Upstream LNG Technology
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Lecture – 13
Combustion Properties

Welcome back. In the last of the property series, we have the Combustion Properties of natural gas. We shall learn about today. Now, we know that natural gas or for that made petroleum also are basically fuels other than fuels that also use for preparation of some chemicals, but basically that fuels.

So, any fuel is characterized by some properties which make them suitable for our consumption and what are those properties because these fuels will be undergoing oxidation or combustion and due to the combustion of these fuels, they will release energy and these energy is used for some purpose for some use.

So, we have to understand that water those properties, which determine the efficacy of a particular fuel. So, this relates to the combustion properties of the natural gas.

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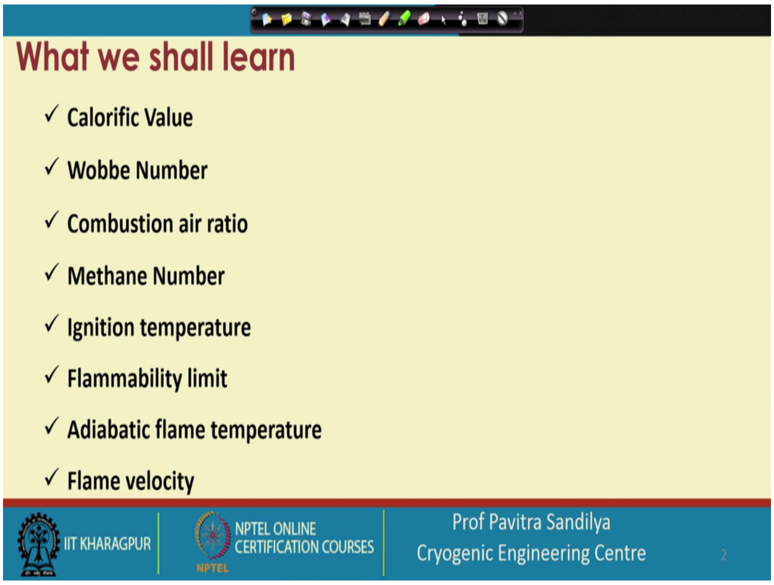

So, in this, we shall learn the following properties one is the first Calorific value, then Wobbe number which is associated with the colorific value, then we have the methane number, Ignition temperature, Flammability limit, Adiabatic flame temperature, Flame velocity and we have the combustion air ratio. So, these are some of the properties, which we shall be looking into in this particular lecture.

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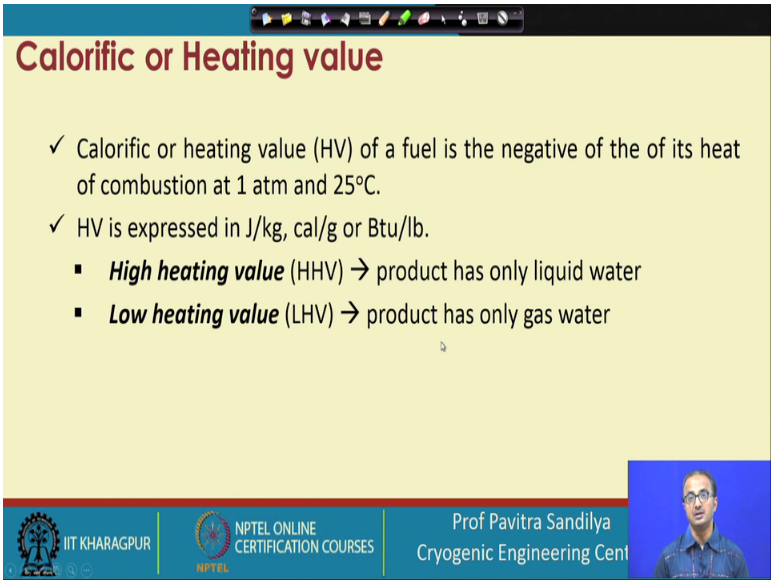

So, let us come first to the calorific value calorific value is represents the heating value of the particular fuel that is the first thing, we have to know whenever we are choosing in fuel, these are first property which should be known for the particular fuel. So, by calorific value or the heating value is generally denoted by HV and it is negative of its heat of combustion, right one atmosphere, 25 degree centigrade, 1 is this negative is the combustion that we put it negative, and in the literature will find it will come to negative value.

So, this is important for us to know that it is minus some value will be there and it is given for some standard condition, the standard condition is 1 atmosphere and 25 degree centigrade the because always, we give standard conditions the same fuel may reviews different amount of energy because after all these are obtained from combustion reactions and reaction depends the temperature pressure.

So, to standardize, it to compare the various types of fuels, we need to standardize the condition at which the fuel is getting combusted. So, that is why this calorific value in the relates to the value obtained at 1 atmosphere and 25 degree centigrade.

