Petroleum Reservoir Engineering

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Lecture 7: Properties of Crude Oil

Hello everyone, and I welcome you again in the class of petroleum reservoir engineering. So, we are in the lecture 3 of week 2 of section 1. In last 2 lecture of this week, we discuss about thermodynamics of hydrocarbon fluids and the properties of the natural gas. So, we are going to continue our discussion about reservoir fluid properties. So, in today's lecture, we will discuss about oil properties along with some properties of the water and some of the laboratory analysis those are used to characterize the fluid.

Properties of the crude oil needs to be measured when we are dealing with the crude oil system for designing purpose for estimating the reserves and other things. So, the crude oil is a complex mixture consisting predominantly hydrocarbon along with some impurities or minor constitute of inorganic compound including hydrogen, helium, sulphur, nitrogen are also present. Important properties of the crude oil are listed here like the properties that include crude oil gravity, specific gravity, oil density, gas solubility, bubble point pressure, oil formation volume factor, compressibility coefficient, important one is viscosity and surface tension. Along with these properties, some more properties are also required when we are dealing with the crude oil, but for the subject of this course, some of these properties we will discuss in detail in today's lecture.

The physical and chemical properties of crude oil vary considerably depending on the compositions. If the composition of the crude oil is changing, the properties will get changed. So, every time whenever we are suspecting the crude oil compositions are changing, the properties need to be re-estimated. So, the natural laboratory measurement can be performed on the actual sample collected from the field to measure these properties or there are several empirical correlation are developed based on the experimental data or those correlation can be used. But these correlations are developed for a range of the parameter and it should be taken care when we are using the correlation or the particular correlation is applicable or not.

In general, when we compare with the natural gas, oil consists more component than the natural gas. The composition varies from C7 onwards up to C70 plus compounds, not only the straight chain compound, aromatic compound, isoparaffins compound and the branch compound, cyclic compound are also the part of the oil composition. Mixture of liquid component exhibit more non-ideality than to mixture of the gas component. So, dealing with the liquid system becomes more complex, not only the composition, but if we see in our diagram here, the crude oil is in the contact of gas on the top part and water in the bottom part. Because of the density differences, it is settled in the reservoir like this.

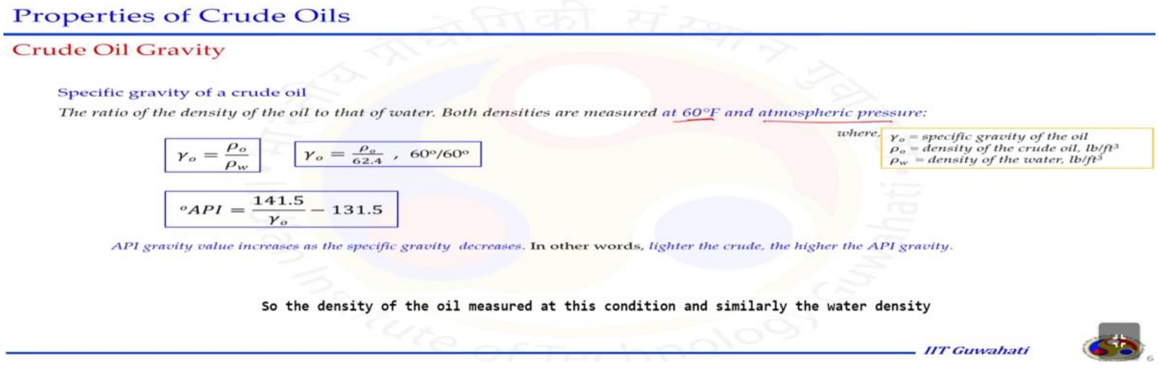
The natural gas that is having good amount of the solubility in the crude oil at reservoir temperature and pressure condition. So when reservoir temperature, pressure condition is varying, even the composition of the natural gas and crude oil are same, the solubility is going to be changed. So we need to understand how much gas is soluble at particular condition in the oil. Accordingly, the properties will also be changed. So we will discuss that setting in today's class.

This is the typical PT diagram we discussed in the thermodynamics class, where the crude oils are classified based on the tie lines between the bubble point curve and the dewpoint curve. We can also estimate the oil shrinkage value or the liquid volume that will be present in the system when we are having the ordinary black oil, low shrinkage oil, volatile crude oil or the near critical crude oil system. The amount of the liquid with change in the pressure assuming the reservoir is isothermal means the temperature is not changing, how much percent of the liquid can vary depending on the type of the composition the crude oil is having or the tie lines between the bubble point and dewpoint curve are spreaded. Broadly we classified that is under saturated oil reservoir that is the liquid phase on the top part and when the crude oil compositions are within this envelope because of the temperature and pressure conditions we are having the two phase reason and the crude oil is called the saturated oil. With this background let us try to understand how to estimate the basic properties of this crude oil those are required.

In the further calculation those calculation include the production of the crude oil, processing of the crude oil, transporting of crude oil. So everywhere whenever we are dealing with the crude oil the basic properties are important to be known. First property is crude oil density we know density is mass per unit volume this need to be defined at a specific temperature and pressure condition because the density varies as the temperature pressure condition vary. So the crude oil density is usually expressed in pounds per cubic feet in terms of the unit several correlations are there those can be used to calculate the density of the liquid when the compositions are not known. So the crude oil that is getting produced or we are dealing with the simplest or the foremost important thing is knowing the composition.

We discussed in detail in the last lecture about how gas chromatography can be utilized for knowing the composition of the substance. Crude oil can also be subjected for the gas chromatographic analysis. So based on the injection and detector in case of the liquid we use the FID detector and a particular type of the column in the gas chromatography we can get the good carbon number distribution that is spreaded on the retention time and we can classify the carbon number distribution of the crude oil. In case when the crude oil compositions are not known correlation can be used to estimate the properties. Gas gravity, oil gravity and gas solubility are the parameter those are going to be important when we are talking about the oil density.

As I already mentioned the crude oil at a particular temperature and pressure is having certain amount of the solubility for the natural gas and natural gas is in the contact of the crude oil at the reservoir conditions it is dissolved the natural gas is dissolved in the oil. So when we are calculating the property we need to understand what is the quality of the gas in terms of the gas gravity what is the quality of the oil means oil gravity and the amount of the gas that is soluble at that condition in the oil. The expression for calculating the density of the crude oil is written here that is in terms of the quality of the oil quality of the gas gamma g and the saturation or the solubility of the gas in the crude oil and that is divided by the volume formation factor of the oil that is relate the reservoir condition to the surface condition. Standing 1981 proposed an empirical correlation to include the effect of the temperature also in this expression and you can see the top part is same but the volume formation factor is represented by an empirical correlation where along with the Rs gamma g and gamma o the effect of the temperature is also included into the expression to calculate the density of the crude oil. The unit and the expression gamma o is the specific gravity Rs is the gas solubility and Ro is oil density T is the temperature in degree ranking.



Properties of Crude Oils

Crude Oil Gravity

Specific gravity of a crude oil

The ratio of the density of the oil to that of water. Both densities are measured at 60°F and atmospheric pressure:

$$\gamma_o = \frac{\rho_o}{\rho_w}$$

$$\gamma_o = \frac{\rho_o}{62.4}\ ,\ 60^\circ/60^\circ$$

where,
γ_o = specific gravity of the oil
ρ_o = density of the crude oil, lb/ft^3
ρ_w = density of the water, lb/ft^3

$$^\circ API = \frac{141.5}{\gamma_o} - 131.5$$

API gravity value increases as the specific gravity decreases. In other words, *lighter the crude, the higher the API gravity.*

So the density of the oil measured at this condition and similarly the water density

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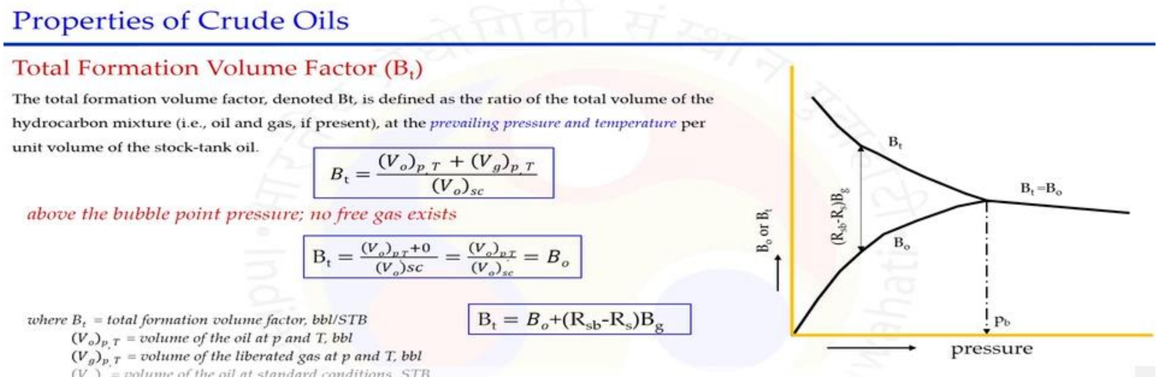
So the unit and the terms are defined in the bracket in almost every slides. So what is this gamma o or the specific gravity of crude oil this is the ratio of density of the oil to the density of the water. The reference substance for the liquid is water definition similar to the natural gas in natural gas the reference substance was the air. Both densities are measured at a particular temperature and pressure to mention the value of the specific gravity the standard condition is 60 degree f and 1 atmospheric pressure. So the density of the oil measured at this condition and similarly the water density is also measured at that condition the ratio of these two value is the gamma o.

