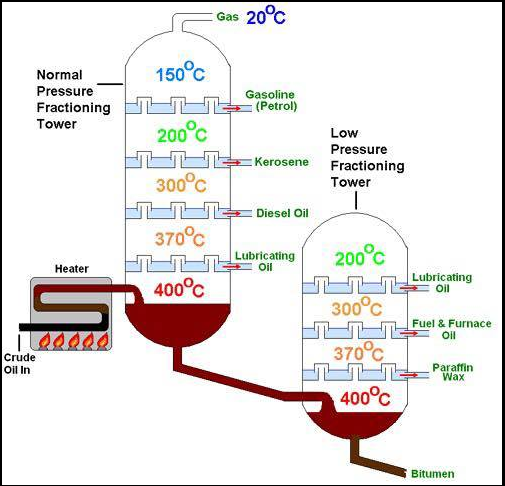
**Vacuum Distillation**

Vacuum distillation of the atmospheric residue yields additional and valuable distillates, which could otherwise be thermally destroyed if further distillation was attempted at atmospheric pressure and above.

The atmospheric bottom, also known as reduced oil, is sent to the vacuum unit where it is further separated into vacuum gas oil and vacuum residues.

Vacuum distillation improves the separation of gas oil distillates from the reduced oil at temperatures less than those at which thermal cracking would normally take place.



*The basic idea on which vacuum distillation operates is that, at low pressure, the boiling points of any material are reduced, allowing various hydrocarbon components in the reduced crude oil to vaporize or boil at a lower temperature. Vacuum distillation of the heavier product avoids thermal cracking and hence product loss and equipment fouling.*

Vacuum distillation can also be referred as "low temperature distillation".

In distilling the crude oil, it is important **not to subject** the crude oil to temperatures above 370 to 380 °C because the high [molecular weight](https://en.wikipedia.org/wiki/Molecular_weight) components in the crude oil will undergo [thermal cracking](https://en.wikipedia.org/wiki/Thermal_cracking) and form [petroleum coke](https://en.wikipedia.org/wiki/Petroleum_coke) at temperatures above that. Formation of coke would result in **plugging** the tubes in the [furnace](https://en.wikipedia.org/wiki/Furnace) that heats the feed stream to the crude oil distillation column. Plugging would also occur in the [piping](https://en.wikipedia.org/wiki/Piping) from the furnace to the distillation column as well as in the column itself.

The constraint imposed by limiting the column inlet crude oil to a temperature of less than 370 to 380 °C yields a residual oil from the bottom of the atmospheric distillation column consisting entirely of hydrocarbons that boil above 370 to 380 °C.

To further distill the residual oil from the atmospheric distillation column, the distillation must be performed at [absolute pressures](https://en.wikipedia.org/wiki/Absolute_pressure) as low as 10 to 40 [mmHg](https://en.wikipedia.org/wiki/MmHg) (also referred to as [Torr](https://en.wikipedia.org/wiki/Torr)) so as to limit the [operating temperature](https://en.wikipedia.org/wiki/Operating_temperature) to less than 370 to 380 °C.

The absolute pressure of 10 to 40 mmHg in the vacuum column is most often achieved by using multiple stages of steam jet [**ejectors**](https://en.wikipedia.org/wiki/Ejector)**.**

A typical vacuum distillation unit is shown in Figure below.

Hot RCO either from the steam-heated storage tank or from the bottom of the atmospheric distillation column is pumped through a series of preheaters (heat exchanger train) followed by heating in a pipe-still heater to raise the temperature to 360°C–370°C. This hot stream is then flashed in a multiplated distillation column where vacuum (below atmospheric pressure) is maintained by steam ejectors by medium pressure superheated steam as the motive fluid that entrains the top hydrocarbon vapors, which are condensed by water coolers.

