Natural Gas Engineering
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Module No # 01
Lecture No # 04
Properties of Natural Gas – I

Hello to everyone and welcome to the class of natural gas engineering in today's lecture we will understand why natural gas properties estimation is important. How they are going to play important role in overall dealing with natural gas?

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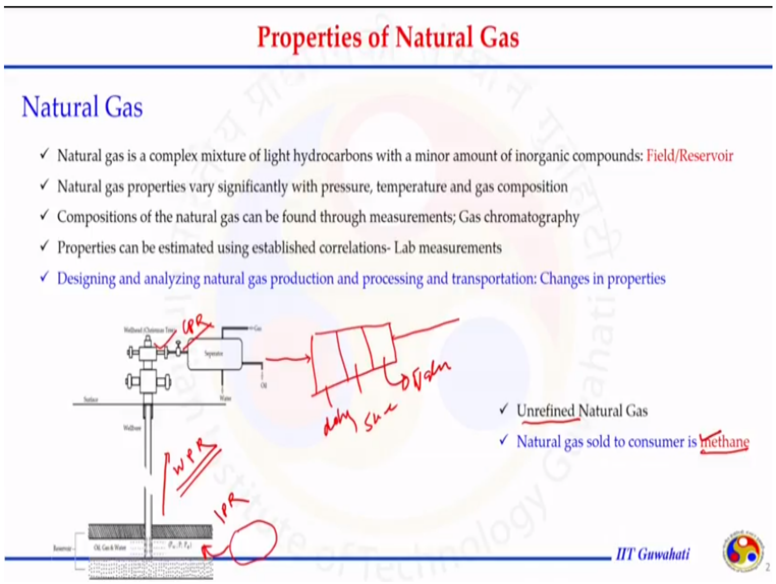

So if we go to our natural gas production system we see the natural gas produces from the reservoir it travels long distance from wellbore to bottom of wellbore to top then it goes to separator and several process units and then finally it gets transport to consumer so if I say the natural gas is a complex mixture of hydro carbons with a minor amount of in organic compound that depends on field reservoir particular well.

So a particular field may produce a natural gas with different composition, the composition of natural gas vary from well to well and from one during the processing the one point to other point from composition may vary. Not only the composition the operating condition like temperature pressure also vary as natural gas is not a ideal gas, not a pure gas, it is a real gas compressing gas thus the property changes.

The composition natural gas can be formed so when the natural gas is being produced from a particular well how to find out the what are the composition those natural gas are those hydro carbon dominating or which hydro carbon is dominating the composition of natural gas and what are the impurities means inorganic gases CO2, S2S nitrogen and other traces amount are present in the natural gas.

So the analysis of the produce gas can be conducted can be performed with the help of gas chromatography since the gas chromatography we can inject the sample through the injector with the help of the column we can separate the different fraction of the gases mixture and the detector most probably it is the TCD thermo conductivity detector or the (()) (02:44) for having hydro carbon can be used.

TCD allow us to deduct the inorganic gases like S2S, CO2, sulfur dioxide it is present so the composition can be estimated with the help of the gas chromatography once the compositions are not the properties can be estimated with the help of well-established fundamental expression, correlations, charts and some empirical correlation.

These ahh the estimation of this properties is very important as I already mentioned the gas which is not ideal gas it is a real gas changes its properties when it travel from one condition to other conditions thus the designing and analyzing natural gas production and processing as well as the transportation needs how the properties of natural gas are being changed. So in semantic when I had shown here so this is the condition where the natural gas is travel from this reservoir to well bore then it travels all the way to of from bottom of the well bore to top.

Choke devises here at the top CPR we will come to know these term later in the coming lecture this WPR this is IPR. So here the pressure and temperature at different here again the condition got change here the CPR that says the condition of the pressure or the point where the production is controlled the pressure will be different and because of the pressure change the temperature changes.

And then it goes to separator where you are separating the gas, liquid and water if the water and oil is present in the being produce with the gas and after the separator it goes to series of the processing unit where we are separating the water or the water which could not be removed by the separator we go to sweetening processes where we go to remove the acid gases like H2S and SO2, H2SCO2 and then it goes to remove of heavier hydro carbon.

Because those heavier hydro carbons are having more value than the methane those can be sold out separately to generate the money like our LPG that is having more energy than the methane. So here we are having the dehydration systems sweetening system removal of value added hydro carbons and then then it is ready to send to consumer it is mostly the pure methane.

So see here when it was being produced the unrefined natural gases as a variety of the composition including hydro carbon and non-hydro carbon gases. Now when it is ready to send to consumer it is mostly the methane iteration amount of ethane and C2 and C3 gases. So now the composition also getting change thus at each point when we are designing the (()) (05:52) dehydration column sweetening column as well as the pipe line for the production side like the wellbore or choke condition everything.

And similar on the transportation side what size of the pipeline should be there at what flow rate we can do during the transportation we install some compression station. The compression duty required to compress the compress from one pressure to other pressure with all this depends on what type of the natural gas we are dealing what are the composition of that natural gas and what are the properties this natural gas is possessing.

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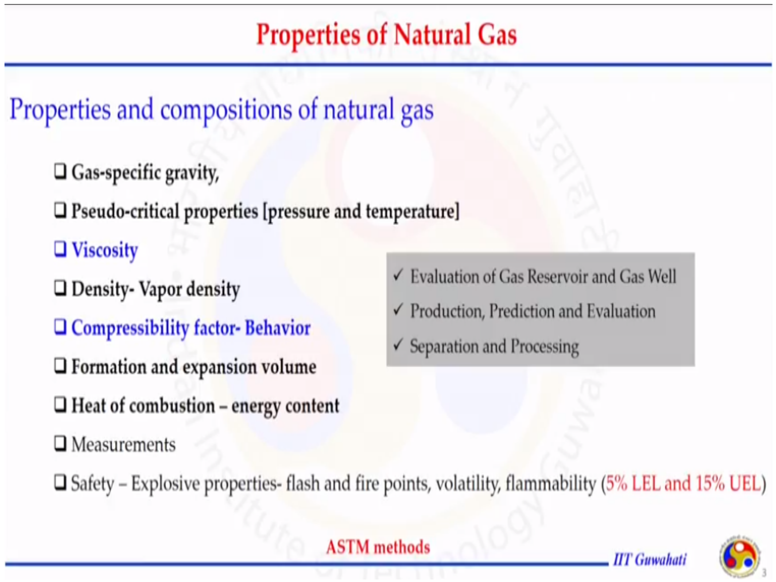

So if we summarize the properties and composition of natural gas are already mentioned composition varies when the composition varies the gas specific gravity are also varies pseudo critical properties also changes with pressure and temperature Viscosity which is very important property also changes density compressibility factor shows the deviation of the natural gas from the ideal gas formation and expansion volume factor.

Heat of combustion that determine the energy contained the natural gas is containing how much energy because is once we transfer the natural gas to end consumer it is being sold in terms of the energy it contains that is measure either in BTU or therm. Measurement when we are measurement when we are designing the measuring device again the properties of natural gas will determine several coefficient those are required to for the measurement.