The density of the water at 60 degree f and 1 atmosphere is 62.4 so the expression of gamma o will appear like this and after the expression you may see the value of the temperature also mentioned so both the properties means density of the water and crude oil are measured at 60 degree f. Another way of expressing the quality of the oil or the gravity of the oil is degree API that is 141.5 divided by gamma o minus 131.5.

So this is one of the way of saying the quality of the oil the oil is going to be light heavy depending on gamma o value and that can be expressed in terms of degree API. API gravity value increases as the specific gravity decreases or in other words lighter the crude oil the API value will be more. For example heavy crude oil 0 to 20 degree API medium grade crude oil it is 20 to 30 degree API and for the lighter crude oil it is more than 30 degree API. 47 degree API for lighter crude oil in general it is expressed and 10 degree API for the heavier asphalting crude oil component is the value of degree API if the asphalting component is more. The specific gravity of the solution gas so the crude oil is not alone when we are talking about the reservoir condition or the condition when the gas is having some solubility in the crude oil the specific gravity of that mixture where the gas is soluble in the crude oil can be expressed using this expression where the gamma g the specific gravity of the solution gas that is dissolved in the oil can be calculated by using set of the separator and those separators are fixed at different temperature and pressure conditions and from each separator we are calculating the gas oil ratio and measuring the gas gravity that is separating out from the oil at that separator and using this expression we can calculate the gamma g value.



Properties of Crude Oils

Total Formation Volume Factor (B_t)

The total formation volume factor, denoted Bt, is defined as the ratio of the total volume of the hydrocarbon mixture (i.e., oil and gas, if present), at the *prevailing pressure and temperature* per unit volume of the stock-tank oil.

$$B_t = \frac{(V_o)_{p,T} + (V_g)_{p,T}}{(V_o)_{sc}}$$

above the bubble point pressure; no free gas exists

$$B_t = \frac{(V_o)_{p,T} + 0}{(V_o)sc} = \frac{(V_o)_{p,T}}{(V_o)_{sc}} = B_o$$

$$B_t = B_o + (R_{sb} - R_s)B_g$$

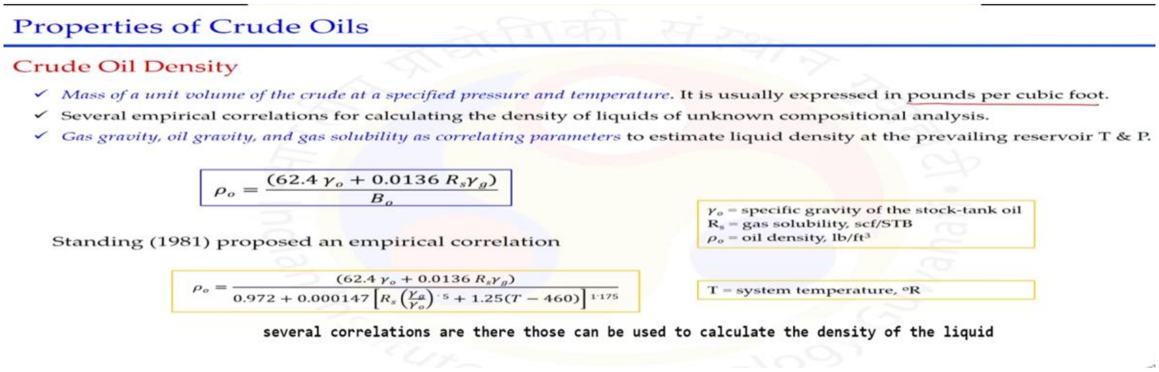
where B_t = *total formation volume factor, bbl/STB*

$(V_o)_{p,T}$ = *volume of the oil at p and T, bbl*

$(V_g)_{p,T}$ = *volume of the liberated gas at p and T, bbl*

$(V_o)_{sc}$ = *volume of the oil at standard conditions, STB*

So we keep talking about this gas solubility what is this gas solubility is defined as the number of a standard cubic feet of gas that is dissolved in the stock tank barrel of crude oil at certain temperature and pressure. Stock tank barrel oil means almost at the atmospheric temperature and pressure condition at that condition how much gas is dissolved in the oil the parameter gas solubility quantify that thing. If you can see in this diagram this is the gas solubility is a function of pressure so not only the pressure it is also a function of the temperature API gravity means quality of the oil and the gas gravity the composition of the gas or the quality of the gas all these affect the solubility of the natural gas in the crude oil. This diagram shows about the effect of pressure so let us say we are having the reservoir pressure P_0 that is higher than the saturation pressure or the bubble point pressure and when we are reducing the pressure because of the production pressure is getting reduced we are in the under saturated crude oil situation where only single phase is present only liquid is present there is no gas is liberating out or no gas is getting released out of the oil so the solubility RS that is at the P_0 condition will remain the same till PS saturation condition and when we further reduce the pressure we are in the saturated crude oil region or the two phase region the gas releases out from the crude oil because of the pressure and in that case the solubility of the gas in the remaining oil also changes and that decreases continuously as the pressure is reduced. The situation can be reached like the atmospheric condition when the all the gas that was soluble in the crude oil is released out and we are having only the oil that is called the dead oil when the gas is just released out and we are having only single phase that is the crude oil phase or the liquid phase only.



Properties of Crude Oils

Crude Oil Density

- ✓ *Mass of a unit volume of the crude at a specified pressure and temperature*. It is usually expressed in pounds per cubic foot.
- ✓ Several empirical correlations for calculating the density of liquids of unknown compositional analysis.
- ✓ *Gas gravity, oil gravity, and gas solubility as correlating parameters* to estimate liquid density at the prevailing reservoir T & P.

$$\rho_o = \frac{(62.4\,\gamma_o + 0.0136\,R_s\gamma_g)}{B_o}$$

γ_o = specific gravity of the stock-tank oil
R_s = gas solubility, scf/STB
ρ_o = oil density, lb/ft³

Standing (1981) proposed an empirical correlation

$$\rho_o = \frac{(62.4\,\gamma_o + 0.0136\,R_s\gamma_g)}{0.972 + 0.000147\left[R_s\left(\frac{\gamma_g}{\gamma_o}\right)^{.5} + 1.25(T - 460)\right]^{1.175}}$$

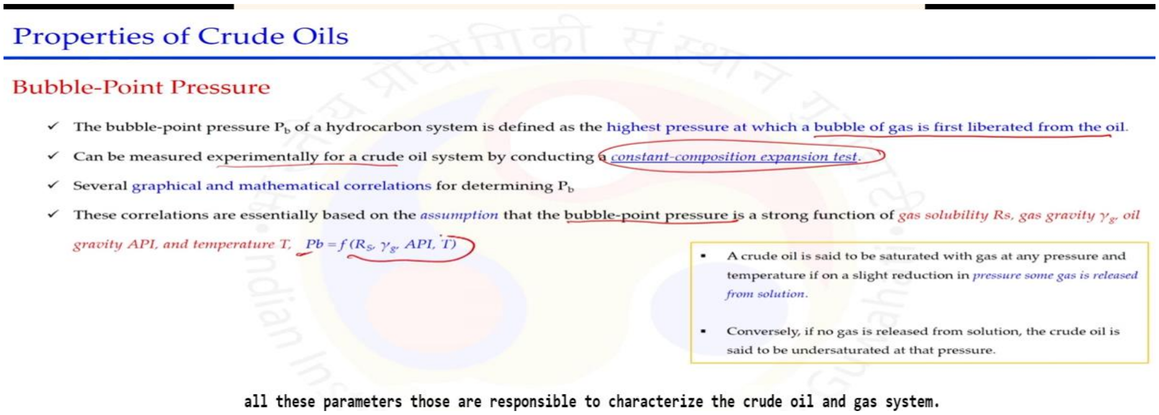
T = system temperature, °R

several correlations are there those can be used to calculate the density of the liquid

So if the original crude oil is under saturated reduction in the pressure up to the bubble point no change in the gas solubility is happening at pressure below PB bubble point pressure gas is evolved and the value of RS decreases. There are several correlations those are given to understand the behavior of the solubility of the gas in the crude oil and the effect of the temperature and pressure. Some of the correlation I listed out here these correlations are developed based on the set of the data set either in the laboratory experiment or from the field are collected and perform the data analysis on it to develop the correlation. For example standing correlation he developed the correlation using the California crude oil in 1947 he gave a graphical representation of how to estimate the gas solubility when the temperature pressure type of the gas and type of the crude oil are considered in the discussion. Later on in 1981 these graphical data has been converted into mathematical expression and that mathematical expression shows here the solubility of the gas at a particular temperature can be estimated using this expression here P is the pressure of interest gamma g is appearing here and here and the quality of the oil is represented in terms of API.