Usually, three numbers of ejectors are used; the first stage sends the uncondensed vapor to the second stage followed by condensation. The uncondensed vapor then enters the third stage followed by condensation and the uncondensed vapor from the third stage is vented out through

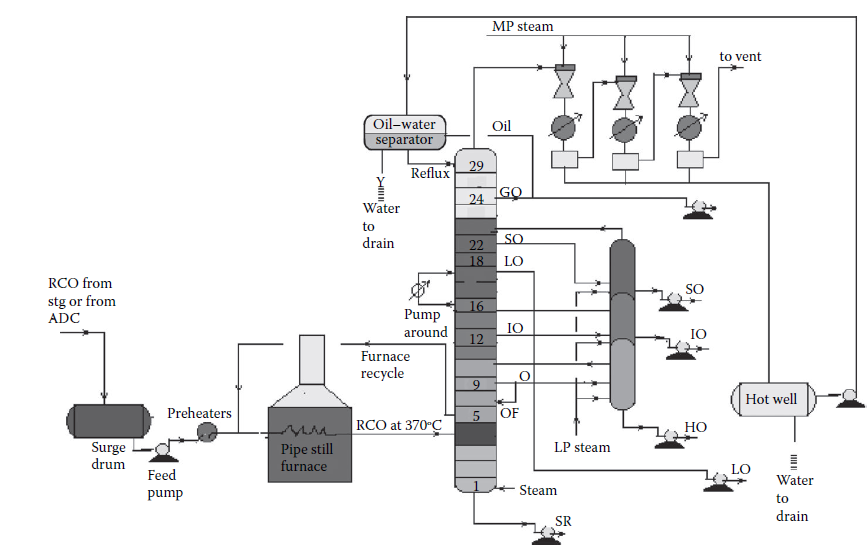
a flare or stack.

A vacuum of 30–40 mm of mercury is maintained at the top of the column and 100–120 mm at the bottom. Condensates from these ejectors are collected in a drum, known as a hot well.

The oily layer is then sent to an oil–water separator vessel from which oil is drawn as vacuum gas oil (**VGO**), part of which is sent to the column as the reflux and the rest to storage. Condensates from the hot well and the separator drum are drained to the sewer or water collection system. A few plates below the top plate of the column, an additional **VGO** is drawn and sent to the diesel/gas oil pool.

**SO** is the next vacuum distillate, which is drawn a few plates below the gas oil draw plate. Similarly, the other vacuum distillates drawn from the plates below are light oil (**LO**), intermediate oil (**IO**), and heavy oil (**HO**) in this sequence.

**LO** is sent to the vis-breaking unit for the production of low viscous fuel oils, whereas **SO**, **IO**, and **HO** distillates are further stripped in a side stripper by steam *to remove the lighter components to adjust the flash points*.



The bottom residue from the tower is called the short residue (**SR**), which is stripped by the bottom steam followed by cooling through a steam generator and sent for storage in the de-asphalting unit.

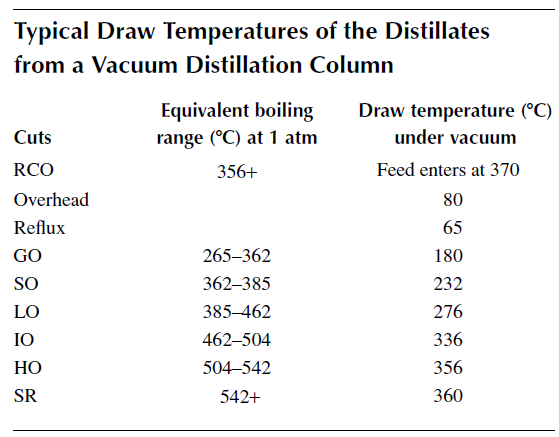
A portion of the hot vacuum distillate is drawn from the column and returned back after cooling to control the heat load of the column. This stream is called the **pump around**. Unlike circulating refluxes in the atmospheric column, pump around is only one stream in the vacuum column.

To aid washing of the HO fraction, 4%–5% of the feed RCO is over flashed. It is to be mentioned that SO, IO, and HO are the lube oil base stocks (LOBS), which are the main ingredients of lubricating oils in the market. Valuable lube oil stock, known as **bright stock**, is obtained from the SR by solvent deasphalting.

