Glossary of Petroleum and Technical Terminology

Abatement: 1. The act or process of reducing the intensity of pollution. 2. The use of some method of abating pollution. 3. Putting an end to an undesirable or unlawful condition affecting the wastewater collection system.

Abrasion (Mechanical): Wearing away by friction.

Abrasive: Particles propelled at a velocity sufficient to cause cleaning or wearing away of a surface.

Absolute Porosity: The percentage of the total bulk volume, which is pore spaces, voids or fractures.

Absolute Pressure: 1. The reading of gauge pressure plus the atmospheric pressure. 2. Gauge pressure plus barometric or atmospheric pressure. Absolute pressure can be zero in a perfect vacuum. Units, psia, bara. e.g., psia = psig + 14.7, bara = barg + 1.013.

Absolute Temperature: Temperature measurement starting at absolute zero. e.g., °R = °F + 460, K = °C + 273.16

Absolute Viscosity: The measure of a fluid's ability to resist flow without regard to its density. It is defined as a fluid's kinematic viscosity multiplied by its density.

Absorbent: The material that can selectively remove a target constituent from another compound by dissolving it.

Absorption: A variation of fractionation. In a distillation column, the stream to be separated is introduced in vapor form near the bottom. An absorption liquid called lean oil is introduced at the top. The lean oil properties are such that as the two pass each other, the lean oil will selectively absorb components of the stream to be separated and exit the bottom of the fractionator as rich oil. The rich oil is then easily separated into the extra and lean oil in conventional fractionation.

Absorption Gasoline: Gasoline extracted from wet natural gas by putting the gas in contact with oil.

Absorption Oil (Facilities): The wash oil used to remove heavier hydrocarbons from the gas stream.

Accident: An event or sequence of events or occurrences, natural or man-made that results in undesirable consequences and requires an emergency response to protect life and property.

Accumulator: A vessel that receives and temporarily stores a liquid used in the feedstock or the processing of a feed stream in a gas plant or other processing facility.

Acentric Factor: A correlating factor that gives a measure of the deviation in behavior of a substance to that for an idealized simple fluid. It is a constant for each component and has been correlated with the component vapor pressure.

Acid Gas: 1. A gas that contains compounds such as CO_2, H_2S or mercaptans (RSH, where R = C_nH_{2n+1}, n=1, 2) that can form an acid in solution with water. 2. Group of gases that are found in raw natural gas and are usually considered pollutants. Amongst these are CO_2, H_2S and mercaptans. 3. Any produced gas primarily H_2S and CO_2 that forms an acid when produced in water.

Acid Inhibitor: Acid corrosion inhibitor. It slows the acid attack on metal.

Acid Number: A measure of the amount of potassium hydroxide (KOH) needed to neutralize all or part of the acidity of a petroleum product. Also referred to as neutralization number (NN) or value (NV) and total acid number (TAN).

Acid Soluble Oil (ASO): 1. High boiling polymers produced as an unwanted by-product in the alkylation processes. 2. Polymers produced from side reactions in the alkylation process.

Acid Treating/Treatment: A process in which unfinished petroleum products, such as gasoline, naphthas, kerosene, diesel fuel, and lubricating oil stocks, are contacted with sulfuric acid to improve their color, odor, and other properties.

Acidity: The capacity of water or wastewater to neutralize bases. Acidity is expressed in milligrams per liter of equivalent calcium carbonate ($CaCO_3$). Acidity is not the same as pH because water does not have to be strongly acidic (low pH) to have a high acidity. Acidity is a measure of how much base must be added to a liquid to raise the pH to 8.2.

AC Motor: Most of the pumps are driven by alternating current, three-phase motors. Such motors that drive pumps are usually fixed-speed drivers. DC motors are rarely used in process plants.

Activity of Catalyst: Activity generally means how well a catalyst performs with respect to reaction rate, temperature or space velocity.

Actual Tray: A physical tray (contact device) in a distillation column, sometimes called a plate.

Adsorbents: Special materials like activated charcoal, alumina or silica gel, used in an adsorption process that selectively cause some compounds, but not others, to attach themselves mechanically as liquids.

Adsorption: 1. A process for removing target constituents from a stream by having them condense on an adsorbent, which is then taken off line so the target constituents can be recovered. 2. The process by which gaseous components adhere to solids because of their molecular attraction to the solid surface.

Alarms: Process parameters (levels, temperatures, pressures, flows) are automatically controlled within a permissible range. If the parameter moves outside this range, it sometimes activates both an audible and a visual alarm. If the panel board operator fails to take corrective action, a trip may also then be activated.

Alcohol: The family name of a group of organic chemical compounds composed of carbon, hydrogen and oxygen. The series of molecules vary in chain length and are composed of a hydrocarbon plus a hydroxyl group, CH_3 (CH_2) n – OH (e.g., methanol, ethanol, tertiary butyl alcohol).

Alkanolamine: An organic nitrogen bearing compound related to ammonia having at least one, two or three of its hydrogen atoms substituted with at least one, two or three linear or branched alkanol groups where only one or two could also be substituted with a linear or branched alkyl group (i.e., methyldiethanolamine MDEA). The number of hydrogen atoms substituted by alkanol or alkyl groups at the amino site determines whether the alkanolamine is primary, secondary or tertiary.

Alkylate: 1. The gasoline produced by an alkylation process. It is made by combining the low boiling hydrocarbons catalytically to obtain a mixture of high-octane hydrocarbons boiling in the gasoline range. 2. The product of an alkylation reaction. It usually refers to the high octane product from alkylation units. This alkylate is used in blending high octane gasoline.

Alkylate Bottoms: A thick, dark brown oil containing high molecular-weight polymerization products of alkylation reactions.

Alkylation: 1. A refining process for chemically combining isobutane (iC_4H_{10}) with olefin hydrocarbons [e.g., propylene (C_3H_6), butylenes (C_4H_8)] through the

control of temperature and pressure in the presence of an acid catalyst. 2. A refining process in which light olefins primarily a mixture of propylene (C_3H_6), butylenes (C_4H_8) and/or amylenes are combined with isobutane (iC_4H_{10}) over an acid catalyst to produce a high octane gasoline (highly branched $C_5 - C_{12}$, i-paraffins), called alkylate. The commonly used catalysts are sulfuric acid (H_2SO_4) and hydrofluoric acid (HF). The major constituents of alkylate are isopentane and isooctane (2,2,4 – trimethyl pentane, TMP), the latter possessing an octane number of 100. The product, alkylate, is an isoparaffin, has high octane value and is blended with motor and aviation gasoline to improve the antiknock value of the fuel.

Aluminum Chloride Treating: A quality improvement process for steam cracked naphthas using aluminum chloride ($AlCl_3$) as a catalyst. The process improves the color and odor of the naphtha by the polymerization of undesirable olefins into resins. The process is also used when production of resins is desirable.

American Petroleum Institute (API): An association, which among many things sets technical standards for measuring, testing and other types of handling of petroleum.

Amine Treating: Contacting of a gas or light hydrocarbon liquid with an aqueous solution of an amine compound to remove the hydrogen sulfide (H_2S) and carbon dioxide (CO_2).

Anaerobic Digestion: Is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen. The process is used for industrial or domestic purposes to manage waste and/or to produce fuels. Much of the fermentation used industrially to produce food and drink products, as well as home fermentation uses anaerobic digestion.

The digestion process begins with bacterial hydrolysis of the input materials. Insoluble organic polymers such as carbohydrates are broken down to soluble derivatives that become available for other bacteria. It is used as part of the process to treat biodegradable waste and sewage sludge. As part of an integrated waste management system, anaerobic digestion reduces the emission of landfill gas into the atmosphere. Anaerobic digestion is widely used as a source of renewable energy. The process produces biogas, consisting of methane, carbon dioxide and traces of other "contaminant" gases. The biogas can be used directly as fuel in combined heat and power gas engines or upgraded to natural gas-quality biomethane. The nutrient-rich digestate also produced can be used as fertilizer.

Aniline Point: The minimum temperature for complete miscibility of equal volumes of aniline and the test sample. The test is considered an indication of the paraffinicity of the sample. The aniline point is used as a classification of the ignition quality of diesel fuels.

Antiknock Agent: 1. Is a gasoline additive used to reduce engine knocking and increase the fuel's octane rating by raising the temperature and pressure at which auto-ignition occurs. The mixture is gasoline or petrol, when used in high compression internal combustion engines, has a tendency to knock (also, referred to as pinging, or pinking) and/or to ignite early before the correctly time spark occurs (pre-ignition, refers to engine knocking). 2. The most wanted and widely used additives in gasoline are the antiknock compounds. They assist to enhance the octane number of gasoline. Lead in the form of tetra ethyl lead (TEL) or tetra methyl lead (TML) is a good antiknock compound. TEL helps to increase the octane number of gasoline without affecting any other properties, including vapor pressure, but when used alone in gasoline gives rise to troublesome deposits.

Antiknock Index: The Research Octane Number (RON) test simulates driving under mild conditions while the Motor Octane Number (MON) test simulates driving under severe conditions, i.e., under load and at high speed. The arithmetic average of RON and MON that gives an indication of the performance of the engine under the full range of conditions is referred to as AntiKnock Index (AKI). It is determined by:

$$\text{Antiknock Index}\left(\text{AKI}\right) = \frac{\text{RON+MON}}{2}$$

Antiknock Quality (Octane Number): Knocking is a characteristic property of motor fuels that governs engine performance and is expressed in terms of octane number. It depends on the properties of hydrocarbon type and nature. Octane number is the percentage of iso-octane in the reference fuel, which matches the knocking tendency of the fuel under test. Research octane number (RON) and motor octane number

(MON) are two methods used and are measured with a standard single cylinder, variable compression ratio engine. For both octane numbers, same engine is used, but operated at different conditions. The distinction between two octane numbers (RON and MON) measurement procedures are engine speed, temperature of admission and spark advance. The motor method captures the gasoline at high engine speeds and loads, and the research octane method at low speed depending on the fuel characteristics. The MON is normally 8–10 points lower than the RON. A high tendency to autoignite, or low octane rating, is undesirable in a gasoline engine, but desirable in a diesel engine.

Antiknock index (AKI) = (RON + MON)/2.

API Gravity: A method for reporting the density of petroleum streams. It is defined as

$$°\text{API} = \left[\frac{141.5}{\text{Sp.Gr}\,@\,60/60\,°\text{F}} - 131.5\right],$$ where Sp.Gr is the specific gravity relative to water. °API gravity is reported at a reference temperature of 60°F (15.9°C).

The scale allows representation of the gravity of oils, which on the specific gravity 60/60°F scale varies only over a range of 0.776 by a scale that ranges from less than 0 (heavy residual oil) to 340 (methane).

According to the expression, 10°API indicates a specific gravity of 1 (equivalent to water specific gravity). Thus, higher values of API gravity indicate lower specific gravity and therefore lighter crude oils, or refinery products and vice-versa. As far as crude oil is concerned lighter API gravity value is desired as more amount of gas fraction, naphtha and gas oils can be produced from the lighter crude oil than with the heavier crude oil. Therefore, crude oil with high values of API gravity is expensive to produce due to their quality.

Classification of crude oils

Crude category	°API gravity
Light crudes	°API > 38
Medium crudes	38 > °API > 29
Heavy crudes	29 > °API > 8.5
Very heavy crudes	°API < 8.5

The higher the API gravity, the lighter the compound. Light crudes generally exceed 38°API and heavy crudes are commonly are crudes with an °API of 22 or below. Intermediate crudes fall in the range of 22–38 °API (See Figures 1a and 1b).

Aromatics: 1. A group of hydrocarbons characterized by having at least one benzene ring type structure of six carbon atoms with three double and three single bonds connecting them somewhere in the molecule. The general formula is C_nH_{2n-6} where n = 6, 7, 8, etc. The simplest is benzene, plus toluene and the xylenes. Aromatics in gas oils and residues can have many, even scores of rings. 2. The three aromatic compounds – benzene (C_6H_6), toluene (C_7H_8), xylene (C_8H_{10}).

As Low As Reasonably Practicable (ALARP): The principle that no industrial activity is entirely free from risk and that it is never possible to be sure that every eventuality has been covered by safety precautions, but that there would be a gross disproportion between the cost in (money, time or trouble) of additional preventive or protective measures, and the reduction in risk in order to achieve such low risks (See Figure 2).

Asphalt: 1. A heavy semi-solid petroleum product that gradually softens when heated and is used for surface cementing. Typically brown or black in color, it is composed of high carbon to hydrogen hydrocarbons. It occurs naturally in crude oil or can be distilled or extracted. 2. The end product used for area surfacing consisting of refinery asphalt mixed with aggregation. 3. Heavy tar-like residue from distillation of some types of crude oil. Asphalt components are high molecular weight derivatives of aromatic compounds. Not all asphalt materials are suitable for use as building agents in road pavement.

Asphaltenes: Highly condensed masses of high molecular weight aromatic compounds. They exit in petroleum residuum as the center of colloidal particles or micelles. The asphaltenes are kept in solution by an outer ring of aromatic compounds of lower molecular weight. They can precipitate when the continuous nature of the surrounding ring of aromatics is broken down by cracking processes.

Assay Data: Laboratory test data for a petroleum stream, including laboratory distillation, gravity, compositional breakdown and other laboratory tests. Numerous important feed and product characterization properties in refinery engineering include:

1.	API gravity
2.	Watson Chracterization factor
3.	Viscosity
4.	Sulfur content, wt %
5.	Nitrogen content, wt %
6.	Carbon residue, wt%
7.	Salt content
8.	Metal contents
9.	Asphaltene, %
10.	Naphthenes, %
11.	True boiling point (TBP) curve
12.	Pour point
13.	Cloud point
14.	Freeze point
15.	Aniline point
16.	Flash and fire point
17.	ASTM distillation curve
18.	Octane number
19.	Conradson carbon
21.	Reid vapor pressure
22.	Bottom sediment and water (BS &W)
23.	Light hydrocarbon yields ($C_1 - C_5$)

The crude quality is getting heavier worldwide. Existing refineries that are designed to handle normal crudes are being modified to handle heavy crude. New technology for upgrading is used to obtain clean and light products from lower cost feeds. The crude assay will determine the yields of different cuts and consequently the refinery configuration.

Associated Natural Gas: Natural gas that is dissolved in crude in the reservoir and is co-produced with the crude oil.

ASTM: American Society of Testing and Materials. Nearly all of the refinery product tests have been standardized by ASTM.

ASTM Distillation: A standardized laboratory batch distillation for naphthas and middle distillates carried out at atmospheric pressure without fractionation.

ASTM Distillation Range: Several distillation tests are commonly referred to as "ASTM distillations." These are usually used in product specifications. These ASTM distillations give results in terms of percentage distilled versus temperature for a sample laboratory distillation with no fractionation. The values do not correspond to those of refinery process distillations, where fractionation is significant.

ASTM D86 Distillation: Of an oil fraction takes place at laboratory room temperature and pressure. Note that the D86 distillation will end below an approximate temperature of 650°F (344°C), at which petroleum oils begin to crack at one atmospheric pressure.

ASTM D1160 Distillation: Of an oil fraction is applicable to high-boiling oil samples (e.g., heavy heating oil, cracker gas oil feed, residual oil, etc.) for which there is significant cracking at atmospheric pressures. The sample is distilled at a reduced pressure, typically at 10 mm Hg, to inhibit cracking. In fact, at 10 mmHg, we can distill an oil fraction up to temperatures of 950–1000°F (510–538°C), as reported on a 760 mm Hg basis. The reduced pressure used for D1160 distillation produces a separation of components that is more ideal than that for D86 distillation.

ASTM D2887 Distillation: Of oil fraction is a popular chromatographic procedure to "simulate" or predict the boiling point curve of an oil fraction. We determine the boiling point distribution by injecting the oil sample into a gas chromatograph that separates the hydrocarbons in a boiling-point order. We then relate the retention time inside the chromatograph to the boiling point through a calibration curve.

ASTM End Point of Distillates: End point is an important specification or way of describing gasolines, naphthas, or middle distillates. It's the approximate relationship between the end point of a fraction and its True Boiling Point (TBP) and other cut points.

Atmospheric Distillation: 1. The refining process of separating crude oil components at atmospheric pressure by heating to temperatures of 600–750°F (316–400°C) (depending on the nature of the crude oil and desired products) and subsequent condensing of the fractions by cooling. 2. Distillation/Fractionation of crude oil into various cuts/fractions under atmospheric condition. The more volatile components (i.e., lower boiling points) rise through trays/bubble caps and are condensed at various temperatures and the least volatile components, short and long residues

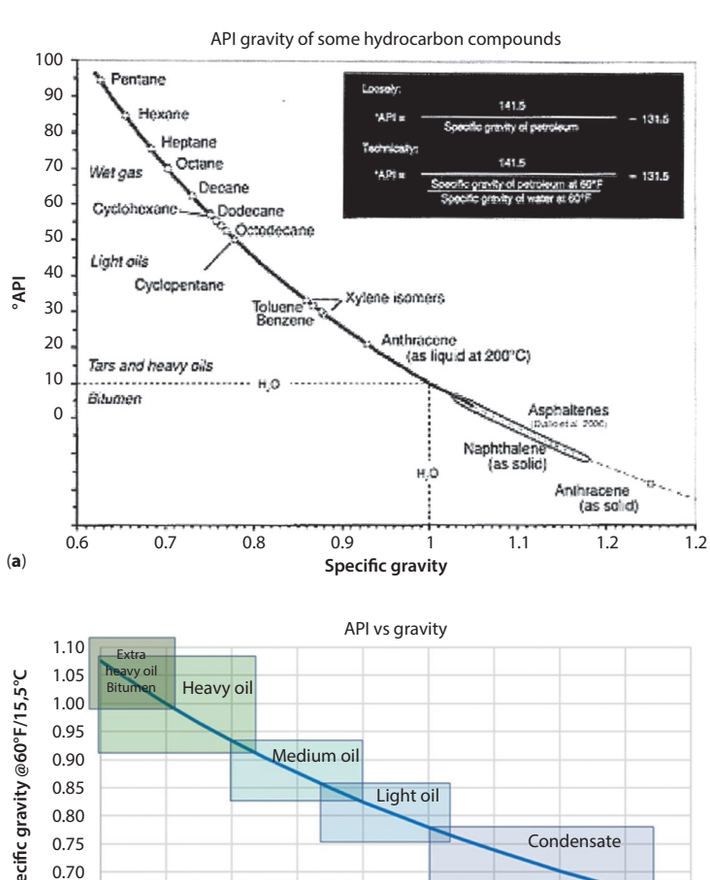


Figure 1 (a) A plot of °API vs. specific gravity of hydrocarbons compounds. (b) Specific gravity vs. °API of hydrocarbons (Source: EngineeringToolBox.com)

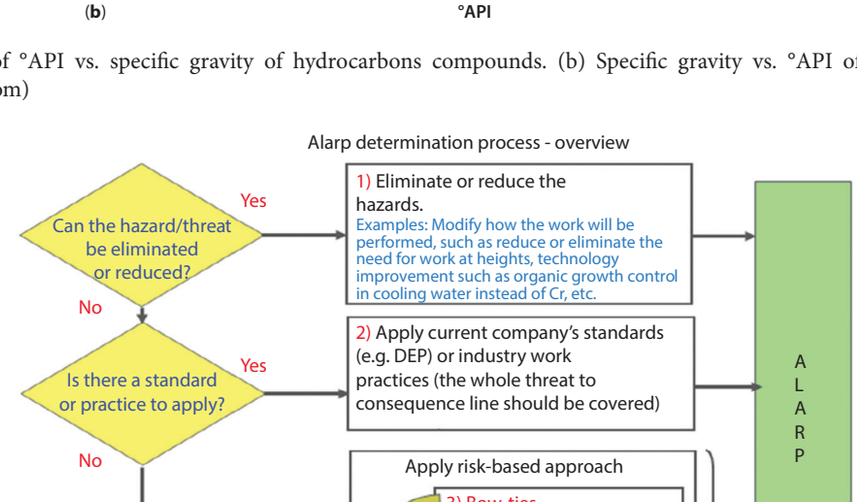


Figure 2 ALARP determination process overview.

DEP = Design Engineering Practice.

(i.e., higher boiler points) are removed as bottom products.

Atmospheric Crude Oil Distillation: The refining process of separating crude oil components at atmospheric pressure by heating to temperatures of about 600–750 °F (316–400°C) (depending on the nature of the crude oil and desired products) and subsequent condensing of the fractions by cooling.

Atmospheric Gas Oil (AGO): A diesel fuel and No. 2 heating oil blending stock obtained from the crude oil as a side stream from the atmospheric distillation tower.

Atmospheric Reduced Crude (ARC): The bottoms stream from the atmospheric distillation tower.

Atmospheric Residuum: The heaviest material from the distillation of crude oil in a crude distillation column operating at a positive pressure.

Autoignition: The spontaneous ignition and resulting rapid reaction of a portion of or all the fuel-air mixture in the combustion chamber of an internal combustion engine. The flame speed is many times greater than that following normal ignition.

Autoignition Temperature (AIT): 1. The lowest temperature at which a gas will ignite after an extended time of exposure. 2. The lowest temperature at which a flammable gas or vapor air mixture will ignite from its own heat source or a contacted heat source without the necessity of a spark or a flame.

Aviation Gasoline Blending Components: Naphtha's which will be used for blending or compounding into finished aviation gasoline (e.g., straight-run gasoline, alkylate, reformate, benzene, toluene, xylenes). Excludes oxygenates (alcohols, ethers), butanes and pentanes. Oxygenates are reported as other hydrocarbons, hydrogen and oxygenates.

Aviation Gasoline (Finished): A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in aviation reciprocating engines. Fuel specifications are provided in ASTM Specification D910 and Military Specification MIL-G-5572. Note: Data on blending components are not counted in data on finished aviation gasoline.

Azeotrope: A constant boiling point mixture for which the vapor and liquid have identical composition. Azeotropes cannot be separated with conventional distillation.

Backflow: 1. A flow condition, caused by differential pressure, resulting in the flow of liquid into the potable water supply system from sources other than those intended; or the backing up of liquid, through a conduit or channel, in a direction opposite to normal flow. 2. Return flow from injection of a fluid into a formation.

Back Pressure: A pressure caused by a restriction or fluid head that exerts an opposing pressure to flow.

Barrel: A volumetric measure of refinery feedstocks and products equal to 42 U.S. gal.

Barrels Per Calendar Day (BPCD or B/CD): Average flow rates based on operating 365 days per year. The amount of input that a distillation facility can process under usual operating conditions. The amount is expressed in terms of capacity during a 24-hour period and reduces the maximum process capability of all units at the facility under continuous operation to account for the following limitations that may delay, interrupt, or slow down production: The capability of downstream facilities to absorb the output of crude oil processing facilities of a given refinery. No reduction is made when a planned distribution of intermediate streams through other than downstream facilities is part of a refinery's normal operation; the types and grades of inputs to be processed; the types and grades of products expected to be manufactured; the environmental constraints associated with refinery operations; the reduction of capacity for scheduled downtime due to such conditions as routine inspection, maintenance, repairs and turnaround, and the reduction of capacity for unscheduled downtime due to such conditions.

Barrels Per Stream Day (BPSD or B/SD): The maximum number of barrels of input that a distillation facility can process within a 24-hour period when running at full capacity under optimal crude and product slate conditions with no allowance for downtime. This notation equals barrels per calendar day divided by the service factor.

Basic Process Control System (BPCS): A system which responds to input signals from the process, its associated equipment, other programmable systems and/or an operator and generates output signals causing the process and its associated equipment to operate

in the desired manner but which does not perform any safety instrumented functions (SIF) with a claimed Safety Instrumented Level, SIL ≥ 1.

Battery Limits (BL): The periphery of the area surrounding any process unit, which includes the equipment for the particular process.

Baume gravity: Specific gravity of liquids expressed as degrees on the Baume scale. For liquids lighter than water,

$$\text{Sp.Gr @15.6 / 15.6 °C} = \frac{140}{130 + \text{deg Be}}$$

For liquids heavier than water

$$\text{Sp.Gr @15.6 / 15.6 °C} = \frac{145}{145 - \text{deg Be}}$$

Bbl: Abbreviation for a quantity of 42 U.S. gal.

Benchmark crude: A reference crude oil with whom the prices of other crudes are compared with.

Benzene (C_6H_6): An aromatic hydrocarbon present in small proportion in some crude oils and made commercially from petroleum by the catalytic reforming of naphthenes in petroleum naphtha. It is also made from coal in the manufacture of coke. Used as a solvent, in manufacturing detergents, synthetic fibers, and petrochemicals and as a component of high-octane gasoline.

Bernoulli equation: A theorem in which the sum of the pressure-volume, potential, and kinetic energies of an incompressible and non-viscous fluid flowing in a pipe with steady flow with no work or heat transfer is the same anywhere within a system. When expressed in head form, the total head is the sum of the pressure, velocity and static head. It is applicable only for incompressible and non-viscous fluids as:

In SI Units

$$\frac{P_1}{\rho_g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho_g} + \frac{v_2^2}{2g} + z_2 + h_f$$

where h_f is the pipe friction from point 1 to point 2 may be referred to as the head loss in metres of fluid.

In Imperial Units.

$$\frac{144P_1}{\rho} + \frac{v_1^2}{2g_c} + z_1\frac{g}{g_c} = \frac{144P_2}{\rho} + \frac{v_2^2}{2g_c} + z_2\frac{g}{g_c} + h_f$$

where h_f is the pipe friction from point 1 to point 2 in foot-pounds force per pound of flowing fluid; this is sometimes referred to as the head loss in feed of fluid.

where, P is pressure, ρ is density, g_c is conversion factor $\left(32.174\frac{lb_m}{lb_f}\bullet\frac{ft}{s^2}\right)$, g is acceleration due to gravity (32 ft/s^2), v is velocity, z is elevation and h_f is frictional head loss. It is a statement of the law of the conservation of energy, which was formulated by Daniel Bernoulli in 1738 (See Figure 3).

Bitumen: That portion of petroleum, asphalt, and tar products that will dissolve completely in carbon disulfide (CS_2). This property permits a complete separation from foreign products not soluble in carbon disulfide.

Blast: A transient change in gas density, pressure (either positive or negative), and velocity of the air surrounding an explosion point.

Blending: One of the final operations in refining, in which two or more different components are mixed together to obtain the desired range of properties in the final product.

Blending Components: Modern gasoline is a blend of various refinery streams produced by distillation, cracking, reforming and polymerization together with additives to achieve the specific fuel performance requirements.

Blending Octane Number: When blended into gasoline in relatively small quantities, high-octane materials behave as though they had an octane number higher than shown by laboratory tests on the pure

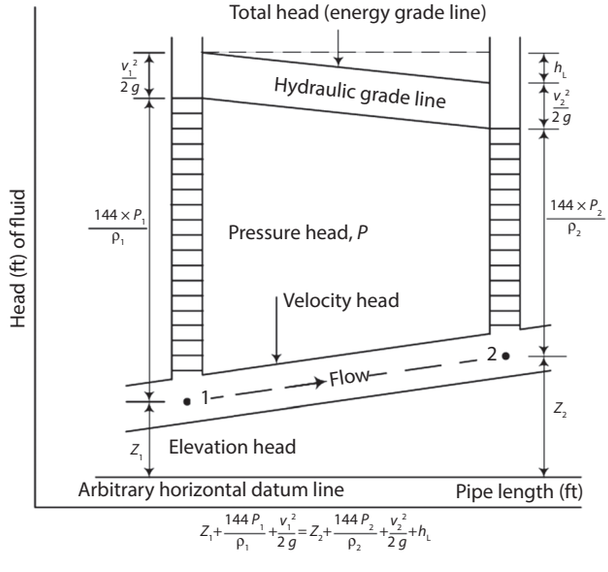


Figure 3 Distribution of fluid energy in a pipeline.

material. The effective octane number of the material in the blend is known as the blending octane number.

Blending Plant: A facility which has no refining capability but is either capable of producing finished motor gasoline through mechanical blending or blends oxygenates with motor gasoline.

Blending Value (hydrocarbon): In octane ratings of a hydrocarbon made on blends of 20 percent hydrocarbon plus 80 percent of a 60 : 40 mixture of isooctane (iC_8H_{18}) and n-heptane (nC_7H_{16}), the blending octane number is a hypothetical value obtained by extrapolation of a rating of 100% concentration of the hydrocarbon.

Blocked operation: A set of operating conditions and procedures that apply to a particular feed stock and/or set of product specifications for a process.

Boiler: 1. A closed vessel in which a liquid is heated or heated and evaporated. Boilers are often classified as steam or hot water, low pressure or high pressure, and capable of burning one fuel or a number of fuels. 2. Vessel in which a liquid is heated with or without vaporization; boiling need not occur.

Boiler Feed Pump: A pump which returns condensed steam, makeup water or both directly to the boiler.

Boiler Feed Water: Water supplied to a boiler by pumping.

Boiling Liquid Expanding Vapor Explosion (BLEVE): 1. The nearly instantaneous vaporization and corresponding release of energy of a liquid upon its sudden release from a containment under pressure than atmospheric pressure and at a temperature above its atmospheric boiling point. 2. A type of rapid phase transition in which a liquid contained above its atmospheric boiling point is rapidly depressurized, causing a nearly instantaneous transition from liquid to vapor with a corresponding energy release. A **BLEVE** is often accompanied by a large fireball if a flammable liquid is involved, since an external fire impinging on the vapor space of a pressure vessel is a common **BLEVE** scenario. However, it is not necessary for the liquid to be flammable to have a **BLEVE** to occur.

Blowdown: The disposal of voluntary discharges of liquids or condensable vapors from process and vessel drain valves, thermal relief or pressure relief valves.

Blowout: An uncontrolled flow of gas, oil or other well fluids from a wellbore at the wellhead or into a ground formation, caused by the formation pressure exceeding the drilling fluid pressure. It usually occurs during drilling on unknown (exploratory) reservoirs.

Boiling Point: 1. Heat a liquid and its vapor pressure increases. When the liquid's vapor pressure equals the pressure in the vessel, the liquid starts to boil. The temperature at which this boiling starts is the liquid's boiling temperature. 2. Typically refers to the temperature at which a component or mixture of components starts to vaporize at a given pressure. When used in petroleum refining, it is usually synonymous with the normal boiling point (i.e., boiling point at one atmosphere). 3. The temperature at which the pressure exerted by molecules leaving a liquid equals the pressure exerted by the molecules in the air above it. A free-for-all of molecules leaving the liquid then ensures. In a solution, the boiling point will be increased by a number that depends on the number of particles in solution:

$$\text{delta (T)} = K_b \text{ x (number of solute molecules per liter)}$$

where

delta (T) = the rise in the boiling point.

K_b = the ebullliosccopic constant and varies from one solvent to another.

Boiling Range: 1. The spread of temperatures over which oil starts to boil or distill vapors and proceeds to complete evaporation. Boiling range is determined by ASTM test procedures for specific petroleum products. It is measured in °F or (°C). 2. The lowest through to highest boiling temperatures for a petroleum stream when distilled. Boiling ranges are often reported on a TBP (true boiling point) basis, i.e., as normal boiling points.

Boiling Temperature: The temperature at which steam bubbles begin to appear within a liquid. When the fluid is a pure compound, the boiling point is unique for each pressure.

Boil Off: A small amount of LNG evaporates from the tank during storage, cooling the tank and keeping the pressure inside the tank constant and the LNG at its boiling point. A rise in temperature is encountered by the LNG being vented from the storage tank.

Boil Off Vapor: Usually refers to the gases generated during the storage or volatile liquefied gases such as LNG. Natural gas boils at slightly above -261°F (-163°C) at atmospheric pressure and is loaded, transported and discharged at this temperature, which requires special materials, insulation and handling equipment to deal with the low temperature and the boil-off vapor.

Boot, Boot Cooler: The section of a distillation column below the trays. For columns with very hot feeds, a portion of the bottom product is cooled and circulated through the boot or lower the temperature of the liquid in the boot and prevent depositing of coke. Many vacuum distillation columns have boot coolers.

Bottoms: 1. The heavy fractions or portions, of a crude oil that do not vaporize during fractionation/distillation. 2. The accumulation of sediments, mud and water in the bottoms of lease tanks. 3. The product coming from the bottom of a fractionating column. In general, the higher-boiling residue that is removed from the bottom of a fractionating tower. 4. The liquid level left in a tank after it has been pumped "empty" and the pump loses suction.

