# Fundamentals of Liquid Measurement

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Rocky Mountain Measurement Association
2015 Trade Show

# Fundamentals of Liquid Measurement

- Wouldn't life be a lot easier if all liquid hydrocarbon transactions would occur with the same product, at the same temperature and pressure, with the same quality ?

# Fundamentals of Liquid Measurement

- If it were all that easy, we wouldn't be able to all get together every year at the Trade Show School !
- We have the School for a reason, so there might be something more to it …

# Fundamentals of Liquid Measurement: Physical Properties

- To minimize the overall measurement uncertainty in liquid petroleum measurement, a fundamental understanding of the physical properties that affect measurement is necessary.

# Fundamentals of Liquid Measurement: Physical Properties

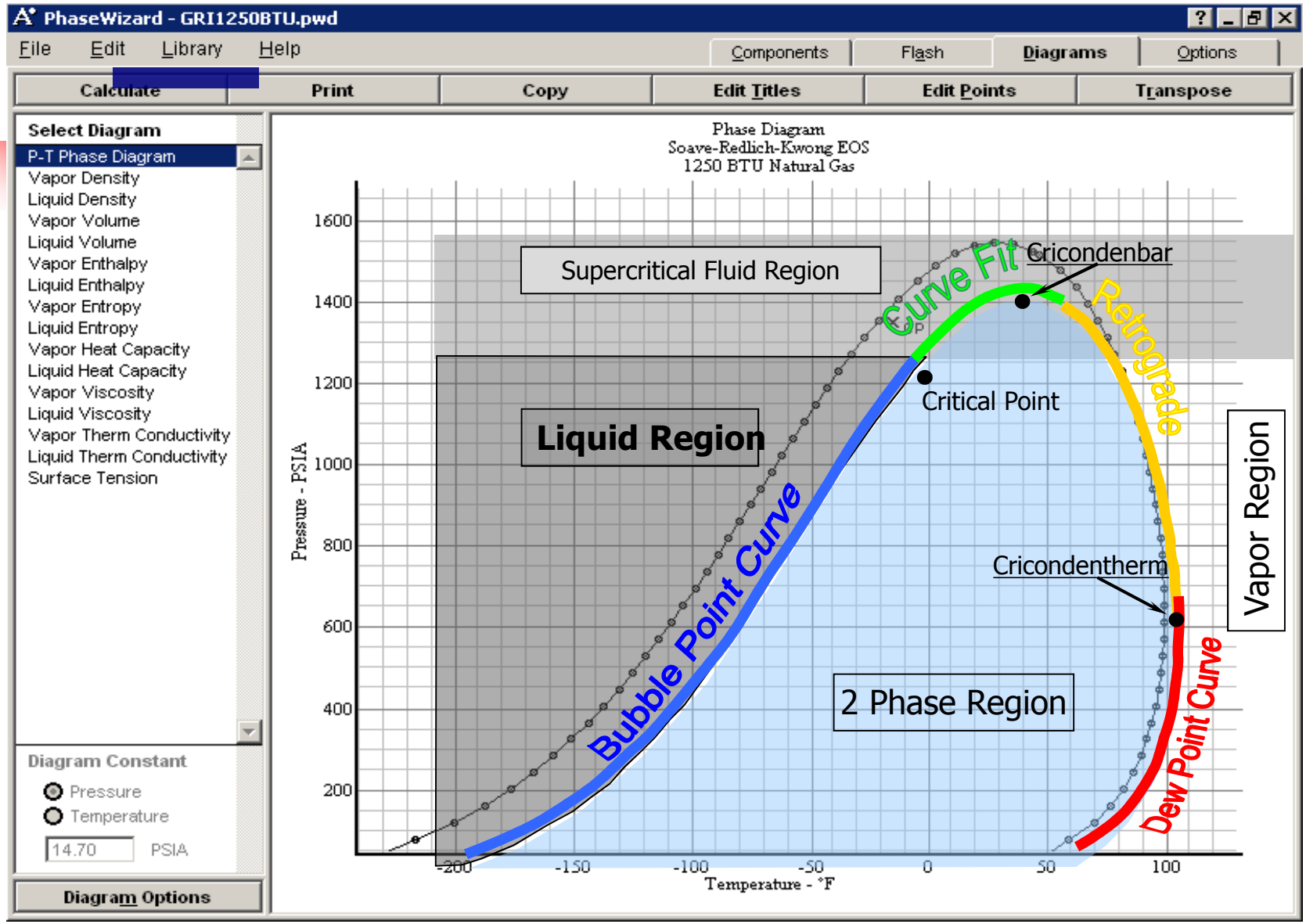
- Importance of the Physical Properties
- The specific physical properties of the unique 'hydrocarbon liquid' will determine:
  - The type of equipment installed to determine 'custody transfer' quality numbers,
  - The equations used to correct the product's behavior to varying operating conditions
  - The techniques used for calibration and maintenance.

# Fundamentals of Liquid Measurement: Physical Properties

Some of the Physical Properties that we will discuss that will affect the design, and the operation of the measurement station include:

- Composition,
- Temperature,
- Pressure,
- Density,
- Sediment and Water,
- Vapor Pressure,
- Viscosity.

# What is a liquid ?


PhaseWizard - GRI1250BTU.pwd
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Transpose
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Vapor Density
Liquid Density
Vapor Volume
Liquid Volume
Vapor Enthalpy
Liquid Enthalpy
Vapor Entropy
Liquid Entropy
Vapor Heat Capacity
Liquid Heat Capacity
Vapor Viscosity
Liquid Viscosity
Vapor Therm Conductivity
Liquid Therm Conductivity
Surface Tension
Diagram Constant
Pressure
Temperature
14.70
PSIA
Diagram Options
Phase Diagram
Soave-Redlich-Kwong EOS
1250 BTU Natural Gas
Supercritical Fluid Region
Curve Fit
Cricondenbar
Retrograde
Critical Point
Liquid Region
Bubble Point Curve
Cricondentherm
Vapor Region
2 Phase Region
Dew Point Curve
Pressure - PSIA
1600
1400
1200
1000
800
600
400
200
-200
-150
-100
-50
0
50
100
Temperature - °F

# Fundamentals of Liquid Measurement: Composition

- Cricondentherm:
  - The Cricondentherm is defined as the maximum temperature above which liquid cannot be formed regardless of pressure.

# Fundamentals of Liquid Measurement: Composition

- Cricondenbar
  - The Cricondenbar is the maximum pressure above which no gas can be formed regardless of temperature.

# Fundamentals of Liquid Measurement: Composition

## Composition

- Not all 'Liquid Hydrocarbons' are the same.
- Composition will determine 'what we call the product '.
- Composition will determine how the product 'behaves' at operating conditions.

