Fundamentals of Aerospace Propulsion

Prof. D. P. Mishra
Department of Aero Space Engineering
Indian Institute of Technology, Kanpur

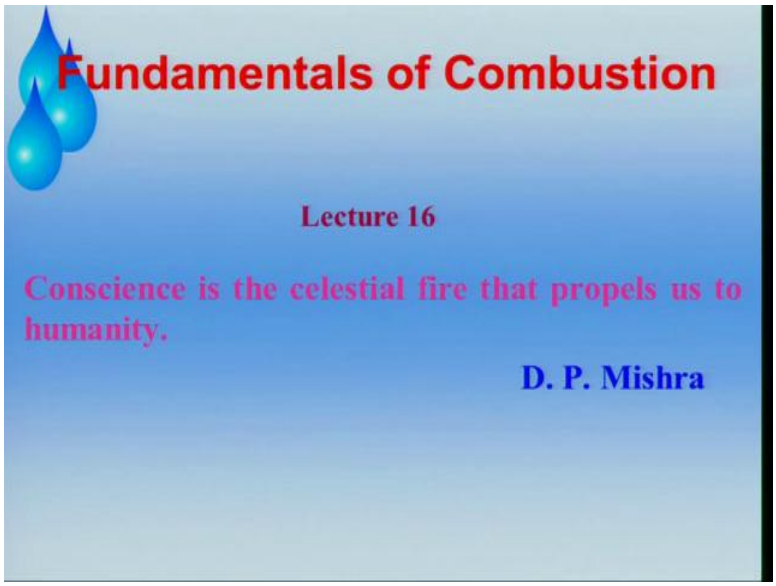
Lecture - 16

In the last 10 or 11 lectures, we have discussed about the fundamentals of compressible flow, which is quite important for analyzing the various aspects in propulsive devices. When I say propulsive devices, it will be the gas turbine engine, the rocket engines or any other internal combustion engines and other things. We need to analyze each component, for that we need to invoke the compressible flow.

We started with the definition of the compressible flow, how it is different from the incompressible flow, then we moved in to the governing equations, like conservation of mass, momentum, energy, and then equation of state. Then, we looked at how to handle the Quasi-one-dimensional flow, and then we derived relations between them, area ratio and Mac number, which can be useful for designing nozzle diffuser and other components as well.

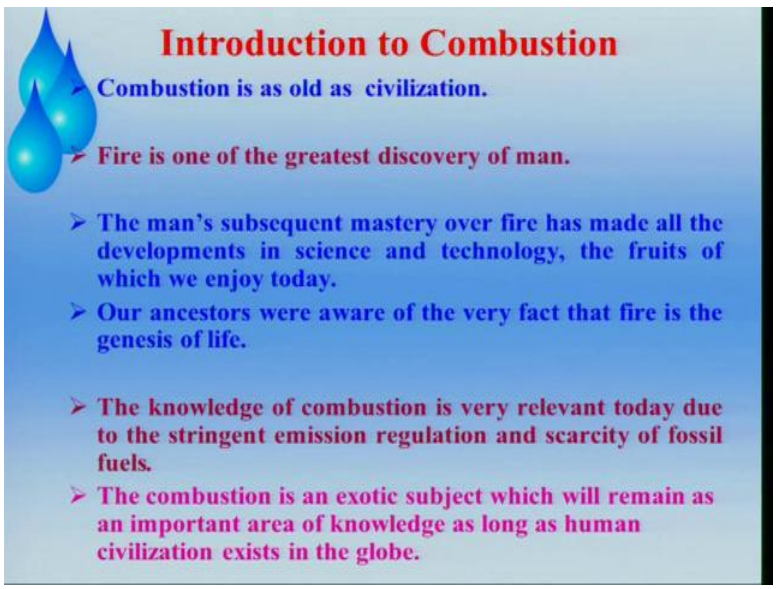
Then, we moved into the normal and oblique shock, and we derived the expressions for various pressure ratio across the shocks, and we learned that how to use those expressions for analyzing the flow with shock. Then we moved into one-dimensional treatments with heat additions, which will be mimicking the combustion process, and how does the properties will be changing with the heat additions. Then we moved into one-dimensional flow with friction, null effect without really invoking the concept of boundary layer. Although this analysis are meant for one-dimensional, similar feature can be for multi dimensional cases, but will be restricting to the one-dimensional flow for design purposes, which is simple and easier to handle.

(Refer Slide Time: 02:42)



Today, we will be looking at the fundamentals of combustion, because the combustion has placed a very important role that most of the power plant for the propulsive devices, relied mostly on the fuel, or the chemical fuels for its energy. As I had discussed in the earlier classes, in the introductory lectures that bearing few devices mostly we used the combustion or the burning of fossil fuels and also the other fuels in rocket engines, like for powering the aircraft or the rocket engines. Therefore, one can say that combustor is the heart of propulsive device. So, it is very important to understand the fundamentals of combustion.

(Refer Slide Time: 03:54)



We will first discuss rudimentary of the combustion. You might be aware that combustion is as old as civilization, and we know historically that man were living earlier in jungles like other animals, and they started discovering fire. Therefore, fire is one of the greatest discovery of the man, they used it, controlled it and they could manage to develop a lot of science and technology that we see. That means man's subsequent mastery over the fire has made, all the developments in science and technology that we enjoy today. However we are enjoying too much and we are also spoiling the Mother Nature to that extent, life survival is at stake at this moment, and that is of course due to the greedy nature of human being.

Of course, our ancestors were aware of the very fact that fire is the genesis of life and they were processing a science and technology which were very benign to the natures at the activities, but today we are at different realm of science and technology. So, it is very important to look at that aspect not only for a propulsive devises, for others as well. You will find that our scriptures are filled with lot of prayers for fire, and also they were knowing how to use that for the sustenance of life human life in the earth, without really spoiling the nature, which is very important.

So, even today the knowledge of combustion is very relevant, because of the scarcity of fossil fuels and also the stringent emission regulations because we are emitting too much of pollutants, particularly from burning of fuels and also from other sources, as I told that the very life on this earth is in trouble at this moment. Therefore, it is very important to understand the combustion aspects more in detail and if want to really understand this combustion we need to go to the fundamentals and talk about it and learn it.

