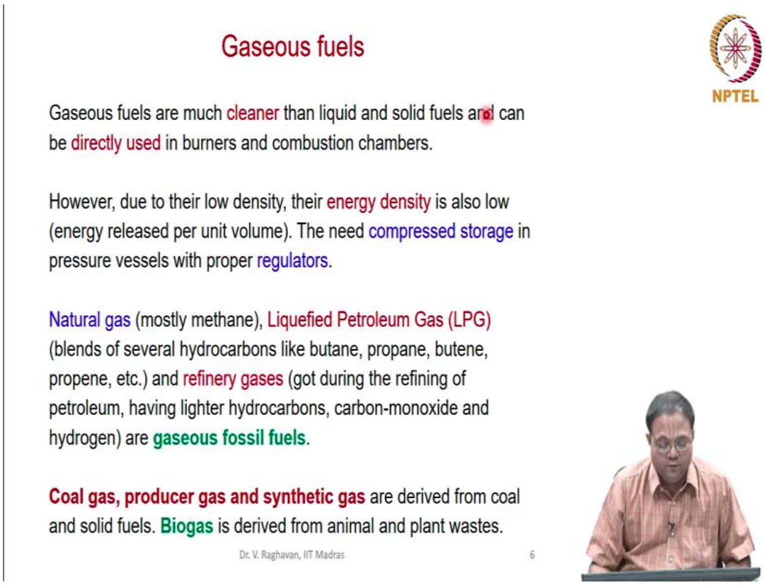

Let us see the characteristics of fuels, starting from gaseous fuels. Gaseous fuels can be classified as a cleaner fuel than when you compare that with the liquid or solid fuels. This is because, gaseous fuels are lighter and they can be stored in a compressed form. And when you use this, we can just pass it on through some moisture trapper or some filters and we can just directly feed into the combustion chamber. There is no preprocessing or anything required in this. Gaseous fuels are much cleaner than liquid and solid fuels and can be directly used in burners in the combustion chambers. When you say liquid fuel, liquid fuel has to be vaporized and the vapors have to be supplied or maybe you have to atomize it and the droplets should be send to the combustion chamber and so on. Those preprocessing are not required for the gaseous fuels. In that way, the usage of gaseous fuels is much easier when compared to the condensed fuels. On the other hand, if you take gaseous fuels, they have low density. That low density causes storage issue; see for example, if you want to store required amount of gaseous fuel, we have to compress this and store in pressure vessels.

For these pressure vessels proper design has to be done and proper regulators have to be used; to control the flow from the pressure vessels to the combustion chamber.

So, valves, regulators etcetera are required. It should be maintained leak proof and other design parameters have to be considered for that. On one hand, it can be directly used in combustion chamber; on the other hand, the energy density is much lower. So, it can be easily used only for the stationary applications not in mobile applications. That is one of the points we should keep in mind.

The fuels are classified into fossil fuels which are naturally occurring and manmade fuels, synthetic fuels. And when you see gaseous fuels, the commonly got gaseous fossil fuels are natural gas, which contains mostly methane, CH_4, and liquefied petroleum gas, LPG. It has several hydrocarbons in it starting from butane, propane, butene; straight chain and cyclic hydrocarbons to some extent, then saturated and unsaturated hydrocarbons and so on.

These are much heavier than air. When compared to natural gas which is methane (methane is lighter than air), we also get some refinery gases when you refine the crude oil. Those mainly contain carbon monoxide and hydrogen and they are used within the refinery itself for heating purposes.

Natural gas and LPG, the Liquefied Petroleum Gas are commercially given for the vendors, and LPG you know that, it is used for domestic cooking purposes. When you come to say synthetic gases, synthetic gases are manmade. We also use coal or solid fuels like sugarcane bagasse, rice straw, wheat brown, wheat straw, and you make gaseous products from that. What you do is, you partially burn them, so that in the rich mode of partial combustion, called gasification; you get fuel gases like CO and H_2. They are called synthetic gases. So, coal gas, producer gas and synthetic gas are formed from reactors which are designed to produce such gases. Some composition difference will be there in the produced gases.

There are common feed solid fuels like coal and biomass. On the other hand, we have gaseous fuels like biogas, derived from animal and plant wastes; like cow dung, vegetable wastes and other plant wastes.