# Fundamentals of Liquid Measurement: Composition

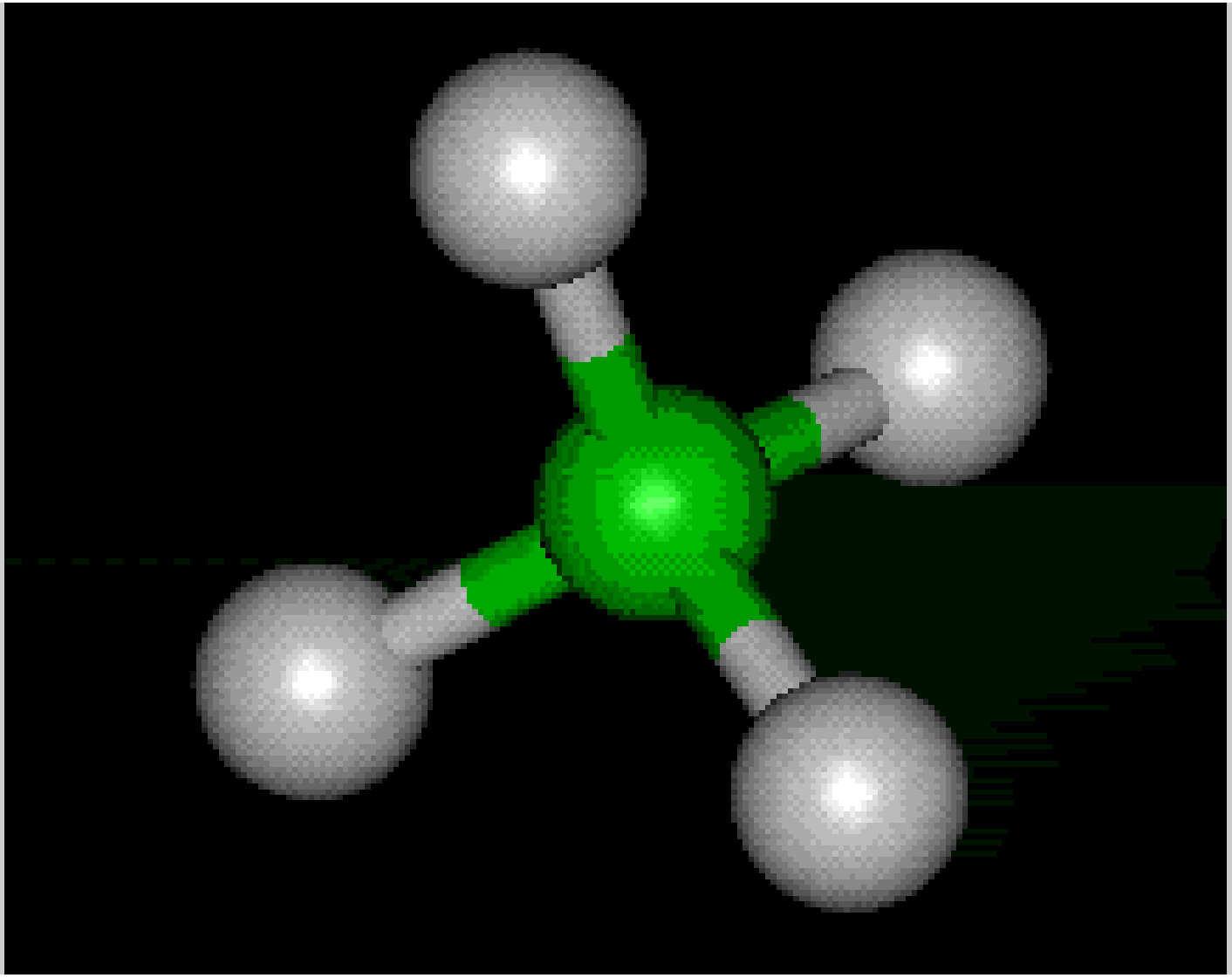
## Composition

- What really is the Liquid?
  - NGL - Condensate
  - Y-Grade
  - Natural Gasoline (c6 –c8)
  - LNG
  - Crude Oil
    - Heavy ?
    - Light ?
  - Pure Product
    - Propane?
    - Butane ?

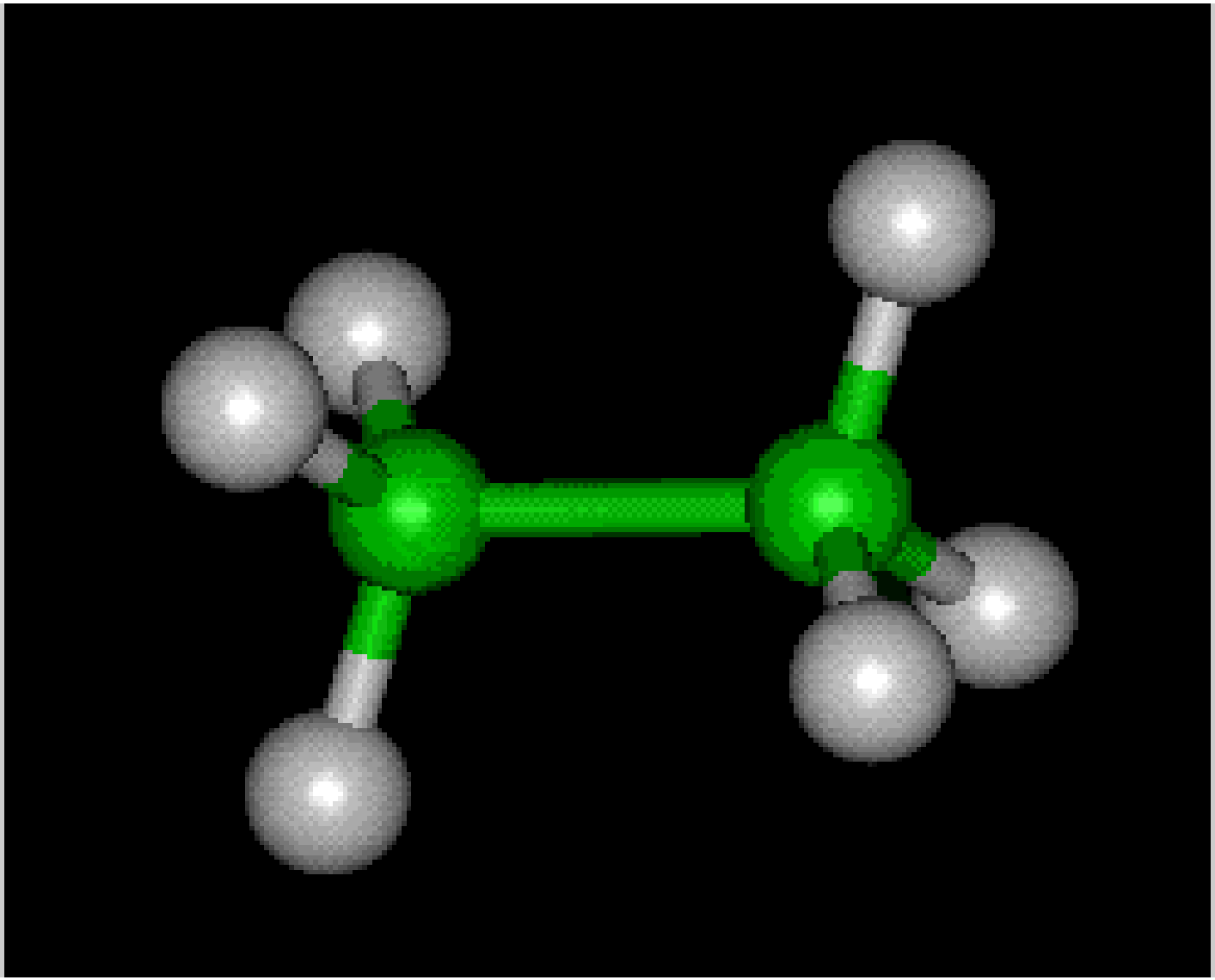
# Fundamentals of Liquid Measurement: Part 1 Composition

- **All Hydrocarbon liquids are made up of Carbon and Hydrogen.**
  - Molecules can be separated into their individual components without a chemical reaction.
  - The analysis of individual components can be determined from Liquid Chromatography.

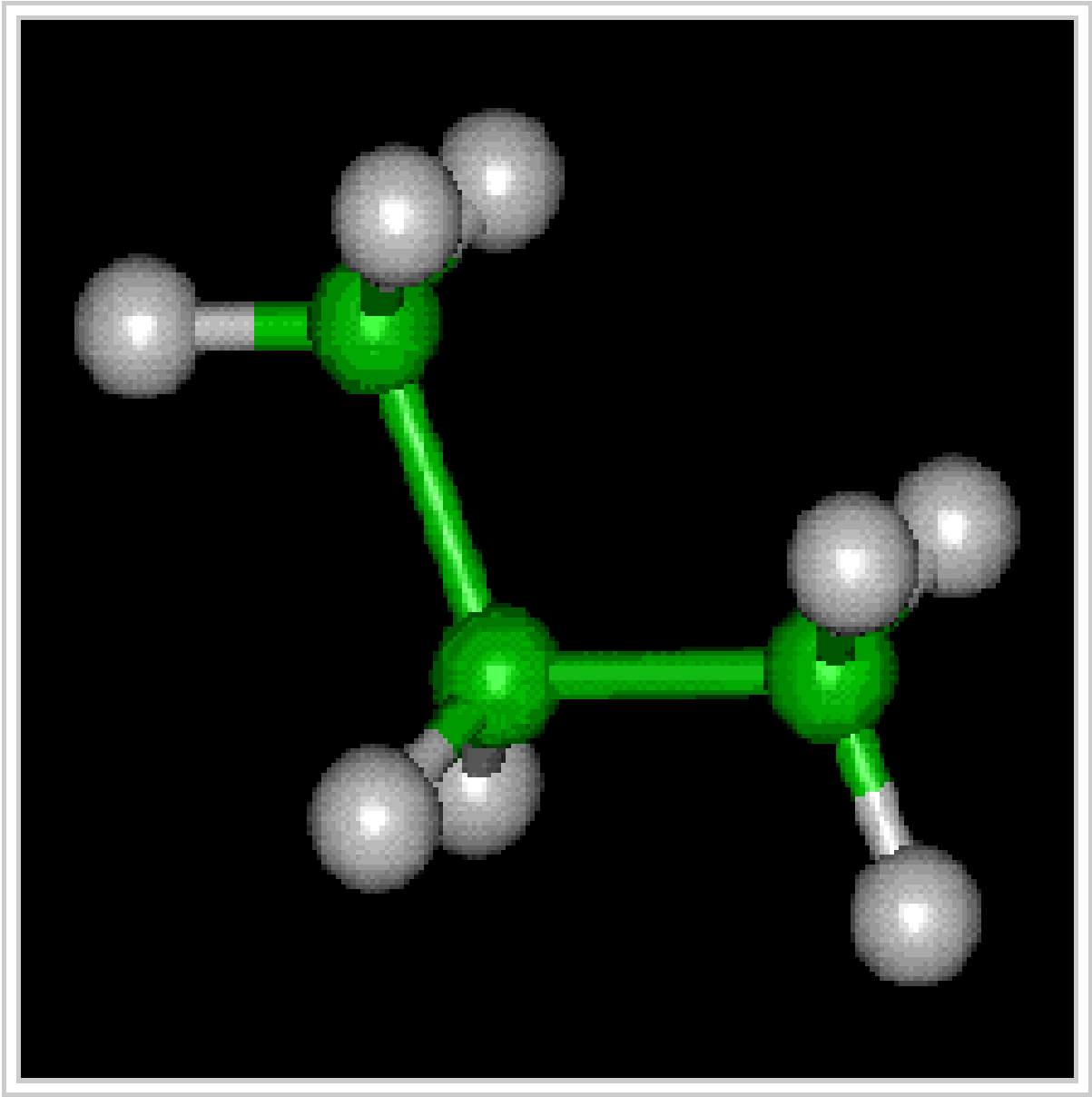
| Name | Carbon | Hydrogen | Formula |
|---|---|---|---|
| Methane | 1 | 4 | CH4 |
| Ethane | 2 | 6 | C2H6 |
| Propane | 3 | 8 | C3H8 |
| Butane | 4 | 10 | C4H10 |
| Pentane | 5 | 12 | C5H12 |
| Hexane | 6 | 14 | C6H16 |
| Heptane | 7 | 16 | C7H16 |
| Octane | 8 | 18 | C8H18 |
| Nonane | 9 | 20 | C9H20 |
| Decane | 10 | 22 | C10H22 |