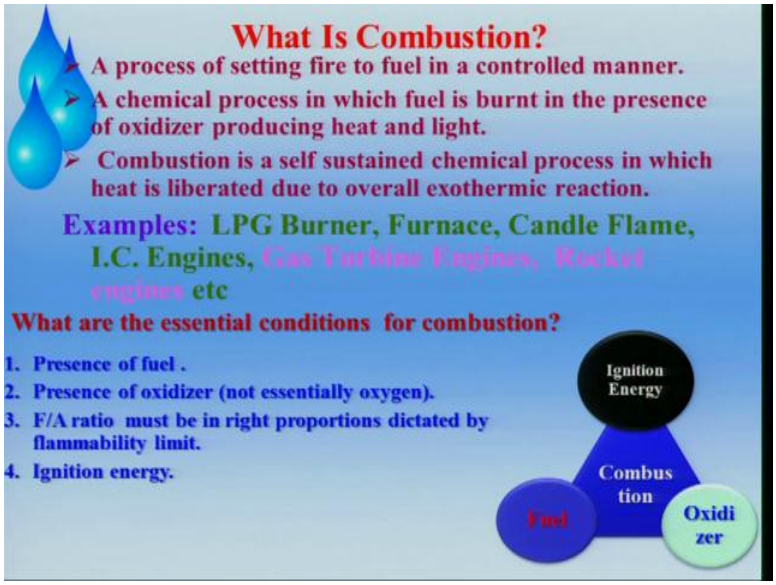
That means, I can conclude, the combustion is an exotic subject which will remain as an important area of knowledge as long as human civilization exists in the globe. Because, the fossil fuel may not be there for, may be another 100 years, however we cannot rely on mute because of greediness of human being, and also it is quite dangerous to handle nuclear power plants and other things. So, we need to go back to nature to pray for, or to ask for the fuel which will be basically biomass and solar and other things. For that combustion is also important and we need to understand that.

Question arises whether we can have some eco-friendly propellant for rocket engines and other things so that we can do that. It is important to look at because we can have that,

but you need to be innovative to do that. So, question arises what do you mean by combustion? Can anybody tell me? Because we use combustion in everyday life. As I told, particularly Indians whenever child will birth, we will burn a lamp, when man will die we incinerate it. We will use the combustion from the birth till the end. Combustion is the part and parcel of human life at least in India, at this moment even earlier days.

So, what do you mean by combustion? You may talk like that, but what do you mean for a layman? It is like setting a fire to a fuel. Is it good enough say that combustion is nothing but setting of fire to a fuel? Certainly no. That means, what is happening when I say fuel? There will be oxidizer. Question arises, what do you mean by fuel and what do you mean by oxidizers?

(Refer Slide Time: 09:08)



When fuel and oxidizer are reacting, then naturally there will be some kind of heat and light being produced. Of course, light need not to be produced all the time, but heat must be produced. Whenever heat is being produced during these chemical reactions, then we call it as exothermic reactions. Is it all the reactions whatever taking place during a combustion will be exothermic? Certainly no, but overall effect will be the exothermic. Therefore, we call combustion as a self sustained chemical process involving several reactions during which heat is a liberated due to overall exothermic chemical reactions.

So, there are several examples of this combustion devises starting from the LPG burners what we use in our home for cooking food, furnace, candle flame, internal combustion

engines, gas turbine engines, rocket engine so an so. There are several applications, as we go long I will talk about it, but we will be restricting our discussion in this course to the gas turbine engines and rocket engines only. However, I will try to give overall pictures about the scope or the magnanimity of the combustion so far application is concerned.

Now, question arises what are the essential conditions for combustion to take place? There will be fuel, there will be oxidizer, and when the fuel and oxidizer are there, they must be mixed somehow. For example, if take this room and it is always having some air. Air means it will be containing oxygen, but if suppose I am having a gas, let us say LPG gas, as you know LPG gas we use for cooking or in a burner.

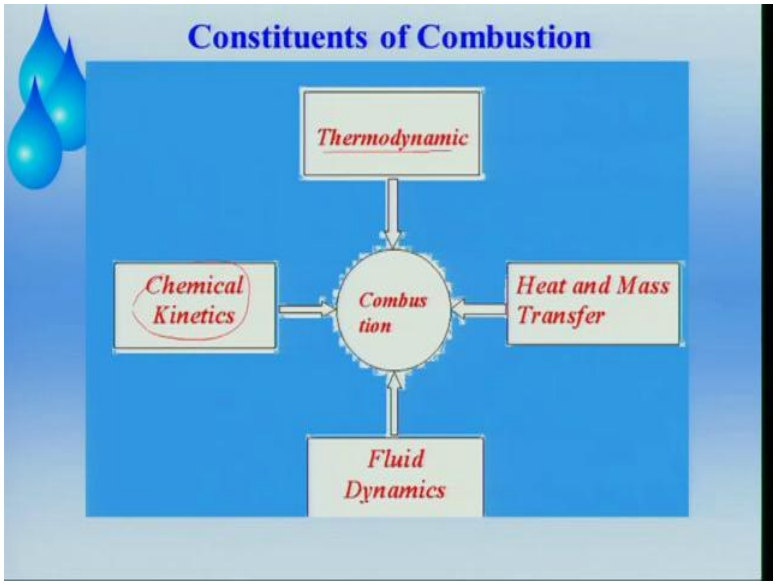
If I just allow the LPG gas to be there in this room and mixed, then is it combustion take place? It will not. That means you need igniting, but even if I am igniting it, ignite means basically initiating it, then is it possible it will ignite? And make it self-sustained because as we have looked that combustion is basically self sustained chemical reactions which must be exothermic in nature overall. It cannot be self-sustained unless it is exothermic, because where heat will come to make itself sustained.

It must be in the right fuel air ratios. To summarize, there must be fuel, and oxidizers must be the there, need not to be only the oxygen, oxidizer can be any other things. And the fuel air ratio must be in the right proportion dictated by flammability limit. What do you mean by this flammability limit? As I go along I will be talking about, but we would not be getting into it. What will be the amount of ignition energy? All those things we need to look. If I want to look at the combustion, we should have a fuel, oxidizer and ignition energy.