Now, the unit is generally joule per kg if you si unit, but this calorie per gram or Btu per pounds are also quiet common in the energy literature, the heating value are of you can two types one is the high heating value, another is the low heating value depending on what kind of product gas fuel obtaining.

Now, when we talk of high heating value, it means that we have the liquid water in the product, whereas, for low heating value we have only gases water in the product.

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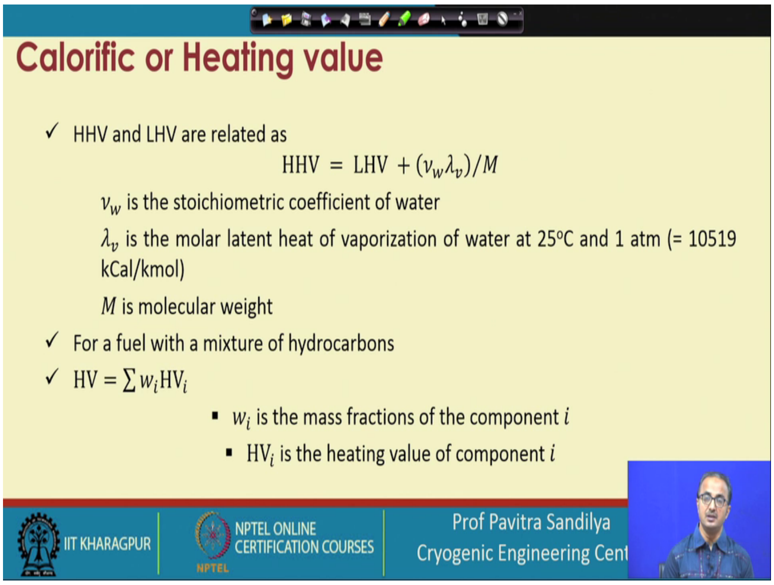

Now, this high heating value denoted by HHV and low heating value denoted by LHV are related, we are not going in to the derivation of the this relations this can derived. So, this HHV is equal to LHV plus this particular term and in this term the v w determines the stoichiometric coefficient of water stoichiometric coefficient of water tells us about that how what is the molecular molecularity and the how many molecules of water is produced during this combustion reaction.

In general, any kind of combustion reaction produces if it is comes to the combusted produces carbon dioxide and water ok. So, this presence of water changes the calorific value. So, that is why it is important for us to know that amount of water and that is accounted for by this v w that is stoichiometric coefficient of water and then we have the latent heat of vaporization. Because these determines that whether the water will be remaining as gas or liquid as we can see that if the gas is remain if the water is remaining gases phase the because if the if whatever energy is produced due to combustion and whatever products of form due to combustion those products are there first their coming has in the gasses ways.

So, this water energy is coming out that energy will be on the lower side why because when the water gets condensed again it will realize the energy for vaporization the heater vaporization is realized. So, this realize of the heat the heat of vaporization gets added to the combustion energy that is why the HHV becomes more than the LHV. So, that is why we have to add the enthalpy of condensation of water to the LHV to get the HHV and lastly we have the molecular weight of the gas.

So, then for various types of fuel with mixture of hydrocarbons we have different types of the heating values and that overall heating value is obtained like in fuel like in a natural gas contains methane, ethane, etcetera, etcetera. So, what we do we can combust them separately and get their heating values and then to get the overall heating value, we take some not averaging based on the mass fraction like earlier also we found that, when we were finding the average property, we were taking average based on the mole fractions and in this case the mass fractions of each of the component of natural gas are considered to get the overall heating value of the natural gas.

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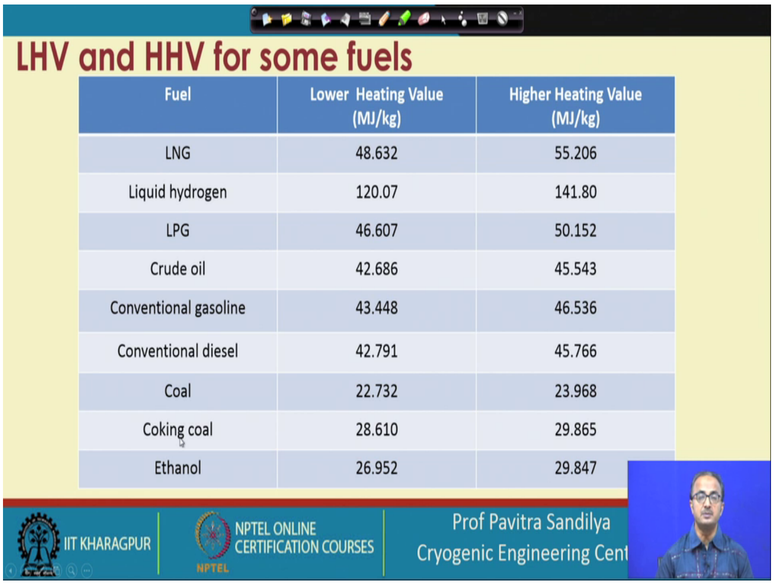