With the help of any meter or device and when we are transporting this natural gas the safety feature like the explosive properties flash point, fire point, volatility, flammability also need to be known. And for this natural gas the lower explosive limit is around 5% and maximum or upper explosion limit if 15% it means when the natural gas in here the concentration natural gas here is 5% or less than 5% it would not burn and when the concentration is more than 15% again it would not burn.

So the flammability ranges 5 to 15% and all these are required for the valuation of gas reservoir and gas well what is the potential of gas reservoir? What is the potential of gas well? What is the total gas in place? And what rate the gas can produced. The production, prediction, future performance all depends on the estimation of this properties you will see in this subsequent lectures how important these properties are because this properties depend on the operating condition.

That is why the complexity comes when we derive the analytical expression system based on the fundamental understanding of the system the equation those come out are very difficult to solve and that is why knowing this properties as accurate as we can is very important to predict the performance of each and every process as well as predicting of the future of gas reservoir as the processing like I am mention separation and processing unit.

And for these safety features the ESTM methods can be used those are standard methods to be used to understand the expressive properties like flash point, fire point but for the other properties we will try to understand the mathematical expression those allow us how to estimate of all those things and the natural gas production when natural gas production started long back the properties were estimated in the form of a very complex chart.

For example if the Viscosity is measured it is measured under different temperature and pressure condition in the laboratory and the chart has been developed that not only for the changes in the temperature pressure but different percent of the inorganic compounds in the natural gas. So we will try to understand how those complex chart has been used to develop the mathematical expression.

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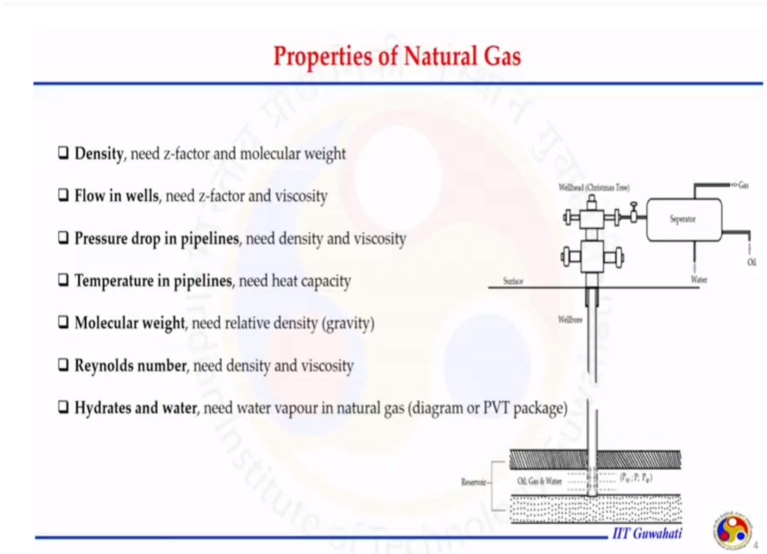

So now what is the use of understanding all these properties for example as I mentioned actual gas is the real gas it is not ideal gas even the density of a natural gas that depends on the compressibility defector. So compressibility factor should be known if you want to be known density of our gas that is the mixture of several hydro carbon non-hydro carbon gases depends on the constituent of the natural gas it is being made.

Flowing pipe so when we are flowing the natural gas through the pipeline either during the production time or during the transportation time the compressibility and viscosity are two very important parameters those comes into picture and both depends on temperature and pressure if they are changing the flow in the well or the behavior of the gas in the well or in the pipeline will also change that is also I mentioned is pressure drop and pipeline for both in the well as well as in the pipeline the behavior will be different.

Again temperature also changes in pipeline and when the temperature is changing the heat capacity value is required to understand how much is the heat loss is happening and do we need when we are changing the pressure for example at the choke device when we change the pressure suddenly because of the joule Thomson effect the temperature can goes down and that determine how much energy is lost and do we need to heat the gas to maintain the temperature it is not going to form the gas hydrate and several other places the heat capacity is also required.

You will see all these when you go in further lectures at a particular point when we will be discussing about the well performance. When we will be discussing about chock performance when we will be designing the separator and discussing the transmits in natural gas by pipelines. So other properties like molecular weight it needs relative density, specific gravity or other way also the property can also be estimated in other ways like perform the laboratory measurement.

The Reynolds numbers need density and Viscosity the Reynolds number is defined as (()) (12:28) and but when we convert this thing even in the quantity those are known still we need density and Viscosity and density can be converted with the help of some other non-parameter in some other term but is still we need to know compressibility or viscosity to define the Reynolds number which determines the flow under certain condition is in the laminar reason or in a turbulent reason.

Not only to understand the flow regime even to calculate several properties like friction factor we need to know the Reynolds number value. So that Reynolds number value depends on the density and viscosity or in the flow rate thus all these things need to be known or the as much as information about the natural gas so should be known to deal with all the process involved in the ahh natural gas business.

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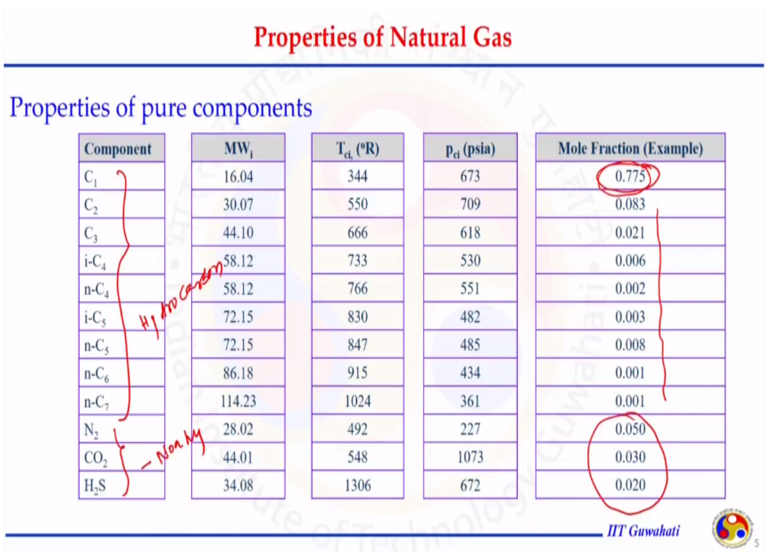

Component	MW_i	T_{ci} (°R)	p_{ci} (psia)	Mole Fraction (Example)
C_1	16.04	344	673	0.775
C_2	30.07	550	709	0.083
C_3	44.10	666	618	0.021
i-C_4	58.12	733	530	0.006
n-C_4	58.12	766	551	0.002
i-C_5	72.15	830	482	0.003
n-C_5	72.15	847	485	0.008
n-C_6	86.18	915	434	0.001
n-C_7	114.23	1024	361	0.001
N_2	28.02	492	227	0.050
CO_2	44.01	548	1073	0.030
H_2S	34.08	1306	672	0.020

Properties of pure compounds so if we see as already mentioned the composition of the natural gas where is from hydro carbon to non-hydro carbon. In hydro carbon let us see they are in the range of this C1 to C7 they could be in isoform or could be in the normal form also. But most of the natural gas are dominated by the methane and their subsequent percent of other hardware carbon C2 C34, C5, C6, C7 and non-hydro carbon gases N2CO2 and H2S.

