Class 1 Thu. 4/9/2014

CHEN 490 - "Fundamentals of Petroleum Engineering"

I. Introduction of Prof..
- Work Experience — More than 35 yrs. oil industry
≈ 10 yrs. Academia
- Education BS, MS, PhD

II Read Syllabus "i.e. go thru the Syllabus"

III. Now, for Class members (students) to introduce themselves:
- Name:
- Dept.:
or - Class:

IV. For next time: Note #1
PW th490S Read the first "handout" titled [Characteristics of Oil and Gas]

- - - - -

V The Ultimate question ---
What is Petroleum?

Definition:

Petroleum is a mixture of naturally occuring hydrocarbons which may exist in the solid, liquid, or gaseous states, depending upon the conditions of Pressure, and temperature to which it is subjected.

Virtually,
~~Virtually~~ All petroleum is produced from the earth in either liquid or gaseous form.

Commonly these materials are referred to as either Crude Oil or natural gas, depending upon the state of the hydrocarbon mixture.

* Petroleum Consists Chemically of ((approximately)):

- 11 to 13 wt% hydrogen
- 84 to 87 wt% Carbon

Traces of
oxygen, sulfur, nitrogen, and helium
May be found as impurities in Crude Petroleum ...

About 18 series of hydrocarbons have been recognized in crude petroleum ...

* Purpose of the Course

Is to present a fundamental treatment of Petroleum engineering and the techniques employed in drilling and well completions, ~~operation~~, production operation
or phases of the petroleum industry.. | Reservoir description, and

Petroleum Engineering Consists of the following phases,

Petroleum Engineering

Exploration

Prospect — Geological → ; Geophysical

Drilling + Workover Engineering → & Well Completion

- Exploratory Well
  - ↓ Discovery
  - ↓ Field Delineation
- Development well
  - Well Stimulation

Reservoir Engineering

- Reservoir Description and Simulation
- Data Source
  - Coring & Core Analysis
  - Logging & formation evaluation
  - Well testing
- Reservoir Managment

Production Engineering (or operation)

- Primary
- Secondary
- Tertiary
- Artificial Lift
  - gas lift
  - Suck Rod pump
  - Hydraulic pump
  - Submersible pump

CHEN 490 – Class 2 T, 9/9/2014

Brief History

✓ Begining with the industrial revolution of the early 19th century, man has turned more and more to the use of mineral fuels or (fossil fuels) to supply energy to operate his machine..

✓ The first commercial well drilled solely for petroleum was completed in the USA in 1859. The drilling was supervised by Edwin L. Drake in Penn. State.

✓ Following the success of the Drake well, Petroleum production and processing rapidly grew into a major industry in the US & in the world.

1st Use → In the early history of the petroleum industry, petroleum products were ~~used~~ largely used for lubricants and for illuminating fuels.

* With the development of internal combustion engine and other devices, the use of petrolem for fuel become very important.

* Today, petroleum is used not only as a fuel and a source of lubricants but as a raw material for many modern industrial products.

Chemical Composion Of Petroleum

Petroleum

"Petroleum is a mineral may be defined as a naturally occuring complex mixture of hydrocarbons which may be either gas, liquid or solid depending upon its own unique composition and pressure, and temperature at which it is confined."

Hydrocarbons

We will consider those organic compounds which contain only two elements, hydrogen and carbon. These compounds are known as hydrocarbons.

On the basis of structure, hydrocarbons are divided into two main classes, aliphatic and aromatic.

Aliphatic hydrocarbons are divided into families: alkanes*, alkenes, alkynes, and their cyclic analogs.

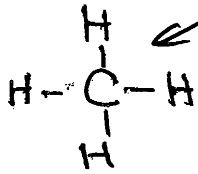
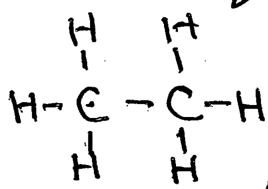
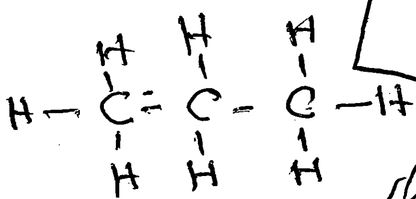
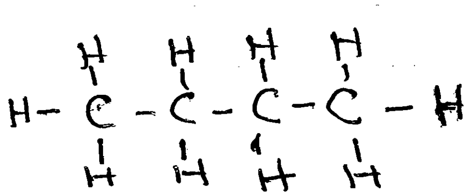
The principal hydrocarbon series found in Petroleum are:

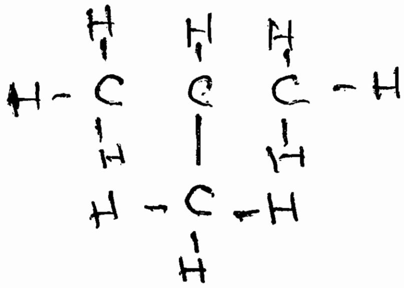
1. Alkanes; These alkanes are called Paraffin hydrocarbons (also called Saturated hydrocarbons) has the general formula C_nH_{2n+2}.

These compounds are chemically stable and have either straight or branched chains: The branched chain members are called isomers which are reserved for substances with two methyl groups attached to carbon atoms at the end of an otherwise straight chain. ~~In a~~ straight chain each carbon atom is connected to no more than two other carbon atoms.

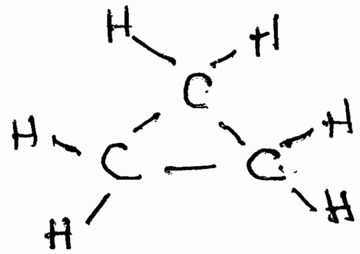
these isomers ~~contain~~ exhibit some what different properties than the ~~chain~~ straight chains

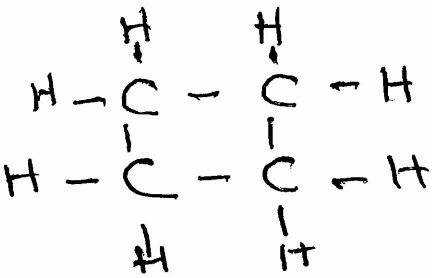
All crude oils contain some paraffins, particularly as the more volatile (low boiling point) constituents. The first few members of this series are:

Abbreviation	Formula	Chemical structure	Name
C_1	CH_4		methane
C_2	C_2H_6		ethane
C_3	C_3H_8		Propane
n-C_4	C_4H_{10}		(normal butane) n-Butane

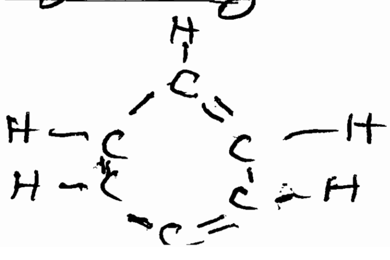
i-C_4 C_4H_{10}  is-butane

2. Cycloparaffins (naphthenes) or cycloalkanes - having the general formula C_nH_{2n}
These compounds have a saturated structure, the simplest member being cyclopropane. Typical members of this group are:

C_3H_6  Cyclopropane

C_4H_8  Cyclobutane

3. Aromatic (benzene series), having the general formula C_nH_{2n-6}. These compounds are chemically active and contain the benzene ring, the simplest member is

C_6H_6  Benzene

In addition to hydrocarbons, petroleum contain numerous impurities, such as CO_2, H_2S, and N, S, and O_2, and helium; O_2 ~~[illegible]~~

Petroleum is often classified by a base ~~crude~~ designation – as either a paraffin base crude, asphalt base crude, or mixed base crude...

✓ Paraffin Base, the crude is an oil whose chief compounds are paraffins, and which, when completely distilled, leave a solid residue of wax.

✓ An asphalt base crude, is an oil composed of cyclic compounds (mostly naphthenes) which, when distilled, leave a solid residue of asphalt.

Oils which fall in the middle of these categories are classified as mixed base.

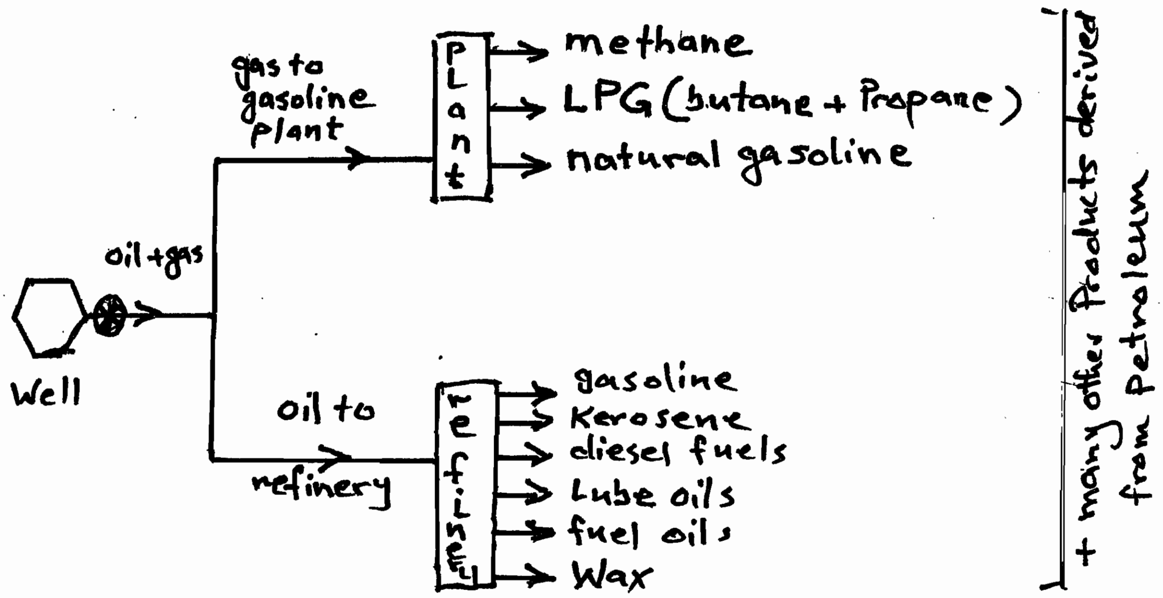
or oils ~~which [illegible]~~ containing large quantities of large paraffins and polymethelen series –

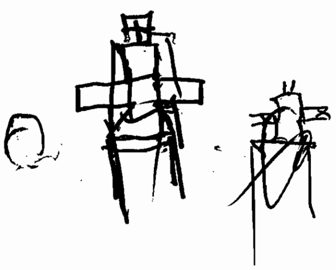
1 A paraffin base crude – is an oil whose chief components are paraffins, and which, when completely distilled, leaves a solid residue of wax.

2 An asphalt base crude – is an oil composed of cyclic compounds (mostly naphthenes) when distilled, leaves a solid residue of asphalt. polymethelene or olefin series hydrocarbons)

3 Oils which fall in the middle of these categories are classified as mixed base. – or oils containing large quantities of large paraffin and polymethelene series.

Crude petroleum yields a large number of products. The simplest refining process is fractional distillation whereby the constituents in the oil are separated by utilizing their differences in boiling points. A few of these products are shown schematically in this figure:





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Properties of Liquid Petroleum

The most widely used indicator of a Crude Oil's Worth to the Producer is its API (American Petroleum Institute) gravity..

* ✓ This value is actually a measure of an Oil's density, and is related to specific gravity by the following formula:

$$\text{API gravity (degrees)} = \frac{141.5}{\text{sp. gr.}} - 131.5$$

Note: An API of gravity of 10° is equivalent to a sp. gr. of 1.

Also Note that:

* → Normally, the price which a producer receives for his oil depends on its gravity, the less dense oils (higher API gravity) being the most valuable.

* The price schedule is based on the premise that the lighter oils contain higher percentages of the more valuable products such as gasoline.

* Crude oils are classified according to their physical properties. Such as

color, odor, refractive index, boiling pt., freezing pt., density, and viscosity, Of these, the most important one from a classification standpoint are the density (sp. gravity) and viscosity of liquid petroleum..

