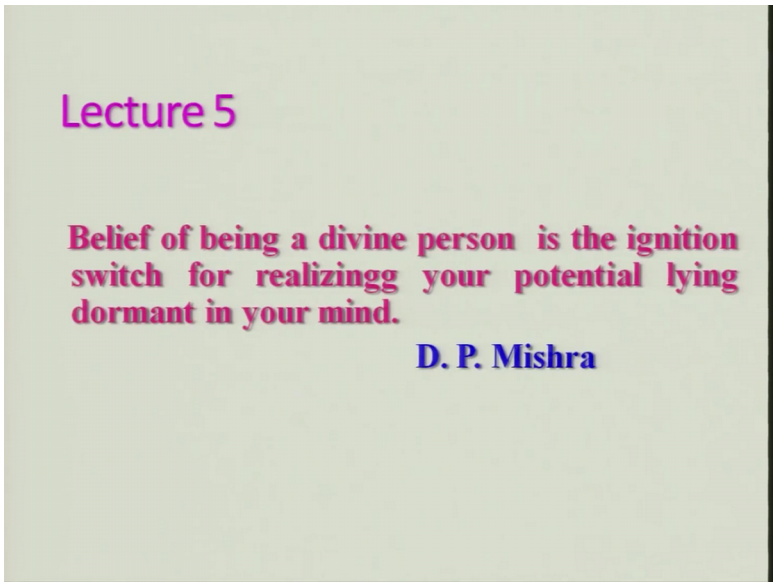
Fundamentals Of Combustion (Part 1)

Dr. D.P. Mishra
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Lecture – 05
Properties of liquid and solid fuels, various modes of combustion

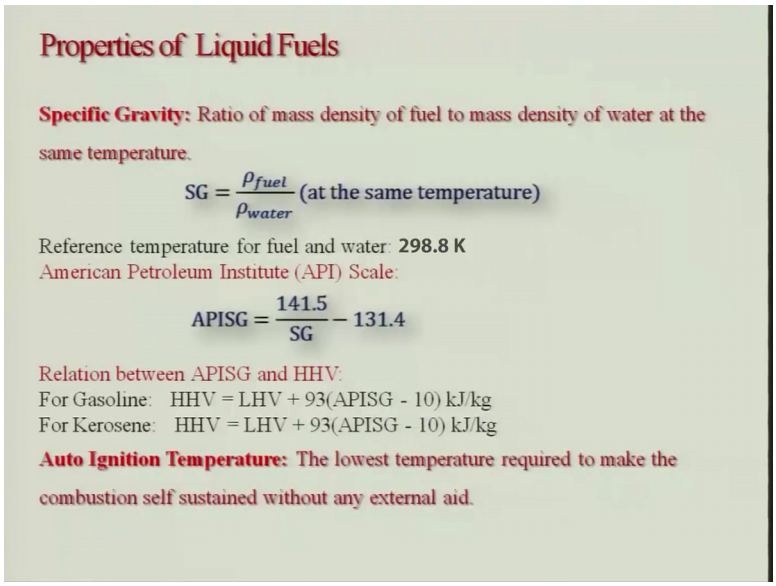
Let us start this lecture with a thought process. Belief of being a divine person is the ignition switch for realizing your potential lying dormant.

(Refer Slide Time: 00:19)



In the last lecture we basically looked at the gaseous fuel and its properties and heating value of the liquid fuels and also various kinds of liquid fuels and oxidizer and today we will be looking at properties of the liquid fuels.

(Refer Slide Time: 00:43)



If you look at the very important property it is a specific gravity because it is fuel liquid fuel is being used for in transportation. So, therefore, the specific gravity plays a very important role and which is defined as a ratio of mass of density of fuel to the mass density of water at the same temperature right. Of course, the people use the standard temperature right and SG is basically rho fuel divided by a rho water and reference temperature is being taken as basically for fuel and water is 298.8 Kelvin ok.

And of course the American Petroleum Institute he has developed a scale by which you can use and that is known as API scale APISG will be 141.5 divided by SG minus 131.4. Of course, they use it and these are all some constant values and whereas, why not we can use this SG. The question might be coming to your mind right. Why not we use SG? Why should I use APISG right? And they have divided this they claim that it can be used for basically finding out a relationship between the higher heating value and APISG.