So either gamma o or API is appearing into the expression to estimate the property. In the similar manner other group of the researcher they have developed the correlation not only for the gas solubility for most of the properties of the oil gas mixture or the crude oil alone like the Vascuus and Weggs they gave the correlation, Glashu correlation that is based on the North Sea crude oil, Marhon correlation they consider the Middle Eastern crude oil sample to develop the correlation and the Petrosky-Farsad correlation is based on the Mexico crude oil. While the second one this Vascuus and Weggs correlation they consider around 5000 data set from different crude oil to develop the correlation. So how rigorously the correlations are developed what wide range of the data set are considered are important to make them the generalized correlation otherwise based on the data available the particular type of the correlation can be used to calculate the properties of the crude oil. So for example the gas solubility can be calculated using the expression given by standing although this expression was developed for the California crude oil but within the range what is that range it is valid at and below bubble point pressure of the crude oil for any type of the crude oil if the situation or the pressure is below or at the bubble point pressure we can use this expression to calculate the gas solubility.

Of course above the bubble point pressure this is just a single phase and the gas is not going to be released out when the mild change in the pressure is happening. So the next properties bubble point pressure we are keep classifying the reservoir based on the bubble point. What is bubble point pressure of hydrocarbon system? It is defined as the highest pressure at which bubble of gas is first liberated from the oil. It can be measured experimentally for crude oil system by conducting constant composition expansion test we will discuss later on this test. Similar to other properties for bubble point pressure also several graphical and mathematical correlations are given those can be utilized to calculate it.



Properties of Crude Oils

Bubble-Point Pressure

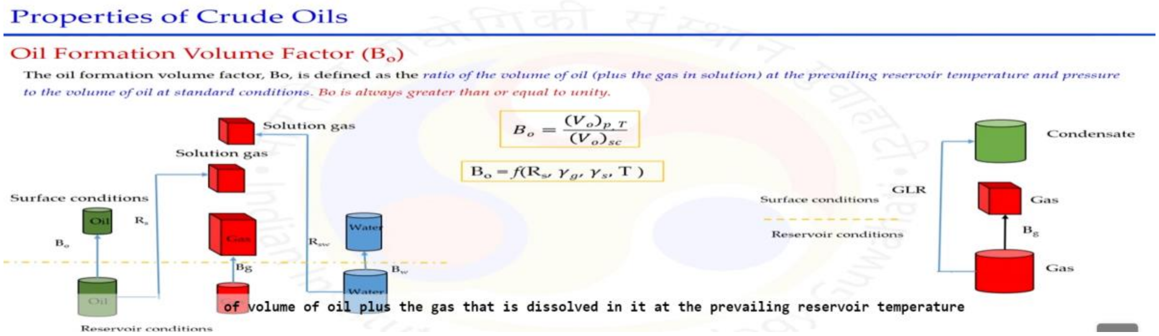
- ✓ The bubble-point pressure P_b of a hydrocarbon system is defined as the highest pressure at which a bubble of gas is first liberated from the oil.
- ✓ Can be measured experimentally for a crude oil system by conducting a *constant-composition expansion test*.
- ✓ Several graphical and mathematical correlations for determining P_b
- ✓ These correlations are essentially based on the *assumption* that the bubble-point pressure is a strong function of *gas solubility Rs, gas gravity* γ_g, *oil gravity API, and temperature T*, $Pb = f(R_S, \gamma_g, API, T)$

- A crude oil is said to be saturated with gas at any pressure and temperature if on a slight reduction in *pressure some gas is released from solution*.
- Conversely, if no gas is released from solution, the crude oil is said to be undersaturated at that pressure.

all these parameters those are responsible to characterize the crude oil and gas system.

These correlations again are based on certain assumptions and it is believed or based on certain assumption that the bubble point pressure is a strong function of gas solubility, gas gravity, degree API of the crude oil, temperature of the system. So the bubble point pressure is function of all these parameters those are responsible to characterize the crude oil and gas system. Based on the bubble point we can classify the reservoir as the saturated and under saturated reservoir. Similar set of the correlation you will see for all these properties so they develop the correlation for one properties and then extended the work based on the data they collected for measuring the other properties. We are just discussing only one set of the data for more detail you can visit Tarek and Ahmed book where the correlation developed by other scientist or researcher are also compiled.

So standing again given the correlation for California crude oil based on around 55 something data point for the PV calculation also. So the PV is a function of RS gamma g degree API here and the temperature that is here. So the expression of PV is in all these parameter along with one parameter A and that A is actually defining the temperature and quality of the crude oil. So using this expression we can calculate the value of PV. Experimentally can also be measured the value of PV that we will discuss later on.



Properties of Crude Oils

Oil Formation Volume Factor (B_o)

The oil formation volume factor, Bo, is defined as the *ratio of the volume of oil (plus the gas in solution) at the prevailing reservoir temperature and pressure to the volume of oil at standard conditions. Bo is always greater than or equal to unity.*

$$B_o = \frac{(V_o)_{p,T}}{(V_o)_{sc}}$$

$$B_o = f(R_s, \gamma_g, \gamma_s, T)$$

of volume of oil plus the gas that is dissolved in it at the prevailing reservoir temperature

Third important property of crude oil is oil formation volume factor. We discussed the volume formation factor for the gas BG. Similar property for the oil is BO it is the ratio of volume of oil plus the gas that is dissolved in it at the prevailing reservoir temperature and pressure to the value of oil at standard condition. So the BO value actually relate the reservoir volume of the oil to the volume at the surface. So BO is always greater than or equal to 1 by this definition and this definition simply mathematically can be expressed like this.

Further we know BO is also going to be the function of solubility of the gas gamma g quality of the gas this should be gamma o quality of the oil and the temperature. This parameter if known we can use the mathematical correlation given in the literature to calculate the BO but what exactly happens in reservoir to the surface these two diagrams are explaining the situation. So in the reservoir condition we are having the oil, gas and water. When it is brought to the surface what happened to this oil pressure declines and the gas that is dissolved in this oil just liberated out and contribute towards the gas quantity that is getting produced from the reservoir. What happened to the gas? The gas that is at the reservoir condition under high pressure when it is brought to the surface it volume expanded because the pressure is less.

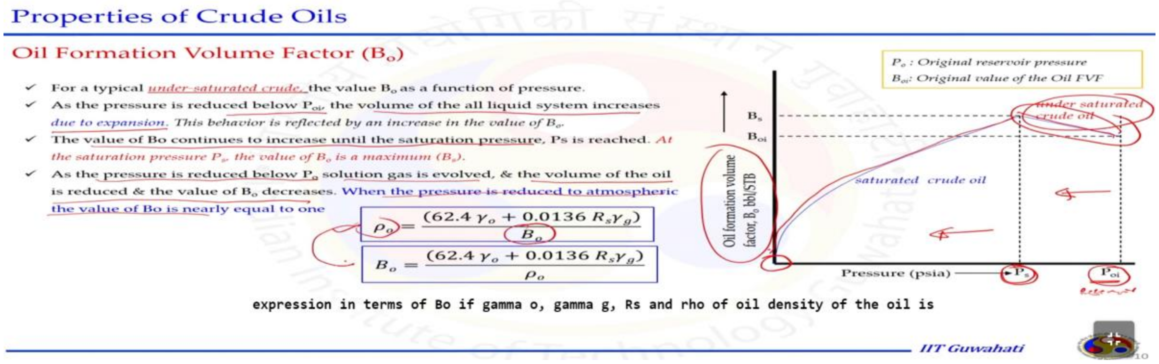
What happens to the water? Water may have a small amount of the gas dissolved in it and that solution gas can be liberated when water is also brought to the surface but the amount of the gas dissolved in the water is very less in that case the volume formation factor of water BW almost remain constant or its value is approximately 1. On the gas alone if we discuss about the gas so this gas is having volume formation factor Bg the gas comes to the surface is having different volume occupied because the pressure is different and some amount of the condensate may also get released from this gas because of the retrograde behavior of the natural gas and the volume may changes. The typical values for the formation factor for oil it range from 1.2 to 2.4 rB per STB that is why it is mentioned the Bo value is going to be always either greater than 1 or equal to 1.

