Natural Gas Engineering
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Module No # 01
Lecture No # 05
Choke Performance Relationship (CPR)

Hello to everyone and welcome in this lecture of properties of natural gas 2 we will understand some more properties of natural gas and how to estimate those. So let us quickly revise what we have learnt in last lecture.

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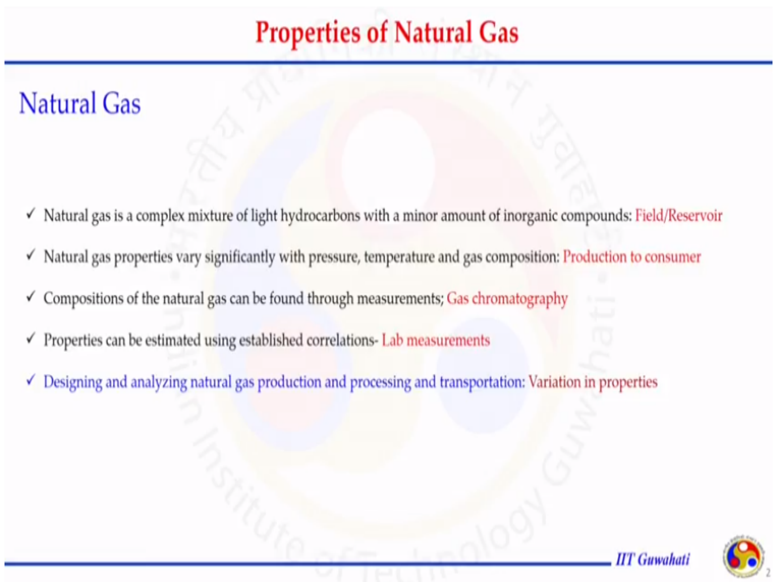

So natural gas is a complex mixture the composition depends on field and reservoir vary from light hydro carbon from C1 up to C7 along with non-hydro carbon gases like CO2 and N2, H2S (()) (01:08) SO2 and others and some of the sour gases those need to be treated before we are sending it to consumer. So from the production side to consumer the composition various because of the field conditions because of the several processes applied to refined the natural gas.

And the composition of the natural gas can be estimated by the analytical techniques one of the analytical techniques is gas chromatography so if the composition are known. We can estimate several properties at different temperature and pressure condition and these properties estimation can be done with the lab measurements or using the correlation developed in the past our objective is learning how to know the properties of the natural gas those are required when we are dealing with the natural gas.

There are several properties required at different stages but we will deal some common properties as we did in the last class and the remaining properties for example this solubility of gas in the water will be treated when we are dealing with dehydration steps and the heat capacity and heat related properties will be understood when we are dealing with cooling the natural gas and heating the natural gas or compress in the natural gas when it is temperature and pressure condition are changing.

All these are required with the designing point of view because from the production to consumer several equipment's need to be designed to handle the natural gas and all these designing things required the properties of material to be handled or when it is a following system what are the flow properties of fluid those should be known. So with the aim of this when the variation in properties happen throughout the process it is well required to understand how to estimate those properties.

So let us say ahh we are having this production system half of the point is shown here where we are having upstream part where natural gas is produced from reservoir to separator.

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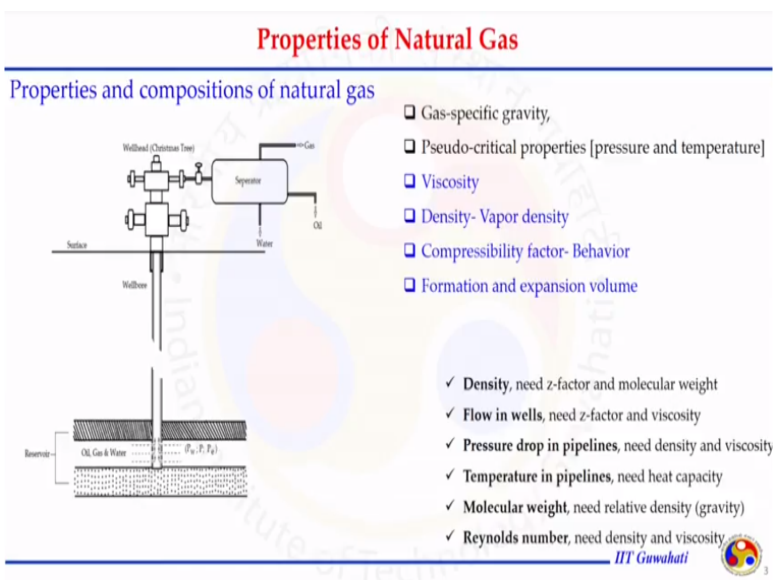

In fact before the separator is the upstream segment from separator till processing point it is mid-stream and when we are transporting the natural gas it is a down-stream segment. So the reservoir fluid that is gas in our case is being fluid from porous media travelling in the pipeline facing the choke device and then the separator and several dehydrate sweetening processors and finally transportation through the pipeline.

The property is the common property is what are the composition of gas? What is the specific gravity of the gas? What is the viscosity? When we are flowing any fluid we need to do to viscosity what is the compressibility factor of the gas because the gas is not the natural gas is not ideal gas it is not compressible gas we need to know and the other properties like formation and expansion volume effector those relate the amount of the natural gas from one condition to other condition must be known how to establish the correlation for this.

And in the bottom part I have shown here like different properties estimation needs some detail that needs to be known before we can estimate for example if we want to know the density we need to know the compressibility factor. Knowing the compressibility factor itself is a combustion jobs but knowing the density need to compressibility factor and that is why knowing the defector natural gas becomes a like tedious job.

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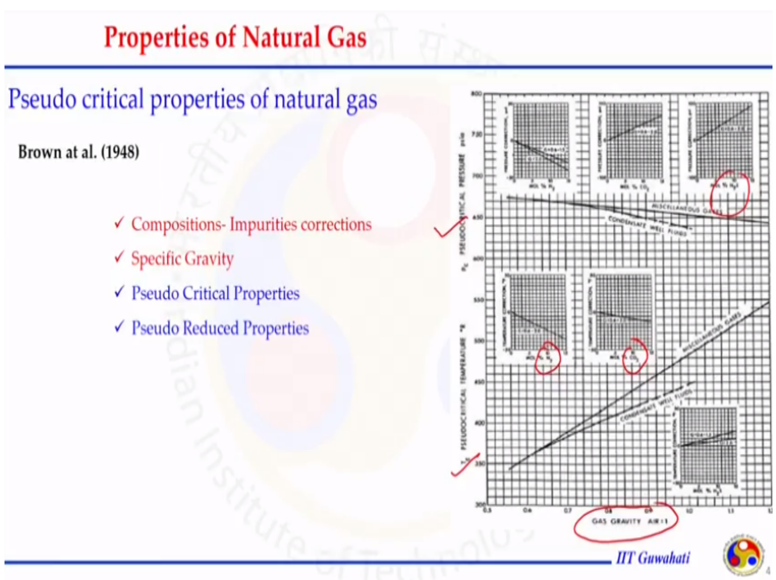

We discuss all this thing in the last class so let us go quickly so pseudo critical properties because most of the correlation given in the literature or given in the reference text book those are laboratory measurement observation and have been put up in the form of chart and those chart cannot be read by the computer it is very difficult to quickly measure the properties that is why the correlation have been developed several by several researchers.

And we had seen in the last lecture also the correlation for example pseudo critical and pseudo pressure measurement from these chart depends on several other factor and those are very tedious we had seen the linear relationship between the gamma g gravity and the critical properties quadrature form are there more complex form are there and as well as not only specific gravity those depends on the impurities present in the system.