I always feel that this combustion is similar to human life. How it is? You people can think out. Can anybody tell me, how I can take a similitude from life. For example, a person has taken bath that means, it is started life and then it will continue till death. Similarly, if you are having a fuel it has to be burned till the fuel is exhausted out. Yes or no? If you do not have a surrounding, can you sustain? Suppose, you do not have food how will do? And you need to have initiated to the life, and your father mothers are initiators, even society help you to learn the things. Therefore, one can think about

combustion is nothing but part and parcel of life. Therefore, our ancestors were always appreciating the fire energy, which is comes from everywhere.

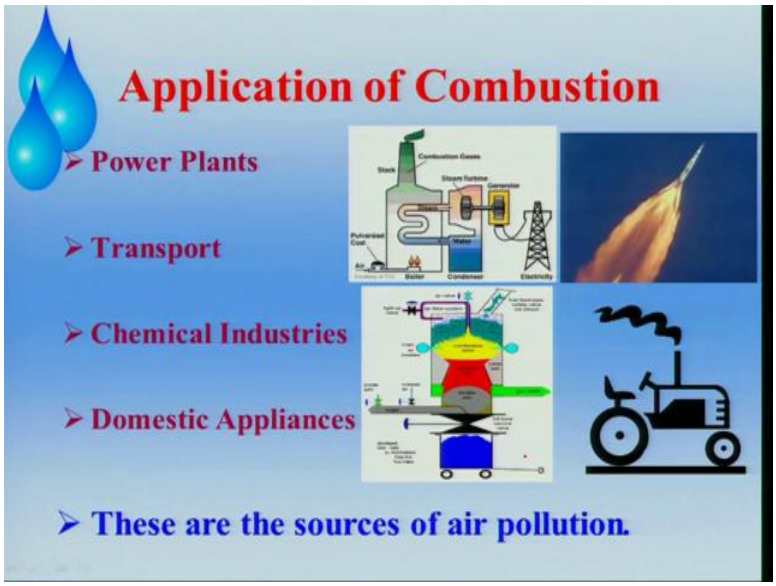
(Refer Slide Time: 14:34)



We will look at what are the constituents of combustion that means, what are the subjects you need to have command over the combustion paths. That means, you need to learn about thermodynamics. This is the thermodynamics and we need to know the chemical kinetics because it is involving chemistry. Also you need to look at the heat and mass transfer, because without heat being transferred you cannot have combustion, mass has to move and mix together. So, you need to have heat and mast transfer, and also the fluid dynamics, each we have already discussed extensively.

Therefore, combustion is basically a multidisciplinary subject. To get a command over combustion, you need to learn other subject very well, and have to devote a lot of time, then only you can be a master in combustion, otherwise no. It is multidisciplinary and engineering is basically multidisciplinary as well. Therefore, it is important to be look at combustion and as told, it is the power house of any vehicle like aircraft or the rocket that means, combustor is the heart of the engine, engine is the heart of the vehicle. So, you can say that, it is the heart of the heart of the vehicle.

(Refer Slide Time: 16:43)

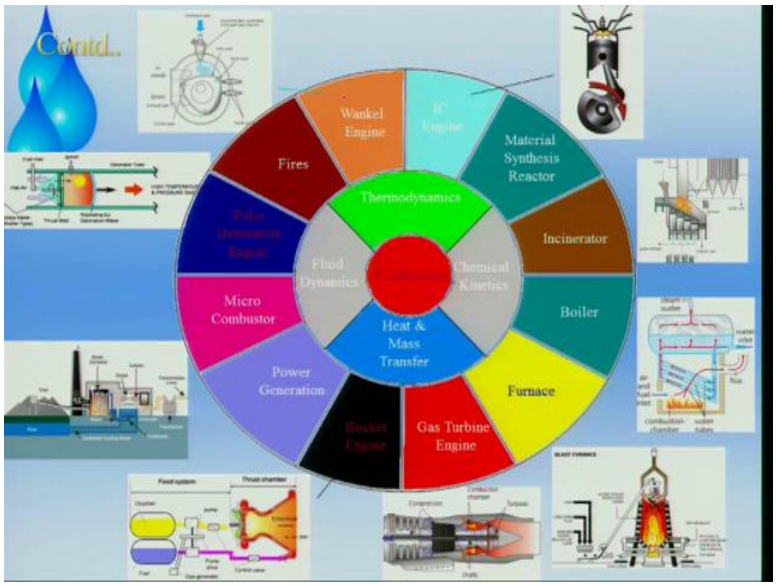


What are the applications? There are several applications. I will just jot down some of them. One is the power plant. Look at this picture, I have shown. Mostly we use the pulverized coal and nowadays the gas is being used to generate power. And there will be of course, the transport. If look at transport there is locomotives in the land, sea or air, rocket engines, gas turbine engines, these are the applications and it can be classified broadly.

There are several chemical industries which rely on this combustion processes, starting from refineries, fertilizers, cement any other chemical producing devices, blast furnaces, metallurgy, there are several applications and I club all those things as chemical industries because all requires chemicals. And of course, we know the domestic appliances.

Keep in mind that all this devises are sources of air pollution and water pollution that means, we need to carefully use the energy for our life without spoiling the nature which support us. That is a very important part what our ancestors were talking about, not going against the nature, nor winning over the nature, rather be a part of nature. That is the philosophy we need to adopt in the modern life to save our earth from the onslaught of this blatant use of science and technology in human life. That does not mean we should not use, we should use inspiringly, you should use in a sustainable manner such that we can develop a good earth for the next generation.

(Refer Slide Time: 18:50)



Look at combustion; it is having a subject thermodynamic, fluid dynamic, heat and mass transfer and kinetic energy. There are several applications, if you remember I had talked about Wankel engine, which is not being used nowadays, but I feel it may one day be used with the contribution from young people like you, and is very good because it is quite compact and it can be used for the aircraft applications. The IC engine which is being used from the time of Wright brothers, till today it is being used profusely for driving and aircraft particularly, small aircraft which we will not be discussing, however it is a very important engine concept. Material synthesis and other things are being used.

As I told, incinerators were knowing by our ancestors, how to incinerate dead bodies, it is a very nice way of doing, and we need to work for that to make it more environmental benign. Boiler is used to get power and I have shown a diagram over here. Furnaces is being used, there are several kinds of furnaces, blast furnace, coke even furnace, and glass melting furnaces, there are several of them which is used in industries and that uses combustion.