Bow-Tie–Analysis (BTA): 1. A qualitative risk analysis that portrays events and consequences on either side of a "bowtie". Barriers or safeguards are shown in between the two sides. It depicts the risks in ways that are readily understandable to all levels of operations and management. 2. A type of qualitative safety review where cause scenarios are identified and depicted on the pre-event side (left side) of a bow-tie diagram. Credible consequences and scenarios outcomes are depicted on the post-event side (right side) of the diagram, and associated barrier safeguards are included(See Figure 4).

Brackish Water: Indefinite term meaning water with small amounts of salt. Saltier than fresh water.

Brainstorming: A group problem-solving technique that involves the spontaneous contribution of ideas from all members of the group primarily based on their knowledge and experience.

Brent: A large oil field in the U.K sector of the North Sea. Its name is used for a blend of crudes widely used as a price marker or benchmark for the international oil industry. Brent crude currently has an average quality of 38°API.

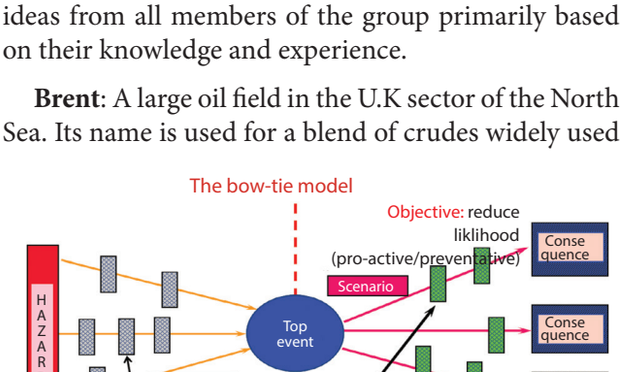


Figure 4 The Bow-Tie – Analysis.

Brent Blend: A light sweet crude oil produced in the North Sea; a benchmark for pricing of many foreign crude oils.

Bright Stock: Heavy lube oils (frequently the vacuum still bottoms) from which asphaltic compounds, aromatics, and waxy paraffins have been removed. Bright stock is one of the feeds to a lube oil blending plant.

British thermal unit (Btu): A standard measure of energy; the quantity of heat required to raise the temperature of 1 pound of water by 1°F.

Bromine Index: Measure of the amount of bromine reactive material in a sample; ASTM D-2710.

Bromine Number: A test that indicates the degree of unsaturation in the sample (olefins and diolefins); ASTM D-1159.

BTX: The acronyms for the commercial petroleum aromatics benzene, toluene and xylene.

Bubble Cap: 1. It is an inverted cup with a notched or slotted periphery to disperse the vapor in small bubbles beneath the surface of the liquid on the bubble plate in a distillation column. The bubble caps cause the vapor coming from the bottom to come in intimate contact with the liquid sitting on the tray. 2. A bubble cap tray has riser or chimney fitted over each hole, and a cap that covers the riser. The cap is mounted so that there is a space between riser and cap to allow the passage of vapor. Vapor rises through the chimney and is directed downward by the cap, finally discharging through slots in the cap, and finally bubbling through the liquid on the tray (See Figure 5).

Bubble Point: 1. This is the same as the boiling point. When a liquid is at its bubble point, it is said to be saturated liquid at the temperature and pressure. If we raise the pressure, the liquid's bubble point temperature goes up. 2. The temperature and pressure at which a liquid first begins to vaporize into gas. 3. The temperature at which the first bubbles appear when a liquid mixture is heated. 4. The temperature at which a component or mixture of components begins to vaporize at a given pressure. It corresponds to the point of zero percent vaporization or 100 percent condensation. The pressure should be specified, if not one atmosphere. 5. The pressure at which gas begins to break out

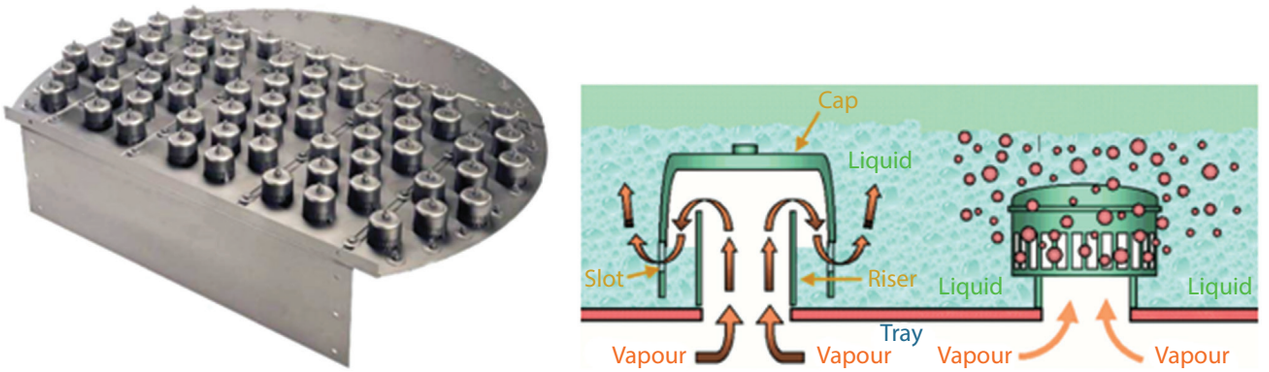


Figure 5 A Bubble cap tray.

of under-saturated oil and form a free gas phase in the matrix or a gas cap.

Bubble Tower or Column: A fractionating tower constructed in such a way that the vapors rising up pass through different layers of condensate on a series of plates. The less volatile portions of vapor condense in bubbling through the liquid on the plate, overflow to the next lower plate and finally back to the boiler.

Bubble Tray: A horizontal tray fitted in the interior of a fractionating tower; meant to give intimate contact between rising vapors and falling liquid in the tower.

Bulk Properties: Provide a quick understanding of the type of the oil sample such as sweet or sour, light and heavy, etc. However, refineries require fractional properties of the oil sample that reflects the property and composition for specific boiling-point range to properly refine it into different end products such as gasoline, diesel, and raw materials for chemical process. Fractional properties usually contain paraffins, naphthenes and aromatics (PNA) contents, sulfur content, nitrogen content for each boiling-point range, octane number of gasoline, freezing point, cetane index and smoke point for kerosene and diesel fuels.

Bulk Station: A facility used primarily for the storage and/or marketing of petroleum products which has a total bulk storage capacity of less than 50,000 barrels and receives its petroleum products by tank car or truck.

Bulk Terminal: A facility used primarily for the storage and/or marketing of petroleum products which has a total bulk storage capacity of 50,000 barrels or more and/or receives petroleum products by tanker, barge or pipeline.

Bunker Fuel Oil: A heavy residual fuel oil used by ships, industry and large-scale heating installations.

Butadiene (C_4H_6): A diolefin with two double bonds and two isomers. A colorless gas resulting from cracking processes. Traces result from cat. cracking from catalytic dehydrogenation of butane (C_4H_{10}) or butylenes (C_4H_8) and in ethylene plants using butane, naphtha or gas oil as feeds. Butadiene is principally used to make polymers like synthetic rubber and acrylonitrile butadiene styrene (ABS) plastics.

Butane (C_4H_{10}): A normally gaseous four-carbon straight chain or branched-chain hydrocarbon extracted from natural gas or refinery gas streams. It includes normal butanes and refinery grade butanes and is designated in ASTM Specification D1835 and Gas Processors Association Specifications for commercial butane. Commercial butane is typically a mixture of normal and isobutene, predominantly normal. Hydrocarbons in the paraffin series with a general formula C_nH_{2n+2}, where n = 1, 2, 3, 4, 5, etc. To keep than liquid and economically stored, butane must be maintained under pressure or at low temperatures.

Butylene/Butene (C_4H_8): Hydrocarbons with several different isomers in the olefin series with a general formula C_nH_{2n}. Used in refining in an alkylation plant or in petrochemicals to make solvents and some polymers.

Carbon Hydrogen Ratio: The carbon hydrogen ratio is determined by the following:

$$\frac{C}{H} = \frac{74 + 15d}{26 - 15d}$$

where d is the specific gravity at 15°C

The carbon hydrogen ratios of different products are:

LPG (d= 0.56)	= 4.68
Naphtha (d = 0.72)	= 5.57
Gasoline (d = 0.73)	= 5.64
ATF (d = 0.79)	= 6.067
SK (d = 0.795)	= 6.10
JP5 (d = 0.80)	= 6.14
HSD (d = 0.845)	= 6.50
LDO (d = 0.87)	= 6.72
LSHS (d = 0.98)	= 7.85
FO (d = 0.99)	=7.97

Calorific Value: 1. A measure of the amount of energy released as heat when a fuel is burned. 2. The quantity of heat produced by the complete combustion of a fuel. This can be measured dry or saturated with water vapor, net or gross.

It is a measure of the heat producing capacity of the fuel. It is determined by:

$$Q_v = 12400 - 2100d^2$$

where

Q_v = calorific value, gross cals/g

d = density at 15°C

Note: 1 cal = 4.184 Joules

Calorific value (average) of different fuels

Fuel	Calorific value, kcal/kg
Naphtha	11330
Kerosene	11070
HSD	10860
Fuel Oil	10219
Charcoal	6900
Hard coal	5000
Fire wood	4750
Lignite-Brown coal	2310

Carbon Number: The number of carbon atoms in one molecule of a given hydrocarbon.

Carbon Residue: Carbon residue is a measure of the coke-forming tendencies of oil. It is determined by destructive distillation in the absence of air of the sample to a coke residue. The coke residue is expressed as the weight percentage of the original sample. There are two standard ASTM tests, Conradson carbon residue (CCR) and Ramsbottom carbon residue (RCR).

Catalyst: A substance present in a chemical reaction that will promote, accelerate or selectively direct a reaction, but does not take part in it by changing chemically itself. Sometimes a catalyst is used to lower the temperature or pressure at which the reaction takes place.

Catalyst/Oil Ratio (C/O): The weight of circulating catalyst fed to the reactor of a fluid-bed catalytic cracking unit divided by the weight of hydrocarbons charged during the same interval.

Catalytic Cracking: 1. The refining process of breaking down the larger, heavier, and more complex hydrocarbon molecules into simpler and lighter molecules. Catalytic cracking is accomplished by the use of a catalyst and is an effective process for increasing the yield of gasoline from crude oil. Catalytic cracking processes fresh feeds and recycled feeds. 2. A central process in reforming in which heavy gas oil range feeds are subjected to heat in the presence of a catalyst and large molecules crack into smaller molecules in the gasoline, diesel and surrounding ranges. 3. A petroleum refining process in which heavy hydrocarbon molecules are broken down (cracked) into lighter molecules by passing them over a suitable catalyst (generally heated). 4. A method of cracking that uses a catalyst to convert hydrocarbons to positively charged carbonations, which then break down into smaller molecules. This can be carried out at much lower temperatures than thermal cracking – still hot 932–1112°F (500–600°C) as compared to around 1292°F (700°C). But that difference adds up to a lot of dollars.

Catalytically Cracked Distillates: These are obtained when high-boiling non-gasoline hydrocarbons are heated under pressure in the presence of a catalyst to obtain lower-boiling gasoline components. Catalytically cracked distillates usually have high octane numbers than straight-run gasoline.

Catalytic Cycle Stock: That portion of a catalytic cracker reactor effluent that is not converted to naphtha and lighter products. This material, generally 340°F (170°C), either may be completely or partially recycled. In the latter case, the remainder will be blended to products or processed further.

Catalytic Hydrocracking: A refining process that uses hydrogen and catalysts with relatively low temperatures and high pressures for converting middle boiling or residual material to high -octane gasoline, reformer charge stock, jet fuel, and/or high-grade fuel

oil. The process uses one or more catalyst, depending upon product output, and can handle high-sulfur feedstocks without prior desulfurization.

Catalytic Hydrotreating: A refining process for treating petroleum fractions from atmospheric or vacuum distillation units (e.g., naphthas, middle distillates, reformer feeds, residual fuel oils, and heavy gas oil) and other petroleum (e.g., cat cracked naphtha, coker naphtha, gas oil, etc.) in the presence of catalysts and substantial quantities of hydrogen. Hydrotreating includes desulfurization, removal of substances (e.g., nitrogen compounds) that deactivate catalysts, conversion of olefins to paraffins to reduce gum formation in gasoline, and other processes to upgrade the quantity of the fractions.

Catalytic Polymerization (cat. poly): A process in which propylene and/or butylenes components are chemically joined to produce gasoline. A phosphoric acid (HPO_3) catalyst is usually employed in the process.

Catalyst Promoter: A substance added to a catalyst to increase the fraction of the total catalyst area which is useful for a reaction.

Catalytic Reforming: 1. A refining process using controlled heat and pressure with catalysts to rearrange certain hydrocarbon molecules, thereby converting paraffinic and naphthenic hydrocarbons (e.g., low-octane gasoline boiling range fractions) into petrochemical feedstocks and higher octane stocks suitable for blending into finished gasoline. 2. A process where low octane straight-run naphthas are chemically changed into high-octane gasoline, called reformate and to produce aromatics (BTX: benzene, toluene and xylene) for petrochemical plants over a platinum (Pt) catalyst. The reformate has higher aromatic and cyclic hydrocarbon contents. Catalytic reforming is reported into two categories, namely:

Low Pressure. A processing unit operating at less than 225 psig measured at the outlet separator.

High Pressure: A processing unit operating at either equal to or greater than 225 psig measured at the outlet separator.

Catalyst Selectivity: The relative activity of a catalyst with respect to a particular component or compound in a mixture.

Catalyst Stripping: The introduction of steam at a point where spent catalyst leaves the reactor, in order to remove or strip the hydrocarbons retained on the catalyst.

Catastrophic Incident: An incident involving a major uncontrolled emission, fire or explosion with an outcome effect zone that extends offsite into the surrounding community.

Cause: The reasons why deviations might occur.

Caustic Soda: Name used for sodium hydroxide (NaOH); used in refineries to treat acidic hydrocarbon streams to neutralize them.

Cavitation: 1. The creating of high-speed, very low pressure vapor bubbles that quickly and violently collapse. It is very detrimental to surfaces in the near proximity, and often seen in severe turbulent flow. 2. Occurs during vaporization of a pumped fluid resulting in vibration, noise, and destruction of equipment. This is when the absolute pressure of the system equals the vapor pressure of the pumped fluid. In a centrifugal pump, it results in the damage of the impeller. 3. When the pressure of liquid flowing into a centrifugal pump gets too low, liquid boils inside the pump case and generates bubbles. The discharge pressure and flow become erratically low.

Centipoise (cP): A measure of viscosity related to centistrokes by adjusting for density. 1. Viscosity measurement, $1/1000^{th}$ of a poise. 2. A centripoise (cP) is $1/1000^{th}$ of a poise (P), which is the fundamental unit of dynamic viscosity in the CGS system of units. In the SI system of units, the fundamental unit of dynamic viscosity is the Pascal second (Pa.s) is equivalent of 10P.

Centistoke (cSt): Is $1/100^{th}$ of a Stoke (St), which is the fundamental unit of kinematic viscosity in the CSG system of units. In the SI system of units, the fundamental unit of kinematic viscosity is the millimeter squared per second (mm^2/s), which is equivalent to the centistokes.

Cetane (Hexadecane, $C_{16}H_{34}$): An alkane hydrocarbon with a chemical formula $C_{16}H_{34}$ used as a solvent and in cetane number determinations. 1. A pure paraffin hydrocarbon used as standard reference fuel in determining the ignition qualities of diesel fuels. 2. A number calculated from the API gravity and the D86 50% distilled for a petroleum stock. It is used to rate the performance of a fuel in diesel engines. It is arbitrarily given a cetane number of 100.

Cetane Index: 1. A number calculated from the average boiling point and gravity of a petroleum fraction in the diesel fuel boiling range, which estimates the cetane number of the fraction according to ASTM

D976. An indication of carbon – hydrogen ratio. 2. An empirical method for determining the cetane number of a diesel fuel by a formula based on API gravity and the mid-boiling point (ASTM D975). (See for example, http://www.epa.gov/nvfel/testproc/121.pdf.)

Cetane Number: 1. The percentage of pure cetane in a blend of cetane and alpha-methyl-naphthalene that matches the ignition quality of a diesel fuel sample. This quality, specified for middle distillate fuel, is the opposite of the octane number of gasoline. It is an indication of ease of self-ignition. 2. A term for expressing the ignition quality of a diesel fuel. 3. A measure of the ignition quality of a diesel fuel, expressed as a percentage of cetane that must be mixed with methyl naphthalene to produce the same ignition performance as the diesel fuel being rated. The higher the number, the more easily the fuel is ignited under compression. It is an important factor in determining the quality of diesel fuel. In short, the higher the cetane number, the more easily the fuel combusts in a compression setting (such as a diesel engine). The characteristic diesel "knock" occurs when fuel that has been injected into the cylinder ignites after a delay causing a late shock wave. Minimizing this delay results in less unburned fuel in the cylinder and less intense knock. Therefore higher-cetane fuel usually causes an engine to run more smoothly and quietly. This does not necessarily translate into greater efficiency, although it may in certain engines. The cetane number is determined in a single cylinder Cooperative Fuel Research (CFR) engine by comparing its ignition quality with that of reference blends of known cetane number.

Cetane number = 0.72 diesel index (10)

Calculated Cetane Index (CCI) is determined by four variables:

$$CCI = 45.2 + (0.0892)(T_{10}N) + [0.131 + 0.901(B)][T_{50}N] + [0.0523 - (0.420)B][T_{90}N] + [0.00049][(T_{10}N)^2 - (T_{90}N)^2] + 107B + 60B^2$$

where T_{10} = 10 % distillation temperature, °C
T_{50} = 50 % distillation temperature, °C
T_{90} = 90% distillation temperature, °C
B = $e^{-3.5DN} - 1$
D = Density @ 15 °C
DN = D – 0.85

CFR: Combined feed ratio. The ratio of total feed (including recycle) to fresh feed.

CGO: Coker gas oil.

Charge Capacity: The input (feed) capacity of the refinery processing facilities.

Characterization Factor (CF): 1. An index of feed quality, also useful for correlating data on physical properties. The Watson or Universal Oil Property (UOP) characterization factor, K_W is defined as the cube root of the mean average boiling point in °R divided by the specific gravity. An indication of carbon to hydrogen ratio. K_w is expressed by

$$K_w = \frac{T_B^{1/3}}{\text{Sp.Gr}}$$

where
T_B = mean average boiling point, °R [°F +460]
Sp.Gr = Specific gravity at 60°F
T_B is the average boiling point in °R taken from five temperatures corresponding to 10, 30, 50, 70 and 90% volume vaporized.

2. A calculated factor used to correlate properties for petroleum streams. It is a measure of the paraffinicity of the stream and is defined as $CF = \left[MABP^{1/3} / \text{Sp.Gr} \right]$, where MABP = mean average boiling point temperature, °R and Sp.Gr. = specific gravity at 60°F (15.9°C) relative to water.

Typically Watson characterization factor varies between 10.5 and 13 for various crude streams. Highly paraffinic crude typically possesses a K_w of 13. On the other hand, highly naphthenic crude possesses a K_w factor of 10.5. Therefore, Watson characterization factor can be used to judge the quality of the crude oil in terms of the dominance of the paraffinic or naphthenic compounds.

Checklist: A detailed list of desired system attributes for a facility. It is used to assess the acceptability of a facility compared to accepted norms.

Clarified Oil: The heaviest stream from a catalytic cracking process after settling to remove suspended catalyst particles.

Clear Treating: An elevated temperature and pressure process usually applied to thermally cracked naphthas to improve stability and color. The stability is increased by the adsorption and polymerization of reactive diolefins in the cracked naphtha. Clay treating is used for treating jet fuel to remove surface agents that adversely affect the water separator index specifications.

Clear: Without lead. Federal regulations require that fuels containing lead must be dyed.

Cloud Point: 1. The temperature at which solidifiable compounds (wax) present in the sample begin to crystallize or separate from the solution under a method of prescribed chilling. 2. The temperature at which a noticeable cloud of crystals or other solid materials appear when a sample is cooled under prescribed conditions. Cloud point is a typical specifications of middle distillate fuels; ASTM D-2500.

Cold Filter Plugging: Is defined as that temperature at which a fuel suspension fails to flow through a standard filter when cooled as prescribed by the test method.

Coke drum: A large upright drum used as a receptacle for coke formed in the delayed coking process.

Coke: 1. A product of the coking process in the form of mostly solid, densely packed carbon atoms. 2. Deposits of carbon that settle on catalysts in cat. crackers, cat. reformers, hydrocrackers and hydrotreaters and degrade their effectiveness. 3. A carbonaceous deposit formed by the thermal decomposition of petroleum.

Coker: A refinery process in which heavy feed such as flasher bottoms, cycle oil from a catalytic cracker, or thermal cracked gas oil is cooked at high temperatures. Cracking creates light oils; coke forms in the reactors and needs to be removed after they fill up.

Coking: A refining process in which petroleum oil is heated destructively such that the heaviest materials are converted to coke. There are two processes: delayed coking and fluid coking, with delayed coking being the most widely used.

Coil: A series of pipes in a furnace through which an oil flows and is heated.

Color: It is an indication of the thoroughness of the refining process. This is determined by Saybolt Chromometer or by Lovibond Tintometer. Saybolt color of petroleum products test is used for quality control and product identification purposes on refined products having as ASTM color of 0.5 or less.

ASTM color of petroleum products applies to products having ASTM color of 0.5 or darker, including lubricating oils, heating oils, and diesel fuel oils.

Pale	= 4.5 ASTM color or lighter
Red	= Darker than 4.5 ASTM
Dark	= Darker than 8.0 ASTM

Compressed Natural Gas: 1. Natural gas that has been compressed under high pressures (typically between 3000 and 3600 psi and held in a container; expands when released for use as a fuel. 2. Natural gas compressed to a volume and density that is practical as a portable fuel supply (even when compressed, natural gas is not a liquid). 3. Natural gas in its gaseous state that has been compressed. 4. Natural gas that is under pressure. The pressure reduces the volume occupied for the gas so it can be contained in a smaller vessel.

Compressibility: The volume change of a material when pressure is applied.

Compressibility Factor (Z): 1. The fractional reduction in the volume of a substance with applied pressure. The compressibility factor is a measure of the compressibility of a gas, Z and used as a multiplier to adapt the ideal gas law for non-ideal gases. 2. The ratio of the actual volume of a gas divided by the volume that would be predicted by the ideal gas law, usually referred to as the "Z" factor.

$$Z = \frac{pV}{RT}$$

where p is the pressure, V is the volume, R is the universal gas constant, and T is the absolute temperature.

Compressible fluid: A fluid in which the density changes with applied pressure. The compressibility of liquids is negligible in comparison with gases and vapors. The isothermal compressibility of a gas is the change in volume per unit volume or density for a unit change in applied pressure given as:

$$c = \frac{-1}{V}\left(\frac{\partial V}{\partial p}\right)_T = \frac{-1}{\rho}\left(\frac{\partial \rho}{\partial p}\right)_T$$

Isothermal compressibility coefficients are frequently used in oil and gas engineering, transient fluid flow calculation, and in the determination of the physical properties of substances.

Compression Ratio: Is a measure of the amount of compression that takes place in an engine's cylinder. The ratio of volumes in an internal combustion cylinder when the piston is at the bottom of the stroke to that when the piston is at the top of the stroke, giving a measure of how much the air or air/fuel mixture is compressed in the compression stroke.

$$CP = \frac{V_1}{V_2} = \frac{\text{Volume when piston is @ bottom of stroke}}{\text{Volume when piston is @ top of stroke}}$$

Compressor: 1. A device that increases the pressure of gas. Commonly used as a production rate increaser by increasing the gas pressure delivered from low-pressure

gas wells to enter the pipeline. The intake into the compressor lowers the wellhead pressure, creating a larger drawdown. 2. An engine used to increase the pressure of natural gas so that it will flow more easily through a pipeline. 3. Thermodynamic machine that increases the pressure of a gas flow using mechanical energy. 4. A mechanical device used to raise the pressure of a gas. Compressors can be of three types: axial, centrifugal or reciprocating. The usual means of providing the required power are electrical motors, steam turbines or gas turbines.

Compressor Station: 1. A booster station associated with a gas pipeline that uses compressors to increase the gas pressure. When gas turbines are used to provide compressor power, stations can use some of the gas moving through the line as fuel. 2. Stations located along natural gas pipelines that recompress gas to ensure an even flow.

Condensation: Reaction in which aromatic ring structures combine to form ring structures larger than the reactants.

Condensate: 1. The relatively small amount of liquid hydrocarbon typically C_4,s through naphtha or gas oil that gets produced in the oil patch with unassociated gas. 2. The liquid formed when a vapor cools.

Conradson Carbon: A test used to determine the amount of carbon residue left after the evaporation and pyrolysis of an oil under specified conditions. Expressed as weight percentage; ASTM D-189.

Conradson Carbon Residue (CCR): Results from ASTM test D189. It measures the coke-forming tendencies of oil. It is determined by destructive distillation of a sample to elemental carbon (coke residue), in the absence of air, expressed as the weight percentage of the original sample. A related measure of the carbon residue is called ***Ramsbottom carbon residue***. A crude oil with a high CCR has a low value as refinery feedstock.

Conradson Carbon Residue (ASTM D 1289): ASTM D 4530 microcarbon residue: This procedure determines the carbon residue left after evaporation and pyrolysis of an oil sample under prescribed conditions and is a rough indicator of oil's relative coke-forming tendency or contamination of a lighter distillate fraction with a heavier distillate fraction or residue.

Carbon residue and atomic H – to – C ratio is correlated by:

$$H/C = 171–0.015CR \text{ (conradson)}$$

Consequence: 1. Is the ultimate harm that may occur due to a credible hazard release scenario. 2. The direct undesirable result of an accident sequence usually involving a fire, explosion, or release of toxic material. Consequence description may include estimates of the effects of an accident in terms of factors such as health impacts, physical destruction, environmental damage, business interruption, and public reaction of company prestige (See Figure 6).

Continuous Catalytic Reforming (CCR) process: Continuous catalytic reforming process occurs where the catalyst is circulated through the reactors and a regeneration step, analogous to catalytic cracking processes.

Continuous stirred tank reactor (CSTR): 1. A type of idealized chemical reactor used to contain a chemical reaction in which liquid reactants continuously flow into the reactor and products continuously removed such that there is no accumulation within the reactor. By assuming perfect mixing of the reactants within the reactor, by using a stirrer/mixer, the composition of the material is therefore assumed to be the same as the composition at all points within the reactor. 2. Reactors that are characterized by a continuous flow of reactants into and a continuous flow of products from the reaction system. Examples are the plug flow reactor and the continuous stirred flow reactor.

Control of Major Accident Hazards (COMAH): The legislation requires that businesses holding more than threshold quantities of named dangerous substances "Take all necessary measures to prevent major accidents involving dangerous substances. Limit the consequences to people and the environment of any major accidents which do occur." Plant designers need to consider whether their proposed plant will be covered by this legislation at the earliest stages.

Control of Substances Hazardous to Health (COSHH): The legislation that requires risk assessment

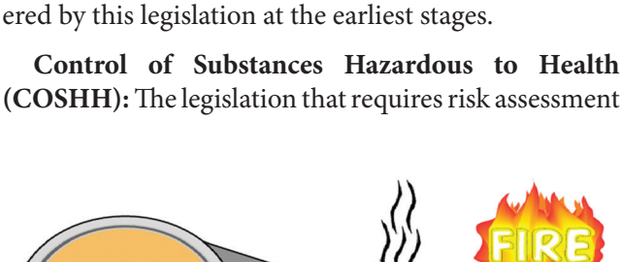


Figure 6 A consequence.

and control of hazards associated with all chemicals and used in a business which has potentially hazardous properties. Consideration of the properties of chemicals used as feedstock, intermediates, and products, is a basic part of plant design. Inherently safe design requires us to consider these issues at the earliest stage.

Conversion: 1. A measure of the completeness of a chemical reaction. It is often presented as the fraction of a particular reactant consumed by the chemical reaction. The ***conversion per pass*** is a measure of the limiting reactant that is converted in a chemical reactor and recycled for combination with fresh reactant feed. Not all reactions are complete within the reactor, and in many cases, unreacted reactants are separated from products and recycled for further reaction. 2. Typically, the fraction of a feedstock converted to gasoline and lighter components.

Correlation Index (CI): The U.S. Bureau of Mines factor for evaluating individual fractions from crude oil. The CI scale is based upon straight chain hydrocarbons having a CI value of 0 and benzene having a value of 100. The lower the CI value, the greater the concentrations of paraffin hydrocarbons in the fraction, and the higher the CI value, the greater the concentrations of naphthenes and aromatics. CI is an indication of the hydrocarbon to carbon ratio and the aromaticity of the sample. CI is expressed by:

$$CI = \frac{87{,}552}{T_B} + 473.7\text{Sp.Gr} - 456.8$$

$$CI = \frac{48640}{K} + 473.7\text{d} - 456.8$$

K = average boiling point (K = °C + 273.15)
d = specific gravity at 15 °C/15 °C
where
T_B = mean average boiling point, °R
Sp.Gr = specific gravity at 60°F

Corrosion: 1. The deteriorating chemical reaction of a metal with the fluids with which it is in contact. 2. The gradual decomposition or destruction of a material by chemical action, often due to an electrochemical reaction. Corrosion may be caused by (a) stray current electrolysis; (b) galvanic corrosion caused by dissimilar metals, (c) differential-concentration cells. Corrosion starts at the surface of a material and proceeds inward.

Corrosion Inhibition: Corrosion can be defined as the unwanted production of a salt from a metal. Adding acid or oxygen is a good way for this to occur. The main way of slowing corrosion down (inhibition) is by providing an impermeable coating to stop the chemical reaction from occurring in the first place or by providing a more easily attacked metal that will be consumed first (a "sacrificial anode").

Corrosion Inhibitor: 1. A chemical substance or combination of substances that when present in the environment, prevents or reduces corrosion. 2. Substance that slows the rate of corrosion.

Corrosive Gas: 1. A gas that attacks metal or other specified targets. Most commonly CO_2 and H_2S. Usually in association with water or water vapor. Oxygen can be described as a corrosive gas in some cases. 2. In water, dissolved, oxygen reacts readily with metals at the anode of a corrosion cell, accelerating the rate of corrosion until a film of oxidation products such as rust forms. At the cathode where hydrogen gas may form a coating on it and therefore, slows the corrosion rate, oxygen reacts rapidly with hydrogen gas forming water and again increases the rate of corrosion.

Cracking: The breaking down of higher molecular weight hydrocarbons to lighter components by the application of heat. Cracking in the presence of a suitable catalyst produces an improvement in yield and quality over simple thermal cracking.

Cracking Correction: Correction to a laboratory distillation to account for the lowering of the recorded temperatures because of thermal cracking of the sample in the distillation flask. Cracking occurs for most petroleum stocks at temperatures greater than about 650°F (344°C) at atmospheric pressure.

Cracked Stock: A petroleum stock that has been produced in a cracking operation, either catalytic or thermal. Cracked stocks contain hydrogen deficient compounds such as olefins (C_nH_{2n}) and aromatics (C_nH_{2n-6}).

Critical Point: The temperature and pressure at which a component or mixture of components enter a dense phase, being neither liquid nor vapor.

Critical Pressure: The vapor pressure at the critical temperature.

Critical Temperature: The temperature above which a component cannot be liquefied. For mixtures, the temperature above which all of the mixture cannot be liquefied.

Crude Assay Distillation: *See Fifteen-five (15/5) distillation.*

Crude Chemistry: Fundamentally, crude oil consists of 84–87 wt % carbon, 11–14% hydrogen, 0–3 wt % sulfur, 0–2 wt % oxygen, 0–0.6 wt % nitrogen and metals ranging from 0–100 ppm. Understanding thoroughly the fundamentals of crude chemistry is very important in various refining processes. The existence of compounds with various functional groups and their dominance or reduction in various refinery products is what is essentially targeted in various chemical and physical processes in the refinery.

