Upstream LNG Technology

Prof. Pavitra Sandilya
Department of Cryogenic Engineering Centre
Indian Institute of Technology, Kharagpur

Lecture – 10
Thermophysical Properties of Natural Gas- I

Welcome, today we are going to look into the various properties of Natural gas and the estimation methods. As we know that the properties play a very important role in any system because the determine the way is system would behave and with the help of the properties, we can analyze a system as well as we can design any kind of process. So, it is very important for us to know the various types of properties and you know that they are so many properties which determine or characterize a particular system behavior, but it is not feasible for us to list out, all the properties we shall be looking into some of the significant ones which are generally used for the analysis and design of the various processes.

And whatever I shall be talking to you about the properties, please keep in mind that the research is ongoing to estimate the various properties and especially in case of natural gases the task becomes still more complicated because the natural gas comes with so many types with so many variations in the type of components, so many variations in the composition that it becomes in feasible at times to give a generalized correlation or some equation to estimate the properties of all types of natural gas.

So, the research is ongoing till now to take up the different types of natural gases and to develop different types of correlations based on the previous data and also based on the new observations. So, in this regard, what I have done that I have divided my lecture of the properties into 2 parts. So, today, we shall be looking into the first part of the lecture on the thermo physical properties of natural gas.

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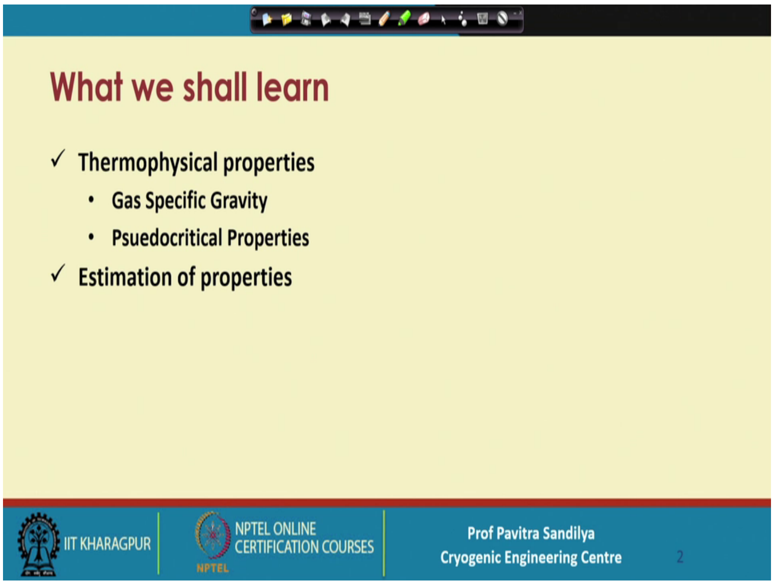

Now, in this particular lecture, we shall be learning about the various types of thermo physical properties and under this, we shall look into the gas specific gravity and pseudo critical properties and we shall see how to estimate this two types of properties.

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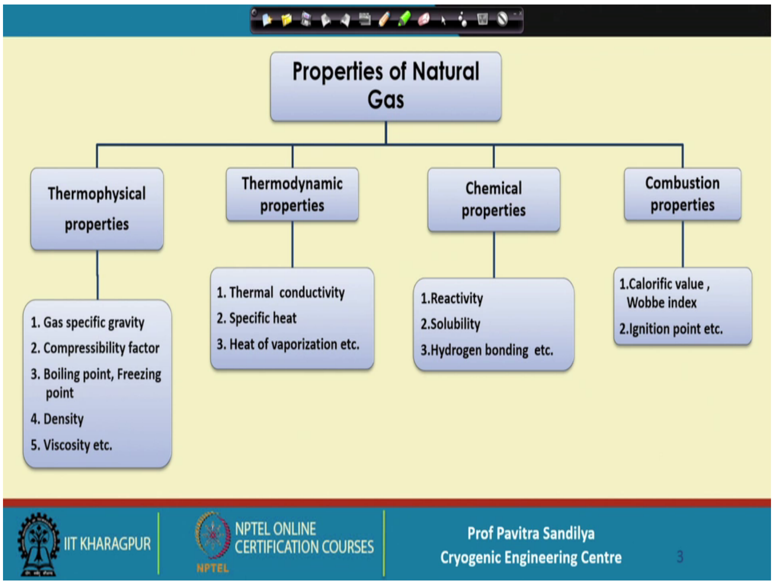

Now first let us see that, what are the classifications of the various types of properties of natural gas the classification. First is the thermo physical property and then thermo dynamic property chemical property and combustion property. So, thermo physical property, it means that those properties, which are dependent on the temperature that is the thermo dynamics, thermo physical properties and they also includes some of the physical properties also about which we shall learn later here under this, we have gas specific gravity the compressibility factor boiling point freezing point density, etcetera.