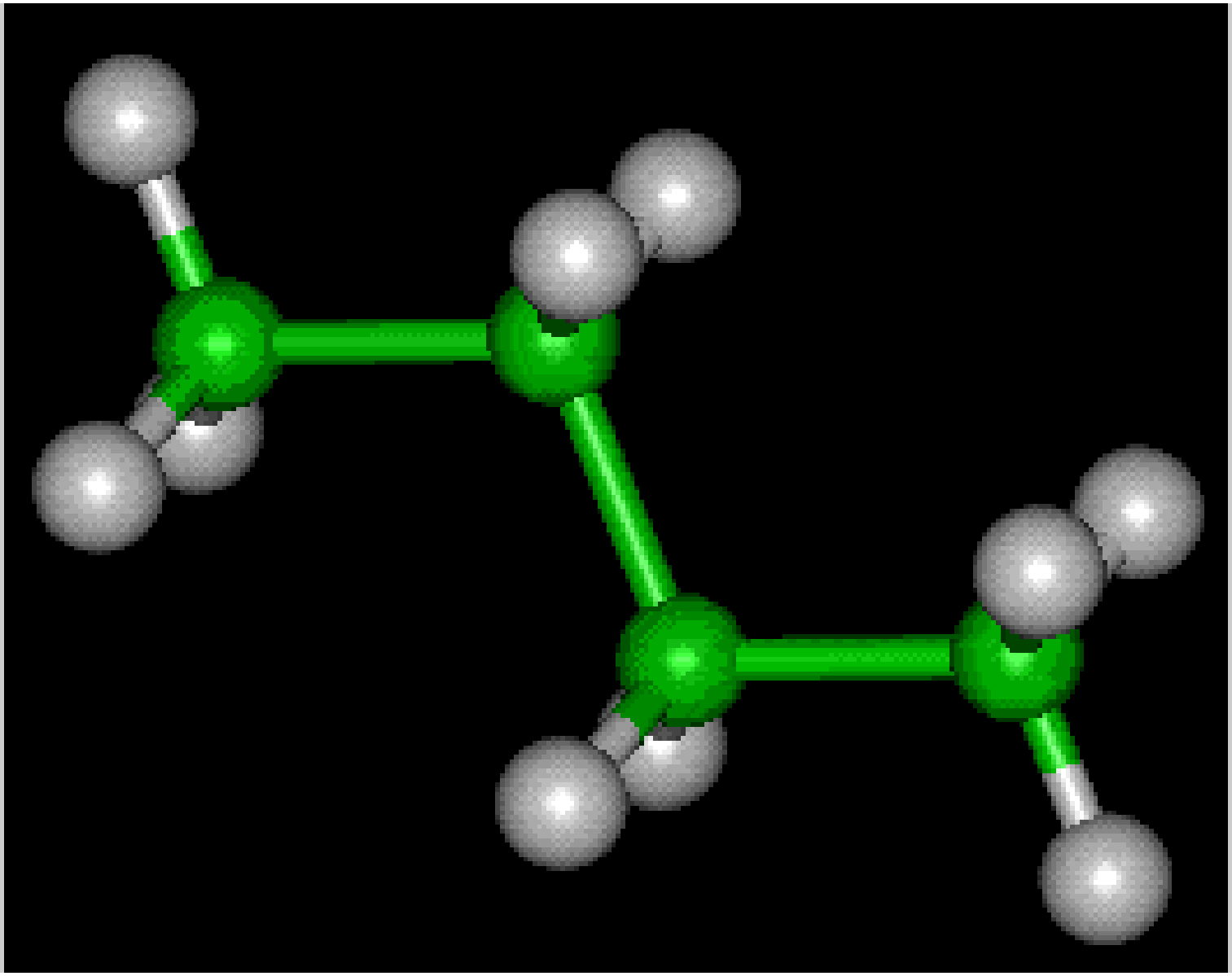
METHANE MOLCULE: CH4



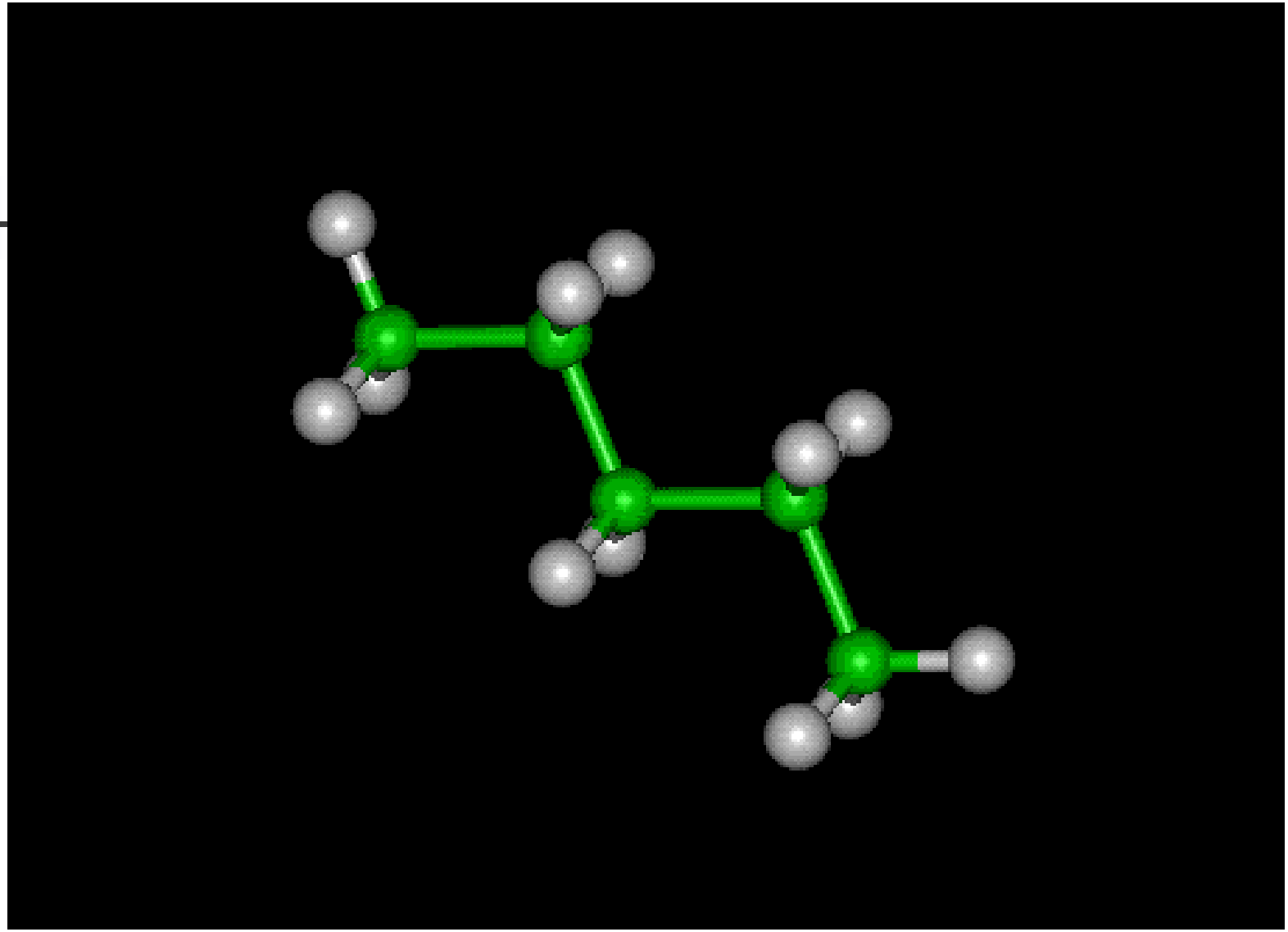
ETHANE MOLUCULE: C2H6



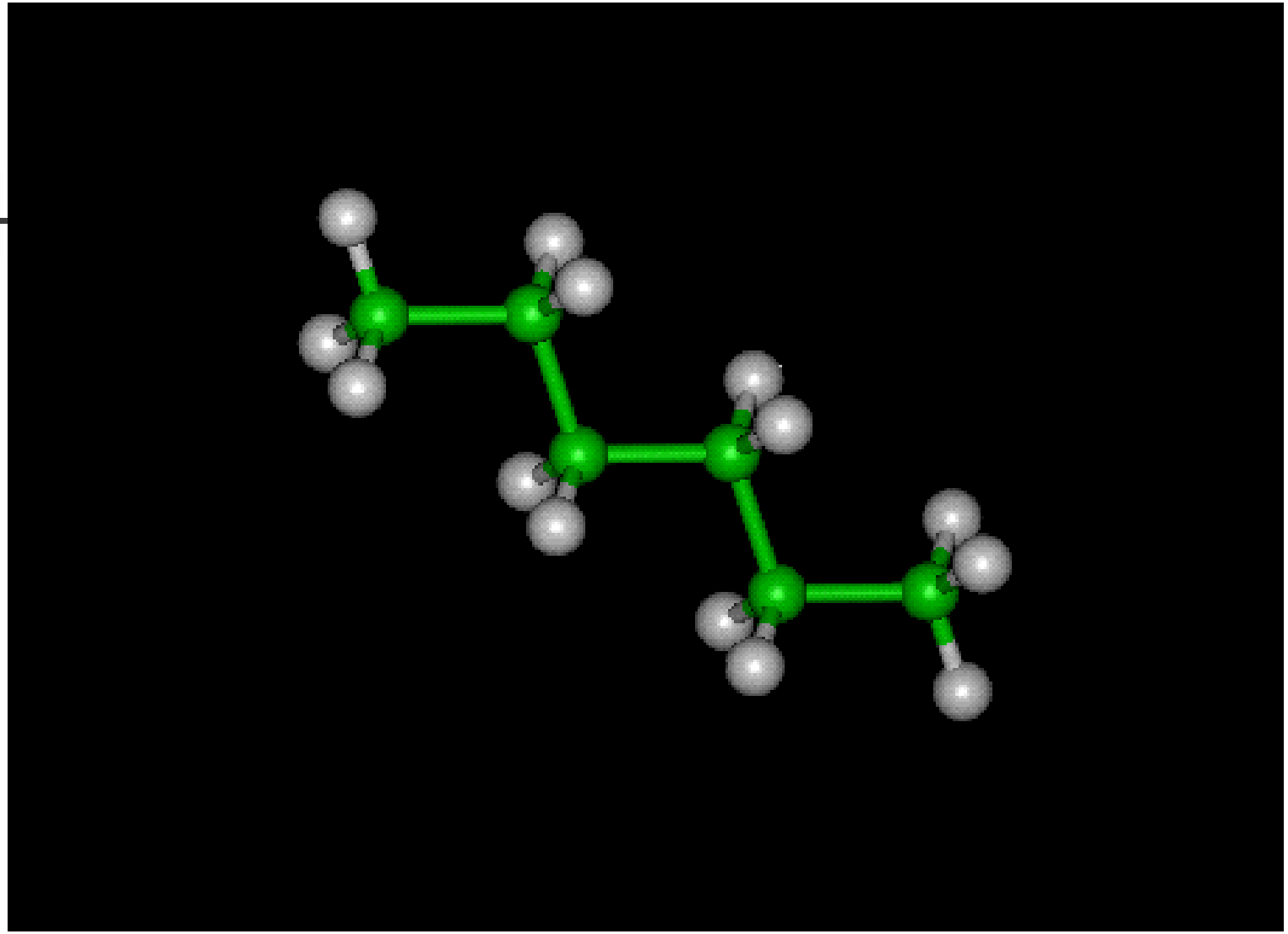
PROPANE MOLCULE: C3H8



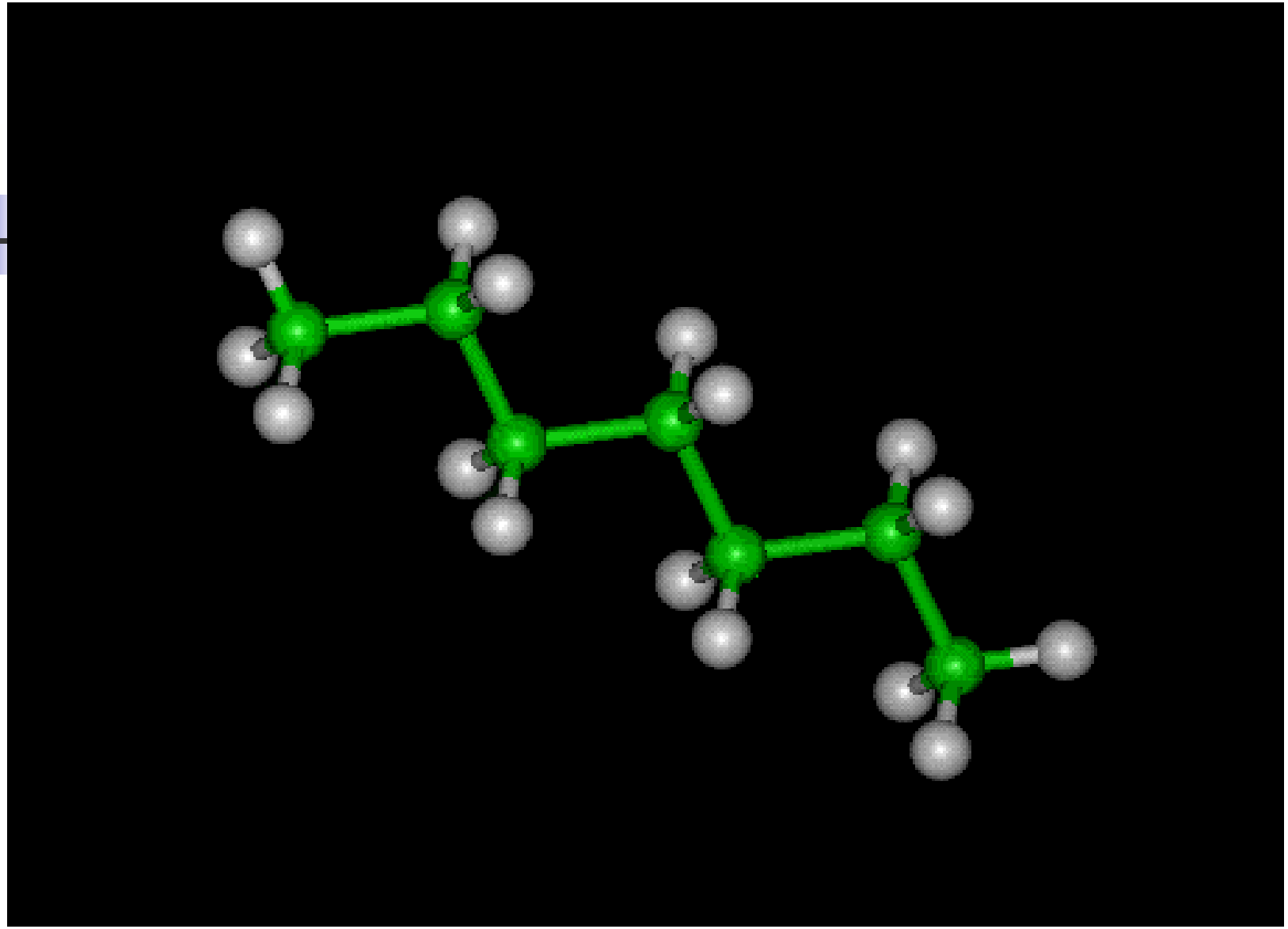
BUTANE MOLCULE:C4H10



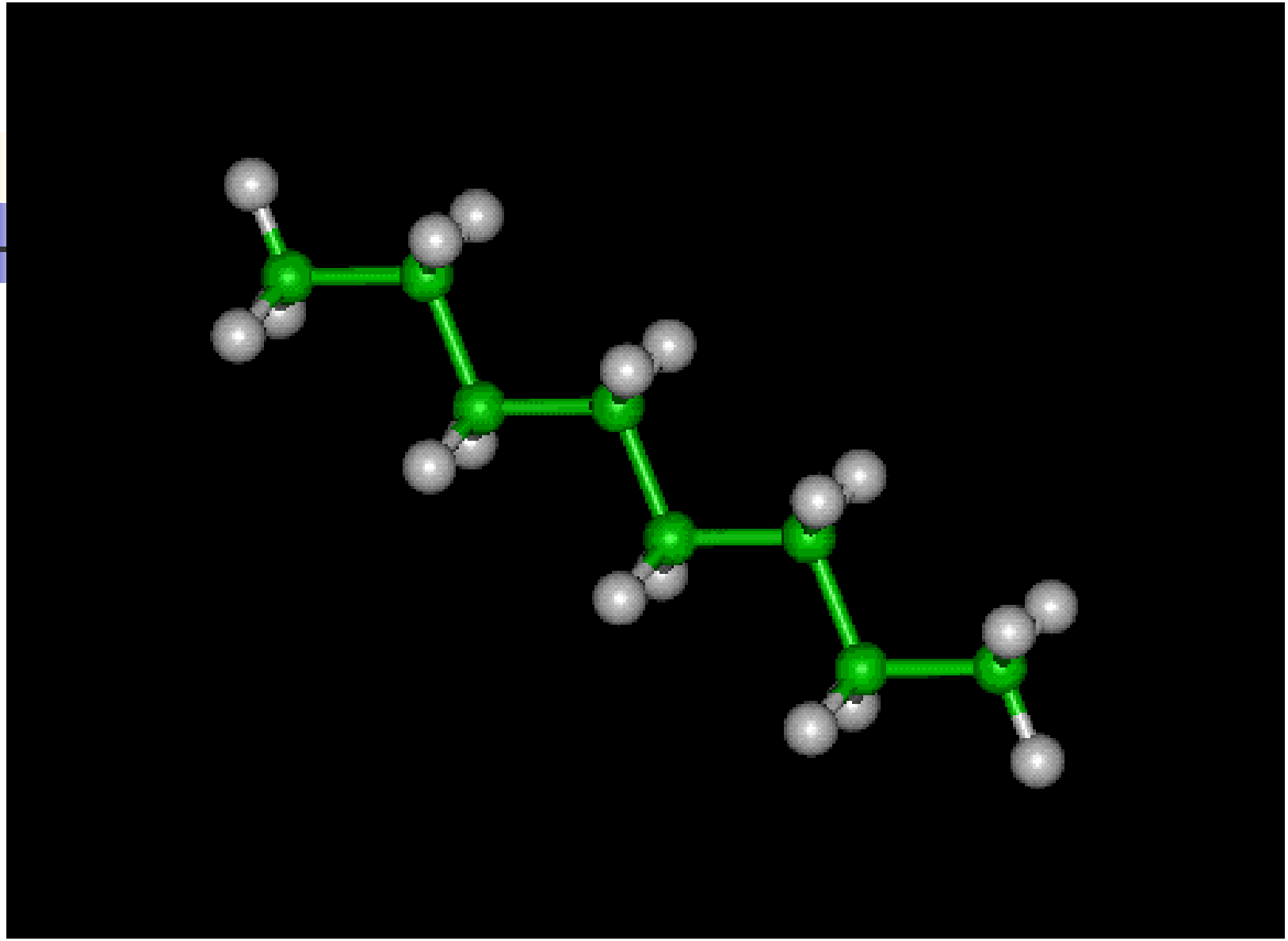
PENTANE MOLCULE:C5H12



HEXANE MOLCULE:C6H16



HEPTANE MOLCULE :  C7H13



OCTANE MOLCULE:C8H18

# Fundamentals of Liquid Measurement Part 1: Solution Mixing

- Solution Mixing
  - Natural gas liquid mixtures especially those containing lighter ends will experience lower total volumes than the combined volume of the individual components.

# Fundamentals of Liquid Measurement Part 1: Solution Mixing

- A Practical Example….

# Fundamentals of Liquid Measurement: Composition

- Composition Terms
  - Mole Percent
    - Relates the number of Molecules for a particular component to the total number of molecules in the liquid.
- M.P. = $\frac{\text{Number for Molecules of component}}{\text{Total number of Molecules}} * 100$

# Fundamentals of Liquid Measurement: Weight Percent

- Weight Percent:
  - Mass of each component divided by the total mass of the composition

- $$W.P. = \frac{\text{Mass of Component}}{\text{Mass of Composition}} * 100$$