The gas turbine engine is being used for our aircraft propulsion and also the power plants generating power. Rocket engine, we will be discussing both the gas turbine engine and rocket engines to propellant air rocket. The power generations and there is a very interesting thing in recent time, the micro combustor, which is having a lot of applications in micro air vehicle kind of things. There is a new engine which is coming

up, is pulse detonation engine which can be used for aero application as well. The fire which is the genesis of our life and if you look at fire everywhere it is there.

So, these all are the applications one we can think of because when I am talking about combustion applied to the gas turbine and rocket engines, you need to have a broader view, that is why put this things before you. Now a question arises, what do you mean by a fuel? Because we need to use fuel, we must know, what do you mean by a fuel? Can anybody tell me?

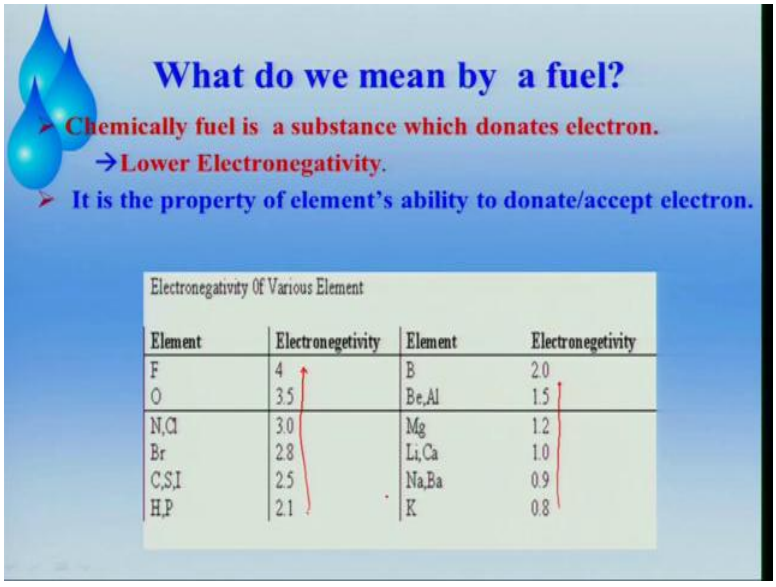
Student: Sir, fuel is the combination of hydrocarbons that release the heat by breaking the bonds between them.

Yeah, but if you look there are several fuel, which are not hydrocarbons, can you not call it as a fuel? But I want to define, what do you mean by a fuel?

Student: It is a chemical, when oxidizes releases energy.

Suppose there is a fuel, but can it act as an oxidizer any time? Not possible, right? For example, we know oxygen, in the air; can it act as a fuel? No. We need to define a term which will tell us whether it is a fuel or not.

(Refer Slide Time: 22:53)



Chemically fuel is a substance which donates electron. That means, what is happening during the chemical reactions? There will be breaking of bonds and forming if bonds.

How does this breaking of bond really occur? Because of exchange of electrons at the level. Then only it can be broken, energy can be released, because whatever energy is there, you are trying to release it, and use it for your purposes.

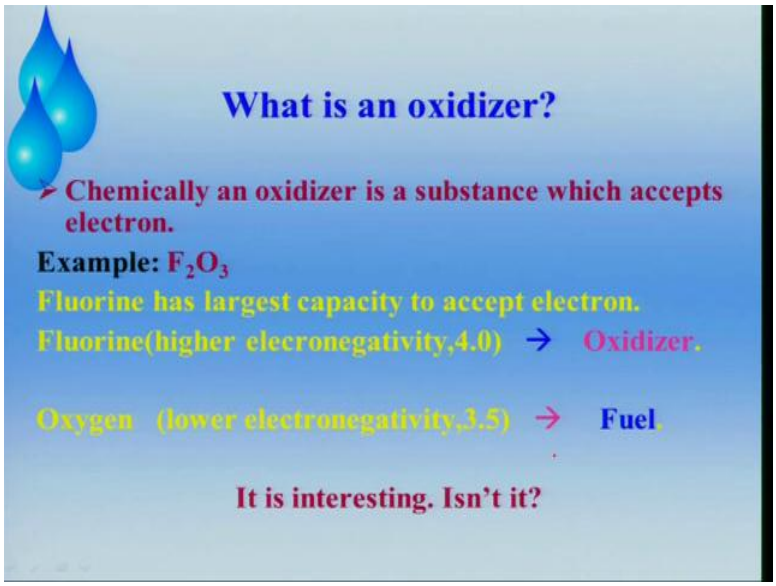
Electrons can be donated that means, one electron can go from one molecule; from the atom level to another in a molecule or it can be accepted. There can be two things, if donation, one is moving other can come in also. It is like a go of the world, like if it is a coin; head is there, tail will be there, that way. If light is there, then darkness is there. That way if you are giving something, you can accept as well. How we will quantify this? Can you say that one electron is moving and another is electron can be accepted? Five can be moved and other thing. For that, we can define a term, electro negativity. That means, a fuel must have lower electro negativity.

You know, this term electro negativity, which was a given by Linus Pauling, who was the Nobel laureate. It is the property of element's ability to donate or a accept electron. In other words, electrons in the atom in a molecule can be attract to itself or it can be repelled from it that will be electro negativity. If you look at this, potassium is having 0.8, electro negative, that means it can donate lot of electrons, it is having higher capability to donate the electron, it is basically a donor.

So, as you go along with this label that means, 0.8 sodium, lithium, magnesium, beryllium, boron electro negativity increases. Similarly, for hydrogen and carbon also, the order is increasing. If you look at oxygen over here, this O is oxygen and F is for fluorine. It indicates that oxygen is having higher electro negativity. What is the meaning of that? That means, it will be accepting the electron, it will not be donating.

What are the fuels in our case? Among all these things, which will be the reactive fuel? If I consider the oxygen as oxidizer which is having a higher electro negativity, which will be the most reactive fuel among this table, whatever I have shown? Potassium. It is quite reactive; however we do not use it. But all these metals can be used as fuel. And we use carbon and hydrogen, as one of you told that hydrocarbons, we use as the fuel because it available. Any of this can be fuel and this can be oxidizer as well, depending upon electro negativity.