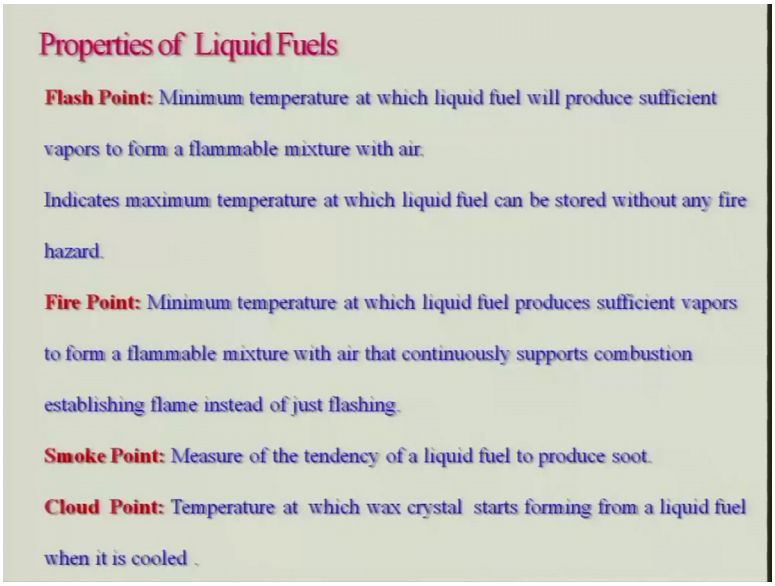
So, they have come up with a formula right for the gasoline HHV is equal to LHV plus 93 APISG minus 10 and the unit is basically kilo joule per kg right and for kerosene they have come with a similar formula right and the constants are same. It may be valid for this constants may change for various fuels keep in mind and these are all semi ampherical, you may use you may not use. Otherwise you can get the SG you can relate and find out your own way of doing right. It is not necessary to use this one, but; however, it will be handy earlier days people were designing. So, they will be very you

know easily do that to calculate and other thing, but today you know it is a different thing.

And some of you have told that basically self ignition temperature or auto ignition temperature, it is the lowest temperature required to make the combustion self sustained without any external aid right. Suppose, I will remove this ignition source, but it will be going on right if the temperature attained by the fuel you know. If it is a low let's say auto ignition temperature low; that means, you know it is very easy to ignite because I will give very little amount of energy so, that it will go to that temperature and after that it is self sustained right.

Even if I withdraw the ignition source then still it will be combustion will be taking place. Lower the self ignition temperature, auto ignition temperature better it will be; however, it will be having problem what is the problem hazardous because if by mistake something is happening then you know all fuel will be getting burnt and coming in contact with the oxygen. So, therefore, it will be dangerous.

(Refer Slide Time: 04:08)



So, there is another property which is known as flash point. Flash point is basically minimum temperature at which liquid fuel will produce sufficient vapors to form a flammable mixture with air. I think you are talking about this point like where vaporization will be there right some amount of vapor and this is known as flash point. Flash point is occurring that does not mean that it will be self sustained combustion ok. It

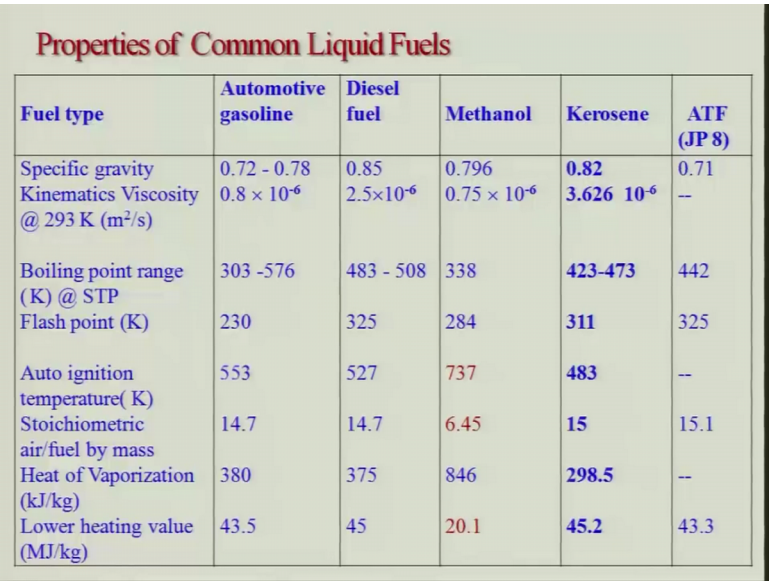
may have a flash some kind of a little fire and after that it may extinguish right so; that means, why it is required because it indicates the maximum temperature at which liquid fuel can be stored without any fire hazard right because if you go beyond this then only the flash will occur then only fire hazard will occur otherwise if a below your storing then you are safe.