So if we know composition of the gas thoroughly we can calculate via the critical properties by the mixing rule otherwise we need to know some of the properties of the natural gas we are dealing like the specific gravity gamma g and CO_2 and N_2 and H_2S. So in this chart we can see like if we know the gas gravity we are having we can measure the pseudo critical temperature and pseudo critical pressure of that gas.

Of course there will need to be correct for presence of N_2CO_2 and H_2S and if we know that things we can estimate the critical properties and knowing critical properties is very important because with the help of critical properties we can read several chart with the help of critical properties we can convert them a reduce properties like reduce temperature pseudo reduce temperature, pseudo reduce pressure and some other chart those are given in the form of pseudo reduce pressure and pseudo reduce temperature can be made readable.

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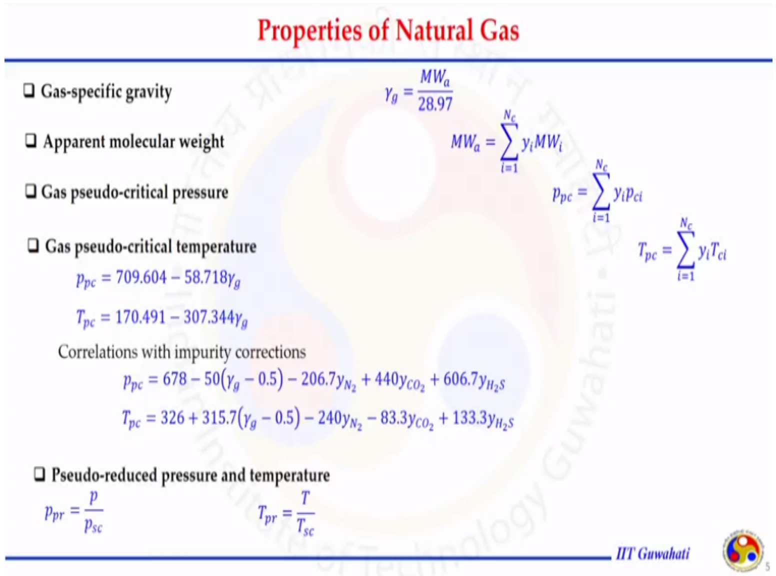

So let us quickly what we learn the in last class gas is specific gravity that is the ratio of operand molecular weight of the natural gas divided by the molecular weight of here we can calculate the operand molecular weight by chain roles similarly chain role can be applied by calculate the critical properties of the mixture or when gamma g is given specific gravity is given we can use some correlation of the quadratic form of linear form.

To establish the critical properties and then those can be converted into reduce pressure, pseudo reduce pressure and pseudo reduce temperature.

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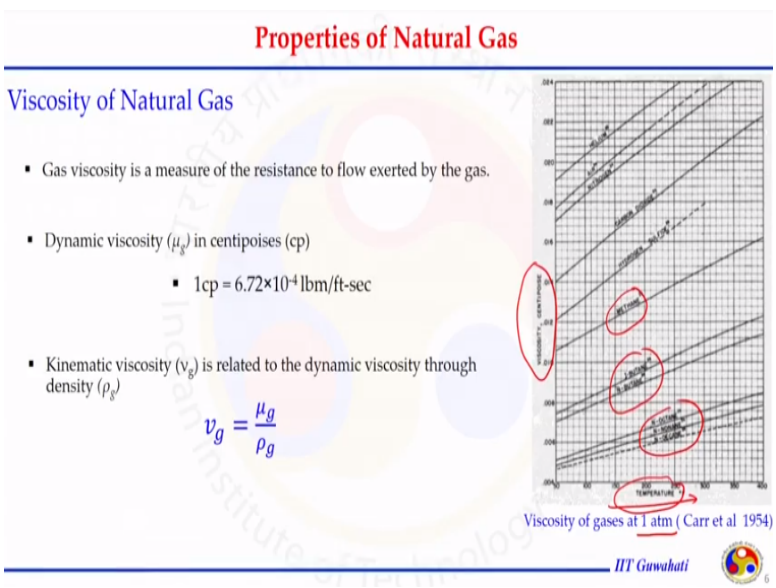

So now let us go ahead in this lecture we are going to understand the viscosity and or some other properties let us start with the viscosity of natural gas. As we know natural gas is not a pure component gas if it is purely methane we can use several simple correlation at the stream in the literature or chart those can allow us to understand the velocity of natural gas if it is very pure methane gas when it is a mixture problem becomes little complex.

This chart shows the viscosity value in a centipoise for a different gases at a one atmospheric pressure it is reported by Carr Et all at 1954. Viscosity depends on temperature as well as on a pressure as well as chart is given for only one atmospheric condition if the pressure is changing this chart need to be replaced by another chart and it simply saying when we are having the temperature variation the viscosity is also changing. So the viscosity of any fluid is a measure of resistance to flow.

So whenever we are having fluid to flow we need to understand the viscosity of that fluid in our case our fluid is gas. So the viscosity of a gas is measure of the resistance to flow exhausted by the gas and it is measured in centipoise and centipoise = 6.72 10 the power -4 lbm per feet second it can be measured in some other unit also like Pascal second the dynamic viscosity can be converted to another property that is the Kinematic viscosity and that is the ratio of dynamic viscosity to gravity of the gas and the unit for the kinetic viscosity is cent stop.

Important part is the properties of natural gas can be established some other correlation or can be established this with the help of the fundamental theory. Natural gas is not a pure gas it is a mixture so the theory kinetic theory cannot be directly applied its individual component of the natural gas in viscosity can be established with the help of some kinetic theory we are not going in detail of the kinetic theory of the gases or some other complex correlation given what is the our objective is.

If we know our natural gas what are the composition of natural gas and we want to know the viscosity the properties of natural gas that is very much responsible for its flow behavior if you want to know at the property at different condition we have to have some strategy some correlation some chart, some fundamental understanding to estimate the things. So dynamic viscosity is the reported in centipoise while kinetic viscosity is centistop.

So remember this unit because whenever the data are given you need to convert from one unit to other unit. So it is very important in what unit the values are given most of the chart as I mentioned are given with respect to field unit system that is centipoise for this dynamic viscosity and centipoise is also equivalent to like CGS unit system.

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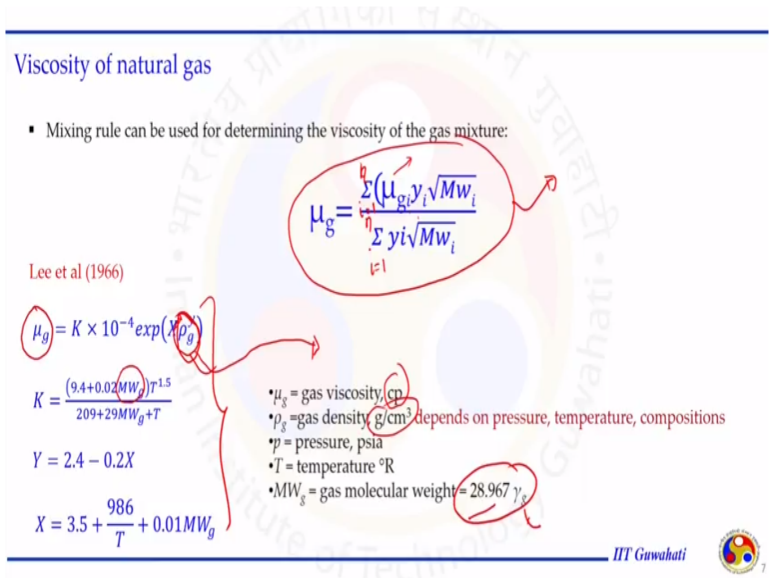

Gas viscosity as I mentioned if I know my gas if I know my composition if I know their mole fraction viscosity of individual component in the gas by applying again the mixing rule I can estimate the viscosity of the gas. So to apply this formula Mu g the viscosity of the gas I need to know the individual component i viscosity it is mole fraction in the small molecular weight.