They are the non-hydro carbon gases these are hydro carbon gases so when we are dealing with these kind of the composition are those are the part of the natural gas we need to know the properties of these compound to estimate the mixture properties and the pure compounds properties can be obtained can be found in several reference books like Ahmed book of the reservoir engineering even the economize data collection or even in any thermodynamics book you can find out the properties of pure compound like what is the properties of methane what is it is molecular weight what is the critical temperature what is the critical pressure.

For all these compounds in the pure found forming the literature and here I just gave an example of the composition of natural gas those composition mostly dominating by the methane the natural gas means methane it other hydro carbon gases and non-hydro carbon gases and the percent of this methane various other compound percent just in very low compare to methane and some percent of the in organic gases.

This is one of the example of the composition of natural gas and this composition of the natural gas can be obtained with the help of gas chromatography or lift by other means also which can tell us what are the composition or the number of moles of individual compound component present in the mixture.

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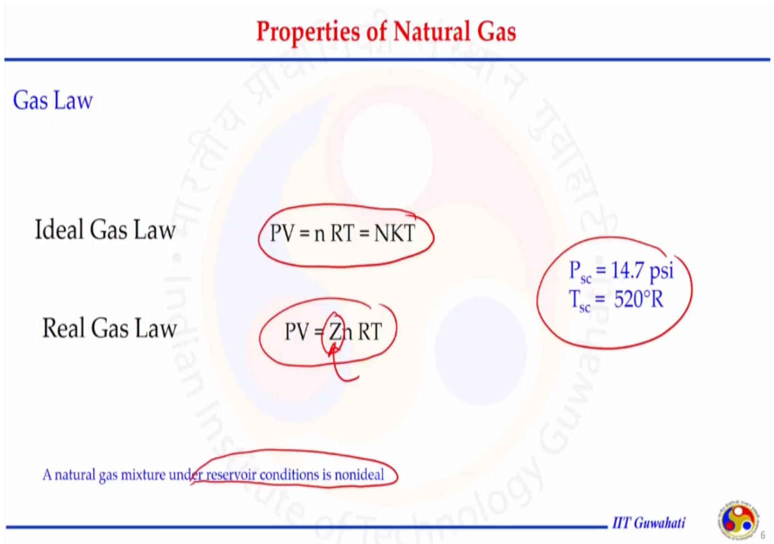

So with the help of knowing this information what we can do we can understand how the gas law will be applicable to natural gas as mentioned. Natural gas is not the ideal gas. So PV = nRT is not going to be applicable if it is pure gas like methane even up to certain point you are at low pressure it may behave like ideal gas but at a very high pressure and having a different have a mixture of hydro carbon, non-hydro carbon gases.

Our natural gas follows the real or in real law we are having this term where this Z compressively factor is accounted for the deviation from the ideal behavior so the compressively factor Z that shows how much deviation our natural gas is having if it is assumed to be ideal gas. Our natural gas mixture under reservoir condition is non- ideal at a very high pressure it is a completely non-ideal gas.

And when we talk about reservoir condition most of the time information is transferred to some non-condition those are this reservoir standard condition and this standard conditions are pressure means pressure value is 14.7 PSI and temperature value is 520 degree those should be in the obsolete term so the temperature either represented in form of degree ranking or degree Fahrenheit either in the form of degree ranking or degree Kelvin not in degree Celsius or degree Fahrenheit.

These are the absolute value and when you are here having the data in other form how to convert into obsolete value to apply to gas law. So this compressibility becomes very important because that compressibility says how much volume especially the deviation in the form of the volume and the natural gas is having and the natural gas which is under the investigation is having from the ideal gas law.

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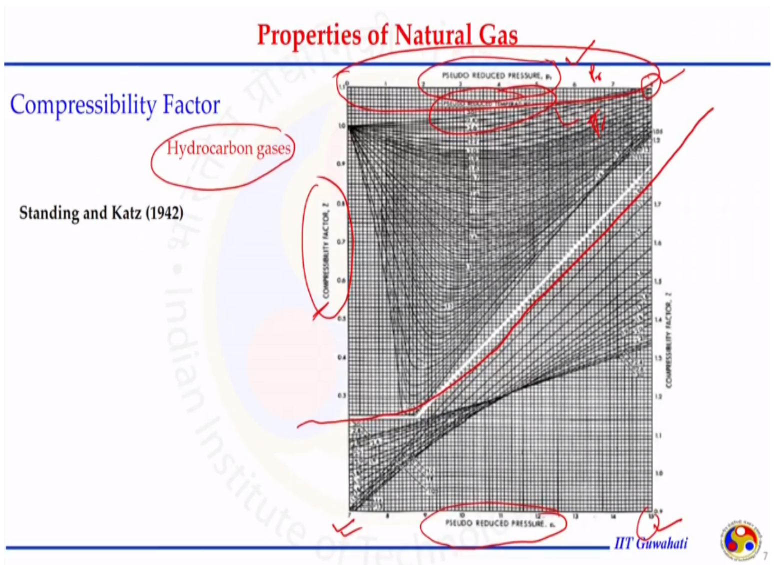

And if we look in the literature we try to find this deviation of the natural gas from the ideal gas there are several charts are given long time back and those charts are very complex in nature because they are showing for example here just for the hydro carbon. So if it is assume the percent of the non-hydrocarbon gases are in the trace amount or not present at all we have to use this kind of the chart and this chart says the compressibility affect us can be determined if we know this pseudo reduced pressure and pseudo reduce temperature that is here.

So if you pseudo reduce pressure here and pseudo reduce temperature here we can use this chart to get the compressibility factor. So let us see this chart is divided in two parts this is one separate and in this way the reading of pseudo reduce pressure is from one to 8 here and from 7 to 15 here. So the chart is same upper side and lower side it is just a representation of the pseudo reduce pressure of an extended scale.

Here is up to 8 only while here its I start from 7 to 15 and at a particular reduce temperature of a mixture remember these are the pseudo reduce pressure or pseudo reduce temperature means these are the mixture properties that is why the pseudo what has been used and the pseudo reduce means pressure divided by critical pressure or temperature divided by critical temperature. So to know these chart to read this chart first we need to know what is the pseudo critical temperature and hydro critical pressure values of the natural gas.

So if we know those things with the help of this complex chart we can get the compressibility factor but again this chart is only for the hydro carbon gases if we are having the non-hydro carbon gases present in our sample or in our gas we have to go to some other chart. This chart for the hydrocarbon gases is reported by standing and Katz 1942 they are then extensive laboratory investigation to develop this chart.