So, for storage it is very important to take you know aware about what is the flash point of the fuel right. So, there is another you know temperature which is known as a mini fire point and fire point is the minimum temperature at which liquid fuel produces sufficient vapors to form a flame mixture with air that will continuously support the combustion right. But the flash point will just have a flash it may not sustain or other it would not sustain, but in this case flame will sustain right, that is the difference between flash point and fire point. As I told that it will be after just flashing the flame will be continuing, but in case of flash point there will flash it may stop or it may not right. There is also a another point which is known as another property known as smoke point.

It is a basically measure the tendency of liquid fuel to produce soot right ok. There is a also similar things is being utilized for the gaseous fuel as well right, there will be smoke point where it will started smoking right. Smoke is must be avoided ok. There is a cloud point the temperature at which wax crystal starts forming from a liquid fuel when it is cooled. Suppose, you cool the things you know it became wax being formed and wax being formed means you know it will be very difficult to use as a fuel; particularly in the cold country or cold region like Himalayan region other thing in winter is the you know cloud point the temperature reaches then you know it is very difficult to start the engine you know right.

So, therefore, it will be better that you know you should we you know avoided right so, these things are to be there from for the liquid fuels.

(Refer Slide Time: 07:15)



Properties of Common Liquid Fuels

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)	553	527	737	**483**	--
Stoichiometric air/fuel by mass	14.7	14.7	6.45	**15**	15.1
Heat of Vaporization (kJ/kg)	380	375	846	**298.5**	--
Lower heating value (MJ/kg)	43.5	45	20.1	**45.2**	43.3

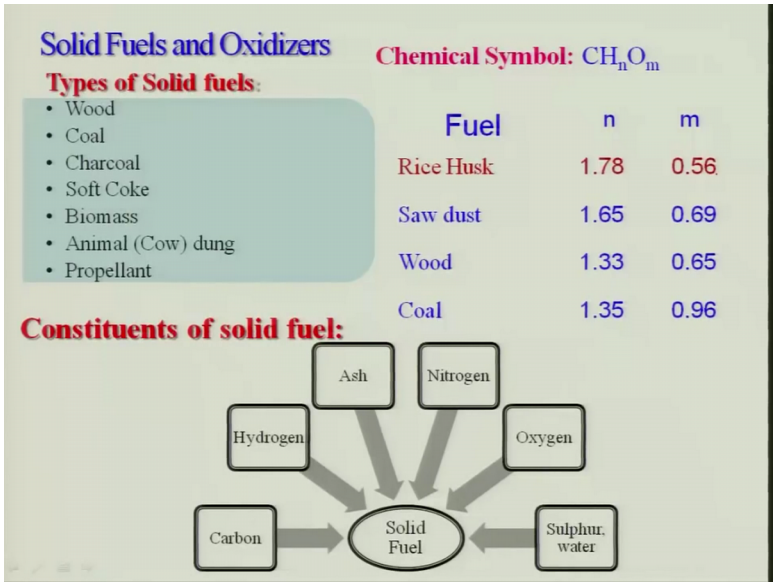
Let us look at a typical values what I am trying to you know give here, that is the specific gravity, automotive gasoline there might be different gasoline like you know like aviation gasoline will be different than the automotive gasoline right and it values this 0.72 to zero 0.78 and diesel of course 0.85; that means, what 0.85 means what with respect to water, this density ok. If it 1000 you take; that means, it will be 850 kg per meter cube right and methanol is 0.796 you can say around point 8, kerosene is 0.82 of course, this is you know like ATF. ATF you know what is meaning? Aviation Turbine Fuel.

