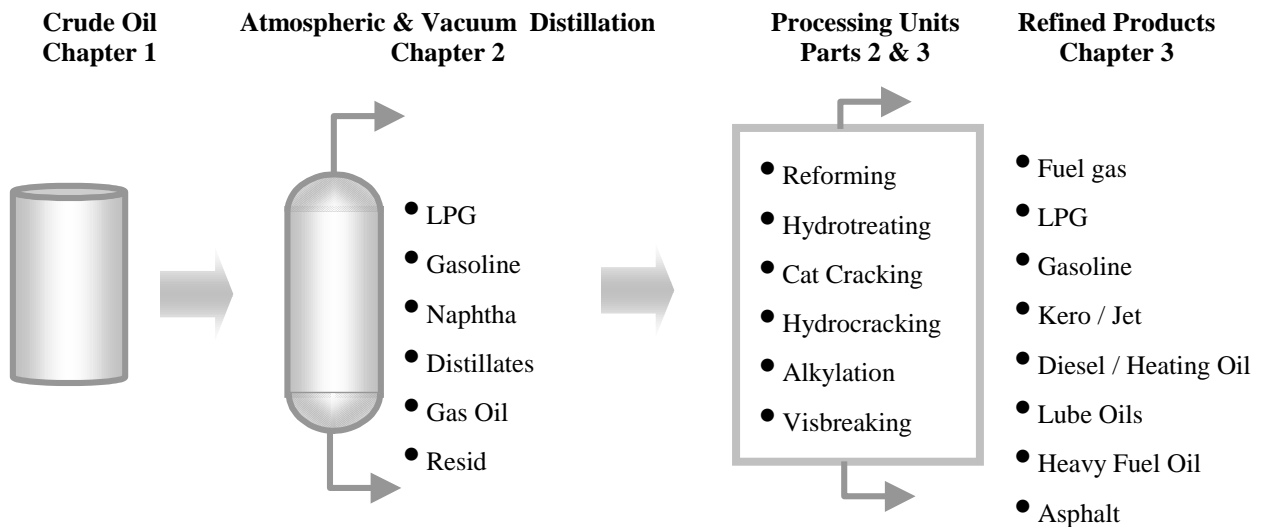# CHAPTER 2
REFINERY FEED STREAMS: STREAMS FROM THE ATMOSPHERIC AND VACUUM TOWERS

About This Chapter

The previous chapter introduced crude oil as a mixture of compounds. The characteristics of these compounds were discussed to provide insights to processing.

This chapter discusses petroleum in terms of the fractions from the atmospheric and vacuum units. The atmospheric and vacuum units are the first units in the process and the fractions from these units lead directly into further processing units. A discussion of boiling point curves is at the end of this chapter.

