Physical and Chemical Properties of Crude Oil and Oil Products

1- Density, Specific Gravity, and API Gravity
Density is defined as mass per unit volume of a fluid. Density is a state function and for a pure compound depends on both temperature and pressure and is shown by \( \rho \). Liquid densities decrease as temperature increases but the effect of pressure on liquid densities at moderate pressures is usually negligible.

Liquid density for hydrocarbons is usually reported in terms of specific gravity (SG) or relative density defined as

\[
SG = \frac{\text{density of liquid at temperature } T}{\text{density of water at temperature } T}
\]

Since the standard conditions adopted by the petroleum industry are 60°F (15.5°C) and 1 atm, specific gravities of liquid hydrocarbons are normally reported at these conditions. Water density at 60°F is 0.999 or almost 1 g/cm\(^3\), thus

\[
SG \text{ (60°F/60°F)} = \frac{\text{density of liquid at 60°F in g/cm}^3}{0.999 \text{ g/cm}^3}
\]

The American Petroleum Institute (API) defined the API gravity (degrees API) to quantify the quality of petroleum products and crude oils. The API gravity is defined as

\[
\text{API gravity} = \frac{141.5}{SG \text{ (at 60°F)}} - 131.5
\]

Crude Oils API = 10 – 50, crude oils can generally be classified according to API as shown:

<table>
<thead>
<tr>
<th>Crude Category</th>
<th>Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light crudes</td>
<td>API &gt; 38</td>
</tr>
<tr>
<td>Medium crudes</td>
<td>38 &gt; API &gt; 29</td>
</tr>
<tr>
<td>Heavy crudes</td>
<td>29 &gt; API &gt; 8.5</td>
</tr>
<tr>
<td>Very heavy crudes</td>
<td>API &lt; 8.5</td>
</tr>
</tbody>
</table>

The definition of specific gravity for gases is somewhat different. The specific gravity of a gas is proportional to the ratio of molecular weight of gas (\( M_g \)) to the molecular weight of air (28.97)

\[
SG_g = \frac{M_g}{28.97}
\]

2- Viscosity
The viscosity of oil is a measure of its resistance to internal flow and an indication of its oiliness in the lubrication of surfaces. There are two types of viscosity: dynamic and kinematics viscosity.

\[
\text{Kinematic viscosity } (\nu) = \frac{\text{dynamic viscosity } (\mu)}{\text{density } (\rho)}
\]

The unit of dynamic viscosity is poise (0.1 Pa·s). It is more commonly expressed, particularly in ASTM standards, as centipoises (cP). While the kinematics viscosity as centiStokes -cSt (10\(^{-6}\)m\(^2\)·s\(^{-1}\)). The following equations can be used to calculate the liquid viscosities of petroleum fractions at atmospheric pressure and at temperatures of 37.8 °C(100 °F) and 98.9 °C (210 °F)
where \( v_{100} \) and \( v_{210} \) are the kinematic viscosities at 100 and 210 °F, in centistokes. The viscosity can be measured by several instruments (U-tube Viscometer, Saybolt Universal Viscosity (SSU), thermo-viscosity, Red wood viscometer and Englar).

\[
\begin{align*}
\log v_{210} &= -0.463634 - 0.166532 \times \text{API} + 5.13447 \times 10^{-4} \times \text{API}^2 \\
&\quad - 8.48995 \times 10^{-3} K(\text{API}) \\
&\quad + \frac{8.0325 \times 10^{-2} K + 1.24899 \times \text{API} + 0.197680 \times \text{API}^2}{\text{API} + 26.786 - 2.6296 K} \\
\log v_{100} &= 4.39371 - 1.94733 K + 0.127690 K^2 + 3.2629 \times 10^{-4} \times \text{API}^2 \\
&\quad - 1.18246 \times 10^{-2} K(\text{API}) \\
&\quad + \frac{0.17161 K^2 + 10.9943 \times \text{API} + 9.50663 \times 10^{-2} \times \text{API}^2 - 0.860218 K(\text{API})}{\text{API} + 50.3642 - 4.78231 K}
\end{align*}
\]

Thermo. = 15 + 148.5 kinematic Vis. = 46 SSU - 1183

The comparison of viscosity by different instruments is shown in Figure 1.