This is JP 8 there will be several like JP 10, there are various kinds of fuels has been used particularly aerospace people they will knowing. This is like kinematics viscosity is very important because if the viscosity is very high. Then what will happen? It is difficult to atomize right and then if it is not atomized then you cannot really burn properly you cannot burn it properly.

So, boiling point range you know also very important and I have already discussed about flash point. If you look at the lowest is the gasoline and auto ignition temperature if you look at highest is the methanol right whereas, the gasoline is next one and the kerosene is lowest. A little dangerous you know like used kerosene as a among all this fuel right and Stoichiometric air fuel mass if you look at most of them around 15 ok and this is 6.45 and this is a heat of vaporization. Generally, we use the lower heating value for our

calculation process that is the lowest one all other things are around 40 to 45 mega joule per kg this a very large amount of heat.

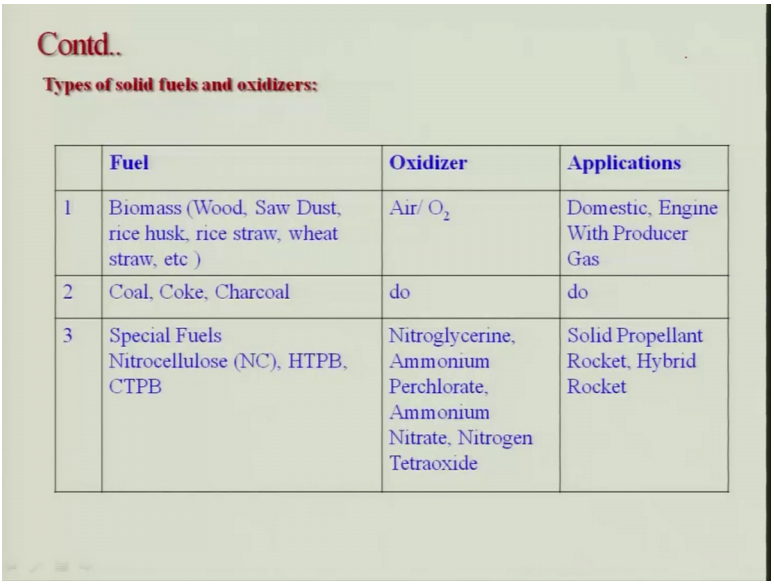
(Refer Slide Time: 09:25)



So, let us look at the solid fuel and the oxidizers there are various kinds of fuel like wood, coal, charcoal, soft coke, biomass, animal dung I mean basically cow dung we use and propellants right and if you look at constituents of solid fuel. What it would be? Of course, you know carbon will be there right. Hydrogen will be there you know that is the thing and what else other thing. There will be several other things carbon will be there, hydrogen will be there, ash will be there, nitrogen will be there, oxygen will be there sulphur and water content will be there right.

But see it is very difficult how to put a chemical formula you know like it is very difficult, but; however, I have given a simple model not I have given it is given by others. I am just quoting like they have said that C H n O m these are the values you know like 1.78, 0.56, saw dust 1.65, 0.69. These are all semi ampherical things right and keep in mind that there is some complex formulas will be there also. Chemical you know this thing where the nitrogen is coming into pictures and sulphur is also coming to pictures there is a some, but I have taken the simplest one.

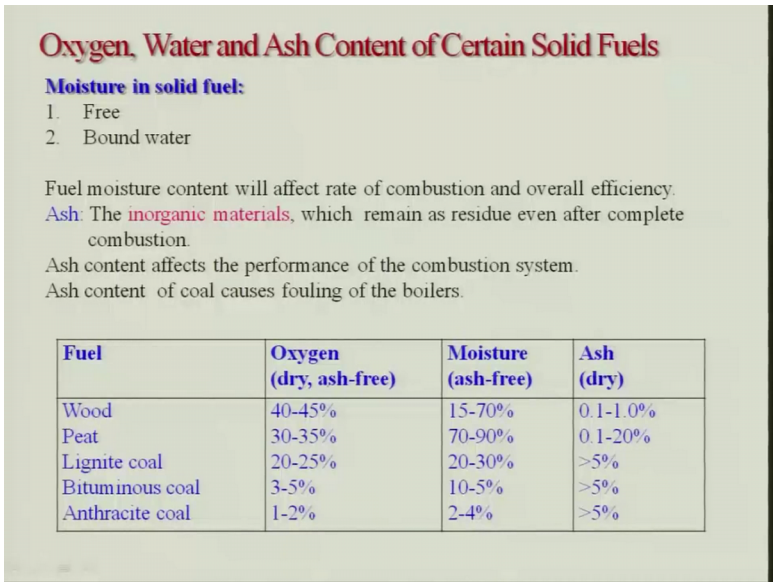
(Refer Slide Time: 10:49)