At the saturation condition or when we are at the bubble point curve in terms of temperature and pressure the value of Bo is going to be 1. For the gas the value is 0.003

to 0.01 reservoir condition to surface condition it may vary. As I mentioned for the water it is around 1.

This is the typical diagram that represent how the oil formation volume factor is changing when we are changing the pressure. So, let us say again this is the reservoir pressure condition where the reservoir is having pressure PoI and we are producing the pressure will get change and PoI is greater than Ps saturation pressure. So, the crude oil is going to be the under saturated crude oil means only the liquid phase. But when we are changing the pressure the volume formation factor is increasing. So, when we are decreasing the pressure the value of Bo is increasing slightly to a situation when we reach the saturation condition.

And further decrease in the pressure the volume formation factor will decrease and at the atmospheric pressure there will be value almost 1 because it has no gas soluble into it. The value at the reservoir condition if assume it is atmospheric condition is similar to what is the condition at the STP in that case the Bo value will be 1. In text form as the pressure is reduced below PoI the volume of oil liquid increases due to the expansion because at the reservoir condition the fluid is having under the pressure condition it has been compressed. But when the pressure is released the oil expansion happens because of that the value of Po is increasing. The value of Bo continue to increase until the saturation pressure Ps is reached as the pressure is reduced below Po solution gas start evolving two phase system start coming to the picture and the volume of the oil is reduced and the value of P0 decreases.



Properties of Crude Oils

Oil Formation Volume Factor (B_o)

- ✓ For a typical *under-saturated crude,* the value B_o as a function of pressure.
- ✓ As the pressure is reduced below P_{oi}, the volume of the all liquid system increases *due to expansion. This behavior is reflected by an increase in the value of B_o.*
- ✓ The value of Bo continues to increase until the saturation pressure, Ps is reached. *At the saturation pressure P_s, the value of B_o is a maximum (B_s).*
- ✓ As the pressure is reduced below P_o solution gas is evolved, & the volume of the oil is reduced & the value of B_o decreases. When the pressure is reduced to atmospheric the value of Bo is nearly equal to one

$$\rho_o = \frac{(62.4\,\gamma_o + 0.0136\,R_s\gamma_g)}{B_o}$$

$$B_o = \frac{(62.4\,\gamma_o + 0.0136\,R_s\gamma_g)}{\rho_o}$$

P_o : Original reservoir pressure
B_{oi}: Original value of the Oil FVF

expression in terms of Bo if gamma o, gamma g, Rs and rho of oil density of the oil is

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When the pressure is reduced to the atmosphere the Bo is nearly equal to 1 as I mentioned about it. How to calculate the Bo value? We know this definition of the density we can just if we know the density value we can calculate the Bo value. So, we can just transform this expression in terms of Bo if gamma o, gamma g, Rs and rho of oil density of the oil is known to us we can calculate the value of Bo. But it is not as simple as given in this expression because this expression is having no effect of the temperature and the pressure solubility changes with temperature and pressure. So, the density of the liquid also changes with temperature and pressure.

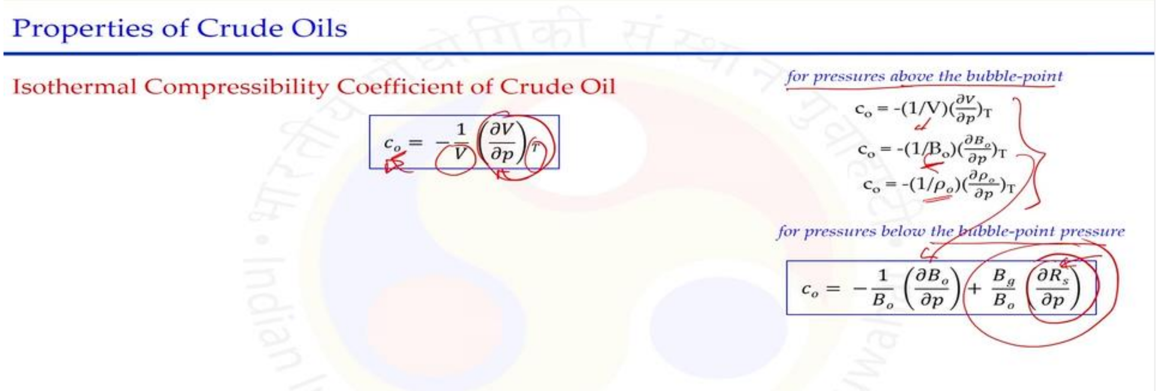
So, similar set of the scientists they had given the correlation based on the data set they used to develop the correlation. Standing correlation included the effect of temperature gamma g, gamma o to calculate the Bo value of crude oil system where the gas is dissolved in the crude oil. So, this expression can be utilized to calculate the Bo value. Total volume formation factor as I am keep explaining the oil under certain condition is having some amount of the gas dissolved in it. So, when we are talking about the total volume formation factor that is for the oil as well as for the gas and this is at the condition.

Let us say reservoir condition and this is the volume at the standard condition. Standard condition we are not having any gas volume because whatever the gas that was dissolved in the crude oil that has been released out at the atmospheric pressure and temperature condition. So, above the bubble point pressure when we are in this region bubble point pressure the total volume formation factor is equal to oil volume formation factor because no gas is releasing out it is just a single phase only the liquid phase is present here. So, the liquid volume formation factor will be equal to total volume formation factor. When we are in this region the Bo value will decrease as we decrease the pressure while the total volume formation factor value will increase because the BG value or the formation volume factor for the gas is going to be changed.

And this is happening because the solubility of the gas will change when we are at reservoir pressure when we are at bubble point pressure it is still in the liquid phase the gas dissolved in it. But when we are coming to the lower pressure side the value of the solubility will change and that is actually going to account the total volume formation factor to be increased when we are decreasing the pressure. So, this is going to be the expression to calculate the Bt value at any temperature and pressure when two phase are present. The temperature and pressure effect will be counted by the solubility of the gas. So, the two formation so the two phase formation volume factor when the experimental data are not available the correlation of standing, Glaso and Marhons can be utilized to calculate the Bt value.

The isothermal compressibility coefficient of crude oil this is also similar to the expression we discussed for the natural gas. This value or parameter is actually characterized how much a substance can be compressed isothermally means at constant temperature with respect to pressure. So, how much volume can be changed when we applying the pressure either increasing the pressure or decreasing the pressure how much change in the volume is happening with respect to the original volume the ratio is the isothermal compressibility coefficient for oil it is denoted as CO. Now this expression for pressure above the bubble point when only liquid phase is present and we can convert this volume into volume formation factor similar definition will hold it and the volume formation factor can be converted into density. So, all these expressions are same either in terms of the volume or volume formation factor or in terms of the density.

For pressure below the bubble point when the two phase are present the solubility of the gas will come into the picture and the change in the solubility with respect to pressure needs to be accounted in this expression like this expression is having this additional term that is need to be included in the expression to calculate the isothermal compressibility coefficient of crude oil. It is required for solving many reservoir engineering problem we will see when we are developing the mathematical expression for inflow performance relation. Determination of physical properties of under saturated crude oil requires the value of CO how much compressible the fluid is or the mixture of fluid oil and gas is in that case the CO value is required. There are several correlation developed to estimate the value of oil compressibility at pressure above the bubble point pressure means for the under saturated crude oil system the similar scientist name are there along with this McCain correlation that can be utilized to calculate the isothermal coefficient or compressibility coefficient for the crude oil. The very important property of the crude oil is viscosity we know viscosity is a resistance to flow offered by any fluid when it is flowing from higher pressure to the lower pressure region.