Based on chemical analysis and existence of various functional groups, refinery crude can be broadly categorized into about nine categories:

1. Paraffins, C_nH_{2n+2}, CH_4, C_2H_6, C_3H_8	4. Aromatics, C_nH_{2n-6}, C_6H_6, C_7H_8, C_8H_{10}	7. Oxygen containing compounds, R-OH, CH_3OH, C_6H_5OH
2. Olefins, C_nH_{2n}. C_2H_4, C_3H_6	5. Naphthalene	8. Resins
3. Naphthenes, C_nH_{2n}, C_6H_{12},	6. Organic sulfur compounds, RSH, CH_3SH, $R-S-R'$	9. Asphaltenes

Crude and Crude Oil: 1. A range of principally carbon-hydrogen chain compounds with generally straight carbon chain lengths of C_1 (methane) to C_{60+}, compounds boiling higher than 2000°F (1094°C). The straight-chain materials are alkanes. 2. Oil as it comes from the well; unrefined petroleum. 3. The petroleum liquids as they come from the ground; formed from animal and vegetable material that is collected at the bottom of ancient seas. 4. Tarry group consisting of mixed carbon compounds with a highly variable composition. 5. A mixture of hydrocarbons that exists in liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface-separating facilities. Depending upon the characteristics of the crude stream, it may also include the following:

- Small amounts of hydrocarbons that exist in gaseous phase in natural underground reservoirs but are liquid at atmospheric pressure after being removed from oil well (casing head) gas in lease separators and are subsequently commingled with the crude stream without being separately measured. Lease condensate recovered as a liquid from natural gas wells in lease or field separation facilities and later mixed into the crude stream is also included.
- Small amounts of non-hydrocarbons produced from oil, such as sulfur and various metals.
- Drip gases and liquid hydrocarbons produced from tar sands, gilsonite and oil shale.
- Liquid produced at natural gas processing plants are excluded. Crude oil is refined to produce a wide range of petroleum products, including heating oils; gasoline, diesel, and jet fuels, lubricants, asphalt; ethane, propane and butane and many other products used for their energy or chemical content.

The basic types of crudes are asphalt, naphthenic, or paraffinic depending on the relative proportion of these types of hydrocarbons present.

Crude Oil Assay: Is a precise and detailed analysis on carefully selected samples of crude thoroughly representative of average production quality. It helps to assess the potential sales value of a new crude oil and to plan for its most effective utilization. Numerous important feed and product characterization properties in refinery engineering include:

1. API gravity
2. Watson Chracterization factor
3. Viscosity
4. Sulfur content
5. True boiling point (TBP) curve
6. Pour point
7. Flash and fire point
8. ASTM distillation curve
9. Octane number

Crude Oil Losses: This represents the volume of crude oil reported by petroleum refineries as being lost in their operations. These losses are due to spills, contamination, fires, etc., as opposed to refinery processing losses.

Crude Oil Production: The volume of crude oil produced from oil reservoirs during given periods of time. The amount of such production for a given period is measured as volumes delivered from lease storage tanks (i.e., the point of custody transfer) to pipelines, trucks, or other media for transport to refineries

or terminals with adjustments for (1) net differences between opening and closing lease inventories, and (2) basic sediment and water (BS & W).

Crude Oil Qualities: This refers to two properties of crude oil, the sulfur content and API gravity, which affect processing complexity and product characteristics.

Cryogenics: The production and application of low-temperature phenomena. The cryogenic temperature range is usually from -238°F (-150°C) to absolute zero -460°F (-273°C), the temperature at which molecular motion essentially stops. The most important commercial application or cryogenic gas liquefaction technique is the storage, transportation and regasification of LNG.

Cryogenic Liquid or Cryogenics: Cryogenic liquids are liquefied gases that are kept in their liquid state at very low temperatures and have a normal boiling point below -238°F (-150°C). All cryogenic liquids are gases at normal temperatures and pressures. These liquids include methane (CH_4), oxygen (O_2), nitrogen (N_2), helium (He) and hydrogen (H_2). Cryogens normally are stored at low pressures.

Cryogenic Recovery: Cryogenic recovery processes are carried out at temperatures lower than -150°F (-101°C). The low temperatures allow the plant to recover over 90% of the ethane in the natural gas. Most new gas processing plants use cryogenic recovery technology.

CSB: An acronym for Chemical Safety and Hazard Investigation Board. An agency of the U.S. government charted to investigate chemical industry incidents, determine their root cause, and publish their findings to prevent similar incidents occurring.

Cut: That portion of crude oil boiling within certain temperature limits. Usually, the limits are on a crude assay true boiling point (TBP) basis.

Cut Point Temperature, Cut Points: A temperature limit of a cut, usually on a true boiling point basis, although ASTM distillation cut point is not uncommon. The boiling point curve most commonly used to define cut points is the true boiling point (TBP) at one atmosphere of pressure.

Cut Point Ranges: A series of cut point temperatures are defined for a petroleum stock. The cut point ranges are the temperature differences between adjacent cut point temperatures. When developing petroleum pseudo-components for a petroleum stock, cut point ranges must be defined that include the total boiling point range of the stock.

Cutter Stock: Diluent added to residue to meet residual fuel specifications for viscosity and perhaps sulfur content. Typically cracked gas oil.

Cycloparaffin: A paraffin molecule with a ring structure.

Cycle Oil, Cycle Stock: An oil stock, containing a hydrogen deficient compound that was produced in a thermal or catalytic cracking operation.

Cyclization: Chemical reaction in which non-ring structure paraffin or olefins are converted into ring structures.

Cyclo-olefins: Unsaturated ring structure with one or two double bonds in the ring.

Darcy-Weisbach equation: An equation used in fluid mechanics to determine the pressure or head loss due to friction within a straight length of pipe for a flowing fluid. The frictional pressure drop, Δp_f (psi) is expressed by

$$\Delta p_f = f_D \left(\frac{L}{d} \right) \frac{\rho v^2}{2}$$

where

$$f_D = \left(\frac{\tau_w}{\frac{\rho v^2}{2}} \right)$$

In the form of frictional head loss, h_f (ft) is:

$$h_f = f_D \left(\frac{L}{d} \right) \frac{v^2}{2g}$$

where, τ_w is the shear stress, f_D is the Darcy friction factor, dimensionless ($f_D = 4f_F$), f_F is the fanning friction factor, L and d and the pipe length (ft) and inside diameter (ft), v is the average velocity of the fluid (ft), ρ is the fluid density (lb_m/ft^3) and g is the acceleration due to gravity (ft/s^2). It is known as the Darcy-Weisbach or Moody friction factor, whose value depends on the nature of the flow and surface roughness of the pipe. This Darcy friction factor is four times the Fanning friction factor (i.e., $f_D = 4f_F$). The value of the friction factor can be determined from various empirical equations and published charts such as the Moody diagram (See Figure 7).

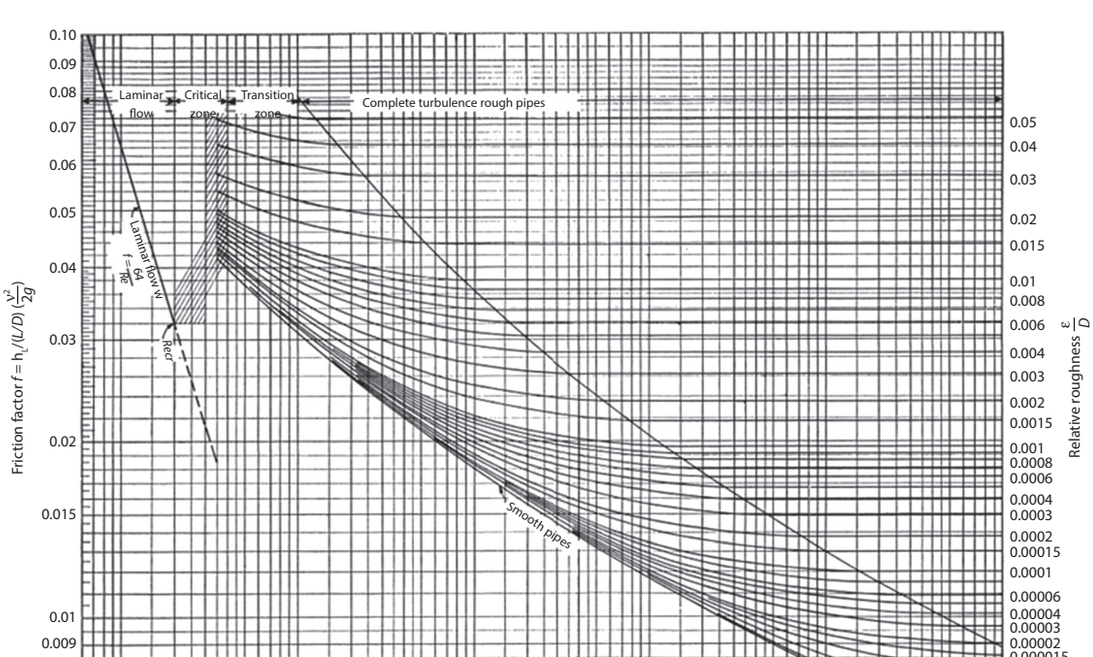


Figure 7 Moody diagram.

An empirical equation known as the Colebrook-White equation has been proposed for calculating the friction factor in the turbulent flow:

$$\frac{1}{\sqrt{f_D}} = -2\log_{10}\left(\frac{e}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{f_D}}\right)$$

where

D = pipe inside diameter, in

e = absolute pipe roughness, in

Re = Reynolds number, dimensionless

The term f_D (L/d) may be substituted with a head loss coefficient K (also known as the resistance coefficient) and then becomes

$$h_f = K\frac{v^2}{2g}$$

The head loss in a straight piece of pipe is represented as a multiple of the velocity head $v^2/2g$. Following a similar analysis, we can state that the pressure drop through a valve or fitting can be represented by $K(v^2/2g)$, where the coefficient K is specific to the valve and fitting. Note that this method is only applicable to turbulent flow through pipe fittings and valves. Recently K is presented by Hooper's 2-K method and Darby's 3 K- method.

DAO - Deasphalted oil: The raffinate product from the propane deasphalting unit.

D1160: ASTM laboratory distillation method for high-boiling streams. The D1160 is performed under vacuum conditions with 10 mm Hg being the most common pressure used for the test. D1160 data are normally reported at a 760 mm Hg basis.

D2887: ASTM simulated distillation method for high-boiling streams. The D2887 has an upper limit of 1000°F (538°C) and the temperatures are reported versus weight percent distilled. A normal paraffin standard is used to convert the chromatographic results to a boiling point curve.

D3710: ASTM simulated distillation method for gasoline and light naphthas. D3710 data are reported on a volume basis.

D86: ASTM laboratory distillation method conducted at atmospheric pressure for streams boiling below approximately 700°F (371°C). The D86 is the most commonly used laboratory distillation for petroleum stocks.

Deasphalting: Process for removing asphalt from petroleum fractions, such as reduced crude.

Debottlenecking: 1. Increasing production capacity of existing facilities through the modification of existing equipment to remove throughput restrictions. Debottlenecking generally increases capacity for a fraction of the cost of building new facilities. 2. The process of increasing the production capacity of existing facilities through the modification of existing equipment to remove throughput restrictions. 3. A program, typically in surface facilities and lines to remove pressure drop causing flow restrictions.

Debutanizer: A column that removes n-butanes (nC_4H_{10}) and lighter in the top product.

Decant Oil: The bottom stream from the FCC unit distillation tower after catalyst has been separated from it.

Decanted Water: Insoluble water that is drawn from a drum containing condensed hydrocarbons and water.

Decoking: The process of removing coke from catalysts in a catalytic cracker, catalytic reformer, hydrocracker or hydrotreaters. Usually heated air will oxidize the coke to carbon monoxide or carbon dioxide.

Deethanizer: A column that removes ethane (C_2H_6) and lighter in the top product.

Deflagration (i.e., "to burn down"): Is a term describing subsonic combustion propagation through heat transfer, hot burning material heats the next layer of cold material and ignites it. Most "fire" found in daily life, from flames to explosions, is deflagration. Deflagration is different from detonation, which propagates supersonically through shock waves.

Delayed Coker: A process unit in which residue is cooked until it cracks to coke and light products.

Delayed Coking: 1. A semi-continuous thermal process for the conversion of heavy stock to lighter material. The method involves pre-heating the feedstock in a pipe still, discharging into large insulated coke drums and retaining there for a particular length of time for cracking to occur. Gas, gasoline and gas oil are recovered as overhead products and finally coke is removed. 2. A process by which heavier crude oil fractions can be thermally decomposed under conditions of elevated temperatures and low pressure to produce a mixture of lighter oils and petroleum coke. The light oils can be processed further in other refinery units to meet product specifications. The coke can be used either as a fuel or in other applications such as the manufacturing of steel or aluminum.

Dehydrogenation: A chemical reaction in which a compound loses bonded hydrogen.

Deisobutanizer: A column that removes isobutane (iC_4H_{10}) and lighter in the top product.

Demethanizer: A column that removes methane (CH_4) and lighter in the top product.

Density: The density of crude oil and petroleum fractions is usually specified in °API, specific gravity or kilograms per cubic meter (kg/m^3). The numerical values of specific gravity and kg/m^3 are equal; that is a fraction with a specific gravity of 0.873 has a density of 0.873 kg/m^3. The API scale runs opposite to that of specific gravity, with larger values for less dense materials and smaller values for more dense fractions (water = 10°API). By definition, °API is always 60°F (15.6°C) for a liquid.

Depentanizer: A column that removes n-pentane (nC_5H_{12}) and lighter in the top product.

Depropanizer: A column that removes propane (C_3H_8) and lighter in the top product.

Desalting: A process that removes chlorides and other inorganic salts from crude oil by injecting water and applying an electrostatic field to force the salt into the aqueous phase.

Desiccant: Absorbent or adsorbent, liquid or solid that removes water or water vapor from an air stream.

Desiccant Drying: The use of drying agent to remove moisture from a stream of oil or gas. In certain product pipelines, great effort is made to remove all the water vapor before putting the line into service. To accomplish this desiccant dried air or an inert gas is pumped through the line to absorb the moisture that may be present even in the ambient air in the line.

Desiccation: The process of drying and removing the moisture within a material. It involves the use of a drying agent known as a desiccant. Desiccants that function by adsorption of moisture include silica gel and activated alumina, while chemical desiccants that function by the reaction with water to form hydrates include calcium chloride and solid sodium hydroxide. A desiccator is a container used for drying substances or for keeping them dry free of moisture. Laboratory desiccators are made of glass and contain a drying agent such as silica gel.

Design Codes (design standards): Published standards required for equipment and working practices within the chemical and process industries that represent good practice and define the level of standard of design. Developed and evolved over many years and based on tried and tested practices. There are a number of national standards organizations and institutions that provide published standards for design, materials, fabrication, testing of processes and equipment. These include the American Petroleum Institute (API), the American National Standards Institute (ANSI), the American Society of Mechanical Engineers (ASME), the American Society for Testing and Materials (ASTM), the American Iron and Steel Institute (AISI) and the British Standards Institute (BSI).

Desorption: The release of materials that have been absorbed or adsorbed in or onto a formation.

Desulfurization: The removal of sulfur, from molten metals, petroleum oil or flue gases. Petroleum desulfurization is a process that removes sulfur and its compounds from various streams during the refining process. Desulfurization processes include catalytic hydrotreating and other chemical/physical processes such as adsorption. Desulfurization processes vary based on the type of stream treated (e.g., naphtha, distillate, heavy gas oil, etc.) and the amount of sulfur removed (e.g., sulfur reduction to 10 ppm). *See also Catalytic Hydrotreating*.

Desuperheating zone: A section of a distillation/fractionating column where a superheated vapor is cooled and some liquid is condensed. FCC main fractionators have a desuperheating zone.

Detonation ("to thunder down"): Is a type of combustion involving a supersonic exothermic front accelerating through a medium that eventually drives a shock front propagating directly in front of it. Detonations occur in both conventional solid and liquid explosives, as well as in reactive gases. The velocity of detonation in solid and liquid explosives is much higher than that in gaseous ones, which allows the wave system to be observed with greater detail.

An extraordinary variety of fuels may occur as gases, droplet fogs, or dust suspensions. Oxidants include halogens, ozone, hydrogen peroxide and oxides of nitrogen. Gaseous detonations are often associated with a mixture of fuel and oxidant in a composition somewhat below conventional flammability ratios. They happen most often in confined systems, but they sometimes occur in large vapor clouds. Other materials, such as acetylene, ozone and hydrogen peroxide are detonable in the absence of oxygen. See also Knocking.

Dewaxing: The removal of wax from lubricating oils, either by chilling and filtering solvent extraction, or selective hydrocracking.

Dew Point: 1. A vapor at its dew point temperature is on the verge of starting to condense to a liquid. Cool the vapor by 1°F, or raise its pressure by 1 psi and it will form drops of liquid. Air at 100% relative humidity is at its dew point temperature. Cool it by 1°F and it starts to rain. 2. The temperature and pressure at which the first drop of liquid will condense for a component or mixture of components. 3. The temperature at a given pressure at which a vapor will form a first drop of liquid on the subtraction of heat. Further cooling of the liquid at its dew point results in condensation of part or all the vapors as a liquid. 4. The temperature at which vaporized materials start to condense into liquid form. 5. The temperature at which liquids begin to condense from the vapor phase in a gas stream. *See also Bubble point.*

Diene: Same as diolefin.

Diesel: 1. An internal combustion engine in which ignition occurs by injecting fuel in a cylinder where air has been compressed and is at very high temperature, causing self-ignition. 2. Distillate fuel used in a diesel engine. *See the Diesel engine.*

Diesel Fuel: A fuel produced for diesel engines with typical ASTM 86 boiling point range of 450–675 °F (233–358°C).

Diesel Index (DI): A measure of the ignition quality of a diesel fuel. Diesel index is defined as

$$DI = \frac{(^{\circ}\text{API})(\text{Aniline Point})}{100}$$

The higher the diesel index, the more satisfactory the ignition quality of the fuel. By means of correlations unique to each crude and manufacturing process, this quality can be used to predict the cetane number (if no standardized test for the latter is available).

Diolefin: C_nH_{2n}: Paraffin-type molecule except that it is missing hydrogen atoms causing it to have two double bonds somewhere along the chains.

DIPE: Di-isopropyl ether. An oxygenate used in motor fuels.

Disposition: the components of petroleum disposition are stock change, crude oil losses, refinery

inputs, exports and products supplied for domestic consumption.

Distillate Fuel Oil: A general classification for one of the petroleum fractions produced in conventional distillation operations. It includes diesel fuels and fuel oils. Products known as No. 1, No. 2, and No. 4 diesel fuel are used on highway diesel engines, such as those in trucks and automobiles, as well as off-highway engines, such as those in railroad locomotives and agricultural machinery. Products known as No.1, No. 2, and No. 4 fuel oils are used primarily for space heating and electric power generation.

No. 1 Distillate. A light petroleum distillate that can be used as either a diesel fuel or a fuel oil.

No. 1 Diesel Fuel. A light distillate fuel oil that has distillation temperatures of 550°F (288°C) at the 90% point and meets the specifications defined in ASTM Specification D 975. It is used in high-speed diesel engines generally operated under frequent speed and load changes, such as those in city buses and similar vehicles.

No. 1 Fuel Oil. A light distillate fuel oil that has distillation temperatures of 400°F (204°C) at the 10 percent recovery point and 550°F (288°C) at the 90% point and meets the specifications defined in ASTM Specifications D 396. It is used primarily as fuel for portable outdoor stoves and portable outdoor heaters.

No. 2 Distillate: A petroleum distillate that can be used as either a diesel fuel or a fuel oil.

No. 2 Diesel Fuel: A fuel that has distillation temperature of 500°F (260°C) at the 10% recovery point and 640°F (338°C) at the 90% recovery point and meets the specifications defined in ASTM Specification D 975. It is used in high-speed diesel engines that are generally operated under uniform speed and load conditions, such as those in railroad locomotives, trucks and automobiles.

Low Sulfur No. 2 Diesel Fuel. No. 2 diesel fuel that has a sulfur level no higher than 0.05% by weight. It is used primarily in motor vehicle diesel engines for on-highway use.

High Sulfur No. 2. Diesel Fuel. No. 2 diesel fuel that has sulfur level above 0.05% by weight.

No. 2 Fuel Oil (Heating Oil): A distillate fuel oil that has distillation temperatures of 400°F (204°C) at the 10% recovery point and 640°F (338°C) at the 90% recovery point and meets the specifications defined in ASTM Specification D 396. It is used in atomizing type burners for domestic heating or for moderate capacity commercial/industrial burner units.

No. 4 Fuel. A distillate fuel oil made by blending distillate fuel oil and residual fuel oil stocks. It conforms with ASTM Specification D 396 or Federal Specification VV – F- 815C and is used extensively in industrial plants and in commercial burner installations that are not equipped with preheating facilities. It also includes No. 4 diesel fuel used for low- and medium-speed diesel engines and conforms to ASTM Specification D975.

No. 4 Diesel Fuel. See No. 4 Fuel.

No. 4 Fuel Oil. See No. 4 Fuel.

Distillate: 1. The liquid obtained by condensing the vapor given off by a boiling liquid. 2. Any stream except the bottoms coming from a fractionator. 3. The products or streams in the light gas oil range such as straight run light gas oil, cat. cracked light gas oil, heating oil or diesel.

Distillation: Same as fractionation. A separation process that results in separated products with different boiling ranges. Distillation is carried out in a way that the materials being separated are not subjected to conditions that would cause them to crack or otherwise decompose or chemically change. It is a physical process.

Distillation Column: A tall vertical cylindrical vessel used for the process of distillation. Hot vapor rises up the column, which is brought into intimate contact with cooled liquid descending on stages or trays for a sufficient period of time so as to reach equilibrium between the vapor and the liquid. The vapor rises up from the tray below through perforations in the tray, and the liquid on the tray flows over a weir to the tray below. In this way, the more volatile component increases in concentration progressively up the column. In continuous distillation, fresh feed is admitted at the tray corresponding to the same composition. Below the feed point, the section of column is known as the stripping section, while above is referred to as the rectifying section. A reboiler heat exchanger is used to boil the bottom product and produce vapor for the column. A condenser is used to condense some or all of the vapor from the top of the column. A small portion of liquid is returned to the column as reflux. The height of the column is an indication of the ease or difficulty of separation. For example, an ethylene splitter in a refinery used to separate ethylene from ethane, which have close boiling points, requires many trays and the column is very tall. The width of the column is an indication of the internal vapor and liquid rates.

Distillation Curves: In addition to True Boiling Point (TBP) or good fractionation distillations, there are at least three other major types of distillation curves or ways of relating vapor temperature and percentage vaporized: (a) equilibrium flash vaporization, (b) ASTM or non-fractionating distillations, and (c) Hempel or semi-fractionating distillations.

Distillation Range: *See boiling range.*

Distillation Train: A sequence of distillation columns used to separate components from a multicomponent feed. Each column is required to perform a particular separation of either a pure component or a cut between two components. For example, in the separation of four components ABCD in a mixture in which A is the most volatile and D is the least, then the five possible separation sequences requiring three columns are:

Separation	Column 1	Column 2	Column 3
1	A:BCD	B:CD	C:D
2	A:BCD	BC:D	B:C
3	AB:CD	A:B	C:D
4	ABC:D	A:BC	B:C
5	ABC:D	AB:C	A:B

Where it is required to separate a larger number of components, the number of possible separation sequences becomes much larger according to the relationship

$$N = \frac{(2n-2)!}{n!(n-1)!}$$

Where N is the number of sequences and n is the number of components:

Components (n)	4	5	6	7	8	9	10
Sequences (N)	5	14	42	132	429	1430	4862

Distributed Component: A component that appears in both the top and bottom products from a distillation/fractionating column separating zone.

Distributed Control System: A system which divides process control functions into specific areas interconnected by communications (normally data highways) to form a single entity. It is characterized by digital controllers and typically by central operation interfaces.

Distributed control systems consist of subsystems that are functionally integrated but may be physically separated and remotely located from one another. Distributed control systems generally have at least one shared function within the system. This may be the controller, the communication link or the display device. All three of these functions may be shared.

A system of dividing plant or process control into several areas of responsibility, each managed by its own Central Processing Unit, in which the whole is interconnected to form a single entity usually by communication buses of various kinds.

Distributor: A device in a vessel that disperses either liquid or vapor to promote better circulation.

Doctor Test: A method for determining the presence of mercaptan sulfur petroleum products. This test is used for products in which a "sweet" odor is desirable for commercial reasons, especially naphtha; ASTM D-484.

Dow Fire and Explosion Index (F & EI): A method (developed by Dow Chemical Company) for ranking the relative fire and explosion risk associated with a process. Analysts calculate various hazard and explosion indexes using material characteristics and process data.

Downcomer: A device to direct the liquid from a distillation column tray to the next lower distillation tray.

Draw, Side Draw: A product stream withdrawn from a distillation column at a location above the bottom tray and below the top tray. Draws may be vapor or liquid phase.

Dropping Point of Lubricating Greases: Dropping points are used for identification and quality control purposes, and can be an identification of the highest temperature of utility for some applications. This is the temperature at which grease passes from a semisolid to a liquid state under prescribed conditions.

Dry Gas: All C_1 to C_3 material whether associated with a crude or produced as a by-product of refinery processing. Convention often includes hydrogen in dry gas yields.

Effective Cut Points: Cut points that can be considered a clean cut, ignoring any tail ends.

Emergency: A condition of danger that requires immediate action.

Emergency Isolation Valve (EIV): A valve that, in event of fire, rupture, or loss of containment, is used to stop the release of flammable or combustible liquids, combustible gas, or potentially toxic material. An EIV can be either hand-operated or power-operated (air, hydraulic, or electrical actuation).

Emergency Shutdown (ESD): A method to rapidly cease the operation of a process and isolate it from incoming and outgoing connections or flows to reduce the likelihood of an unwanted event from continuing or occurring. Critical valves shut to isolate sections of the process. Other valves may be opened to depressurize vessels or rapidly discharge contents of reactors to quench tanks. Emergency shutdowns may occur due to changes in process conditions causing unstable or unsafe operating conditions, a failure in the control system, operator intervention causing unsafe conditions, plant and pipe failure or some other external event such as an electrical storm or natural catastrophes like earthquakes or coastal flooding.

Emulsion: A colloidal suspension of one liquid dispersed within another. The dispersed phase has droplet sizes usually less than 1 mm. Surfactants or emulsifiers are surface-active agents and used to stabilize emulsions. In the offshore oil industry, emulsions form at the interface of water and oil in crude oil gravity separators. Sufficient hold-up time is used to separate the emulsion, or alternatively surface-active agents are used to encourage separation.

Endothermic reaction: 1. A chemical reaction that absorbs heat from its surroundings in order for the reaction to proceed. Such reactions have a positive enthalpy change and therefore do not occur spontaneously. 2. A reaction in which heat must be added to maintain reactants and products at a constant temperature.

E85: Fuel containing a blend of 70 to 85% ethanol.

End Point (final boiling point): 1. The highest boiling point recorded for a laboratory distillation. Usually, there is some residual material in the laboratory still, and the end point is not the highest boiling point material in the mixture being distilled. 2. The lowest temperature at which virtually 100% of petroleum product will boil off to vapor form.

Energy: The capacity or ability of a system to do work. It may be identified by type as being kinetic, potential, internal, and flow or by source such as electric, chemical, mechanical, nuclear, biological, solar, etc. Energy can be neither created nor destroyed, but converted from one form to another. It can be stored as potential energy, nuclear, and chemical energy, whereas kinetic energy is the energy in motion of a body defined as the work that is done in bringing the body to rest. The internal energy is the sum of the potential energy and kinetic energy of the atoms and molecules in the body. Energy as the units, Btu, cal, Joules.

Energy Balance: 1. An accounting of the energy inputs and outputs to a process or part of a process, which is separated from the surroundings by an imaginary boundary. All energy forms are included in which the energy input across the boundary must equal the energy output plus any accumulation within the defined boundary. When the conditions are steady and unchanging with time, the energy input is equal to the energy output. The most important energy forms in most processes are kinetic energy, potential energy, enthalpy, heat and work. Electrical energy is included in electrochemical processes and chemical energy is in processes involving chemical reactions that occur in various reactor types (e.g., batch, continuous stirred tank, plug flow, fixed and catalytic reactors). 2. Summation of the energy entering a process and the summation of the energy leaving a process. They must equal for a steady-state process.

Energy Management: Is the planning and operation of energy production and energy consumption units. Objectives are resource conservation, climate protection and cost savings, while the users have permanent access to the energy they need. Energy management is the proactive, organized and systematic coordination of procurement, conversion, distribution and use of energy to meet the requirements, taking into account the environmental and economic objectives. It is also the solution for electric power producers to reduce emissions and improve efficiency and availability. Energy management requires reducing NO_x and greenhouse gas emissions, improving fuel efficiency and reducing SCR operating costs, and streamlining the detection, diagnosis and remediation of plant reliability, capacity and efficiency problems. Energy management programs incorporate energy policies, benchmarking, local and corporate goals, types of energy audits and assessments, reporting systems and integration of energy efficiency elements into engineering procedures and purchasing protocols.

Pinch analysis is a tool that is employed in energy management of chemical facilities and is a methodology

for minimizing energy consumption of chemical processes by calculating thermodynamically feasible energy targets (or minimum energy consumption) and achieving them by optimizing heat recovery systems, energy supply methods and processing operating conditions. It is also known as process integration, heat integration, energy integration or pinch technology (See Process Integration).

Engler Distillation: A standard test for determining the volatility characteristics by measuring the percent distilled at various specified temperature (see ASTM D86).

Engine knocking (knock, detonation, spark knocking, pinging, or pinking): Spark ignition in internal combustion engines occur when combustion of the air/fuel mixture in the cylinder does not start off correctly in response to ignition by the spark plug, but one or more pockets of air/fuel mixture explode outside the envelope of the normal combustion front.

The fuel-air charge is meant to be ignited by the spark plug only, and at a precise point in the piston's stroke. Knock occurs when the peak of the combustion process no longer occurs at the optimum moment for the four-stroke cycle. The shock wave creates the characteristic metallic "pinging" sound, and cylinder pressure increases dramatically. Effects of engine knocking range from inconsequential to completely destructive. See also Knocking.

Engineering line diagram (ELD): A diagrammatic representation of a process. Also referred to as ***engineering flow diagram***. It features all process equipment and piping that is required for start-up and shutdown, emergency and normal operation of the plant. It also includes insulation requirements, direction of flows, identification of the main process and start-up lines, all instrumentation, control, and interlock facilities, key dimensions and duties of all equipment, operating and design pressure and temperature for vessels, equipment elevations, set pressures for relief valves, and drainage requirements.

Engineering, Procurement, and Construction Contract: 1. A legal agreement setting out the terms for all activities required to build a facility to the point that it is ready to undergo preparations for operations as designed. 2. The final contracting phase in the development of the export portion of the LNG chain that defines the terms under which the detailed design, procurement, construction, and commissioning of the facilities will be conducted. Greenfield LNG project development involves a wide range of design, engineering, fabrication and construction work far beyond the capabilities of a single contractor. Therefore, an LNG project developer divides the work into a number of segments, each one being the subject of an engineering, procurement and construction (EPC) contract. 3. Contract between the owner of a liquefaction plant and an engineering company for the project development and erection. *See Front-End Engineering and Design Contract*.

Enthalpy (H): The thermal energy of a substance or system with respect to an arbitrary reference point. The enthalpy of a substance is the sum of the internal energy and flow of energy, which is the product of the pressure and specific volume.

$$H = U + pV$$

The reference point for gases is 273K and for chemical reactions is 298K.

Enthalpy balance: A form of energy accounting for a process in which the stream energies to and from the process are expressed as enthalpies. At steady state, the total enthalpy into a process is equal to the total enthalpy out. Where there is an inequality, there is either a loss or an accumulation of material with an associated loss increase in enthalpy. An enthalpy balance is used to determine the amount of heat that will be generated in the process or that needs to be removed to ensure that the process operates safely and to specification.

Entrainment: A non-equilibrium process by which liquids are mechanically carried into a vapor leaving a process vessel or contacting device.

Entrance and exit losses: The irreversible energy loss caused when a fluid enters or leaves an opening, such as into or out of a pipe into a vessel. Where there is a sudden enlargement, such as when a pipe enters a larger pipe or vessel, eddies form and there is a permanent energy loss expressible as a head loss as:

$$H_{exit} = \frac{v^2}{2g}\left(1 - \frac{a}{A}\right)^2$$

Where v is the velocity in the smaller pipe, a is the cross-sectional area of the smaller pipe, A is the cross-sectional area of the larger pipe. For a considerable enlargement the head loss tends to

$$H_{exit} = \frac{v^2}{2g}$$

With a rapid contraction, it has been found experimentally that the permanent head loss can be given by:

$$H_{exit} = K\frac{v^2}{2g}$$

where for very large contraction, K= 0.5

Entropy (dS): The extent to which energy in a closed system is unavailable to do useful work. An increase in entropy occurs when the free energy decreases or when the disorder of molecules increases. For a reversible process, entropy remains constant such as in a friction free adiabatic expansion or compression. The change in entropy is defined as:

$$dS = \frac{dQ}{T}$$

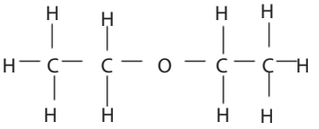
where Q is the heat transferred to or from a system, and T is the absolute temperature. However, all real processes are irreversible, which means that in a closed system there is a small increase in entropy.