So, types of solid fuels if you look at biomass. The biomass several of them wood, saw dust, rice husk, rice straw, wheat straw and several of them right anything whatever even like things if you can burn and it is used for domestic or engine application because a you can produce the bio producer gas out of this biomass and coke, coal, charcoal you know you can use same application.

The special fuel like nitrocellulose nitro glycerin is basically oxidizer and HTPB Hydroxyl Terminated Poly Butadiene and CTPB. CTPB means Carboxyl Terminated Poly Butadiene. These are used by ISRO profusely, but there will be several other chemicals in propellants and Ammonium Perchlorate as a oxidizer, Ammonium Nitrate, Nitrogen Tetroxide. These are all oxidizers right it can be used and it is used for solid propellant rocket engine, hybrid propellant rocket engines and other thing which will be not dealing with, but for the completeness sake I have just included here.

(Refer Slide Time: 12:00)



Let us look at basically oxygen water and content of certain solid fuels basically moisture will be free and bounded. Free means we just vaporize it will go away and will affect because fuel moisture why we are concern about moisture of solid fuels because it will affect the rate of combustion overall efficiency. First of all, you will have to supply amount of energy so, that it will vaporize right.

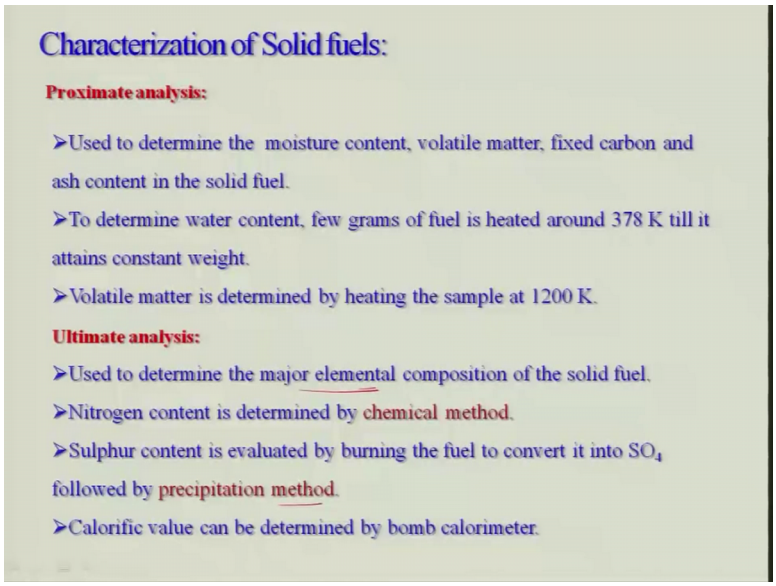
Beside this if it is air then it will hamper the combustion to take place right and ash the inorganic materials which remain as right. Beside this if it is there then it will hamper the combustion to take place right and ash the inorganic materials which remain as a residue even after complete combustion takes place. So, therefore, this cannot be burnt you know it will be a just your carrying a piggy bag under in your shoulder you know like as a fuel so, therefore, it is wastage.

Ash content also affect the performance of combustion because it will be you know what you call on the layers. It will be like acting like insulations and then absorbing the heat therefore, combustion efficiency. Ash content of coal causes fouling of the boilers and when it will emit it will causing a lot of problems and if you look at the given some of fuel like Wood, Peat, Lignite, coal, Bituminous coal, Anthracite coal.

If you look at the these are the constituents which are you know are there in the range. The oxygen generally the wood will be lot of things will be there dry ash and ash free like whereas, ash moisture is much more in the wood right as compared to anthracite

coal and ash is very less right here, but whereas, the this coals is Indian coals you know will be having something 20 to 40 percent of ash that is biggest challenge right for us to handle. How to handle those kind of coal which we are having a very good you know very vast reserve we are having.