* The sp. gravity of liquids is defined as the ratio of the density of liquid to the density of water.- both at specified conditions of pressure and temp.-

* The sp. gravity of crude oils ranges from 0.75 to 1.01. Since crude oils are lighter than water a Baume' type scale is used in the petroleum industry. The scale is referred to as the API or American Petroleum Institute scale for crude petroleum and relates the sp. gravity thru a mathematical expression to density called API gravity.

$$(\text{Sp. gravity})\ \gamma = \frac{141.5}{131.5 + API}$$

then

$$\text{API gravity (degrees)} = \frac{141.5}{\text{sp.gr.}} - 131.5$$

The surface or tank Oil as finally sold by the producer is not the same liquid which existed Underground.

Note: The differences between tank Oil and reservoir Oil are of fundamental importance, and we will cover them later in the course. There are certain basic concepts which can be discussed at this time..

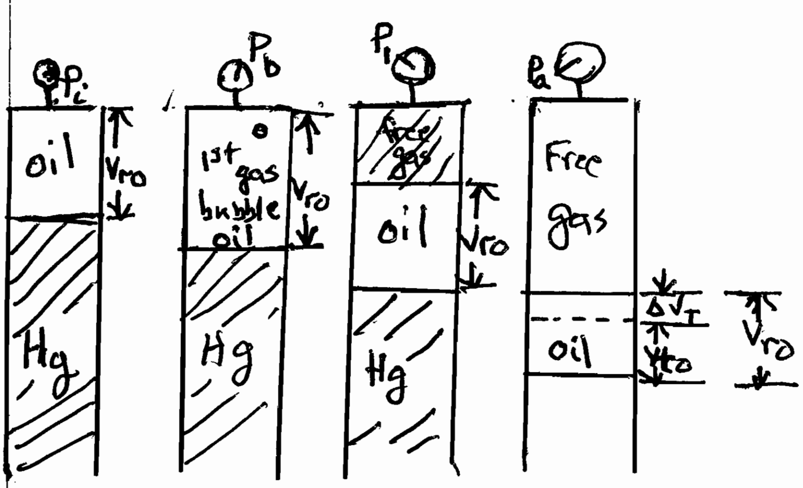
* Reservoir Oil always contains in solution some components which would be gases at standard temp. and pressure. their solubility is due to the elevated pressure and temp. existing underground.

* As Oil is produced (brought from underground to the surface), the pressure is decreased until it reaches atmospheric conditions in the stock tanks..

* This pressure reduction causes certain changes in the reservoir fluid properties:
  a) Some of the volatile fractions vaporize, causing
  b) the liquid volume to shrink, and
  c) The liquid viscosity to increase.

The effects are shown in the following figures:

Figure 1, shows the behavior of typical reservoir oil sample on isothermal pressure reduction.



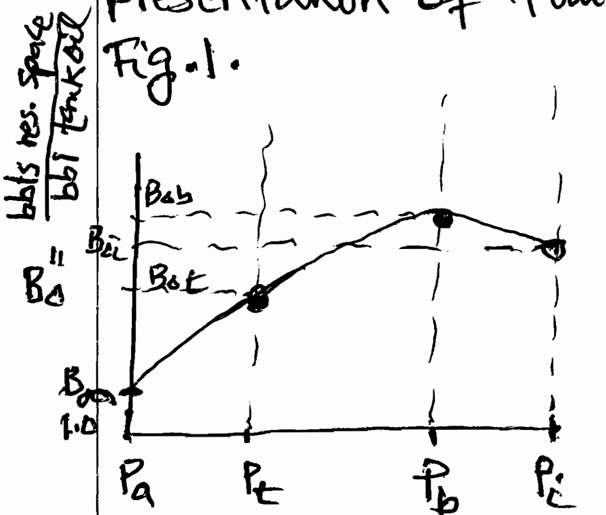
(A) Oil sample at original reservoir conditions. All gas is in solution and oil is undersaturated since $P_i > P_b$

(B) Pressure is reduced to P_b by removing mercury from the cell. First bubble of gas, from solution, escapes hence P_b = bubble point or saturation pressure of the oil. Liquid volume has expanded slightly.

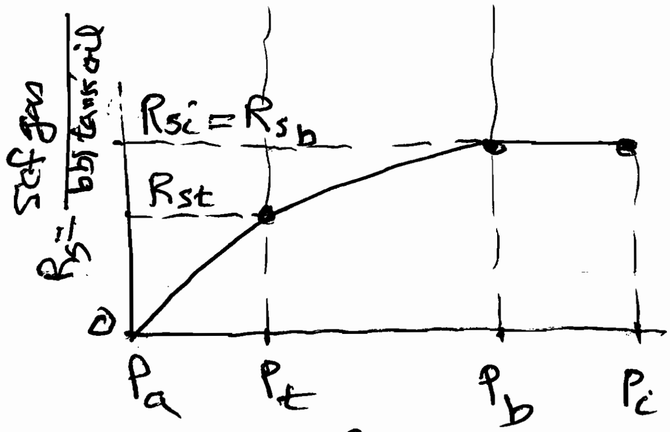
(C) Pressure is reduced to P_1 and considerable free gas has evolved. Liquid volume has shrunk due to loss of volatile fractions.

(D) Pressure is now atmospheric. Liquid volume has shrunk to V_{ro}, the oil volume at the reservoir temperature, and 14.7 psia. Cooling this oil to saturated temp. (60°F) results in its shrinking by an amount ΔV_T to the tank oil volume, V_{to}.

The following Fig. 2 shows the graphical presentation of fluid properties depicted in Fig. 1.



(A)

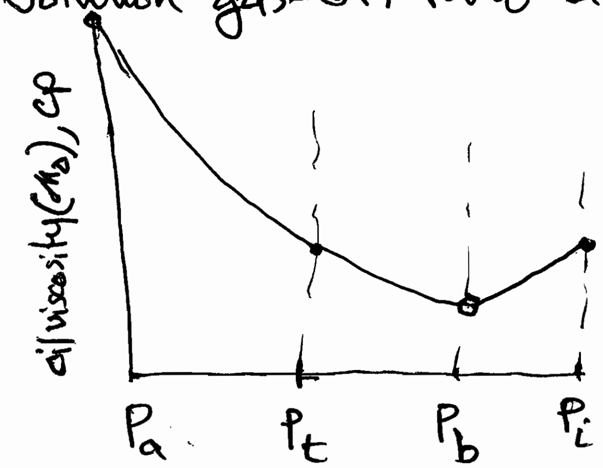


(B)

(A) Formation Volume Factor for oil as a function of Pressure.

$$B_o = \frac{V_{ro}\text{ (at each Pressure)}}{V_{to}}$$

(B) Solution gas-Oil ratio as a function of pressure



(C) Oil viscosity as a function of Pressure is typical and is found by stepwise determinations in a high pressure Viscosimeter. This behavior may be explained as follows:

(i) Viscosity decreases as pressure is reduced from P_i to P_b due to the liquid's expansion; greater intermolecular freedom of motion is possible, and internal friction is reduced.

(ii) Viscosity increases with pressure reduction below P_b because the low viscosity fractions are lost; this more than compensates for the effect of liquid expansion.

This is the <u>flash vaporization</u> since the composition of the system remained constant.

If the cell pressure had been reduced by removing liberated gas while holding cell volume constant, the process would have been a <u>differential vaporization</u>. The actual process taking place in the underground petroleum reservoir more nearly fits the differential process, and it is commonly used in lab. analyses.

* The effects shown in the figures - also illustrated in these are ~~a~~ a number of fundamental properties which must be defined

<u>Solution Gas-Oil Ratio, R_s</u>. Is the number of standard cubic feet (SCF) of gas dissolved per bbl. of tank oil.

<u>Bubble Point Pressure, P_b</u>. Is the bubble pressure or saturation pressure. It is the pressure at which the first gas is liberated from the reservoir oil upon isothermal pressure reduction @ the reservoir temperature.

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Gaseous Petroleum (Natural Gas)

In recent years natural gas has come into its own as a highly valuable product.

Prior to the present extensive transcontinental gas transmission lines, gas produced with oil was sold on a local scale and any excess was flared. Certainly these practices were wasteful, but the time, necessary.

As the natural gasoline and liquified petroleum gas (butane and propane) industry developed, the utilization of the residue gas (dry gas remaining after liquids removed) also increased.

The recent growth of this phase of the oil industry has been very rapid, and today natural gas and it's associated liquid products are virtually as much in demand as oil.

* Natural gas is produced from 3 classes of wells:
  1. From wells where the dominent product is oil (oil wells)
  2. From wells where the gas itself is the principal product (gas wells)

3. as gas from condensate wells.

"Condensate wells produce from reservoirs in which the hydrocarbons (gas and liquid) originally existed as a single fluid (or phase), the reservoir temperature and pressure being above the critical point of the hydrocarbon mixture."

* Each natural gas, like each crude oil, is a unique mixture of hydrocarbons. All are, however, composed primarily of the light members of the paraffin series and predominantly methane.

Numerous impurities are found in petroleum gases, some of the more common being CO_2, H_2S, water vapor, N, and helium.

There are a number of basic definitions which I will presented here:

Wet gas: A natural gas is said to be wet if it contains an appreciable natural gasoline content as determined by std. tests.

GPM: The natural gasoline content of a gas expressed in gallons per thousand std. cubic feet (MCF)

Note: Gases having a GPM of 1 to 2 are wet while gas with a GPM of 0.2 would be considered dry.

Sour Gas: Natual gas containing hydrogen sulfide.

Sweet Gas: Natural gas containing no hydrogen sulfide.

Gas Gravity: The ratio of the of the density of a gas to the density of air at std. conditions.

Std. Conditions: 14.7 psia and 60°F.

Equation of state

Definition of gas:— A gas may be defined "as a homogeneous fluid of low density and low viscosity, which has neither independent shape nor volume but expands to fill completely the vessel in which it is contained."

* The properties of gases differ from the properties of liquids, mainly because the molecules in gases are much farther apart than molecules in liquids. For example, a change in pressure has a much greater effect on the density of a gas than of a liquid....

Notes: We will use the term equation of state to mean an equation which relates volume to pressure and temperature.

The Ideal Gas

A starting point in the study of equation of state of real gases, we will consider a hypothetical gas known as an ideal gas.

The eqn. of state of an ideal gas will be developed in two ways, the first from experimental evidence and then from kinetic theory. The form of the equation for ideal gases will be used as the basis of equations for real gases.

An ideal gas has these properties:

1. The volume occupied by the molecules is insignificant with respect to the volume occupied by the gas.
2. there are no attractive or repulsive forces between the molecules or between the molecules and the walls of the container.
3. All collisions of molecules are perfectly elastic, there is no loss of internal energy upon collision.

Boyle's Equation: — Boyle experimentally observed that the volume of an ideal gas is inversely proportional to pressure for a given mass of gas when temp. is maintained constant. This may be expressed as

$$V \sim \frac{1}{p} \quad \text{or} \quad pV = \text{Constant.}$$

Charles' Equation

The volume of an ideal gas is directly proportional to temp. for a given mass of gas when pressure is maintained constant.

$$V \sim T \text{ or } \frac{V}{T} = \text{Constant.}$$

Avogadro's Law: — states that, under the same conditions of temp. and pressure, equal volumes of all ideal gases contain the same number of molecules.

✓ Based on the above ~~eqns.~~ law of Boyles', Charles' + Avogadro, the ideal gas law was derived ~~empir~~.

$$PV_m = nRT$$

where

$$R = \frac{PV_m}{T}$$ for a given mass of gas = const. when the quantity of gas is equal to one molecular weight.

and it is the same for all ideal gases and is called the Universal constant.

R is evaluated from a single measurement of the volume occupied by a known molar quantity of any gas @ a known temp. and known reduced P.

$R = 10.73$ – P in psi and volume cubic feet – ~~[illegible]~~ $\frac{psi\text{-}ft^3}{lb\text{-}mole\ {}^\circ R}$

V_m = the volume of one molecular weight of the gas, the molar volume,

For n moles of ideal gas the above eqn. becomes

$$PV = nRT$$

Where V is the volume of n moles of gas at temp. T and pressure P. Since n is the mass of gas divided by the molecular weight, the eqn. $PV = nRT$ can be written as

$$PV = \frac{m}{M} RT \quad \text{or} \quad \text{as } pv = \frac{RT}{M}$$

where m is mass and v is volume of one unit of mass, the sp. volume

Problem
Give example!