Fuel	Lower Heating Value (MJ/kg)	Higher Heating Value (MJ/kg)
LNG	48.632	55.206
Liquid hydrogen	120.07	141.80
LPG	46.607	50.152
Crude oil	42.686	45.543
Conventional gasoline	43.448	46.536
Conventional diesel	42.791	45.766
Coal	22.732	23.968
Coking coal	28.610	29.865
Ethanol	26.952	29.847

Now, in this particular table, the LHV and HHV values of some of the common fuels have been listed and here we can see that we have LNG, we have liquid hydrogen LPG, crude oil conventional gasoline, conventional diesel, coal coking, coal ethanol. So, you can see that in this the highest amount of energy is obtained for liquid hydrogen; that is why liquid hydrogen is also another fuel which people are developing, it also has its some negative points, but without going to those details just here we learned that the hydrogen has the highest heating value among all the other all the fuels that is why so much work is going on to develop hydrogen fuel.

And other than that we see that LNG, LPG, crude oil and conventional gasoline their heating values are almost nearby on the other hand coal, coking coal, etcetera ethanol, they have quite low heating values that is why, we are emphasizing more on the hydrocarbon based fuel oil and ah. So, LNG has another advantage that it is quite less polluting than the other LPG other things that is why so much emphasis and that is also available at taking a good quantity in the art.

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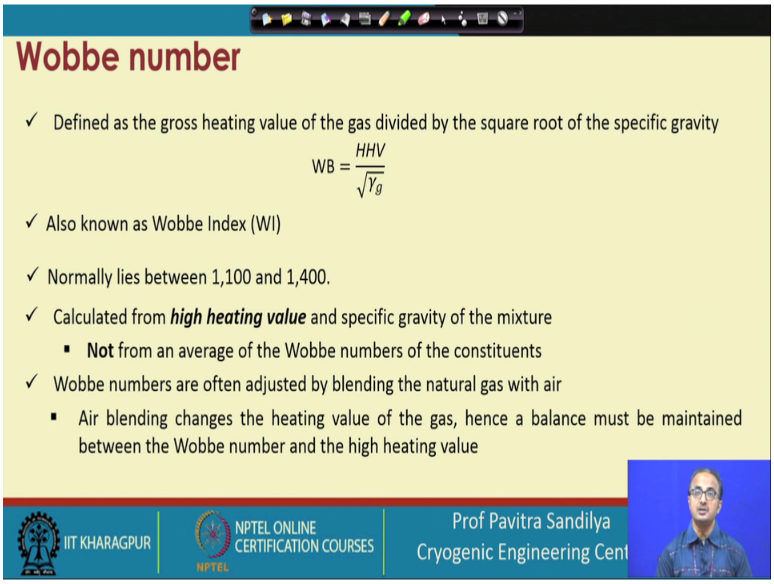

So, that is why we are learning about this LNG associated with the calorific value is another parameter that is called the Wobbe number. Now the let us first see, how it is defined this Wobbe number is defined like this that it is the ratio of the HHV to the square root of the specific gravity. This is by definition and this Wobbe number is also called Wobbe index, Wobbe index or Wobbe number and the value generally lies between 1100 and 1400, understand this that this Wobbe index is calculated based on the HHV and not from the average Wobbe number of the constituents.

So, because we are talking about the fuel as a whole. So, we will be talking about the highest amount of energy that is obtained by the combustion of the fuel and this Wobbe number like perhaps, you know, we have octane number certain number for other gases diesel etcetera.

So, Wobbe number is adjusted by blending with natural gas with air. So, we blend the this blend means we dilute it, we dilute it and adjust this Wobbe number and this by blending what we are doing we basically change the heating value of the gas and this has to be carefully done. So, that we can keep a balance between the Wobbe number and the high heating value.

So, we should not make it. So, dilute that it loses its utility.

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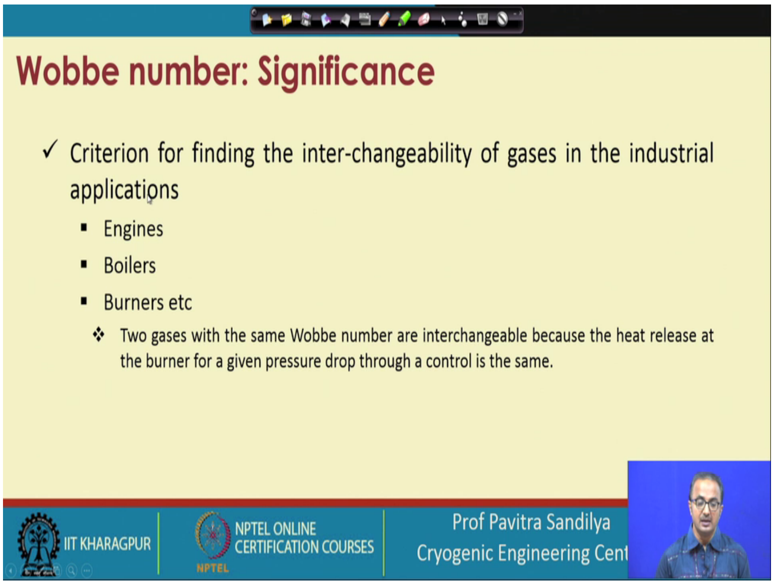