Properties of Crude Oils

Isothermal Compressibility Coefficient of Crude Oil

$$\boxed{c_o = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T}$$

for pressures above the bubble-point

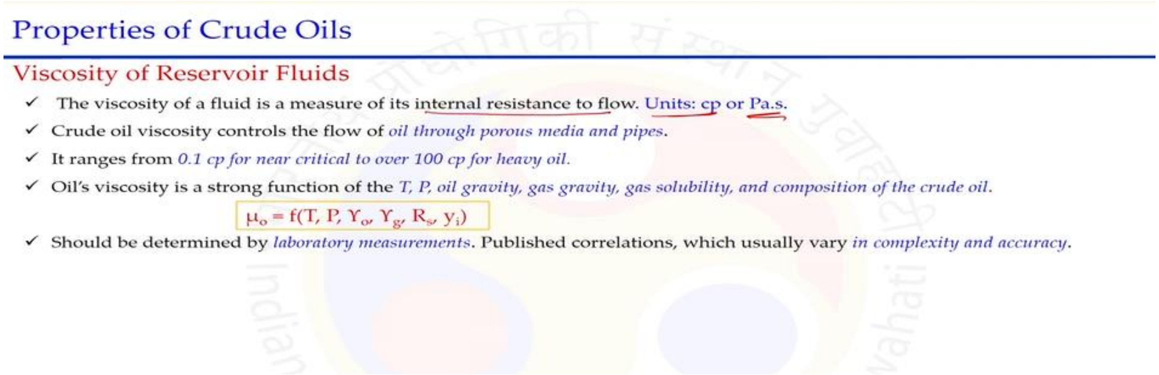
$$c_o = -(1/V)\left(\frac{\partial V}{\partial p}\right)_T$$

$$c_o = -(1/B_o)\left(\frac{\partial B_o}{\partial p}\right)_T$$

$$c_o = -(1/\rho_o)\left(\frac{\partial \rho_o}{\partial p}\right)_T$$

for pressures below the bubble-point pressure

$$\boxed{c_o = -\frac{1}{B_o}\left(\frac{\partial B_o}{\partial p}\right) + \frac{B_g}{B_o}\left(\frac{\partial R_s}{\partial p}\right)}$$



Properties of Crude Oils

Viscosity of Reservoir Fluids

- ✓ The viscosity of a fluid is a measure of its internal resistance to flow. Units: cp or Pa.s.
- ✓ Crude oil viscosity controls the flow of *oil through porous media and pipes*.
- ✓ It ranges from *0.1 cp for near critical to over 100 cp for heavy oil.*
- ✓ Oil's viscosity is a strong function of the *T, P, oil gravity, gas gravity, gas solubility, and composition of the crude oil.*

$$\boxed{\mu_o = f(T, P, \Upsilon_o, \Upsilon_g, R_s, y_i)}$$

- ✓ Should be determined by *laboratory measurements*. Published correlations, which usually vary *in complexity and accuracy*.

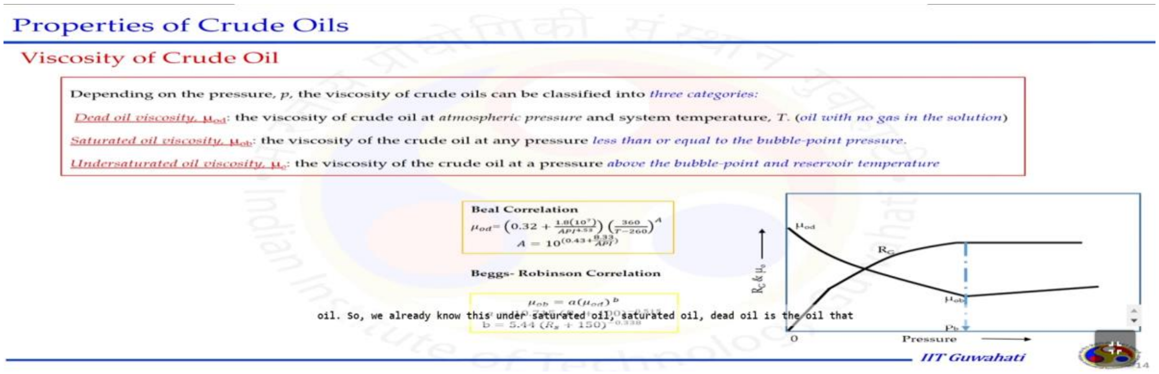
The viscosity of fluid is measure of its internal resistance to flow and the unit of viscosity is centipoise or also expressed in Pascal second. Crude oil viscosity is very important parameter whenever we are flowing the fluid either we are flowing the fluid in the porous media or in pipe system or anywhere the resistance to flow is characterized by the viscosity. It ranges from 0.1 centipoise for near critical fluid which is lighter or above 100 centipoises for heavy oil that is having the heavier component and difficult to flow. Similar to other properties oil viscosity is a strong function of temperature, pressure, gravity of oil, gravity of gas, solubility of gas and of course the composition of crude oil.

Although the composition of crude oil are represented in gas gravity but sometimes the compositions are different while the value of the gas gravity is same by the mathematical calculation. So, the composition of crude oil also play important role when we are calculating the viscosity. So, you can see in the expression along with the gamma o, gamma g, r, s the composition of crude oil are also included to get the as much as accurate value of viscosity can be calculated. It should be determined by laboratory experiment or publish correlation but those public correlation usually varies in complexity and accuracy depending on the composition and the other parameter those are appearing in those correlation. It is considered the most difficult properties to calculate with a reasonable accuracy from the correlation.

So, in most of the time it is measured in the laboratory by using the rheometer but when it comes to the laboratory experiment it becomes very difficult because at the atmospheric pressure the gas will liberated out from the oil and it will be only the dead oil whose properties or viscosity we are going to measure. To measure the live oil viscosity the special type of the apparatus are required to perform the viscosity measurement. For hydrocarbon liquids certain generalization can be made with respect to the viscosity. So, as we know for any liquid substance we increase the temperature the viscosity decreases similar happen for the crude oil. Viscosity increases with increasing pressure that we will see in more detail about how the pressure affect the viscosity.

Viscosity decreases as the gas in solution increases. If more gas is dissolved in the solution the viscosity will be less and that is one of the feature in enhanced oil recovery process is utilized to reduce the viscosity of the remaining oil we inject the gas into the system. So, what about this pressure effect on the viscosity if we are in this under saturated region reservoir pressure is here and we are decreasing the pressure the viscosity first decreases and that is rewards to this one and this happens because the effect of solution gas. So, the viscosity decreases when we are decreasing the pressure and this is different than what is mentioned here increase with increasing the pressure actually when we are in this region below the bubble point region this expression holds good because here the viscosity here when the reservoir pressure is P i we are in this under saturated region under saturated region only liquid phase is there and when we are decreasing the pressure the viscosity also decreasing. So, this is holding good when we are increasing the pressure viscosity also increases but on the other side when we are having the two phase region where the gas is also soluble into liquid in that case reducing the pressure the viscosity of the mixture or the crude oil that is having the solution gas into it is going to be increased this is happens because for most reservoir liquid the effect of liquid compression is more than counter balance by the effect of solution gas. So, the viscosity decreases with pressure until the saturation pressure is reached this point a further increase in pressure will cause an increase in viscosity due to compression of the liquid.

So, here the compression of the liquid is happening that is why the viscosity is increasing here we are having the effect of the solution gas that is why the viscosity decreases when we increase the pressure. Depending on the pressure the viscosity of the crude oil can be classified into three segments dead oil, saturation oil, under saturation oil. So, we already know this under saturated oil, saturated oil, dead oil is the oil that we are dealing at atmospheric pressure and system temperature the condition when oil with no gas in the solution. So, this is only the liquid or only the oil saturated we know this is a two phase system and under saturated this is above the bubble point and only the liquid phase is there. Several correlations are developed again for calculating the viscosity of the dead oil viscosity of the saturated oil and under saturated oil.



Properties of Crude Oils

Viscosity of Crude Oil

Depending on the pressure, p, the viscosity of crude oils can be classified into *three categories:*

<u>Dead oil viscosity, μ_{od}</u>: the viscosity of crude oil at *atmospheric pressure* and system temperature, T. (*oil with no gas in the solution*)

<u>Saturated oil viscosity, μ_{ob}</u>: the viscosity of the crude oil at any pressure *less than or equal to the bubble-point pressure.*

<u>Undersaturated oil viscosity, μ_o</u>: the viscosity of the crude oil at a pressure *above the bubble-point and reservoir temperature*

Beal Correlation

$$\mu_{od} = \left(0.32 + \frac{1.8(10^7)}{API^{4.53}}\right)\left(\frac{360}{T-260}\right)^A$$

$$A = 10^{\left(0.43 + \frac{8.33}{API}\right)}$$

Beggs- Robinson Correlation

$$\mu_{ob} = a(\mu_{od})^b$$

$$a = 10.715\,(R_s + 100)^{-0.515}$$

$$b = 5.44\,(R_s + 150)^{-0.338}$$

oil. So, we already know this under saturated oil, saturated oil, dead oil is the oil that