This expression is known as the Ideal Gas Law, the General Gas Law, or the Perfect Gas Law

Density of an ideal Gas

Since density is defined as the mass of gas per unit volume, ~~the~~ an eqn. of state can be used to calculate the densities of a gas at various temp. and pressures. The equation for the density of an ideal gas

$$\rho_g = \frac{m}{V} = \frac{PM}{RT}$$

Apparent Molecular weight of a Gas Mixture

Since a gas mixture is composed of molecules of various sizes, saying a gas mixture has a molecular weight is not strictly correct. However, a gas mixture behaves as if it has definite molecular weight. This molecular weight is known as the apparent molecular weight and is defined as

$$M_a = \sum_i y_i M_i$$

give example

Specific Gravity of a Gas

Is defined as the ratio of the density of the gas to the density of dry air with both measured at the same temp. and pressure --

sp. gravity of a gas $\rightarrow \gamma_g = \dfrac{\rho_g}{\rho_{air}}$

Assume that the behavior of both the gas and air may be represented by the ideal gas eqn; sp. gravity may be given as

$$\gamma_g = \frac{\frac{PM_g}{RT}}{\frac{PM_{air}}{RT}} = \frac{M_g}{M_{air}} = \frac{M_g}{29}$$

Where Mair is the apparent molecular weight of air and Mg is molecular weight of the gas. If the gas is a mixture, this equation

2 give example

$$\gamma_g = \frac{M_g}{M_{air}} = \frac{M_a}{29}$$

where M_a = apparent molecular weight of the gas mixture.

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The gaslaw as applied to the behavior of natural gas is most commonly stated as

$$PV = ZnRT \quad (1)$$

where p = pressure, absolute
V = volume
n = number of moles
R = gas constant = 10.7 dependent on the ~~unit~~ system of units used...
T = Absolute temp.
Z = deviation factor, to account for the difference between actual and ideal gas volumes..

~~notes~~

Eqn. (1) may be written:

$$PV = Z \frac{W}{M} RT$$

where $W/M = n$
W = total wt. of gas
M = molecular wt. of gas

Hence

$$P \frac{V}{W} = \frac{ZRT}{M}$$

or $$v = \frac{ZRT}{PM}$$

where $v = \frac{V}{W}$ = sp. volume of the gas

Also, $$\frac{1}{v} = \rho = \frac{PM}{ZRT}$$

where ρ = gas density

Behavior of Real Gases
Compressibility Equation of State

$$PV = ZnRT$$

$$PV_M = ZRT \;, \quad Pv = \frac{ZRT}{M}$$

$$\text{and } \rho_g = \frac{PM}{ZRT}$$

Where Z = Correction factor
= Gas deviation factor
= Z-factor
= Gas Compressibility factor

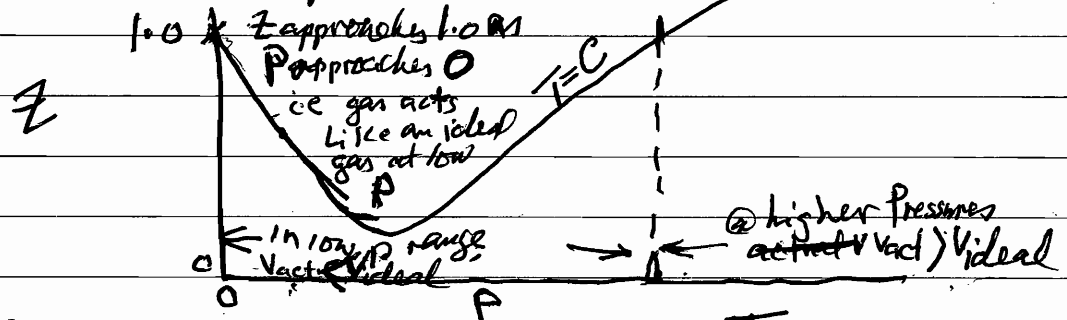
The z-factor is the ratio of the volume actually occupied by a gas at given P and T to the volume the gas would occupy at the same P and T if it behaved like an ideal gas.

$$Z = \frac{V_{actual}}{V_{ideal}}$$

Z-factor is not constant. It varies with changes in gas composition, T, & P

so The values of Z for natural gas mixtures have been experimentally correlated as a function of

Z must be determined experimentally. Here, is the results of experimental determination of Z



Typical Shape of Z as a function of p @ constant T.

→

The Law of Corresponding States

The law of Corresponding states says that all pure gases have the same Z-factor at the same values of reduced P and reduced T.

$$T_r = \frac{T}{T_c} \quad \& \quad P_r = \frac{P}{P_c}$$

The Compressibility Equation of state for Gas Mixtures

the law of Corresponding states has been extended to cover mixture of gases. ~~As the~~

Obtaining the critical point for multicomponent mixture's is somewhat difficult; therefore, pseudocritical T and pseudocritical P have been invented.

These quantities are defined as

give example

$$T_{pc} = \sum_i y_i T_{ci} \quad \& \quad P_{pc} = \sum_i y_i P_{ci}$$

Pseudocritical properties are not equal to the actual critical properties of a gas mixture.

Physical properties of gas mixtures are correlated with pseudoreduced T and pseudoreduced P

$$T_{pr} = \frac{T}{T_{pc}} \quad \& \quad P_{pr} = \frac{P}{P_{pc}}$$

~~Theorem~~

In preparing a correlation for hydrocarbon mixtures, the ratios of actual pressure and temperature to the molal average critical or pseudo-critical pressure and temperature have been used. These ratios are called reduced pressure and reduced temperature.

$$\cancel{P_{pr} = \frac{P}{P_{pc}}}$$

Fig. 1.4 Of Standing & Katz is a correlation of Z as a function of these quantities.

* The chemical analysis of a natural gas is not always available and an alternative method is needed for determination of the pseudo-critical properties. Correlations of these as functions of gas gravity, have been found to be sufficiently accurate for engineering purposes. Fig. 1.5 shows the correlation as presented by Brown et al. This approach is recommended if chemical analysis is not available.

Pound-Atom and Pound-Mol

The mass in pounds of a given element, which is equal numerically to its atomic weight, is referred . a pound-atom, when the mass of a molecule is expressed in pounds numerically equal to its molecular weight, the term is referred to as a pound-Mol. A pound-mol of methane (CH_4) would weigh 16.043 lb.

Mol Fraction

If natural gas is composed of two hydrocarbon gases such as methane and ethane, there are two kinds of molecules. The number of methane molecules divided by the sum of methane and ethane molecules would represent the mol fraction of methane in the gaseous mixture. The mol fraction times 100 is the mol percent.

Critical Properties

Critical temperature, T_c — is the temperature above which a hydrocarbon gas cannot be liquified no matter how much pressure is applied.

Critical Pressure, P_c: is the pressure required to liquify a gas at its critical temperature.

Example: methane has a $T_c = -116.6$ F. At this temp. a pressure of 667.8 psia would be needed in order to liquify the gas.

Gauge pressure (Psig) : Is that pressure indicated by a pressure gauge and is the pressure above or below that of the atmospheric pressure at the point of measurement. -

The avg. atmospheric pressure at sea level is 14.7 psi or 29.92 in. of mercury. Gauge pressure is reported as pounds per square inch gauge (psig).

Absolute Pressure

The absolute pressure (psia) must be used in all calculations involving volume and pressure relationships. To obtain the absolute pressure, the pressure of the atmosphere must be added to the guage pressure.

To be accurate, the atmospheric pressure on the gauge at the time the gauge pressure is read should be determined, but for most calculations the avg. sea-level pressure of 14.7 psia can be added.

Temperatures

In the centigrade scale

$0^\circ C$ Correspond to 273.1 K.

For the Fahrenheit scale, absolute zero is 460° below $0^\circ F$. This absolute scale is referred to as the Rankine. Thus

$$X C = (X + 273.1)\ K \text{ (kalvin)} +$$

$$X F = (X + 460)\ R \text{ (Rankine)}.$$

CHEN 490-Class 6 T 23/9/2014

So far, we have discussed the followings:

The Nature of Petroleum

* Defined Petroleum + Hydrocarbon

1. Chemical Composition of Petroleum

a) The principal HC series found in petroleum

2. Properties of Liquid Petroleum

a) API Gravity (degrees)

$$= \frac{141.5}{sp.gr.} - 131.5$$

b) Behavior of typical reservoir oil sample on isothermal Pressure reduction

c) Graphical representation of fluid properties:

OFVF, B_o as a function of P

Solution gas oil ratio as a function of P

Bubble-pt. Pressure, P_b

Oil viscosity, μ_o

* Gaseous Petroleum (Natural Gas)

1. Defined Gas

2. Natural gas produced from 3 Classes of wells

3. Defined a number of basic definition such as wet gas, GPM, ... etc.

* The Gas Law as applied to the behavior of Natural gas.

2

Real Gas $= PV = ZnRT$; $PV = nRT$ = ideal gas or perfect gas

Number of moles, $n = W/M$: W = Total wt. of gas

M = Molecular wt. of gas

$$PV = Z\frac{W}{M}RT$$

Hence

$$P\frac{V}{W} = \frac{ZRT}{M}$$

or

$$v = \frac{ZRT}{PM} = \frac{V}{W}$$ = sp. volume of the gas

Also,

$$\frac{1}{v} = \rho = \frac{PM}{ZRT}$$

where ρ = gas density.

* Determination of Z = gas compressibility factor

* To day we will introduce the Concepts of Petroleum Geology and Basic Rock Properties

1st determine pseudocritical properties

$$T_{pc} = \sum_{i=1} y_i T_{ci}$$

$$P_{pc} = \sum_{i} y_i P_{pc_i}$$

2nd Calculate pseudoreduced properties

$$T_{pr} = \frac{T}{T_{pc}}, \quad P_{pr} = \frac{P}{P_{pc}}$$

3rd determine Z. Fig. 1.4, After Standing + Katz

Example: Given a mixture of gas:

CO_2	y_i	P_c	T_c
C_1	.85	~~1~~666.4	343.3
C_2	.04		
C_3	.03		

—

1st determine the pseudo-critical P + T

$$P_{pc} = \sum y_i P_{ci}$$

$$T_{pc} = \sum y_i T_{ci}$$

2nd calculate the pseudo-reduced P + T

$$P_{pr} = \frac{P}{P_{pc}}$$

$$T_{pr} = \frac{T}{T_{pc}}$$

3) determine Z factor from correlation Chart of Standing + Katz fig. (4.5)

Concepts of Petroleum Geology and Basic Rock Properties

Petroleum is not found in undergound lakes or rivers, but it exists within the void space of certain rocks... such as sandstones (sand grains that make up sandston beds) and fragments of carbonate rocks (make up limestone and dolomite beds)...

- The void spaces or pore spaces (sometimes called interstices) in reservoir rocks, provide the containers for the accumulation of oil and gas deposits.

- Pore space, or porosity, in rock gives the rock its characteristic ability to absorb and hold fluids.

Requirements for Commercial Oil Accumulations:

Certain requirements must be fulfilled for a commercial petroleum deposit to be present. These are

1. A source: material from which oil is formed (or Origin)
2. Porous and permeable beds (reservoir rocks) in which the petroleum may migrate

and accumulate after being ~~[illegible]~~ ~~[illegible]~~ formed.

3. A trap: Subsurface condition restricting further movement of oil such that it may accumulate in commercial quantities.

Source of Petroleum (or Origin of petroleum):

A complete understanding of the origin of petroleum would be of great benefit to exploration operations
There are many theories explaining the origin of oil and natural gas.

However, it has not been possible to determine the ~~[illegible]~~ exact origin because it has not been possible to identify the exact place or materials from which oil accumulation originated.

There are two accepted theories to explain the origin of oil:
1. Inorganic theory
2. Organic theory

Inorganic theory — holds that hydrogen and carbon were brought together under great pressure and temp. deep in in the earth to form oil and gas, which ~~and~~ found its way thru porous rocks and collect in traps in the underground formations.

2. The Organic theory — Petroleum originates from organic ~~things~~ material, primarily vegetable, which has been altered by heat, bacterial action, pressure and other agents over long periods of time.

Conditions favoring petroleum formation are found in sedimentary rocks only -- the sandstones and shale, and the limestones and dolonites —

Porous and Permeable Beds (Reservoir Rocks)

After its formation, petroleum may migrate from the source rock ~~rock~~ into porous and permeable beds where it accumulates and continues its migration until finally trapped.