Now, significance of this thing that it is a criterion for interchangeability of gases interchangeability is means that two gases with the same Wobbe numbers are interchangeable why because when we are combusting these gases for a given at a given pressure drop through a burner, we will be having the same amount of combustion value. So, that is why it is important for us to know the Wobbe number.

So, we may have different gases we may not be having the same gas available to us all the times, but if you have even if we have different gases, but if they are Wobbe numbers come out to be the same, then we can interchange these gases and these are used for various applications like engines, boilers, burners, etcetera.

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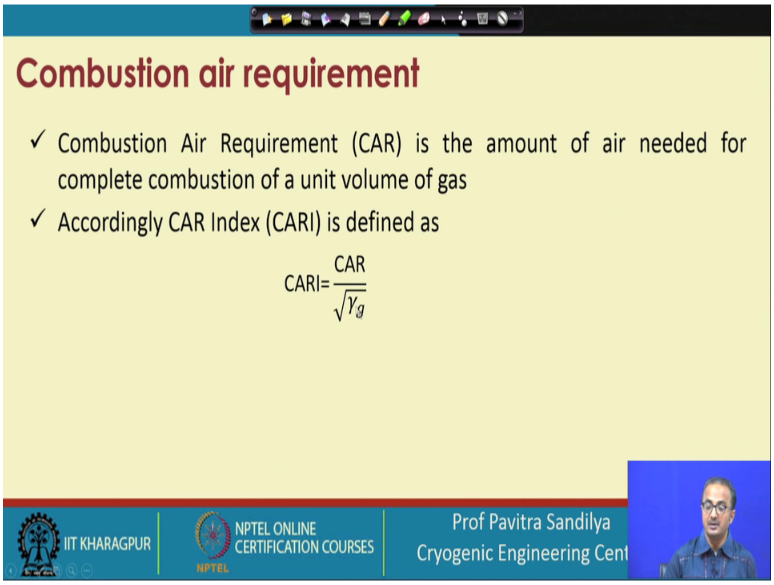

Next important parameter is the combustion air requirement combustion air requirement means it gives us that how much air we need to combust a given fuel completely. Now air means basically from air, we are deriving the oxygen. So, oxygen is one which causes the combustion. So, we need to know that how much of the air is needed to make the fuel burnt completely and here the amount of here needed.

ah This combustion air requirement is based on the unit volume of the gas; that means, per cubic meter or per liter of the gas how much air is needed and this is in short given by car combustion air requirement and analogous to Wobbe number here, we have also another parameter that is CARI that is combustion air requirement index and which is defined like Wobbe number like the car value divided by the square root of the specific gravity of the gas.

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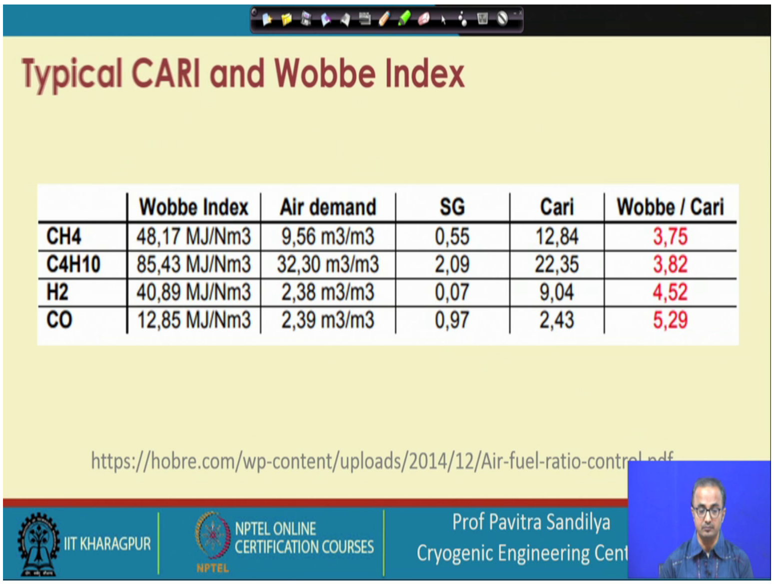

	Wobbe Index	Air demand	SG	Cari	Wobbe / Cari
CH4	48,17 MJ/Nm3	9,56 m3/m3	0,55	12,84	3,75
C4H10	85,43 MJ/Nm3	32,30 m3/m3	2,09	22,35	3,82
H2	40,89 MJ/Nm3	2,38 m3/m3	0,07	9,04	4,52
CO	12,85 MJ/Nm3	2,39 m3/m3	0,97	2,43	5,29

And in this particular table, we have shown some of the values of the space this Wobbe index, then the air demand, then in this and then the specific gravity then car I value and the ratio of the Wobbe number to CARI, here we have listed methane then butane and the methane represents natural gas this butane represents the LPG and this the for the hydrogen and carbon monoxide means carbon monoxide plus oxygen can give carbon dioxide.