Environmental Protection Agency (EPA), United States: 1. Governmental agency, established in 1970. Its responsibilities include the regulation of fuel and fuel additives. 2. The U.S. federal agency that administers federal environmental policies, enforces environmental laws and regulations, performs research, and provides information on environmental subjects. The agency also acts as chief advisor to the president on American environmental policy and issues. 3. A federal agency created in 1970 to permit coordinated and effective government action, for protection of the environment by the systematic abatement and control of pollution, through integration of research monitoring, standard setting, and enforcement activities. 4. U.S. pollution control enforcer. 5. A regulatory agency established by the U.S. Congress to administer that nation's environmental laws. Also called the US EPA.

Error: Discrepancy between a computed, observed or measured value or condition and the true specified or theoretically correct value or condition.

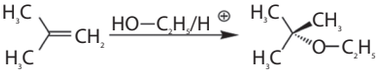
Ethane (C_2H_6): A colorless gas; a minor constituent of natural gas and a component in refinery gas that, along with methane is typically used as refinery fuel. An important feedstock for making ethylene.

Ether ($C_2H_5OC_2H_5$): 1. A generic term applied to a group of organic chemical compounds composed of carbon, hydrogen and oxygen, characterized by an oxygen atom attached to two carbon atoms (e.g., methyl tertiary butyl ether). 2. Any carbon compound containing the functional group (C – O – C). Commonly used ether is diethyl ether, which is used as an anesthetic.



Ethylene (C_2H_4): A colorless gas created by cracking processes. In refineries, it is typically burned with the methane and ethane. In chemical plants, it is purposefully made in ethylene plants and it is basic building block for a wide range of products including polyethylene and ethyl alcohol.

ETBE: Ethyl Tertiary Butyl Ether ($(CH_3)_3COC_2H_5$): 1. A colorless, flammable, oxygenated hydrocarbon blend stock. It is produced by the catalytic etherification of ethanol with isobutylene. 2. An oxygenated gasoline blending compound to improve octane and reduce carbon monoxide emissions. It is commonly used as an oxygenate gasoline additive in the production of gasoline from crude oil.



Equation of state: A relationship that links the pressure, volume and temperature of an amount of a substance. It is used to determine thermodynamic properties such as liquid and vapor densities, vapor pressures, fugacities and deviations from ideality and enthalpies. Various equations of state have been developed to predict the properties of real substances. Commonly used equations of state include the ideal gas law, virial equation, van der Waals' equation, Peng-Robinson, Soave-Redlich Kwong and Lee-Kesler equations. Cubic equations are relatively easy to use and are fitted to experimental data. The van der Waals equation is comparatively poor at predicting state properties. The Lee-Kesler model, which is based on the theory of corresponding states, uses reduced temperature and pressure and covers a wide range of temperatures and pressures.

Equilibrium: A condition or state in which a balance exists within a system, which may be physical or chemical. A system is in equilibrium if it shows no tendency to change its properties with time. Static equilibrium occurs if there is no transfer of energy across the system boundary, whereas dynamic equilibrium is when transfer occurs, but the net effect of the energy is

zero. Thermodynamic equilibrium occurs when there is no heat or work exchange between a body and its surroundings. Chemical equilibrium occurs when a chemical reaction takes place in the forward direction, when reactants form products at exactly the same rate as the reverse reaction of products revert to their original reactant form.

Equilibrium constant (K_c): A reversible process, chemical or physical in a closed system will eventually reach a state of equilibrium. The equilibrium is dynamic and may be considered as a state at which the rate of the process in one direction exactly balances the rate in the opposite direction. For a chemical reaction, the equilibrium concentrations of the reactants and products will remain constant providing the conditions remain unchanged for the homogeneous system:

$$wA + xB \leftrightarrow yC + zD$$

The ratio of the molar concentrations of products to reactants remain constant at a fixed temperature, the equilibrium constant, K_c is:

$$K_c = \frac{[C]^y [D]^z}{[A]^w [B]^x}$$

For the Haber process for the synthesis of ammonia, nitrogen is reacted with hydrogen as:

$$N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g)$$

The equilibrium constant is expressed as partial pressure as:

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{p_{NH_3}^2}{p_{N_2} p_{H_2}^3}$$

Equilibrium K – value (K-value): the ratio of the mole fraction in the vapor divided by the mole fraction in the liquid for a component in the equilibrium state. Each K value corresponds to a given temperature, pressure and mixture composition.

Equilibrium ratio (K): the ratio of the mole fraction in the vapor phase y of a component in a mixture, to the mole fraction in the liquid phase x, at equilibrium.

$$K_A = \frac{y_A}{x_A}$$

It is a function of both temperature and pressure. The relative volatility α, is less dependent on temperature and pressure than the equilibrium constant where for an ideal mixture of two components, A and B:

$$\alpha_{AB} = \frac{K_A}{K_B}$$

Equilibrium-Flash Vaporizer: When a mixture is heated without allowing the vapor to separate from the remaining liquid, the vapor assists in causing the high-boiling parts of the mixture to vaporize. Thus continuous-flash vaporization is used in almost all plant operations. The equipment is used to determine a flash vaporization curve, where a series of runs at different temperatures are conducted, and each run constitutes one point (of temperature and percentage vaporized) on the flash curve.

Equipment Reliability: The probability that, when operating under stated environment conditions, process equipment will perform its intended function adequately for a specified exposure period.

Equivalent length: A method used to determine the pressure drop across pipe fittings such as valves, bends, elbows and T-pieces. The equivalent length of a fitting is that length of pipe that would give the same pressure drop as the fitting. Since each size of pipe or fitting requires a different equivalent length for any particular type of fitting, it is usual to express equivalent length as so many pipe diameters and this number is independent of pipe. For example, if a valve in a pipe of diameter d, is said to have an equivalent length, n, pipe diameters, then the pressure drop due to the valve is the same as that offered by a length, and of the pipe.

Ergun equation: Sabri Ergun developed an equation in 1952 to determine the pressure drop per unit length of a fixed bed of particles such as catalyst at incipient gas velocity, v:

$$\frac{-\Delta p}{L} = \frac{150(1-e)^2 \mu v}{\phi e^3 d^2} + \frac{1.75(1-e)\rho v^2}{\phi e^3 d}$$

Where $-\Delta p/L$ is the pressure drop over the depth of bed, e is the bed voidage, d is the mean particle diameter, ρ is the fluid density, μ is the fluid viscosity, and ϕ is the sphericity. The incipient point of fluidization corresponds with the highest pressure drop at the minimum fluidization velocity.

Erosion: The physical removal of material from a surface by mechanisms that exclude chemical attack. The usual phenomenon that causes erosion is

impingement by either liquid droplets or entrained solid particles. If there are no corrosive substances present, then in many cases, the most common mechanism for material damage due to erosion is impingement by solid particles.

Exothermic reaction: 1. A chemical reaction that gives out/liberates heat. No energy input is required for the reaction to proceed. It has a negative enthalpy change and therefore under the appropriate conditions the reaction will occur spontaneously. Chemical reactors used to contain exothermic reactions therefore require cooling facilities to remove the excess heat that is generated and to maintain a constant temperature. 2. A reaction in which heat is evolved. Alkylation, polymerization, and hydrogenation reactions are exothermic reactions.

Expansion Loop: Piping thermally expands as it gets hot. Allowance must be made for the growth in pipe length, otherwise the pipe will break by cracking at its welds. A fractionator at the Good Hope Refinery in the U.S. was burned down because of such an omission.

Explosion: 1. The sudden conversion of potential energy (chemical or mechanical) to kinetic energy with the production and release of gases under pressure, or the release of a gas under pressure. 2. A release of energy that causes a pressure discontinuity or blast wave.

Exports: Shipments of crude oil and petroleum products from countries, e.g., in the United States. shipments from the 50 states and the District of Columbia to foreign countries, Puerto Rico, the Virgin Islands, and other U.S. possessions and territories.

Failure: 1. Termination of the ability of a functional unit to perform a required function. 2. An unacceptable difference between expected and observed performance.

Fail Safe: A system design or condition such that the failure of a component, subsystem or system or input to it, will automatically revert to predetermined safe static condition or state of least critical consequence for the component, subsystem or system.

Fail Steady: A condition wherein the component stays in its last position when the actuating energy source fails. May also be called Fail in Place.

Failure Mode: The action of a device or system to revert to a specified state upon failure of the utility power source that normally activates or controls the device or system. Failure modes are normally specified as fail open (FO), fail close (FC) or fail steady (FS) which will result in a fail safe or fail to danger arrangement.

Failure Mode and Effects Analysis (FMEA): A systematic, tabular method for evaluating and documenting the causes and effects of known types of component failures.

Fault: Abnormal condition that may cause a reduction in, or loss of, the capability of a functional unit to perform a required function.

Fault Tree: A logic method that graphically portrays the combinations of failures that can lead to a specific main failure or accident of interest.

Field Production: Represents crude oil production on leases, natural gas liquids production at natural gas processing plants, new supply of other hydrocarbons/oxygenates and motor gasoline blending components and fuel ethanol blended into finished motor gasoline.

Final Boiling Point (FBP): The final boiling point of a cut, usually on an ASTM distillation basis.

Fifteen-five (15/5) distillation: A laboratory batch distillation performed in a 15-theoretical plate fractionating column with a 5:1 reflux ratio. A good fractionation results in accurate boiling temperatures. For this reason, this distillation is referred to as the true boiling point distillation. This distillation corresponds very closely to the type of fractionation obtained in a refinery.

Fire:1. A combustible vapor or gas combining with an oxidizer in a combustion process manifested by the evolution of light, heat and flame. 2. The rapid thermal oxidation (combustion) of a fuel source resulting in heat and light emission. There are various types of fire, classified by the type of fuel and associated hazards. In the U.S., the National Fire Protection Association (NFPA) classifies fires and hazards by types of fuels or combustible in order to facilitate the control and extinguishing of fires:

Class A	Ordinary combustibles such as wood, cloth, paper, rubber and certain plastics.
Class B	Flammable or combustible liquids, flammable gases, greases and similar materials.
Class C	Energized electrical equipment.
Class D	Combustible metals, such as magnesium, titanium, zirconium, sodium, and potassium.

Fireball: The atmospheric burning of a fuel-air cloud in which the energy is mostly emitted in the form of radiant heat. The inner core of the fuel release consists of almost pure fuel whereas the outer layer in which ignition first occurs is a flammable fuel-air mixture. As buoyancy forces of the hot gases begin to dominate, the burning cloud rises and becomes more spherical in shape.

Fire Point: Is the temperature well above the flash point where the product could catch a fire. The fire point and flash point are always taken care of in the day to day operation of a refinery. (*See also Flash point*).

Fireproof: Resistant to a specific fire exposure. Essentially nothing is absolutely fireproof, but some materials or building assemblies are resistant to damage or fire penetration at certain levels of fire exposures that may develop in the petroleum, chemical or related industries.

Fireproofing: A common industry term used to denote materials or methods of construction used to provide fire resistance for a defined fire exposure and specified time. Essentially nothing is fireproof if it is exposed to high temperatures for extended period of time.

Fire suppression system: A method, device or system used to detect a fire or ignition source, and to extinguish the fire in sufficient time so as to prevent structural damage and/or debilitation of personnel.

Fire triangle: A way of illustrating the three factors necessary for the process of combustion which are fuel, oxygen and heat. All three are required for combustion to occur. A fire can therefore be prevented or extinguished by removing one of the factors. A fire is not able to occur without sufficient amounts of all three (See Figure 8).

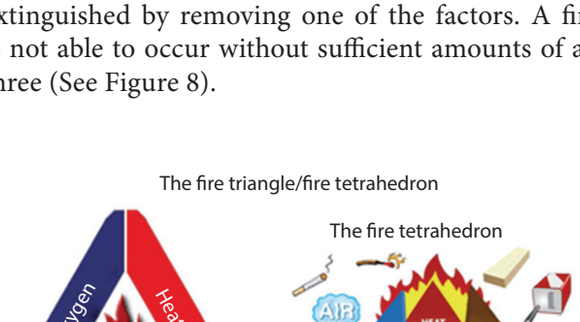


Figure 8 Diagram of a fire triangle.

First law of thermodynamics: A law that is applied to the conservation of energy in which the change in internal energy, ΔU of a system is equal to the difference in the heat added, Q to the system and the work done by the system:

$$\Delta U = Q - W$$

When considering chemical reactions and processes, it is more usual to consider situations where work is done on the system rather than by it.

Fittings: Connections and couplings used in pipework and tubing. The type of fittings used depends largely on the wall thickness as well as in part on the properties of the pipes and tubes including welds, flanges and screw fittings. Fittings include elbow, bends, tees, reducers and branches.

Fixed Bed: A place in a vessel for catalyst through or by which feed can be passed for reactions, as opposed to a fluidized bed, where the catalyst moves with the feed.

Fixed-Bed Reactor: A reactor in which the catalyst is loaded into an immovable bed. The reactants enter the top of the bed, and the products exit from the bottom of the bed. The process must be taken off line, and hot gases circulated through the catalyst bed to burn off coke deposits and restore the catalyst activity.

Flame: The glowing gaseous part of a fire.

Flammable: 1. A substance or material that has the ability to support combustion and be capable of burning with a flame. It is easily ignited or highly combustible. The term is more widely used than inflammable as this is often confused with incombustible, which means an inability or lack of ability to combust. A flammable liquid is a liquid that has the capability of catching fire. In the U.S., the National Fire Protection Association defines a flammable liquid as a liquid that has a flash point below 100°F (37.8°C) and a vapor pressure not exceeding 40 psia (2.72 bar) at that temperature. 2. In general sense refers to any material that is easily ignited and burns rapidly. It is synonymous with the term inflammable that is generally considered obsolete; due to its prefix which may be incorrectly misunderstood as not flammable (e.g., incomplete is not complete).

Flammable Liquid: 1. As defined by NFPA 30, a liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 2068 mm Hg (40 psia) at 100°F (37.8°C) as determined under specific conditions. 2. Any liquid having a flash point below

100°F (37.8°C), except any liquid mixture having one or more components with a flash point at or above the upper limit that makes up 99% or more of the total volume of the mixture, 3. Liquid with a flash point below 100°F (37.8°C). At that temperature, vapors from the substance can be ignited by a flame, spark or other sources of ignition.

Flammability Limit: 1. The flammability limit of a fuel is the concentration of fuel (by volume) that must be present in air for an ignition to occur when an ignition source is present. 2. The range of gas or vapor amounts in air that will burn or explode if a flame or other ignition source is present. Importance: The range represents an unsafe gas or vapor mixture with air that may ignite or explode. Generally, the wider the range the greater the fire potential.

Flange: It is a flat end of a pipe that is used to bolt up to a flange on another piece of piping. Bolts, with nuts at each end, are used to force the flanges together.

Flange Rating: Connections on vessels, spool pieces and valves have a pressure rating called a flange rating. This rating can be confusing; e.g., a 150 psig flange rating is actually good for about 230 psi design.

Flare: 1. A burner on a remote line used for disposal of hydrocarbons during clean-up, for emergency shut downs, and for disposal of small-volume waste streams of mixed gases that cannot easily or safely be separated. 2. A flame used to burn off unwanted natural gas; a "flare stack" is the steel structure on a processing facility from which gas is flared. 3. An open flame used to burn off unwanted natural gas. 4. To burn unwanted gas through a pipe or stack. 5. The flame from a flare; the pipe or the stack itself.

Flared: Gas disposed of by burning in flares usually at the production sites or at gas processing plants.

Flare Stack: The steel structure on an offshore rig or at a processing facility from which gas is flared.

Flare System: This is a piping network that runs through the plant to collect vents of gas so that they can be combusted at a safe location in the flare stack.

Flaring: Is the burning of a natural gas that cannot be processed or sold. Flaring disposes off gas, and it releases emissions into the atmosphere.

Flaring/Venting: The controlled burning (flare) or release (vent) of natural gas that cannot be processed for sale or use because of technical or economic reasons.

Flashing: Vaporization of water or light ends as pressure is released during production or processing.

Flash Calculation: Determination of the compositions and quantities of liquid and vapor that co-exist in a mixture under equilibrium conditions.

Flash Chamber: A wide vessel in a vacuum flasher thermal cracking plant or similar operation into which a hot stream is introduced causing the lighter fractions of that stream to vaporize and leave by the top.

Flash Fire: The combustion of a flammable vapor and air mixture in which flame passes through that mixture at less than sonic velocity, such that negligible damaging overpressure is generated.

Flash Point: 1. The minimum temperature at which a liquid, under specific test condition gives off sufficient flammable vapor to ignite momentarily on the application of ignition source. 2. The lowest temperature at which any combustible liquid will give off sufficient vapor to form an inflammable mixture with air (i.e., that can be readily ignited). Flash points are used to specify the volatility of fuel oils, mostly for safety reasons. They are generally used as an indication of the fire and explosion potential of a product; ASTM D-56, D-92, D-93, D-134, D-1310. 3. Hold a flame over a cup of diesel fuel; it will start to burn at its 160°F (71°C) flash temperature. Gasoline's flash point is below room temperature. Jet fuel is 110°F (43°C). The lighter the hydrocarbon, the lower the flash point.

Flash Tank: Container where the separation of gas and liquid phases is achieved after pressure reduction in flow fluid. Both phases appear when pressure is decreased as a consequence of the Joule-Thomson effect.

Flash Vapors: Vapors released from a stream of natural gas liquids as a result of an increase in temperature or a decrease in pressure.

Flash Zone: The section of a distillation/fractionating column containing the column feed nozzle(s). The column feed separates or "flashes" into liquid and vapor at it expands through the feed nozzle(s) and enters the column.

Flexicoking: A thermal cracking process which converts heavy hydrocarbons such as crude oil, oil sands bitumen, and distillation residues into light

hydrocarbons. Feedstocks can be any pumpable hydrocarbons including those containing high concentrations of sulfur and metals.

Flooding: 1. An excessive build-up of liquid in absorption columns or on the plate of a distillation column. It is due to high vapor flow rates up the column. In distillation columns, this is caused by high heating rates in the reboiler. 2. An all-inclusive term that is given to non-equilibrium behavior in a distillation/fractionating column because of larger flows of liquid and/or vapor than the column can process. Flooding can be caused by liquid backing up in the column, vapor blowing through the column and lifting the liquid off the trays, etc. All columns are designed to handle about 80% of the flow before flooding occurs. Sometimes flooding is caused by mechanical restrictions or damage to the internals in the column. The ***flooding point*** is a condition in a packed column such as an absorption column which receives a counter current flow of gas at the bottom and a liquid descending under gravity from the top where there is insufficient liquid hold-up in the packing for mass transfer to take place effectively. The liquid therefore descends to the bottom of the column without mass transfer. The rate of flow through the packing for effective mass transfer is controlled by the pressure drop across the packing material.

Flow: The movement of a fluid under the influence of an external force such as gravity or a pump.

Flowline: A pipeline that carries materials from one place to another. In the offshore industry, a flowline is a pipeline that carries oil on the seabed from a well to a riser. On a process flow diagram, the flowline is indicated by a line entering and leaving a vessel or unit operation. An arrow indicates the direction of flow.

Flow meter: A device used to measure the flow of process fluids. Flow meters are mainly classified into those that are intrusive and those that are non-intrusive to the flow of the fluid. Flow meters include differential pressure meters, positive displacement meters, mechanical, acoustic and electrically heated meters. The measurement of the flow of process fluids is essential not only for safe plant control but also for fiscal monitoring purposes. It is essential to select correctly the flow meter for a particular application, which requires a knowledge and comprehension of the nature of the fluid to be measured and an understanding of the operating principles of flow meters.

Flow rate: The movement of material per unit time. The material may be a gas, liquid or solid particulates in suspension or combination of all of these, and expressed on a mass, volumetric or molar basis. The volumetric flow of material moving through a pipe is the product of its average velocity and the cross-sectional area of the pipe.

Flow regime: The behavior of a combined gas and liquid flow through a duct, channel or pipe can take many forms, and there are descriptions used to define the possible flow patterns. Depending on the conditions of flow of the two phases, one phase is considered to be the continuous phase while the other is the discontinuous phase. An example is the flow of mist or fine dispersion of liquid droplets in a gas phase. The smaller the liquid droplets, the higher are the surface tension effects. Distortion of the discontinuous phse results in the shape to become non-spherical. Also, there is a tendency for the liquid phase to wet the wall of the pipe and for the gas phase to congregate at the center. An exception to this is in evaporation such as in refrigeration where nuclear boiling occurs on the pipe surface resulting in a vapor film or bubbles forming at the surface with a central core of liquid. The flow of fluids through pipes and over surfaces can be described as:

1. Steady flow in which flow parameters at any given point do not vary with time.
2. Unsteady flow in which flow parameters at any given point vary with time.
3. Laminar flow in which flow is generally considered to be smooth and streamline.
4. Turbulent flow in which flow is broken up into eddies and turbulence.
5. Transition flow, which is a condition lying between the laminar and turbulent flow regimes

Flow regime maps are charts representing the various flow patterns that are possible for two-phase gas-liquid flow in both horizontal and vertical pipes and tubes. There are many types of flow regime maps that have been developed. The simplest form of the map involves a plot of superficial velocities or flow rates for the two phases with the most widely used generalized flow regime map for horizontal flow as shown below:

The maps are populated with experimental data in which lines are drawn to represent the boundaries between the various flow regimes. These include dispersed, bubble or froth, wavy, annular, stratified, slug and plug flow. The boundaries between the various flow

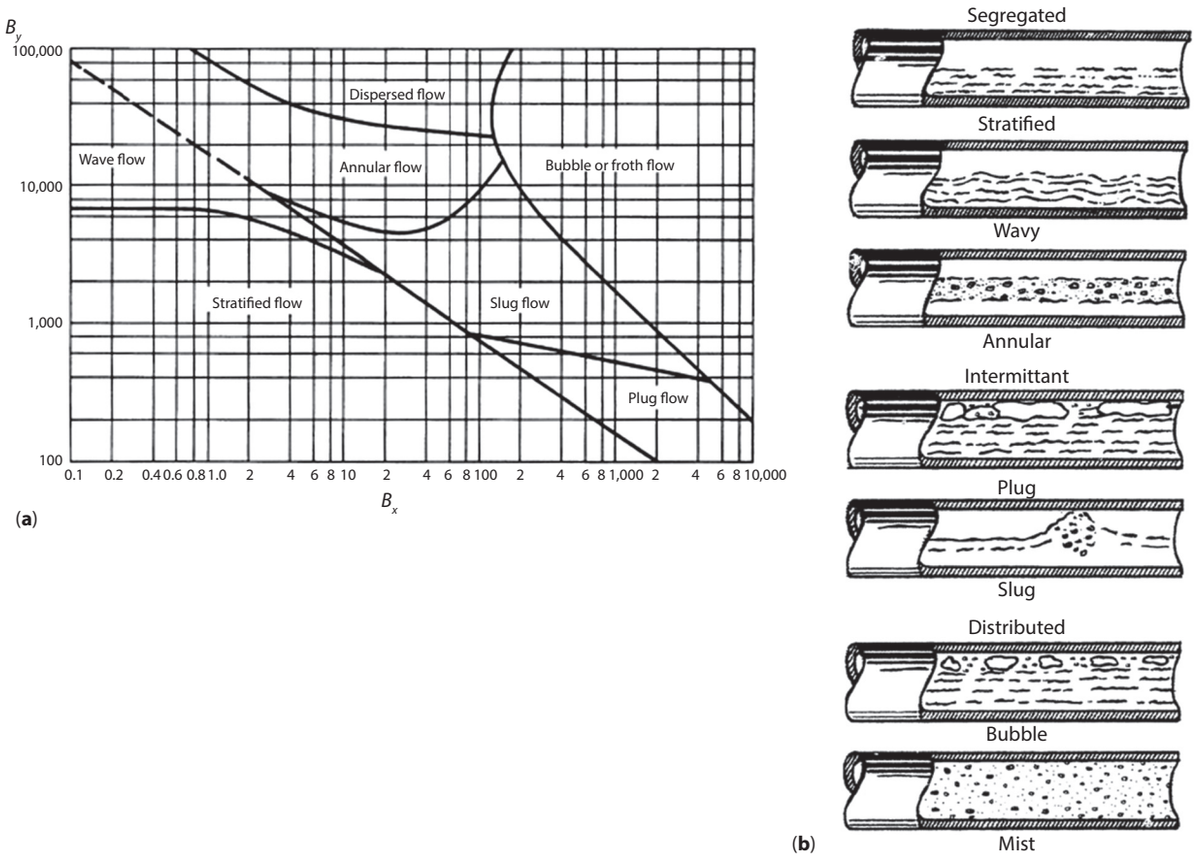


Figure 9 (a)Flow patterns for horizontal two-phase flow (Based on data from 1, 2, and 4 in. pipe by Baker, O., *Oil & Gas J.,* Nov. 10, p. 156, 1958.). (b) Representative forms of horizontal two-phase flow patterns as indicated in Figure 9a.

patterns are due to the regime becoming unstable as it approaches the boundary with the transition to another flow pattern. As with the transition between laminar and turbulent flow in a pipe, the transitions in a flow regime are unpredictable. The boundaries are therefore not distinct lines but loosely defined transition zones. A limitation of the maps is that they tend to be specific to a particular fluid and pipe. The seven types of flow regimes in order of increasing gas rate at constant liquid flow rate are given below (See Figure 9).

Bubble or Froth flow: Bubbles of gas are dispersed throughout the liquid and are characterized by bubbles of gas moving along the upper part of the pipe at approximately the same velocity as the liquid. This type of flow can be expected when the gas content is less than about 30% of the total (weight) volume flow rate. (Note: 30% gas by weight is over 99.9% by volume, normally.)

Plug flow: Alternate plugs of liquid and gas move along the upper part of the pipe and liquid moves along the bottom of the pipe.

Stratified flow: The liquid phase flows along the bottom of the pipe while the gas flows over a smooth liquid-gas interface.

Wave flow: Wave flow is similar to stratified flow except that the gas is moving at a higher velocity and the gas-liquid interface is distributed by waves moving in the direction of flow.

Slug flow: This pattern occurs when waves are picked up periodically by the more rapidly moving gas. These form frothy slugs that move along the pipeline at a much higher velocity than the average liquid velocity. This type of flow causes severe and in most cases, dangerous vibrations in equipment because of the high velocity slugs against fittings.

Annular flow: In annular flow, liquid forms around the inside wall of the pipe and gas flows at a high velocity through the central core.

Dispersed, Spray or Mist flow: Here, all of the liquid is entrained as fine droplets by the gas phase. This type

of flow can be expected when the gas content is more than roughly 30% of the total weight flow rate. Some overhead condenser and reboiler-return lines have dispersed flow.

Flowsheet: A schematic diagram or representation of a process illustrating the layout of process units and their functions linked together by interconnecting process streams. The development of a flowsheet involves the process synthesis, analysis and optimization. The heat and material balances are solved using thermodynamic properties and models. An economic analysis is also completed as well as a safety and environmental impact assessment. The choice of equipment and their interconnectivity are optimized along with the choice of operating parameters such as temperature, pressure and flows. Steady-state flowsheet computer software packages are frequently used to develop flowsheets.

Flue: Passage through which flue gases pass from a combustion chamber to the outside atmosphere.

Flue Gas: 1. A mixture of gases produced as a result of combustion that emerge from a stack or chimney. The gases contain smoke, particulates, carbon dioxide, water vapor, unburnt oxygen, nitrogen, etc. An Orsat analysis is a reliable device to determine the composition of the flue gas and the efficiency of combustion although it has been replaced by other techniques. 2. Gas from the various furnaces going up to the flue (stack).

Fluid Catalytic Cracking (FCC): A thermal process in which the oil is cracked in the presence of finely divided catalyst which is maintained in an aerated or fluidized state by the oil vapors. The powder or fluid catalyst is continuously circulated between the reactor and the regenerator, using air, oil vapor and steam as the conveying media. The most commonly used catalytic cracking process. The catalyst is a fine powder that is designed to form a fluidized bed in the reactor and regenerator.

Fluid Coking: 1. A coking process in which the feed is preheated and sprayed into a reactor where it contacts a hot fluidized bed of coke returning from a burner vessel. The hot oil products are stripped from the coke which is circulated back to the burner vessel. Coke not returned to the reactor from the burner vessel is withdrawn as a coke product. 2. A thermal cracking process utilizing the fluidized-solids technique to remove carbon (coke) for continuous conversion of heavy, low-grade oils into lighter products.

Fossil Fuels: Fuels formed by natural processes such as anaerobic decomposition of buried dead organisms. The age of the organisms and their resulting fossil fuels is typically millions of years, and sometimes exceeds 650 million years. Fossil fuels contain high percentage of carbon and include coal, petroleum and natural gas. Other more commonly used derivatives of fossil fuels are kerosene, and propane. They range from volatile materials with low carbon: hydrogen ratios like methane, to liquid petroleum to nonvolatile materials composed of almost pure carbon, like anthracite coal. Methane can be found in hydrocarbon fields, alone, associated with oil, or in the form of methane clathrates (See Figure 10).

Georg Agricola in 1556 first introduced the theory that fossil fuels were formed from the fossilized remains of dead plants by exposure to heat and pressure in the Earth's crust over millions of years. The theory was later expounded by Mikhail Lomonosov in the 18th century. Coal is one of the fossil fuels (See Figure 10).

The use of fossil fuels raises serious environmental concerns. The burning of fossil fuels produces around 21.3 billion tonnes (21.3 gigatonnes) of carbon dioxide (CO_2) per year, but it is estimated that natural processes can only absorb about half of that amount, so there is a net increase of 10.65 billion tonnes of atmospheric carbon dioxide per year (one tonne of atmospheric carbon is equivalent to 44/12 or 3.7 tonnes of carbon dioxide). Carbon dioxide is one of the greenhouse gases that enhances the radiative forcing and contributes to global warming, causing the average surface temperature of the Earth to rise with major adverse climatic effects. A global movement towards the generation of renewable energy is therefore essential to help reduce global greenhouse gas emissions.

Ratio of gross domestic product to kilograms of fossil fuel carbon consumed, for the world's 20 largest economies. The two countries with the highest GDP per

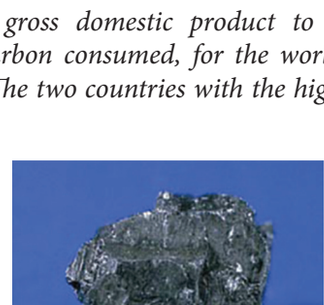


Figure 10 Coal.

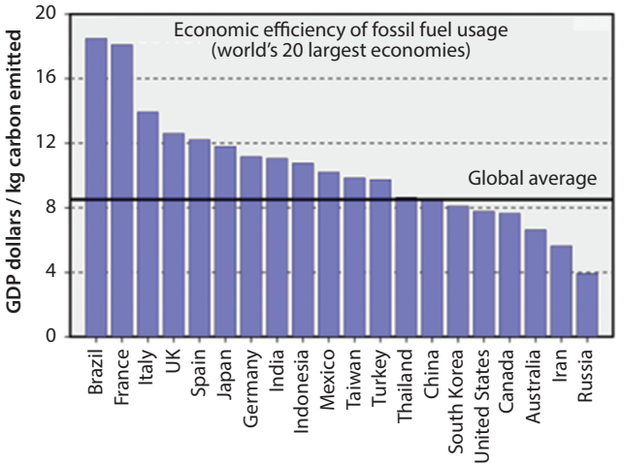


Figure 11 Economic efficiency of fossil fuel usage.

kilogram carbon ratios, Brazil and France, produce large amounts of hydroelectric and nuclear power, respectively (See Figure 11).

Fractionation: The general name given to a process for separating mixtures of hydrocarbons or other chemicals into separate streams or cuts or fractions.

Free Carbon: The organic materials in tars which are insoluble in carbon disulfide.