The forces causing this migration are:

1. Compaction of sediments as depth of burial increases.

2. Diastrophism: Crustal movements causing pressure differentials and consequent subsurface fluid movements.

3. Capillary forces causing oil to be expelled from fine pores by the preferential entry of water.

4. Gravity which promotes fluid segregation according to density differences.

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The terms porous and permeable denote two rock properties whose measurements and quantitative definitions have comprised much of the technical literature of the Oil industry.. They must be defined and discussed in some detail..

Porosity

"Porosity is a measure of the pore space within a rock expressed as a fraction (or percentage) of the bulk volume of that rock."

The general expression for porosity is

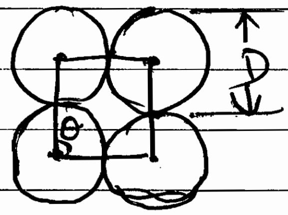
$$\phi = \frac{V_b - V_s}{V_b} = \frac{V_p}{V_b}$$

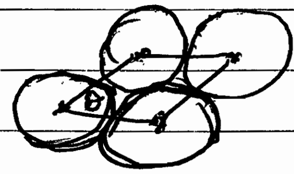
Where ϕ = porosity
V_b = bulk volume of the rock
V_s = net volume occupied by solid. (also called grain volume)
V_p = pore volume = the difference between bulk and solid volumes

To illustrate this principle consider the following figure which shows various arrangements of packed spheres and their computed porosities...

→

1





A. Cubic packing. Top row is directly above bottom row.

$$\theta = 90^\circ$$

$$V_b = D^3$$

$$V_s = \pi D^3/6$$

$$\therefore \phi = \frac{D^3(1-\pi/6)}{D^3}$$

$$= 0.476 = 47.6\%$$

B. Hexagonal Packing. Top row has been moved one radius to the right

$$\theta = 60^\circ$$

$$V_b = D^2 \cdot D \sin\theta$$

$$= 0.866 D^3$$

$$V_s = \pi D^3/6$$

$$\phi = \frac{D^3(0.866 - \pi/6)}{0.866 D^3}$$

$$= 0.395 = 39.5\%$$

In actual rocks porosity is classified as

a) Absolute porosity: Total porosity of a rock, regardless of whether or not the individual voids are connected, and

b) Effective Porosity: Only that porosity due to voids which are interconnected. - -

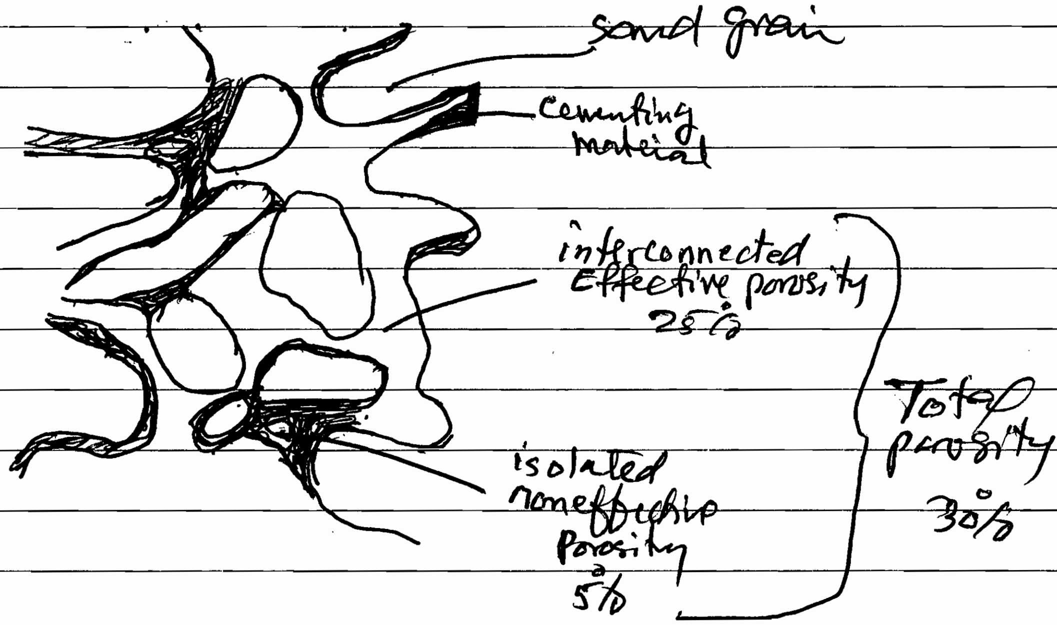
Note - It is the effective porosity which is of interest to the oil industry, and all further discussion will pertain to this form - -

Geologically, Porosity has been classified in two types, according to the time of formation:

1. Primary porosity (intergranular): Porosity formed at the time the sediment was deposited. The voids are spaces between grains of the sediment.

2. Secondary Porosity: Voids formed after the sediment was deposited. Porosity of this type has been subdivided into 3 classes based on the mechanism of formation.

a) Solution Porosity - Voids formed by the solution of the water containing carbonic acids (or other organic acids). This is called Vugular Porosity and the individual holes are called vugs.



sand grain
Cementing material
interconnected Effective porosity 25%
isolated noneffective Porosity 5%
Total porosity 30%

b) Fractures, Fissures & joints — Voids of this type are common in sedimentary rocks under loads caused by diastrophism such as folding and faulting.

c) Dolomitization — This is the process by which limestone ($CaCO_3$) is transformed into dolomite $CaMg(CO_3)_2$.

the chemical reaction —

$$2CaCO_3 + MgCl_2 \rightarrow CaMg(CO_3)_2 + CaCl_2$$

Typical Porosity Magnitude:

Typical value of porosity for a clean, consolidated, and uniform sand ≅ 20%

The carbonate rocks (limestone + dolomite) normally exhibit lower values with a rough average near 6 to 8% — these values are approximate and will not fit all situations.

The principal factors which complicate intergranular porosity magnitude are:

1. Uniformity of grain size.
   The presence of small particles such as clay, silt, etc.— which may fit in the voids between larger grains reduces the porosity. Such rocks are called dirty or shaly.

2. Degree of cementation: Cementing material deposited around grain junctions reduces porosity.

3. **Packing**: — Geologically young rocks are often packed in an inefficient manner and are as a result highly porous.

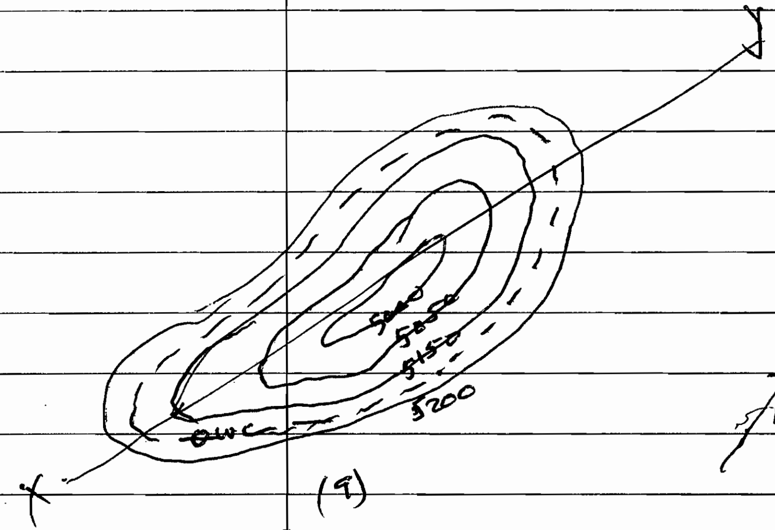
4. **Particle Shape**. — —

Quantitative Use of Porosity Data

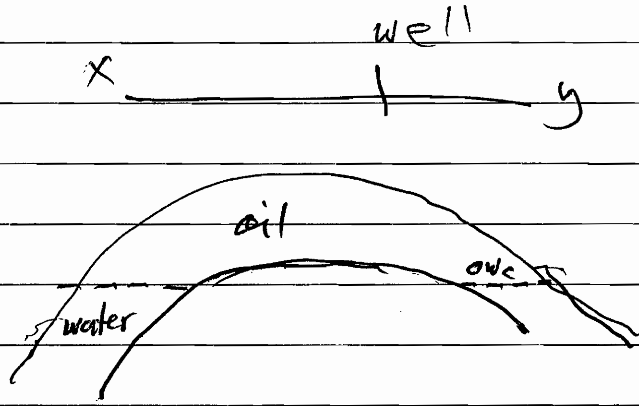
The subject of how porosity measurements are performed will be discussed briefly in a ~~later~~ ~~this~~ core ~~course~~ analysis.
For the present, it will be assumed that such measurements have been made ~~and~~ that the porosity is known.

As defined previously, porosity is a measure of the void space within a rock, and as such may be used to determine the quantity of fluid which may be stored within that rock.

Consider a bulk volume of rock with a surface area of one acre and a thickness of one foot. This constitutes the basic rock volume measurement used in oil field calculations, an acre-foot. It is also standard practice to express all liquid volumes in terms of barrels. The following conversion factors are useful:



(a)



(b)

a) Structure ~~Contour~~ map of the top of the reservoir,
b) cross section through the reservoir, along the
line XY.

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A bulk volume of rock with
surface $A = 1$ acre $= 43560\ ft^2$
Thickness, $h = 1$ foot
Basic rock volume used in an oil field calculations,
an Acre-foot = 43560 cu ft
It is stdand practice to express all liquid volmes in barrels:

$$1\ bbl = 42\ \text{galons} = 5.61\ \text{cu ft}$$

then,

$$1\ \text{acre-foot} = \frac{43560}{5.61} = 7758\ bbl.$$

then, the pore space within a rock $= 7758\,\phi$
$=$ Pore volume, V_p
(bbl/acre-ft)

where ϕ = porosity

This will lead us to to further reasoning by the well known volumetric equation of oil in place

$$N = \frac{7758\,\phi\,S_o}{B_{oi}}$$

$$= \frac{7758\,\phi(1 - S_w)}{B_{oi}}$$

Concept of volumetric Equation

1 acre = 43560 ft^2

1 acre-foot = 43560 ft^3

1 bbl = 42 galons = 5.61 cu ft

$$1 \text{ acre-ft} = \frac{43560}{5.61} = \underline{\underline{7758}} \text{ bbl}$$

It is then obvious that the pore space within a rock is equal to $7758 * \phi = V_p$ (bbl/acre-ft) where ϕ = porosity of the rock in question. Further reasoning as shown by the following figure (→) results in the well known Volumetric Equation of Oil in Place:

$$N = \frac{7758 \phi S_o}{B_{oi}}$$ (stock tank volume)

or

$$N = \frac{7758 \phi (1 - S_w)}{B_{oi}}$$

where N = tank oil in place, bbl/acre-ft

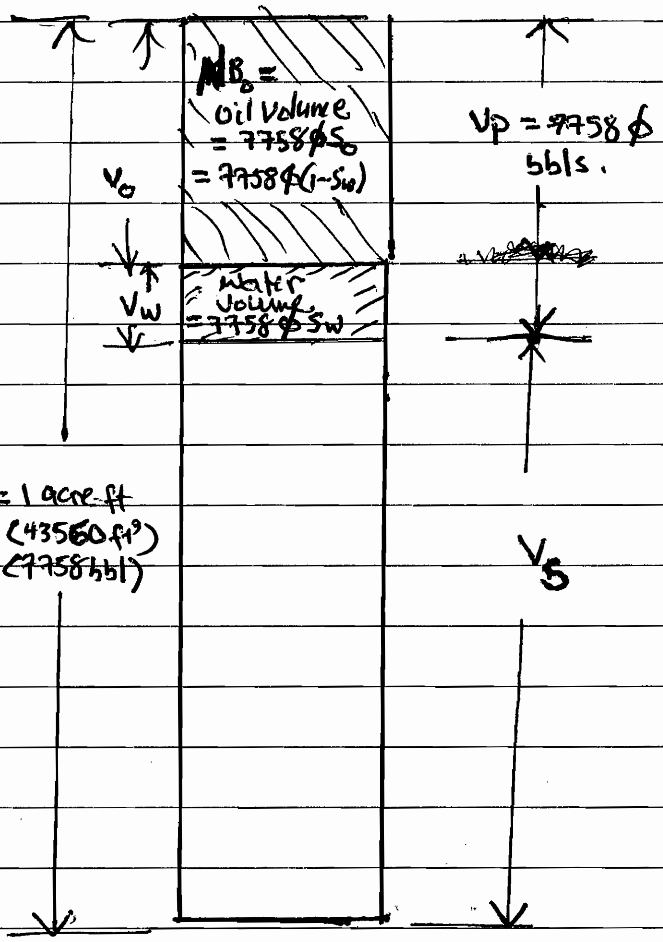
S_o = fraction of pore space occupied by oil (the oil saturation)

S_w = the water saturation

B_{oi} = the formation volume factor for the oil at the reservoir pressure, barrels reservoir space/barrel tank oil.

under initial conditions,

+ has the units res. volume/st volume



apparent relationships

$$(1)\quad S_o = \frac{V_o}{V_p}$$

$$(2)\quad S_w = \frac{V_w}{V_p}$$

$$S_o + S_w = 1$$

$$(3)\quad V_o + V_w = V_p$$

or

$$NB_o + 7758\phi S_w = 7758\phi$$

from which

$$N = \frac{7758\phi(1-S_w)\ \text{bbls/acre-ft}}{B_o}$$

Concepts of Volumetric equation

Note:
Some water will always exist within the reservoir rock and that its volume must be subtracted from the space available for oil. This water is commonly called connate water and is assumed incompressible in this eqn.