# Fundamentals of Liquid Measurement: Volume Percent

- Volume Percent
  - Volume of the individual component divided by the total volume of the composition.

- $$V.P. = \frac{\text{Volume of Component}}{\text{Total Volume of Mixture}} * 100$$

# Typical Natural Gas Liquid Composition

| | Mole % | Mole Weight | Mass- LBM | Weight Fraction | Weight Percent |
|---|---|---|---|---|---|
| Methane | **0.0** | 16.043 | 0.0 | 0.0 | 0.0 |
| Ethane | **0.2** | 30.07 | 0.0601 | 0.00078 | 0.07799 |
| Propane | **2.0** | 44.097 | 0.8819 | 0.0114 | 1.1437 |
| Iso-Butane | **7.5** | 58.123 | 4.3592 | 0.05653 | 5.6532 |
| Normal-Butane | **7.5** | 58.123 | 4.3592 | 0.05653 | 5.6532 |
| Iso-Pentane | **25.5** | 72.15 | 18.398 | 0.2386 | 23.8597 |
| Normal-Pentane | **25.5** | 72.15 | 18.398 | 0.2386 | 23.8579 |
| n-Hexane | **16.47** | 86.177 | 14.1933 | 0.18406 | 18.4066 |
| Heptanes | **7.5** | 100.204 | 7.5153 | 0.09746 | 9.746 |
| Octanes + | **7.83** | 114.231 | 8.9442 | 0.1159 | 11.5994 |
| **Totals** | **100** | | **77.1099** | **1.00** | **100.0** |

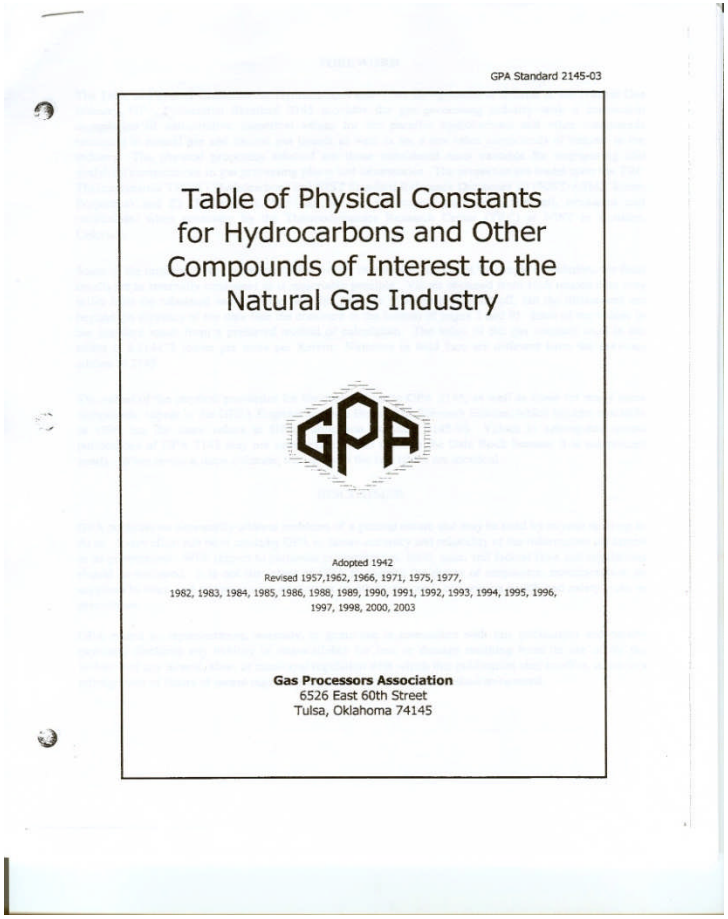
# Typical Crude Oil Composition

| Component | Mole% | Weight % | Liquid Volume % |
|---|---|---|---|
| Methane | 0.2390 | 0.0335 | 0.0835 |