Free Energy of Formation: the change in free energy when a compound is formed from its elements with each substance in its standard state at 77°F (25°C). The heat of reaction at 25°C may be calculated by subtracting the sum of the free energies of formation of the reactants from the sum of the free energies of formation of the products.

Free Water: Condensed water that exits as a separate liquid phase. Most refinery distillation columns are designed such that free water will not be present, since it can result in column upsets and promote corrosion of the metal in the column.

Freeze Point: 1. The temperature at which the hydrocarbon liquid solidifies at atmospheric pressure. It's an important property for kerosene and jet fuels, because of the very low temperatures encountered at high altitudes in jet planes. One of the standard test methods for the freeze point is ASTM D4790. 2. The temperature at which a chilled petroleum product becomes solid and will no longer pour when a sample tube is tipped. Freeze point is a laboratory test. 3. The temperature at which crystals first appear as a liquid is cooled, which is especially important in aviation fuels, diesel and furnace oil.

Front-End Engineering and Design (FEED) Contract: 1. A legal agreement setting out the terms for all activities required to define the design of a facility to a level of definition necessary for the starting point an EPC contract. 2. Generally, the second contracting phase for the development of the export facilities in the LNG chain that provides greater definition than the prior conceptual design phase. In an LNG project, the single most important function of the FEED contract is to provide the maximum possible definition for the work ultimately to be performed by the engineering, procurement, and construction (EPC) contractor. 3. A study used to analyze the various technical options for new field developments with the objective to define the facilities required. 4. The stage of design between concept evaluation and detailed design during which the chosen concept is developed such that most key decisions can be taken. Output of FEED includes estimate of total installed cost and schedule. *See also Engineering, procurement and construction contract*.

Fuel Gas: 1. A process stream internal to a facility that is used to provide energy for operating the facility. 2. Gas used as fuel in a liquefaction plant. It typically involves processing waste streams to LNG that are not profitable. It is used in gas turbines, boilers and reaction furnaces.

Fuel Oil: Usually residual fuel but sometimes distillate fuel.

Fuel Oil Equivalent (FOE): The heating value of a standard barrel of fuel oil, equal to 6.05 x 10^6 Btu (LHV). On a yield chart, dry gas and refinery fuel gas are usually expressed in FOE barrels.

Furnace Oil: A distillate fuel made of cracked and straight run light gas oils primarily for domestic heating because of its ease of handling and storing.

FVT: The final vapor temperature of a cut. Boiling ranges expressed in this manner are usually on a crude assay, true boiling point basis.

Gas/Liquid chromatography (GC, GLC): Equipment used to determine the composition of a sample in the laboratory.

Gap: Gas is usually based on ASTM 86 distillation temperatures and is defined as the 5% distilled temperature of a distillation column product minus the 95%

distilled temperature of the next higher product in the column. When the difference is positive, the difference is called a gap. When the difference is negative, the difference is sometimes called an overlap. The gap or overlap is a measure of the sharpness of the separation between adjacent products in a distillation column.

Gas Cap: An accumulation of natural gas at the top of a crude oil reservoir. The gas cap often provides the pressure to rapidly evacuate the crude oil from the reservoir.

Gasket: This is the softer material that is pressed between flanges to keep the fluid from leaking. Using the wrong gasket is a common cause of fires in process plants. Gaskets have different temperature and pressure ratings.

Gas Oil: 1. Any distillate stream having molecular weights and boiling points higher than heavy naphtha > 400°F (> 205°C). The name gas oil probably traces its roots to "gasoline" bearing oil in the early days of refining. Early refiners used thermal cracking processes to produce more motor gasoline (MOG) from gas oil stocks. 2. The term is used for petroleum stocks with boiling ranges between approximately 650–1100°F (344–594 °C). Unreacted gas oils produced by distilling crude oil in crude and vacuum columns. Cracked gas oils are produced in refinery reaction processes, such as thermal and catalytic cracking, coking, visbreaking and hydrocracking.

Gasoline: 1. A light petroleum product in the range of 80–400°F (27–204°C) for use in spark-ignition internal combustion engines. 2. An all-inclusive name for petroleum stocks that are used as fuel for internal combustion engines. Retail gasoline is a blend of several refinery gasolines and must meet specifications of octane, Reid vapor pressure, distilling boiling range, sulfur content, and so on. Additives such as ethers or alcohols are used to improve the octane for the blended product.

Gasoline Blending Components: Naphthas which will be used for blending or compounding into finished aviation or motor gasoline (e.g., straight-run gasoline, alkylate, reformate benzene, toluene, and xylenes). Excludes oxygenates (alcohols, ethers), butane, and natural gasoline.

Gas sweetening: A process used to remove hydrogen sulfide and mercaptans from natural gas. Commonly used in petroleum refineries, the gas treatment uses amine solution such as monoethanolamine. The process uses an absorber unit and a regenerator. The amine solution flows down the scrubber and absorbs the hydrogen sulfide as well as carbon dioxide from the upflowing gases. The regenerator is used to strip the amine solution of the gases for reuse. It is known as gas sweetening as the foul smell is removed from the gas.

Gas Treating: Amine treating of light gases to remove such impurities as H_2S and CO_2. Molecular sieves are also used to concentrated hydrogen streams by removing inerts and light hydrocarbon contaminants.

Gas Turbine: An engine that uses internal combustion to convert the chemical energy of a fuel into mechanical energy and electrical energy. It uses air, which is compressed by a rotary compressor driven by the turbine, and fed into a combustion chamber where it is mixed with the fuel, such as kerosene. The air and fuel are burnt under constant pressure conditions. The combustion gases are expanded through the turbine causing the blades on the shaft to rotate. This is then converted to electrical energy. Gas turbines are used in the process industries and on offshore gas platforms for electrical generation.

Grain: A unit of mass where one pound is equivalent to 7000 grains and a specification of 0.25 grain of H_2S per 100 scf is equivalent to an H_2S concentration of 4.0 ppmv.

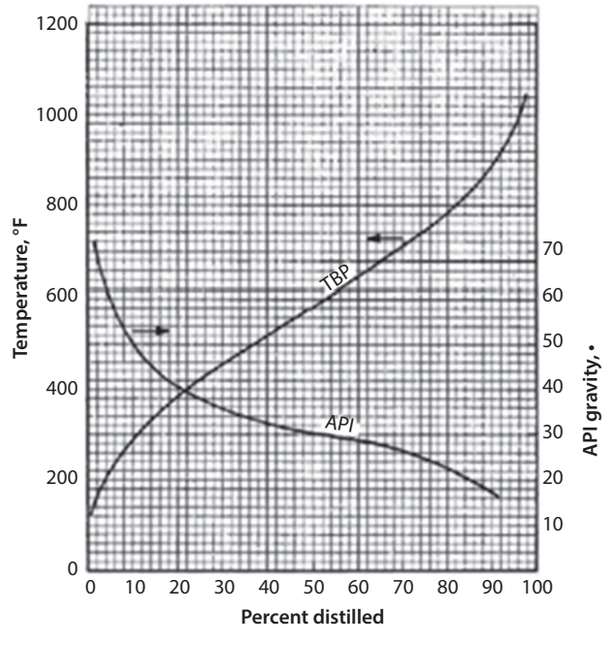


Figure 12 TBP and gravity – mid percent curves.

Gravity: The specific gravity (Sp.Gr.) of a stream, often expressed as API Gravity by petroleum refiners. The basis is always the density of water.

Gravity Curve: The gravity of the material distilled from a petroleum stock in a laboratory still. The gravity curve is plotted against the percent distilled for the stock. Gravity curves are most commonly reported for true boiling point distillation (See Figure 12).

Greenhouse Gas (GHG): A greenhouse gas is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone. Without greenhouse gases, the average temperature of Earth's surface would be about 15°C (27°F) colder than the present average of 14°C (57°F).

Gross Heating Value: Is the total energy transferred as heat in an ideal combustion reaction at a standard temperature and pressure in which all water formed appears as liquid. The gross heating is an ideal gas property in a hypothetical state (the water cannot all condense to liquid because some of the water would saturate the CO_2 in the products).

Gross Heating Value of Fuels (GHV): The heat produced by complete oxidation of material of 60°F (25°C) to carbon dioxide and liquid water at 60°F (25°C).

Gross Input to Atmospheric Crude Oil Distillation Units: Total inputs to atmospheric crude oil distillation units. Includes all crude oil, lease condensate, natural gas plant liquids, unfinished oils. Liquefied refinery gases, slop oils, and other liquid hydrocarbons produced from oil sands, gilsonite and oil shale.

Gum: A complex sticky substance that forms by the oxidation of gasoline especially those stored over a long period of time. Gum fouls car engines especially the fuel injection ports.

Harm: Physical injury or damage to the health of people, either directly or indirectly, as a result of damage to property or to the environment.

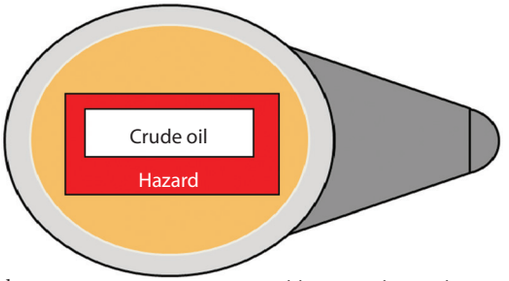
Hazard: 1. A condition or object that has the potential to cause harm. 2. An unsafe condition, which if not eliminated or controlled may cause injury, illness or death. 3. A physical or chemical characteristic that has the potential for causing harm to people, the environment, or property. Examples of hazards:

- *Combustible/Flammable substance. E.g., Ethylene is flammable*
- *Corrosive. E.g., Sulfuric acid is extremely corrosive to the skin.*
- *Explosive substance. E.g., Acrylic acid can polymerize, releasing large amounts of heat.*
- *Toxic fumes. E.g., Chlorine is toxic by inhalation.*
- *Substances kept at high pressure in containment (e.g., a vessel, tank)*
- *Objects or material with a high or low temperature.*
- *Radiation from heat source.*
- *Ionizing radiation source.*
- *Energy release during decomposition of a substance. E.g., Steam confined in a drum at 600 psig contains a significant amount of potential energy (See Figure 13).*

Hazard Analysis: Is the first step in a process used to assess risk. The result of a hazard analysis is the identification of different type of hazards.

It is assigned a classification, based on the worst-case severity of the end condition. Risk is the combination of probability and severity. Preliminary risk levels can be provided in the hazard analysis. The validation, more precise prediction (verification) and acceptance of risk is determined in the risk assessment (analysis). The main goal of both is to provide the best selection of means of controlling or eliminating the risk.

Hazard Communication: Employees' "right-to-know" legislation requires the employers to inform employees (pretreatment inspectors) of the possible health effects resulting from contact with hazardous substances. At locations where this legislation is in force, employers must provide employees with information regarding any hazardous substances, which they might be exposed to under normal work conditions or reasonably foreseeable emergency conditions



Consider pressure, temperature, composition, quantity, etc. into account.

Figure 13 A hazard.

resulting from workplace conditions. OSHA's Hazard Communication Standard (HCS) (Title 29 CFR Part 1910.2100) is the federal regulation and state statutes are called Workers' Right-to-Know Laws.

Hazard Communication Program: A written plan to manage the hazards associated with the use of chemicals in the workplace.

Hazardous Chemical: A substance that may harm the worker either physically (e.g., fire, explosion) or chemically (e.g., toxic, corrosive).

Hazardous Events: Hazardous event is defined as hazardous situation which results in harm. Each identified hazard could give a number of different hazardous events. For each identified hazardous event, it should also be described which factors contributed to it.

E.g., the hazard combustible substance could give the following hazardous events:

- Pool fire outside a tank, due to leakage, when an ignition source is present.
- Flash fire inside a tank when an ignition source is present.
- Factors that could contribute to the leakage in the tank could for instance be:
- *Bad connection joint.*
- *Gasket damage.*
- *Tube damage.*
- *Pipe damage.*

Hazardous Situation: Circumstance in which a person is exposed to hazards.

HAZID/HAZOP: 1. HAZard Identification/ HAZard and Operability analysis systematic design review methods to identify and address hazards to ensure that the necessary safety measures to eliminate or mitigate hazards are incorporated in the design and operation of the unit. 2. A qualitative process risk analysis tool used to identify hazards and evaluate if suitable protective arrangements are in place. If the process were not to perform as intended, and unexpected consequences were to result.

HCGO: Heavy coker gas oil.

HCO: Heavy FCC cycle gas oil. *See Heavy Cycle Oil.*

Heart cut recycle: That unconverted portion of the catalytically cracked material which is recycled to the catalytic cracker. This recycle is usually in the boiling range of the feed, and by definition, contains no bottoms. Recycle allows less severed operation and suppresses the further cracking of desirable products.

Heat Balance: *See energy balance.*

Heat Exchangers: A pressure vessel for transferring heat from one liquid or vapor stream to another. A typical heat exchanger consists of a cylindrical vessel and nozzles through which one stream can flow and a set of pipes or tubes in series in the cylinder through which the other can flow. Heat transfer mechanisms are conduction and convection. *See also Shell & Tube Heat Exchanger.*

Heat Flux: The rate of heat transfer per unit area normal to the direction of heat flow. It is the total heat transmitted by radiation, conduction and convection.

Heat Pump: Thermodynamic heating/refrigerating system to transfer heat. The condenser and evaporator may change roles to transfer heat in either direction.

Heat Rate: The measure of efficiency in converting input fuel to electricity. Heat rate is expressed as the number of Btu of fuel (e.g., natural gas) per kilowatt hour (Btu/kWh). Heat rate for power plants depends on the individual plant design, its operating conditions, and its level of electric power output. The lower the heat rate, the more efficient is the plant.

Heat Recovery: Heat utilized that would otherwise be wasted from a heating system.

Heat Transfer Coefficient: Coefficient describing the total resistance to heat loss from a producing pipe to its surroundings. Includes heat loss by conduction, convection and radiation.

Heating Oil: Any distillate or residual fuel. 1. Oil used for residential heating. 2. Trade term for the group of distillate fuel oils used in heating homes and buildings as distinguished from residual fuel oils used in heating and power installations. Both are burner fuel oils.

Heating Value: 1. The average number of British thermal units per cubic foot of natural gas as determined from tests of fuel samples. 2. The amount of heat produced from the complete combustion of a unit quantity of fuel. 3. The amount of energy or heat that is generated when a hydrocarbon is burned (chemically combined with oxygen). 4. Energy released in the complete combustion of a unit of mass, matter or volume

of a fuel in a stoichiometric mixture with air. 5. The amount of heat produced by the complete combustion of a unit quantity of fuel.

Heat of Combustion: The amount of heat released in burning completely an amount of substance is its heat of combustion. The general formula for the combustion of a hydrocarbon compound is:

$C_nH_{2n+2} + (3n+1)/2\ O_2 \rightarrow (n+1)\ H_2O + n\ CO_2 + \text{Energy}$

Heat of Reaction: The heat release of heat absorbed when a chemical reaction takes place. The heat of reaction may be computed from the free energies of formation for the reacting components and the resultant products at the standard temperature of 77°F (25°C).

Heat of Vaporization: The amount of heat energy required to transform an amount of a substance from the liquid phase to the gas phase.

Heavy Crude: Crude oil of 20° API gravity or less; often very thick and viscous.

Heavy Cycle Oil (HCO): Gas oil produced in an FCC operation that boils in the approximate TBP range of 400–1000°F (205–358°C). Heavy cycle oil is not generally withdrawn as a product, but it is recycled back to the reactor for further cracking to improve the overall conversion of the process.

Heavy Ends: The highest boiling portion of a gasoline or other petroleum oil. The end point as determined by the distillate test reflects the amount and character of the heavy ends present in a gasoline.

Heavy Gas Oil: Petroleum distillates with an approximate boiling range from 651°F to 1000°F (344°C to 538°C).

Heavy Key: A distributed component in a distillation section that is recovered in the (bottom) heavy product, with a small, specified amount leaving in the top product.

Heavy Oil: Lower gravity, often higher viscosity oils. Normally less than 28° API gravity.

Hempel distillation: U.S. Bureau of Mines (now Department of Energy, DOE). Routine method of distillation. Results are frequently used interchangeably with TBP distillation.

Heptane (nC_7H_{16}): Normal heptane is a straight chain alkane hydrocarbon with the chemical formula $H_3C(CH_2)_5CH_3$ or C_7H_{16}. Heptane (and its many isomers) is widely applied in laboratories as a totally non-polar solvent. As a liquid, it is ideal for transport and storage. Heptane is commercially available as mixed isomers for use in paints and coatings, as pure n- heptane for research and development and pharmaceutical manufacturing and as a minor component of gasoline.

n – heptane is defined as the zero point of the octane rating scale. It is undesirable in gasoline because it burns explosively, causing engine knocking, as opposed to branched-chain octane isomers, which burn more slowly and give better performance. When used as a fuel component in antiknock test engines, a 100% heptane fuel is the zero point of the octane rating scale (the 100 point is 100% iso-octane). Octane number equates to the antiknock qualities of a comparison mixture of heptane and isooctane which is expressed as the percentage of isooctane in heptane and is listed in pumps for gasoline dispensed in the U.S. and internationally.

HF Alkylation: alkylation using hydrofluoric acid as a catalyst.

High Pressure (HP): A processing unit operating at either equal to or greater than 225 psig measured at the outlet separator.

High Temperature Simulated Distillation (HTSD): Laboratory test designed for petroleum stocks boiling up to 1382°F (750°C).

HSR: Heavy Straight-Run. Usually naphtha side stream from the atmospheric distillation tower.

HVGO: Heavy vacuum gas oil. A side stream from the vacuum distillation tower.

Hydrocarbon: Any organic compound that is comprised of hydrogen and carbon atoms, including crude oil, natural gas and coal.

Hydrocrackate: The gasoline range product from a hydrocracker.

Hydrocracking: 1. A process in which high or heavy gas oils or residue hydrocarbons are mixed with hydrogen under high pressure and temperature and in the presence of a catalyst to produce light oils. 2. A refining process in which a heavy oil fraction or wax is treated with hydrogen over a catalyst under relatively high pressure and temperature to give products of lower molecular mass.

Hydrocracked Naphtha: A high-quality blending stream obtained when high boiling cracked distillates undergo a combination of processes like cracking, hydrogenation and reforming in the presence of a catalyst and hydrogen.

Hydrocyclone: A cone-shaped device for separating fluids and the solids dispersed in fluids.

Hydrodesulfurization: A process in which sulfur is removed from the molecules in a refinery stream by reacting it with hydrogen in the presence of a catalyst.

Hydrodesulfurizing: A process for combining hydrogen with the sulfur in refinery petroleum streams to make hydrogen sulfide, which is removed from the oil as a gas.

Hydrogen: The lightest of all gases, the element (hydrogen) occurs chiefly in combination with oxygen in water. It also exists in acids, bases, alcohols, petroleum and other hydrocarbons.

Hydrogen Consumption: The amount of hydrogen that is consumed in a hydrocracking or hydrotreating process, usually expressed on per unit of feed basis. Hydrogen may be consumed in chemical reactions and dissolved and lost from the process in the liquid hydrocarbon products.

Hydrogen Embrittlement: A corrosion mechanism in which atomic hydrogen enters between the grains of the steel and causes the steel to become very brittle.

Hydrogen-Induced Cracking: Stepwise internal cracks that connect hydrogen blisters.

Hydrogen Sulfide: 1. "Rotten egg gas", H_2S. It is responsible for the distinctive odor of Rotorua. 2. An objectionable impurity present in some natural gas and crude oils and formed during the refining of sulfur-containing oils. It is removed from products by various treatment methods at the refining. 3. Hydrogen sulfide is a gas with a rotten egg odor. This gas is produced under anaerobic conditions. Hydrogen sulfide gas is particularly dangerous because it dulls the sense of smell so that one does not notice it after one has been around it for a while. In high concentrations, hydrogen sulfide gas is only noticeable for a very short time before it dulls the sense of smell. The gas is very poisonous to the respiratory system, explosive, flammable, colorless and heavier than air. 4. A toxic, corrosive, colorless gas with the characteristic smell of rotten eggs in low concentration. An acid gas.

Hydrogen Sulfide Cracking: Minute cracking just under a metal's surface caused by exposure to hydrogen sulfide gas.

Hydrogenation: 1. Filling in with hydrogen the "free" places around the double bonds in an unsaturated hydrocarbon molecule. 2. A refinery process in which hydrogen is added to the molecules of unsaturated hydrocarbon fractions.

Hydrofining: A process of treating petroleum fractions and unfinished oils in the presence of catalysts and substantial quantities of hydrogen to upgrade their quality.

Hydroforming: A process in which naphtha is passed over a solid catalyst at elevated temperature and moderate pressures in the presence of added hydrogen to obtain high-octane motor fuels.

Hydroskimming Refinery: A topping refinery with a catalytic reformer.

Hydrostatic Pressure: Pressure created by a column of fluid that expresses uniform pressure in all directions at a specific depth and fluid composition above the measurement point.

Hydrotreating: 1. A refinery process to remove sulfur and nitrogen from crude oil and other feedstocks. 2. This is a term for a process by which product streams may be purified and otherwise be brought up to marketing specifications as to odor, color, stability, etc. 3. A process in which a hydrocarbon is subjected to heat and pressure in the presence of a catalyst to remove sulfur and other contaminants such as nitrogen and metals and in which some hydrogenation can take place. Hydrotreating for the removal of sulfur is the major treating process in refineries. Cracked streams could be saturated and stabilized by converting olefins, albeit under more severe treating conditions. The process involves hydrogen under suitable temperature, pressure and a catalyst.

Hyperforming: A catalytic hydrogenation process used for improving the octane number of naphtha by the removal of sulfur and nitrogen compounds.

H_2/Oil Ratio and Recycle Gas Rate: The H_2/oil ratio in standard cubic feet (scf) per barrel (bbl) is determined by

$$\frac{H_2}{\text{oil}} = \frac{\text{total hydrogen gas to the reactor, scf/day}}{\text{total feel to the reactor, bbl/day}} [=] \frac{\text{scf}}{\text{bbl}}$$

H_2/oil ratio in m^3/bbl is obtained by multiplying H_2/oil ratio in (scf/bbl) by a conversion factor 0.028317. A molar H_2/oil ratio can be calculated from the volumetric H_2/oil ratio by the following equation:

$$\frac{\text{molar H}_2}{\text{oil}} = 1.78093\times10^{-7}\left(\frac{\text{H}_2}{\text{oil}}\frac{\text{scf}}{\text{bbl}}\right)\frac{\text{MW}_{\text{oil}}}{\text{MW}_{\text{H}_2}}\frac{\rho_{\text{H}_2}}{\rho_{\text{oil}}}$$

where MW_{oil} and MW_{H2} are the molecular weights of the oil to be hydrotreated and of hydrogen respectively, and ρ_{oil} and ρ_{H_2} are the densities of the oil and hydrogen (p_{H_2} at 15°C and 1 atm. is 0.0898 kg/cm^2).

Hypothetical State: Is defined as a fluid in a state that cannot actually exist, e.g., methane as a liquid at 60°F and 14.696 psia. Methane cannot be in its liquid phase at this temperature and pressure, but such a state when defined, can be used in calculations.

Identification and Structural Group Analysis: The crude oil is a complex mixture of saturated hydrocarbons, saturated hetero-compounds, and aromatic hydrocarbons, olefinic hydrocarbons and aromatic hetero-compounds. With the advancement of the instrumental analysis techniques like chromatography and spectroscopic methods, now it has been possible to study in depth, the identification and structural group analysis. Some of the major analytical instruments used are gas chromatography, ion exchange chromatography, simulated distillation by gas chromatography, absorption chromatography, gel permeation chromatography, high-performance liquid chromatography and supercritical fluid chromatography. The application of spectroscopy, mass spectroscopy, electron spin resonance, X-ray diffraction, inductively coupled plasma emission spectroscopy, X-ray absorption spectroscopy and atomic absorption spectrophotometer.

Initial boiling point (IBP): Initial boiling point of a cut, usually on an ASTM basis. The lowest temperature at which a petroleum product will begin to boil. The boiling temperature in a laboratory still at which the first drop of distilled liquid is condensed. The initial boiling point may be higher than the boiling point for light components in the sample that are not condensed by the apparatus.

Ignition: The process of starting a combustion process through the input of energy. Ignition occurs when the temperature of a substance is raised to the point at which its molecules will react spontaneously with an oxidizer and combustion occurs.

Ignition Quality: Ignition quality is very important in the case of high-speed automotive diesel engines. The diesel engine knock, engine noise, smoke, gaseous emissions and so on, all depend upon this factor. Ignition quality is measured in terms of cetane number using an ASTM standard test engine. The test method designated as D613 comprises a single-cylinder engine with a variable compression ratio combustion pre-chamber.

Incident: *See Accident*

Independent Protection Layer (IPL): Protection measures that reduce the level of risk of a serious event to 100 times, which have a highly degree of availability (greater than 0.99) or have specificity, independence, dependability and auditability.

Inerting: The process of removing an oxidizer (usually air or oxygen) to prevent a combustion process from occurring, normally accomplished by purging.

Inflammable: Identical meaning as flammable, however the prefix "in" indicates a negative in many words and can cause confusion, therefore the use of flammable is preferred over inflammable.

Inherently Safer: 1. A chemical process is inherently safer if it reduces or eliminates the hazards associated with materials and operations used in the process, and this reduction or elimination is permanent and inseparable. 2. An essential character of a process, system or equipment that makes it without or very low in hazard or risk. Inherent safety is a way of looking at processes in order to achieve this. There are four main keywords:

- *Minimize (Intensification):* Reduce stocks of hazardous chemicals.
- *Substitute:* Replace hazardous chemicals with less hazardous ones.
- *Moderate(Attenuation):* Reduce the energy of the system – lower pressures and temperatures or adding stabilizing additives generally make for lower hazards.
- *Simplify*: Make the plant and process simpler to design, build and operate, hence less prone to equipment control and human failings.

Note: The principles of inherent safety are applied at conceptual design stage to the proposed process chemistry. In certain instances, these hazards cannot be avoided; they are basic properties of the materials and the conditions of usage. The inherently safer approach is to

reduce the hazard by reducing the quantity of hazardous material, or energy or by completely eliminating the hazardous agent.

Inherently Safer Design: Is a fundamentally different way of thinking about the design of chemical processes and plants. It focuses on the elimination or reduction of the hazards, rather than on management and control. This approach should result in safer and more robust processes, and it is likely that these inherently safer processes will also be more economical in due course.

Instrument: Apparatus used in performing an action (typically found in instrumented systems).

Note: Instrumented systems in the process sector typically composed of sensors (e.g., pressure, flow, temperature transmitters), logic solvers or control systems (e.g., programmable controllers, distributed control systems), and final elements (e.g., control valves). In special cases, instrumented systems can be safety instrumented systems.

Internal Combustion Engine (ICE): Is a heat engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine, the expansion of the high-temperature and high-pressure gases produced by combustion apply direct force to some component of the engine. The force is applied typically to pistons, turbine blades or a nozzle. This force moves the component over a distance transforming chemical energy into useful mechanical energy (See Figure 14).

C	Crankshaft
E	Exhaust camshaft
I	Inlet camshaft

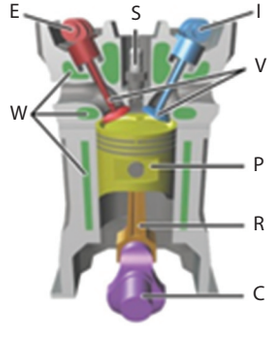


Figure 14 Diagram of a cylinder as found in 4-stroke gasoline engines.

P	Piston
R	Connecting rod
S	Spark plug
V	Valves. Red: exhaust, blue: intake
W	Cooling water jacket
	Gray structure: Engine block.

Intrinsically Safe (IS): A circuit or device in which any spark or thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air under prescribed test conditions.

IPTBE: Isopropyl tertiary butyl ether. An oxygenate used in motor fuels.

Isocracking: A hydrocracking process for the conversion of hydrocarbons to more valuable lower boiling products by operation at relatively lower temperatures and pressures in the presence of hydrogen and catalyst.

Isomerate: The product of an isomerization process.

Isomerization: 1. A refining process, which alters the fundamental arrangement of atoms in the molecule without adding or removing anything from the original material. Used to convert normal butane into isobutane (iC_4H_{10}), an alkylation process feedstock, and normal pentane and hexane into isopentane (iC_5H_{12}) and isohexane (iC_6H_{14}) high-octane gasoline components. 2. The rearrangement of straight-chain hydrocarbon molecules to form branched-chain products. Pentanes and hexanes, which are difficult to reform are isomerized using precious metal catalysts to form gasoline blending components of fairly high octane value. Normal butane may be isomerized to provide a portion of the isobutene feed needed for alkylation processes. The objective of isomerization is to convert low-octane n-paraffins to high-octane i-paraffins by using a chloride-promoted fixed bed reactor. 3. Isomerization is the process by which one molecule is transformed into another molecule that has exactly the same atoms, but the atoms are rearranged. In some molecules and under some conditions, isomerization occurs spontaneously. Many isomers are equal or roughly equal in bond energy, and so exist in roughly equal amounts, provided that they can interconvert relatively freely, that is the energy barrier between the two isomers is not too high. When the isomerization occurs intermolecularly, it is considered a rearrangement reaction.

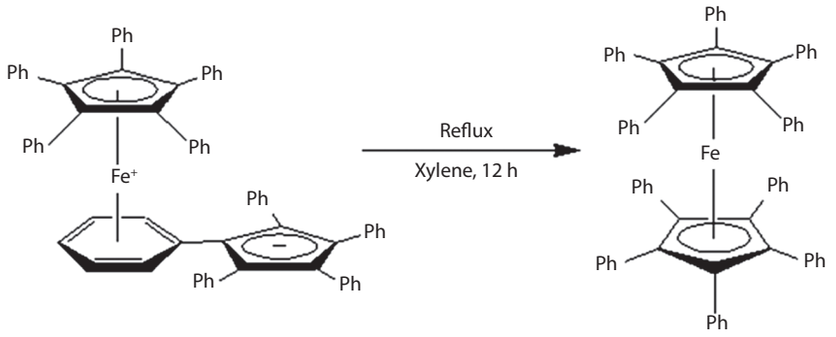


Figure 15

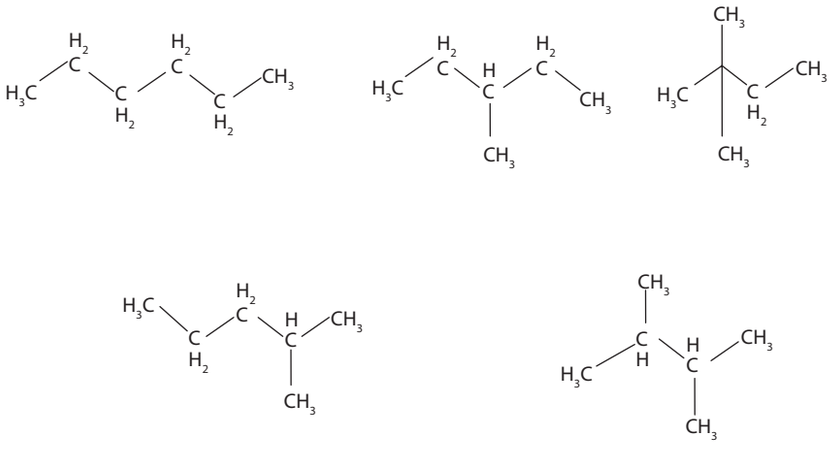


Figure 16

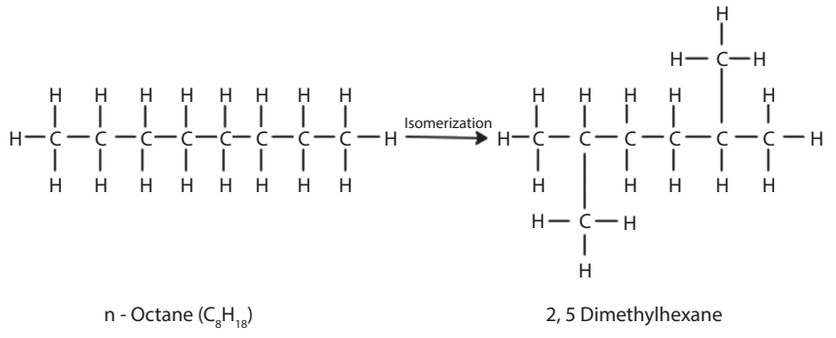


Figure 17

An example of an organometallic isomerization is the production of decaphenylferrocene, $[(\eta^5\text{-}C_5Ph_5)_2Fe]$ from its linkage isomer.