Similarly, we have thermo dynamic properties under which those properties, which are necessary for understanding and studying the energy transfer, there we have the thermal conductivity specific heat; heat of vaporization heat of fusion heat of sublimation, etcetera.

Then we have the chemical properties, this is especially true for the natural has because natural gas have many components which may be reactive which may be solubility to other liquids. So, here we have the reactivity solubility and hydrogen bonding which is not a property in itself, but it dictates many of the properties of substances, especially, we know that in case of water this bonding plays a very very significant role.

And lastly, we have another property which is unique to natural gas and oil that is the combustion properties because they determine the type of the natural gas in the sense that how much energy, we may be able to derive by the combustion of the natural gas or the oil. So, these are related to the calorific value and there is something another parameter that is a verb index and the ignition point, etcetera.

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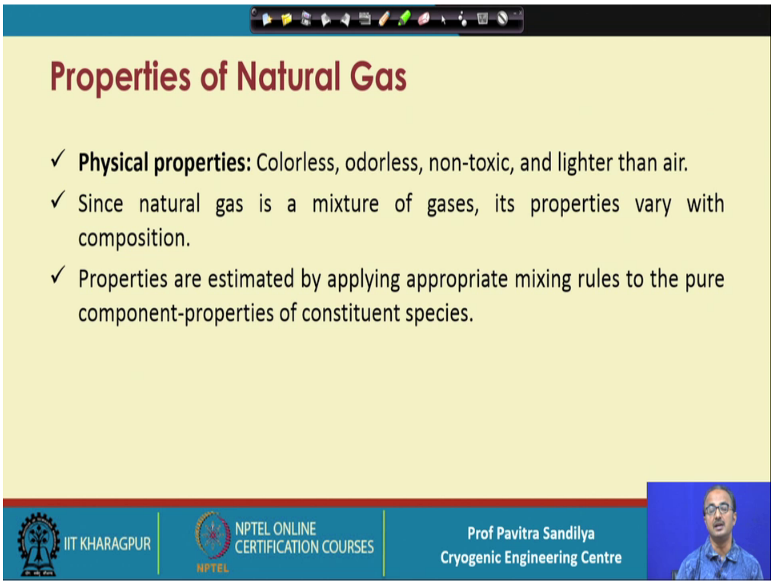

So, first we shall let us go into the physical properties of natural gas, it has been found that natural gas is colorless odorless and non toxic and lighter than air when we say non toxic of course, it means that general, it is under normal conditions if you take it, it will not be causing any kind of problem unlike carbon monoxide or carbon dioxide and lighter than air means it will be always be if there is any kind of leak, it will move up the air and will get dispersed. So, that is the meaning of the significance of lighter than air.

Since natural gas contains several components. So, as I told you that its property would be varying with the composition of the natural gas, hence, we find the natural gases which are there in the different reservoirs, the world over will be showing different types of characteristics and behavior when they are handled for the various certain processing we do with the natural gas.

The properties are estimated by using some appropriate mixing rule mixing rule why we need mixing rule because we might be knowing the properties of the individual components of the natural gas, but when we want to find the average property of natural gas, we need a appropriate mixing rule and we have to understand the mixing rule is not a very simple job because there are again you have to figure out that what kind of mixing rules will be appropriate under certain conditions.

And several researchers the world over are working on the on evolving a mixing rule if the existing ones are do not apply. So, this is very important to know that mixing rules have to be appropriate the chosen to find out the overall property of the natural gas.

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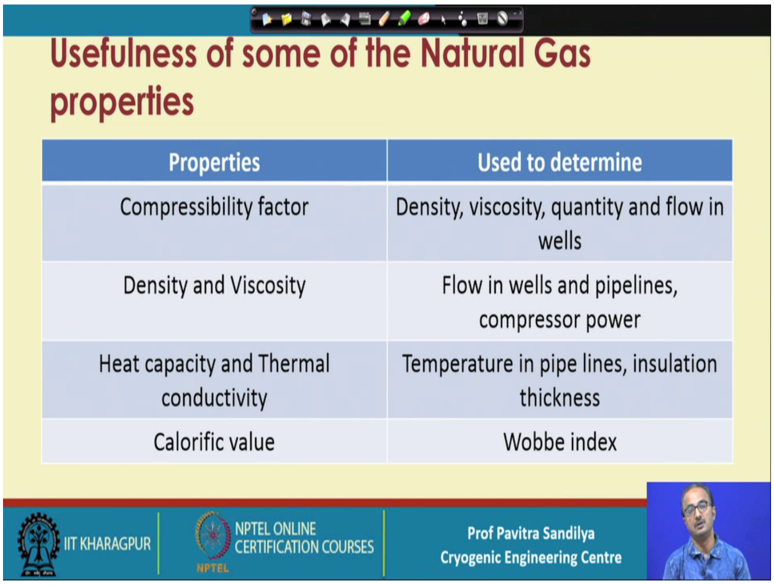

Now, let us see that why means some significance of the properties like for example, we come to compressibility factor perhaps you will know about it and we shall learn about it also there to this, compressibility factor is used to find out the density viscosity and again, this density viscosity dictate the flow characteristics for example, you know that Reynolds number has both the density and the viscosity in it. So, it determines the type of flow, we shall be having in a pipeline and how much will be the resistance to the flow into the pipeline that is this determined by the viscosity. So, and these quantities density viscosity they are obtained from the compressibility factor.