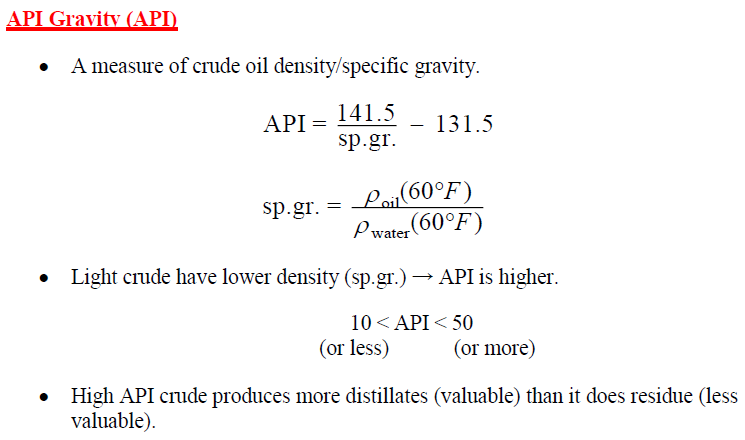
However, the quality of vacuum distillates varies from crude to crude and, as a result, many crudes may not yield LOBS, but are converted to fuel products.

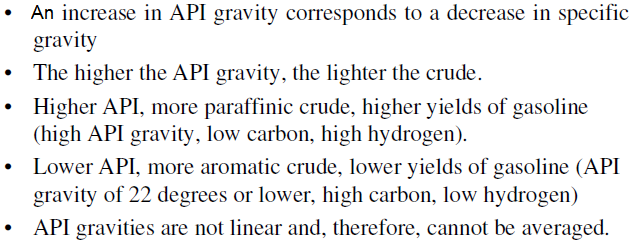
It is commonly found that most of the Middle East or Gulf crudes are suitable for the manufacture of LOBS from vacuum distillates.

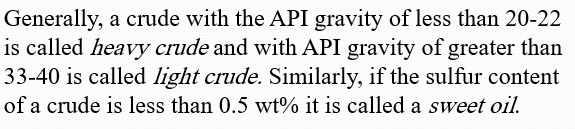
Typical boiling ranges at atmospheric pressure and the draw temperature under vacuum are listed below.



**Petroleum Tests**

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►Using the following formula, API gravity can also be used to calculate how many barrels of crude oil can be produced per metric ton.

= 1/ (sp.gr x 0.159)

**Example:** How many barrels per metric ton of West Texas Intermediate crude oil (with an API of 39.6)?

A metric ton of West Texas Intermediate, with an API of 39.6, will produce 7.6 barrels (at 42 gallons each).

**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) ASTM test procedures (D-524 and D-189).



**The smoke point (SP)** is a maximum flame height at which a fuel can be burned in a standard wick-fed lamp without smoking. It is expressed in millimeters and a high smoke point indicates a fuel with low smoke-producing tendency. Measurement of smoke point is described under ASTM D 1322.

*Smoke point* is a characteristic of aviation turbine fuels and kerosenes and indicates the tendency of a fuel to burn with a smoky flame. Higher amount of aromatics in a fuel causes a smoky characteristic for the flame and energy loss due to thermal radiation.

**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 the 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.

**Nitrogen Content, wt%**

Ahigh nitrogen content is undesirable in crude oils because organic nitrogen compounds cause severe poisoning of catalysts used in processing and cause corrosion problems such as hydrogen blistering.

Crudes containing nitrogen above 0.25% by weight require special processing to remove the nitrogen.

**Metals Content, ppm**

The metals content of crude oils can vary from a few parts per million to more than 1000 ppm and, in spite of their relatively low concentrations, are of considerable importance.

Minute quantities of some of these metals (**nickel**, **vanadium**,

and **copper**) can severely affect the activities of catalysts and result in a lower value product distribution.

**Vanadium** concentrations above 2 ppm in fuel oils can lead to severe corrosion to turbine blades and deterioration of refractory furnace linings.

Distillation concentrates the metallic constituents of crude in the residues, but some of the organometallic compounds are actually volatilized at refinery distillation temperatures and appear in the higher-boiling distillates.

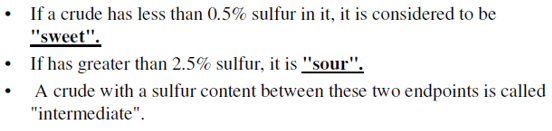
The metallic content may be reduced by solvent extraction with propane or similar solvents as the organometallic compounds are precipitated with the asphaltenes and resins.



**Sulfur Content, wt%**

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.