Isomers: Two compounds composed of identical atoms, but with different structures/configurations giving different physical properties. For example, hexane (C_6H_{14}) could be n-hexane, 2- methyl pentane, 3- methyl pentane, 2, 3-dimethyl butane, and 2, 2, - dimethylbutane.

A simple example of isomerism is given by propanol. It has the formula C_3H_8O (or C_3H_7OH) and occurs as two isomers: propanol-1 – ol (n-propyl alcohol; II) and propanol- 2- ol (isopropyl alcohol; III)

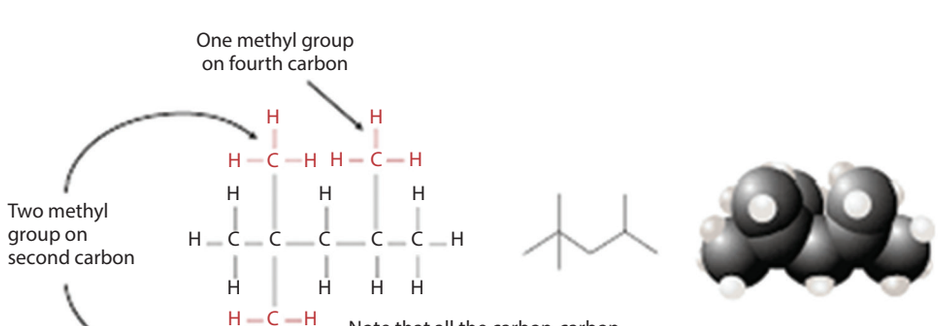


Figure 18

Note that the position of the oxygen atom differs between the two: It is attached to an end carbon in the first isomer, and to the center carbon in the second.

Isomerization of n-Octane to 2, 5 Dimethylhexane (See Figures 15, 16 and 17)

Isooctane - 2, 2, 4 – Trimethlypentane: Also known as isooctane or iso-octane is an organic compound with the structure formula $(CH_3)_3CCH_2CH(CH_3)_2$

It is one of several isomers of octane (C_8H_{18}). Engine knocking is an unwanted process that can occur during combustion in internal combustion engines.

Graham Edgar in 1926 added different amounts of n- heptane and 2,2,4 – trimethylpentane to gasoline, and discovered that the knocking stopped when 2,2,4 trimethlypentane was added. Test motors, using 2,2,4 trimethylpentane gave a certain performance which was standardized as 100 octane. The same test motors, run in the same fashion, using heptane gave a performance which was standardized as 0 octane. All other compounds and blends of components then were graded against these two standards and assigned octane numbers. 2,2,4 trimethylpentane is the liquid used with normal heptanes (nC_7H_{16}) to measure the octane number of gasoline. It is an important component of gasoline, frequently used in relatively large proportions to increase the knock resistance of the fuel (See Figure 18).

Isopentane: *See Natural Gasoline.*

IVT: Initial vaporization temperature of a cut, usually based on a crude assay distillation.

Jack: An oil well pumping unit that operates with an up-and-down, or seesawing motion; also called a pumping jack.

Jet fuel: A kerosene material of typical ASTM D86 boiling point range 400–550 °F (205–288 °C) used as a fuel for commercial jet aircraft.

Joule Thompson expansion: The pressure of a mixture is reduced with no heat transfer to or from the surroundings. A pressure decrease typically results in a temperature decrease except for systems comprised largely of hydrogen gas.

Joule-Thompson Effect: 1. The change in temperature of a fluid that occurs when the fluid is allowed to expand in such a way that no external work is done and no heat transfer takes place. The case of most interest is cooling of a compressed gas upon J-T expansion. NB: the J-T effect is not limited to gases; J-T expansion can, in some cases, produce an increase in temperature rather than a decrease, although this is not frequently encountered. 2. Thermodynamic effect in a fluid whereby the reduction in its temperature is caused by pressure reduction without energy exchange with the environment. 3. When a real (not ideal) gas expands, the temperature of the gas drops. During passage of a gas through a choke, the internal energy is transferred to kinetic energy with a corresponding reduction in temperature as velocity increases. The effect for natural gas is approximately 7°F for every 100 psi pressure reduction.

Joule-Thompson Valve: A device which, taking an advantage of the Joule-Thompson effect enables the cooling of a fluid through throttling or reduction of its pressure.

K factor: Sometimes used as synonym for characterization factor.

K-value: Shortcut notation for the equilibrium K value.

Kerogene: An initial stage of oil that never developed completely into crude. Typical of oil shales.

Kerosene/Kerosine: 1. A medium range (C_9 – C_{16}) straight chain blend of hydrocarbons. The flash point is

about 140°F (60°C), the boiling point is 345°F – 550°F (174°C – 288°C) and the density is 747–775 kg/m^3. 2. A medium-light distillate from the oil refining process; used for lighting and heating and for the manufacture of fuel for jet and turboprop aircraft engines. 3. Any petroleum product with a boiling range between the approximate limits of 284°F and 518°F (140°C and 270°C), which satisfies a specific quantity requirements. 4. A middle distillate product material from distillation of crude oil that boils in the approximate ASTM D86 range of 400–550°F (205–288°C) or from thermal and catalytic cracking operations (coker, visbreaker, FCC, hydrocracker, etc.). The exact cut is determined by various specifications of the finished kerosene. 5. A light petroleum distillate that is used in space heaters, cook stoves, and water heaters and is suitable for use as a light source when burned in wick-fed lamps. Kerosene has a maximum distillation temperature of 400°F (204°C) at the 10% recovery point, a final boiling point of 572°F (300°C), and a minimum flash point of 100°F (38°C). Included are No. 1-K and No. 2 – K, the two grades recognized by the American Society of Testing Materials (ASTM) Specification D3699 as well as all other grades of kerosene called range or stove oil, which have properties similar to those of No. 1 fuel oil. It is colorless and has a characteristic odor and taste. Kerosene is insoluble in water, moderately soluble in alcohol and very soluble in ether, chloroform or benzene.

Key Components: In a conventional distillation column with two products, two components or groups of components that define the separation. Both components must be distributed to the top and bottom products. The light key appears in the bottom product in a small significant quantity and the heavy key appears in the top product in small significant quantity.

Kinematic viscosity: Viscosity in centipoises (cP) divided by the liquid density at the same temperature gives kinematic viscosity in centistokes (cS) (100 cSt = 1 stoke). Water is the primary viscosity standard with an accepted viscosity at 20°C of 0.01002 poise. Kinematic viscosity is usually determined by the flow of a substance between two points in a capillary tube.

$$\text{K inematic viscosity} = \frac{\text{Dynamic viscosity}}{\text{Density of fluid}}, \text{cSt}$$

$$\nu = \frac{\mu}{\rho}$$

Kinetic: The word "kinetic" is derived from the Greek word for "motion". In chemistry, kinetics is the study of how fast reactions occur. In many chemical reactions where there are a number of possible products, the first product formed may be the one that is formed most quickly, not necessarily the one that is most stable; if the reaction is left to proceed, eventually a product is formed that involves the greatest change in bond energy – the thermodynamic product.

Knock: 1. The sound associated with the auto ignition in the combustion chamber of an automobile engine of a portion of the fuel-air mixture ahead of the advancing flame front. 2. The noise associated with premature ignition of the fuel-air mixture in the combustion chamber; also known as detonation or pinking.

Knocking (Knock, Detonation, Spark knock, Pinging or Pinking): In spark-ignition internal combustion engines occurs when combustion of the air/fuel mixture in the cylinder does not start off correctly in response to ignition by the spark plug, but one or more pockets of air/fuel mixture explode outside the envelope of the normal combustion front. *See also Engine Knocking.*

Knocking is more or less unavoidable in diesel engines, where fuel is injected into highly compressed air towards the end of the compression stroke. There is a short lag between the fuel being injected and combustion starting. By this time there is already a quantity of fuel in the combustion chamber which will ignite first in areas of greater oxygen density prior to the combustion of the complete charge. This sudden increase in pressure and temperature causes the distinctive diesel "knock" or "clatter", some of which must be allowed for in the engine design. Careful design of the injector pump, fuel injector, combustion chamber, piston crown and cylinder head can reduce knocking greatly, and modern engines using electronic common rail injection have very low levels of knock. Engines using indirect injection generally have lower levels of knock than direct injection engine, due to the greater dispersal of oxygen in the combustion chamber and lower injection pressures providing more complete mixing of fuel and air.

Knocking should not be confused with pre-ignition – they are two separate events. However, pre-ignition is usually followed by knocking. See Pre-ignition.

Knockout: A separator used to remove excess gas or water from the produced fluid stream.

Knockout Drum: A vessel wherein suspended liquid is separated from gas or vapor.

Laminar flow: The streamline flow of a fluid in which a fluid flows without fluctuations or turbulence. The velocities of fluid molecules are in the direction of flow with only minor movement across the streamlines caused by molecular diffusion. The existence was first demonstrated by Osborne Reynolds who injected a trace of colored fluid into a flow of water in a glass pipe. At low flow rates, the colored fluid was observed to remain as discrete filaments along the tube axis, indicating flow in parallel streams. At increased flow rates, oscillations were observed in the filaments, which eventually broke up and dispersed across the tube. There appeared to be a critical point for a particular tube and fluid above which the oscillations occurred. By varying the various parameters, Reynolds showed that the results could be correlated into terms of a dimensionless number called the Reynolds number, Re. This is expressed by:

$$\mathrm{Re} = \frac{\rho \mathrm{vd}}{\mu}$$

where ρ is the density of the fluid, v is the velocity of the fluid, d is the inside diameter of the pipe, and μ is the fluid viscosity. The critical value of Re for the break-up of laminar flow in the pipes of circular cross-section is about 2000.

LCGO: Light coker gas oil.

Leaded Gasoline: A gasoline that has TEL (tetraethyl lead) added to boost the octane number.

Lean Oil: The absorption oil entering the top tray of an absorber column.

Lease Condensate: A mixture consisting primarily of pentanes and heavier hydrocarbons which is recovered as a liquid from natural gas in lease separation facilities. This category excludes natural gas liquids, such as propane and butane, which are recovered at downstream natural gas processing plants or facilities. *See also Natural Gas Liquids*.

LHSV: Liquid hour space velocity, volume of feed per hour per volume of catalyst.

LHV: Lower heating value of fuels (net heat of combustion). The heat produced by complete oxidation of materials at 60°F (25°C) to carbon dioxide and water vapor at 60°F (25°C).

Light Cycle Oil (LCO): Gas oil produced in a catalytic cracking operation that boils in the approximate ASTM D86 range of 400–695 °F (205–369°C).

Light Ends: Hydrocarbon fractions in the butane (C_4H_{10}) and lighter boiling range.

Light Gas Oils: Liquid petroleum distillates heavier than naphtha, with an approximate boiling range from 401–650°F (205–343°C).

Light key: A distributed component in a distillation section that is recovered in the top light product, with a small specified amount leaving the bottoms product.

Light oil: Generally gasoline, kerosene and distillate fuels.

Light Straight Run (LSR): The low-boiling naphtha stream from the atmospheric distillation, usually composed of pentanes and hexanes.

Liquefaction: 1. The process by which gaseous natural gas is converted into liquid natural gas. 2. Physical process of gas to liquid that is condensation. For natural gas, this process requires cryogenic temperature since it is impossible to liquefy methane – main component of natural gas – at a temperature above-117°F (-82.6°C), which is its critical temperature.

Liquefaction of Gases: Any process in which a gas is converted from its gaseous into liquid phase.

Liquefaction Plant: Industrial complex that processes natural gas into LNG by removing contaminants and cooling the natural gas into its condensation.

Liquefaction Unit or Liquefaction Train: Equipment that processes purified natural gas and brings it to liquid state. Natural gas has been purified in the pretreatment unit before cooling and liquefying it.

Liquefied Natural Gas (LNG): 1. Natural gas that has been refrigerated to temperatures at which it exists in a liquid state. 2. An odorless, colorless, noncorrosive and non-toxic product of natural gas consisting primarily of methane (CH_4) that is in liquid form at near atmospheric pressure. 3. Natural gas liquefied either by refrigeration or by pressure to facilitate storage or transportation. 4. A liquid composed of chiefly of natural gas (e.g., mostly methane, CH_4). Natural gas is liquefied to make it easy to transport if a pipeline is not feasible (e.g., as across a body of water). LNG must be put under low temperature and high pressure or under extremely low (cryogenic) temperature and close to atmospheric pressure to liquefy. 5. Natural gas mainly methane refrigerated to reach liquid phase suitable for transportation in specialized vessels. 6. Natural gas that has been cooled to -26°F (-32°C) and converted into a liquid so that

its volume will be reduced for transportation. 7. Hydrocarbons mixture, predominantly methane, kept in liquid state at a temperature below its boiling point. 8. Methane that has been compressed and cooled to the liquefaction point for shipping.

Liquefied Petroleum Gas (LPG): 1. Gaseous hydrocarbons at normal temperatures and pressures but that readily turns into liquids under moderate pressure at normal temperatures, i.e., propane, (C_3H_8) and butane (C_4H_{10}). 2. Butane and propane mixture, separated from well fluid stream. LPG can be transported under pressure in refrigerated vessels (LPG carriers). 3. A mixture of propane and butane, and other light hydrocarbons derived from refining crude oil. At normal temperatures, it is a gas, but it can be cooled or subjected to pressure to facilitate storage and transportation. 4. of the gaseous hydrocarbons, propanes and butanes can be liquefied under relatively low pressure and at ambient temperature. Mixtures of these are known as LPG. 5. A mixture of propane, propylene, butane and butylenes. When compressed moderately at normal temperature, it becomes a liquid. It is obtained as light ends from fractionation of crude oil. It has a good caloric value; it is used as cooking fuel; because LPG has no natural odor, a distinctive odorant is added so that it will be noticeable should a leak occur. 6. Light ends, usually C_3 and C_4 gases liquefied for storage and transport. 7. Propane, propylene, normal butane, butylenes, isobutane and isobutylene produced at refineries or natural gas processing plant (includes plants that fractionate raw natural gas plant liquids). 8. A group of hydrocarbons-based gases derived from crude oil refining or natural gas fractionation. They include ethane, ethylene, propane, propylene, normal butane, butylenes, isobutane and isobutylene. For convenience of transportation, these gases are liquefied through pressurization.

Liquefied Refinery Gases: Liquefied petroleum gases fractionated from refinery or still gases. Through compression and/or refrigeration, they are retained in liquid state. The reported categories are ethane/ethylene, propane/propylene, normal butane/butylene and isobutane/isobutylene.

Liquid Extraction: Light and heavy liquid phases are contacted in a column with contact surfaces and possibly mixing. Some components are transferred (extracted) from one liquid phase to the other.

Lock-Out-Tag-Out (LOTO): Refers to a program to control hazardous energy during the servicing and maintenance of machinery and equipment. Lock-out refers to the placement of a locking mechanism on energy-isolating device, such as a valve, so that the equipment cannot be operated until the mechanism is removed. Tag-out refers to the secure placement of a tag on energy-isolating device to indicate that the equipment cannot be operated until the tag is removed.

Long Residue: The bottoms stream from the atmospheric distillation tower.

Long-term exposure limit (LTEL): The time-weighted average concentration of a substance over an 8-h period thought not to be injurious to health.

Lower Explosive Limit (LEL): The minimum concentration of combustible gas or vapor in air below which propagation of flame does not occur on contact with an ignition source. Also known as the lower flammable limit or the lower explosion limit.

Low Pressure (LP): A processing unit operating at less than 225 psig measured at the outlet separator.

Lubricants: Substances used to reduce friction between bearing surfaces or as process materials either incorporated into other materials used as processing aids in the manufacture of other products, or used as carriers of other materials. Petroleum lubricants may be produced either from distillates or residues. Lubricants include all grades of lubricating oils from spindle oil to cylinder oil and those used in greases.

Light Vacuum Gas Oil (LVGO): A side stream from the vacuum distillation tower.

Make Up Stream: A feed to a process to replace a component that reacts or is otherwise depleted in a process.

Main Cryogenic Heat Exchanger: Main heat exchanger in the liquefaction unit where cooling and liquefaction of natural gas take place by means of heat exchange with cooling fluids.

Main Fractionators: The first distillation column for a FCC or coking process.

Main Line: Branch or lateral sewers that collect wastewater from building sewers and service lines.

Main Sewers: A sewer that receives wastewater from many tributary branches and sewer lines and serves as an outlet for a large territory or is used to feed an intercepting sewer.

Management of Change (MOC): 1. A process to understand all the implications of a change to a procedure. 2. A process for evaluating and controlling hazards that may be introduced during modifications to facility, equipment, operations, personnel or activities; MOCs can also be used to identify, evaluate and control unintended hazards introduced by modifying procedures or when developing a new plan or procedure.

Manhole: An opening in a sewer provided for the purpose of permitting operators or equipment to enter or leave a sewer. Sometimes called an "access hole" or a "maintenance hole".

Manifold(s): 1. A junction or center for connecting several pipes and selectively routing the flow. 2. A pipe spool in which a number of incoming pipes are combined to feed to a common output line.

Manometer: Instrument for measuring head or pressure; basically a U-tube partially filled with a liquid, so constructed that the difference in level of the liquid leg indicates the pressure exerted on the instrument.

MAOP: *See Maximum allowable operating pressure*.

Mass Balance: Summation of the mass entering a process and the summation of the mass leaving a process. They must equal for a steady-state process.

Material Safety Data Sheet (MSDS): 1. A description of the Health, Safety and Environment (HSE) data for a marketed product. 2. Printed information that describes the properties of a hazardous chemical and ways to control its hazards. 3. A document that provides pertinent information and a profile of a particular hazardous substance or mixture. An MSDS is normally developed by the manufacturer or formulator of the hazardous substance or mixture. The MSDS is required to be made available to employees and operators whenever there is the likelihood of the hazardous substance or mixture being introduced into the workplace.

MAWP: *See Maximum allowable working pressure*.

Maximum Allowable Operating Pressure (MAOP): The maximum gas pressure at which a pipeline system or process facility is allowed to operate.

Maximum Allowable Working Pressure (MAWP): 1. This is a legal maximum pressure that a process vessel is allowed to experience. Above this pressure, a relief valve should open to protect the vessel from catastrophic failure. 2. The maximum pressure to which a surface vessel can be operated or the maximum pressure during treating to which a well should be exposed.

Mechanical Seal: This is the part of a centrifugal pump that keeps the liquid from squirting out along the shaft. It is often subject to leakage due to pump vibration and cavitation.

Melting Point: The temperature at which a solid turns into a liquid. As temperature is a measure of the kinetic energy of molecules (i.e., how much they are moving around), this means that the molecules are moving too much to stay in one place.

Mercaptans: 1. Compounds of carbon, hydrogen, and sulfur (RSH, R = CH_3) found in sour crude and gas; the lower mercaptans have a strong, repulsive odor and are used, among other things to odorize natural gas. 2. A class of compounds containing carbon, hydrogen, and sulfur. The shorter chain materials are used as odor marker in natural gas. 3. Organic sulfides of the formula RSH where R represents the organic radical and SH represents the thiol group.

Methane (CH_4): A light odorless flammable gas that is the principal component of natural gas.

Methanol (CH_3OH): Methyl alcohol from the general formula (ROH), where R = C_nH_{2n+1} is known as a radical and n = 1, 2, 3, etc. Methanol can be made by the destructive distillation of wood or through a process starting with methane or a heavier hydrocarbon, decomposing it to synthesis gas and recombining it to methanol.

Methyl Tertiary Butyl Ether (MTBE, - $(CH_3)_3COCH_3$): 1. Is manufactured by etherification of methanol and isobutylene. Methanol is derived from natural gas and isobutylene is derived from butane obtained from crude oil and natural gas. 2. A gasoline additive used to increase octane number. MTBE is produced by reacting methanol (CH_3OH) with isobutylene (iC_4H_8). 3. Blends up to 15.0% by volume of MTBE which must meet the ASTM D4814 specifications. Blenders must take precautions that the blends are not used as base gasolines for other oxygenated blends (commonly referred to as the "Sun waiver").

An ether intended for gasoline blending as described in oxygenate definition.

In the U.S. it has been used in gasoline at low levels since 1979 to replace tetraethyl lead and to increase its octane rating helping prevent engine knocking. Oxygenates help gasoline burn more completely, reducing tailpipe emissions

from pre-1984 motor vehicles; dilutes or displaces gasoline components such as aromatics (e.g., benzene) and sulfur; and optimizes the oxidation during combustion. Most refiners chose MTBE over other oxygenates primarily for its blending characteristics and low cost.

Middle Distillates: Atmospheric pipe still cuts boiling in the range of 300 - 700°F (149 - 371°C) vaporization temperature. The exact cut is determined by the specifications of the product. 1. A general classification of refined petroleum products that include distillate fuel oil and kerosene. 2. Medium-density refined petroleum products, including kerosene, stove oil, jet fuel and light fuel oil. 3. Refinery products in the middle distillation range of refined products: kerosene, heating oil and jet fuel.

Mid-Percent Point: The vapor temperature at which one half of the material of a cut has been vaporized. Mid-percent point is used to characterize a cut in place of temperature limits.

Mixed Phase: More than one phase. Usually implies both vapor and liquid phase(s) present.

Molecular Sieve: A separation process that usually works by gaseous diffusion. A membrane is selected through which the compounds being removed or purified can pass while the remaining compounds in the stream being processed cannot pass.

MONC: Motor octane number clear (unleaded).

Motor Octane Number (MON, ASTM ON F2): A measure of resistance to self-ignition (knocking) of a gasoline under laboratory conditions that correlates with road performance during highway driving conditions. The percentage by volume of isooctane in a mixture of isooctane and n-heptane that knocks with the same intensity as the fuel being tested. A standardized test engine operating under standardized conditions (900 rpm) is used. This test approximates cruising conditions of an automobile; ASTM D – 2723.

MPHC: Medium pressure hydrocracking or partial conversion hydrocracking.

Motor Gasoline or Petrol: Gasoline is a volatile, flammable, complex petroleum fuel used mainly in internal combustion engines. It is used as fuel in specially designed heaters and lamps.

Motor Gasoline Blending: 1. Naphthas (e.g., straight-run gasoline, alkylate, reformate, benzene, toluene, xylenes) used for blending or compounding into finished motor gasoline. Includes receipts and inputs of Gasoline Treated as Blendstock (GTAB). Excludes conventional blendstock for oxygenate blending (CBOB), reformulated blendstock for oxygenate blending, oxygenates (e.g., fuel ethanol and methyl tertiary butyl ether), butane, and natural gasoline. 2. Mechanical mixing of motor gasoline blending components, and oxygenates when required, to produce finished motor gasoline. Finished motor gasoline may be further mixed with other motor gasoline blending components or oxygenates, resulting in increased volumes of finished motor gasoline and/or changes in the formulation of finished motor gasoline (e.g., conventional motor gasoline mixed with MTBE to produce oxygenated motor gasoline).

Motor Gasoline Blending Components: Naphthas (e.g., straight-run gasoline, alkylate, reformate, benzene, toluene, xylene) used for blending or compounding into finished motor gasoline. These components include reformulated gasoline blendstock for oxygenate blending (RBOB), but exclude oxygenates (alcohols, ethers), butane and pentanes plus.

Motor gasoline (finished): A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in spark-ignition engines. Motor gasoline as defined in ASTM Specification D4814 or Federal Specification VV – G – 1690C, is characterized as having boiling range of 122°F to 158°F (50°C to 70°C) at the 10% recovery point to 365°F to 374°F (185°C to 190°C) at the 90% recovery point. "Motor gasoline" includes conventional gasoline; all types of oxygenated gasoline, including gasohol; and reformulated gasoline but excludes aviation gasoline

Naphtha: 1. Straight-run gasoline distillate, below the boiling point of kerosene. Naphthas are generally unsuitable for blending as a component of premium gasoline; hence they are used as a feedstock for catalytic reforming in hydrocarbon production processes or in chemical manufacturing processes. 2. A term that is applied to low boiling mixtures of hydrocarbons with typical TBP boiling ranges between 150–450°F (66–233°C). Light and heavy naphthas are produced in the distillation of crude oils. Cracked naphthas are also produced by many of the refinery reaction processes.

Naphthas are subdivided according to the actual pipe still cuts – into light, intermediate and heavy and very heavy virgin naphthas. A typical pipe still operation would be

C_5–160°F (C_5–71°C): light virgin naphtha
160–280°F (71–138°C): intermediate virgin naphtha
280–380°F (138–193°C): heavy virgin naphtha
Naphtha, the major constituents of gasoline, generally needs processing to make a suitable quality gasoline.

Naphtha less than 401°F: A naphtha with a boiling range of less than 401°F (205°C) that is intended for use as a petrochemical feedstock.

Naphtha-Type Jet Fuel: A fuel in the heavy naphtha boiling range having an average gravity of 52.8 °API, 20 to 90 percent distillation temperature of 290–470°F (143–243°C) and meeting Military Specification MIL – T- 5624L (Grade JP – 4). It is used primarily for military turbojet and turboprop aircraft engines because it has a lower freeze point than other aviation fuels and meets engine requirements at high altitudes and speeds.

Special Naphthas: All finished products within the naphtha boiling range that are used as paint thinners, cleaners, or solvents. These products are refined to a specified flash point. Special naphthas include all commercial hexane and cleaning solvents conforming to ASTM Specification D 1836 and D484, respectively. Naphthas to be blended or marketed as motor gasoline or aviation gasoline and synthetic natural gas (SNG) feedstocks are excluded.

Naphthenes: Hydrocarbons of the cyclane family, sometimes called cycloalkanes. Naphthenes have no double bonds and are saturated ring structures with the general formula C_nH_{2n}, where C = carbon atoms, H = hydrogen atoms, and n = 6, 7, 8, …

Naphthenic: Having the characteristics of naphthenes, saturated hydrocarbons whose molecules contain at least one closed ring of carbon atoms.

Naphthenic Acids: Organic acids occurring in petroleum that contain a naphthenic ring and one or more carboxylic acid groups. Naphthenic acids are used in the manufacture of paint driers and industrial soaps.

Naphthenic Crudes: A type of crude petroleum containing a relatively large proportion of naphthenic-type hydrocarbon.

Natural Gas: Naturally occurring gas consisting predominantly of methane, sometimes in conjunction with crude (associated gas) and sometimes alone (unassociated gas). 1. A mixture of light hydrocarbons found naturally in the Earth's crust, often in association with oil (when it is known as associated gas). Methane is the most dominant component. It may also include some short-chain hydrocarbons (ethane, propane, butane) that may be in gaseous state at standard conditions. 2. A mixture of hydrocarbon compounds and small quantities of various non-hydrocarbons existing in the gaseous phase or in solution with crude oil in natural underground reservoirs at reservoir conditions. The primary constituent compound is CH_4. Gas coming from wells also can contain significant amounts of ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}) and pentanes (C_5H_{12}) and widely varying amounts of carbon dioxide (CO_2) and nitrogen (N_2).

Natural Gas Heating Value: The amount of thermal energy released by the complete combustion of one standard cubic foot of natural gas.

Natural Gas Liquids (NGL): 1. Liquid hydrocarbons, such as ethane, propane, butane, pentane, and natural gasoline, extracted from field natural gas. 2. Those hydrocarbons in natural gas that are separated from the gas as liquids through the process of absorption, condensation, adsorption, or other methods of gas processing or cycling plants. Generally, such liquids consist of propane and heavier hydrocarbons and are commonly referred to as lease condensate, natural gasoline and liquefied petroleum gases. Natural gas liquids include natural gas plant liquids (primarily ethane, propane, butane and isobutane. See Natural gas plant liquids and lease condensate (primarily pentanes produced from natural gas at lease separators and field facilities. 3. Liquids obtained during natural gas production that include ethane, propane, butanes and condensate.

Natural Gasoline: A gasoline range product separated at a location near the point of production from natural gas streams and used as a gasoline blending component.

Natural Gasoline and Isopentane: A mixture of hydrocarbons, mostly pentanes and heavier, extracted from natural gas, that meets vapor pressure, end point and other specifications for natural gasoline set by the Gas Processors Association. Includes isopentane that is a saturated branch-chain hydrocarbon (iC_5H_{12}), obtained by fractionation of natural gasoline or isomerization of normal pentane (nC_5H_{12}).

Natural Gas Plant Liquids: Those hydrocarbons in natural gas that are separated as liquids at natural gas processing plants, fractionating and cycling plants, and in some instances, field facilities. Lease condensate is excluded. Products obtained include ethane, liquefied

petroleum gases (propane, butanes, propane-butane mixtures, ethane-propane mixtures), isopentane, and other small quantities of finished products, such as motor gasoline, special naphthas, jet fuel, kerosene and distillate fuel oil.

Natural Gas Processing: 1. The purification of field gas at natural gas processing plants (or gas plants) or the fractionation of mixed NGLs to natural gas products to meet specifications for use of pipeline-quality gas. Gas processing includes removing liquids, solids and vapors absorbing impurities and odorizing. 2. The process of separating natural gas liquids (NGLs) by absorption, adsorption, refrigeration, or cryogenics from a steam of natural gas.

Natural Gas Processing Plant: Facilities designed to recover natural gas liquids from a stream of natural gas that may or may not have passed through lease separators and/or field separation facilities. These facilities control the quality of the natural gas to be marketed. Cycling plants are classified as gas processing plants.

Net Heating Value: is the total energy transferred as heat in an ideal combustion reaction at a standard temperature and pressure in which all water formed appears as vapor. The net heating is an ideal gas property in a hypothetical state (the water cannot all remain vapor because, after the water saturates the CO_2 in the products, the rest would condense).

Net Positive Suction Head (NPSH): The net positive suction head required to keep a centrifugal pump from cavitating. Cooling a liquid in a pump's suction line increases the pump's available NPSH, as does increasing the liquid level in the suction drum.

Nonassociated gas: Natural gas that exists in a reservoir alone and is produced without any crude oil.

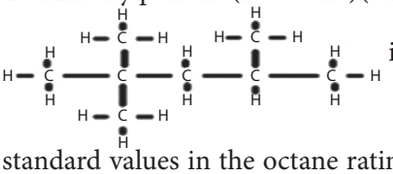
Normal boiling point: *See boiling point.*

Nusselt number (Nu): A dimensionless number Nu is used in heat transfer calculations characterizing the relation between the convective heat transfer of the boundary layer of a fluid and its thermal conductivity.

$$Nu = \frac{hd}{k}$$

Where h is the surface heat transfer coefficient, d is the thickness of the fluid film, and k is the thermal conductivity.

Octane (C_8H_{18}): 1. Is a hydrocarbon and an alkane with the chemical formula C_8H_{18}, and the condensed structural formula $CH_3(CH_2)_6CH_3$. Octane has many structural isomers that differ by the amount and location of branching in the carbon chain. One of the isomers, 2, 2, 4–trimethylpentane (isooctane) $(CH_3)_3CCH_2CH(CH_3)_2$



is used as one of the standard values in the octane rating scale. Octane is a component of gasoline (petrol). As with all low molecular weight hydrocarbons, octane is volatile and very flammable. 2. A test used to measure the suitability of a gasoline as motor fuel. The octane test determines the knocking characteristics of a gasoline in a standard test engine relative to a standard of 2-2-4 trimethyl pentane (2 2 4 TMP). 2 2 4 TMP is assigned an octane number of 100.0. There are two octane tests. One is designated the research octane (F-1) and the second as the motor octane (F-2). Motor octane is determined in an engine more representative of actual operating conditions for automobiles and is lower than research octane for any gasoline stock.

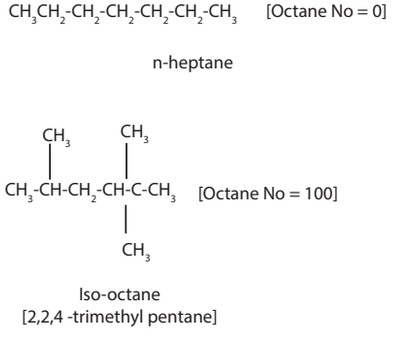
Historically, gasoline was marketed based on the F-1 octane, but in recent years, the average of the F-1 and F-2 octane has been used. At the gasoline pump, this is reported as (R + M)/2.

The Research Octane Number (RON) test simulates driving mild conditions while the Motor Octane Number (MON) test simulates driving under more severe conditions, i.e., under load and at high speeds. The arithmetic average of RON and MON, which gives an indication of the performance of the engine under the full range of condition, is projected as Anti Knock Index (AKI), i.e. Anti Knock Index (AKI) = (RON + MON)/2.