And using this expression for all component it should be i = 1 to n this should also be i = 1 to n we can get the viscosity of the mixture. This is common rule for any type of the gas mixture so if we go further if we are not knowing the composition of natural gas if we do not know the properties of individual component at the temperate and pressure we want to know the viscosity of the mixture we have to go to literature we have to find out some correlation some already adjusting chart those can help us at the elevated temperature and pressure condition or any temperature reference any temperature and pressure condition you want to know.

So Lee Et Al they have given sort of expression or correlation to estimate the viscosity of the gas and that expression include the molecular weight of the gas and density of the gas and others are like temperature and pressure we want to know. In these expression you will see the pressure is not appearing but later on we will see in one of the slide we will see the density gamma g depends on composition it depends on the temperature as well as pressure.

So pressure is here implicitly in the form of the density as so the viscosity of natural gas will vary temperature and pressure using this correlation proposed by Lee et al we can estimate. So either if we are having the composition known molecular weight known we can use this mixing just to have the estimated property but again to know this we have to know the viscosity of individual component at the temperature and pressure of interest and this M Wg is apparent molecular weight of the natural gas that is equivalent to this expression 28.97 gamma g. 28,967 is the molecular weight of here.

So if we know the gamma g we can calculate MWg put in the expression we can get the viscosity again remember the numerical coefficient appearing here depend on the unit system as been chosen with the help of with the expression proposed by Lee et al we can get the viscosity of the natural gas in centipoise Rho g should be in the form of gram per centimeter cube that we remember this units system is very important accordingly the coefficient will get change pressure is in PSI temperature and degree rankine system.

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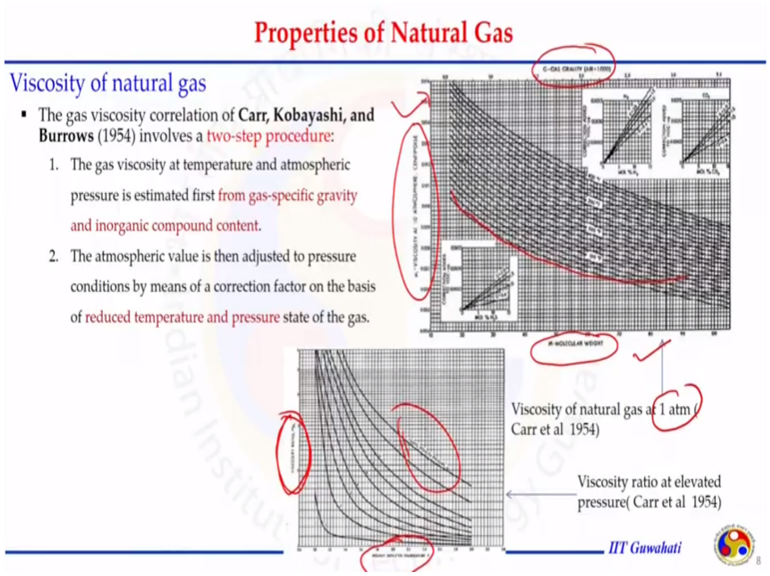

So if we see further is this correlation good enough how accurately one particular method will give us so the lee et al method which we chose we just discussed is considered good enough to accurate enough to have the viscosity of natural gas there are some other method proposed and very famous and those methods are frequently used in the natural gas industry to estimate the viscosity of natural gas one of them is developed by Carr, Kobayashi and Burrows is called CKB method developed in 1954.

This involve two-step process so if we see the chart here it is reported if we know the molecular weight of the gas natural gas and we know the gas gravity that can be calculated just by knowing molecular weight we can know the gas gravity. So the viscosity at one centipoise viscosity is one atmospheric pressure and the unit of centipoise can be estimated with the help of this chart but this chart is for at one atmospheric condition in the but with the help of this we can get at different temperature how viscosity is changing with respect to temperature at one atmosphere pressure.

Once knowing this we can correct again for the impurities those are CO2 and 2 and H2S impurities in the system after knowing this the value of the viscosity from this chart first step is complete that says I know the viscosity of the natural gas at 1 atmospheric condition and at the temperature of interest. Now we want know the viscosity at elevated pressure that is the temperature whatever we have or what the temperature of the interest that we had calculated the viscosity with the help of the chart 1 this one.

Now we can calculate the Viscosity ratio and the viscosity ratio will be related to reduce temperature this is reduce temperature this is reduce pressure. So if we know critical temperature and critical pressure of the gas we can convert them in reduce temperature and reduce pressure using those reduce temperature pseudo reduce temperature and pseudo reduce pressure we can read this chart and calculate the viscosity ratio at that elevated condition.

Elevated condition is the condition of pressure of interest so with the help of chart one we could estimate at one atmospheric condition and in that temperature with the help of chart 2 we can convert that into the temperature of interest as well as the pressure of interest and this two-step processor can give us the viscosity at the condition we want.

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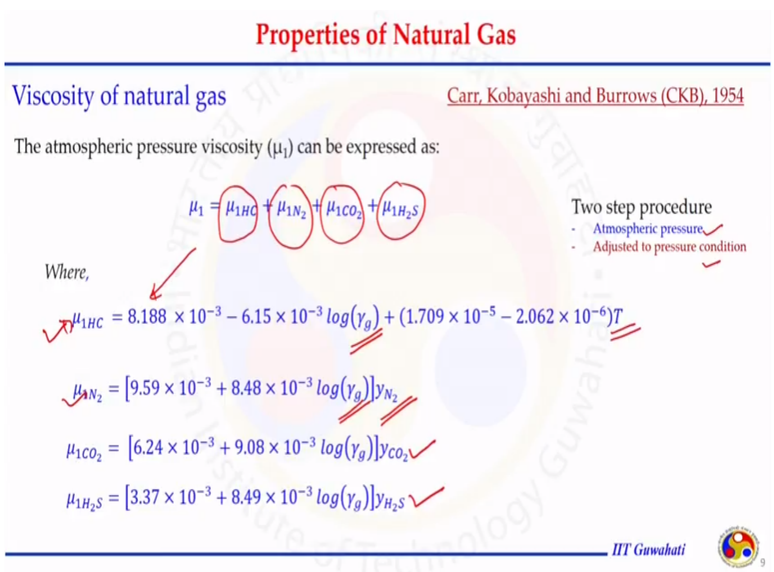

So how to use this chart let us understand the mathematical relationship given to read this chart that simply says the atmospheric pressure viscosity Mu 1 can be estimated just combining this factor this factor simply represent viscosity contribution because of hydro carbon gas present because of nitrogen because of CO2 and because of H2S and all are at atmospheric condition and Mu HC this 1 for hydro carbon just simply include gamma g.

Gamma G means the specific gravity of the natural and the temperature of interest with the help if that we can get the hydro carbon viscosity, the viscosity of the hydro carbon present in the natural gas or the viscosity fraction of natural gas because of hydro carbon. Similar for the nitrogen gas we are having the relationship where gamma g is again used and corrected this value with the help of nitrogen mole fraction.