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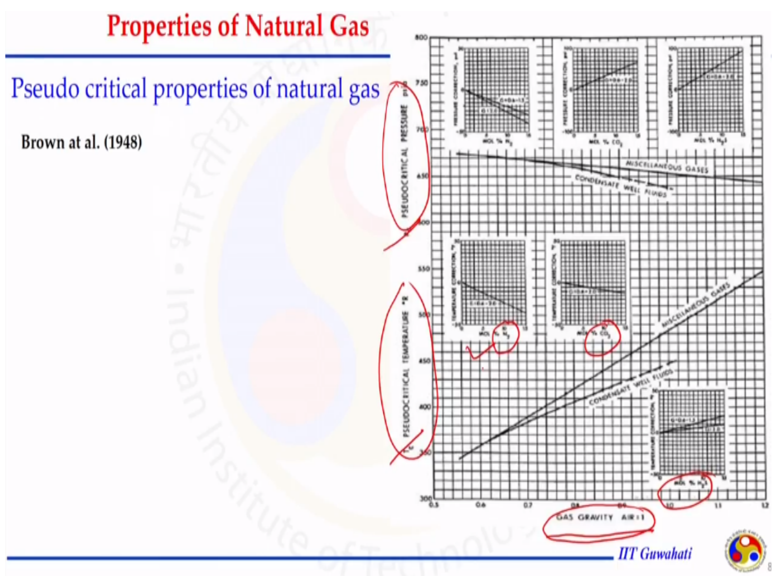

For the non-hydro carbon gases if the non- hydro carbon gases are present in the natural gas the correction has to be applied for the natural gas of compressibility factor which is calculated assuming there is no non-hydro carbon gases are present. So if the gas gravity or specific gravity with respect to here of our natural gases known with the help of pseudo critical temperature and pseudo critical pressure.

This chart can be read and the value of compressibility factor can be corrected for different inorganic gases like N2CO2 and H2S is apply the correction factor to correct the value. Again this the complex chart and this chart need specific gravity as well as pseudo critical temperature and pseudo critical pressure.

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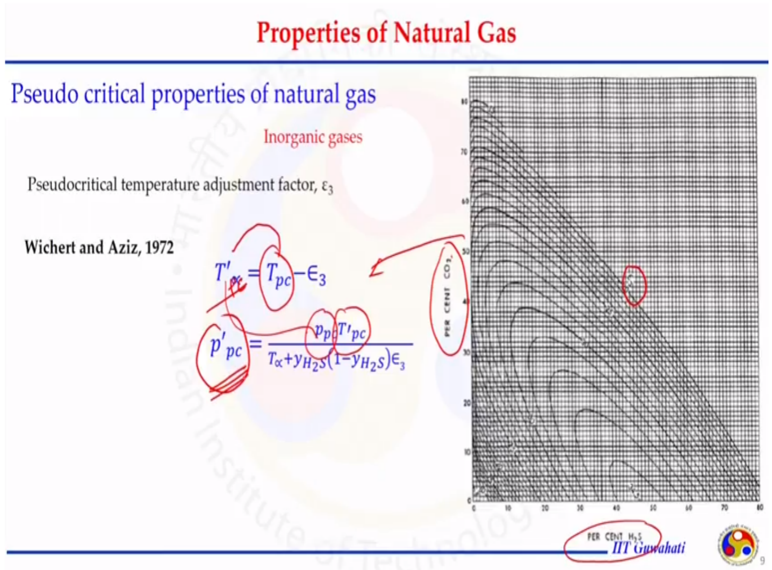

So when long time back when this chart were developed there was lot computational facility available to read this chart and develop some mathematical calculation but several researchers have put lot of effort to make very complex expression or the correlation those can replace the chart and those correlation can be used directly in a mathematical frame work or to calculate the value of the properties like the compressibility factor in this case similar we will see for the Viscosity also.

Another for the inorganic gases this Wichert and Aziz in 1972 they said for the inorganic they had considered the CO2 and S2S they said with the help of this chart you can estimate this F silent 3 and this F silent 3 can be used to correct the value of critical temperature and critical pressure so these are the corrected critical value of pressure for the mixture which accounts for the presence of the inorganic gases but only for CO2 and S2S.

So with the help of this chart knowing to the value of CO2 and S2S again to read this chart we need to know the percent of CO2 and percent of S2S then only this chart can be used to correct the values what we corrected is TPC has been corrected to T primal for and this T prime PC for sorry this PPC has been corrected with the help of this T prime and I think this should be TPC and PPC this has been converted to corrected value of critical pressure.

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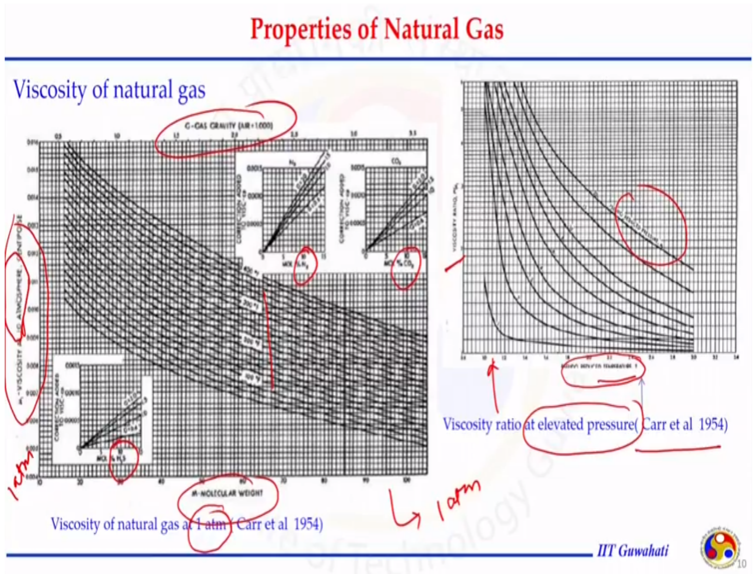

Similarly for the Viscosity if we are going to estimate the value of Viscosity of the natural gas again remember natural gas is a combination of hydro carbon, non-hydro carbon gases mostly dominated by methane. Even in that case also when the gas gravity is known and molecular weight is also known with the help of this chart at a different temperature we can estimate the viscosity of the natural gas at 1 atmosphere this is 1.0 means 1 atmosphere.

1 Atmosphere we can calculate the viscosity of the natural gas later on that can be extended to high pressure how the viscosity will change when the gas is exposed to a high pressure condition but at 1 atmospheric condition what is the value of viscosity at different temperature can be obtained with the help of this chart. This chart also suggest how to apply the correction factor for S2S and 2 and CO2.

So this chart is given for natural gas viscosity at one atmosphere where Carre Et Al at 1954 they also develop another relation for elevated pressure condition they said. Once you are having the value of reduce pressure sorry here reduce temperature and reduce pressure you can calculate the viscosity ratio that viscosity ratio is simple viscosity at elevated pressure divided by viscosity at elevated condition one atmospheric condition.

So with this chart we can get the viscosity at one atmospheric pressure with the help of this we can get the viscosity ratio knowing both the value we can calculate the viscosity at elevated pressure conditions. Again reading this charts are very complexes so before understanding how the mathematical correlations will be useful for let us understand how the simple properties those are required to read this chart can be estimated.