The third and final chapter in this part will describe refined products and an overview of specifications.
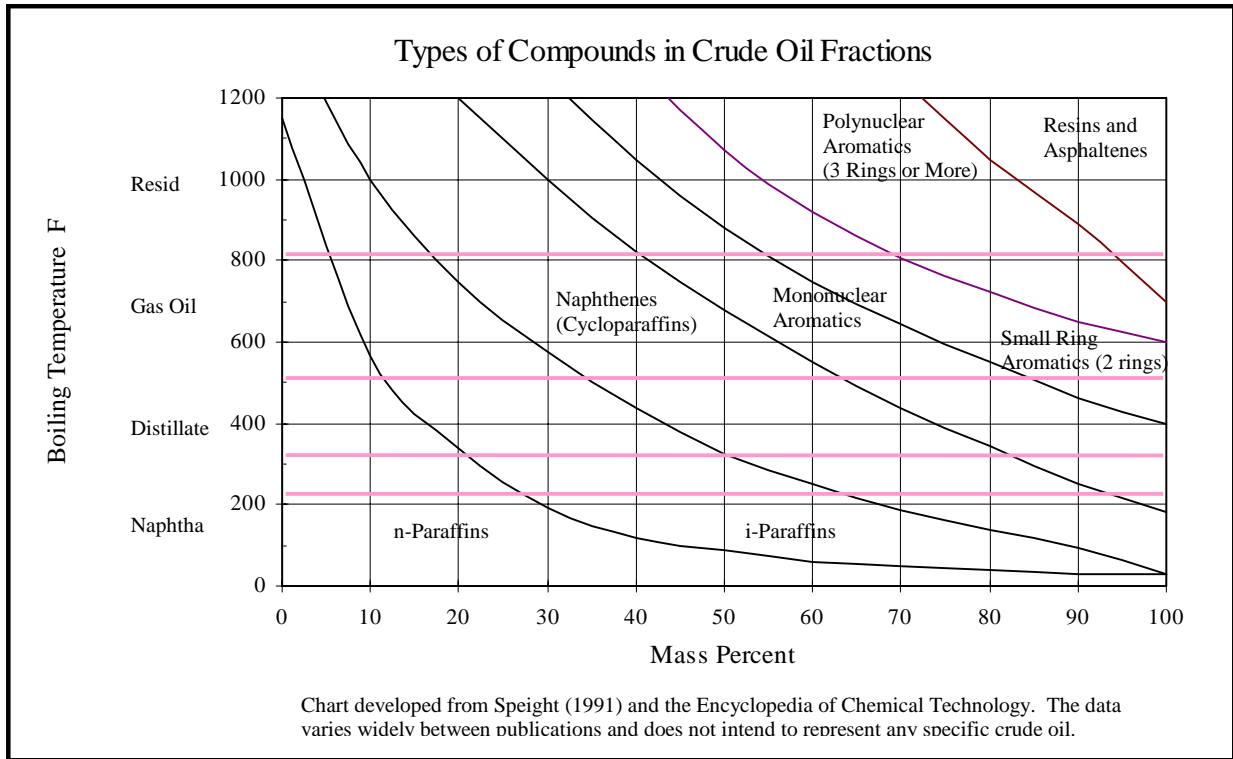
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Chapter 1

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Refinery Feeds Streams - Streams from the Atmospheric and Vacuum Towers

The following chart illustrates the types of compounds in crude oil. It has been developed as a function of the products from the atmospheric and vacuum towers, a typical reference point.

For an analogous contrast, the distillation curve is also provided for the products from the atmospheric and vacuum towers. Shown are six streams, although the number can vary as a function of crude quality, product mix and other factors specific to a given refinery.

All of the stipulated initial and final boiling points of both the products and the streams are expressed as true boiling temperatures. The values presented are reasonably typical although the values differ between authors and operating companies.

Types of Compounds in Crude Oil Fractions

Chart developed from Speight (1991) and the Encyclopedia of Chemical Technology. The data varies widely between publications and does not intend to represent any specific crude oil.

The distillation curve for products from the atmospheric and vacuum towers is provided. The temperatures are true boiling points and are typical.