And again density and viscosity themselves are determining the type of flow and also the compressor power; that means, if you are using any kind of pump or compressor, then how much power is required for to make the flow happen will also be determined by the density and the viscosity.

Next we look into heat capacity and thermal conductivity we know that heat capacity is the amount of energy needed to change the temperature by a degree per unit mass of the particular substance there is a heat capacity. So, how much and that also signifies the time or how easy or how difficult it will be to change the temperature of a particular substance that is the significance of the heat capacity means how much energy.

It can retain inside itself is the heat capacity and thermal conductivity signifies that how fast the energy can be conducted from one location to the other. So, that is the significance of the thermal conductivity and these 2 properties dictate that whenever some there is a kind of flow inside any pipeline or any kind of system equipment, then these two properties determine that, how much energy will be stored by the particular substance as well as how this energy will get dispersed into the system and this energy dispersion as we know they dictate the temperature distribution inside a system.

So, this is very important for us to know that whether the particular system is going to cool down or whether it is going to heat it up. So, these all these characteristics are dictated by heat capacity thermal conductivity in addition in addition to the type of flow ok. So, when if you look into the energy balance equation, you will find there are some convictive term, there is some conductive term the convictive term comes due to the flow of the system.

So, in case of flowing fluid, this both the conductivity specific heat in addition to the density viscosity will determine the distribution of the energy which in turn will be reflected in terms of the temperature profile inside the system. So, that is why it is also important for us to know the how to obtain the values of the heat capacity and the thermal conductivity.

Next comes the calorific value and as we know this signifies the amount of energy that can be derived by combustion for example, in our home we are using LPG every time, every day, we are using LPG and nowadays, we are also getting LNG or CNG at our in some vehicles or for household uses, we find that all these LPG or LNG or CNG whenever, we are burning them every time we are burning them and combusting them and we are deriving the combustion in energy and we sometimes are using it to propel or various types of vehicles or we are also using this energy too for our cooking purpose.

So, this is very important for us to know important for us to know that how much energy, we can derive by combustion; combustion of these gases and that is signified by the calorific value and there is something called Wobbe index about which we shall be studying later.

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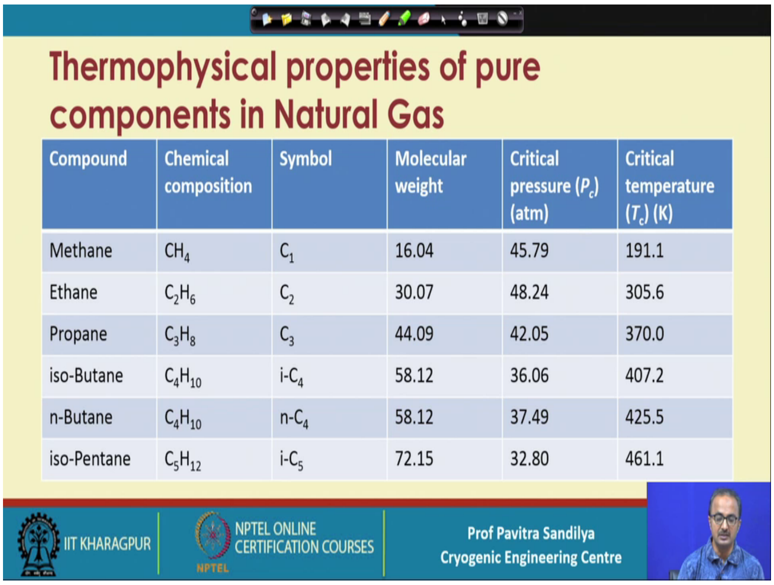

Thermophysical properties of pure components in Natural Gas

Compound	Chemical composition	Symbol	Molecular weight	Critical pressure (P_c) (atm)	Critical temperature (T_c) (K)
Methane	CH_4	C_1	16.04	45.79	191.1
Ethane	C_2H_6	C_2	30.07	48.24	305.6
Propane	C_3H_8	C_3	44.09	42.05	370.0
iso-Butane	C_4H_{10}	i-C_4	58.12	36.06	407.2
n-Butane	C_4H_{10}	n-C_4	58.12	37.49	425.5
iso-Pentane	C_5H_{12}	i-C_5	72.15	32.80	461.1

Now, here in this particular table, what I have shown is to the just give you some idea about the thermo physical properties of the various components present in the natural gas and here, I started with methane because methane is the main component of the natural gas, generally, it will be in a good reservoir, it will be above 80 percent or more. So, methane, this is chemical formula is CH 4 and it is written like as C 1; C 1 components methane and its molecular weight is 16 critical pressure critical temperature are also given here.