(Refer Slide Time: 14:13)



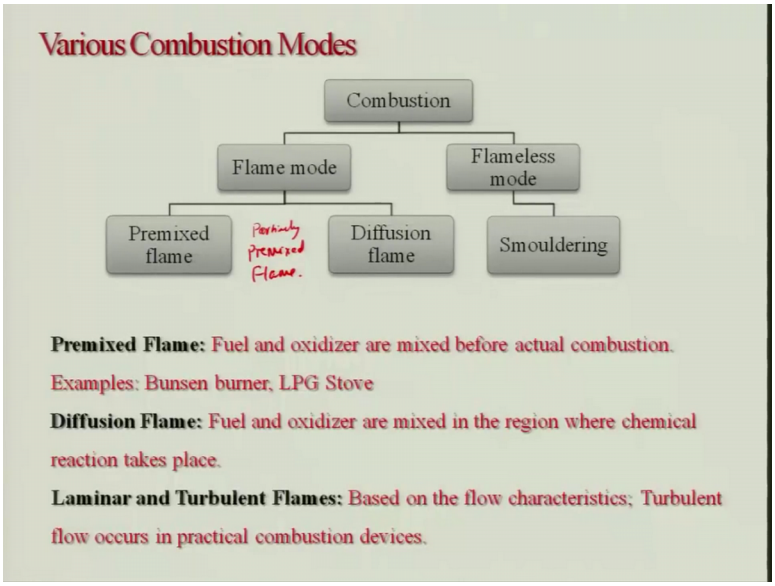
So, characterization of solid fuels if you look at there are two ways of looking at one is Proximate analysis, that is used to determine moisture content. Volatile matter fixed carbon and ash content in the solid fuel right because this moisture content is very you know is important. You will have to find out what is the volatile content. Why you will look at volatile content? Because that will help to ignite because it will be gaseous fast you know and fixed carbon which will give sustainable combustion and ash content of course, it should be minimized so, that that hampers the combustion.

And we need to determine water content, few grams of fuel is heated around 378 Kelvin till it attains constant weight, see this is generally a procedure. A standard what is being used to you know analyze these thing and volatile matter you know can be determined provided if it is heated. The you know the sample is heated at 1200 Kelvin for certain period of time. So, these are to be done such that you will find out ultimate analysis basically a various methods are used like a because you need to determine the major elements right. What are the things is having compositions? And for that you will have to use you know chemical methods for getting the nitrogen content and sulphur method is

evaluated by the precipitation methods right and of course, calorific value can be determined by the bomb calorie meter. See what am trying to give you basically a general view how you can do because these are the important things to be done particularly in know the constituents of the solid fuels so, that you can come up with a ampherical formula. As I told C H O like m and n are a coefficient I have put it.

Or a such that you can you know do a some calculations and understand what is happening that is one objective, other objective is to basically look at what it contains you know. So, various combustion modes will be there right because now we are talked about the fuel. Now, we should understand what kind of combustion will be taking place right.

(Refer Slide Time: 16:39)



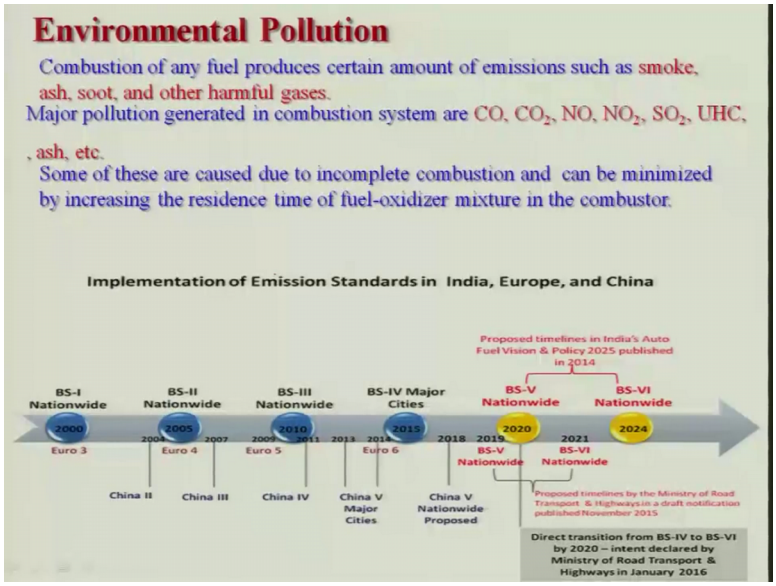
So, if you look at the combustion can be broadly divided into flame mode and flameless mode because flame is a genesis of combustion ok and the flame mode is basically premixed flame. One combustion there is a another mode is the diffusion flame right and there is a another mode which is partially premixed flame right. If you look at premixed means where fuel and oxidizer are mixed before the combustion takes place right. The example is Bunsen burner, LPG Stove and other thing right and whereas, a diffusion flame is like where the fuel and oxidizer will be mixed on the surface of the combustion or on the surface of the flame or during the combustion right. Now, and partial premix it is in between, if you look at premixed basically what. It will be premixed means it is love