Fractions from Distillation Curve for Arabian Light
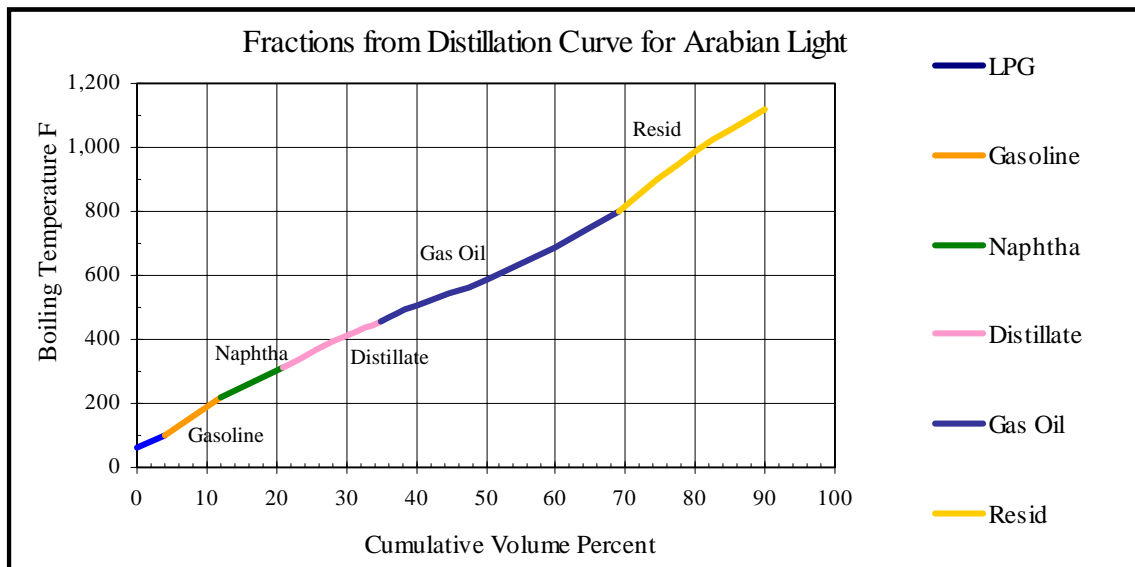
The distillation curve for products from the atmospheric and vacuum towers will differ depending on the crude, as illustrated for three different crudes. Heavier crudes have higher true boiling points at a specified cumulative volume percent, which is especially noticeable at the middle of the curve.
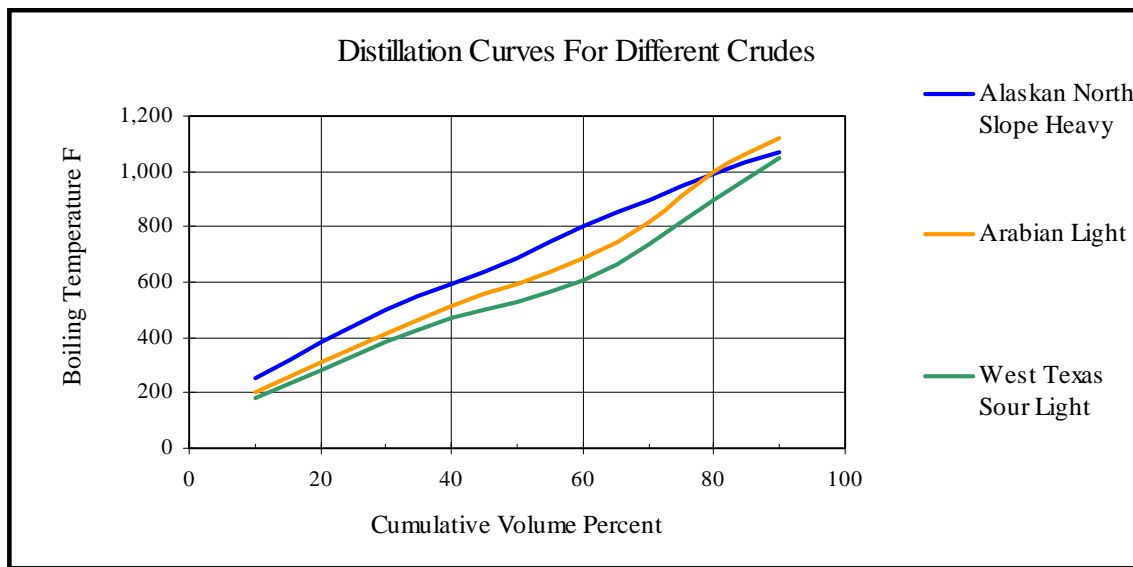
Light Ends   Butanes and lighter, condensing at the atmospheric tower pressure below 99°F, are taken overhead and directed to the refinery saturates gas plant for removal of sulfur compounds and separation into fuel gas, LPG, and butanes, along with associated liquids (pentanes-plus) vaporized with the light ends. The principal marketable product of light ends is Liquefied Petroleum Gas (LPG), a product consisting of ethane, propane, ethylene and propylene of various proportions.

Straight Run Gasoline   Straight run gasoline, which is sometimes called *light straight run gasoline*, has a true boiling range of about 99°F to 216°F. It is the stream that is taken as either the overhead liquid separated in the gas plant or as the top sidestream from the atmospheric crude unit. This stream was the original motor gasoline and is still known as straight run gasoline although it normally undergoes processing to upgrade it before gasoline blending.