So, here we see that it is not worthwhile to combust carbon monoxide, but other things are giving very nice thing, here we see that the air demand for the various fuels also change like here with the for the LPG we need the highest air, whereas, it is quite low for hydrogen and then also for methane and then these are the specific gravities and we find that the LPG is heavier than air and; that means, if it leaks, it will settle down it will come down rather and whether there whether the natural gas and the hydrogen will move up the air and these are the CARI values of these and lastly, we have the Wobbe index and the CARI value ratio.

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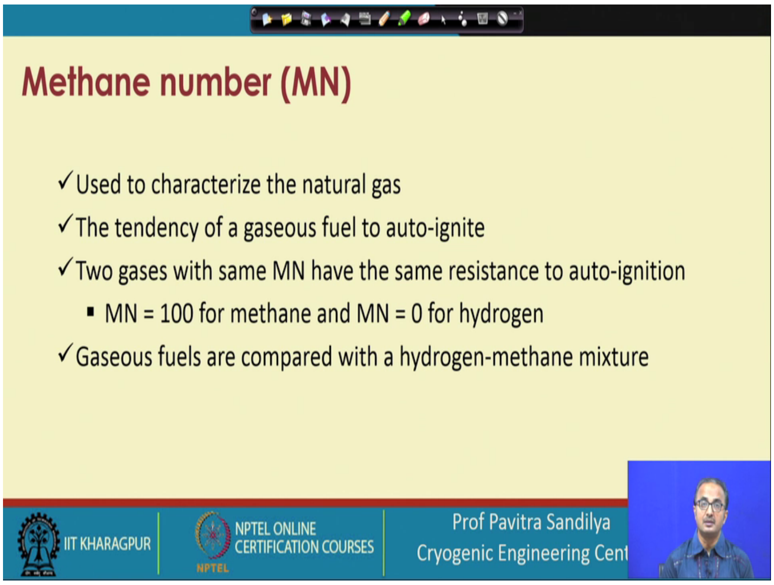

Next, we have the methane number methane number is another parameter which is used for the characterization of the natural gas this signifies the tendency of the fuel to auto ignite auto ignite means without any pressurization or temperature thing we just it on its own it will ignite in the presence of the oxygen.

So, that is given a methane number and two gases with the same methane number have same resistance to auto ignition. So, here we see that methane number is given arbitrarily make a scale of methane number in the scale the 100 methane number is given to methane and 0 to hydrogen, it means hydrogen has this tendency to self ignite in the presence of air, whereas, methane will be igniting very quickly much much easier in a easier than hydrogen and various gaseous fuels are compared with this hydrogen methane ratio.

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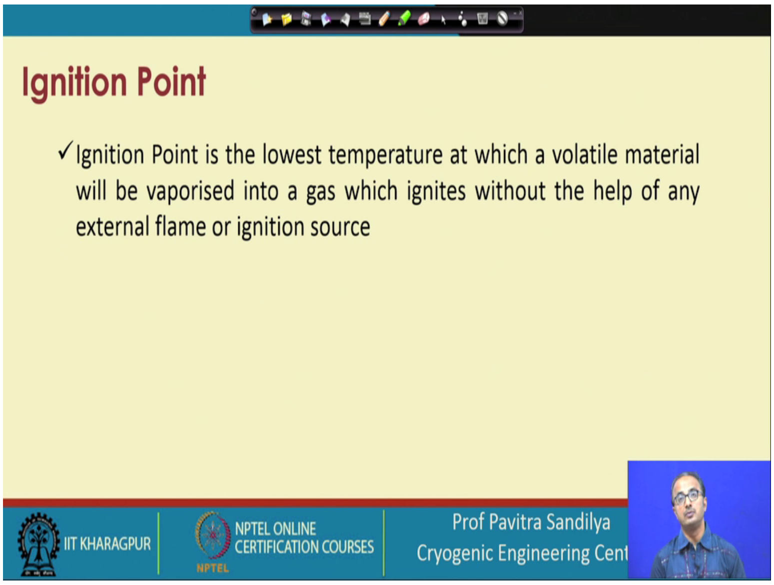

Next is the ignition point ignition point, we also know from the combustion literature that it represents the lowest temperature at which a volatile material will get vaporized into gas and will be igniting with some external flame. So, gas has to volatilized; that means, suppose we are using some liquid fuel like kerosene like diesel like gasoline. So, first these things have to go into the vapor state and then they will ignite. So, of course, natural gas is un unless, it is LNG it is already in the vapor state. So, the first vaporization followed by the combustion.