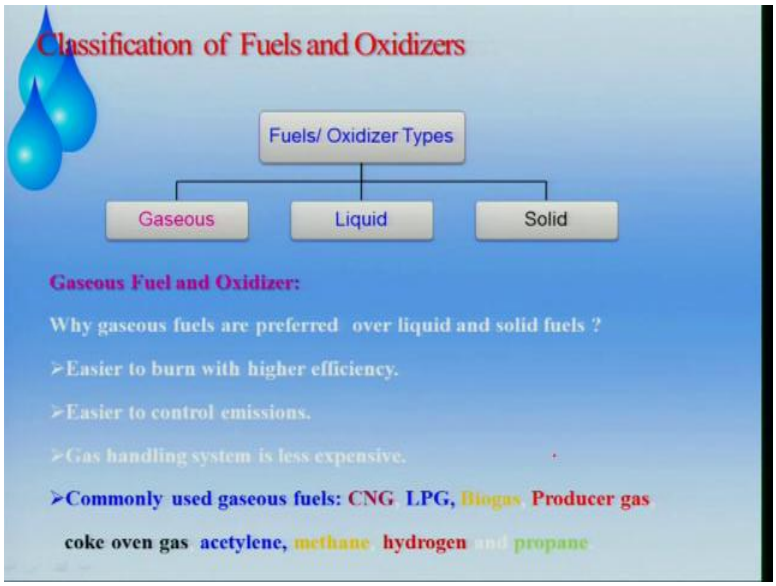
(Refer Slide Time: 27:29)



So, we can say that chemically an oxidizer is a substance which accepts electron and we will take an example where we can say that oxygen can be acted as a fuel. For example, F 2O 3. Fluorine has largest capacity to accept electron, because it is having electro negativity of 4, so it will be acting like an oxidizer. Whereas, the oxygen which is a commonly known as an oxidizer, it is a fuel because it is having a lower electro negativity. Therefore, when you talk about this, one has to know, what electro negativity is, then only one can talk about it.

Although fluorine is quite reactive in the nature, in free form it is not available in India, in the earth crest although the percentage is more, that is the good boon for us. Otherwise it could have been more problem. Isn't it? Because is a very higher fume. See how nature has been made? Air contains a large amount of nitrogen which is the inert gas. So, that is the beauty of nature. So, don't you think that it is quite interesting that oxidizer which is commonly believed to can be active as a fuel.

(Refer Slide Time: 29:20)



We can classify these fuels and oxidizers based on the physical states like for example, gaseous fuel, liquid fuel and solid fuel, these are all physical states. The gaseous fuel is quite easy to handle, am I right or wrong? Is it easy to handle? Certainly no, because there can be a lot of leakage and to store a gaseous fuel is quite difficult and to carry from one place to another is quite difficult. However, it will be very easy to burn a gaseous fuel as compared to the liquid and solid. Why it is so?

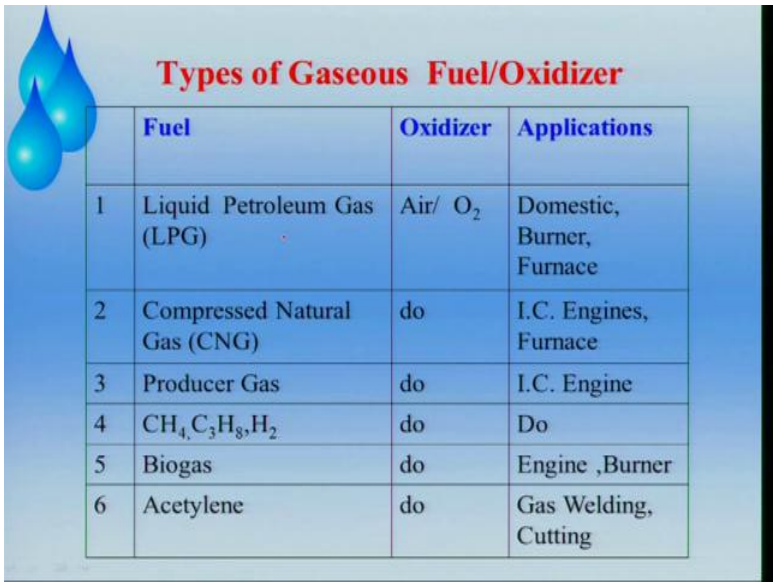
Gaseous fuel as I told, are preferred over the liquid and solid fuel, because it is easier to burn with higher efficiency, but do you agree with this point that it is easier to burn with higher efficiency? Why not the liquid fuel and solid fuel? That question must be bothering you as you go along. It easier to control the emission which is a greater concern at this moment, than what it was may be a hundred years back.

And gas handling system is less expensive, do you agree with this statement? Yes, why because if I want to atomize a liquid, I will have to supply a large amount of pressure. If I want to use a solid like a bulk, let us say a wood or something, I will have to pulverize it and to transport the pulverized fuel is quite difficult. And how I will control it, it is also a difficult thing that means, I need to feed certain amount of liquid and or the solid fuel. Whereas, the controlling will be easier in case of gaseous fuel. That is the reason what I can give, but if you are having different opinions, we can discuss it.

Commonly used gaseous fuels are basically CNG, LPG, biogas, producer gas, coke oven gas, acetylene, methane, hydrogen and propane and so on. There are several kinds of gases. You might be knowing the full form CNG is compressed natural gas. People are talking about PNG, IIT Kanpur will be having PNG that is pie natural gas, let me see you will get gas in your home through a pipe. LPG is liquefied petroleum gas, biogas is being used in rural area from the cow dung and other animals dung kind of things or even leaves, you can get by fermentation process.

Producer gas can be obtained by thermo chemical conversion from the biomass and other bio materials. I think you may the surprised to know that most of the auto mobiles were being run using producer gas, before the Second World War. Coke oven gas from the coke oven furnace, acetylene, methane, hydrogen and propane, we do use.