This is very important because if you see this chart the correlation has been developed from this chart only and to read this chart we need to know how to calculate the molecular weight of natural gas? We need to know what is the gravity of the natural gas? How to calculate the critical pseudo critical temperature and Pseudo critical pressure of the natural gas?

All these chart are in the form of these parameters and these will be again reflected in the mathematical expression or the correlation mathematical model develop to estimate compressibility factor and viscosity or any other properties if that is the function of critical temperature, critical pressure, specific gravity, molecular weight.

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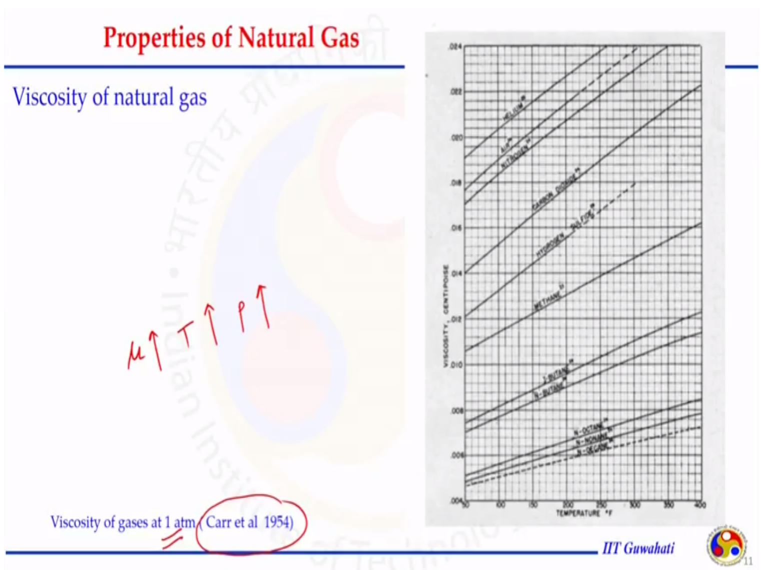

So let us go one by one to understand these things so before going further let us see one more properties again developed by Carr et al for the viscosity of gases at one atmosphere they said for a different pure gases even the pure gases the viscosity changes with temperature even at one atmospheric pressure and the gas compressed gas viscosity changes with temperature and we can see viscosity increase with increase in temperature. Similar behavior viscosity increases this increase in pressure.

We will come back to understand all these things these are just so why there is a need to understand how to calculate the basic properties of the natural gas just to understand viscosity compressibility factor and some other parameter we will revisit viscosity compressibility factor later on.

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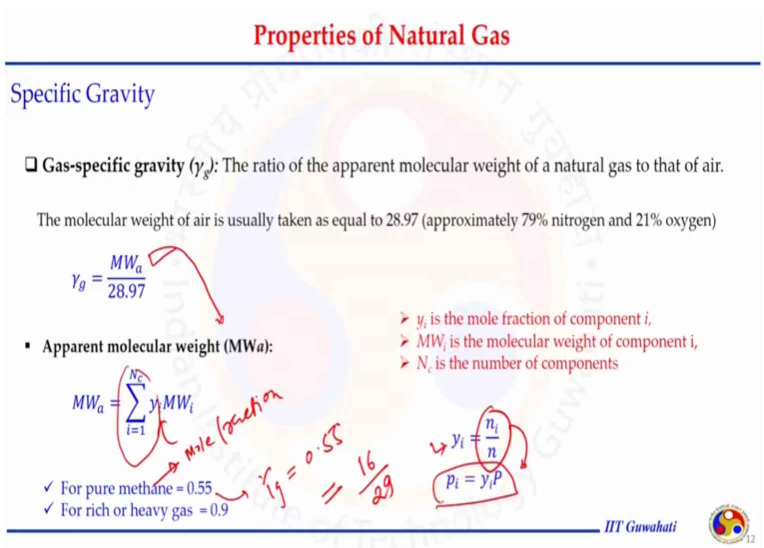

So let us see let us start with first property that is the specific gravity so gas is specific gravity is denoted by gamma G this is the ratio of apparent molecular weight of a natural to that of air. So it is simply in a mathematical term gamma G that is gas specific gravity is a ratio of apparent molecular weight of natural gas. Apparent molecular weight means we need to know the composition of the natural gas applying the mixing rule or change rule.

We can estimate the apparent molecular weight of the natural gas that will give the numerator and the denominator is the molecular weight of air either we can take value 29 or we can calculate this with the approximation of assuming here is just composed of 79% nitrogen and 21% oxygen other gases are in traces amount and not counted with the help of that if we calculate the molecular weight of air that turns out is 28.97 that can assumed approximately 29.

So the apparent molecular weight of the natural gas as I mentioned if we know the composition of each and every compound present in the natural gas by I is the mole fraction. So we convert the information of the composition of natural gas in terms of mole fraction multiply this with the respective molecular weight and to this summation for all compound present in the gas we can get the accurate molecular weight.

We will do a numerical calculations to understand this so I already mentioned ya is the mole fraction of component I and WI is the molecular weight of compound I and C is the total number of the compounds present. So we have to do the summation for all the component present. For pure methane if we calculate for a pure methane value of specific gravity gamma G will come out as 0.55.

This is very simple calculation apparent molecular weight of pure method is simply 16 or 16 point something if we go with the more accuracy divided by 29 if we do this it will come out around 0.54 or 0.55. And for a reach over heavy gases the composition of the natural actual gas are dominated by higher percent of the higher carbons like C2, C3, C4 the apparent molecular weight will increase in the same proportionality and so the specific gravity of the natural gas.

So for heavy or rich gases the value may reach up to 0.9 or even further how to calculate YI either perform the gas chromatography know the area, convert that area in mass percent. From mass percent even convert into mole percent or mole fractions to yi is ni / n. ni is the number of moles of component i divided by n total number of moles of the total number of moles of natural gas and with the doing this yi we can also calculate the partial pressure of component i in mixture just applying this (()) (30:07) okay.

So important point is knowing the composition that says even if we want to calculate any properties of natural gas at atmospheric condition or STP standard temperature and pressure conditions we need to know the composition of the natural gas if this dominated methane 99% methane then we can roughly calculate it the properties just assuming it is methane or otherwise we need to know composition.