| Ethane | 0.2938 | 0.0773 | 0.1625 |
| Propane | 1.0957 | 0.4227 | 0.6230 |
| Isobutane | 1.0421 | 0.5298 | 0.7034 |
| n-Butane | 1.6354 | 0.8315 | 1.0639 |
| Neopentane | 0.1743 | 0.1100 | 0.1378 |
| Isopentane | 2.1034 | 1.3275 | 1.5887 |
| n-Pentane | 1.9377 | 1.2229 | 1.4481 |
| 2,2-Dimethylbutane | 0.1945 | 0.1466 | 0.1675 |
| 2,3-Dimethylbutane | 0.5789 | 0.4364 | 0.4894 |
| 2-Methylpentane | 1.7079 | 1.2875 | 1.4624 |
| 3-Methylpentane | 1.0428 | 0.7861 | 0.8779 |
| n-Hexane | 2.5077 | 1.8904 | 2.1272 |
| Heptanes | 23.0747 | 19.4277 | 19.3564 |
| Octanes | 16.3885 | 15.0922 | 14.7522 |
| Nonanes | 21.7218 | 21.8364 | 20.4648 |
| Decanes plus | 24.2353 | 34.5348 | 34.4851 |
| Nitrogen | 0.0274 | 0.0067 | 0.0062 |
| Carbon Dioxide | 0.0000 | 0.0000 | 0.0000 |
| Total | 100.0000 | 100.0000 | 100.0000 |

# Fundamentals of Liquid Measurement: Fundamental Calculations

- GPA Standard 8182-03, API MPMS 14.7 dictate the methods that determine proper Mass Methods of Liquid Hydrocarbons.
  - Generally Mass Measurement techniques are used for liquids in the .350 < SG <.689 range.
  - Per the Standard:
    - Volumes derived from mass measured quantities are always higher than the quantities measured on a volumetric basis for these streams.