A similar expression may be derived for the amount of gas stored in a sand. In this case it is convenient to express the gas volume in terms of SCF or in MCF (thousands of standard cubic feet). Recall the form of the Gas Law

$$\frac{P_s V_s}{T_s} = \frac{P V_p}{ZT} \quad (1) \qquad V_s = G = V_p \times \frac{P T_s}{ZT P_s} \quad (2)$$

Where subscript, s, denotes std. cond. $Z_s = 1$, and is not shown, then

where G is the std. gas volume contained in V_p at conditions P, T, Z.

But $V_p = 43560\,\phi\,(1 - S_w)$ cu ft/acre-ft

$T_s = 460^\circ + 60^\circ = 520^\circ R$

$P_s = 14.7$ psia

Substitution of these values in eqn. (2)

$$G = 43560\,\phi(1-S_w) \times \frac{520}{14.7} \times \frac{P}{ZT}$$

$$G = \frac{1540\,\phi\,(1-S_w)}{ZT} \quad \text{MCF/Acre-ft}$$

Permeability – Darcy's Equations

In addition to being porous, a reservoir rock must be permeable; that is, it must allow fluids to flow through its pore network at practical rates under reasonable pressure differentials.

Permeability is defined as a measure of rock's ability to transmit fluids.

* The quantitative definition of Permeability was first given in an empirical relationship developed by the French hydrologist Henry D'Arcy who studied the flow of water through unconsolidated sands.

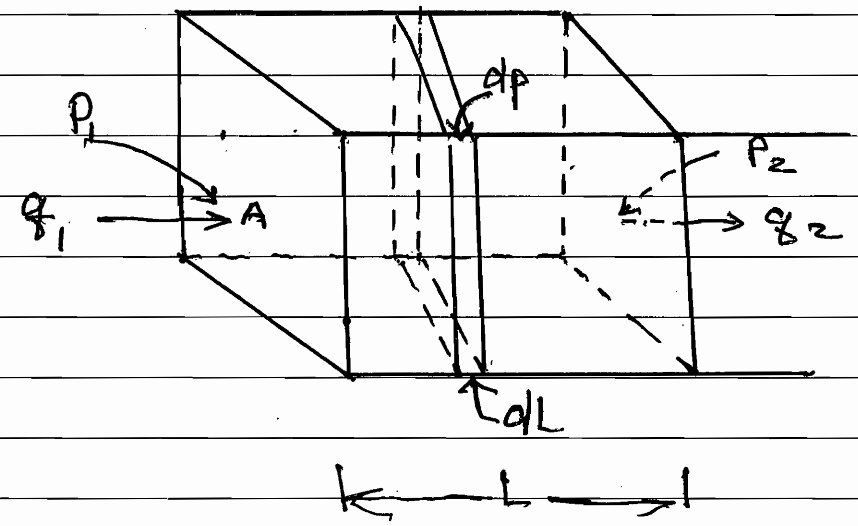
This law in its differential form is:

$$v = -\frac{K}{\mu}\frac{dP}{dL}$$

where v = apparent flow velocity
μ = viscosity of the flowing fluid
dP/dL = pressure gradient in the direction of flow
K = Permeability of the porous media

To illustrate the above notations of Darcy's equation, Let us consider the linear system

For incompressible fluids, where $q_1 = q_2$



The following assumptions are necessary to the development of the basic flow equations:

1. SS flow conditions exist
2. The pore space of the rock is 100% saturated with the flowing fluid. Under this restriction K is the absolute permeability.
3. the viscosity of the flowing fluid is constant. This is not true since $\mu = f(P,T)$ for all real fluids. Hint — this effect is negligible if μ at the average pressure is used, and if
4. Isothermal conditions prevail
5. Flow is horizontal and linear
6. Flow is laminar

With these restrictions in mind, let

$$v = \frac{q}{A}$$

where q = volumetric rate of fluid flow
A = total cross-sectional area perpendicular to flow direction

☆ This is a further assumption since only the pores, and not the full area, conduct fluid. Hence v = an apparent velocity. The actual velocity, assuming a uniform medium

$$= \frac{v}{\phi}.$$

Case I: Linear Incompressible Fluid Flow

By substitution of $v = \frac{q}{A}$ in

$$v = -\frac{K}{\mu}\frac{dP}{dL}$$

gives

$$\frac{q}{A} = -\frac{K}{\mu}\frac{dP}{dL}$$

Seperation of variable and insertion of the limits depicted by the above figure gives

$$\frac{q}{A}\int_0^L dL = -\frac{K}{\mu}\int_{P_1}^{P_2} dP$$

which, when integrated, is

$$q = \frac{KA(P_1 - P_2)}{\mu L}$$

or

$$K = \frac{q\mu L}{A\Delta P}$$

The following units serve to define the darcy.

If $q = 1$ cc/sec, $\mu = 1$ centipoise
$A = 1\ \text{cm}^2$, $\Delta P/L = 1$ atm./cm

then, $K = \underline{1 \text{ darcy}}$ or a more common unit is the millidarcy where 1 darcy = 1000 millidarcy

Linear Compressible Fluid Flow

Consider the same linear system of the previous figure, except the flowing fluid is now compressible, then $q \neq$ constant, but is a $f(P)$.

Assuming that Boyle's law is valid ($Z=1$)

$$P_1 q_1 = P_2 q_2 = P q = \text{constant}$$

where subscripts denote point of measurement, then

$$P q = \frac{-KA}{\mu} \times \frac{dP}{dL} \quad P = P_2 q_2$$

$$q_2 \int_0^L dL = -\frac{KA}{\mu} * \frac{1}{P_2} \int_{P_1}^{P_2} P\, dP$$

from which

$$q_2 = \frac{KA}{\mu L} \times \frac{P_1^2 - P_2^2}{2} \times \frac{1}{P_2}$$

Expressing this equation in terms of $\bar{q}_g$, the rate of gas flow at the average pressure in the system is

$$\bar{q}_g = \frac{KA}{\mu L} \times \frac{P_1^2 - P_2^2}{2} \times \frac{1}{\bar{P}}$$

But

$$\bar{P} = \frac{P_1 + P_2}{2} \quad \text{and} \quad \frac{P_1^2 - P_2^2}{2} = \frac{(P_1+P_2)(P_1-P_2)}{2}$$

$\therefore$,

$$\bar{q}_g = \frac{KA\,\Delta P}{\mu L}$$

which is exactly the same as the previous eqn of flow rate of the incompressible fluids.

An expression for the standard flow rate, q_{gs}, is obtained from Charles' law:

$$\frac{P_s q_{gs}}{T_s} = \frac{P_2 q_g}{T_f} = \frac{KA}{2\mu L}(P_1^2 - P_2^2)\frac{1}{T_f}$$

Where

$T_s = 60°F\ (520°R)$

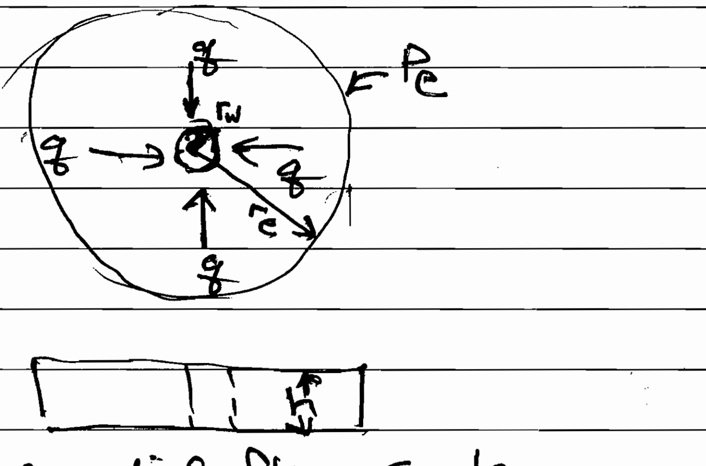
$P_s = 1$ atm

T_f = flowing temperature

Thus

$$q_{gs} = \frac{KA(P_1^2 - P_2^2)}{2\mu L} \times \frac{T_s}{T_f} \times \frac{1}{P_s}$$

Note: For std. units, $P_s = 1$ atm. and is often omitted from the above eqn.. The use of these linear equations is limited to laboratory testing. The equations which normally apply to field calculations are based on a radial system as shown in the following figure:



ideal radial flow system

Radial Incompressible Fluid Flow

We will start with the differential form of equation

$$q/A = \frac{K}{\mu} \times \frac{dP}{dL}$$

with notation and sign convention as applied to the radial flow figure..

$$\frac{q}{A} = \frac{K}{\mu}\frac{dP}{dr}$$

But for radial flow $A = 2\pi r h$

where r = radius or distance from center, cm

h = thickness of bed, cm.

Substituting of $2\pi r h$ for A and seperation of variables gives

$$q\int_{r_w}^{r_e}\frac{dr}{r} = \frac{2\pi h K}{\mu}\int_{P_w}^{P_e} dP$$

Which when integrated is

$$\boxed{q = \frac{2\pi h K}{\mu}\frac{(P_e - P_w)}{\ln(r_e/r_w)}}$$

this is the basic equation for the steady state radial flow of liquid..

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Exam I (Midterm) ● 9

Let us Summarize what we have talked about on Tuesday:—

1. Pore space within a rock, $V_p = 7758\,\phi\,(\text{bbl/acre-foot})$..
2. Concept of Volumetric Equation of oil in place:

$$N = \frac{7758\,\phi\,S_o}{B_{oi}} \Rightarrow \text{stock tank volume}$$

or

$$N = \frac{7758\,\phi\,(1-S_w)}{B_{oi}}$$

where N = tank oil in place, bb/acre-ft

S_o = fraction of pore space occupied by oil (the oil saturation)

S_w = the water saturation

B_{oi} = initial formation volume factor for the oil at the reservoir pressure, $\frac{\text{bbl res.}}{\text{bbl tak oil}}$

3. A similar expression for the gas stored in a sand. Expressed the gas volume in terms of SCF or MCF (thousands of std. cu-ft).

$$G = 43560\,\phi\,(1-S_{wc})\,\frac{T_s}{P_s} \times \frac{P}{ZT}$$

or

$$G = \frac{1540\,\phi\,(1-S_w)\,P}{ZT} \quad \text{MCF/acre-ft.}$$

4. Permeability — Darcy's Equation

"Permeability is defined as a measure of rock's ability to transmit fluids."

→

The quantitative definition of K was first given in a relationship developed by Henry Darcy who studied the flow of water thru unconsolidated sands.

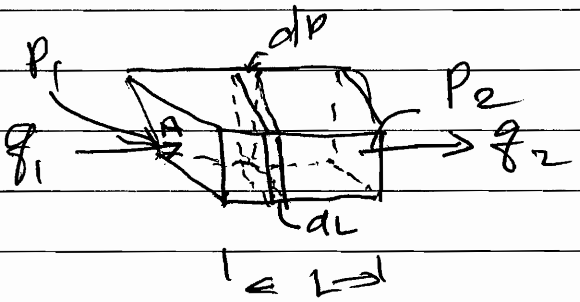
The law in it's differential form is

$$v = -\frac{K}{\mu}\frac{dP}{dL}$$

where v = apparent flow velocity
μ = viscosity of the flowing fluid
dP/dL = pressure gradient in the direction of flow
K = permeability of the porous media.

illustration — of Darcy's eqn.