So, we find that all these components have a methane ethane propane iso-Butane, n-Butane, iso-Pentane, etcetera, they have been represented by different types of symbols C 1 for those hydrocarbons, we have only 1 carbon and C 2 are those which have 2 carbons, C 3 means those hydrocarbons, we have which have 3 carbon and similarly and so on and each of them, we find that they have different types of molecular weight and the critical pressure and critical temperature and these values are necessary.

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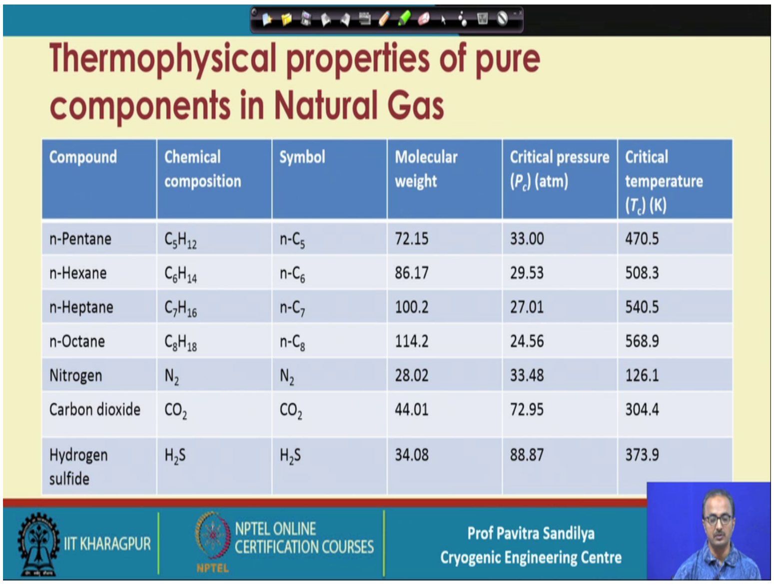

To find out the overall property of the natural gas in this table, again, we find some other components like pentane hexane, heptanes, octane.

Now, we have stopped up to octane because we have to remember that natural gas cannot have a too heavy hydrocarbons because if heavy hydrocarbons are there in a in his system, then they will tend to go to the liquid phase rather than staying in the vapor phase. So, natural gas generally contains up to O C 8 component, C 8 component that is octane and other components which are also present in natural gas are nitrogen, then carbon dioxide hydrogen sulfide and we showed in our previous lecture likes norm some kind of radioactive materials are also there in the natural gas.

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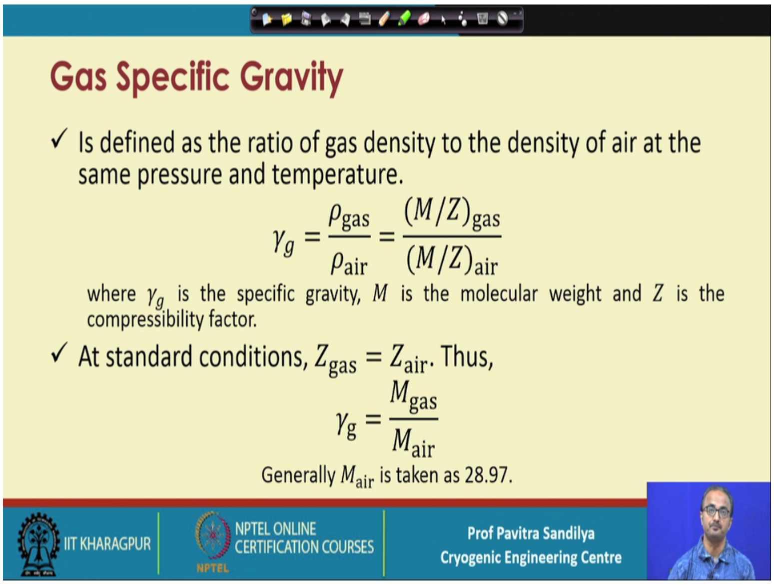

Now, now let us start seeing that how we estimate the property of natural gas in this case, first, I start with the gas specific gravity specific gravity we already know that is it represents a kind of a ratio between the density of a substance to the density of a standard substance. So, the people can use different types of standards somebody use can use water as a standard generally we use water standard sometimes for gases we use air as standard.

So, the specific gas specific gravity, in case of natural gas is defined like this the way, we define it in general that gamma g is the gas specific gravity and is defined as the density of the gas to the density of the air, we have to remember that when we talk of density of the gases and because the gases are compressible. So, their densities are a very strong function of both pressure and temperature.