Ex) Calculate the kinematic viscosities for oil which has a MeABP of 320 °C and API gravity of 34.

Sol.:

The boiling point is 593.15 K or 1067.7 R. the specific gravity is 0.855 and the Watson K factor is 11.95.

\( v_{100} = 5.777 \text{ cSt} \) and \( v_{210} = 1.906 \text{ cSt} \)
Fig. 1. Comparison of viscosity by different instruments. (Viscosity must be at the same T.)

3- Pour Point
The pour point is defined as the lowest temperature at which the sample will flow and is a rough indicator of the relative paraffiniciy and aromaticity of the crude. A lower pour point means that the paraffin content is low and greater content of aromatics.

To estimate the pour point of petroleum fractions from viscosity, molecular weight, and specific gravity, the following form is used for this purpose:

$$T_p = 130.47 \left[ SG^{2.070546} \right] \times \left[ M^{0.41235 - 0.473575 SC} \right] \times \left[ \nu^{0.11031 - 0.32834 SC} \right]$$

where $T_p$ is the pour point (ASTM D 97) in kelvin, $M$ is the molecular weight, and $\nu^{38(100)}$ is the kinematic viscosity at 37.8°C (100°F) in cSt. This equation was developed with data on pour points of more than 300 petroleum fractions with molecular weights ranging from 140 to 800 and API gravities from 13 to 50.
4- **Carbon Residue, wt%**
Carbon residue is determined by distillation to a coke residue in the absence of air. The carbon residue is roughly related to the asphalt content of the crude and to the quantity of the lubricating oil fraction that can be recovered. In most cases the lower the carbon residue, the more valuable the crude. This is expressed in terms of the weight percent carbon residue by either the Ramsbottom (RCR) or Conradson (CCR).

**Crude distilled (%) at 1100°F= 100 – 3*CCR**, CCR is the Carbon residue for whole crude oil

5- **Salt Content, lb/1000 bbl**
If the salt content of the crude, when expressed as NaCl, is greater than 10 lb/1000 bbl, it is generally necessary to desalt the crude before processing. If the salt is not removed, severe corrosion problems may be encountered. If residua are processed catalytically, desalting is desirable at even lower salt contents of he crude. Although it is not possible to have an accurate conversion unit between lb/1000 bbl and ppm by weight because of the different densities of crude oils, 1 lb/1000 bbl is approximately 3 ppm.

6- **Sulfur Content, wt%**
Sulfur content and API gravity are two properties which have had the greatest influence on the value of crude oil, although nitrogen and metals contents are increasing in importance. The sulfur content is expressed as percent sulfur by weight and varies from less than 0.1% to greater than 5%. Crudes with greater than 0.5% sulfur generally require more extensive processing than those with lower sulfur content.

7- **Flash point**
Flash point TF, for a hydrocarbon or a fuel is the minimum temperature at which vapor pressure of the hydrocarbon is sufficient to produce the vapor needed for spontaneous ignition of the hydrocarbon with the air with the presence of an external source, i.e., spark or flame. From this definition, it is clear that hydrocarbons with higher vapor pressures (lighter compounds) have lower flash points. Generally flash point increases with an increase in boiling point. Flash point is an important parameter for safety considerations, especially during storage and transportation of volatile petroleum products (i.e., LPG, light naphtha, gasoline) in a high-temperature environment.

The flash point can be estimated using the following equation:

\[ T_F = 15.48 + 0.70704 T_{10} \]

Where \( T_{10} \) is normal boiling point for petroleum fractions at 10 vol% distillation temperature. Both temperatures (\( T_{10} \) and flash point (\( T_F \)) in Kelvin).

**Example:** A kerosene product with boiling range of 175-260°C from Mexican crude oil has the API gravity of 43.6 and \( T_{10} \) is 499.9K. Estimate its flash point and compare with the experimental value of 59°C.

**Solution:**
By using the last equation, \( T_F = 60.4^\circ C \), which is in good agreement with the experimental value of 59°C.