Let us consider the linear system of an incompressible fluids, where $q_1 = q_2$



Let $v = \frac{q}{A}$

By substitution of $v = \frac{q}{A}$ in Darcy's eqn.

$$v = q/A = -\frac{K}{\mu}\frac{dP}{dL}$$

Seperate variable

$$q = \frac{KA(P_1 - P_2)}{\mu L}$$

or $K = \frac{q\mu L}{A\Delta P}$ — darcy or md. (where 1 darcy = 1000 md.

If $q = 1\ cc/sec$, $\mu = 1$ centipoise
$A = cm^2$ $\Delta P/L = 1\ atm/cm$

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Summary of the last sessions:

1. Permeability, K, - Darcy's Equation of a porous media

a) For a linear System - Incompressible fluid flow:

$$q = \frac{KA(P_1 - P_2)}{\mu L}$$

and

$$K = \frac{q\mu L}{A\Delta P}, \text{ darcy, or md.}$$

b) For a linear System - Compressible fluid flow:

$$\bar{q}_g = \frac{KA\Delta P}{\mu L}$$

At standard conditions

$$q_{gs} = \frac{KA(P_1^2 - P_2^2)}{2\mu L} \times \frac{T_s}{T_f} \times \frac{1}{P_s}$$

c) Radial Incompressible Fluid Flow:

for a steady state - $q = \frac{2\pi h K(P_e - P_w)}{\mu \ln(r_e/r_w)}$

d) Radial Compressible Fluid Flow:

$$q_g = \frac{2\pi h K(P_e - P_w)}{\mu \ln(r_e/r_w)}$$

@ std. conditions

$$q_{gs} = \frac{\pi h K(P_e^2 - P_w^2)}{\mu \ln(r_e/r_w)} \times \frac{T_s}{T_f} \times \frac{1}{P_s}$$

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The Darcy's equation for linear horizontal flow, in the absence of a gravitational field, is

$$q = -\frac{KA}{\mu}\frac{dp}{dx}$$

This eqn. has a negative sign because, if the flow rate is considered positive in the positive X direction, the pressure decreases in that direction.

$$K = -\frac{q\mu}{A} \Big/ \frac{dp}{dx}$$

$$K = -\frac{q\mu}{A}\frac{dx}{dp}$$

Darcy = 1000 md.

Fluid Saturation —

The ratio of the volume that a fluid occupies to the PV is ~~the~~ called fluid saturation and has the symbol S_w, S_o, S_g • or

$S_w = \frac{V_w}{V_p}$, $S_o = \frac{V_o}{V_p}$, $S_g = \frac{V_g}{V_p}$

By definition, the saturations of all fluids present in a porous medium sum to 1.

$$S_w + S_o + S_g = 1$$

Traps —

In order for petroleum to accumulate in commercial quantities, it must, in its migration process, encounter a subsurface rock condition which

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Radial Compressible Fluid Flow

Here Boyl's law is assumed valid, hence,

$$P_e q_{ge} = P_w q_{gw} = \bar{P}\bar{q}_g = \text{constant}$$

$$q_{gw}\int_{r_w}^{r_e}\frac{dr}{r} = \frac{2\pi h K}{\mu P_w}\int_{P_w}^{P_e} p\,dp$$

$$q_{gw} = \frac{\pi K h (P_e^2 - P_e^2)}{\mu \ln(r_e/r_w)} * \frac{1}{P_w}$$

Similarly

$$\bar{q}_g = \frac{2\pi h K (P_e - P_w)}{\mu \ln(r_c/r_w)}$$

and

$$q_{gs} = \frac{\pi h K (P_e^2 - P_w^2)}{\mu \ln(r_e/r_w)} \times \frac{T_s}{P_f} \times \frac{1}{P_s}$$

Conversion To Practical Units:

The standard units which define the darcy are useful in laboratory calculations. For computations of the field problems it is convenient to convert to practical units by use of the appropriat constant.

For example let us convert the eqn.

$$q = \frac{2\pi h K (P_e - P_w)}{\mu \ln(r_c/r_w)}$$

Where h = ft, K = darcys, P_e, P_w = psia, μ = cp. q = barrels/day. The following conversion factors are needed:

1 bbl = 159000 cc
1 ft = 30.48 cm
1 atm = 14.7 psia

Dimensional Analysis of Permeability

The physical concept of the Darcy is enhanced by dimensional analysis of Darcy's equation. This is done by resolving all quantities into their basic dimensions of mass M, length L, and time t, and solving for the dimensions of K.

$$K = \frac{q \mu L}{A \Delta p}$$

where

$$q = \text{volume}/\text{time} = L^3/t$$

$$L = L, \quad A = \text{area} = L^2$$

$$\Delta p = \text{force}/\text{area} = \frac{\text{mass} \times \text{acceleration}}{\text{area}}$$

$$\Delta p = \frac{ML/t^2}{L^2} = \frac{M}{Lt^2}$$

$$\mu = \frac{M}{Lt}$$

$$\therefore \quad K = \frac{(L^3/t)(M/Lt)(L)}{(L^2)(M/Lt^2)} = L^2$$

In fact that K is not a dimensionless quantity but has the units of area, — It's magnitude is dependent on pore size.

Conversion to Practical Units (continued):

Then,

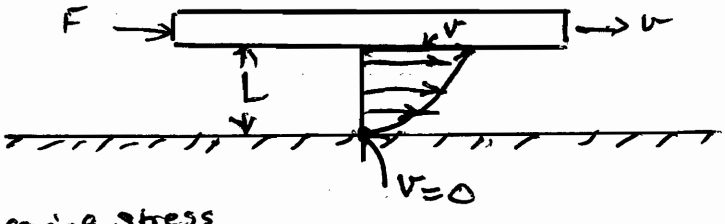
$$q \ \frac{bbl}{day} \times \frac{159000 \ cc/bbl}{24 \times 3600 \ sec/d} = \frac{2\pi \left(h \ ft \times 30.48 \frac{cm}{ft}\right) k \left[(P_e - P_w) \ psi \times \frac{1}{14.7} \frac{atm}{psi}\right]}{\mu \ln (r_e/r_w)}$$

$$q = \frac{(24)(3600)(2\pi)(30.48)}{(159000)(14.7)} \times \frac{kh(P_e - P_w)}{\mu \ln(r_e/r_w)}$$

$$q = \frac{7.07 \ kh(P_e - P_w)}{\mu \ln(r_e/r_w)}, \quad \text{where } C = 7.07$$

Dimensions of Dynamic Viscosity

Are obtained by analyzing the forces exerted on a plate of area A, moving on a viscous liquid with velocity, v, caused by a force, F.



$$\mu = \frac{\text{Shearing stress}}{\text{rate of shearing strain}}$$

$$= \frac{F/A}{dv/dL} = \frac{\frac{ML/t^2}{L^2}}{\frac{L/t}{L}} = \frac{M}{Lt}$$

Lower plate is stationary. Fluid velocity between plates varies from v at top to zero at bottom.

Typical Permeability Magnitudes

Rock having K = 100 md or greater are fairly permeable.
while, rocks with < 50 md are considered tight.

Many productive limestone and dolomite matrices have permeabilities ≤ 1 md, however; these have associated solution cavities and fractures which contribute the bulk of the flow capacity. – – –

Traps

In order for petroleum to accumulate in commercial quantities, it must, in its migration process, encounter a subsurface rock condition which halts further migration and causes the accumulation to take place.

Trap Classification:

Numerous systems of trap classification exist, such as the following:

1. Structural traps: Formed by deformation of the earth's crust by either faulting or folding. Such as anticline or dome (sealing rock caps the structural feature)

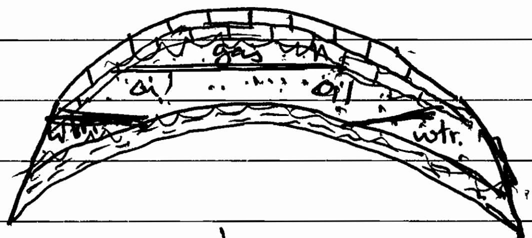
2. Stratigraphic traps: These formed by changes in lithology, generally a disappearance

of the containing bed or porosity zone.

or occurs when the res. pinches out against some other impermeable formation, thus trapping the oil/gas from migrating higher.

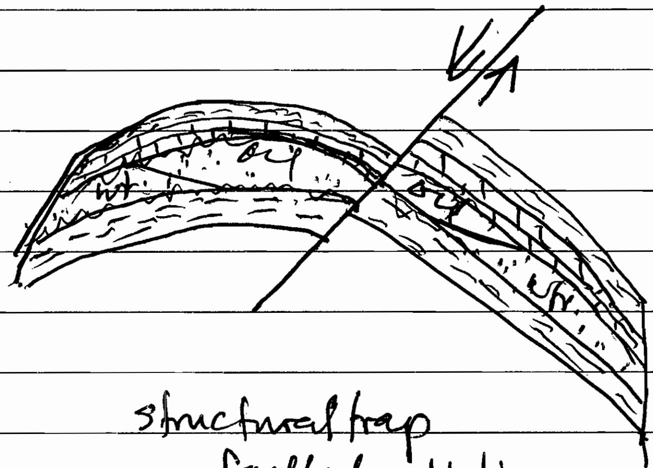
3. Combination traps: Traps having both structural and stratigraphic features.

Typical trap examples:

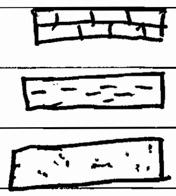


fold

Structural trap _ simple anticline



structural trap
faulted anticline



* Trapping Mechanisms

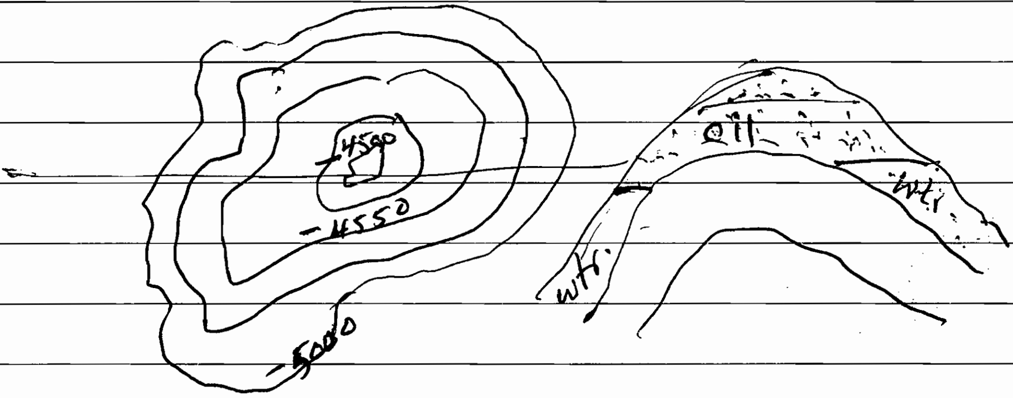
For an oil or gas accumulation to exist, four things are required: source rock, a reservoir, and a trapping mechanism...

The basic question to be answered here is what is keeping this oil accumulation in place.

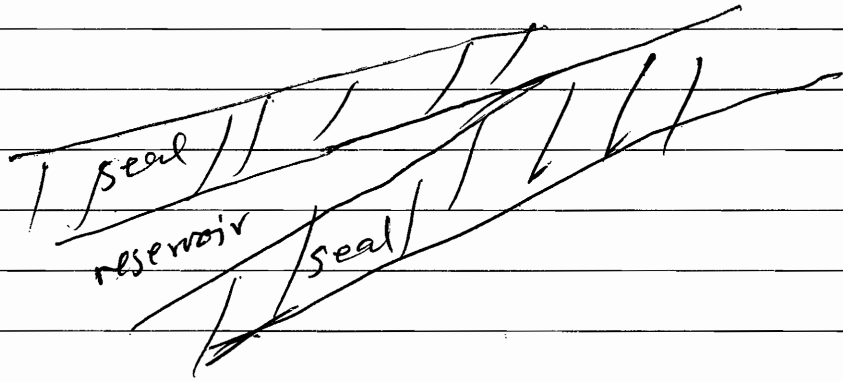
While many different types of trapping exist, they can be classified into the following categories:

* Structural traps
* Stratigraphic traps, fault traps,
* and Combination traps.