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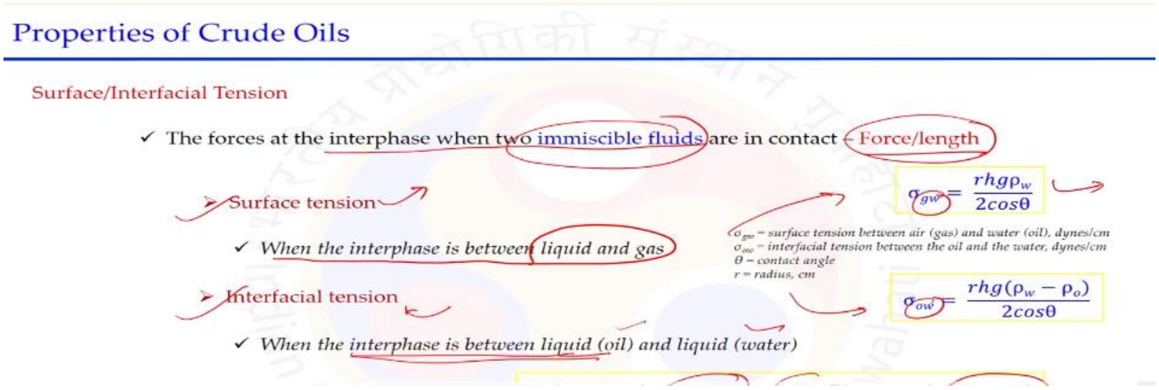
So, the expression shown here given by the bills for the dead oil where the viscosity of the dead oil is a function of API temperature and this can be expressed by using this expression this is for the dead oil means atmospheric oil. So, the pressure effect is not included into the expression. Bags and Robinson again given the correlation for calculating the viscosity of the dead oil using this expression where the solubility of the gas is also included. So, this is for the saturated crude oil this expression for the dead oil this is for the saturated oil and when we are talking about the under saturated oil more correction need to be included in the expression, expression becomes little complex where we are dealing with the saturated oil and under saturated oil system. The diagram here shows how the solubility of the gas changes when we are changing the pressure and accordingly the viscosity are also combined in this graph how the viscosity of the oil changes when it is at the bubble point or when it is at the dead point.

So, this expression actually Bags and Robinson when the oil is at just the condition at the bubble point when the bubble point is here using the dead oil viscosity we can calculate the viscosity of the oil at the bubble point condition. Several more correlations are given more complex correlation are given but the important one is here the viscosity is a function of temperature, pressure, quality of the oil, quality of the gas, solubility of the gas as well as the composition of the crude oil. When we talk about the two phase system the surface tension, interfacial tensions also need to be discussed. This is the force at the interface when the two immiscible fluid are in contact. We will discuss in more detail about the surface tension, interfacial tension in the reservoir rock properties.

In system where the two immiscible fluid are in contact the force will be there at the interface it is measured at force per unit length. Surface tension and interfacial tensions are different in terms of the types of the fluid we are dealing with. Surface tension when the interface is between liquid and gas. So, we are having a system where just the liquid is filled above that liquid there is air and the surface tension offered by the liquid at the interface is actually the surface tension or the force offered by the layer or the interface per unit length is surface tension. When the interface is between two liquid those are immiscible in nature like the oil and water.

The properties of the interface in terms of force per unit length is known as interfacial tension. The surface tension can be measured in the laboratory and is unusually expressed in dine per centimeter. 72 dine per centimeter for the water air, 20 to 30 dine per centimeter for water oil mixture depending on the composition of the water is it having certain salinity or other impurities and similarly composition of the oil. But when it is a pure water and pure air the value is around 72 dine per centimeter. Surface tension is an important property in reservoir inching calculation and designing enhanced soil recovery project.



Properties of Crude Oils

Surface/Interfacial Tension

- ✓ The forces at the interphase when two immiscible fluids are in contact – Force/length
- ➢ Surface tension
  - ✓ *When the interphase is between liquid and gas*
- ➢ Interfacial tension
  - ✓ *When the interphase is between liquid (oil) and liquid (water)*

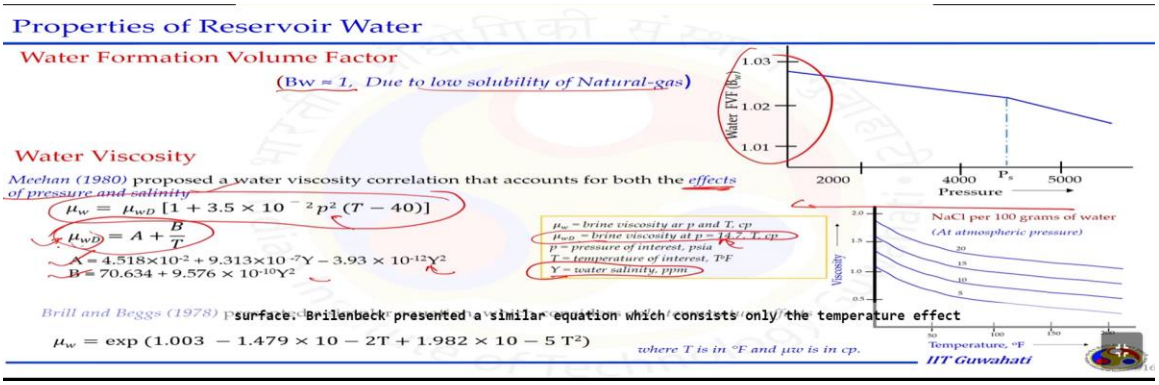
$$\sigma_{gw} = \frac{rhg\rho_w}{2cos\theta}$$

σ_{gw} = surface tension between air (gas) and water (oil), dynes/cm
σ_{ow} = interfacial tension between the oil and the water, dynes/cm
θ = contact angle
r = radius, cm

$$\sigma_{ow} = \frac{rhg(\rho_w - \rho_o)}{2cos\theta}$$

So, more discussion will be in this section when we are discussing the enhanced soil recovery. The expression mathematically for interfacial tension here oil and water and gas and water can be represented by this expression. We will discuss in more detail about this expression in the later classes. Along with the crude oil we are also supposed to discuss some of the properties of the water. So formation volume factor for the water as I mentioned earlier also the value of the volume formation factor of water is around 1 due to low solubility of the natural gas.

So, the water is there it is not compressible in the nature first thing or you can consider very slightly compressible. In fact, water is considered the incompressible fluid. So, because of the pressure effect is not there solubility is also very less of the natural gas in the water. So, if we look on the scale when we are varying the pressure from 2000 to 5000 range the value is changing but the change is 1.03 to 1.01. So, almost one value of the volume formation water factor can be counted as and when required in the calculation. The viscosity of the water Meehan 1980 proposed a correlation to calculate the viscosity of the water that is accounting both the effect of the pressure as well as the salinity. The expression is here which is having the pressure into it and this is the viscosity of the water and this is viscosity of water considering the salinity into H. So, A and B are the correlation parameter those are accounting for the salinity that is Y in ppm for the water that is coming into this expression and finally going to calculate the viscosity of the water under the saline environment and the pressure where the atmospheric pressure is considered for Wd. So, this is again Wd is actually the dead water viscosity when water is brought to the surface.



Properties of Reservoir Water

Water Formation Volume Factor

(*Bw ≈ 1, Due to low solubility of Natural-gas*)

Water Viscosity

Meehan (1980) proposed a water viscosity correlation that accounts for both the *effects of pressure and salinity*

$$\mu_w = \mu_{wD}\left[1 + 3.5 \times 10^{-2} p^2 (T - 40)\right]$$

$$\mu_{wD} = A + \frac{B}{T}$$

$A = 4.518\times10^{-2} + 9.313\times10^{-7}Y - 3.93\times10^{-12}Y^2$

$B = 70.634 + 9.576\times10^{-10}Y^2$

μ_w = brine viscosity ar p and T, cp
μ_{wD} = brine viscosity at p = 14.7, T, cp
p = pressure of interest, psia
T = temperature of interest, T°F
Y = water salinity, ppm

Brill and Beggs (1978) p surface. Brilenbeck presented a similar equation which consists only the temperature effect

$$\mu_w = \exp\left(1.003 - 1.479 \times 10 - 2T + 1.982 \times 10 - 5\,T^2\right)$$

where T is in °F and μw is in cp.

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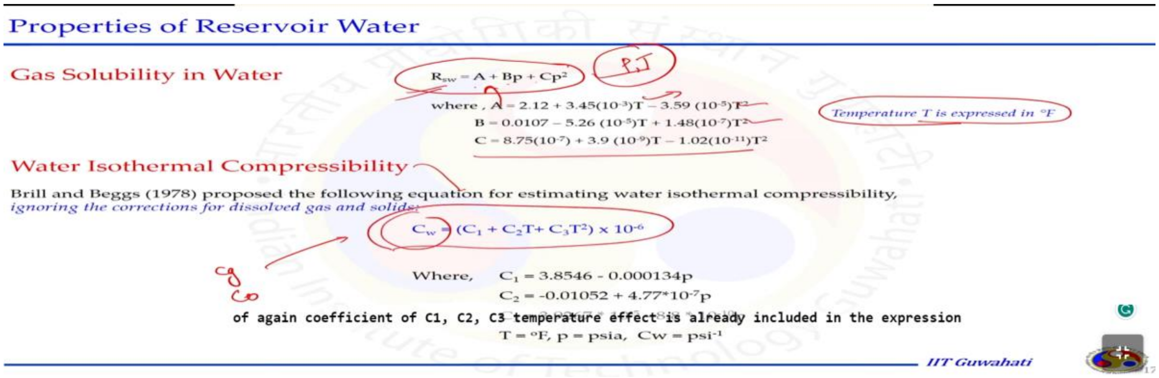
Brilenbeck presented a similar equation which consists only the temperature effect no salinity effect was considered and the viscosity of the water is just a function of temperature here. When we see the effect of temperature on the viscosity for the water we see increasing the temperature viscosity of the water decreases this is normal for most of the liquid and the effect of the salinity is also combined here. So, the nature of the curve will remain same for different saline water but when the salinity is high the viscosity of the water is also higher than the low saline water. Here the temperature is represented in degree F while the viscosity is in centipoise for all these expressions. Gas solubility in water gas is very less soluble in the water but when it comes to calculate the solubility of the gas in the water the expression can be used where A, B, C are the coefficient or the parameter those represent in terms of temperature and the unit of temperature is degree F this expression then will include both pressure as well as temperature for measuring the solubility of gas in water.