So, the temperature which will be needed to first cause the vaporization and then combustion the minimum temperature that temperature is called the ignition temperature; that means, if the initial temperature is lower, then that particular fuel will be easily combusted and it will be easily used for getting the energy then we have flammability limits.

Now, we have to understand that flammability means it is not that any fuel we take will be flammable at any temperature pressure, why because if fuel can get combusted only if it has the supply of oxygen without oxygen nothing can happen. So, what are the limits is what is the minimum amount or the maximum amount at which because if the amount of fuel is very very low, then also it may not get enough combusted and if it is too high it may be so that it is not getting enough oxygen supply to make it combusted.

So, these limits that what are the minimum and maximum limits for making the fuel burn are given by the flammability limits.

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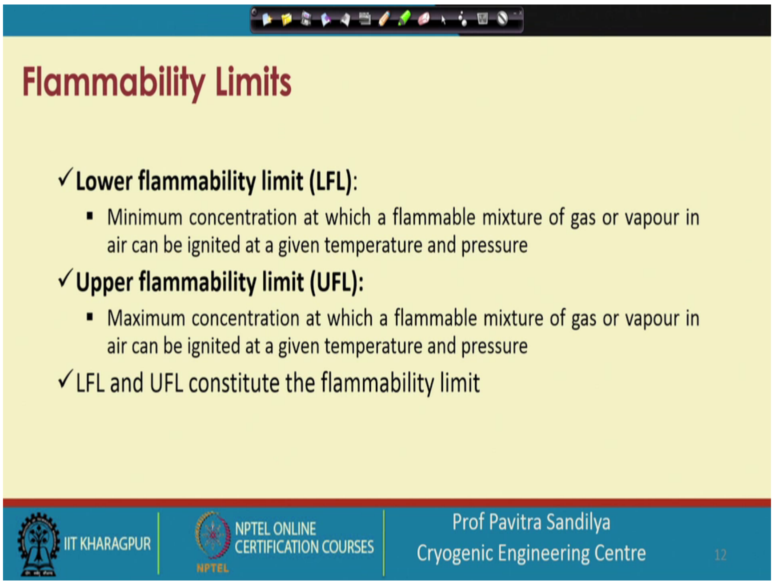

So, accordingly we have two limits first is the lower flammability limit that is given by LFL and it says that minimum concentration at which a flammable mixture of gas or vapor in air can be combusted or ignited at a given temperature pressure as I told you that if it falls below this minimum it will not be getting ignited.

Similarly, there is something called upper flammability limit that is given by UFL and this UFL signifies the maximum concentration at which a mixture of gas or vapor can get ignited at a given temperature pressure. So, this LFL and UFL are functions of the temperature pressure dip at different temperature pressure we will be having different flammability limits for the same kind of fuel. So, we can adjust the temperature pressure to see to it that when we are storing or transporting the particular fuel, we are well outside the flammability limits.

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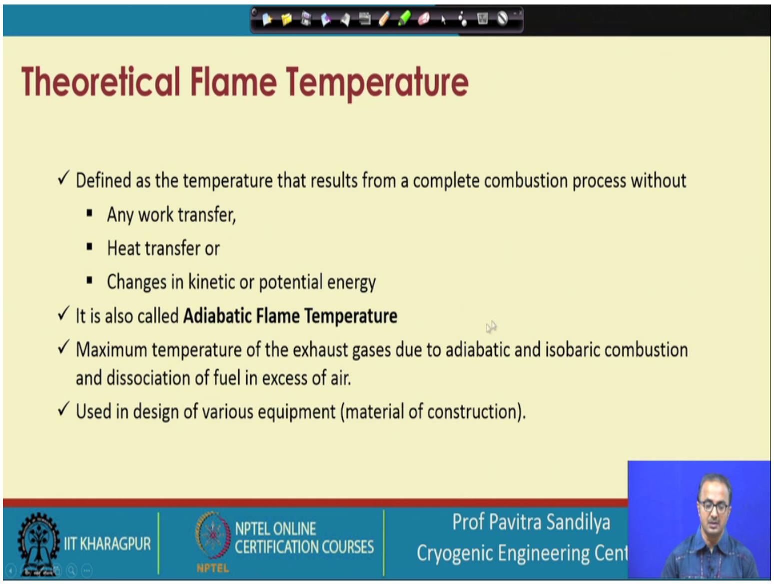

Next we have theoretical flame temperature which is also called sometimes the adiabatic flame temperature, what it means that whenever we are combusting the fuel that there will be release of energy and that will cause the temperature shoot up.

So, this temperature that results from the complete combustion of the fuel and the conditions are that there should not be any external work transfer or heat transfer or any changes in the kinetic or potential energy of the system only, then whatever combustion happens; that means, we are not compressing it or we are not supplying the heat from the outside.