So this is kind of a correction in the value because of nitrogen presence similar corrections can be made for CO2 and H2S the numerical coefficient appearing in all this equations are obtained by fitting the data fitting different curve or different values to the curve shown in the previous slide. So now this two-step processor can give us viscosity at atmospheric pressure and then in the next step the value of viscosity can be adjusted to the pressure condition we want.

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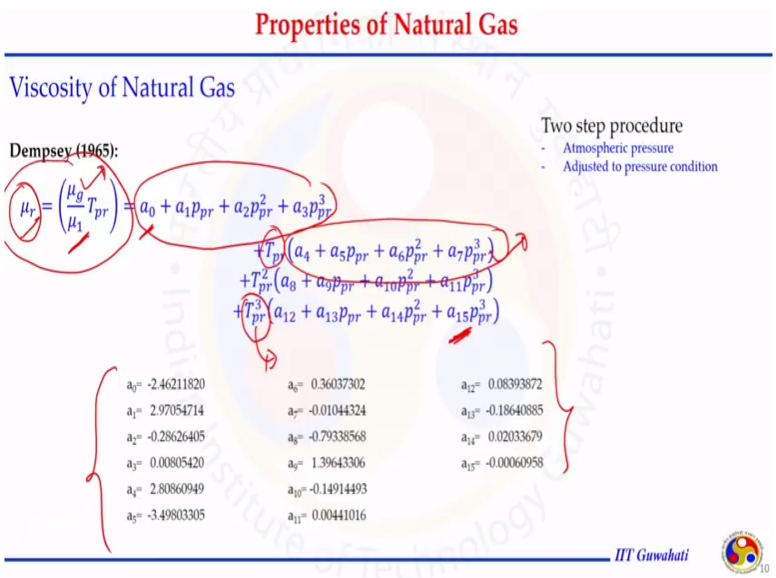

Now how to read the second chart for system we had done in the previous slide we said Mu 1 the viscosity at atmospheric pressure can be estimated with the help of this numerical expression instead of reading the chart or another is for the viscosity ratio or it is called the Mu r the parameter that relate the viscosity of the natural gas at the interest condition like at a particular temperature and pressure we want and this is Mu 1 viscosity of natural gas at one atmospheric condition and the temperature of interest.

In this expression simply says and it is actually the representation of the second chart that we had discuss in CKB method here that says Mu r can be related to reduce pressure pseudo reduce pressure and pseudo reduce temperature in this complex form where you are having one set of the data of the reduce pressure in a polynomial of third order then second set of the data for the pressure in the polynomial of the third order multiply by the temperature.

Similar here in up to T3pr we are having this complex and if the model is fit we got different value for this constant those are appearing here up to c15. So a0 to a15 sorry a15 we are having this numerical coefficient so what we can do we can write a mathematical model either in the excel or in a mat lab or in platform where we can include all this numerical coefficient can develop the relation for Mu r using this Mu r and previously develop relation for hydro carbon viscosity and correction because of an N2CO2 and H2S.

We can estimate the viscosity at the point of interest at the condition of interest let us see how this can be done.

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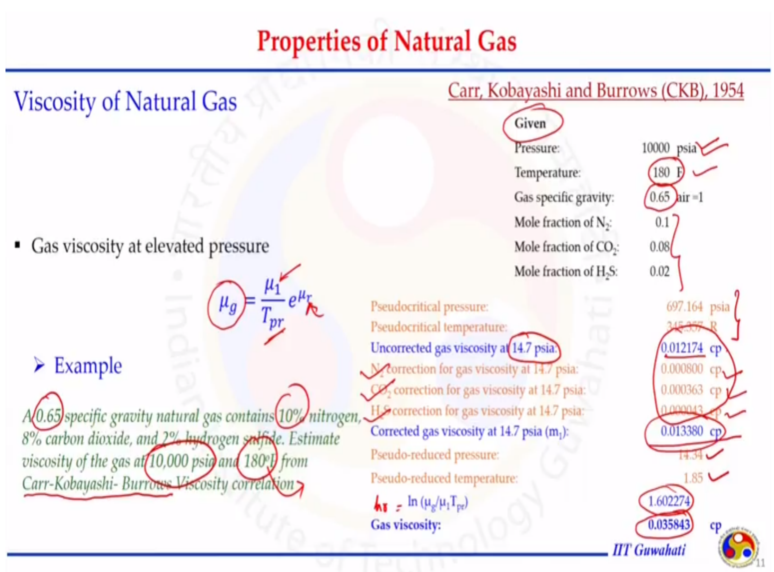

So once this Mu r is known and Mu 1 from two slides back we can get this Mu g let us understand this with the help of an example. That example says like is natural gas with a particular gravity 0.65 containing 10 % nitrogen and 8% carbon dioxide and 2% hydrogen. So the composition are known the hydro carbon composition are known in the form of the gamma g while the impurities nitrogen CO2 and H2S are none in terms of the mole fraction given to us.

And it is asked to estimate the viscosity of the gas at particular temperature and pressure in this case it is 10000 psia is a pressure 180 degree Fahrenheit is the temperature. So we need to convert this 180 degree Fahrenheit into ranking. So what we can do we can apply the method that is asked to be applied CKB method that is two step procedure in first step processor we can get the viscosity at a atmospheric pressure condition.

So let us see what is given us similar whatever is written to us you can develop your own program where you can estimate very quickly the value of the viscosity just by knowing the information. For example what are the composition of the natural gas what are the impurities present in the natural gas and what particular temperature and pressure we are supposed to calculate the viscosity.

So instead of going again and again on those expression you can write a mathematical program in excel sheet for that I am showing few steps that says what is given to us or should be known to us to calculate the viscosity of natural gas of course the temperature and pressure at that condition we want to know the viscosity. So that is given 10000 psi 180 Fahrenheit and the gravity 0.65 and the composition the mole fraction are given to us.

What we can do? We can calculate with the help of the correlation we understood previously how to calculate the pseudo critical pressures, pseudo critical temperature. If we know this we can calculate the gas viscosity at one atmospheric pressure that is 14.7 psia we got this we can use those correction for nitrogen correction for CO2 correction for H2S so here the expression is written we just entering the data and getting this correction because of impurities present and once we had all these four what we get?

The viscosity of the natural gas because of hydro carbon, nitrogen, CO2 and H2S at one atmospheric pressure and the temperature of interest that is 180F. Now we need to convert this viscosity to condition of interest that is 10000psi and 180 F. So what we can do again we can again use that big correlation and to use that correlation we need to know this reduce temperature pseudo reduce temperature and pseudo reduce pressure.

We can calculate if we are knowing the other pseudo critical temperature and pseudo critical pressure if we can once we are knowing this thing we can use that correlation to get this value of Mu r. So this is actually the value of Mu r the value of Mu r we can get and if once we know the value of Mu r in this expression this is kind of a ratio relationship we can get the gas viscosity and that gas viscosity we will obtain in the unit of centipoise.

So I think it is clear how to calculate the viscosity using this CKB method we understood the lee et el method and this CKB method any one of the method can be modeled just to have the quick estimation of the quick and accurate estimation of the viscosity while knowing the information required to apply those correlations.