So, whenever we are saying that the ratio of the density of gas to density of air, we have to we have to understand that these referred to some specific temperature pressure. So, with respect to that we talked and here, we show that how we can represent the density in terms of a compressibility factor, I as I told you in the earlier slide that this compressibility factor is a very important parameter to find out density and the viscosity. So, here we find that we are representing the gas specific gravity in terms of the compressibility factor.

So, here this M represents the molecular weight and Z represents the compressibility factor and at standard conditions as you know there are stp conditions the generally the compressibility factor of the gas and air are almost the same. So, if these to Zs are same then we can write this gas specific gravities simply as a ratio of the molecular weights the mole ratio of the molecular weight of the gas to the molecular weight of the air and perhaps you know that generally not, we take the molecular weight of air about 29.

So, this is the value we take or 28.96 to be more specific. So, this is the kind of well we take for the air and we can find the gas specific gravity.

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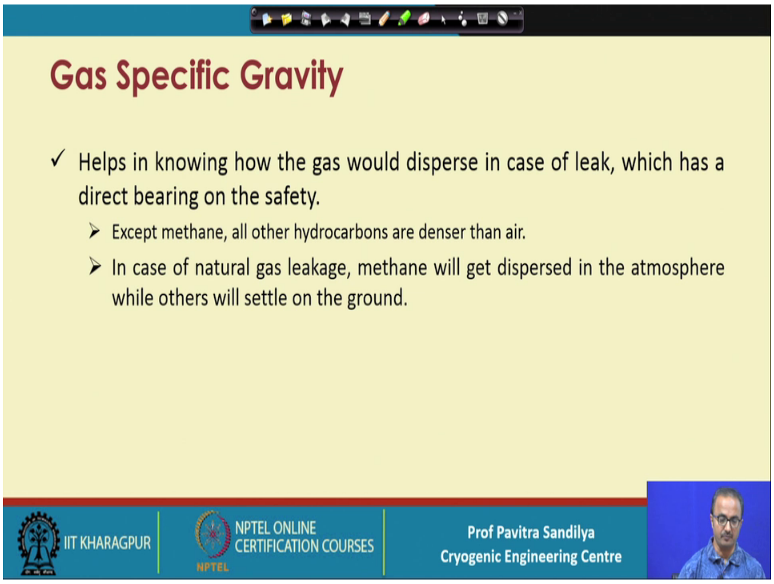

Then we know that this if I know the value of the specific gravity, then we know that how a gas would be behaving when it leaks and leakage is very we have to know the leakage behavior because that is a direct bearing on the safety of the safety because if some gas some toxic gas is not dispersing well, it is settling down like what happens in case of LPG, it may settles down because its heavier than air. So, it will have a direct safety issues all those.

So, it is important for us to know the gas specific gravity except methane all hydrocarbons are denser than air that because the natural gas is primarily methane that is why generally natural gas is lighter than air, but if you look at LPG, which is basically iso-Butane and some amount of propane. So, that is heavier than air. So, if there is any kind of gas leakage from the gas cylinder at our home then it will settle down rather than moving up.

So, that is the knowledge we gather from the gas specific gravity. So, in case of natural gas leakage, we find the methane will get dispersed in the atmosphere while the other components like ethane, propane, etcetera, they will tend to settle down. So, methane will be going into the atmosphere. So, it will move away from the point of leakage.

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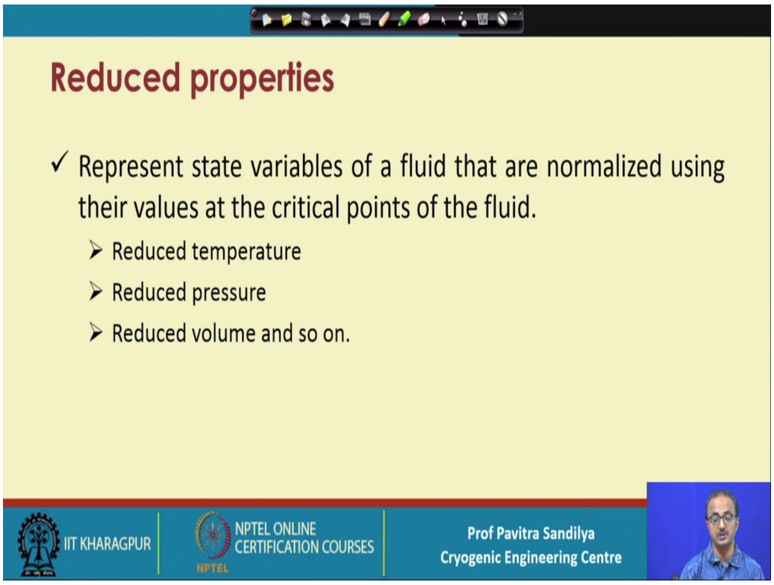

Now, next we come to another very important set of properties, before we proceed to find out the other properties reduced properties. Now why we need reduced properties you know that when whenever we are talking of any kind of density other properties there are so different components we have different combinations of temperature pressure, according to which we shall be having different property values, it becomes a mind boggling affair to archive or to put all these to develop any kind of database.