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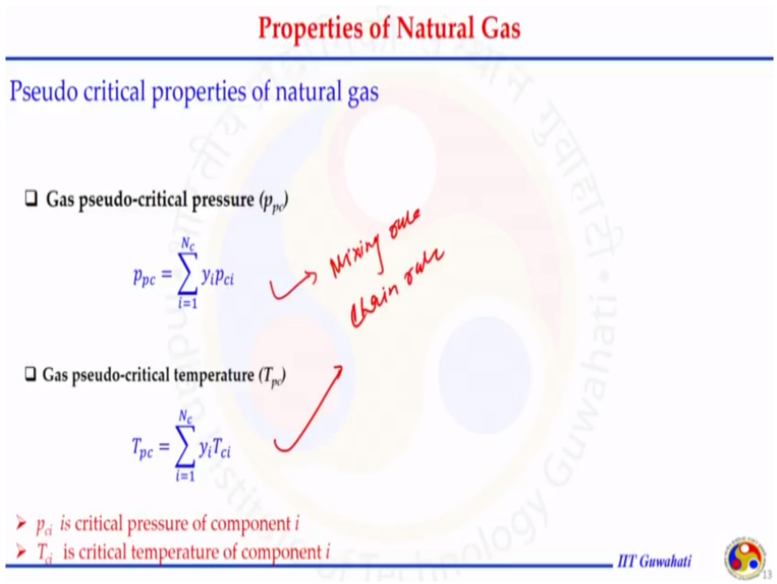

So further if we go further Pseudo critical properties of natural gas as I already mentioned these properties are called Pseudo properties because these are the properties of mixture not of a pure compound critical because the critical temperature and critical pressure are the pressure where gas and liquid can adjust in the equilibrium. So for pure compound this are available methane, ethane, propane, CO2, H2S these are available in the literature.

And for the mixture If we know the mole fraction of each compound as in the case of the molecular weight if we know the value of yi we can multiply these mole fraction with their respective critical pressure and critical temperature to get value of critical pressure Pseudo critical pressure and Pseudo critical temperature. Again this called either the mixing role we can call it is a mixing role or chain role.

So for both the cases similar expression can be applied to know the critical properties of a mixture we call them Pseudo critical properties of natural gas.

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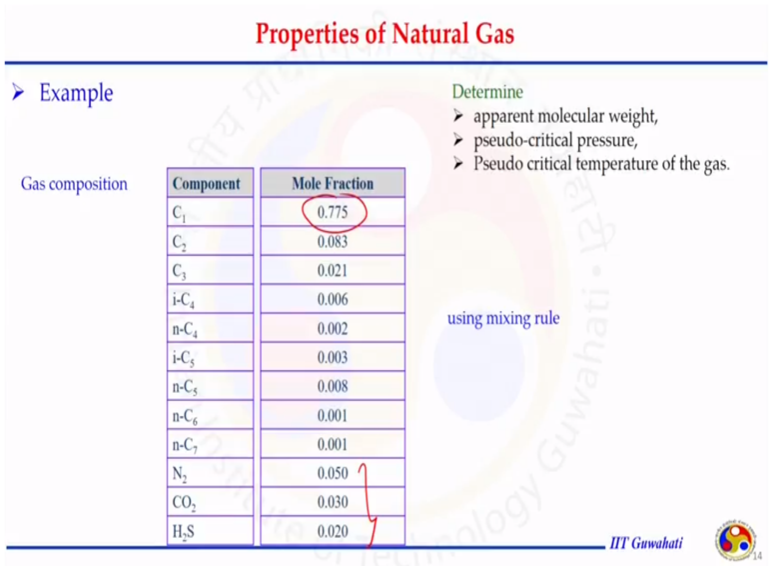

So let us take example that example simple it says if the composition are given calculate the apparent molecule weight Pseudo critical pressure and Pseudo critical temperature of the gas. So first thing should be known is gas composition. So the gas composition for example we can identify with the help of any lab measurement technique like gas chromatography or something and let us assume the same number as put that which as shown in earlier slide.

C1 to C7 are the hydro carbon gases with this percent dominated by methane relatively dominated by methane is present and N2CO2 and H2S are also in the significant quantity they are appearing in the analysis. So we know the gas compositions what is the next step we can apply the mixing rule to calculate the apparent molecular weight, Pseudo critical temperature, Pseudo critical pressure and once we now apparent molecular weight we know we can also calculate the specific gravity.

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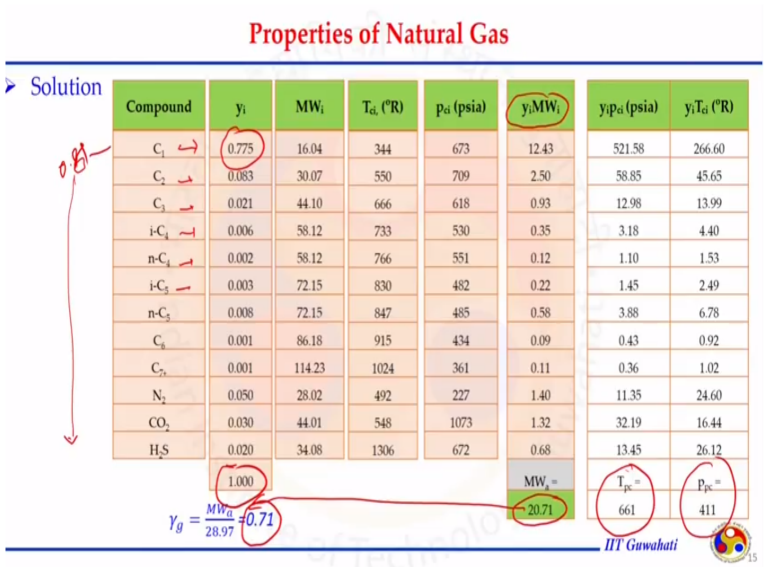

Compound	y_i	MW_i	T_{ci} (°R)	p_{ci} (psia)	y_iMW_i	y_ip_{ci} (psia)	y_iT_{ci} (°R)
C_1	0.775	16.04	344	673	12.43	521.58	266.60
C_2	0.083	30.07	550	709	2.50	58.85	45.65
C_3	0.021	44.10	666	618	0.93	12.98	13.99
i-C_4	0.006	58.12	733	530	0.35	3.18	4.40
n-C_4	0.002	58.12	766	551	0.12	1.10	1.53
i-C_5	0.003	72.15	830	482	0.22	1.45	2.49
n-C_5	0.008	72.15	847	485	0.58	3.88	6.78
C_6	0.001	86.18	915	434	0.09	0.43	0.92
C_{7+}	0.001	114.23	1024	361	0.11	0.36	1.02
N_2	0.050	28.02	492	227	1.40	11.35	24.60
CO_2	0.030	44.01	548	1073	1.32	32.19	16.44
H_2S	0.020	34.08	1306	672	0.68	13.45	26.12
	1.000				MW_a =	T_{pc} =	p_{pc} =
					20.71	661	411

$$\gamma_g = \frac{MW_a}{28.97} = 0.71$$

So on this solutions side let us say we are having the compound we know the composition or the mole fraction of those compounds with present in the natural gas and the summation of mole fraction should be 1 that I did here the summation and they say okay the calculation done for calculate the mole fraction is correct and from the literature from the friend book or from other sources I know the molecular weight, critical temperature or critical pressure of individual pure components present in the natural gas.

So what is the next step I can apply the mixing rule and calculate individual yi multiply by molecular weight I can get the data to get the apparent molecular weight and I just need to do this summation over this I will get this value. Similar for critical pressure and critical temperature I can calculate individual compounds fraction and do the summation over it I can get the value of critical temperature and critical pressure of the measure.

So simple calculation and knowing the apparent molecular weight here I can divide this with the molecular weight of the air I can get the specific gravity of my natural gas. That is so simple calculation and why I had shown this calculation because you may write one excel program or a mat lab program or any program were we can identify you can list down all the possible compound those could be present in the natural gas with their properties from the literature.