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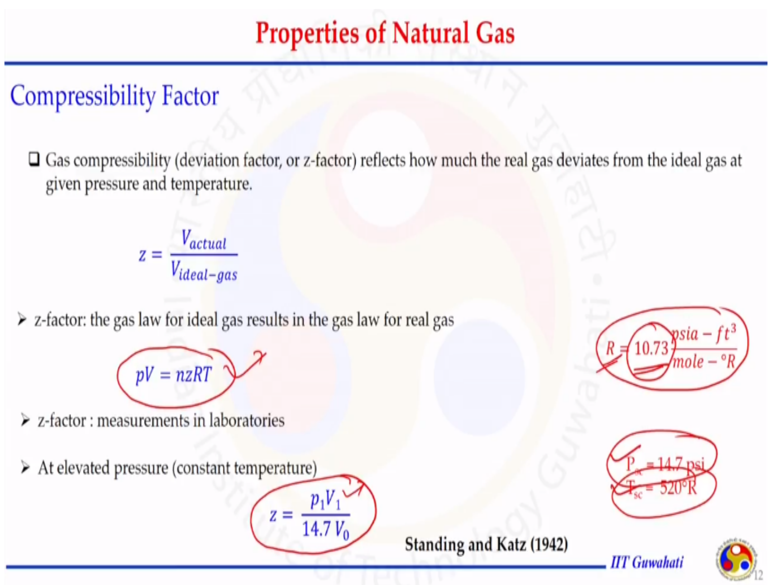

Another important properties is compressibility factor so the compressibility factor is a property of natural gas that is shows how much deviation natural gas is having from ideal gas so if we assume ideal gas law how much deviation in the properties or in the quantity we are going to measure in the help of this ideal gas law how much deviation we will obtain will be represented by this compressibility factors.

In very short term compressibility factor reflects how much the real gas deviate from the ideal gas at given temperature and pressures. So compressibility factor depend on temperature and pressure as the temperature and pressure condition are changing the compressibility factor will also change compressibility of course depend on the composition of the natural gas also. So by mathematical expression it is a ratio of V actual volume of the gas occupied divided by if the gas is considered as ideal gas how much volume the same amount of the gas will occupy that is the compressibility factor.

So the compressibility factors is the gas law for ideal gas result in the gas law for real gas so this is measure of how much deviation are happening or if we assume the natural gas as a ideal gas how much deviation how much error we will get error means how much deviations we will get in the real or in the real data. The expression can be modified the ideal gas law can be modified as a $pV = nzRT$ where z is the compressibility factor these information can be this is the value of compressibility factor can be measured in the laboratory but every time.

Like for example in the case of natural if any one property is changing like the natural gas composition are changing and in temperature and pressure condition changing the value will get change so it is important to develop some chart or correlation those are depend only on the properties of the natural gas is the composition of natural gas and with the knowing the composition of the natural or that gas we are dealing we can estimate very easily the compressibility factor value at different temperature and pressure conditions.

So for example at elevated pressure if we want to calculate the compressibility factor this is just simply is $p_1V_1 / 14.7\ V_0$ if and only if the temperature is kept constant. So this relation is if we are having natural gas that atmospheric condition that is the store in a volume V_0 and if we compress it or we elevate the pressure to p_1 the volume is occupied by the volume of occupied by gas is V_1 than the compressibility is $p_1V_1 / 14.7\ V_0$.

So in this kind of relationship we can estimate the compressibility factor value at a particular pressure knowing the volume occupied by the gas. And in all this relation we also need to know the value of R for simple here applying this R is the gas constant the numerical value is 10.73 psia if for mole degree ranking and the numerical value gets change when we are using a different unit system.

For example 8.314 when we are having the SI unit system these standard pressure is 14.7 and standard temperature is 520 degree ranking. And this value should be known always because whenever we are converting properties from one condition to other condition and if the other condition is the standard condition we need to apply these numerical values for the standard pressure and standard temperature to convert the expression.

And the R value of course most of the cases we are going to use 10.73 because it is a US field unit system and most of the reservoir system deals with the US field unit system. But whenever needed we have to convert this value into the unit system of interest.

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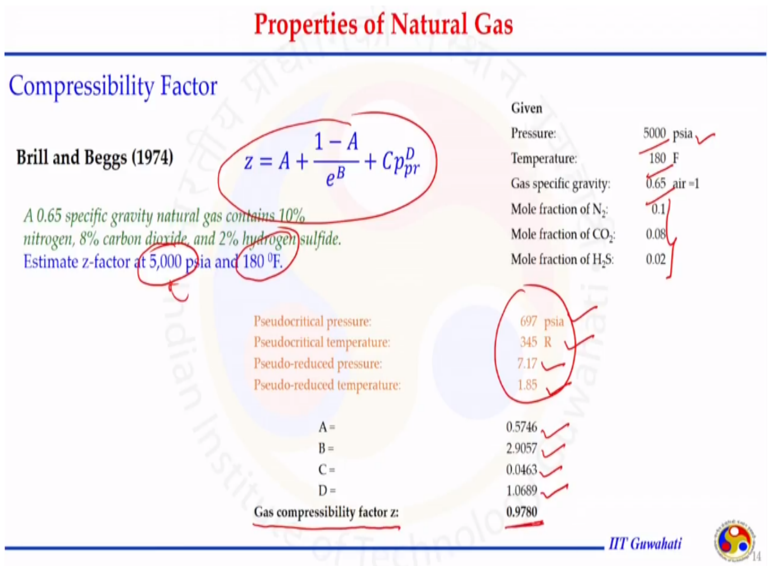

So let us go back to compressibility factor these chart we had seen in the last lecture also so if we know the reduce pressure and reduce temperate that is here reduce temperature and this is reduce pressure of the natural gas we can calculate the compressibility of the natural gas.

Instead of reading this complex chart we can use some correlation very complex correlation proportion to literature one of them is Brill and Beggs that is simply says the compressibility of natural gas z can be estimated with the help of this correlation and that is include A, B, C, D type of the parameters those A, B, C, D are defined in the form of pseudo reduce temperature and pseudo reduce pressure.

So if we know this pseudo reduce temperature and pseudo reduce pressure of the natural gas we have we can calculate the value of compressibility factor at the pressure and temperature of interest with the help of this correlation here in like D we are having this F. So F is defined here and similarly we can write mathematical expression for this system also to quickly estimate the value of compressibility factor.

So for the Brill and Beggs also one excel sheet could or manipulate it could be can be retained in that can be should be done actually to reduce the time consumption every time we are deal with the similar system. So for example if just viscosity need to be estimated in p1V1 condition we can do the calculation when we are going to another condition just even a small deviation like T2 ahh p2 we have to do again each steps it is better to write mathematical code ahh it is better to write ahh the code in the excel sheet or in a mat lab.

So this standing Katz methods sorry this is standing and katz chart read by the Brill and Beggs 1974 and we got one mathematical expression to calculate the compressibility factor. Another method is there but before going to that let us understand how this methods Brill and Beggs going to work. We are having almost same composition as in the previous example in fact the same composition just only the pressure value got change now we want to know the viscosity sorry the compressibility factor of nature gas as 5000 psia.

So what is given to us estimate the compressibility factor at 5000 psi temperature is 180F viscosity gravity means given as 0.65 the composition of the impurities are also given to us. So what we can do just let us calculate the critical temperature and critical pressure with the help of those values and knowing the test temperature and interest pressure we can convert them into reduce pressure and reduce temperature.

Now we know all these things those are required to calculate the coefficient appearing here ABCD we can write for ABCD and put in this expression we get the gas compressibility again in the unit of centipoise.