Properties of Reservoir Water

Gas Solubility in Water

$R_{sw} = A + Bp + Cp^2$ P,T

where, $A = 2.12 + 3.45(10^{-3})T - 3.59\,(10^{-5})T^2$
$B = 0.0107 - 5.26\,(10^{-5})T + 1.48(10^{-7})T^2$
$C = 8.75(10^{-7}) + 3.9\,(10^{-9})T - 1.02(10^{-11})T^2$

Temperature T is expressed in °F

Water Isothermal Compressibility

Brill and Beggs (1978) proposed the following equation for estimating water isothermal compressibility, *ignoring the corrections for dissolved gas and solids:*

$$C_w = (C_1 + C_2T + C_3T^2) \times 10^{-6}$$

Cg
Co

Where, $C_1 = 3.8546 - 0.000134p$
$C_2 = -0.01052 + 4.77 \times 10^{-7}p$

of again coefficient of C1, C2, C3 temperature effect is already included in the expression

$T = °F$, $p = psia$, $Cw = psi^{-1}$

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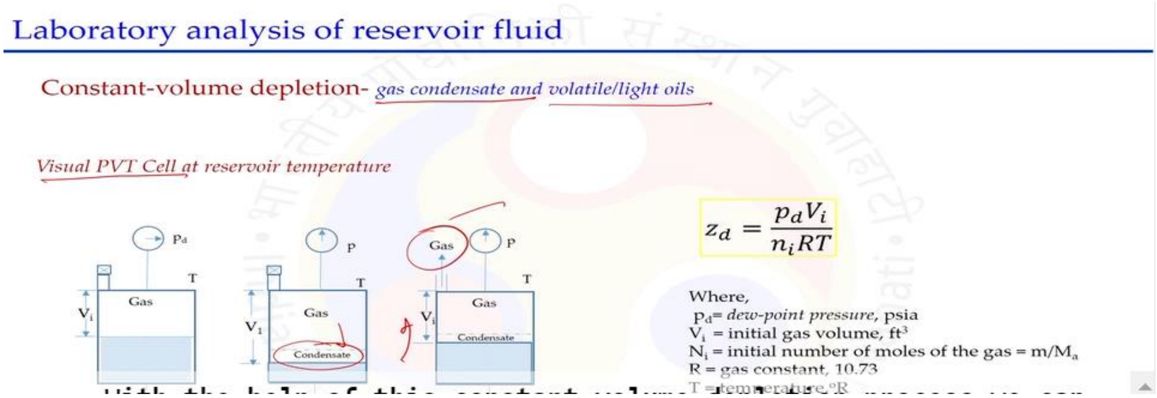
Isothermal compressibility coefficient Cw similar to C gas Cg for the gas similar to Co for oil the compressibility of the water can also be measured and that is in terms of again coefficient of C1, C2, C3 temperature effect is already included in the expression pressure effect is counted in the form of these coefficients C1, C2, C3 where the temperature is in degree F pressure is in psi and the value of Cw that will be estimated using this correlation will be having the unit of pressure inverse or particularly psi inverse. But this expression given for the isothermal compressibility is not counting for the any gas dissolved or solid dissolved in the water it is just considered for the water only. So let us discuss some of the laboratory analysis those are used to characterize the fluid foremost is the composition of the reservoir fluid. So gas chromatography can be utilized to know the composition of the fluid but in general the laboratory analysis are classified in three categories first one is the primary test because the reservoir fluid produced at the site itself or in the field certain characterization are done one of them is the specific gravity specific gravity of the gas specific gravity of the crude oil. Second properties is gas oil ratio so those are measured for the hydrocarbon fluid oil and gas produced on the site.

Some of the routine analysis are performed to keep characterizing the reservoir fluid as the production is happening or when we are dealing with the reservoir fluid. So the routine test are conducted to characterize the reservoir hydrocarbon fluid those include the composition analysis that is done with the help of the gas chromatography constant composition expansion test that is mostly done for the crude oil and the gas condensate system differential labration test that is kind of a separation process test where the composition of the reservoir fluid are subjected at different temperature and pressure condition and the separation of the gas and liquid is happening specific separated test are also done for the volumetric behavior and understanding how much maximum oil production can happen in the system.



Laboratory analysis of reservoir fluid

Constant-volume depletion- *gas condensate and volatile/light oils*

Visual PVT Cell at reservoir temperature

$$z_d = \frac{p_d V_i}{n_i RT}$$

Where,
p_d= *dew-point pressure*, psia
V_i = initial gas volume, ft^3
N_i = initial number of moles of the gas = m/M$_a$
R = gas constant, 10.73
T = temperature,°R

Another test is constant volume depletion test that is for gas condensate and volatile light oil system other than these several more test could be performed but some of these test we are going to discuss in today's lecture in very brief not in very detail no mathematical expression will be discussed only I will give you the brief idea how these test are performed because the ultimate aim as we understood from the thermodynamics lecture and the correlation those are developed we want to know PVT relationship how the volume pressure and temperature is changing how the properties of the crude oil or the phase change is happening when the PVT values are changing and these values in terms of how much volume of the liquid how much volume of the gas is present at different temperature and pressure condition allow us to estimate lots of the properties those could be gamma g gamma o rs and others those are required to estimate the properties of the reservoir fluid. Some spatial laboratory test are done in third category those are mostly done for the miscible gas injection should we discuss in his oil recovery lecture or in secondary recovery lecture but let us discuss briefly about what is slim tube test that is used to calculate the minimum miscibility pressure for gas or to understand is the gas can be injected in the reservoir under the miscible condition for the enhanced oil recovery purpose. Second test is the swelling test swelling behavior of the oil when it is subjected to gas injection certain pictures are shown here pycnometer can be used to calculate the density of the fluid similarly capillary viscometer can be used to calculate the viscosity of the liquid but certain other test those are mentioned here are kind of a special test those are done for the hydrocarbon fluid only to understand the behavior of the oil and gas when it is subjected for different temperature and pressure condition.

Performing all these tests it is far most important to collect the sample successfully from the reservoir collection of the sample may occur before the reservoir pressure fall below saturated pressure or bubble point pressure because when it is above the bubble point pressure the reservoir is under the under saturated oil condition when it is below it is a two phase reason collected the sample is collected immediately after the hydrocarbon discovery or during the early production stage that will give us more valuable information or more accurate information about the reservoir fluid. So when the pressure or formation pressure is higher than the bubble point pressure the sample can be collected from the bottom hole by certain means we are reaching to the bottom hole of the production system from where the sample is getting collected or samples are collected at the separator for oil and gas after the separator oil and gas are separated the samples are collected there. Composition analysis of the system are done using the gas chromatography routinely this is done for the gas sample similar gas chromatography can be used that is known as true boiling point analysis that can also be done for the oil sample. So the composition analysis can be done with gas chromatography. So the routine test that is constant composition expansion test done for the crude oil and the gas condensate system also known as pressure volume relationship, flash liberation test, flash vaporization test or flash expansion test.

In this test what is done the pressure in this cell that is called the PVT cell which is having the visual component into it. So one part of the cell is having the transparent glass through which we can look inside the cell and this PVT cell pressure volume temperature cell is set inside a system where the temperature can be maintained. So let us say the reservoir temperature is maintained and now changing the pressure with certain means let us say here the mercury pump or by any mean we are able to move this piston and changing the pressure in the cell itself and observing how much oil and gas is present in the system. So what happens in this kind of the test when we are having the pressure above the reservoir pressure. So what happens in this kind of the test let us say first case when the reservoir pressure is above the bubble point pressure the system is having only the oil.