When we ferment this under some conditions, we get biogas. These are manmade things. You can see that the solid fuels are used primarily to generate these gases, synthetic gas or biogas; you can take a solid fuel like coal or biomass and do this.

Now, why we do this? because to burn coal or biomass completely, lot of challenges are present. It is easy to convert into gases and use these gases in the combustion chambers; because you can see that gaseous fuels can be directly used in the combustion chambers.

So, due to that, producing gases will be advantageous for us; In gas turbines, engines and so on, it is easy to use gaseous fuels. So, just use the solid fuels to create or produce gaseous fuels like synthetic gas or use animal and plant wastes to produce biogas and use it in several applications.

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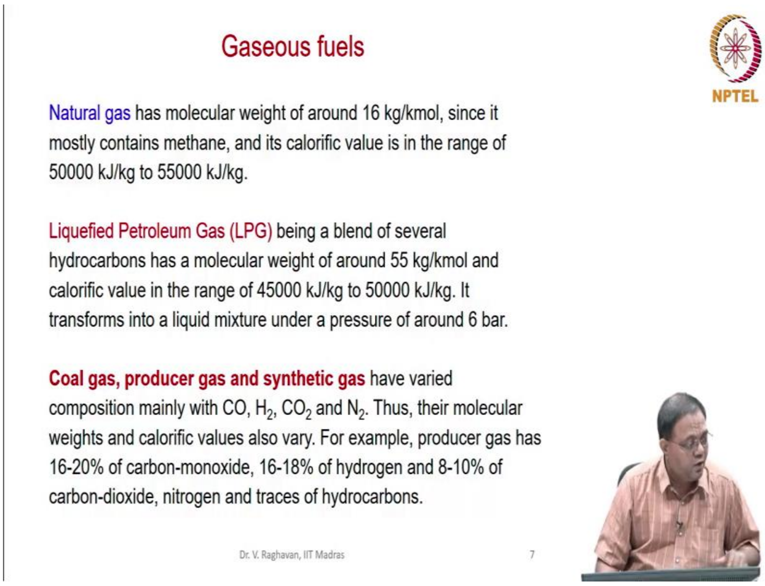

Manmade fuels can be classified like this. Natural gas as I told you it is mostly methane. So, molecular weight will be around 16 kilogram per kilo mole and its calorific value is about 50000 kilo Joule per kg to 55000 kilo Joule per kg. When you compare this with methane, it is about 90 to 95 percent of methane. It is almost the methane's calorific value and it is lighter than air.

The molecular weight of air is 28.8 and here you can see it (natural gas) is 16. So, it is lighter than air. And if you compress this natural gas, you can use it for automobile applications. Compressed Natural Gas (CNG) vehicles are available in India. We can drive vehicles using the CNG.

Petroleum gas, as I told you, several heavier hydrocarbons (C_3's and C_4's) are involved in this. It has a molecular weight of about 55 kilogram per kilo mole, which is much higher than the atmospheric air's molecular weight which is 28.8.

Now, this is heavier and this calorific value is about 45000 kilo Joules per kilogram to 50000 kilo Joules per kilogram, which is comparable to what you get from natural gas, but slightly less than that. When you compress this petroleum gas, which is a mixture of several gases, to a pressure of about 6 bar, you liquefy it. It becomes liquid and now this liquid can be stored in tanks, and a simple regulator can be used to release this; and when the pressure drops to atmospheric pressure, the liquid vaporizes instantaneously to gas. This is one of the advantages. Very low pressures like 6 bar can be used to compress these gases to get liquids and this liquid can be stored.

Again, you can use it for automobile applications also; apart from cooking applications, which is mostly used in India. If you come to the synthetic gases, where you use coal and biomass, gasify that and produce gases. The predominant fuel components in that are CO and H_2. You can see that carbon monoxide and hydrogen are the main fuel components.

But since you are partially burning that, you get CO_2 and nitrogen; because air is supplied as oxidizer you get nitrogen. If you use only oxygen say, pure oxygen or steam as gasifying agent; you will not get nitrogen.

So, that means, when nitrogen fraction decreases; your calorific value will increase. Similarly, if you do not burn it fully; then you will get lower CO_2 and more CO. So, the fraction of the fuel component can be increased by controlling the process; but additional cost is involved in this.