# Properties Standard: GPA 2145



GPA Standard 2145-03

Table of Physical Constants for Hydrocarbons and Other Compounds of Interest to the Natural Gas Industry

Adopted 1942
Revised 1957,1962, 1966, 1971, 1975, 1977,
1982, 1983, 1984, 1985, 1986, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996,
1997, 1998, 2000, 2003

**Gas Processors Association**
6526 East 60th Street
Tulsa, Oklahoma 74145

# Calculation example

| Component | COMPONENT | | | | | | std | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | IN MOL % | | mw | lb-mass | weight | weight | density | 1/f | gal | volume | vol |
| | | | | | fraction | % | lb/gal | | | fraction | % |
| n2 | 0 | | | | | | | | | | |
| co2 | 0 | | | | | | | | | | |
| c1 | 0 | 0 | 16.043 | 0 | 0 | 0 | 1.6 | 0.625 | 0 | 0 | 0 |
| c2 | 0.2 | 0.002 | 30.07 | 0.06014 | 0.00072045 | 0.07204516 | 2.9714 | 0.3365417 | 0.02023962 | 0.0013211 | 0.13211008 |
| c3 | 2.2 | 0.022 | 44.097 | 0.970134 | 0.01162179 | 1.16217919 | 4.2301 | 0.23640103 | 0.22934068 | 0.01496976 | 1.4969757 |
| ic4 | 5.5 | 0.055 | 58.123 | 3.196765 | 0.03829588 | 3.82958822 | 4.6934 | 0.21306516 | 0.68111923 | 0.0444587 | 4.44587043 |
| nc4 | 5.45 | 0.0545 | 58.123 | 3.1677035 | 0.03794774 | 3.79477379 | 4.8696 | 0.20535568 | 0.65050589 | 0.04246048 | 4.24604795 |
| ic5 | 22.62 | 0.2262 | 72.15 | 16.32033 | 0.1955106 | 19.5510598 | 5.2074 | 0.19203441 | 3.13406498 | 0.20456986 | 20.4569864 |
| nc5 | 25.5 | 0.255 | 72.15 | 18.39825 | 0.22040319 | 22.0403194 | 5.2618 | 0.19004903 | 3.49656961 | 0.22823163 | 22.8231633 |
| c6 | 10.2 | 0.102 | 86.177 | 8.790054 | 0.1053011 | 10.5301101 | 5.5363 | 0.18062605 | 1.58771273 | 0.10363479 | 10.3634793 |
| c7 | 8.5 | 0.085 | 100.204 | 8.51734 | 0.1020341 | 10.2034103 | 5.7375 | 0.17429194 | 1.4845037 | 0.09689803 | 9.68980292 |
| c8 | 9.83 | 0.0983 | 114.231 | 11.2289073 | 0.13451752 | 13.4517524 | 5.8942 | 0.16965831 | 1.90507742 | 0.12435014 | 12.4350142 |
| c9 | 10 | 0.1 | 128.258 | 12.8258 | 0.15364762 | 15.3647618 | 6.0183 | 0.16615988 | 2.13113338 | 0.1391055 | 13.9105496 |
| | | | | | | | | | | | |
| Totals | 100 | | | 83.4754238 | | | | | 15.3202672 | 1 | 100 |

# Fundamentals of Liquid Measurement Part 1: Practical Application of Temperature

- I would like to buy oil from you at a colder temperature,
- And I would like to sell oil to you at a warmer temperature.

# Fundamentals of Liquid Measurement Part 1: Practical Application

WHY ?

- Liquids contract with decreasing temperature.
  - I would actually get more oil – on a volumetric basis.
- Liquids expand with increasing temperature.
  - I would actually sell less oil – on a volumetric basis

# Fundamentals of Liquid Measurement Part 1: Temperature Compensation

- Operating temperatures are never the same and vary from minute to minute.
- Fluids will expand with increasing temperature, and contract with decreasing temperature.
- Correction equations have been developed, as a function of density to correct the fluid to a standard of 60 F.
- CTL and CPL factors are actually factors that attempt to correct for the density change of the product.
- The Temperature Correction Factor must be used: CTL.

# Fundamentals of Liquid Measurement: Part 1 Temperature

- For liquids that maintain constant expansion relationships with temperature, various equations have been developed, primarily based on gravity to correct to a standard temperature in the US of 60 F.

# Temperature Effects: CTL Factors

| Temp Deg F | 45.0 API | 45.5 API | 46.0 API | 46.5 API | 47.0 API |
|---|---|---|---|---|---|
| 75.0 | 0.9920 | 0.9920 | 0.9919 | 0.9919 | 0.9918 |
| 75.5 | 0.9917 | 0.9917 | 0.9916 | 0.9916 | 0.9915 |
| 76.0 | 0.9915 | 0.9914 | 0.9913 | 0.9913 | 0.9913 |

# Fundamentals of Liquid Measurement: Computer Equations

- In modern Flow Computers it is much easier to calculate the CTL factor without the Tables, but with an equation. The API algorithms uses density, temperature, and thermal expansion factor to determine CTL:

$$VCF = \rho\tau/\rho 60 = EXP[-\alpha\, 60\Delta\tau(1+0.8\alpha\, 60\Delta\tau)]$$

In which:

VCF = Volume Correction Factor

$\rho\tau$ = density at temperature $\tau$

$\rho 60$ = density at 60˚F

$\alpha\, 60$ = thermal coefficient of expansion for that type of liquid at 60˚F

$\Delta\tau = \tau - 60.0$

# Fundamentals of Liquid Measurement: Pressure

- Like temperature, operating pressures are never the same and vary from minute to minute.

- Hydrocarbon liquids are compressible, and will contract when pressure is increased, and expand when pressure is decreased.
- Liquid Volumes corrected to 14.696 or their equilibrium vapor pressure.

# Fundamentals of Liquid Measurement: Pressure

- The net effect of the expansion and contraction of the liquid is the associated density change

- CPL factors are actually factors that attempt to correct for the density change of the product due to the application of pressure different than the standard pressure.

# Pressure Effects: CPL Correction

$$CPL = 1/[1(P - Pe) * F]$$

In Which:

P = Operation pressure in PSIG

Pe = Equilibrium vapor pressure at operating pressure ( or zero for liquids with vapor pressures less than atmospheric)

F = Compressibility factor

# Pressure Effects: Compressibility Factors at 500psi

| Temp Deg F | 18.0 | 18.5 | 19.0 | 19.5 | 20.0 |
|---|---|---|---|---|---|
| 99.0 | 0.00000434 | 0.00000437 | 0.00000440 | 0.00000444 | 0.00000447 |
| 99.5 | 0.00000434 | 0.00000437 | 0.00000441 | 0.0000444 | 0.00000448 |
| 100.0 | 0.00000435 | 0.00000438 | 0.00000441 | 0.00000444 | 0.00000448 |

# CPL Factor at 500 psi

| | 18.0 | 18.5 | 19.0 | 19.5 | 20 |
|---|---|---|---|---|---|
| 99.0 | 1.00217 | 1.00219 | 1.00200 | 1.00225 | 1.00224 |
| 99.5 | 1.00217 | 1.00219 | 1.00221 | 1.00225 | 1.00245 |
| 100.0 | 1.00218 | 1.00219 | 1.00221 | 1.00225 | 1.00245 |

# CPL Example

- Crude Oil with a 20.0 API Gravity (at 60.0 F) metered at a pressure of 500 psi and a temperature of 100F, has an 'F' factor of 0.00000448 from Table 5. The corresponding CPL is:

CPL = 1 / [ 1- (500-0) * 0.00000448] = 1.0023

# Does Pressure Really Matter?

- Crude oil sensitivity to pressure

# Fundamentals of Liquid Measurement: Density

- Density is the term that will relate the volume of the fluid to the mass of the fluid.
- Specific gravity:
  - Ratio of Mass of a given volume of a substance to that of an equal volume of another substance used as a reference.
- Relative Density
  - Ratio of the density of a liquid at a given temperature to the density of pure water at a standard temperature.

# Fundamentals of Liquid Measurement: API Gravity

- The American Petroleum Institute gravity, or ***API gravity***, is a measure of how heavy or light a petroleum liquid is compared to water. If its API gravity is greater than 10, it is lighter and floats on water; if less than 10, it is heavier and sinks.

# Fundamentals of Liquid Measurement: API Gravity

- Special Scale of relative densities used for Hydrocarbon Liquids.
  - Degree API @ 60 deg F = $\frac{141.5}{\text{Relative Density}} - 131.5$

# Fundamentals of Liquid Measurement: API Gravity

| Petroleum Liquid | Relative Densities | API Gravity Range |
|---|---|---|
| Crude Oil | 1.00 – 0.78 | 10 - 50 |
| Fuel Oils, Jet Fuel | 0.875 – 0.780 | 30 - 50 |
| Gasoline | 0.780 – 0.685 | 50 - 75 |
| Natural Gas Liquids | 0.50 – 0.68 | 75 - 110 |
| Butanes - Propane | 0.695 – 0.505 | 75 - 115 |

# Fundamentals of Liquid Measurement: S&W

- Not all hydrocarbon liquids are pure fluids at the sales point.
- Typical in Crude Oil custody transfers where there is minimal processing, Sediment and Water must be accounted for.
- 'non-commercial volumes'