So the visual PVT cell is just showing only the oil when the pressure is reduced still above the bubble point pressure we are having only the oil in the visual cell. When it becomes equal to bubble point pressure the pressure that is changed with the help of some mechanism. The oil is just at the words when the gas is just about to liberate out but in the PVT cell we are not seeing any gas. Further reduction in the pressure when we are below the bubble point we see the pressure effect on the oil and the gas is released out of the oil that was soluble at the PV pressure or above the PV pressure. So now in the PVT cell we can see this gas and the oil further reduction the volume of the gas will increase and you will be having oil and gas in the significant quantity and when we reach a situation a saturated condition or the condition where the further reduction in the pressure is not going to change we are having the gas and oil in the system.

When this data of pressure and measuring the volume in this PVT cell are plotted we can get two curves above the bubble point curve and below the bubble point curves and when the curves are plotted or the data are plotted the intersect point is actually the saturation pressure at that reservoir condition the temperature was maintained using the thermostat in the system. So this kind of the tests are useful for saturation pressure measurement that could be bubble point or dew point instead of releasing the pressure we can start with the two phase system and then increasing the pressure. Isothermal compressibility coefficient for the single phase can be estimated once we are having the change in the volume with respect to pressure data at a constant temperature. Compressibility factor Z can be calculated for the gas and the relative volume of oil and gas in reservoir at various condition when we are changing the pressure how the fraction of the oil and gas is changing can be estimated with this test.

Similar to this test is the differential liberation test. In this test the similar set of the steps are done it is start with the saturation pressure and then when the pressure is reduced below the saturation gas will evolved out from the oil it will keep evolving but the difference between the previous test and this test is the gas that is getting produced is taken out. So at this condition P2 is lesser than PB or P saturated gas produced that is having the natural buoyancy if we open the valve here gas will come out of the cell and in this PVT cell only the oil will remain and the piston movement to pressurize the system can further be lower down and again the gas will get produced. So set of the experiments are performed to get the amount of the gas quality of the gas that is liberating out when the pressure is changed from saturation pressure to lower side. So differential liberation test considered to be better to describe the separation process it tells us within this pressure range how much gas is going to be liberated out from the oil. If the second set of the separator or another separator is placed in the series is further separation of the oil and gas is going to happen or not again depending on the temperature and pressure setting of that separator.

So with this type of the test we get the amount of the gas in solution as a function of pressure. So different pressure are set up and the amount of the gas that is getting produced can be calculated and the other way whatever the oil remains in the system that will give us the oil's increase volume as a function of pressure. Properties of the evolved gas once gas is collected in this case we can calculate the properties of the gas. Density of the remaining oil as a function of pressure can also be estimated with this differential liberation or expansion test. Expansion in the other way here we are reducing the pressure we can do the other way also when we are increasing the pressure.

More specific test on the pressure change are done on the separator test those are important to measure the volumetric behaviour of the system and finding out the maximum oil production can be happen. So what happened like say stage 1 the fluid hydrocarbon fluid is just passed through this stage 1 separator because of the change in temperature and pressure gas will release out and the oil will be separated. So the oil and gas separation is happening now this oil is not completely the oil it is also having some solubility of the gas at this pressure and temperature condition. So when it is subjected for the second stage where the pressure and temperature conditions are more favorable to release the gas further will release out from this oil and we will get oil too and when it is going to the third stage we will get the gas and the oil that is kind of a dead oil or stock tank oil at the end. So different steps can be performed to calculate the amount of the gas getting released out amount of the oil that is remaining and the remaining oil from each stage is sent to the next stage for the further processing.

With this kind of the things we can determine the change in the volumetric behaviour of the reservoir fluid as the fluid passes through series of the separator and finally it is reaching to the stock tank. For determining the optimum surface temperature condition at what condition for example we are having only one separator what optimum temperature and pressure condition should be said that can be estimated with this kind of the analysis means optimum temperature pressure condition when we are getting maximum recovery of the oil. It provides a mean for providing PVT data once we are having the PVT data we can calculate the properties those depend on pressure and temperature like volume formation factor, solubility and those values are required for engineering calculation.

Pressure and temperature of the stages are said to represent the desired or actual separation conditions so the conditions of each stage are defined in such a manner they are going to be applicable for the field applications. The gas liberated from each stage is removed and its specific gravity and volume at standard conditions are measured.

So once we are collecting the gas from each stage it can be subjected for the analysis. Constant volume depletion test it is done for gas condensate or very light crude oil system. Here also visual PVT cell is there at a reservoir condition and we are changing the pressure and because of the retrograde behavior change in the pressure will allow some of the gas component to condense out and when we are getting the condensate here we are re-pressurizing it back collecting the gas equal amount of the gas at the top and then repeating this process. With the help of this constant volume depletion process we can calculate Zd that is the compressibility factor at dew point. So all these tests actually gave us the understanding of how the phase change is happening when the fluid is subjected for different pressure regime at a constant volume system. Either we are increasing the pressure we are decreasing the pressure how the phase separation is happening when the phase separation is happening.

So in the further discussion of laboratory analysis the slim cube test is also performed in the laboratory that is performed to estimate the minimum miscibility pressure of gas that is need to be there so the gas can dissolve in the crude oil. So the gases could be considered nitrogen, CO2 and natural gas. It is injected into the oil reservoir with the purpose of obtaining enhanced oil recovery. The lowest pressure at which the miscibility is obtained called the minimum miscibility pressure MMP it means single phase becomes. So we are having the crude oil we are injecting the gas it is a two phase system but a pressure when we are applying the pressure a situation will come when it is just a single phase gas get dissolved into crude oil.

And this is done with the help of the slim tube test. So here it is the pump to use the pumping of oil and the gas into this system. This is a slim tube system where a small diameter slim tube in the coil shape or a spiral shape of a very large length is placed in the spiral form and coated inside with some pebbles or something to create a reservoir kind of the situation. Here this side glass is there to observe whenever the fluid is flowing from here we can see it is oil or gas. Back pressure regulator is used to maintain the pressure and then the separator when the fluid is getting produced beyond this VPR back pressure regulator it is separated in oil and gas.

Gas is subjected for gas chromatography or the flow meter. What we do in this kind of the test the slim tube is first saturated with oil and then the oil volume fed to the slim tube is recorded at constant temperature and pressure. After that we stop sending the oil gas is subsequently forced through the slim tube with purpose of displacing the oil. The oil is there and the gas is displacing it and it is observed through this side glass here we are getting the oil production or some gas. Separator does the job to determine the amount of gas and oil that is getting produced.

The lowest pressure at which the recovery is 90% is the minimum visibility of actual oil and gas system. What happens we collect the oil here in the separator measure the oil recovery factor by changing the pressure and we will get two curves at the low-pressure region and the high pressure region and the crossing point of these two is actually the minimum visibility pressure where the recovery is not high beyond this point as compared to the lower part. Initially the gas was pushing the crude oil to get produced we were getting in this side glass the crude oil is coming but after certain recovery around 90% recovery it happens the pressure is such high the gas just get dissolved into crude oil. Similar test is done for the swelling test to understand the oil and gas solubility behavior. This is swelling behavior of the oils when subjected to gas injection. Gas injection is actually secondary recovery process we will discuss later on I think in third section of this course.

So the test start with a reservoir oil at its saturation point in a PVT cell kept at reservoir pressure condition. So this is the system where the crude oil is kept and now in this crude oil we are injecting the gas and increasing the pressure. So a non amount of the gas is injected into this well the pressure is increased when we are increasing the pressure the gas will get dissolved into crude oil maintaining a constant temperature until all gas has dissolved there is no more gas remain every gas dissolved because of the pressure. What will happen the oil swelling will happen and the gas dissolved into it and the volume of the oil increases. When the last gas bubbles disappear the new cell mixture oil and gas injected is at its saturation it will reach the new saturation value and this process is repeated.

So the gas is injected oil swelling happen further increase in the pressure inject more amount of the gas and see the oil swelling and then inject again and finally you will get the oil at that pressure when there is no gas it is having all the gas that is injected dissolved into oil. Why it is important this kind of the test gas dissolved in the oil the oil volume will increase so we can understand the solubility of the gas as well as the expansion or swelling property of the crude oil. This is important to investigate how a reservoir fluid will react to gas injection when we are injecting the gas to the reservoir. The increase in volume and saturation pressure helps determining whether gas injection will result additional oil recovery or not during the enhanced oil recovery processes.

So with this I would like to summarize my today's lecture. In today's lecture we discussed crude oil properties those are important to understand oil and gas system.

These properties are important when we are setting up the mathematical equation understanding the reservoir performance along with the properties estimation their definition and the correlation is to calculate those properties. We also discussed briefly about the laboratory analysis those are performed to understand the PVT behavior or collecting the data those can be used to calculate the basic properties of the oil and gas system. With this I would like to thank you for watching the video. Thank you very much.