So, one way to ease out the representation of the properties is through these reduced properties and what a reduced properties reduced properties represent the state variables of any fluid that are normalized by using the critical values of those variables, what is the meaning of the state variables state variables are those variables which represent the state of a system, for example, we represent in terms of pressure temperature volume, etcetera. So, these are state variables and when we normalize them using their values at the critical point, we have the reduced values.

So, in that manner, we have here reduced temperature we have reduced pressure reduced volume and so on so forth. Now once we now let us take one by one all of these.

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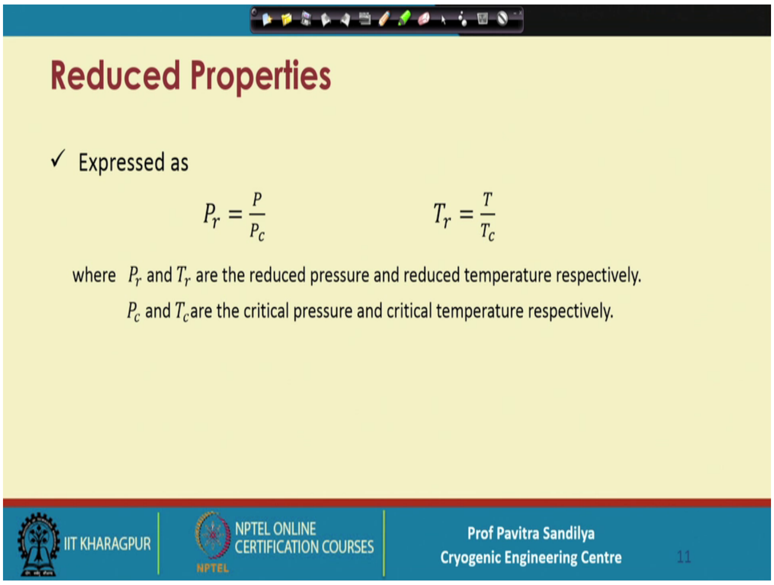

First, we come to the general definition of reduced pressure and reduced temperature here first we have the reduced pressure this reduced pressure where these values are given by a subscript r. So, Pr means reduced pressure similarly here Pr means reduced temperature and these are defined as the value actual value to the critical value. So, in case of reduced pressure, we have the ratio of the pressure to the critical pressure. Similarly, for the reduced temperature, we have the temperature divided by the critical temperature.

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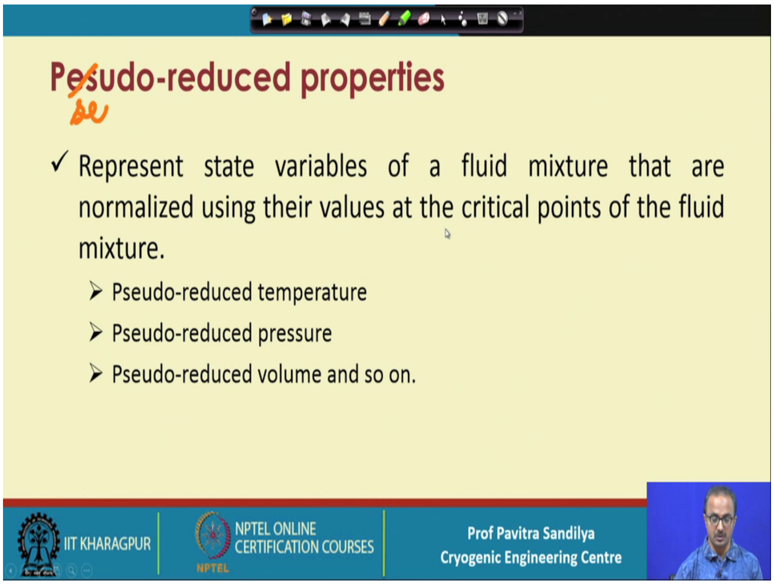

Now, when we talk of a mixture of gases like natural gas, we do not have a singles critical value of any of the properties because it has means several gases with it. So, in that case, we have to figure out that how to represent the reduced values to know that we need to know how to have the reduced critical reduced sorry the overall critical values.

So, first let us go to the definition that reduced properties it is similar to the reduced properties the pseudo reduced properties we define pseudo means it is not actual there is a slight mistake in the spacing, it will be se. So, it is pseudo reduced property in which is means it is not actual it is fictitious. So, this all sometimes they call it apparent.

So, this pseudo reduced properties are defined in similar manner as reduced properties for the pure components like the ratio of the state value of state variable to their average values at the critical points.