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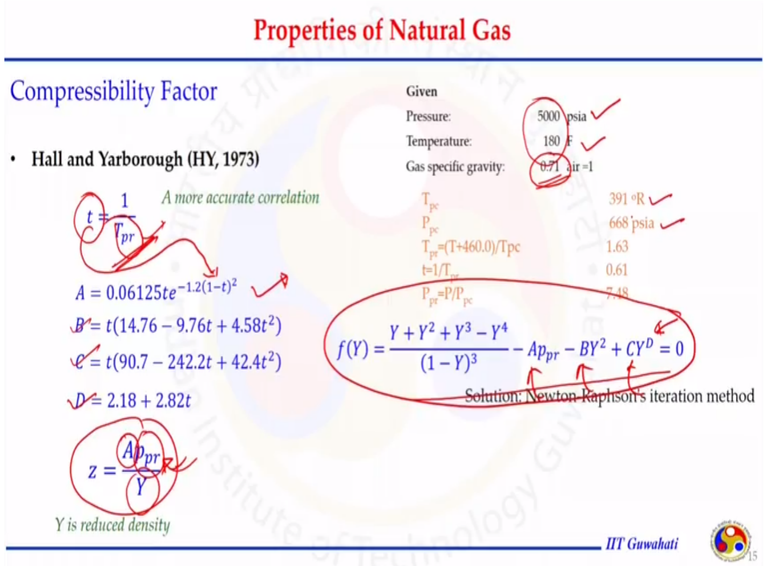

Another method for compressibility factor is Hall and Yarborough known as HY method it is more accurate correlation and that is simply says calculate the parameter S1 upon Tpr and if we know that we can also calculate similar for the pressure pseudo reduce pressure this is pseudo reduce temperature and this is pseudo reduce pressure of the natural gas of interest multiply this some coefficient A and divided by another coefficient Y we can get the compressibility.

So what are those A and Y let us see A simply says if this correlation t = 1 upon Tpr can be used here in this form and we can get the value of A. All these are like model fitting approach for the experimental data or for the chart they appear very complex that is why it is very important to setup some mathematical framework calculate this value very easily. Similarly B can be calculate C can be calculate and D can be calculate then when we need BCD another expression is there for the by known as reduce density and that parameter has a numerical value that is satisfy this condition.

So in this condition you can say here it is A, B, C and D are appearing and those A, B, C, D are in the form of reduce temperature because small t is just one upon pseudo reduce temperature. So if we know pseudo reduce temperature we can calculate A, B, C, D and knowing A, B, C, D in this equation we can get a fourth order polynomial equation with respect to Y and we can solve this or we can just optimize the value of Y that satisfy this equation that be done with the help of Newton Raphson iteration method or (()) (34:41) method or trial and error analysis.

We can calculate the value of Y that is going to satisfy this condition and once we know Y and A value we can use this expression to get the compressibility factor at temperature and pressure of interest. Let us see if you are having the same example as in the previous slide we can calculate the compressibility factor by using this HY method at the temperature and pressure of interest that is 5000 psi pressure and 180F temperature the viscosity if this is changing 0.71 what we are going to get we are not going to have much effect here in this calculation what we remember the critical temperature and critical pressure are the function of gamma g.

So when gamma g value is changing our pseudo critical temperature and pseudo critical pressure value will change knowing those value using this value given to us temperature and pressure we can calculate this pseudo reduce temperature and pressure those pseudo reduce temperature and pressure can put up here knowing other parameter we can get the value of compressibility factor.

So this is just similar manner it is written so the values are different than the previous example and the reduce temperature, reduce pressure also different and assuming value of Y solving for this expression we can get the compressibility factor of the natural that is 0.977 centipoise is appearing. So it looks very simple but we need to have some optimization technique especially for this value of Y to solve this complex equation that can be done with the Newton Raphson method.

So now we know how to estimate the viscosity and compressibility factor of a natural gas at point of interest, point of interest means the condition ahh temperature and pressure of interest.

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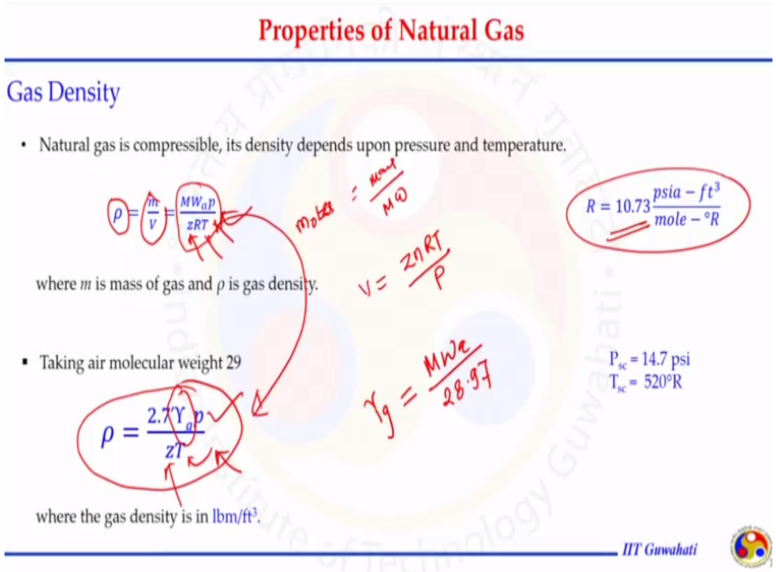

Now let us move to the next property that is gas density and natural gas is compressible that is density depend on temperature and pressure it is not constant we know why the definition of density for any fluid this is mass divided by volume and for the natural gas case we can say the mass divided by volume can be converted to this system just by having mass is equal to or we know moles is equal to mass divided by molecular weight.

And we know volume is equal to by real gas law znRT / p if we put both of them here we will get this expression that says density can be related to the apparent molecular weight of this natural gas and the condition of like interest, temperature or pressure is gas constant that is 10.73 in the US field unit system. Now you see here the compressibility is appearing that compressibility is a function of temperature and pressure.

So if you want to know the density first we need to know the compressibility factor of natural gas at that temperature and pressure R is okay T is in obsolete turn like degree ranking we can further modify this expression to achieve this and that can be done with the help of the non-parameter like gamma g we know it is apparent molecular weight of the gas divided by 28.97 R value is 10.73 if we put both of them here we are going to get this expression of gas density that is simply say gas density of natural gas depends on pressure, temperature, compressibility factor as well as composition.

And those composition can be represented in the form of specific gravity gamma g and the value comes out as 2.7 gamma gp / zT. So density is inversely proportional to temperature and directly proportional to pressure. But again this compressibility factor that also depends on temperate and pressure that will have effect on the density calculation.

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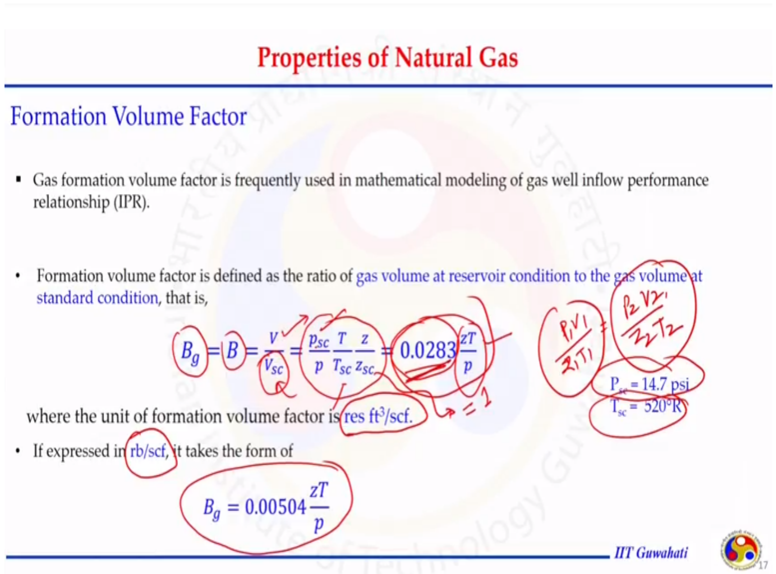

Now we know density, viscosity and compressibility factor let us know some more properties of natural gas those are important not to have dealing with the natural gas but to knowing the value of some of the parameter of natural in some standard condition. One of them is formation volume factor when we will be dealing about how the natural gas is being produced from the reservoir to wellbore the relationship called this IPR.