As can be seen from the above graph, straight run gasoline is predominately paraffinic. Normal paraffins have considerably lower octane numbers than the isomeric forms. Although straight run gasoline is sometimes used directly for gasoline blending, it is shown as being upgraded by isomerization to improve octane number before being blended. There are not enough cycloparaffins (naphthenes) present to warrant feeding to the catalytic reformer for aromatics production and octane enhancement. Gasoline from other processing units is added to gasoline from the atmospheric column. Storage tank vapor emission considerations dictate light ends be removed from this stream.

Naphtha   The naphtha stream will typically have a true boiling range of about 216°F to 315°F. Whereas straight run gasoline is primarily paraffinic, naphtha additionally has a significant proportion of cycloparaffins (naphthenes) and aromatics. For years, naphtha has been catalytically reformed to add branches to paraffins, thus increasing the octane number for prime gasoline blend stock.   Just as importantly, reforming dehydrogenates cycloparaffins to aromatics. Although high in octane, aromatics are now environmentally limited in gasoline. They are removed as the source of orthoxylene and paraxylene for aromatics units. Naphtha from other processing units is sometimes added to naphtha from the atmospheric column.

Distillate   The distillate stream will typically have a boiling range of 315°F to 455°F. Distillates have considerably more cycloparaffins and aromatics than naphtha and are utilized for products from kerosene to heating oil. Distillates are often described as either light distillate or heavy distillate depending on the product.

■ <u>Light Distillate for Kerosene and Jet Fuel</u>   The next lower sidestream on the atmospheric crude unit is utilized for kerosene and jet fuel.   Since the materials are heavier, sulfur compounds increase and the stream is normally hydrotreated to remove sulfur compounds. However, the stream can be hydrotreated more intensively to remove the aromatics if smoke point is a problem. If the refinery has a hydrocracker, some products of the hydrocracker can be added to the pool. Products from the catalytic cracker are generally more useful as alkylation feed than for use as kerosene and jet fuels.

■ <u>Heavy Distillate for Diesel and Heating Oil</u>   The next lower sidestream on the atmospheric crude unit is utilized for diesel and heating oil. As with light distillate, the stream is hydrotreated to remove sulfur. Diesel and heating oil are both blends. Lighter automotive diesel and No. 1 heating oil are comparable in boiling ranges and heavy diesel and No. 2 heating oil have similar boiling range with several components added to control flash, sulfur, and aromatics in diesel. Heavy distillate from other processing units is added to heavy distillate from the atmospheric column.

Gas Oil   The atmospheric gas oil stream will typically have a boiling range of 455°F to 800°F. Gas oils are usually divided into atmospheric gas oil from the bottom side stream of the atmospheric tower and vacuum gas oils (light and heavy) from the top of the vacuum tower. Gas oils have substantial naphthenic and aromatic characteristics. As such, they have substantial sulfur and other contaminants and are generally hydrotreated for removal of sulfur and metals and reduction of aromatics to improve gas oil quality. All gas oil streams are normally directed to the gas oil pool for feed to the catalytic cracking unit. About one third is from the atmospheric column and two thirds is from the vacuum column. A small amount of gas oil is produced in the visbreaker. These units maximize the production of gas oil. Although gas oil feeds could be routed to the hydrocracker for diesel production, it is generally not economic with low diesel demand. After catalytic cracking, the streams are used for a spectrum of products from gasoline to heavy fuel oil.