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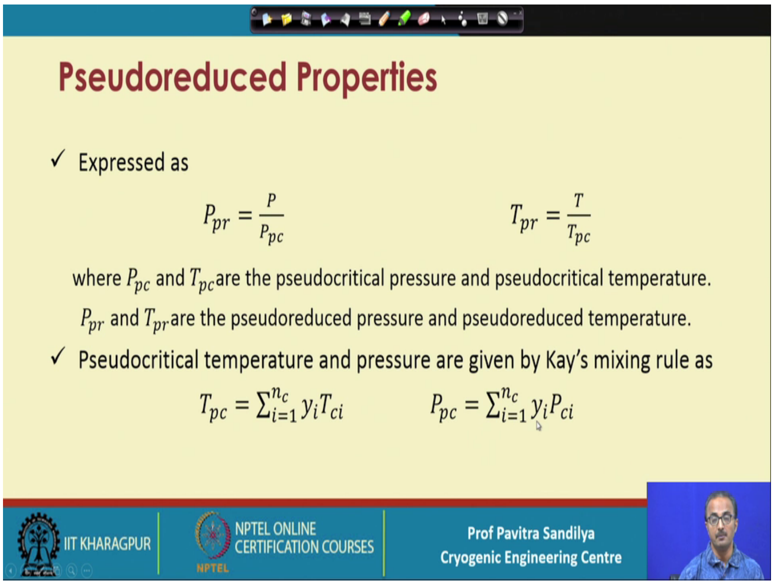

So, similar to reduced temperature reduced pressure etcetera we have the reduced, we have the definitions for the various reduced properties and these are the pseudo this P for pseudo and r for reduced to pseudo reduced pressure, pseudo reduced temperature this is defined as the pressure divided by the pseudo critical pressure and then this is pseudo critical temperature.

Now, there are various types of mixing rule and very common mixing rule is given by k and this k gives a mixing rule as the pseudo critical as some kind of average weighted average with respect to the mole fraction. So, this Tpc is equal to summation of the product of the mole fraction and the critical temperature of each of the components, similarly, the pseudo critical pressure is the summation of the product of the mole fraction and the critical pressure of each of the components that is the mixing rule for pseudo critical temperature and pseudo critical pressure.

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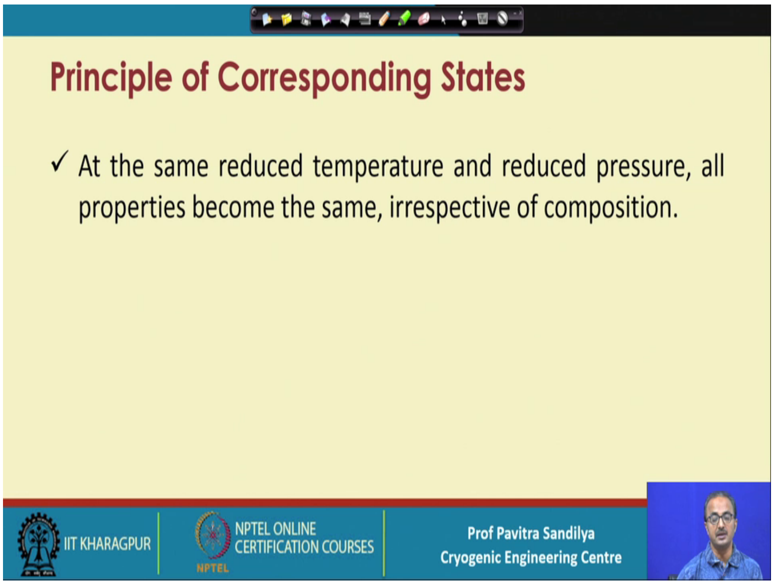

Now, there is a very important principle there is a principle of the corresponding states which perhaps, we know already it says that the says that at the same reduced temperature and reduced pressure all properties become the same, irrespective of the composition and this way it makes our life easier to maintain the databases.

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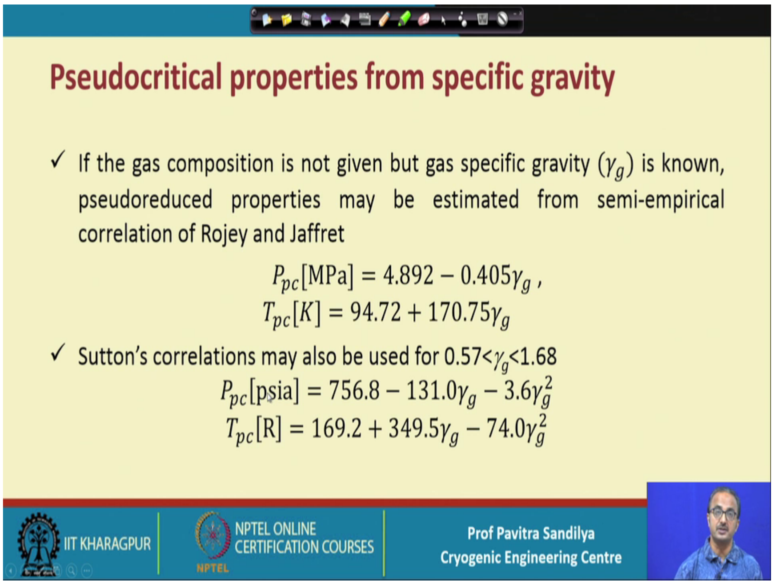

So, if you know the reduced temperature reduced pressure of various types of gas samples we know that their reduced properties will also be the same.