And whenever you are given this set of data in terms of composition of natural gas which is need to enter that the calculation can be done automatically and you will get the parameters like these specific gravity molecular weight apparent molecular weight the specific gravity critical temperature critical pressure by just entering the data. Otherwise every time if I change the next time the composition I have taken another sample of the gas and the composition changes.

For example this changes to 0.81 and accordingly other composition will also get change because the summation of the mole fraction should be one. And in that case if it is done by hand or it is done not in a proper manner you have to repeat the processor again and again and you will see when we will go further all these are very important steps to reduce the work load in more complex system when we need to understand more and more detail of more complex parameter involved.

So better from the beginning from this first example itself we are start writing our own excel program or in a met lab program and whenever the data are given we can calculate. So for example here critical temperature and critical pressure because you see any chart we had seen if we are going to read those chart and composition got change if a natural gas of different composition given to us and we want to read those chart again we have to calculate critical temperature and critical pressure thus writing program in the excel or MS office excel is very important.

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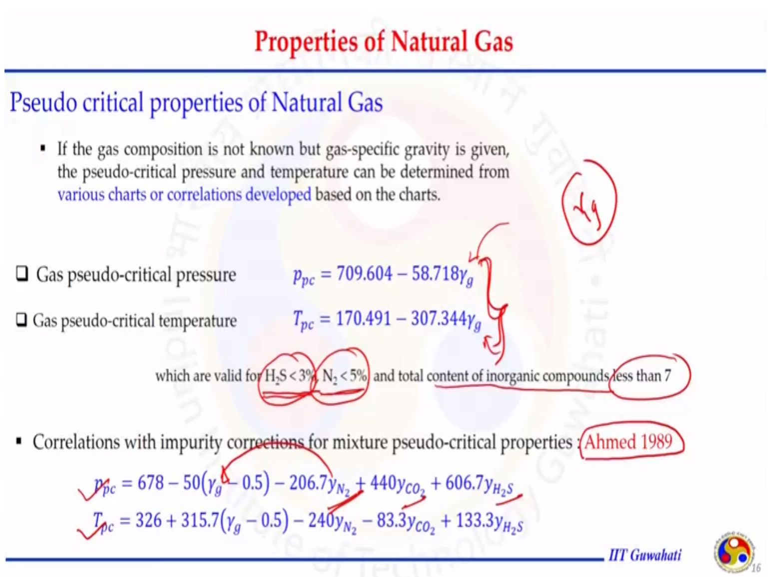

Now let us see how Pseudo critical properties of natural gas can be estimated if we know the compositing of the natural gas whether might be possibility when the composition or not known but specific gravity was told to us. So the data are given us in the form of specific gravity not in terms of the composition then how to calculate the critical Pseudo critical properties of natural gas.

So correlation for Pseudo critical properties can be used and this temperature and pressure can be determined from various chart or correlation developed in the past, and based on this chart this correlation has been developed and we can see if Gamma g is given to us. That is specific gravity with the help of this set of the parameters those are very simple linear expression or linear relationship between the pseudo critical properties and gamma g can be used to estimate the pseudo critical properties.

Just we need to put the gamma g value the specific gravity because it is known to us we can get this value but there might be a situation when these are not valid only these correlation only old good when we are having the H_2S is less than 3% nitrogen less than 5% and total content of inorganic compound is less than 7% then only this correlation are good enough to use. But the situation is not like this the correlation with impurities correction for mixture pseudo critical properties has been proposed by Ahmed in 1989.

Ahmed said improved the position of nitrogen, CO_2 and H_2S in the expression and use gamma g because this properties was you can calculate the Pseudo critical properties and pressure and temperature. But again to use this expression for the correction impurities we need to know the composition or the percent of the mole fraction of those impurities and N_2CO_2 and H_2S as well as gamma g should be known to us.

The mole fraction of CO_2 or H_2S are known to us the with help of this chart we can correct the pseudo critical properties what we can do we can calculate the Pseudo critical properties the type of this Guo and Ghalambhur and this is a very simplified methods and these values TPC and PPC can be corrected for the inorganic gases present at the inorganic gases with the help of the sub salient 3 it can be read from this chart and we can get the correction this is proposed by Wichert and Aziz in 1972.

And further these chart has been read in a mathematical sense and it says if we know the percent of H2S in CO2. And let us say percent of mole fraction of H2S is B and mole fraction submission of mole fraction H2S and CO2 is A we can put in this manner A and B and get directly the sub-salient 3 instead of reading the chart we can calculate the help of this correlation and this correlation has been developed form this chart only.

So using this we can go back and correct pseudo critical temperature and pseudo critical pressure value.

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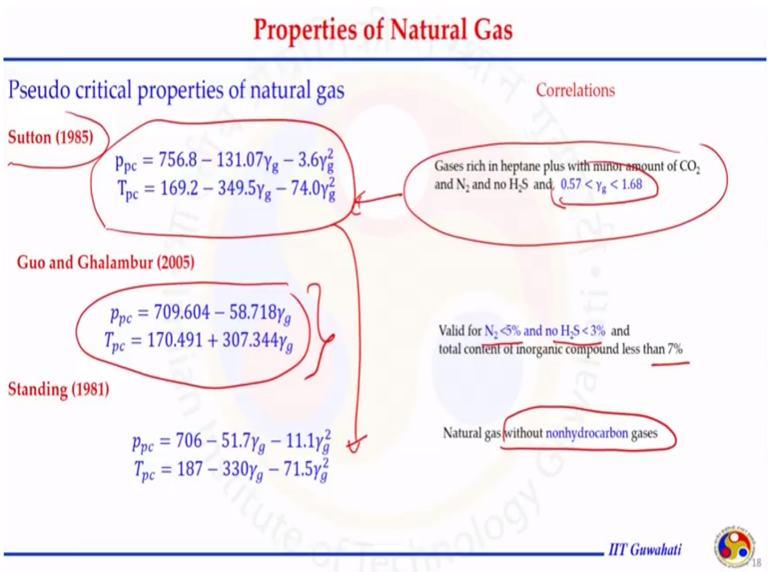

Several correlation have been developed so reading the chart developed when the computational facility are not developed we were forced to use only the chart and read the chart with the information required to read this chart like the critical temperature, critical pressure specific gravity at the percent of the inorganic compound present. Later on several researchers have put lot of effort to develop several correlation last has some two correlation here you can several correlation.

This is the same Guo and Ghalambhur correlation that we have started discussing this is linear relationship between the critical properties and the specific gravity gamma g, Sutton in 1985 here correlate here developed the correlation and that correlation is quadratic form of the gamma g to estimate the critical properties pressure and temperature.

But each model that has been developed or the each correlation that has been developed based on the chart or having certain limitation because the particular data set has been used to develop the such relationship or they hold good only certain limit of the of the other parameter like what is the percent of the organic compound present? What is the specific gravity of gas being handled? For example let us go one by one Sutton in 1985 he has a quadrating expression for more gamma g and this correlation is good when we are having the gamma g in the range of 0.57 to 1.68.