And in that IPR we can relate the flow rate or other parameter of the natural gas with some non-condition and that can be done that can also be done with the help of formation volume factor that is the ratio of gas volume at reservoir condition to guess volume at standard condition. So when we are having a fluid in the reservoir domain it is occupying some of the volume of core volume of the reservoir and instead of knowing the porosity and pore volume that reservoir.

We can convert those value to some standard condition and our standard condition is one atmospheric pressure and absolute temperature that is 520 degree ranking gas value formation factor Bg sometimes it is represented it as B this is the ratio of actual volume under the reservoir condition divided by the volume of the same amount of the gas at standard condition we can convert this volume under standard condition with the help of the relationship is p1V1 divided by z1 T1 = p2 V2 / z2 T2.

So representing the same amount of the natural gas at one set of the conditions to another set of condition that is 1 and 2 and similar we can do with the reservoir condition to standard condition we know the value of standard condition compressibility factor of the natural gas at standard condition is always assumed as one and knowing this we will get the expression for formation volume factor that appears at 0.0283 zT / p remember zT /p ahh so it is proportional to temperature inversely proportional to pressure.

And the numerical coefficient again depends on the unit system has been chosen to put this Psc, Tsc value and these values in the numerical value appearing here is when the volume formation factor is shown in reservoir feet cube per cubic feet. If the same is expressed in rb, rb stand for reservoir per standard cubic feet we will get this expression where the numeral value of will be 0.000504 multiply by the parameter zT upon p.

So this formation volume factor become very important we will see later on how to relate reservoir condition to standard condition.

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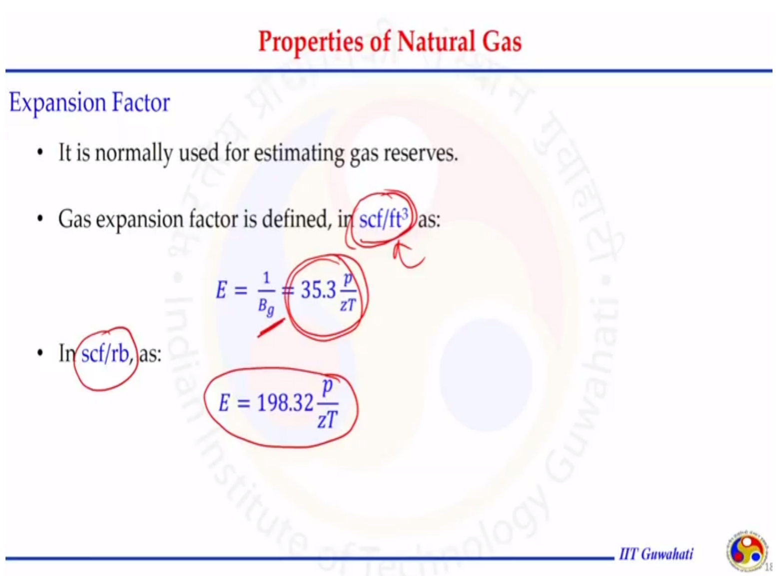

The reverse of volume formation factor is known as expansion factor it is normally used for estimating gas reserve how much gas reserve is available and express as the reverse of formation volume factor the numerical coefficient comes out as 35.3 because of the unit system is chosen the volume is represented in feet cube. If we convert this into scf per reservoir barrel the numerical value will get change and we had the expansion factor E = 19.32 or p / zT.

This properties will be helpful B and E property will be helpful relate one condition to other condition the other condition is always the standard condition.

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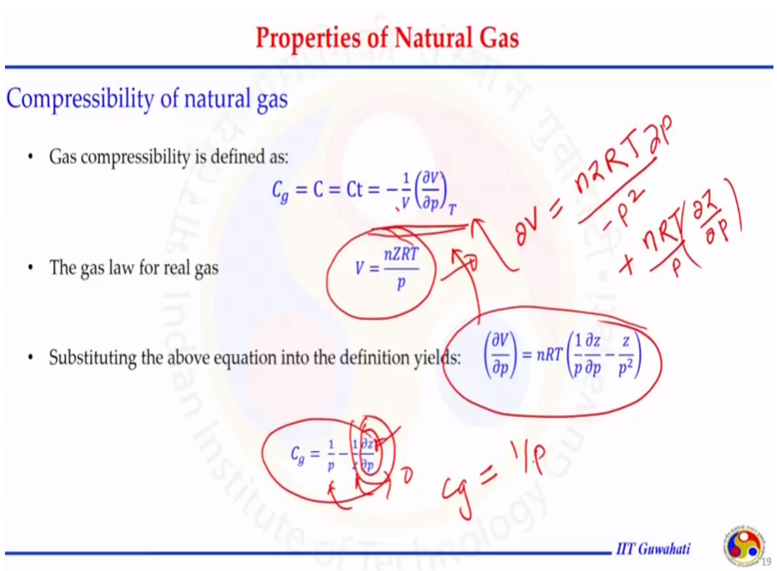

So another property of natural gas is compressibility of natural gas it is not incompressible it is compressible gas. So the compressibility of the gas is defined at a condition like represented by Cg sometimes C. Sometime Ct so this is also known as thermal compressibility of gas that says the compressibility of a natural gas is the ratio of change in volume with respect to pressure at constant temperature divided by the volume of the gas.

So negative sign comes once we increase the pressure volume decrease so – 1 / v Dou v / Dou p at a constant temperature. So this is mathematical definition the compressibility can be expressed, And for the real gas law we know how to replace the volume and if we take the derivative of this what we can get Dou v = nz R we can assumed that T is constant because under isothermal condition this will become –p square or Dou p + n constant R constant T constant p is taken out the Dou z by Dou p.

If we adjust these here putting the value of this putting the value of this Dou p or Dou v what are going to get this expression we can put it here and we will get the expression for thermal compressibility of natural gas and that is easy = 1 / p – 1 / z Dou z by Dou p. With knowing the pressure knowing the compressibility and how compressibility is going to change with pressure.

We can get the compressibility of natural gas or thermal compressibility of natural gas or the other mean if we know the thermal compressibility of the natural gas knowing the pressure and compressibility factor z we can understand the change in compressibility with the pressure the slope of this linear equation in the form of the linear parameter we will tell us the slope or the change in compressibility with respective to pressure.

We can also calculate the compressibility of ideal gas with the same sort of definition and it comes out as ideal gas compressibility is not a function of anything compressibility does not appear in the ideal gas law this turn will becomes 0 so the thermal compressibility of natural gas is 1 / p.