(Refer Slide Time: 33:18)



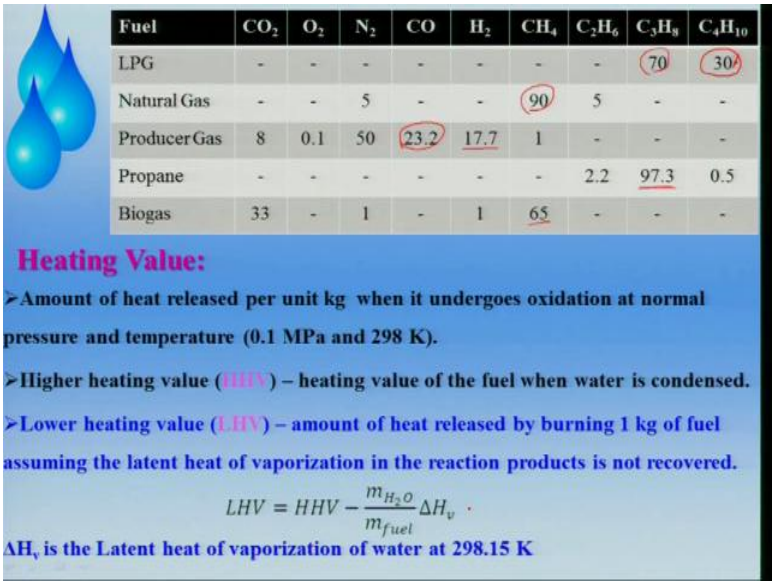
Let us look at types of gaseous fuel and oxidizer. Liquefied petroleum gas, we know that it is used in houses domestic purposes and all. So, it can be used in industrial purposes, air and oxidizers. Can anybody tell me what this liquid petroleum gas is? A 1 gas or it is a multi gas or 2 gases? It is the propane and butane, and what is the percentage, we will be looking at it.

Compressed natural gas, what are its constituents, we will look at it, it can be used in I C engine. In Kanpur city, few years back, we were using diesel and it was creating lot of soot. Nowadays we are using CNG, compressed natural gas and as a result the soot level

or the particulate level in the atmosphere has been reduced drastically. Therefore, it is being used in I C engine furnace and several other places.

Bio mass and even coal can be used to produce the producer gas. People are talking about gasification process as the better way of awaiting the emition level from the power plants. So, I C engines, boilers and furnace. Methane, propane and hydrogen can be used in several applications particularly, hydrogen is a very good fuel, but unfortunately, it is not available in nature. We need to convert the fossil fuels and other forms of fuels for hydrogen that is a big challenge, because it is a good fuel and having a higher calorific value. Biogas which is being used in engine and burners, we know this acetylene we use for gas welding, cuttings and other things.

(Refer Slide Time: 35:45)



Let us look at what are the constituents of five fuels I have shown here. You can see that LPG which contains propane 70 percent and butane 30 percent. Keep in mind that all data given in this table are in percentage. I have given some typical number 70 or 30 like 70 is propane and 30 is butane, but in several other places, you may find 60, 40 may be 50, 50 that means these will be varying from different well to well or from place to place.

For example, if you take LPG in Godavari versions, then it will be in different from that of if I take Assam or some other place. Therefore, it will be in varying. In other countries also the percentage varies, there is nothing sacrosanct about this percentage. But it is having propane and butane and actually in case of a cylinder, it is a liquid at higher

pressure, when open it, then it is converted into gas and you get the gas, that is the beauty of liquefied petroleum. Otherwise, you will have to carry is very difficult.

Natural gas in this table, is something around 90 percent of methane, 5 percent of ethane and 5 percent of nitrogen, you may get several other composition, as I told it depends upon where it has been taken from which well it has been taken. But generally it contains methane in a large proportion. Similarly, the producer gas contains basically the CO, CO is the fuel, it contains also hydrogen and rest of the things are not really part of fuel, 50 percent nitrogen and 0.1 of oxygen and 8 percent CO 2, but this constituents will be varying depending on the type of gasification units you are using, and also whether we are using oxygen or air. If you are using air nitrogen will be more. Propane generally contains large amount of propane and small amount of other hydrocarbons, and majority of biogas methane. Therefore, the caloric value of biogas and the producer gas are quite low as compared to the natural gas or the LPG that we will see a little later on.

The amount of heat released per unit kg, when it undergoes oxidation at normal pressure and temperature, we call it as a heating value, which is very important. Question arises, how we will evaluate the heating value of the fuel? What are the ways of doing that? Can anybody tell me? Let us say methane, what will be the calorific value? Heating value is nothing but calorific value of the fuel. If I will go for a liquid fuel, let us say kerosene, how will we evaluate it? If I will go for a solid fuel, how I will evaluate it? I need to know. How to find out what is the value? For example, you have come up with another exotic fuel, let us say for propellant, for a rocket engine, we need to evaluate, how much energy it will give?

Student: Change the heat energy into work; from work we can calculate it.

Is it really so? Why not directly? Why I will convert into heat into work, it comes in the efficiency, then how I will evaluate the efficiency perfectly? It is a very simple way. You just burn it, and then find out, how much heat being generated per unit kg of fuel. Two units are being used, one is known as Bomb calorimeter, you must be knowing, it has been taught to you. That is meant for liquid and solid fuels that means, you can measure the heating value or the caloric value of solid and liquid fuel using Bomb calorimeter, whereas, for gaseous fuel we cannot use it. We will have to use Junker calorimeters for

measuring the calorific value of a gaseous fuel and you can refer my book. It is given by schematic which I will not be showing here, and understand how it can be done.

When you talk about heating values, there will be two heating values. One is higher heating value that is the heating value of fuel when water is condensed. That means whenever combustion is taking place particularly, hydrocarbon and hydrogen, water will be formed. If it is condensed, then you will get the heating value, which is known as higher heating value.

There will be low heating value, where the amount of heat released of burning 1 kg of fuel and assuming the latent heat of vaporization in the reaction product is not recovered. That means it is not condensed, it is a part of it. So, we call it as a lower heating value. So, lower heating value is, higher heating values minus m that is the amount of water being formed per kg of fuel, and the amount of fuel into delta H v, were delta H v is the heat of vaporization for water, which is taken at 298.15 Kelvin and all with the reference to this value. We will discuss little bit, as you go along, how we will evaluate and other things about the caloric value of a fuel.