Lube Fractions   Lube oil fractions are called mineral lubes to distinguish from "synthetic" lubes that are derived from alpha-olefins. Lube oil fractions taken from the vacuum column side draw are called Neutral Stocks. Lube fractions derived from the vacuum resid are called Bright Stocks. Important constituents of mineral lube fractions include normal paraffins, isoparaffins, cycloparaffins (naphthenes), and aromatics. Paraffinic lube stocks, prevalent in Pennsylvania crude, help develop the Pennsylvania oil industry due to high viscosity, good oxidation stability, and high thermal stability. However paraffin waxes, particular normal paraffins, raise the pour point and decrease automotive cold start ability. Isoparaffins are in general the preferred component with broad acceptable performance while aromatics perform poorly for all parameters. The current trend is for lower viscosity to improve fuel economy and lower pour point for better cold weather operation. Mineral lubes are processed using a variety of techniques including hydrotreating. Synthetic motor lubes are mostly manufactured of alpha-olefins from ethylene feedstock. Others are synthesized as esters or polyalkane glycols for turbine engine lubricants and refrigeration oils.

Resid   Resid - or residuum – are the bottoms from the atmospheric tower and the vacuum tower. The atmospheric tower bottoms are designated *long residuum* while the vacuum tower resid is termed *short residuum*.   Residuum contains substantial amounts of single ring and polynuclear aromatics that complicate the processing question.

■ <u>Atmospheric tower bottoms</u>, traditionally known as long residuum or 650°F plus bottoms, cannot be further fractionated at atmospheric pressure because the increased temperature will lead to cracking and coke formation. Since it still contains a majority of the recoverable gas oil recoverable, it undergoes further "residuum processing" or "bottom of the barrel" processing. Generally it is routed to the vacuum tower for fractionation. Other options are discussed with the applicable chapters on processing.

■ Vacuum tower bottoms, traditionally known as vacuum residuum, short residuum, or 1050°F plus bottoms, is all materials that have not been volatilized after the temperature is raised to 1050°F true boiling point. The use of vacuum allows for further fractionation without causing cracking or coking. The vacuum tower bottoms can comprise 10% to 20% of the crude oil. For many years the principal outlet for this material was fuel oil for ships and railroads before the age of the diesel locomotives. With locomotives using diesel, and marine applications turning more to lighter fuel oils for use in diesels and gas turbines, heavy fuel oils are limited to boilers for the steam turbines of marine and stationary power plants. But in recent years this market is declining. Vacuum resid still contains gas oil but if it is to be recovered it must be processed with solvent deasphalting, delayed coking, visbreaking or hydroprocessing. These options are discussed with the applicable chapters on processing.

■ Asphalt Resid   If the crude oil contained sufficient asphaltic material it can be processed to produce asphalts for use on roads and roofs. Vacuum distillation is the most common production method and the starting point for further processing. The basic product, heavily dependent on the quality of the crude asphalt content, is Reduced Asphalt. Three subsequent processes operating on reduced asphalts to improve their qualities or meet special markets are air blowing (mild oxidation), naphtha dilution or naphtha cutback, and emulsification.

Examples of Distillation Curves

The principal descriptor for nearly all petroleum streams is boiling range, whether or not it is in some specification. There are three distillation curves in use depending on whether one is describing feeds or products.

■ **True Boiling Point** (TBP): this is used for crude oil.
■ **ASTM distillation** (ASTM): this is used for intermediate refinery streams and products.
■ **Equilibrium flash vaporization** (EFV): this closely represents flashes used for process design.

The distillation curve compares TBT, ASTM and EFV curves for a distillate fraction.