So, all these things will not be done under natural condition whatever combustion takes place complete combustion takes place from with that whatever temperature is reached the maximum temperature reached is called the theoretical frame temperature and why it is important because the maximum temperature of the exhaust gasses due to this due to adiabatic and isobaric combustion and dissociation of fuel in excess air.

So, this are maximum temperature and it is used for designing various types of equipment in the sense that if I know the highest temperature attainable by the particular fuel, I have to choose a suitable materials of construction of the various types of equipment, otherwise, what will happen, this high temperature may cause damage to the particular equipment. So, that is why it is important for us to know the theoretical flame temperature.

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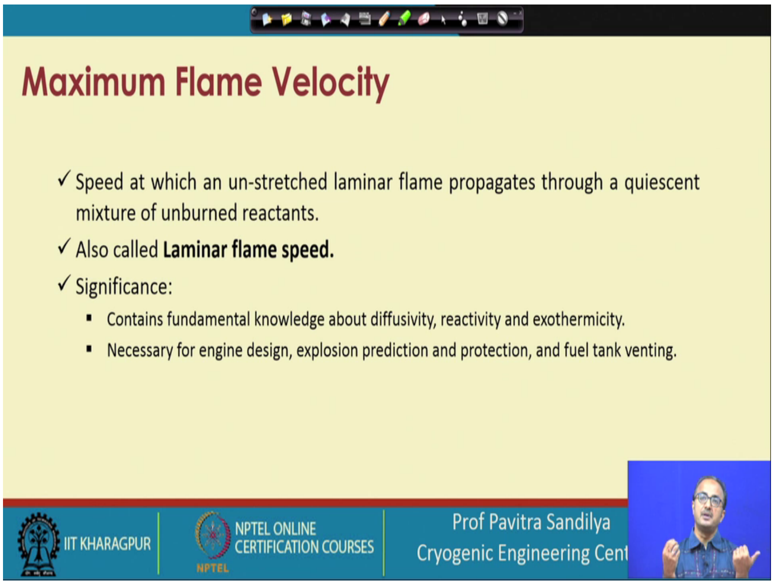

Next, the flame velocity; now as you have seen an observed around that whenever some particular combustion or some curve some there is some kind of fire any place, you see that the also the places around that place of combustion gets affected if the fire get spread. So, there is spreading of fire and the spreading of fire determines the speed at which the other associated area surrounding areas can get affected.

So, this flame velocity is a very important parameter to understand the danger from the combustion of any fuel. So, first let us see the definition that each gives the speed at which and on straight laminar flame propagates to a quiescent mixture of unburned reactants. So, quiescent mixture means the mixture is stagnant quiescent. It is not moving here and there and the unstretched means we are not trying to means make some external effort to stretch the particular flame.

It is just on its own water is coming out that is moving away that is spreading here and there that is the flame velocity because if I am suppose I am using a fan the flame may be forced to propagate in a at a separate velocity. So, it is not by some external means on its own how much it is spreading in the surrounding areas that is given by the flame velocity and sometimes, it is also called laminar flame speed because a the process this the velocity is not too high it goes as a laminar fashion. So, it is called laminar flame with a speed.

The significance of these are that it gives fundamental knowledge about the diffusivity reactivity and exothermicity means how the frame; frame is diffused through the air and surroundings and the reaction rates which are reaction because after the combustion or reactions between oxygen and the particular fuel and the how much energy is getting released and that energy disease is important because that energy is also carried by the flame.

So, it is this in kind of information is provided by the flame velocity and these information are necessary for designing of engines and to predict and to protect any kind of explosion whether they will be explosion or not and if there is explosion how we can protect it all this information are given by the flame velocity and in fuel tank venting because venting means we release any kind of overpressure is happening the fuel tank.

So, we so, that that may not lead to any kind of combustion in presence of the air and we vent it out into the atmosphere and these things all these things are given from flame velocity.

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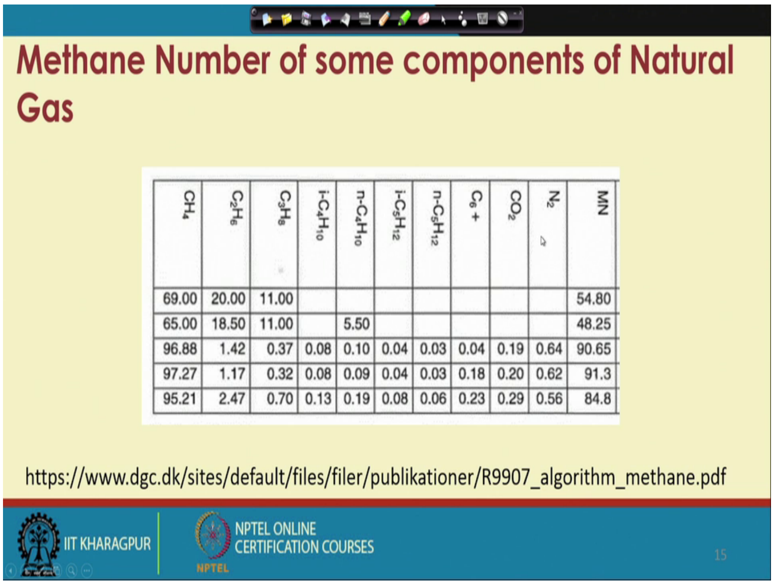