So, before we go on to talk about this more, we see that how we represent these pseudo critical properties from the specific gravity, if we do not know the composition of natural gas sometimes may it may so happen, we do not have the analysis, but we know what we know the specific gravity.

So, in this these two equations, we find the pseudo critical properties have been given in terms of the specific gravity. So, this will not need the knowledge of the composition of the natural gas and this is another set of expressions for the pseudo critical pressure temperature, that is given by certain and this is another thing, but here you see there is a restriction on the value of the specific gravity. So, within this zone this particular expression may be used without knowing the actual composition of the gas.

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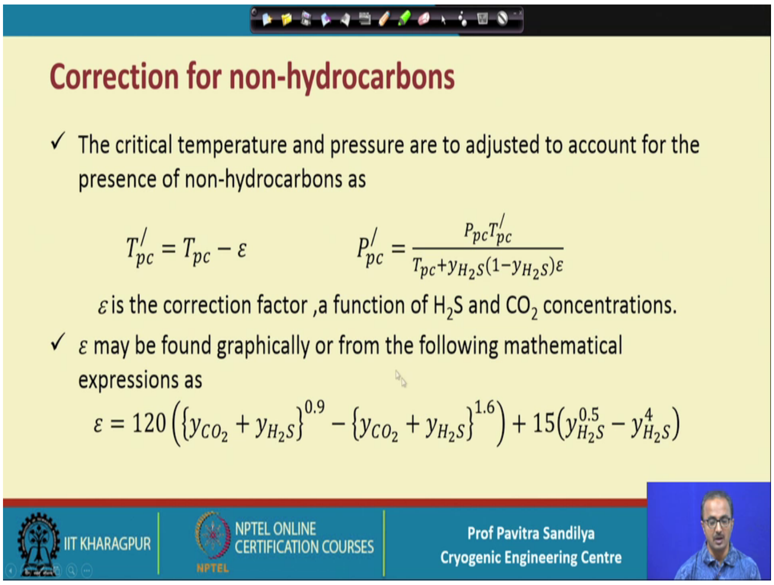

And also it is also important for us to know that these properties are affected by the presence of the non hydrocarbons. So, here we have found, there is people have proposed various types of correction factors, this prime represents the corrected pseudo critical temperature and the corrected pseudo critical pressure and this epsilon is the correction factor which accounts for the presence of the carbon dioxide and the H 2 S and this may be obtained graphically or from these following correlations and in this correlation this, we find that the correction factor has been correlated with the mole fraction of carbon dioxide and the hydrogen sulfide.

So, this expression may be used and incorporated here to correct the pseudo critical temperature and pseudo critical pressure.

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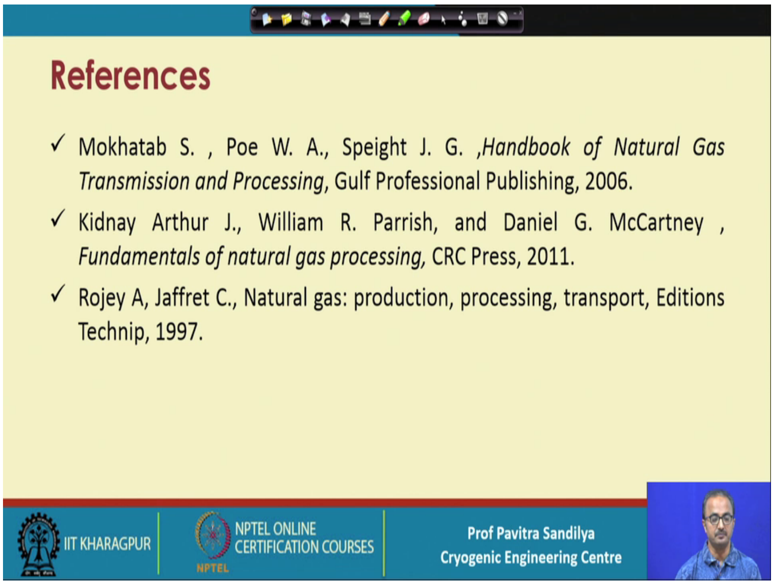

With this, we come to an end to this first part of the property estimation and these are few of the references, you may refer to for further understanding and analysis.

Thank you.