Octane Number: 1. Is a measure of the knocking characteristics of a fuel in a laboratory gasoline engine according to ASTM D2700. We determine the octane number of a fuel by measuring its knocking value compared to the knocking of a mixture of n-heptane and isooctane of 2-2-4 trimethylpentane (224 TMP). 2. An index measured by finding a blend of isooctane (iC_8H_{18}) and normal heptanes (nC_7H_{16}) that knocks under the identical conditions as the gasoline being evaluated. It is a measure of the ease of self-ignition of a fuel without the aid of a spark plug. 3. The octane number is a measure of the antiknock resistance of a gasoline. It is the percentage of iso-octane in a mixture of iso-octane and n-heptane, which gives a knock

of the same intensity as the fuel being measured when compared in a standard engine. For example, if the fuel being tested matches in knocking to a blend of 90% iso-octane and 10% n-heptane, then the test fuel is said to have an octane number of 90.

Iso-octane which produces the least knocking or which knocks only at a much higher compression ratio is given an octane number of 100, while n-heptane which is very poor in its resistance to knocking or which knocks at a much lower compression ratio is given an octane number of zero.



Generally, octane number increases as the degree of branching of the carbon chain increases and thus iso-paraffins are found to give higher octane numbers than the corresponding normal isomers. Olefins are found to give higher octane numbers than the related paraffins. Naphthenes also give better octane numbers than the corresponding normal paraffins. Aromatics usually exhibit high octane numbers.

A single cylinder test engine is made to obtain the antiknock characteristics of gasoline in terms of octane numbers. The octane numbers formed a scale ranging from 0 to 100; the higher the number the greater the antiknock characteristics. The scale has been extended above 100 by comparing the knocking intensity with iso-octane to which tetraethyl lead (TEL) is added. Numbers greater 100 on the scale are referred to as performance numbers rather than octane numbers. *See also Motor Octane number and Research Octane number.*

Octane numbers are very relevant in the reforming, isomerization and alkylation processes in refining facilities. These processes enable the successful reactive transformations to yield long side chain paraffins and aromatics that possess higher octane numbers than the feed constituents which do not consist of higher quantities of constituents possessing straight chain paraffins and non-aromatics (naphthenes).

It is a measure of the ease of self-ignition of a fuel without the aid of a spark plug.

Octane Scale: A series of arbitrary numbers from 0 to 120.3 used to rate the octane number of gasoline. Three reference materials define the scale; n-heptane (Octane number = 0), isooctane (Octane number = 100), and isooctane plus six ml tetramethyl lead (Octane number = 120.3). Above 100, the octane number of a fuel is based on the engine ratings, in terms of ml of tetra ethyl lead in isooctane which matches that of the unknown fuel.

Off Gas: The gas leaving a reflux drum or top tray of an absorber column.

Off Line: When a process unit is shut down it is said to be off line.

Table 1 Octane numbers of pure hydrocarbons*

Hydrocarbon	RON	MON	Hydrocarbon	RON	MON
n-pentane	61.7	61.9	2,4 – Dimethyl hexane	62.5	69.9
n-hexane	24.8	26.0	2,2,4 –Trimethyl pentane (iso-octane)	100.0	100.0
n-heptane	0.0	0.0	1 – Pentene	90.9	77.1
n-octane	–19.5	–15.0	1 – Octane	28.7	34.7
n-nonane	–17.0	–20.0	3 - Octene	72.5	68.1
2-methyl butane (Iso-pentane)	92.3	90.3	4 – Methyl – 1- Pentene	95.7	80.9
2 – Methyl hexane (Iso-heptane)	42.4	46.4	Benzene	–	114.8
2 – Methyl heptane (Iso-octane)	21.7	23.8	Toluene	120.1	103.5

*(Source: Speight, James G., *The Chemistry & Technology of Petroleum*, Marcel Dekker, Inc. 1991).

Oil: One of the various liquid, viscid, usually inflammable, chemically neutral substances that is lighter and insoluble in water, but soluble in alcohol and ether and classified as non-volatile. Natural plant oils comprise terpenes and simple esters such as essential oils. Animal oils are glycerides of fatty acids. Mineral oils are mixtures of hydrocarbons. Oils have many uses and include fuels lubricants, soap constituents, vanishes, etc.

Oil and gas: Refer to the industry associated with the recovery of liquid and gaseous hydrocarbons from underground deposits as reservoirs found both onshore and offshore around the world. A collection of localized deposits is known as an oil field or gas field. When they are drilled, they are known as oil and gas wells. Oil is mainly used as fuel for transportation purposes, whereas gas is primarily used as fuel for domestic and industrial purposes, and for converting into other chemicals such as plastic. Oil is widely transported in ships. Gas is transported in underground, sub-sea, or overland pipelines covering large distances.

Oil refinery: An industrial process plant where crude oil is converted into useful products such as naphtha, diesel fuel, kerosene, and LPG. Also known as petroleum refinery, the process involves the separation of the crude oil into fraction in the process of fractional distillation. By boiling the crude oil, the light or more volatile components with the lowest boiling point rise towards the top of the column, whereas the heavy fractions with the highest boiling points remain at the bottom. The heavy bottom fractions are then thermally cracked to form more useful light products. All the fractions are then processed further in other parts of the oil refinery, which may typically feature vacuum distillation used to distill the bottoms; hydrotreating, which is used to remove sulfur from naphtha, catalytic cracking, fluid catalytic cracking, hydrocracking, visbreaking, isomerization, steam reforming, alkylation, hydrodesulfurization, and the Claus process used to convert hydrogen sulfide into sulfur, solvent dewaxing and water treatment.

Olefins: Hydrocarbons of the alkenes family. Olefins have two carbon atoms in the molecular structure linked by a double bond to satisfy the absence of two hydrogen atoms that are present in the corresponding paraffin. This hydrogen deficiency is called unsaturation. The general formula for olefins is C_nH_{2n}, where C = carbon atoms, H = hydrogen atoms, and n = 2, 4, 6.

Olefins do not occur naturally in crude oil and are created in the thermal and catalytic cracking processes.

Online: When a process unit is in operation and processing feed, it is said to be online.

OPEC: Organization of Petroleum Exporting Countries. These countries have organized for the purpose of negotiating with oil companies on matters of oil production, prices and future concession rights. Current members are Algeria, Indonesia, Iran, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates and Venezuela.

Operability Capacity: 1. The amount of capacity that, at the beginning of the period, is in operation; not in operation and not under active repair, but capable of being placed in operation within 30 days; or not in operation but under active repair that can be completed within 90 days. Operable capacity is the sum of the operating and idle capacity and is measured in barrels per calendar day or barrels per stream day. 2. The component of operable capacity that is operation at the beginning of the period.

Operating Pressure: Pressure indicated by a gauge when the system is in normal operation (working pressure).

Operation and Maintenance Manual: A manual that describes detailed procedures for operators to

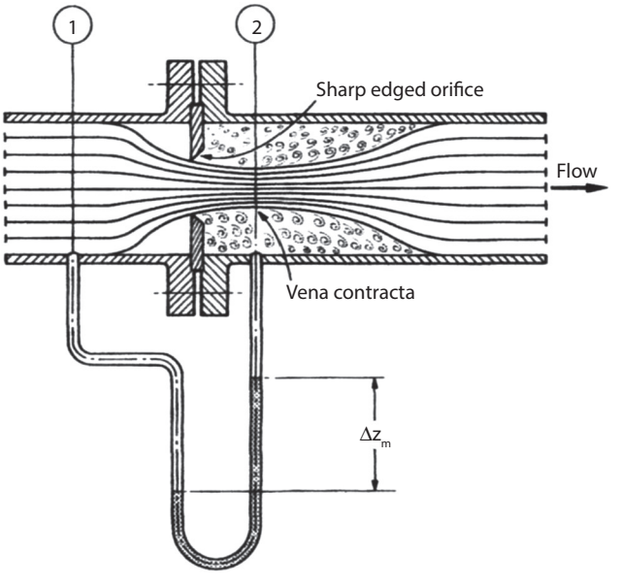


Figure 19 Orifice Meter with Vena contracta formation.

follow to operate and maintain specific water or wastewater treatment, pretreatment or process plants and the equipment of the plants.

Operator: 1. Term used to describe a company appointed by venture stakeholders to take primary responsibility for day- to-day operations for a specific plant or activity. 2. The company or individual responsible for managing an exploration, development or production operation. 3. The company that has legal authority to drill wells and undertake the production of hydrocarbons that are found. The operator is often part of a consortium and acts on behalf of this consortium. 4. The company that makes the decisions and is responsible for drilling, completing, operating and repairing the well.

Operable Utilization Rate: Represents the utilization of the atmospheric crude oil distillation units. The rate is calculated by dividing the gross input to these units by the operable refining capacity of the units.

Organic Compounds: Compounds that include carbon and hydrogen atoms. Generally organic compounds can be classified as either aliphatics (straight chain compounds), cyclic (compounds with ring structures), and combinations of aliphatics and cyclic.

Orifice: An opening in wall or plate used to control the rate of flow into or out of a tank or pipe.

Orifice Meter: A single phase flow meter, primarily for gas that measures the pressure drop created by the hole as gas is flowed (See Figure 19).

Orifice Plate: Part of an orifice metering system. A plate with a hole through which a single phase flow produces a pressure drop.

Other Hydrocarbons: Materials received by a refinery and consumed as a raw material. Includes hydrogen, coal tar derivatives, gilsonite, and natural gas received by the refinery for reforming into hydrogen. Natural gas to be used as fuel is excluded.

OSHA: 1. Occupational Safety and Health Administration: U.S. government agency. 2. The Williams-Steiger Occupational Safety and Health Act of 1970 (OSHA) is a federal law designed to protect the health and safety of industrial workers, including the operators of water supply and treatment systems and wastewater treatment plants. The Act regulates the design, construction, operation, and maintenance of water supply systems, water treatment plants, wastewater collection systems, and wastewater treatment plants. OSHA also refers to the federal and state agencies that administer the OSHA regulations.

Oxidation: Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite is the reduction.

Oxidation Inhibitor: A substance added in small quantities to a petroleum product to increase its oxidation resistance, thereby lengthening its service or storage life; also called an antioxidant. Oxidation of fuels creates gums which become colloidal, then agglomerate and precipitate. Cracked distillates are found more prone to oxidation and deterioration then straight run distillates. Oxidation fuels can also result in the formation of various acids, ketones, aldehydes and esters from hydrocarbons. Amino guanidine derivatives when used in the range 3–30 ppm are found effective as antioxidants. Cyclic borates of polymers alkanolamines are effective anti-oxidants even in the 10 ppm range.

Oxidation Stability: 1. It is used for the evaluation of storage stability and resistance to oxidation as most of the oils, when exposed to air over time, react with oxygen, which are then degraded. Oil with poor oxidation stability, forms corrosive acids at high temperature condition in the engine. 2. Gasoline contains cracked components having tendency to form gum materials during storage and handling which affect performance. Oxidation stability provides an indication of the tendency of gasoline and aviation fuels to form gum in storage. In this test, the sample is oxidized inside a stainless steel pressure vessel initially charge with oxygen at 689 kPa and heated in a boiling water bath. The amount of time required for a specified drop in pressure (gasoline) or the amount of gum and precipitate formed after specific aging period (aviation fuel) is determined.

Oxidizers: Reactants that oxidize, for example, bleach, chlorine, sodium hypochlorite, sodium persulfate. Also, a compound that releases oxygen.

Oxidizing Agent: Any substance, such as oxygen (O_2) or chlorine (Cl_2) that will readily add (take on) electrons. The opposite is a reducing agent.

Oxygen: A chemical element used by all known life forms for respiration.

Oxygenated Fuel: Any organic compound containing oxygen. Specifically for the petroleum industry, this term refers to oxygen-containing organic compounds, such as ethers, and alcohols, added to fuels to reduce carbon monoxide in the engine exhausts. They are used as gasoline blending components. Oxygenated fuels tend to give a more complete combustion of its carbon into carbon dioxide (rather than monoxide), thereby reducing air pollution from exhaust emissions.

Oxygenated Fuels Program Reformulated Gasoline: A reformulated gasoline that is intended for use in an oxygenated fuels program control area during an oxygenated fuels program control period.

Oxygenated Gasoline: 1. Gasoline with an oxygen content of 1.8% or higher, by weight that has been formulated for use in motor vehicles. 2. Finished motor gasoline, other than reformulated gasoline, having an oxygen content 2.7% or higher by weight. It includes gasohol.

Oxygenates: Substances that, when added to gasoline, increase the amount of oxygen in that gasoline blend, and thus boost the octane number of gasoline or petrol. Ethanol, methyl tertiary butyl ether (MTBE), ethyl tertiary butyl ether (ETBE), tertiary amyl methyl ether (TAME) and methanol are common oxygenates. MTBE, ETBE, TAME have 1. Low water solubility, 2. Lower volatility and 3. Compatibility with hydrocarbon fuels.

Overall Tray Efficiency: Overall tray efficiency can be defined as the number of theoretical trays in a distillation column section divided by the number of actual trays in the section and is reported as a percentage. Overall tray efficiencies are less than 100% for all refinery distillation columns.

Overflash: The liquid that returns to the flash zone of a column.

Overhead: Usually refers to the vapor leaving the top tray of a distillation column. For an absorber column the overhead and the top product are the same.

Overlap: *See Gap.*

Overpressure: Is any pressure relative to ambient pressure caused by an explosive blast, both positive and negative.

Ozone (O_3): An oxygen molecule with three oxygen atoms that occurs as a blue, harmful, pungent-smelling gas at room temperature. The stratosphere ozone layer, which is a concentration of ozone molecules located at 6 to 30 miles above sea level, is in a state of dynamic equilibrium. Ultra violet radiation forms the ozone from oxygen but can also reduce the ozone back to oxygen. The process absorbs most of the ultraviolet radiation from the sun, shielding life from the harmful effects of radiation.

Packed Bed Scrubber: Vertical or horizontal vessels, partially filled with packing or devices of large surface area, used for the continuous contact of liquid and gas such that absorption can take place. Frequently, the scrubber liquid or liquor has had chemicals added to react with the absorbed gas.

Packing (Seals): Seals around a moving shaft or other equipment.

Paraffins: 1. Hydrocarbons of the alkanes family. Paraffins are saturated compounds, i.e., hydrogen atoms are appropriately attached to the carbon atoms such that the carbon atoms have only single bonds in the molecular structure. General formula for paraffin is C_nH_{2n+2}, where C = carbon atoms, H = hydrogen atoms, and n = 1, 2, 3, 4, 5, …2. A white, odorless, tasteless, chemically inert, waxy substance derived from distilling petroleum; a crystalline, flammable substance composed of saturated hydrocarbons. 3. Normal or straight carbon chain alkanes with carbon chain lengths of C_{18+}. The alkanes in this range solidify at temperatures from 80°F to over 200°F (27°C – 93°C).

Partial Pressure: In a gaseous mixture, the pressure contribution for a particular component of the mixture. The sum of the partial pressures of the components in the mixture is the total pressure. For example, in a mixture of two components A and B, with partial pressures as p_A, p_B respectively. The total pressure p_{Total} is: $P_{Total} = p_A + p_B$.

Penetration: A measure of the hardness and consistency of asphalt in terms of the depth that a special pointed device will penetrate the product in a set time and temperature.

Performance Rating: A method of expressing the quality of a high-octane gasoline relative to isooctane. This rating is used for fuels that are of better quality than isooctane.

Petroleum Administration for Defense Districts (PADD): Geographic aggregations of the 50 U.S.states and the District of Columbia into five districts by the Petroleum Administration for Defense in 1950. These

districts were originally defined during World War II for purposes of administering oil allocation.

Petroleum Coke: A residue high in carbon content and low in hydrogen that is the final product of thermal decomposition in the condensation process in cracking. This product is reported as marketable coke. The conversion is 5 barrels (of 42 U.S. gallons each) per short ton. Coke from petroleum has a heating value of 6.024 million Btu per barrel.

Marketable coke: Those grades of coke produced in delayed or fluid cokers which may be recovered as relatively pure carbon. This "green" coke may be sold as is or further purified by calcining.

Catalyst coke: The only catalytic coke used as a fuel is the coke on catalyst in the FCC process. In other catalytic processes there is coke deposited on catalyst, but it is not regenerated in a way such that the heat of combustion is recovered.

Petrolatum: Microcrystalline wax or Petroleum jelly.

Petroleum ether: A volatile fraction of petroleum consisting mainly pentanes and hexanes.

Petrochemical Feedstocks: Chemical feedstocks derived from petroleum principally for the manufacture of chemicals, synthetic rubber, and a variety of plastics. These categories reported are "Naphthas less than 401°F and Other Oils Equal to or greater than 401°F".

Petroleum Products: Petroleum products are obtained from the processing of crude oil (including lease condensate), natural gas, and other hydrocarbon compounds. Petroleum products include unfinished oils, liquefied petroleum gases, pentanes plus, aviation gasoline, motor gasoline, naphtha type jet fuel, kerosene-type jet fuel, kerosene, distillate fuel oil, residual fuel oil, petrochemical feedstocks, special naphthas, lubricants, waxes, petroleum coke, asphalt, road oil, still gas, and miscellaneous products.

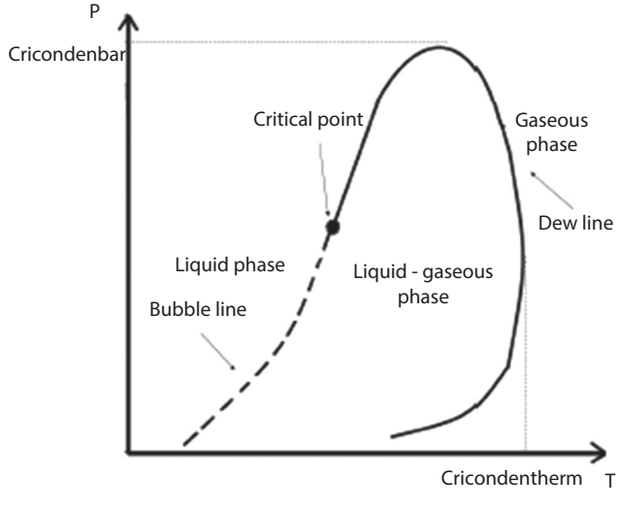


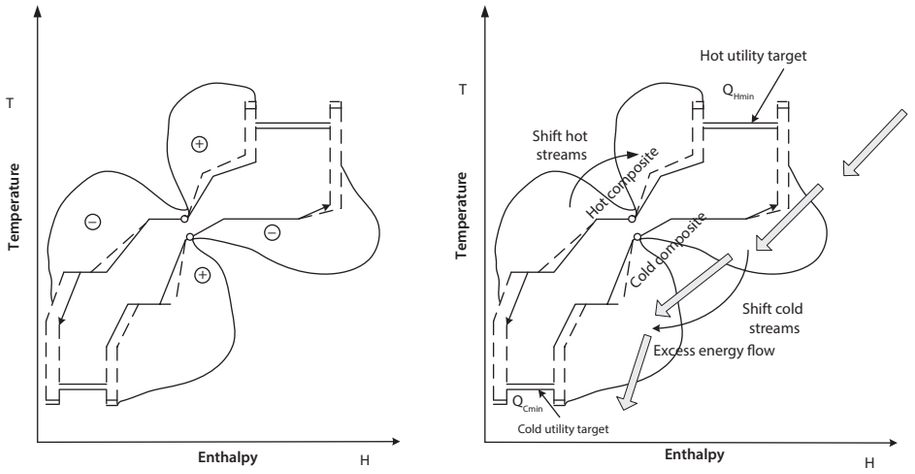
Figure 20 Phase diagram (Phase Envelope).

Phase Envelope: 1. The boundaries of an area on the P-T diagram for the material which encloses the region where both vapor and liquid coexist. 2. Phase diagram or phase envelope is a relation between temperature and pressure that shows the condition of equilibria between the different phases of chemical compounds, mixture of compounds, and solutions. Phase diagram is an important issue in chemical thermodynamics and hydrocarbon reservoir. It is very useful for process simulation, hydrocarbon reactor design, and petroleum engineering studies. It is constructed from the bubble line, dew line, and critical point. Bubble line and dew line are composed of bubble points and dew points, respectively. Bubble point is the first point at which the gas is formed when a liquid is heated. Meanwhile, dew point is the first point where the liquid is formed when the gas is cooled. Critical point is the point where all of the properties of gases and liquids are equal, such as temperature, pressure, amount of substance, and others. Critical point is very useful in fuel processing and dissolution of certain chemicals

According to thermodynamic definition of phase diagram (phase envelope) is a graph showing the pressure at which transition of different phases from a compound with respect to temperature. Bubble point which forms bubble line is a point separating the liquid phase and the two phases region, namely the liquid phase and the gaseous phase. The dew point which forms the dew line is a point separating the gaseous phase and two phase region, namely the liquid and gaseous phase. At the dew point, the following conditions must be satisfied (See Figure 20).

Physical Solvent: A liquid capable of absorbing selected gas components by solubility alone without associated chemical reactions.

Pig: 1. A cylindrical device that is inserted into a pipeline to clean the pipeline wall or monitor the internal condition of the pipeline. 2. Device for cleaning a pipeline or separating two liquids being removed down the pipeline. (Intelligent pig – fitted with sensors to check for corrosion or defects in pipelines.).



(**a**) The plus-minus principle.

(**b**) Shifting streams through the pinch in the right direction enacts the plus-minus principle.

Figure 21 The plus-minus principle guides process design to reduce utility consumption (Source: Smith, R. and Linnhoff, B., Trans. IChemE ChERD, 66, 195, 1988).

3. A flow line clearing device, pumped through the line with normal flow. 4. Refers to a poly pig that is a bullet-shaped device made of hard rubber or similar material. This device is used to clean pipes. It is inserted in one end of a pipe, moves through the pipe under pressure, and is removed from the other end of the pipe.

Pinch analysis: Bodo Linnhoff at the University of Leeds in 1977 developed a technique for minimizing energy usage in a process. It is based on calculating the minimum energy consumption by optimizing the heat recovery, energy supply and process operating conditions. It uses process data represented as energy flows or streams as a function of heat load against temperature. These data are combined for all the hot and cold streams requiring heat. The point of closest approach between the hot and cold composite curves is called the pinch point and corresponds to the point where the design is most constrained. Using this point, the energy targets can be achieved using heat exchange to recover heat between the hot and cold streams in two separate systems, with one temperature above the pinch temperature and one for the temperature below the pinch temperatures.

Figure 21 shows the point in a pinch analysis that corresponds to the point where the hot and cold streams in an integrated process are most constrained.

Pipelines: Tubular arrangement for the transportation of crude oil, refined products and natural gas from the well head, refinery and storage facility to the consumer. Pipeline measures 14–42 in. (356–1067 mm) in diameter but is usually 20–36 in (508–914 mm). It is often composed of 40 ft. (12 m) lengths, but lengths may be as long as 60 or 80 ft. (18–24 m). The pipe is wrapped and coated for protection against corrosion, especially since it runs underground. About half of all gases and oils are moved by pipeline.

Pipe still: A heater or furnace containing tubes through which oil is pumped while being heated or vaporized. Pipe stills are fired with waste gas, natural gas or heavy oils, and by providing for rapid heating under conditions of high pressure and temperature, are useful for thermal cracking as well as distillation operations.

Pipe size: Process piping comes in particular nominal sizes:

0.75 in.	-
1 in.	25 mm
2 in.	50 mm
2.5 in.	-
3 in,	80 mm
4 in,	100 mm
6 in.	150 mm
8 in.	200 mm
10 in.	250 mm

The nominal size does not refer either to the outside or the inside diameter of the pipe. Pipe thickness affects the ID.

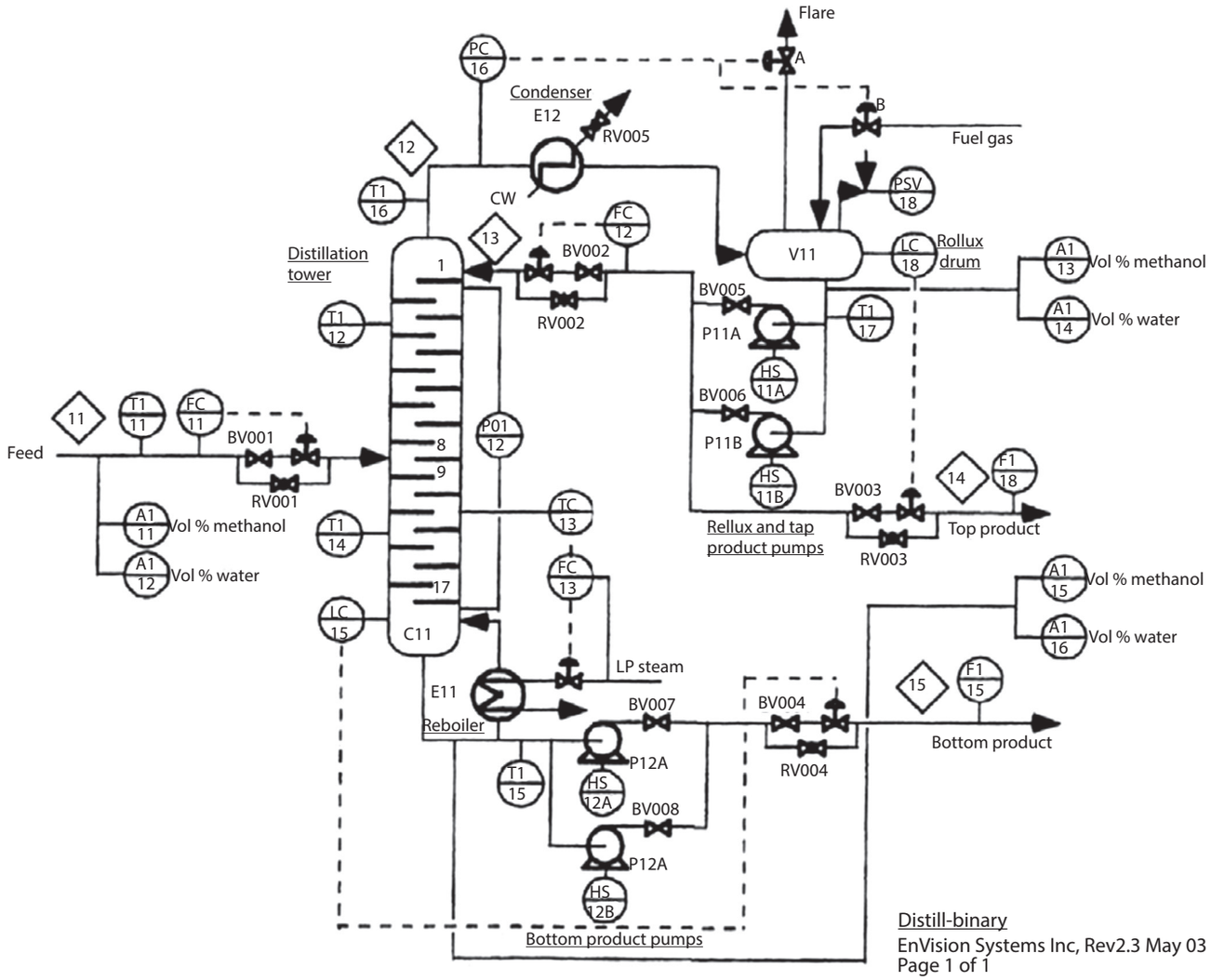


Figure 22 Piping and instrumentation diagram.

Piping and instrumentation diagram (P &ID): A schematic representation of the interconnecting pipelines and control systems for a process or part of a process (see Figure 22). Using a standard set of symbols for process equipment and controllers. It includes the layout of branches, reducers, valves, equipment, instrumentation and control interlocks. They also include process equipment names, numbers; process piping including sizes and identification; valves and their identification; flow directions, instrumentation, and designations; vents, drains, sampling lines, and flush lines. P & IDs are used to operate the process system, operators' trainings as well as being used in plant maintenance and process modifications. At the design stage, they are useful in carrying out safety and operations investigations such as Hazop. List of P & ID items are:

- Instrumentation and designations
- Mechanical equipment with names and numbers
- All valves and their identifications
- Process piping, sizes and identification
- Miscellanea – vents, drains, special fittings, sampling lines, reducers, enlargers, and swagers
- Permanent start-up and flush lines
- Flow directions.
- Interconnections references
- Control inputs and outputs, interlocks
- Interfaces for class changes

- Computer control systems
- Identification of components and subsystems.

Polymerization: A reaction in which like molecules are joined together to form dimer and trimer compounds, etc., of the reactant(s). This most often occurs with olefinic compounds in oil refineries. The objective of a polymerization unit is to combine or polymerize the light olefins propylene and butylenes into molecules two or three times their original molecular weight. The feed to this process consists of light gaseous hydrocarbons (C_3 and C_4) produced by catalytic cracking, which are highly unsaturated. The polymer gasoline produced has octane numbers above 90.

PONA Analysis: Analysis for paraffins (P), olefins (O), naphthenes (N), and aromatics (A). Method used is ASTM D 1319.

Pour Point: 1. Is a measure of how easy or difficult to pump the crude oil, especially in cold weather. Specifically, the pour point is the lowest temperature at which a crude oil will flow or pour when it is chilled without disturbance at a controlled rate. The pour point of the whole crude or oil fractions boiling above 450°F (232°C) is determined by the standard test ASTM D97. Both pour and cloud points are important properties of the product streams as far as heavier products are concerned. For heavier products, they are specified in a desired range and this is achieved by blending appropriate amounts of lighter intermediate products. 2. The temperature at which oil starts to solidify and no longer flows freely. Pour point usually occurs 40 to 42°F (4.5 to 5.5°C) below the cloud points. A sample tube of petroleum oil is chilled in the pour point test. The pour point is defined as the temperature at which the sample will still pour (move) when the sample tube is tipped. The pour temperature is typically about 5°F (2.8°C) lower than the cloud point.

Power Stroke: Is the downward motion of a piston that occurs after ignition as the fuel combusts and expands.

ppmv: A volume concentration of a species in a bulk.

Prandtl number (Pr): A dimensionless number, Pr representing the ratio of the momentum of diffusivity to thermal diffusivity in fluid convection.

$$\mathrm{Pr} = \frac{c_p \mu}{k}$$

where c_p is the specific heat, μ is the viscosity, and k is the thermal conduction.

Pre-Ignition: Describes the event when the air/fuel mixture in the cylinder ignites before the spark plug fires. Pre-ignition is initiated by an ignition source other than the spark, such as hot spots in the combustion chamber, a spark plug that runs too hot for the application, or carbonaceous deposits in the combustion chamber heated to incandescence by previous engine combustion events. It is a technically different phenomenon from engine knocking.

The phenomenon is also referred to as 'after-run', or 'run-on' or sometimes dieseling, when it causes the engine to carry on running after the ignition is shut off. This effect is more readily achieved on carbureted gasoline engines, because the fuel supply to the carburetor is typically regulated by a passive mechanical float valve and fuel delivery can feasibly continue until fuel line pressure has been relieved, provided the fuel can be somehow drawn past the throttle plate.

Pre-ignition and engine knock both sharply increase combustion chamber temperatures. Consequently, either effect increases the likelihood of the other effect occurring and both can produce similar effects from the operator's perspective, such as rough engine operation or loss of performance due to operational intervention by a computer. See Knocking.

Pre-Startup Safety Review (PSSR): Audit check performed prior to equipment operation to ensure adequate process safety management (PSM) activities have been performed. The check should verify (1) Construction and equipment is satisfactory, (2) Procedures are available and adequate, (3) A process hazard analysis (PHA) has been undertaken and recommendations resolved, (4) The employees are trained.

Precursor: Compounds which are suitable or susceptible to specific conversion to another compound. e.g., methyl cyclopentane is a good precursor for making benzene in a catalytic reformer.

Preheat, Preheat Train: Heat exchanger or network of heat exchangers in which the feed to a process (usually a distillation column) is heated by recovering heat from products being cooled.

Pressure, Absolute: 1. The force applied over a given area. Instrument gauges used to measure the pressure of fluids are either expressed as absolute pressure, which is measured above a vacuum. 2. Gauge pressure plus barometric or atmospheric pressure. Absolute pressure can be zero only in a perfect vacuum. 3. The pressure

due to the weight of the atmosphere (air and water vapor) on the Earth's surface. The average atmospheric pressure at sea level has been defined as 14.69 lb_f/in^2 absolute.