marriage ok and diffusion flame means basically arrange marriage. Where you do not know each other your marriage, partial flame means love and arranged together that is the combustion what you will be talking about right. Are you getting?

So, now which is good? Which is bad? Which is ugly? Is a matter of debate and discussion as you go along will see particularly you remember this thing corollary and when I will get into premixed flame and then diffusion flame we will discuss ok and again based on the flow we can divide into two categories. One is Laminar Flame and Turbulent Flame right and if you look at flameless mode is a Smouldering combustion. Smouldering combustion you know what is that? Any of you take cigarette? Smoking right. Smoking you have seen is there any flame, but this is smoldering is occurring right.

Even the carbon when you look at there is no flame as such carbon is burning right then it will be glowing and then moving right so, that is smoldering. Now-a-days it is not the smoldering is the flameless combustion there is combustion coming off is a flameless we will do it artificially right so, that there would not be any flame. I had done some work on that earlier and that is the new technology which is coming out new way of doing combustion right.

(Refer Slide Time: 19:42)



So, the if you look at the environment pollution is very important because combustion of any fuel produces certain amount of smoke, ash, soot and other harmful gases right and

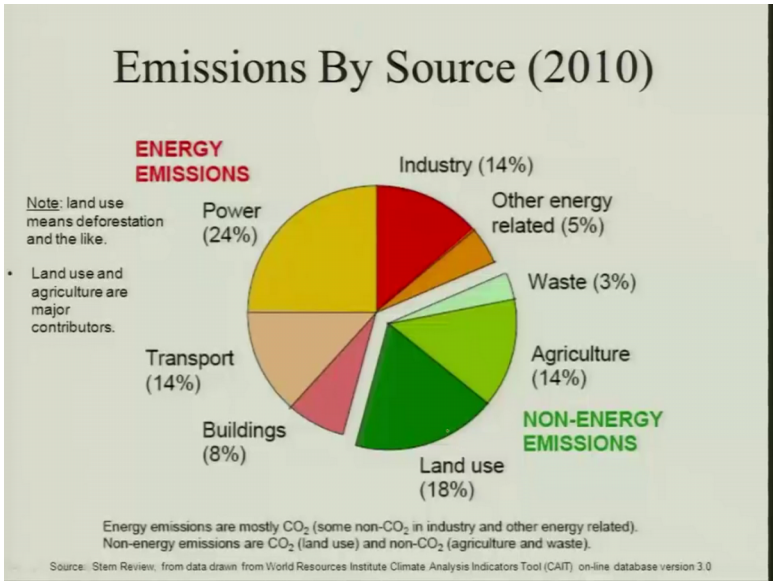
major pollutants generated during combustion. What are those? Basically carbon monoxide, carbon dioxide, nitric oxide, nitrous oxide, sulphur dioxide, unburned hydro carbon right. These are the and others right may be ash, then smoke, then soot particles you know all those things will be coming, but those are causing a lot of problem why this coming particularly carbon monoxide and unburned hydro carbon.

These are basically due to incomplete combustion right and it can be minimized by enhancing the residence time of the fuel and oxidizer mixture in the combustor or you can provide more amount of oxygen so, that or oxidizer as. So, that combustion can take place to the full extent right and because of these thing there is a lot of concern across the globe right and people are saying because we are all using a lot of combustion systems. For our transportation, for our food, for our you know like other activities producing electricity then emission is coming.