And the gases are rich on the gas sample are rich in (()) (41:51) in minor amount of CO2N2 should be present and there should not be any H2S present in the sample. So if this conditions we are having the natural gas with this condition we can use this Sutton correlation to calculate the pseudo properties and if nitrogen is less than 5% H2S is less than 3% and total inorganic compound is less than 7% we can always go with the Guo and Ghalambur and this is the simplest form of calculating the pseudo properties.

The standing 1981 he had given similar expression as with the as given by the Sutton but in this case the coefficient got change because the data has been used from the other source and the correlation of this standing are good only without known hydro carbon gases. If the natural gas is not having is without non hydrocarbon gases the standing expression should be used instead of the other expression.

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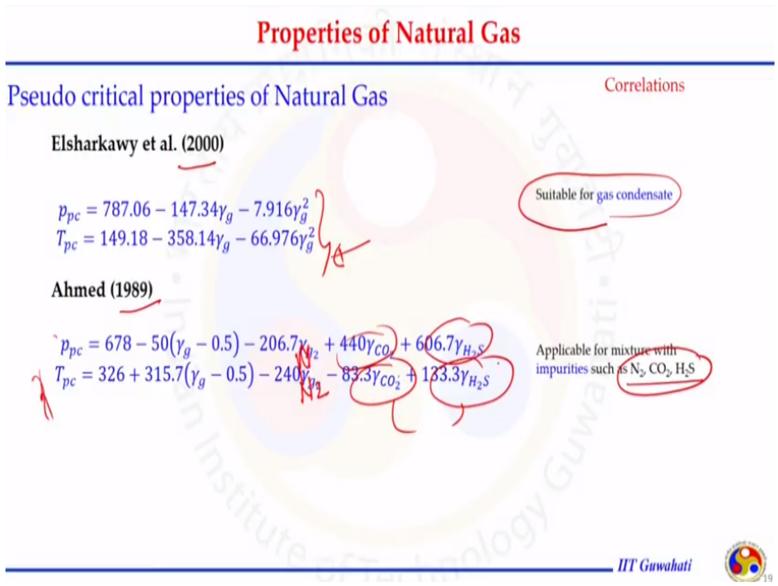

Similarly other expression in 2000 and 1989 by Ahmed they also has given both this is the quadratic form and this are suitable for gas condensate system we are dealing mostly with the dry gas or gas with the very small amount of the liquid present. So mostly this correlation is only for the gas condensate system or suitable for gas condensate system it will give a more reliable value for gas condensate system.

Ahmed 1989 that we have already discussed that if we are having the information about the individual compound of inorganic gases mostly the nitrogen. Mostly the CO2 and H2S we can use Ahmed expression to calculate and this is applicable for mixture which is including such as nitrogen O2 and H2S should be present in the sample. I think this should be N2 sorry for the this should be N2.

So the Ahmed 1989 expression is good when it go to CO2 and H2S are present as the impurities and knowing the percent N2CO2 and H2S we can calculate pseudo properties this should be N2.

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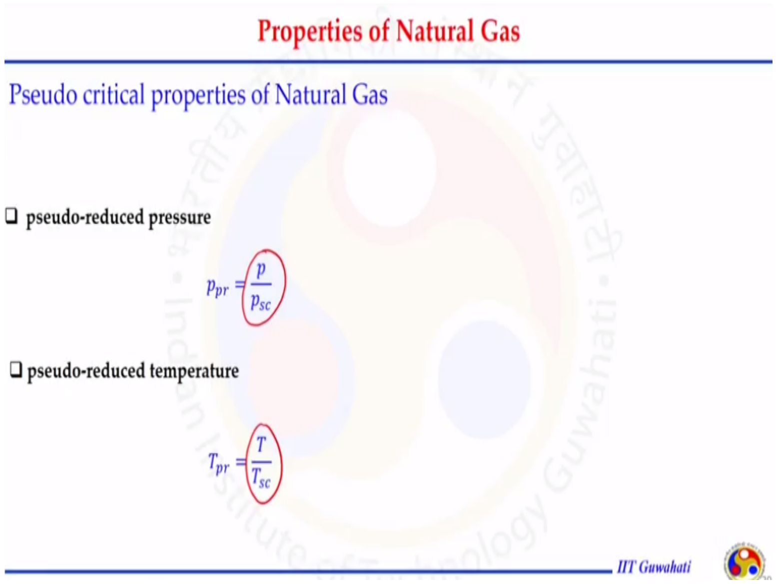

So other correlation are in the form of pseudo reduce pressure or pseudo reduce temperature can get these value of natural gas mixture just at what pressure the natural gas is divided by the pseudo critical properties of pseudo critical properties of natural gas. Similarly can be done for the temperature and knowing the pseudo critical value we can calculate the pseudo reduce value both for temperature as well as pressure and they are important because some correlation are given in the form of pseudo reduce conditions.

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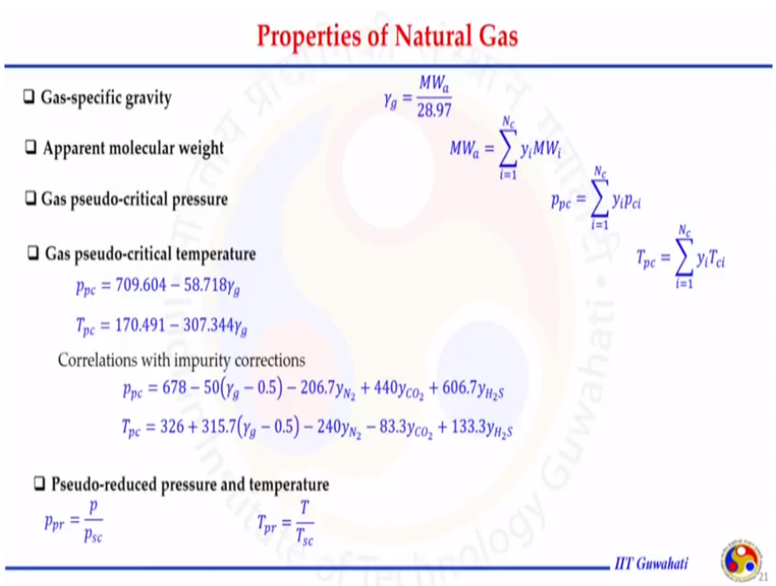

So let us see in summary what we learnt today the specific gravity of the gas that is simple molecular weight apparent molecular weight divided by the molecular weight of here.

Apparent molecular weight can be calculated if the mole fraction of individual compound are known.

Gas critical properties like pseudo critical properties like pressure as well as temperature can be known with the help of known composition of the gas or the mole fraction of the gas if gamma g is given to us instead of the composition we can still calculate the critical properties depends on the other information available are known to us.

We can calculate this and after knowing the critical properties we can also calculate this pseudo reduce pressure and temperature of the natural gas with this I would like to end the lecture here and in the next lecture we will understand how to estimate the viscosity, compressibility factor and some other important properties of the natural gas those are important in designing, processing and transporting natural gas thank you very much for listening lecture thank you.