# Fundamentals of Liquid Measurement: S&W

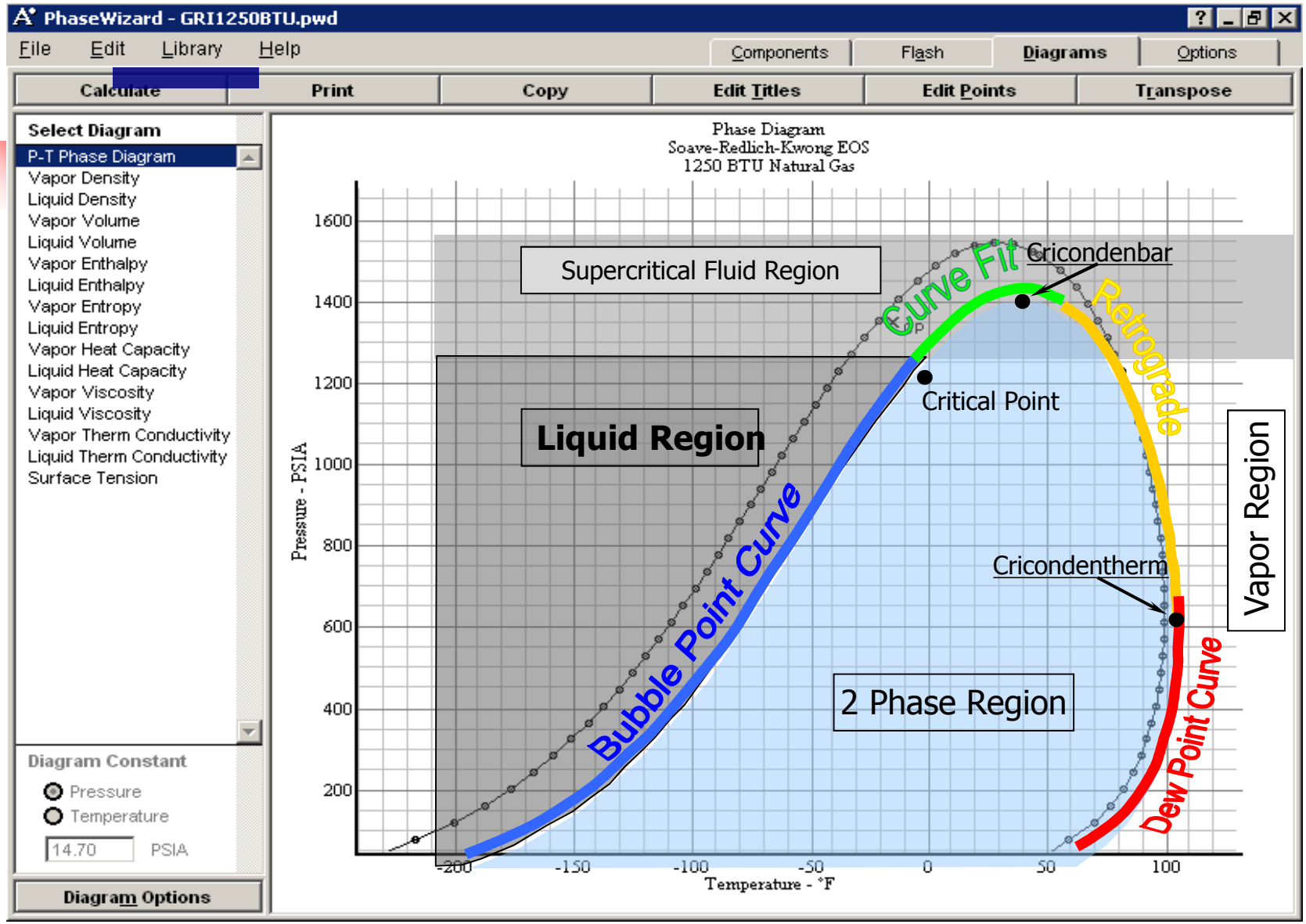
- S & W is taken account of in two fashions
  - Continuous measurement to divert fluid into a bypass tank if value is above specification.
  - Sampling of Hydrocarbon Liquid to determine the CSW – Correction of Sediment and water.

# Fundamentals of Liquid Measurement: S&W

# Fundamentals of Liquid Measurement: Vapor Pressure.

- The pressure at which liquid hydrocarbon is in equilibrium between it liquid and vapor state.
- For a liquid at a given temperature, it refers to the pressure at which bubbles just start to form.

- 'Bubble Point Liquid'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Components
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Edit Points
Transpose
Select Diagram
P-T Phase Diagram
Vapor Density
Liquid Density
Vapor Volume
Liquid Volume
Vapor Enthalpy
Liquid Enthalpy
Vapor Entropy
Liquid Entropy
Vapor Heat Capacity
Liquid Heat Capacity
Vapor Viscosity
Liquid Viscosity
Vapor Therm Conductivity
Liquid Therm Conductivity
Surface Tension
Diagram Constant
Pressure
Temperature
14.70
PSIA
Diagram Options
Phase Diagram
Soave-Redlich-Kwong EOS
1250 BTU Natural Gas
Supercritical Fluid Region
Curve Fit
Cricondenbar
Retrograde
Critical Point
Liquid Region
Bubble Point Curve
Cricondentherm
Vapor Region
2 Phase Region
Dew Point Curve
Pressure - PSIA
1600
1400
1200
1000
800
600
400
200
-200
-150
-100
-50
0
50
100
Temperature - °F

# Fundamentals of Liquid Measurement: Vapor Pressure.

- Reid Vapor Pressure
  - Testing done at 100 deg F per ASTM D323-28
  - Usually the minimum specification for transport of Hydrocarbon Liquids is 10 RVP.
    - Recently RVP Values of as low as 6 are being required.
  - Insures that losses due to evaporation, and flashing in meters is kept to a minimum.

# RVP at 100 deg F in PSIA

| | |
|---|---|
| Ethane | 800 |
| Propane | 188.696 |
| i-Butane | 72.484 |
| n-Butane | 51.683 |
| i-Pentane | 20.456 |
| n-Pentane | 15.558 |
| n-Hexane | 4.961 |
| n-Heptane | 1.62 |
| n-Octane | 0.366 |
| n-Nonane | 0.17 |
| n-Decane | 0.616 |

# Measurement of Liquids

Effect of Varying Composition: S.G.= 0.475

| C1 | C2 | C3 | C4 | NC4 | IC5 | IC5 | C6+ | CO2 | VP |
|---|---|---|---|---|---|---|---|---|---|
| 1.1 | 37.6 | 33.9 | 4.1 | 12.5 | 0.9 | 3.1 | 4.37 | .37 | 492 |
| .71 | 39.4 | 31.0 | 4.8 | 11.9 | 3.4 | 3.4 | 5.21 | .2 | 470 |
| .9 | 39.9 | 30.3 | 4.7 | 11.1 | 3.3 | 3.3 | 5.9 | .42 | 487 |
| 1.9 | 37.2 | 33.8 | 3.9 | 12.2 | 2.9 | 3.2 | 4.5 | .45 | 546 |
| .65 | 39.3 | 31.6 | 4.7 | 12.1 | 3.3 | 3.4 | 4.9 | .13 | 464 |
| .96 | 37.2 | 34.3 | 5.2 | 12.9 | 3.1 | 2.8 | 3.5 | 0 | 476 |
| 1.4 | 36.7 | 33.5 | 5.2 | 12.9 | 3.3 | 3.1 | 3.8 | 0 | 510 |
| .86 | 40.7 | 29.4 | 4.5 | 10.9 | 3.4 | 3.2 | 6.7 | .29 | 490 |
| .87 | 36.9 | 34.9 | 5.5 | 12.9 | 3.2 | 2.8 | 2.9 | 0 | 466 |
| .46 | 41.7 | 28.7 | 4.5 | 10.5 | 3.4 | 3.4 | 6.8 | .45 | 464 |

# Fundamentals of Liquid Measurement: Viscosity

- Viscosity is the characteristic of a fluid that causes it to resist flow.
- The higher value of Viscosity the greater it's resistance to flow.

# Fundamentals of Liquid Measurement: Viscosity

- Fundamental unit of absolute viscosity is the Poise.
- Kinematic Viscosity is absolute viscosity divided by density represented in units of Centistokes: cSt.
- Including density is more useful in predicting pressure loses in meters, pumps, and pipe friction loss.

# Viscosity Values of Selected Substances @ 20°C (64°F)

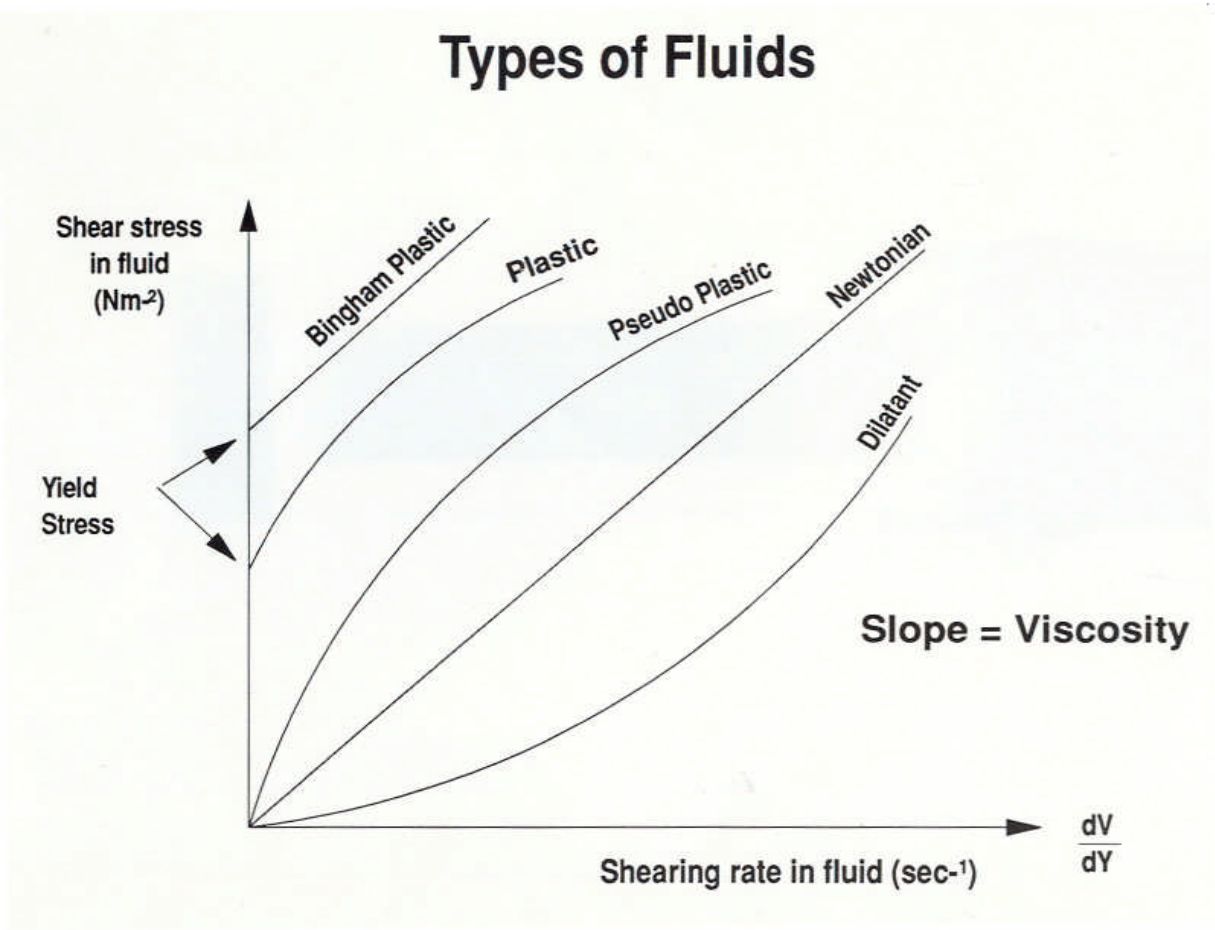
| Substance | Dynamic Viscosity cP |
|---|---|
| Gases | 0.01 to 0.02 |
| Liquid Hydrogen | 0.01 |
| Air | 0.018 |
| Acetone | 0.32 |
| Water | 1.0 |
| Mercury | 1.55 |
| Blood plasma | 1.77 |
| Full blood | 5 to 120 |
| Sugar solution | 57 |
| Engine oil | 100 to 500 |
| Castor oil | 1000 |
| Honey | 10,000 |
| Molten plastic | 10e4 to 10e8 |
| Tar | 1-e5 to 10e8 |
| Earth Crust | 10e24 |