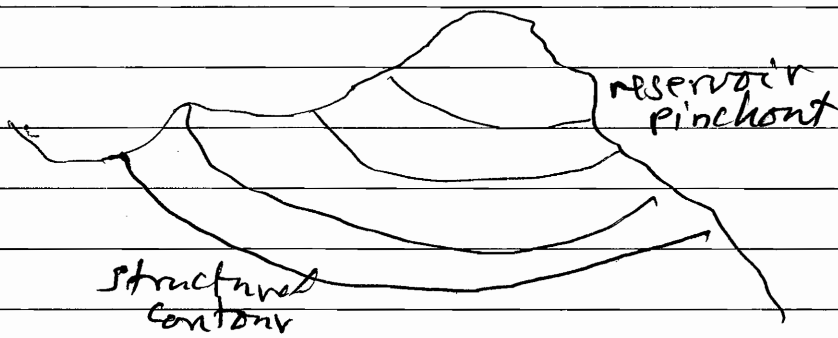
Structural Traps — A structural trap consists of a structural high, such as an anticline or dome, where oil and gas can accumulate and cannot migrate any higher thru the reservoir. The sealing rock caps ~~the~~ the structural feature. For a structural trap to exist, the structural contours must be closed.



Stratigraphic traps – A stratigraphic trap occurs when the reservoir pinches out against some other impermeable formation, thus trapping the oil from migrating higher.
The pinchout can occur when the reservoir thickness, porosity, or permeability are reduced to zero



stratigraphic trap showing reservoir pinchout.



halts further migration and causes the accumulation to take place. These subsurface conditions are numerous in type ranging from simple to extremely complex forms.

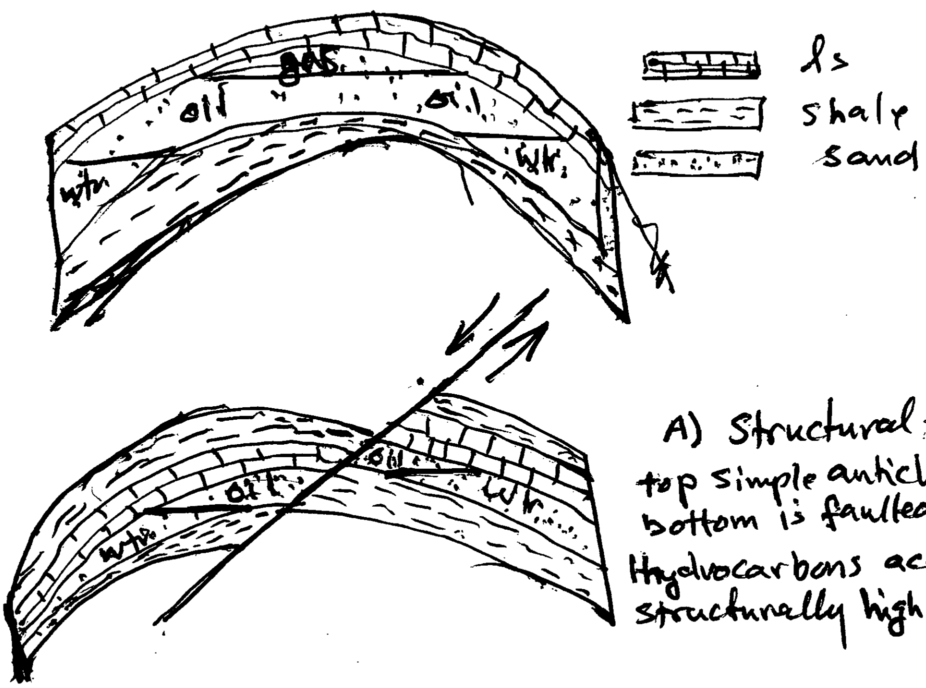
✓ Numerous systems of trap classification exist; the following are ~~▬~~ proposed by Sanders:

✓ 1. Structural traps :— Those traps formed by deformation of the earth's crust by either faulting or folding.

✓ 2. Stratigraphic traps :— Those formed by changes in lithology, generally a disappearance of the containing bed or porosity zone.

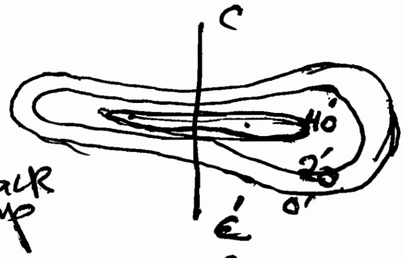
✓ 3. Combination traps :— Having both structural and stratigraphic features.

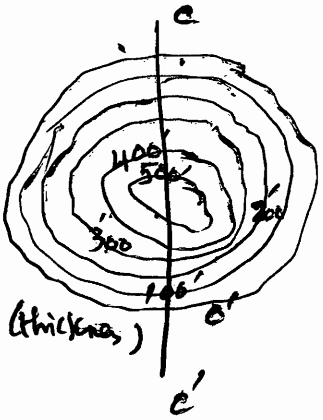
Here two typical examples of each type are shown here in this figure (A, B, +C)



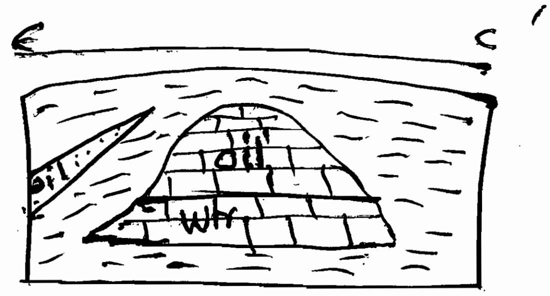
A) Structural traps.
top simple anticline.
bottom is faulted anticline
Hydrocarbons accumulate at structurally high positions.

(thickness) isoback map





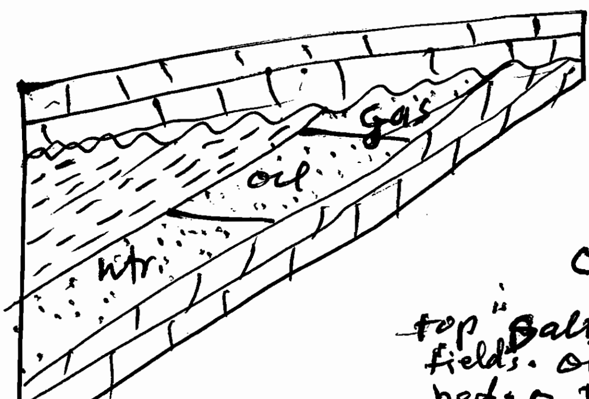
isoback (thickness) map



B) Stratigraphic traps. Top is classic shoe string sand type (in Kansas + oklahom)

Bottom is a reef deposit similar to those found in west texas.

C) Combination traps



C) Combination traps.

top "Salt dome type typical of Gulf Coast fields. oil is found in flank sands, upper beds or the caprock.

lower is unconformity trap. Hydrocarbon have been trapped by impervious bed above the unformity —
Typical of East Texas Field — —

Subsurface Pressures and Subsurface Temperatures:

Subsurface Pressures

It is readily seen in Darcy's equation that the fluid movement from a reservoir rock to a wellbore can take place if a pressure differential can be established between the reservoir and the well. This requires that the fluids in the rock be confined under an elevated pressure.

* Source of Subsurface Pressures

The elevated pressures encountered with depth are due to the following:

1. Hydrostatic pressure imposed by the weight of fluid (predominantly water) which fills the voids of the rocks above, and/or contiguous with the reservoir in question.

Most common in soft rock areas — Gulf coast (young sediments) → 2. Overburden Pressure due to the weight of the rocks and their fluid contents existing above the reservoir.

* It is common to find subsurface pressures varying as a linear function of depth with a gradient close to the hydrostatic pressure of fresh to moderately saline water.

Magnitude of Subsurface Pressure

Pressure-depth relationships are gradients. The hydrostatic gradient in fresh water is 0.433 psi/ft of depth which is the quotient of $62.4\ lb/ft^3 \div 144\ in^2/ft^2$.

Since most ~~saline~~ subsurface waters are saline, it is common to find the gradient to be above 0.433

Note: The earth or overburden pressure gradient is one, is obtained by using an average water saturated rock sp. gravity of 2.3. Hence the overburden gradient is

$2.3 \times 0.433 \cong 1$ psi/ft.

Subsurface Temperature

Since the earth is assumed to contain a molten rock, it is logical to assume that temp. should increase with depth. The temperature-depth relationship is a linear function of the form:

$$T_D = T_a + \alpha D$$

where

T_D = temp. of the reservoir at any depth, D

T_a = average surface temp.

α = temp. gradient, degrees/100 ft

D = depth, hundred of feet

2) Core drilling:-
shallow, small hole drilling for information purposes only. The formations encountered are cored, i.e., obtained as small cylindrical samples which are readily and accurately identified.

3) strat tests : deep exploratory holes drilled primarily for information.

4 start

Geophysical Exploration

* Geophysical exploration methods are those employing a physical measurement of subsurface conditions made from a surface location. The methods are
1. Gravitational
2. Magnetic
3. Seismic

Gravitational Methods

This type of geophysical prospecting is based on
* Newton's hypothesis that every particle in the universe attracts every other particle in the manner defined by the equation

$$F = \gamma \frac{m_1 m_2}{r^2}$$

where F = attractive force
m_1, m_2 = masses of particle in eqn.
r = distance between particle
γ = gravitational constant (6.67×10^{-8} in cgs units)

Petroleum Exploration Methods

The most successful methods are:

1. Direct indications
2. Geological methods
3. Geophysical methods

Direct Indications

Nearly all of the oil provinces of the world exhibit some surface evidence of the presence of petroleum. Typical of these indications are:

- natural seepage of oil,
- outcrops of oil-bearing rocks

and - various forms of gas seepages such as mud volcanoes.

Note: the visible presence of hydrocarbons suggests that an area deserves attention; it does not, however, necessarily prove that oil exists in commercial quantities.

In the US these types of occurences have been thoroughly explored & no longer exist as an exploration method... De Golyer has pointed out, that there is one surface indication which is still of primary importance in any area, namely, an oil well...

Geological Exploration Methods

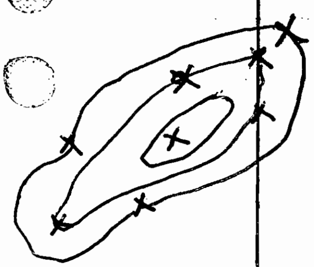
* A petroleum geologist's main job is to select promising sites for the drilling of exploratory wells based on his prediction of an area's subsurface stratigraphy and structure . .

✓ In order to make these predictions he prepares maps, both surface and subsurface, * on which known points are used to extrapolate the probable conditions at unknown points.

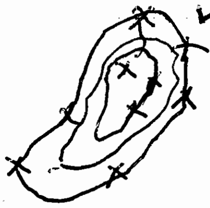
✓ SubSurface clues — surface features such as elevations, dips and strikes of outcrops, and lithological changes may be mapped as clues to subsurface features — —
✓ — Areal photographs also prove valuable in locating subsurface structures in many areas.

The current depths to which exploratory wells are being drilled are such that the petroleum geologist must prepare maps from subsurface data in attempting to predict the conditions at these depths.

✓ Subsurface Maps — subsurface maps are numerous in variety and types; the following are typical, basic forms:

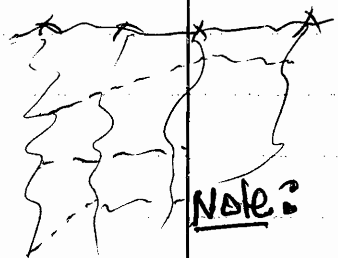


1. Structural Contour maps:
   Maps composed of lines connecting points of equal elevation above or below a datum (normally sea level).



2. Isopachous maps:
   Maps composed of lines connecting points of equal bed (layer) thickness

3. Cross sections:



   A form of subsurface presentation which depicts the position and thickness of various strata..