If you want to use pure oxygen then that is going to be costlier than using atmospheric air. But one thing is very clear, we are going to use fuels like say rice straw; then sugarcane bagasse etcetera, which are otherwise not used anywhere. If you use those and produce this; you get benefit of producing some gases, which can be used in several applications.

The only requirement is that you need to design your burners to use these gases and have stable flames out of them. For example, producer gas has 16 to 20 percent of CO and 16 to 18 percent of hydrogen, and 8 to 10 percent of CO_2; but you can see that rest will be mostly nitrogen.

So, that is the main disadvantage, nitrogen is not a fuel; even CO_2 is not a fuel, they are inert and CO_2 can absorb heat, because it is a radiation absorption species. So, it can absorb heat and radiate to the far field; nitrogen and carbon dioxide will take the heat from the flame and calorific value comes down; because of the increased presence of these two species. But as I told, nevertheless you can use this for several applications; because you will get decent calorific value.

We always do not need to use very high calorific value fuels like natural gas or LPG; we can also work with lower calorific value fuels, properly design your combustion chamber for that. You have to supply the fuel at higher rate and try to accomplish stable combustion.

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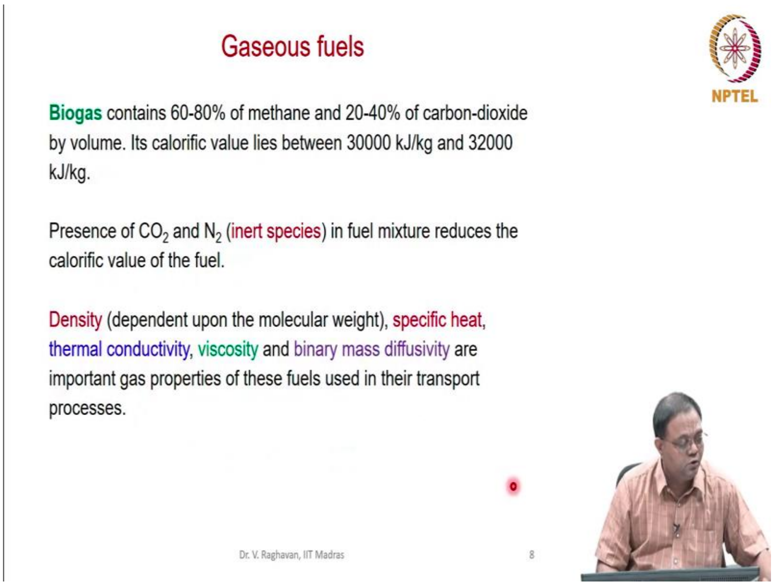

Biogas contains mostly methane, but the inert substance there is carbon dioxide. So, you just ferment the wastes, animal wastes and plant vegetation wastes, you will get biogas, which is a combination of methane and carbon dioxide 60 to 80. So, based upon the process or the source, varying amounts of methane and carbon dioxide are available. The calorific value is about half of what we get from natural gas.

As I told you CO_2 and N_2 are not going to be participating in any combustion reaction. They are inert species that brings down the calorific value and act as thermal sink. They take the thermal energy. Apart from the calorific value of these gases, the other properties which are very important for our analysis are density, which is dependent upon molecular weight, specific heat and thermal conductivity, which are thermal properties, viscosity and density together will be used in momentum conservation. Viscosity and binary mass diffusivity are transport properties. Binary mass diffusivity is used in species mass conservation. So, these are the important properties which are used in analysis of gaseous fuels, apart from the calorific value.