# Temperature Dependency

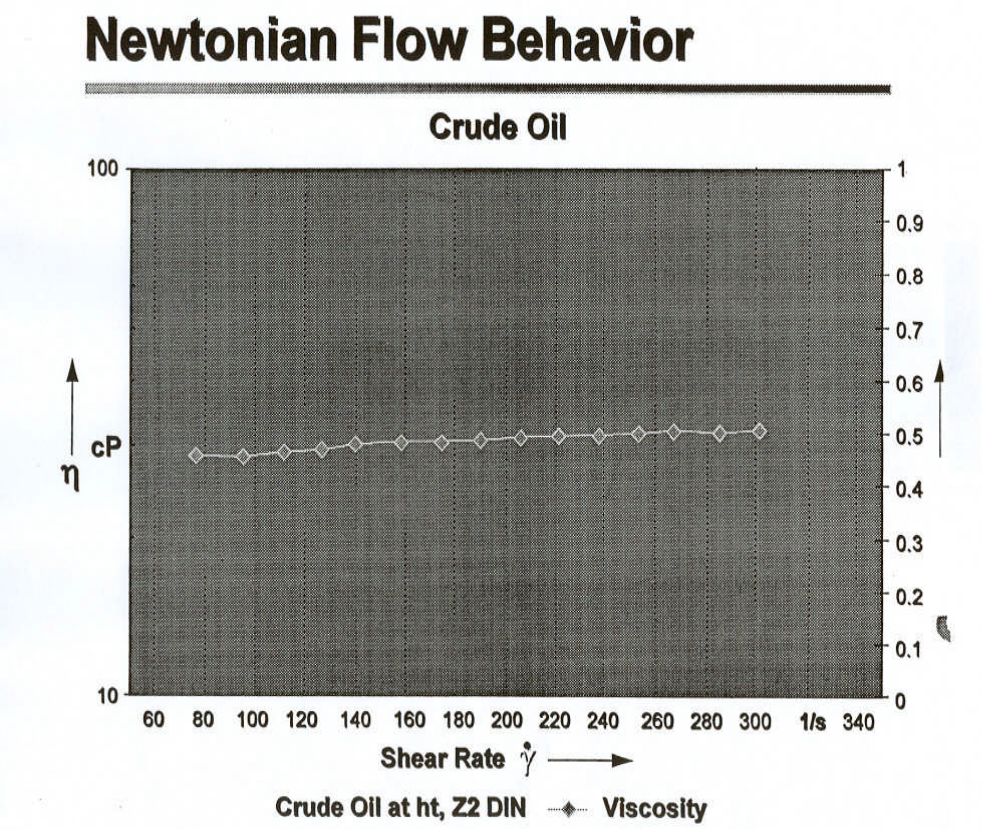
## Viscosity is Temperature Dependent

| | 60°F | 210°F |
|---|---|---|
| Fuel Oil | 13,000 cSt | 45 cSt |
| Diesel | 750 cSt | 30 cSt |
| SAE 40 | 1,000 cSt | 14 cSt |

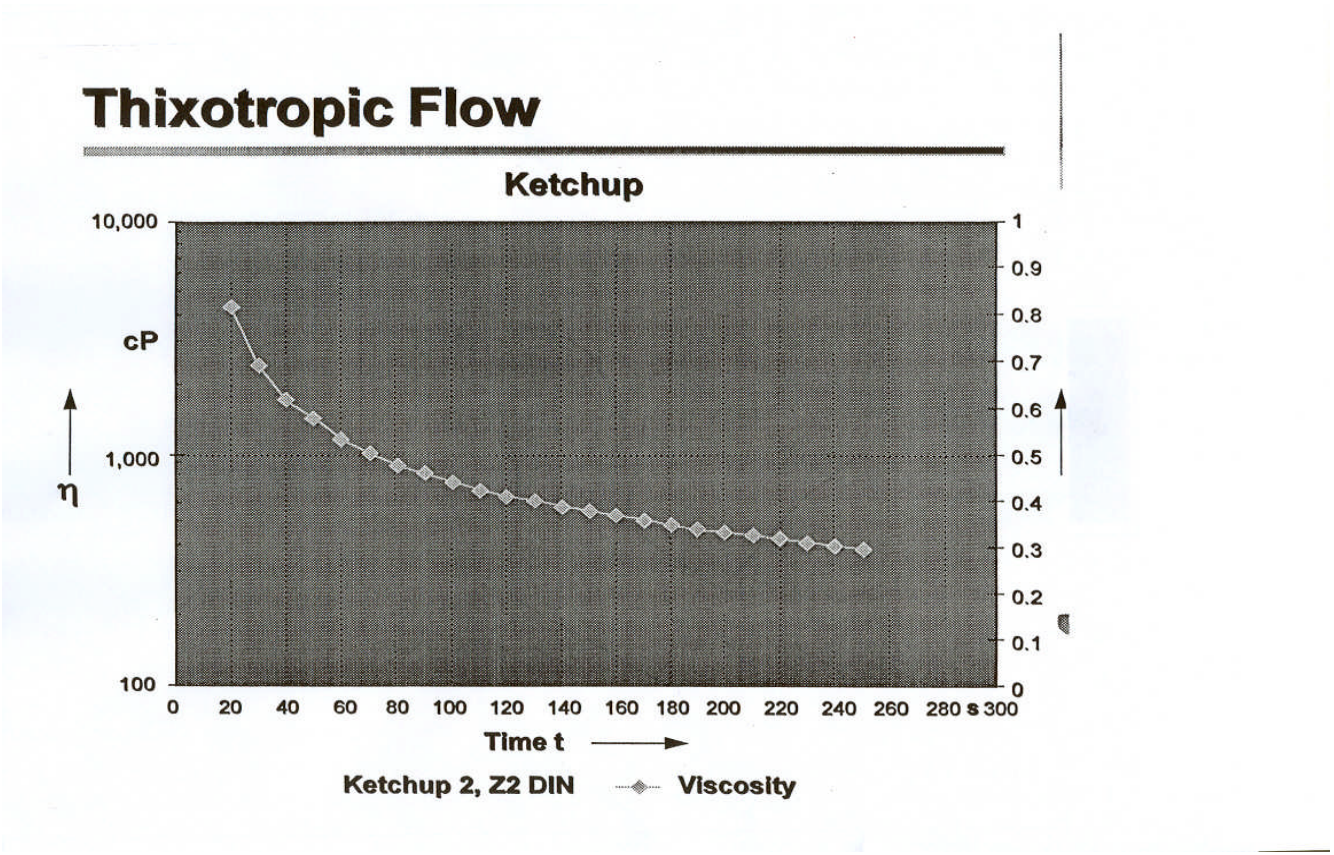
# Types of Viscous Fluids



# Viscosity of Crude Oil



# Viscosity of Ketchup



# Fundamentals of Liquid Measurement: Part 1

- Questions ?

# Fundamentals of Liquid Measurement: Degree Baume

- The U.S. National Bureau of Standards in 1916 established the Baumé scale (see: Degree Baumé) as the standard for measuring specific gravity of liquids less dense than water (see: Density of water). Investigation by the U.S. National Academy of Sciences found major errors in salinity and temperature controls that had caused serious variations in published values. Hydrometers in the U.S. had been manufactured and distributed widely with a modulus of 141.5 instead of the Baumé scale modulus of 140. The scale was so firmly established that by 1921 the remedy implemented by the American Petroleum Institute was to create the API Gravity scale, recognizing the scale that was actually being used.