***►*Flash & Fire & Auto-ignition Points**

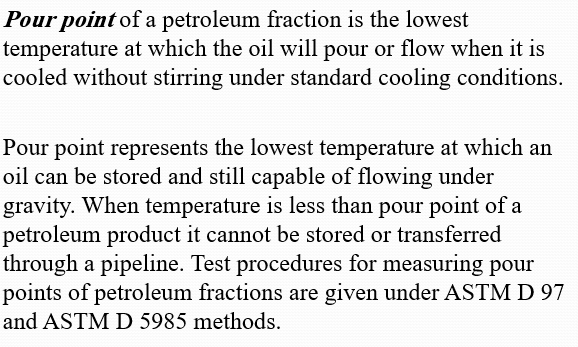
***Flash point***for a hydrocarbon or a fuel is the minimum temperature at which vapor pressure of the hydrocarbon is sufficient to produce the vapor needed for spontaneous ignition of the hydrocarbon with the air with the presence of an external source, i.e., spark or flame. The standard procedure to measure the Flash point is ASTM D 93.

Flash point is an important parameter for safety considerations, especially during storage and transportation of volatile petroleum products (i.e., LPG, light naphtha, gasoline). The surrounding temperature around a storage tank should always be less than the flash point of the fuel to avoid possibility of ignition.

Flash point should not be mistaken with ***fire point****,* which is defined as the minimum temperature at which the hydrocarbon will continue to burn for at least 5 s after being ignited by a flame.

***Autoignition temperature*** is the minimum temperature at which hydrocarbon vapor when mixed with air can spontaneously ignite without the presence of any external source. Values of autoignition temperature are generally higher than flash point. This is particularly important from a safety point of view when hydrocarbons are compressed. Standard test is ASTM D 2155.

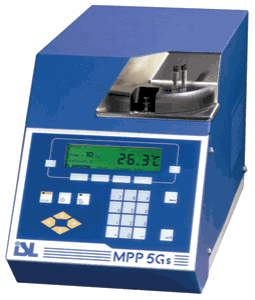
**►Pour & Cloud Points**





***Cloud point*** is the lowest temperature at which wax crystals begin to form by a gradual cooling under standard conditions. At this temperature the oil becomes cloudy and the first particles of wax crystals are observed. The standard procedure to measure the cloud point is ASTM D 2500.

Low cloud point products are desirable under low-temperature conditions. Wax crystals can plug the fuel system lines and filters, which could lead to stalling aircraft and diesel engines under cold conditions. Cloud points are measured for oils that contain paraffins in the form of wax and therefore for light fractions (naphtha or gasoline) no cloud point data are reported.



**► Octane & Cetane Numbers**

***Octane number*** is a parameter defined to characterize antiknock characteristic of a fuel (gasoline and jet fuel) for spark ignition engines. Octane number is a measure of fuel's ability to resist auto-ignition during compression and prior to ignition. Higher octane number fuels have better engine performance.

For diesel engines, the fuel must have a characteristic that favors auto-ignition. The ignition delay period can be evaluated by the fuel characterization factor called ***cetane number (CN).*** The shorter the ignition delay period the higher CN value.

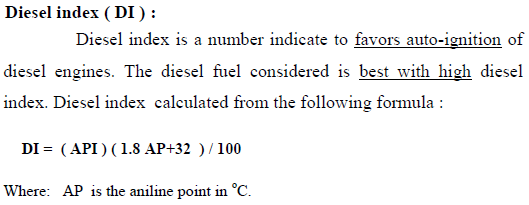
The cetane number of a diesel fuel can be measured by the ASTM D 613 test method.

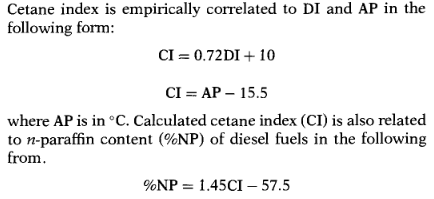
Higher CN fuels:

1. reduce combustion noise
2. permit improved control of combustion resulting in increased engine efficiency and power output.
3. tend to result in easier starting and faster warm-up in cold weather and can cause reduction in air pollution.

The product distributed in France and Europe have CN in the range of 48-55. In the United States and Canada the cetane number of diesel fuels are most often less than 50. Cetane number of diesel fuels can be improved by adding additives such as 2-ethyl-hexyl nitrate or other types of alkyl nitrates.