Note: In addition to being useful as an exploration tool, subsurface maps are a necessary part of reservoir engineering study;

The data for subsurface maps are obtained from a number of sources, such as

1. Well logs: representations of some rock properties vs. depth. Some of these are:
   - a) Sample logs
   - b) Drilling time logs
   - c) Electric logs
   - d) Radioactivity logs
   - e) Caliper logs
   - f) NMR Logs (MRIL, CMR L)

Porosity logs (i.e) density log, Sonic log

Geophysical Exploration

Here these methods employing a physical measurement of subsurface conditions made from a surface location. the methods ~~to~~ to be discussed briefly are
Gravitational
Magnetic
Seismic

Gravitational Methods

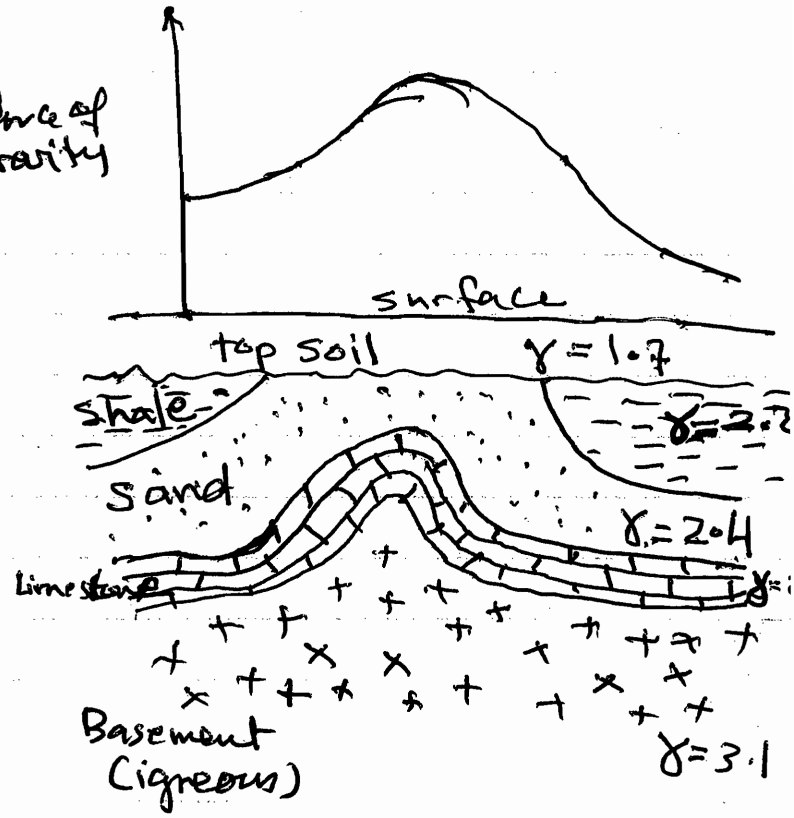
This type of geophysical prospecting is based on Newton's hypothesis that every particle in the universe attracts every other particle in the ~~m~~ manner defined by the eqn.

$$F = \gamma \frac{m_1 m_2}{r^2}$$

Where F = attractive force
m_1, m_2 = masses of paticles in question
r = distance between particles
γ = gravitational constant (6.67×10^{-8} in cgs units)

Conside this figure – which portrays a buried anticline. The denser rocks are closer to the surface and cause a higher gravitational force in the vicinity.

Such an area, when mapped, shows a gravity high indicating a possible structure,



Note: The instruments record these small variations must be very sensitive and yet portable to field use...

~~Instruments used~~ such as the gravimeter (std.)

Other instruments used in gravity work are $\boxed{\text{torsion balance}}$ and the pendulum. and these are replaced by the gravimeter..

Magnetic Prospecting

This method maps $\boxed{\text{anomalies}}$ in the earth's magnetic field and to correlate those with underground structure. – – *Sedimentary rocks are non-magnetic; any magnetic irregularities found are due to depth variations of basement rocks. The vertical component of the magnetic field is important in this method

Instruments used in magnetic prospecting vary from a simple dip needle (a vertical compass) to elaborate airborne magnetometers, by which large areas may be quickly mapped. *Numerous oil fields have been located by this method. (ex.. New Mexico, Hobbs, -

Present usage of this method is restricted to reconnaissance work.

Seismic Method

How do Seismic surveys work?

Seismic surveys have become the primary tool of petroleum exploration, both onshore and offshore.

* Seismic surveys is conducted by creating a shock wave ~~on~~ (a seismic wave) the surface of the ground along a predetermined line, using an energy source...
* The seismic wave travels into the earth, is reflected by ~~the~~ subsurface formations, and returns to the surface where it is recorded by receivers called geophones - similar to microphones..

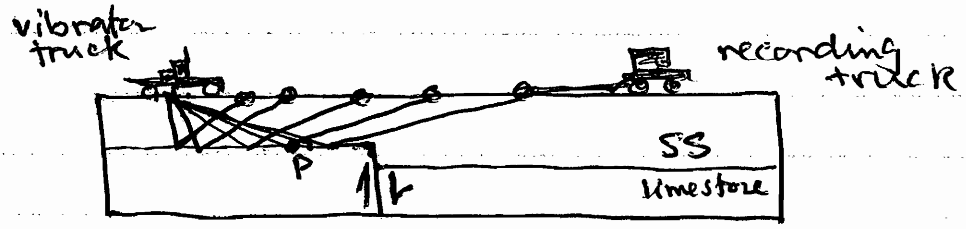
how seismic waves are created?

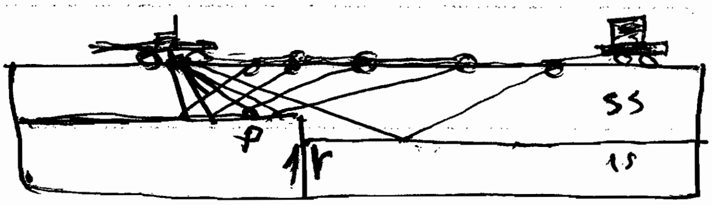
* The seismic waves are created ~~by~~ either by small explosive charges set off in shallow holes "shot holes or points) or by large vehicles equiped with heave plates ("Vibroseis" trucks) that vibrate on the ground.

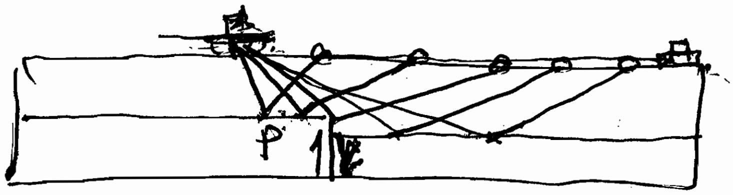
Analyze the time the seismic wave it takes to reflect back

by analyzing the time it takes for the seismic waves to ~~refflect~~ reflect off of subsurface formations and return to the surface.

A geophysicist can map subsurface formations and anomal and predict where oil or gas may be trapped -- in sufficient quantities for exploration activities.







* Seismic surveys were conducted along a single line on the ground, and their analysis created a 2-D picture akin to slice thru the earth beneath that line, showing the subsurface geology along that line. This is a 2-D seismic data. (2D seismic image)

3D seismic image:

3D surveys can be conducted in any environment - in the ocean, in swamps, and in urban areas.

3D can cover many square miles & may cost $40,000 - $100,000 per square mile or more.

How seismic Surveys Work?

Seismic surveys have become the primary tool of exploration companies, both onshore and offshore.

3-D seismic surveys have lowered costs and allowed exploration for reserves not locatable by other means, i.e. revolutionizing the industry ---

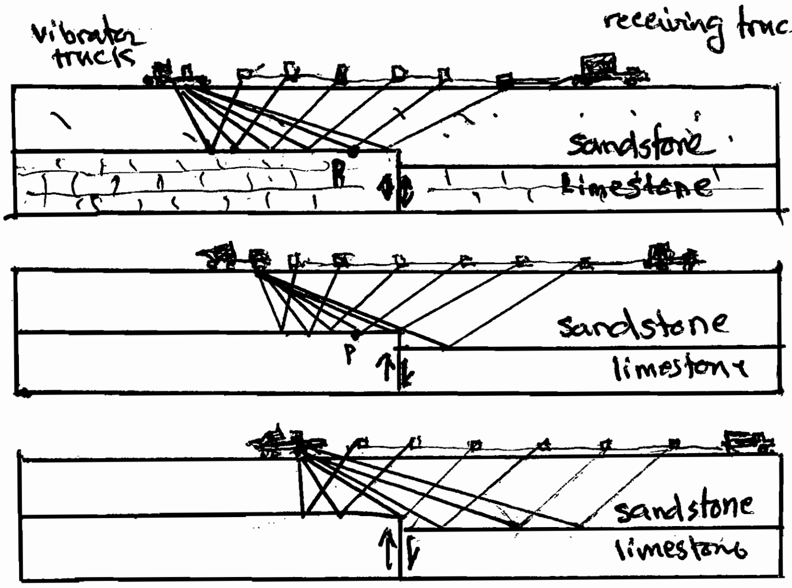
A seismic survey is conducted by creating a shock wave - a seismic wave - on the surface of the ground a long a line, using an energy source.

The seismic wave travels into the earth, is reflected by subsurface formations, and returns to the surface where it is recorded by receivers called geophones--

The seismic waves are created either by small xplosive charges set off in shallow holes "shot holes" or by large vehicles equiped with heave plates (Vibroseis trucks) that vibrate on the ground.

By analyzing the time it takes for the seismic waves to reflect off of subsurface formations and return to the surface, a geophysicist can map subsurface formations and anomalies and

Predict where oil or gas may be trapped in sufficient quantities for exploration ~~g~~ activities.



Depth calculate

$$Z = \frac{1}{2}\sqrt{T^2V^2 - X^2}$$

where Z = depth
t = time
V = velocity of travel
X = distance between shot pt. + geophone

Until recently, seismic surveys were conducted along a single line on the ground, and their analysis created a two-dimensional picture akin to a slice thru the earth beneath that line, showing the subsurface geology along that line. This is referred to as two-dimensional or 2D seismic data.

In the last 20-30 yrs., with the development of computers, geophysists have been able to take seismic surveys to a new level by conducting 3D seismic tests.
To day were being able to conduct 200 to 300 3D surveys a year --- In 1980's it took the most ~~most~~ sophisticated Cray computers to analyze the data. To day, the analysis is performed on a super-desk-top computers.

indicate structure :- -

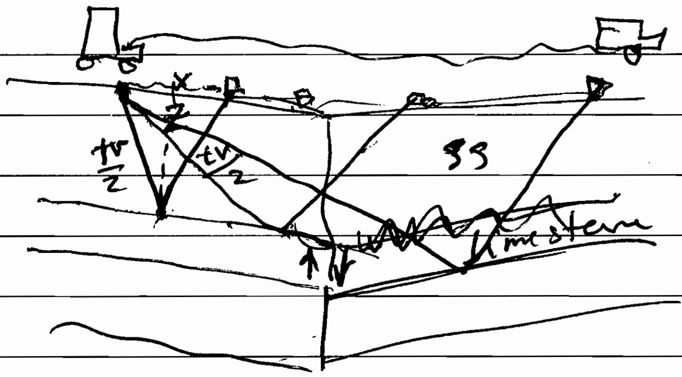
$$Z = \frac{1}{2}\sqrt{t^2 v^2 - x^2}$$

where z = depth

t = time

v = velocity of travel

x = distance between shot point and geophone.



There are 3 phases of seismic surveys: data acquisition, processing, and interpretation.

Data Acquisition

3D surveys are acquired by laying out energy source points and receiver points in a grid over the area to be surveyed.

The receiver pts. - to record the reflected vibrations from the source pts,

Must be conducted over a large area in order to provide sufficient data for accurate interpretation of the subsurface geology - 3D surveys commonly cover 50 to 100 sq. miles or more.

Data processing

use Cray computers to analyze the data.

Data recorded is a raw data or "unprocessed" form. Before it can be used it must go thru a series of computerized processes. These processes - filtering, stacking, migrating and other Cray computers analysis, make the data useable

Data Interpretation

currently, almost all oil + gas exploratory wells are preceeded by 3D seismic surveys.

The processed data must be interpreted by the geophysists or geologist. All seismic data is subject to integretation, and no two experts will interpret data identically.

Fundamentals of Petroleum Reservoir ;
Read : P23 - 32

Note : The proper interpretation of 3D data is a critical step in the process.