(Refer Slide Time: 42:08)

Types of Liquid Fuel/oxidizer

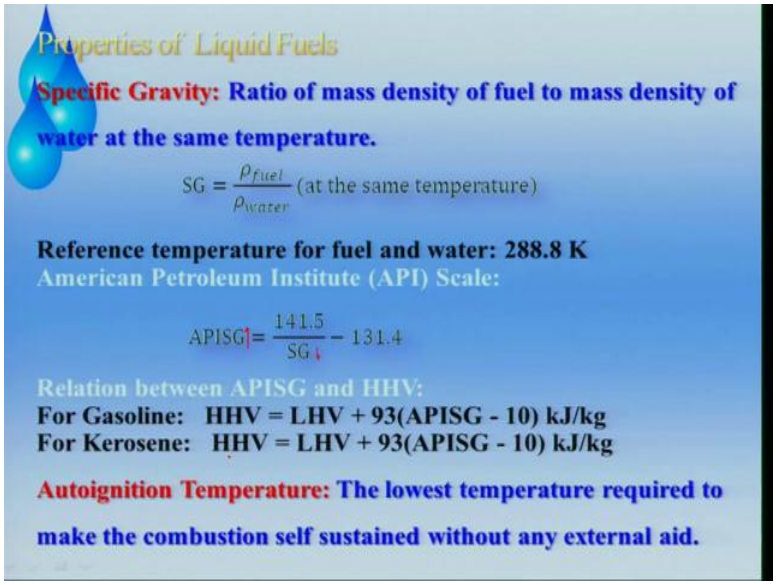
	Fuel	Oxidizer	Application
1	Gasoline (Petrol)	Air	S.I. Engine, Aircraft Piston Engine
2	HSD	Air	C.I. Engine
3	Furnace Oil	Air	Furnaces
4	Kerosene	Air	Aircraft, Gas Turbine Ramjet Domestic
5	Alcohols	Air	I.C. Engine
6	Hydrazine, UDMH, MMH, Liquid Hydrogen, Triethyl Amine	Liquid O_2 RFNA (Red Fuming Nitric Acid) N_2O_4	Ramjet/Scramjet, Liquid Propellant Rocket

If you look at the types of liquid fuels, we know this gasoline is nothing but petrol, we are all familiar with petrol, petrol price and diesel price is going up. This is the high speed diesel which has been used for some places generally the normal diesel is being used in the auto mobiles. Furnace oil is used in furnaces, kerosene which is used for

domestic purposes, aircraft engine, gas turbine, Ramjet engines; I will be talking about kinds of kerosene. Alcohol can be used in I C engine.

Besides these, there are several fuels which are used in Scramjet engines, liquid propellant rocket engines, Ramjet engines like those are hydrazine and UDMH, unsymmetrical dimethylhydrazine, MMH, liquid hydrogen and triethyl amine, these are the all kinds of fuel which will be discussing as you go along. This liquid oxygen, red fuming nitric acid, dinitrogen tetra oxide and those things will be discussing as you go along.

(Refer Slide Time: 43:33)



Liquid fuel will be having certain properties, this is must be looked at carefully. Specific gravity is one of the properties which all of you know. It is basically ratio of mass density of fuel to mass density of water at the same temperature. There will be SG, the specific gravity; it is the density of the fuel divided by density of water at the same temperature. Generally the reference temperature is taken for both the fuel and water is 288.8 Kelvin, and this specific gravity is a very important aspect because that will tell you about the volume contents and also the amount of reactions in the combustion and other things.

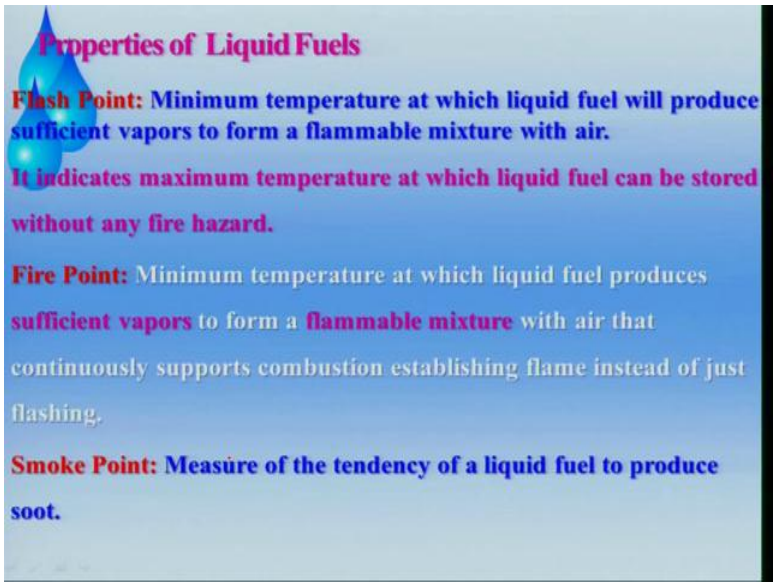
In order to have a scale, the American Petroleum Institute have come up with a scale which is empirical in nature, that is the APISG is equal to 141.5 divided by SG minus 131.4. That means if SG is smaller that means, it is a lighter liquid fuel, then this

American Petroleum Institute scale will be higher. If it will go down, then this will go up kind of things, and you can evaluate for various fuel kind of things.

And as I told, specific gravity can be connected to the heating value of the fuel, because the amount and weight of molecules will be deciding. Therefore, American petroleum institute scale specific gravity can be related with the HV. For gasoline, this high heating value is equal to the low heating value 93 APISG minus 10 kilojoules. These are basically empirical constant, for gasoline they have used. Similarly, for the kerosene it is having similar numbers.

If you look at the density will be changing because these are all petro chemicals, I can have density changing, depending upon what I want, I can really play around get this heating values as well. There is another important property which we need to look at that is the auto ignition temperature, the lowest temperature required to make the combustion self sustained without any external aid, because if you want to make a combustion self sustained, we should go a temperature beyond the auto ignition. Otherwise we need to continuously giving the ignition energy. So, this is the very important parameter which needs to be looked at and it can also be used for safety reason to avoid the explosion kind of thing.