CH_4	C_2H_6	C_3H_8	$i\text{-}C_4H_{10}$	$n\text{-}C_4H_{10}$	$i\text{-}C_5H_{12}$	$n\text{-}C_5H_{12}$	C_6 +	CO_2	N_2	MN
69.00	20.00	11.00								54.80
65.00	18.50	11.00		5.50						48.25
96.88	1.42	0.37	0.08	0.10	0.04	0.03	0.04	0.19	0.64	90.65
97.27	1.17	0.32	0.08	0.09	0.04	0.03	0.18	0.20	0.62	91.3
95.21	2.47	0.70	0.13	0.19	0.08	0.06	0.23	0.29	0.56	84.8

And here in this particular table we have provided the methane numbers of some of the components like methane, ethane, propane, etcetera, etcetera, and also nitrogen and we can see that nitrogen has very low methane number.

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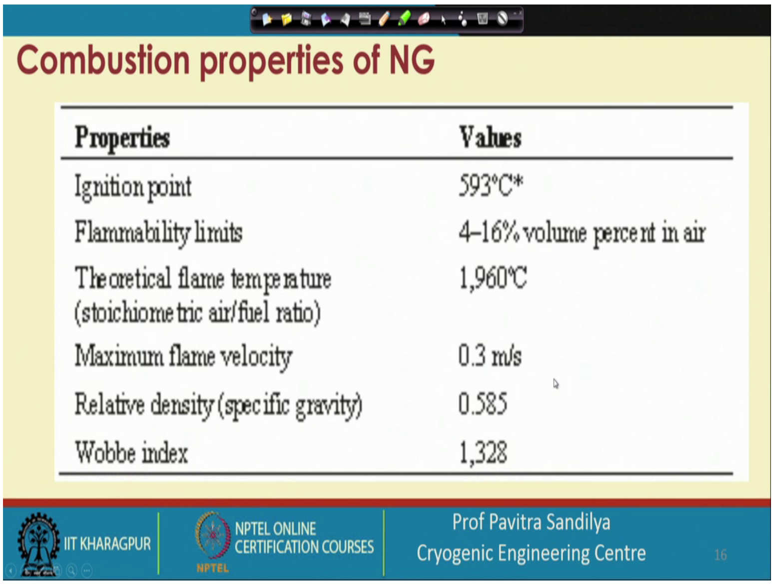

And lastly, we come to the combustion properties typical combustion properties of natural gas here we have give you some typical values like the ignition point, it is quite high the flammability limits, we see it goes from 4 to 16 volume percent in air then theoretical flame temperature it is about 2000, which is quite more than the angstrom temperature as expected and then we have the maximum flame velocity as 0.3 meter per second.

We can see that it is not much it is only thirty centimeter per second then specific gravity is about 0.585 which is; that means, it is lighter than air and the Wobbe index is 1328 and these are the references which we may refer to learn more about these topics.

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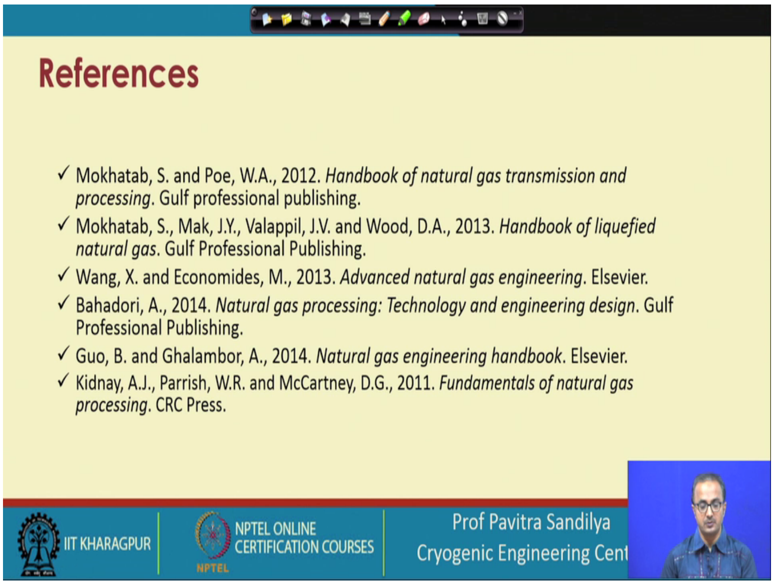

Thank you.