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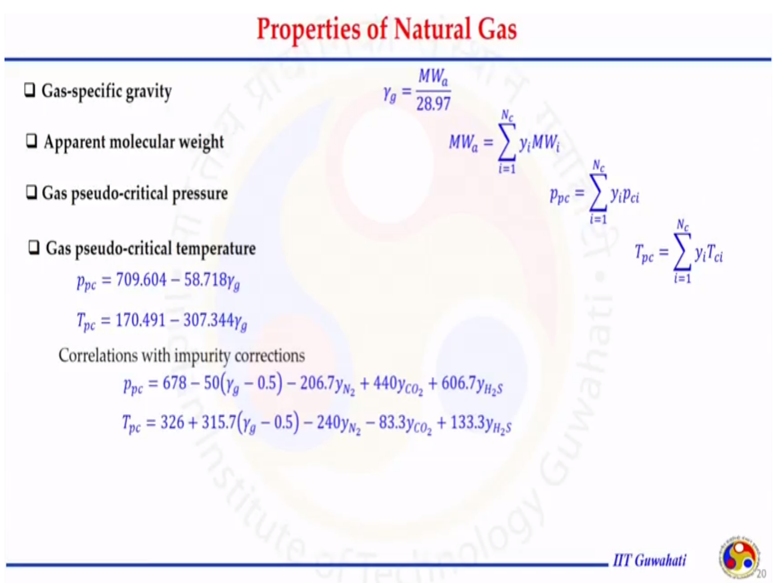

So let us summarize gas is specific gravity we know how to calculate molecular weight apparent molecular weight pseudo critical pressure, pseudo critical temperature when the composition are given when composition is not given gamma g is given. We can still calculate with the correlation, linear correlation, quadratic correlation correction for the impurities we can get the critical properties using this critical properties.

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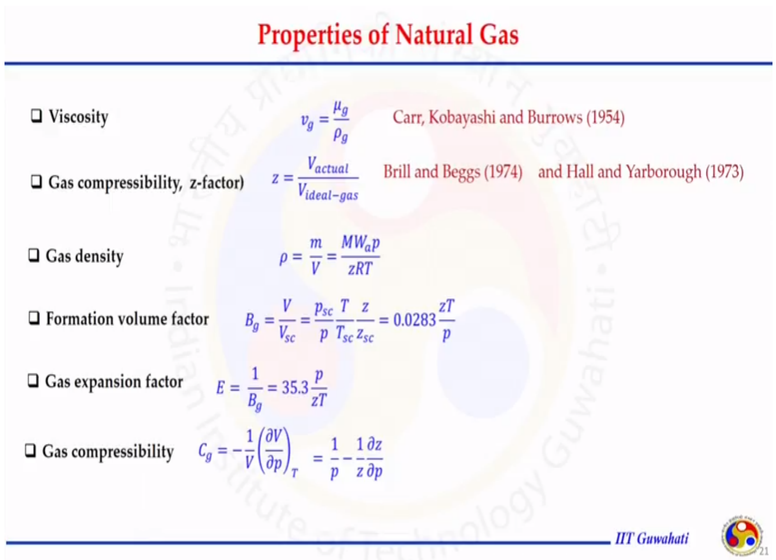

We can get the pseudo reduce properties of natural gas and viscosity can be at the mathematical expression could be established for the viscosity measurement one of the method is CKB method similarly for gas compressibility two three methods we have discussed like Bril and Beggs and HY method those can be used and gas density can be estimated if the compositions or the gamma g is known to us formation volume factor.

And expression factor can be estimated with the help of these expression and gas compressibility and all these will be useful when we are dealing how the natural gas is being treated at different stages from the production zone within the reservoir within the porous media in the reservoir to supply when we are sending to consumer at the end and the consumer is using this natural gas all these properties will be used.

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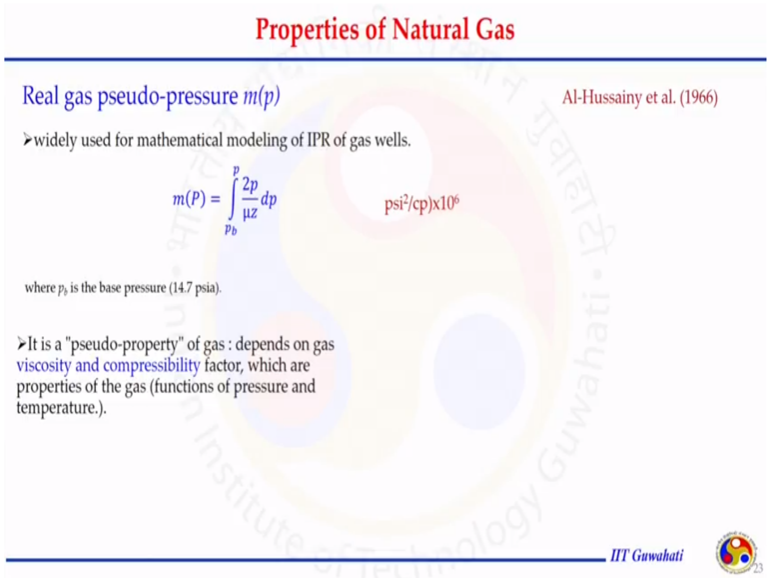

Some other properties of natural gas those directly does not characterize the natural gas but knowing those calculation how to calculate those properties or those parameters characterize the combination of the properties of natural gas. For example real gas pseudo pressure it is one way of showing how the compressibility factor and how the viscosity of natural gas altogether will change when we are changing the pressure condition from one point to other condition.

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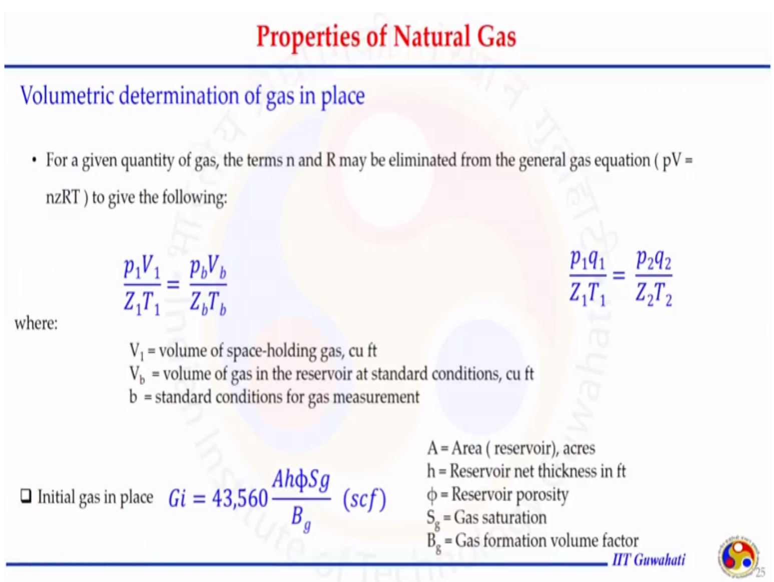

By knowing all these things we can get volumetric determination of gas in place let us see the application of the properties we have just learned how they are going to help us one of the application is volumetric determination of gas in place. So now another parameter that more often appears in dealing with flow system the Reynolds number for natural gas depends not only on the composition of the natural gas but also at what temperature and pressure the Reynolds number needs to be calculated to understand the flow resume in a pipeline.

In the next lecture what we are going to understand is the parameter on the reservoir side so far what we have understood is fluid but in the production side when we talk about the production from the reservoir domain it is not only the fluid property but also the reservoir properties those are responsible for the production we will try to understand some of the properties those are related to natural gas production system thank you very much for seeing the video.