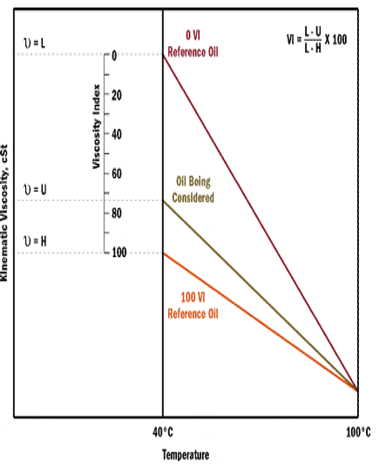


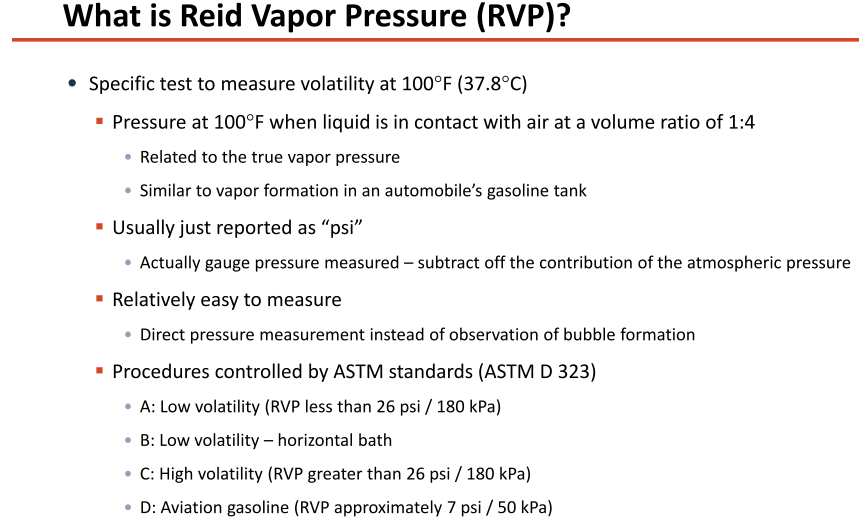
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**Viscosity index (VI):**  is an arbitrary measure for the change of viscosity with variations in temperature. The lower the VI, the greater the change of viscosity of the oil with temperature and vice versa.

It is used to characterize viscosity changes with relation to temperature in lubricating oil. It is based on comparing the kinematic viscosity of the test oil at 40oC with the kinematic viscosity of two reference oils (one of which has VI = 0, the other of VI =100) each having the same viscosity at 100oC.



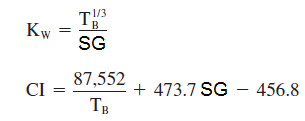


***Aniline point*** for a hydrocarbon or a petroleum fraction is defined as the minimum temperature at which equal volumes of liquid hydrocarbon and aniline are miscible.

The aniline point is important in characterization of petroleum fractions and analysis of molecular type. The aniline point is also used as a characterization parameter for the ignition quality of diesel fuels. It is measured by the ASTM D 611 test method. Aromatics have very low aniline points in comparison with paraffins, since aniline itself is an aromatic compound (C6H5-NH2) and it has better miscibility with aromatic hydrocarbons.

**Characterization Factors**

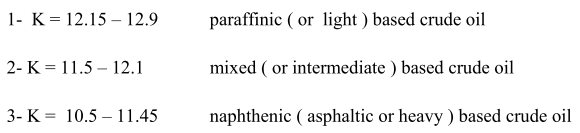
There are several correlations between yield and the aromaticity and paraffinicity of crude oils, but the two most widely used are the UOP or Watson ‘‘characterization factor’’ (KW) and the U.S. Bureau of Mines ‘‘correlation index’’ (CI).



where

TB :Average boiling point, °R , [ºF+460].

SG : Specific gravity at 60°F.



The correlation index is useful in evaluating individual fractions from crude oils.

The CI scale is based upon straight-chain paraffins having a CI value of 0 and benzene having a CI value of 100. The CI values are not quantitative, but the lower the CI value, the greater the concentrations of paraffin hydrocarbonsin the fraction; and the higher the CI value, the greater the concentrations of naphthenes and aromatics.

**Example:**

Calculate the Watson characterization factor and correlation index for n-pentane (TB = 97 ºF and sp.gr. = 0.63).

**Solution:**