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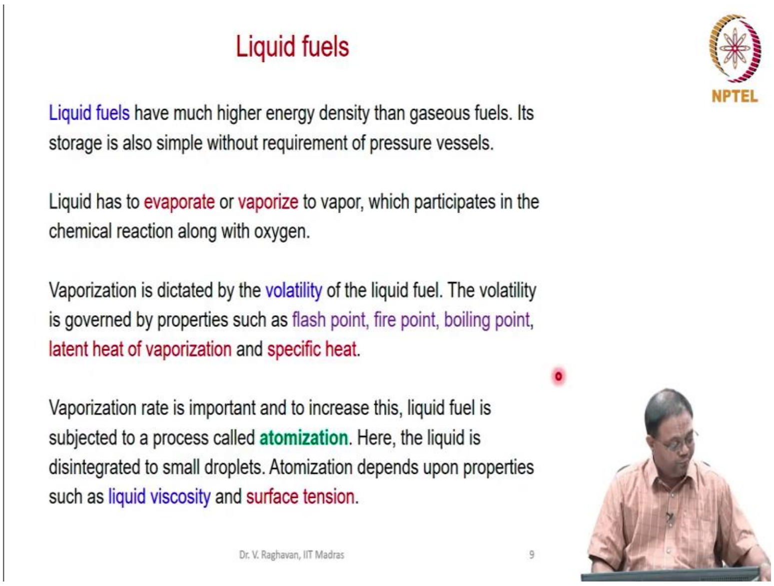

Now, coming to liquid fuels, the advantage of liquid fuels is they are cleaner than solid fuels; I will come to solid fuels, where you will see the heterogeneity there. But liquid fuel is much cleaner, and they have higher energy density. For example, if you take the density of gasoline, it is about 800 kilogram per meter cube. So, you can store more fuel in a smaller volume, when compared to what you store in the same volume with the gaseous fuel.

That is one of the advantages of liquid fuels; but the only thing you have to take care is the flammability of these fuels. So, classify the liquid fuel properly. In some cases, if you just open the lid of the can, the vapors will be automatically generated (e.g. petrol cans). Such fuels are highly volatile. Some fuels will not easily vaporize at all; but some fuels will very easily vaporize.

Now, the disadvantage is, you cannot just use a liquid fuel straight into the combustion chamber. You have to make sure that, you feed the liquid fuel at the same rate as it vaporizes. So, the vaporization rate controls the entire process. So, liquid has to vaporize or evaporate into vapor, and this vapor participates in the predominant gas phase reaction with oxygen in air in the combustion chamber. So, that means, the vaporization rate is very important. In order to understand the vaporization features; you need to understand, what is the volatility of the liquid fuel? how fast or how good the vaporization will be? whether the liquid fuel will vaporize instantaneously or you have to feed more heat to do that and so on.

The volatility is a property which is governed by other properties like flash point, fire point, boiling point, latent heat of vaporization and specific heat. These three temperatures; flash point, fire point, and boiling point indicate how much vapors can evolve from the liquid. Once the liquid starts to burn; predominantly its surface will reach more or less the boiling point.

Boiling point is one of the important temperatures which has to be attained by the liquid. However, liquid will not attain the boiling point, it will be slightly less than that. Latent heat of vaporization is the energy you supply to vaporize the liquid to vapor; specific heat is the heat which you have to supply to heat that liquid from the room temperature to the temperature close to the boiling point. So, these are the three important properties which in combination will define the volatility of the liquid fuel.

These are the three additional properties we need. Flash point and fire point are important in classifying the liquid fuels, as flammable or not. So, we have these additional properties which we do not see in the gaseous fuel. These are additional properties which we have to characterize a liquid fuel.

Now, vaporization is a surface phenomenon. So, from the liquid surface, vapors evolve. On the other hand, when you say boiling, that is a volumetric phenomenon. Vaporization rate depends upon the surface area available. So, what you do to increase the surface area? You have to atomizes the liquid fuel and disintegrate into droplets of several size, size ranges.

Atomization is disintegrating the liquid into several droplets. It depends upon two more properties, liquid viscosity and surface tension. In a combustion chamber, where you spray or inject the liquid into a spray of droplets; you have to use an atomizer. These atomization process depends upon these two properties of liquid, viscosity and surface tension.

The vaporization now depends upon all these properties. To classify the fuel; we need fire point and flash point and for volatility you need boiling point, latent heat of vaporization and specific heat. Then for atomization, for example, if you take a very viscous liquid; it is almost impossible for us to atomize that. If you take water like fuel, viscosity of which is equal to water type, then it will much easier to atomize.

So, atomizing a water will be much easier than atomizing an oil, say vegetable oil and so on. So, these are the additional properties which we need in our analysis, when a liquid fuel is involved.