(Refer Slide Time: 47:19)



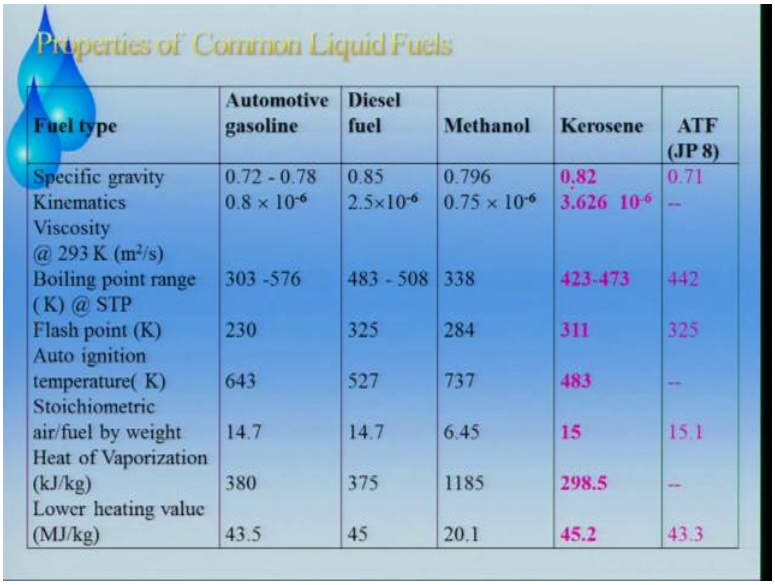
There is another very important point that is, the flashpoint which is the minimum temperature at which liquid fuel can produce sufficient vapors to form a flash or a

flammable mixture with air. That means it will vaporize, as a result there will be flash and then it will again discontinue. It is a phenomenon which will be remaining for certain time. So, it is very important from the storage point of view. In other words, this is the maximum temperature, below which a liquid fuel can be stored without any fire hazard. Therefore, this is very important aspect to store this liquid fuel under set. Otherwise, it can incur a fire which is hazardous in nature.

So, the fire point which indicate, the minimum temperature at which liquid fuel produces sufficient vapors to form a flammable mixture with air, that continuously supports combustion establishing flame instead of just flashing. That means, it will end in a continuous combustion. That means, when I am talking about the sustained combustion, I should go beyond the fire point, and when I am talking about storage, I need to have a temperature at which I can store a fuel, must be less than the fire flash point.

Whenever you use hydrocarbon fuel, lot of soot will be formed because of incomplete combustion and other thing, and liquid fuel is prone to soot formation. Therefore, we need to find out soot point, which is a measure of tendency of liquid fuel to produce soot, because the soot is not really good for the gas turbine or any other applications. Therefore, it must be also talked about when you are judging whether this fuel can be used for your engines or not. So, these are the properties which are very important.

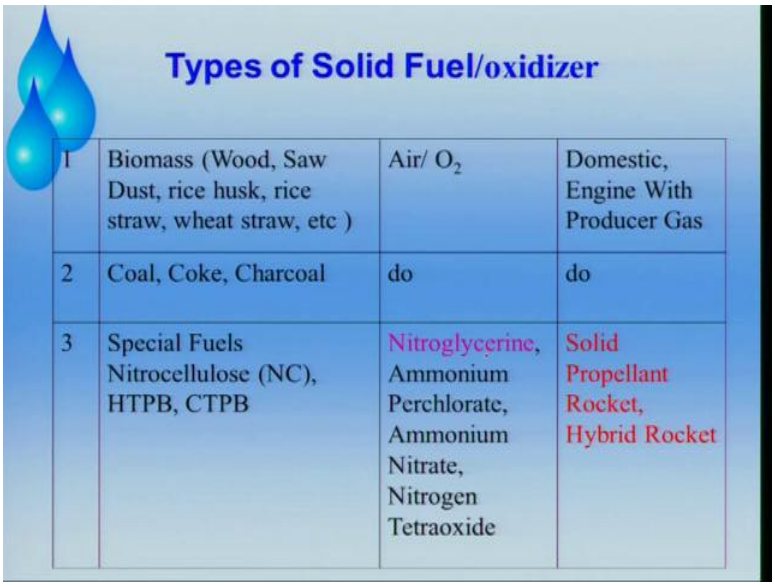
(Refer Slide Time: 49:45)



Fuel type	Automotive gasoline	Diesel fuel	Methanol	Kerosene	ATF (JP 8)
Specific gravity	0.72 - 0.78	0.85	0.796	0.82	0.71
Kinematics Viscosity @ 293 K (m^2/s)	0.8 × 10^{-6}	2.5×10^{-6}	0.75 × 10^{-6}	3.626 10^{-6}	--
Boiling point range (K) @ STP	303 -576	483 - 508	338	423-473	442
Flash point (K)	230	325	284	311	325
Auto ignition temperature(K)	643	527	737	483	--
Stoichiometric air/fuel by weight	14.7	14.7	6.45	15	15.1
Heat of Vaporization (kJ/kg)	380	375	1185	298.5	--
Lower heating value (MJ/kg)	43.5	45	20.1	45.2	43.3

I just tell you the specific gravity which I have shown for the kerosene and ATF, aviation turbine fuel, JP 8, there are several kind of thing, we can look at the number. Viscosity kinematics shown here and boiling point is having range, flash point is 311 and 325, which is nearby and auto ignition temperature is higher than the flash point. The stoichiometric ratios of generally hydrocarbon fuel will be around 15. The heating values are similar numbers like 45.2 and 43.5 mega joules per kg.

(Refer Slide Time: 50:37)



There are the types of solid and fuel oxidizer; there is several kind of thing. Biomass like wood and saw dust and lot of things are there, you need to use air oxidizes domestic purposes and the engine can be run. Coal, coke and charcoal several kind of thing, but the special fuels particularly for the rocket engines is nitrocellulose HTPB, CTPB which will be discussing little later on.

There are several other oxidizers like nitroglycerine which are solid in nature keep in mind ammonium per chlorate, ammonium nitrate and nitrogen tetra oxide kind of thing which is used in solid propellant rocket engine and hybrid rocket. I will just ask a question, is there any possibility that we can have a solid propellant fuel or the fuel from the natural paradox, not like this chemicals. You please think about it. Let us see. As you go along, I will give some clue about it. With this I will stop over.