Types of Distillation Curves
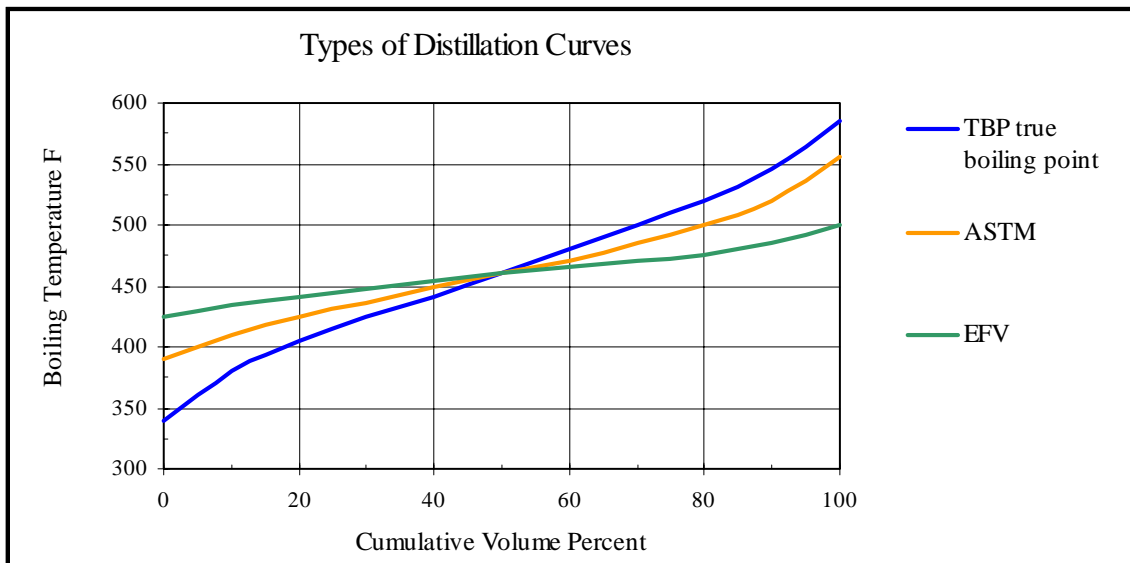
True Boiling Point (TBP) Distillation Curves For Crudes   Boiling ranges for crude oil are determined by a true boiling point distillation or TBP, which is a batch refluxed distillation. The characterization is presented as

profile of true boiling temperature versus volume percent vaporized. A crude assay will include the TBP and maybe other distillation curves. There are correlations for conversion between TBP, ASTM and EFV typically presented in the computer manual for the process simulation program.

The narrow cuts produced can be considered to be the equivalent of pure compounds and the boiling point is considered the true actual boiling point for the cut. Graphically, the true boiling point curve has the steepest temperature profile of the distillation curves.

True boiling point determinations are not standardized nor are there standard designs for the apparatus. A typical configuration is the 15/5, implying 15 stages and a 5 to 1 reflux ratio. One slightly less rigorous is the Hempel distillation. It has been found that constant conditions in the rectification portion of the lab still are more important than the number of stages or the reflux ratio. However, variations in results from the various devices are considered within engineering accuracy.   There is a vapor temperature measuring point at the outlet of the still column, after which the overhead vapors are condensed and collected in fractions for other testing as density. The true boiling point temperature is the measured vapor temperature at the reported volume percent vaporized.

ASTM Distillation (ASTM) Curves for Products   Boiling ranges for products and intermediate refinery streams are determined by a simple ASTM distillation, which is a non-refluxed batch distillation. ASTM distillations are much simpler and quicker to run than true boiling point distillations and for that reason ASTM distillations are the test for boiling ranges of products and blend stocks.

Because of the absence of external reflux, an ASTM distillation does not have the sharp separation and the steep temperature profile of the refluxed true boiling point curve.

The atmospheric distillation procedure is identified as ASTM D-86 and the vacuum distillation equivalent for higher boiling fractions is D-1160. The ASTM batch distillation is conducted with no external reflux and minimum internal reflux due to heat losses from the Engler flask. Vapor is withdrawn and condensed at essentially a constant rate.

Equilibrium Flash Vaporization (EFV) Distillation Curves For Process Design   The equilibrium flash vaporization or EFV reflects equilibrium phase behavior and is the distillation curve utilized for process design. However, it is seldom measured due to the expense. A TBP or ASTM will be converted to an EFV utilizing proprietary correlations or public correlations furnished with the process simulation program.

The EFV is the temperature for a vapor in equilibrium with its liquid as a function of the volume percent vaporized. The EFV initial boiling point of the fraction is the bubble point and the EFV final boiling point is the dew point. Since it is a series of equilibrium flashes, the EFV has the flattest curve of the distillation curves.

The equilibrium flash vaporization curve maybe physically determined in a series of flashes at increasing temperatures with liquid and vapor in equilibrium at correspondingly higher percentages vaporized. The EFV apparatus most commonly employed permits determination of EFV data at pressures greater than atmospheric.