Therefore across the globe you know people are trying to make the emission standards stringent day by day. For example, 2000 this a BS, you know Bharath Standard I, nationwide 2000. It was a very low you know like very higher you know values like a C O and C O 2 all those things numbers are there, but in 2004 they have people started using Euro 4 and China I and China III and Bharath Standard II right and 2010 we are saying nationwide right will be doing and of course, that 2015 the Bharath Standard IV in the major cities. What I would suggest am not put those numbers, what are the values because it will be very worst for diesel engine it will be different, for petroleum engine this one for the you know what you call buses will be different so, numbers are different they have given. So, therefore, I thought due to sparsity of time I will not discuss, but what am trying to draw your attention is that they look at it is becoming more stringent and stringent and then people are trying to divide this so, they will regulate right.

But now; that means, technology has to come up otherwise you know will be in trouble. What is happening now? They are developing technology they are saying you buy us and you became proper are you getting. So, therefore, we need to develop our technology understanding the combustion and utilizing so, that we need not to be depend on them more and more depending on them because they are framing the rule and they are saying you will have to do it. Otherwise you will be in trouble they will twist arms right and let me tell you that emission by sources this is 2000 like energy emission means industry power transport and buildings right.

(Refer Slide Time: 22:59)

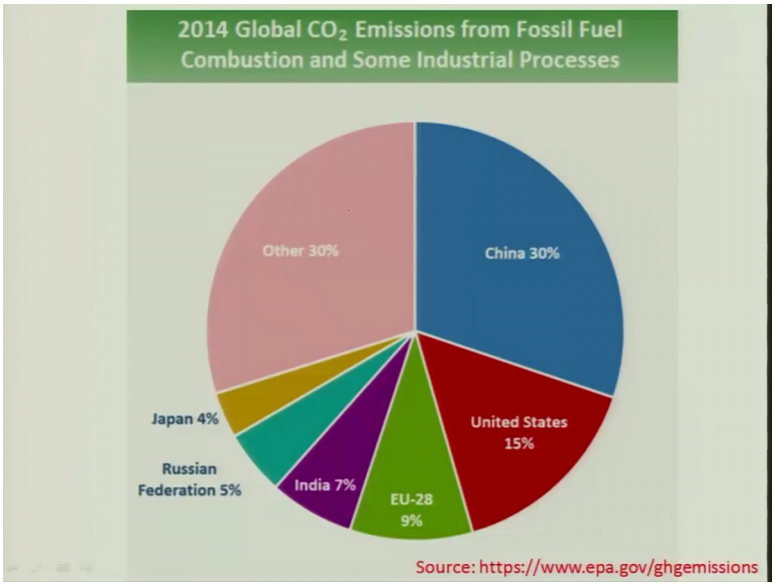


These are energy related you know this thing, but other resources will be waste agriculture, land use you know right land use and agriculture major contribute are in this wastes wastage is very less right means land use means basically deforestation kind of in differs to the increasing; that means, we our main concern is here combustion energy emissions you know where combustion is plays a very important role and that has to be looked at. Otherwise we are in big trouble it is not that you will be eh solving this problem by the technology you cannot of course, technology is required, but you need to also minimize the utility utilization of energy because India is a populist country right. We cannot look at modern western people they say that if the energy congestion for capita higher means you what developed.

I say that we will define in other way around, if energy congestion is a lowest we are developed right. We should go other way around unfortunately nobody is talking about it because you will increase the consumption right it is a problem for everybody and emission will be more, energy cost will be more, will be dependent on them that particular petroleum will be more will be more dependent on them right. So, therefore, we need to solve this both the social for the economical and also the technological solution; that means, multi prong (Refer Time: 24:42) should be adopted for solving this problem right.

So, let me just tell you there global C O 2 emissions is a if you look at India is 7 percent of the total.

(Refer Slide Time: 24:50)



And we are having 130 crore people so, therefore, it is very less ok. Whereas, china is 30 percent, United States is 15 percent right and European 9 percent and of course, others are there; that means, we are not really polluting that much. But if you will minimize our utilization then naturally we can solve the problem and we can be self sustain also provided will move to the agro based energy production and also consumption right.

So, will this I will tell you a lot of work can be done particularly in the combustion, provided we understand the fundamentals of combustions and in the next lecture we will be basically starting the thermodynamics of the combustion or whatever related to the combustion that thermodynamics will be discussing in the next lecture.

Thank you very much.