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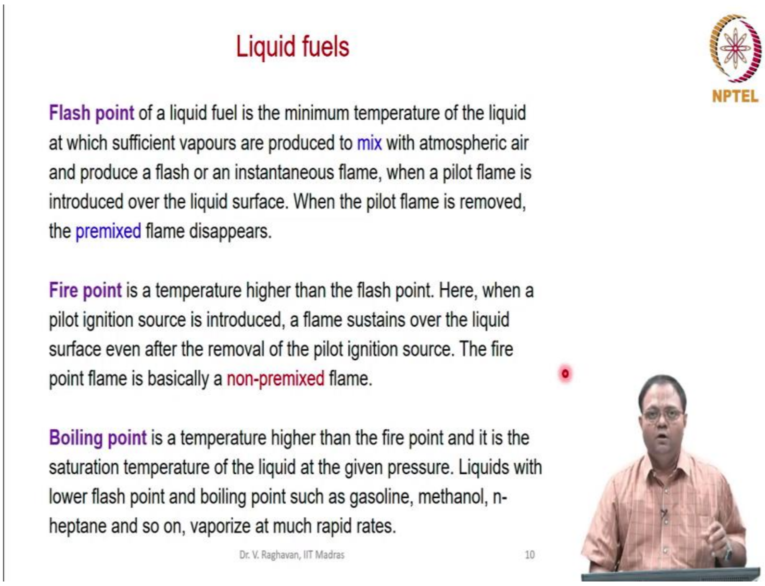

Flash point is the minimum temperature of the liquid fuel at which sufficient vapors evolve from the surface of the fuel. Careful experiments are conducted for this; we take the fuel in a brass crucible and try to heat it slowly, gradually and stir it, so that the entire liquid is at a uniform temperature and we also monitor the temperature.

Now, if you often bring in an ignition source towards its surface, at a particular temperature you will see a flash or flame formed and it will disappear. When the liquid has reached a particular temperature, which is equal to flash point; sufficient amount of vapor is generated from the surface and has mixed with the atmospheric air and a cloud of reactant mixture is formed over a surface.

Upon bringing in an ignition source towards that, it instantaneously burns and a flash is produced. This is called flash point. So, you can see that, they have premixed, vapor and air is available and when an ignition source is brought it burns. So, a premixed flame forms and disappears, when you introduce a pilot flame there; but for achieving that the liquid should be at a minimum temperature called flash point.

Fire point is a temperature which is higher than the flash point. Now, you continuously heat it. You are increasing the temperature from the flash point. Now, when you bring in the ignition source towards the surface; you see a flash and when you remove it, the flash disappears. This continues until at a particular temperature of the liquid called fire point; now when you bring in the ignition source towards the surface, you see a flame which is formed over the surface and if you remove the ignition source, the flame does not disappear, it anchors to the surface of the fuel.

So, you can see a flame which is continuously formed over the surface and sustains there and this flame, receives the fuel from the surface and receives air from the ambient and the fuel vapor and ambient air mixes at the flame surface itself. So, this mode of combustion is called non-premixed mode; and that means at the fire point, you see a non-premixed flame.

When you classify a fuel, you can see that flash point and fire point are the important temperatures; if you have a very low flash point, it is dangerous. For example, the flash point of methanol is 11 degree centigrade. Normally the standard atmospheric temperature is 25 degree centigrade; that means, when you just open the lid of the methanol container, you can see vapors evolving from that. They are highly inflammable.

Even in petrol we have the same story; the petrol’s flash point is at sub atmospheric temperature. They are very inflammable liquids. We have to be very careful in handling them. So, to classify that, these two temperatures are very important; lower flash point and fire points are dangerous.

If the flash point and fire points are higher, you have to supply more energy to the liquid to increase it from the atmospheric temperature to flash point; then only the enough vapor will be evolved. So, classification of the liquid fluids can be done based upon these values.

Boiling point is another important temperature which is higher than the flash point. What happens here is, the entire liquid will start to vaporize. Once the liquid temperature reaches the boiling point; then whatever energy comes from the ambient will be used for vaporizing the liquid to vapor. That means, the energy coming in will be used only for latent heat of vaporization.

Boiling point is the saturation temperature at a given pressure. At atmospheric pressure it is called normal boiling point and at other temperatures, as operational pressure increases; the saturation temperature also increases.

So, higher the boiling point, you have to heat it more; that means, it is not going to easily vaporize. You have to first heat it towards the boiling point, so that enough vapors are produced and continuous burning is taking place.