Pressure, Atmospheric: 1. The pressure due to the weight of the atmosphere (air and water vapor) on the Earth's surface. The average atmospheric pressure at sea level is 14.696 lb_f/in^2. absolute. 2. The pressure exerted by the atmosphere on a given point. It decreases as the elevation above sea level increases.

Pressuring Agent: The hydrocarbon, usually butane used to bring gasoline blends up to an acceptable vapor pressure.

Pressure drop: 1. The decrease in pressure between two points in a system caused by frictional losses of a moving fluid in a pipe or duct, or by some other resistance such as across a packed bed, a filter or catalyst, or due to the effects of hydrostatic head such as across the liquid on the tray of a distillation column. 2. Change in pressure with depth.

Pressure drop multiplier (φ^2): A parameter used in two-phase gas-liquid frictional pressure drop calculations where the overall pressure drop along a length of pipe is due to combination from the flowing gas and liquid. This is expressed by:

$$\frac{dp_f}{dz} = \varphi_g^2 \left(\frac{dp_g}{dz} \right)_g = \varphi_L^2 \left(\frac{dp_L}{dz} \right)_L$$

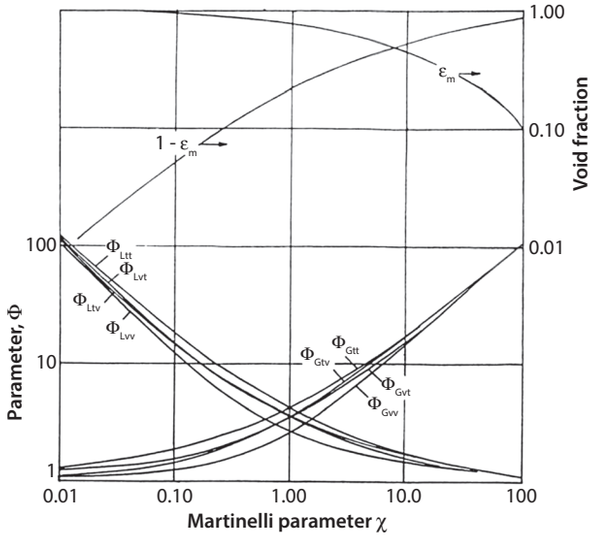


Figure 23 Lockhart-Martinelli two-phase multiplier.

where φ_g^2 and φ_L^2 are the pressure drop multipliers for the liquid and gas phases in which the parameters X^2 is defined as:

$$X = \sqrt{\left[\frac{\left(\frac{dp_L}{dz} \right)_L}{\left(\frac{dp_g}{dz} \right)_g} \right]} = \left(\frac{\varphi_g^2}{\varphi_L^2} \right)^{0.5}$$

Correlations have been developed to determine relationships for the multipliers for combinations of laminar and turbulent gas and liquid phases (See Figure 23).

Pressure, Hydrostatic: The pressure, volume per unit area, exerted by a body of water at rest.

Pressure Integrity Test: A pressure test of a vessel formed by the entire well or part of a well. It usually measures the ability of a pressure vessel to hold pressure without leaking at a given pressure.

Pressure, Negative: A pressure less than atmospheric.

Pressure Reducing Valve: Valve used to reduce a high supply pressure to a usable level.

Pressure Relief Valve: A mechanical valve that opens at a preset pressure to relieve pressure in a vessel (See Figure 24).

Primary Absorber: The first absorber in a FCC gas plant.

Pretreatment: Group of processes that natural gas is subjected to prior to its liquefaction. Its purpose is to remove mainstream contaminants or compounds that may cause operational problems in the liquefaction unit.

Pretreatment Facility: Industrial wastewater treatment plant consisting of one or more treatment devices designed to remove sufficient pollutants from wastewaters to allow an industry to comply with effluent limits established by the US EPA General and Categorical Pretreatment Regulations or locally derived prohibited discharge requirements and local effluent limits.

Preventative Maintenance: Maintenance carried out prior to unit or system failure.

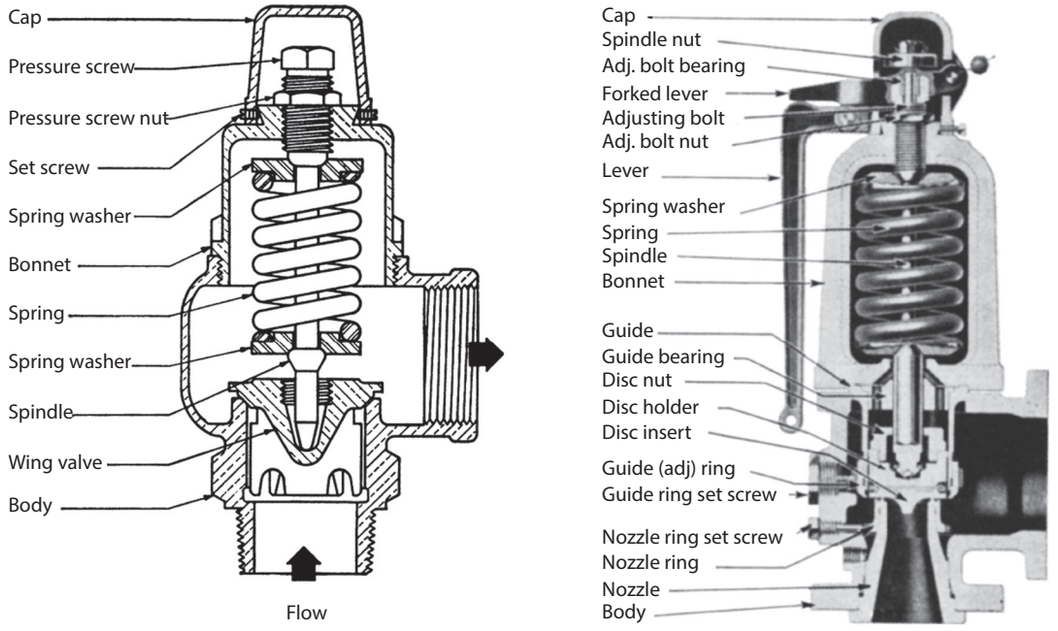


Figure 24 Relief valve Safety valve.

Preventive Maintenance: Regularly scheduled servicing of machinery or other equipment using appropriate tools, tests and lubricants. This type of maintenance can prolong the useful life of equipment and machinery and increase its efficiency by detecting and correcting problems before they cause a breakdown of the equipment.

Probability: The likelihood that the impact or event will occur. Impact (or consequence) is the effect on conditions or people if the hazard is realized (occurs) in practice, and probability is the likelihood that the impact will occur. Risk is a function of probability and impact (consequence). With this discrete data, it is determined by taking the number of occurrences for the particular type of event being considered and dividing that by the total number of outcomes for the event. Expressed as a deterministic value (quantitative single value or high, medium, low, etc.) or as a range of values – that is, uncertainty – that is represented by a probability distribution.

Probability Distribution (Risk): A mathematical relationship between the values and the associated probabilities for a variable across the entire range of possible values for that variable. Typically, probability distributions are displayed as frequency or cumulative frequency plots.

Probability Distillation: The characteristic shape of laboratory distillation boiling curves tends to follow the shape of a normal distribution function, especially the TBP method. Probability distillation paper is constructed with a probability scale for the boiling point scale and laboratory distillation curves may be plotted as straight lines on this paper. This provides a reasonable way to extrapolate partial laboratory distillation data.

Process: Any activity or operation leading to a particular event.

Process Flow Diagram (PFD): A schematic representation of a process or part of a process that converts raw materials to products through the various units operations (Figure 25). It typically uses a symbolic representation for the major items of equipment such as storage vessels, reactors, separators, process piping to and from the equipment, as well as bypass and recirculation lines, and the principal flow routes. Key temperatures and pressures corresponding to normal operation are included, as well as equipment ratings, minimum and maximum operational values. Material flows and compositions are included. It may also include important aspects of control and pumping, as well as any interaction with other process equipment or flows. The design duties or sizes of all the major equipment are also featured, which can collectively provide

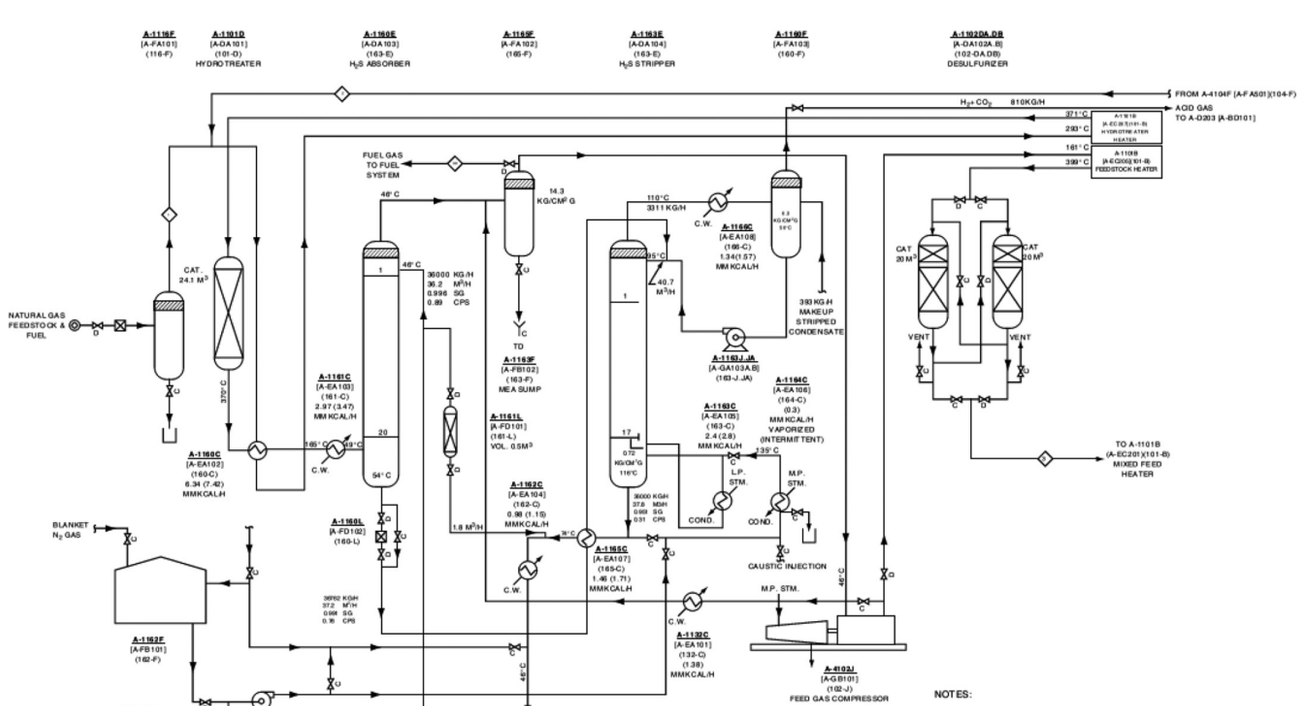


Figure 25 Process flow diagram (Feed and fuel desulfurization section).

a comprehensive representation of the process. PFDs generally do not include the following:

- Pipe classes or piping line numbers
- Process control instrumentation (sensors and final elements).
- Minor bypass lines
- Isolation and shutoff valves.
- Maintenance vents and drains
- Relief and safety valves
- Flanges.

Programmable Logic Controller (PLC): A digital electronic controller that uses computer based programmable memory for implementing operating instructions through digital or analog inputs and outputs.

Process Hazard Analysis (PHA): An organized formal review to identify and evaluate hazards with industrial facilities and operations to enable their safe management. The review normally employs a qualitative technique to identify and access the importance of hazards as a result of identified consequences and risks. Conclusions and recommendations are provided for risks that are deemed at a level not acceptable to the organization. Quantitative methods may be also employed to embellish the understanding of the consequences and risks that have been identified.

Process Risk: Risk arising from the process conditions caused by abnormal events (including basic process control system (BPCS) malfunction.

Note: The risk in this context is that associated with the specific hazardous event in which Safety Instrument Systems (SIS) are to be used to provide the necessary risk reduction (i.e., the risk associated with functional safety).

Process Safety Management (PSM): Comprehensive set of plans, policies, procedures, practices, administrative, engineering and operating controls designed to ensure that barriers to major incidents are in place, in use and are effective.

Processing Gain: The volumetric amount by which total output is greater than input for a given period of time. This difference is due to the processing of crude

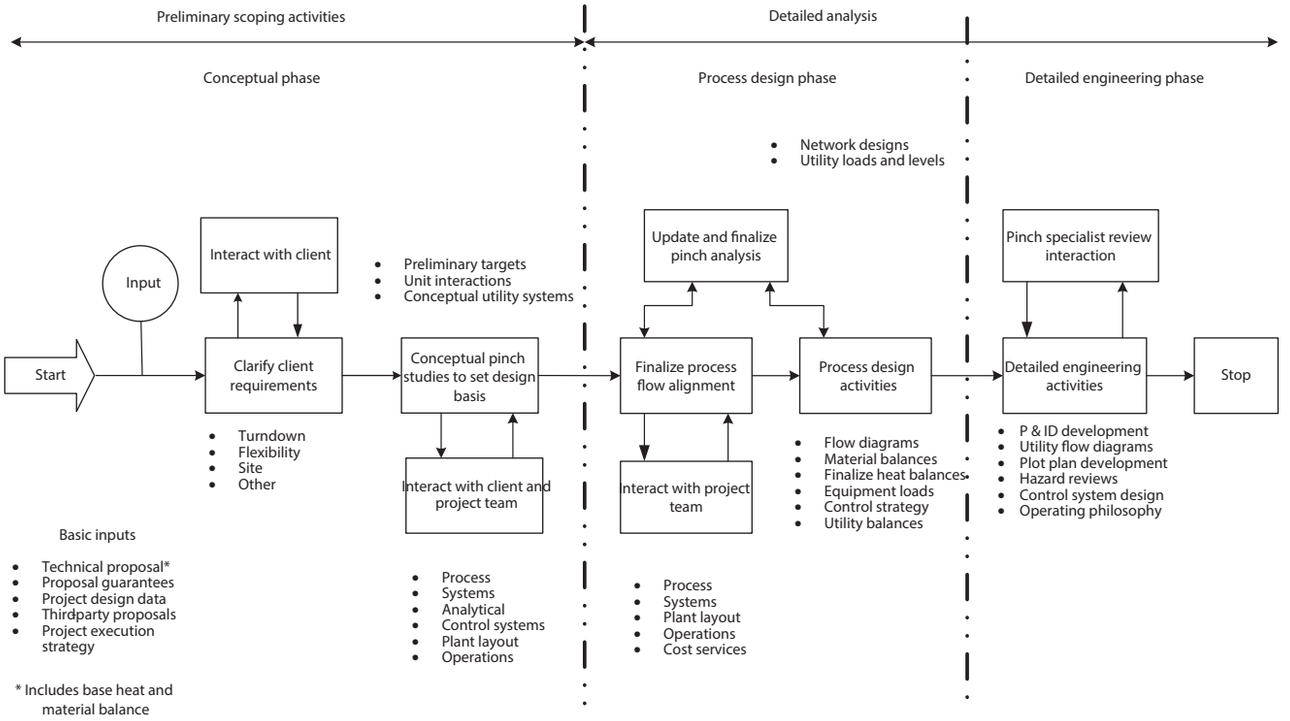


Figure 26 This new process design work process implements process integration effectively. (Source: Stephen W. Morgan, "Use Process Integration to Improve Process Designs and the Design Process", Chemical Engineering Process, p 62, September 1992 [5]).

oil into products which in total have a lower specific gravity than the crude oil being processed.

Processing Loss: The volumetric amount by which total refinery output is less than input for a given period of time. This difference is due to the process of crude oil into products which in total have a higher specific gravity than the crude oil being processed.

Production Capacity: The maximum amount of product that can be produced from processing facilities.

Products Supplied: 1. Crude Oil: Crude oil burned on leases and by pipelines as fuel. 2. Approximately represents consumption of petroleum products because it measures the disappearance of these products from primary sources, i.e., refineries, natural gas processing plants, blending plants, pipelines, and bulk terminals. In general, product supplied of each product in any given period is computed as follows: field production, plus refinery production, plus imports, plus unaccounted for crude oil (plus net receipts when calculated on a PAD District basis), minus stock change, minus crude oil losses, minus refinery inputs, minus exports.

Propane (C_3H_8): A hydrocarbon gas that is a principal constituent of the heating fuel. LPG. Propane is

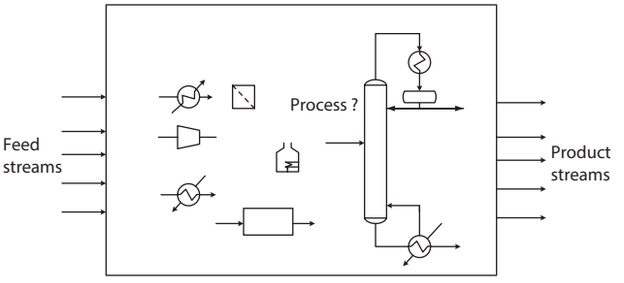


Figure 27 Process integration starts with the synthesis of a process to convert raw materials into desired products.

used extensively for domestic heating and as a feed to ethylene plants.

Propylene (C_3H_6): A hydrocarbon in the olefin series resulting from olefin plant operations and refinery cracking processes and used as alkyl plant feed or chemical feedstock.

Propylene (C_3H_6) (nonfuel use): Propylene that is intended for use in nonfuel applications such as petrochemical manufacturing. Nonfuel use propylene includes chemical-grade propylene, polymer-grade propylene, and trace amounts of propane. Nonfuel use propylene also includes the propylene component of

propane/propylene mixes where the propylene will be separated from the mix in a propane/propylene splitting process. Excluded is the propylene component of propane/propylene mixes where the propylene component of the mix is intended for sale into the fuel market.

Process design: The design of industrial process that uses physical, chemical or bio-chemical transformations for the production of useful products. It is used for the design of new processes, plant modifications, and revamps (Figure 26). It starts with conceptual and feasibility studies, and includes detailed material and energy balances, the production of block flow diagrams (BFDs), process flow diagrams (PFDs), engineering line diagrams (ELDs), and piping and instrumentation diagrams (P & IDs). It also includes the production of reports and document for plant construction, commissioning, start-up, operation and shut-down. The reports and documents are used by vendors, regulatory bodies, operators and other engineering disciplines.

Process economics: An evaluation of a process in terms of all the costs that are involved. It considers the cost of raw materials and how they are processed, as well as the costs associated with waste processing such as recycling or disposal. It also includes the optimization of a process to best utilize materials and energy. The fixed costs of a process are not dependent on the rate of production, but the variable costs are and must be met by the revenue generated by sales. Taxes are deducted resulting in the net profit.

Process engineer: He or she uses the principles of heat and material balances, hydraulics, vapor-liquid equilibrium, and chemistry to solve plant operating problems and optimize operating variables.

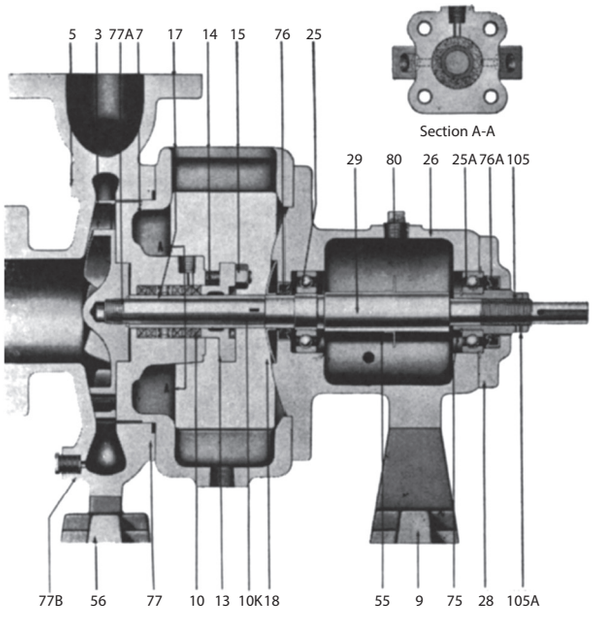
Process integration: 1. A holistic approach used in process design that considers the process as a whole with the interactions between unit operations in comparison with the optimization of unit operations separately and independently. It is known as process synthesis (See Figure 27). 2. A technique used to minimize the energy consumption and heat recovery in a process. It is also known as process heat integration and pinch analysis (See Energy Management).

Process intensification: An approach to engineering design, manufacture, and operation of processes that aims to substantially improve process performance through energy efficiency, cost effectiveness, reduction in waste, improvement in purification steps, reduction of equipment size, increase in safety and operational simplicity. It involves a wide range of innovative reactor, mixing and separation technologies that can result in dramatic improvements in process performance. It involves an integrative approach that considers overall process objectives rather than the separate performance of individual unit operations; process intensification can enable a process to achieve its maximal performance leading to the development of cheaper, smaller, cleaner, safer, and sustainable technologies.

Process plant: A collective name for an industrial facility used to convert raw materials into useful products. It includes all the process equipment such as reactors, mixers and separating units, all the associated pipework and pumps, heat exchangers, and utilities such as steam, and cooling water.

Process safety: A comprehensive management system that focuses on the management and control of potential major hazards that arise from process operations. It aims at reducing risk to a level that is as low as is reasonably practicable by the prevention of fires, explosions, and accidental or unintended chemical releases that can cause harm to human life and to the environment. It includes the prevention of leaks, spills, equipment failure, over and under-pressurization, over-temperatures, corrosion, and metal fatigue. It covers a range of tools and techniques required to ensure safe operation of plant and machinery to ensure the safety of personnel, the environment, and others through detailed design and engineering facilities, maintenance of equipment, use of effective alarms and control points, procedures, and training. It also includes risk assessment, layers of protection analysis and the use of permit to work authorizations.

Process simulation: The use of computers to model and predict the operational and thermodynamic behavior of a process. Commercial software packages are used to simulate and model batch, continuous, steady-state and transient processes. They require combined material and energy balances, the properties of the materials being processed, and sometimes combine the use of experimental data with mathematical descriptions of the process being simulated. Most software packages feature optimization capabilities involving the use of complex cost models and detailed process equipment size models. Some commercial software products are shown in the table below:



3	Impeller	26	Bearing housing
5	Casing	28	Bearing end cover
7	Back head cradle	29	Pump shaft
9	Bearing housing foot	55	Oil disc. (flinger)
10	Shaft sleeve	56	Casing foot
10K	Shaft sleeve key	75	Retaining ring
13	Stuffing box gland	76	Oil seal—front
14	Stuffing box gland stud	76A	Oil seal—rear
15	Stuffing box gland stud Nut	77	Gasket—casing
		77A	Gasket—sleeve
17	Seal cage	77B	Gasket—drain plug
18	Splash collar	80	Oil vent
25	Shaft bearing—radial	105	Shaft adjusting sleeve
25A	Shaft bearing—thrust	105A	Sleeve lock nut

Figure 28 General service centrifugal pump.

Software	Developer	Applications	Website
Aspen Plus/ Aspen Hysys	Aspen Technology	Process simulation and optimization	www.aspentech.com
CHEMCAD	Chemstations	Software suite for process simulation	www.chemstations.com
Design II for Windows	WinSim Inc.	Process simulation	www.winsim.com
gPOMS	PSE Ltd.	Advanced process simulation and Modeling	www.psenterprise.com
PRO II	SimSci	Process simulation	www.software.schneider-electric.com/simsci
ProSim Plus	ProSim	Process simulation and optimization	www.prosim.net
UniSim	Honeywell	Process simulation and optimization	www.honeywellprocess.com

Process synthesis: The conceptual design of a process that identifies the best process flowsheet structure, such as the conversion of raw materials into a product(s). This requires the consideration of many alternative designs. The complex structure of most processes is such that the flowsheet is split into smaller parts and each is reviewed in turn. Then choices and decisions are made. Many techniques are used in arriving at the best flowsheet such as those based on total cost, which needs to be minimized. Use is made of graphical methods, heuristics, and various other forms of minimization such as the use of process integration.

Process upset: A sudden, gradual or unintended change in the operational behavior of a process. It may be due to process equipment failure or malfunction, operator intervention, a surge or fall in pressure, flow, level, concentration, etc.

Process variable: A dynamic feature of a process or system that is required to be controlled to ensure that it operates according to design requirements and does not deviate as to be unsafe or result in undesirable consequences. The commonly measured process variables include temperature, pressure, flow, level and concentration.

Pseudo-component: For engineering calculation purposes, a component that represents a specified portion of the TBP distillation curve for a petroleum mixture. The pseudo-component is assigned a normal boiling point and gravity corresponding to the average for the boiling point range. Molecular weight and other properties are derived from the boiling point and gravity using literature correlations for hydrocarbons.

Pump: A mechanical device used to transport a fluid from one place or level to another by imparting energy to the fluid. The three bonds groupings are centrifugal, reciprocating and rotary type pumps. The most commonly used is the centrifugal type, which has a rotating impeller used to increase the velocity of the fluid and where part of the energy is converted to pressure energy. Rotary and reciprocating pumps are positive displacement pumps in which portions of fluid are moved in the pump between the teeth of gears, and by the action of a piston in a cylinder. There are many variations of these types and each has a particular application and suitability for a fluid in terms of its properties, required flow rate and delivery pressure (See Figure 28).

Pumparound: A liquid side-draw from a distillation/fractionating column that is pumped cooled and returned to a higher location in the column. Pumparounds recover useable heat that would be lost at the condenser. They also lower the vapor flow in a column and reduce the required column diameter for vapor loaded columns such as crude and vacuum columns.

Pumpdown: A liquid side draw that is pumped down to a tray below the draw tray, usually the next tray lower. Pumpdowns are sometimes cooled prior to returning to the column.

Pump priming: Used for the start-up and successful operation of centrifugal pumps in which the casing housing the "impeller" is first filled or primed with liquid before operation begins. Since the density of a liquid is many times greater than that of a gas, vapor, or air, the suction pressure is otherwise insufficient to draw in more liquid. Depending on the type of pump, priming can be achieved either manually or by drawing liquid in using a vacuum pump. Valves can be used to prevent drainage, and ensure that the pump does not require priming once the pump stops.

Purge: A stream that is removed from a recycle process to prevent buildup of one or more components in the process streams.

Pyrolysis: 1. Heating a feedstock to high temperature to promote cracking as in an ethylene plant. 2. Destructive distillation that involves decomposition of coal, woody materials, petroleum, and so on, by heating in the absence of air.

Pyrolysis Gasoline: The gasoline created in an ethylene plant cracking gas oil or naphtha feed stocks. Sometimes called pygas, it has high content of aromatics and olefins and some diolefins.

Pyrophoric Iron Sulfide: A substance typically formed inside tanks and processing units by the corrosive interaction of sulfur compounds in the hydrocarbons and the iron and steel in the equipment. On exposure to air (oxygen), it ignites spontaneously.

Quality: The weight fraction of vapor in a vapor-liquid mixture.

Quench: Hitting a very hot stream coming out of a reactor with a cooler stream to stop immediately the reaction runaway.

Quench Crack: A crack in steel resulting from stresses produced during transformation from austenite to martensite.

Quench Hardening: Heat treating requiring austenitization followed by cooling, under conditions that austenite turns into martensite.

Quenching Oil: An oil introduced into high-temperature process streams during refining to cool them.

Quench Stream: A cooled stream that is used to cool another stream by direct contact. For example, hydrogen quench streams are used to quench the hot effluents from hydrocracker reactors.

Quench Zone: A section of a distillation column where a hot stream, usually vapor is cooled by direct contact with a stream that has been cooled, usually a liquid.

Radiant Heat Transfer: Heat transfer without convection or conduction. Sunshine is radiant heat.

Radiation: Transmission of energy by means of electromagnetic waves emitted due to temperature.

Radical: A group of atoms that separate themselves from a compound momentarily and are highly reactive. For example, two methyl radicals $*CH_3$ can come from cracking an ethane compound, but they will rapidly attach themselves to some other atom or compound.

Raffinate: 1. The leftover from a solvent extraction process. 2. In solvent refining, that portion of the oil that remains undissolved and is not removed by the selective solvent.

Rating Calculations: Calculations in which a unit operation such as a column, heat exchanger, pump, and so on, is checked for capacity restrictions.

Ratio of Specific Heats: 1. Thermodynamic comparison ($k = C_p/C_v$) of the ratio of a specific heat (k) at a constant pressure (C_p) to a specific heat at a constant volume (C_v). The ratio range for most gases is 1.2–1.4. 2. For gases, it is the ratio of the specific heat at constant pressure to the specific heat at constant volume. The ratio is important in thermodynamic equations as compressor horsepower calculations, and is given the symbol k, where $k = C_p/C_v$. The ratio lies between 1.2 and 1.4 for most gases.

Reactor: The vessel in which chemical reactions takes place.

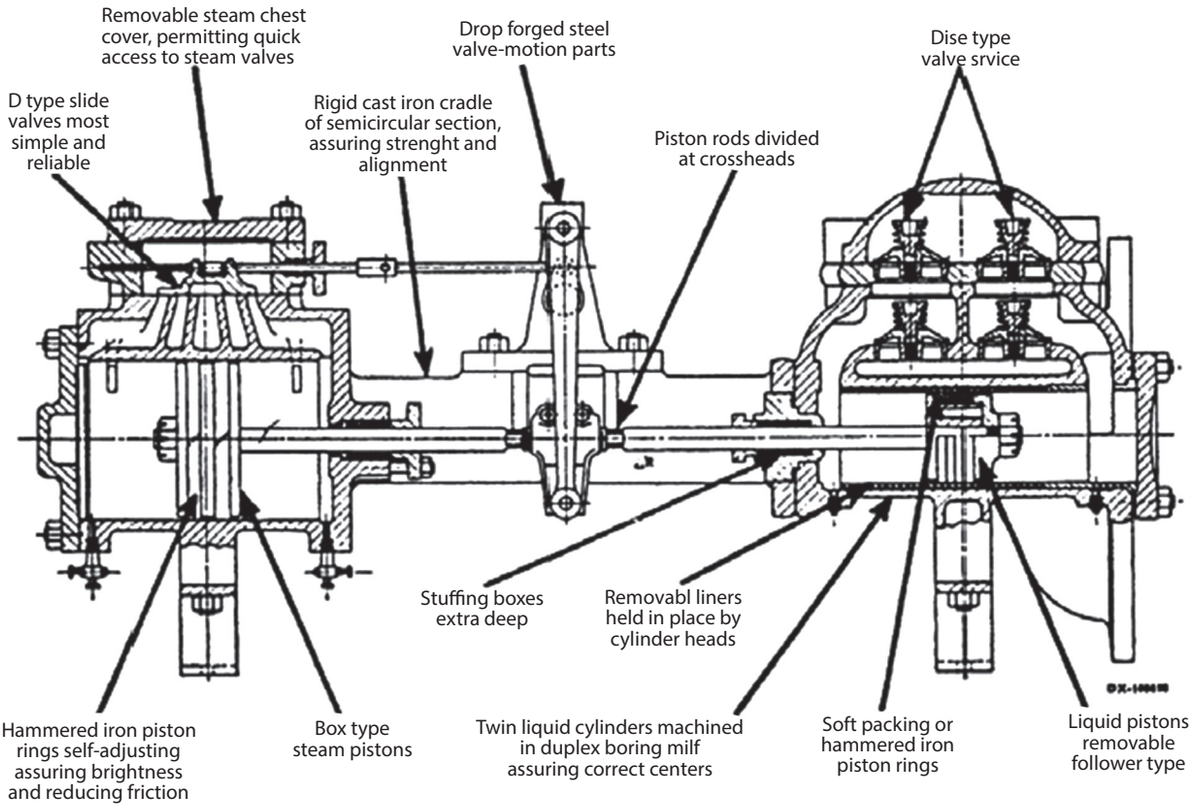


Figure 29 General service duplex steam-driven piston pump.

Reactive Distillation: A distillation column in which there is a section designed for chemical reaction, usually containing a catalyst bed. Some MTBE and TAME processes use a reactive distillation column in place of a second reactor prior to the product separation column.

Reactor Effluent: The outlet stream from a reactor.

Reboiler: 1. A heat exchanger used towards the bottom of a fractionator to reheat or oven vaporize a liquid and introduce it several trays higher to help purify the incoming stream or get more heat into the column. 2. An auxiliary unit of a fractionating tower designed to supply additional heat to the lower portion of the tower.

Reciprocating Pump: 1. A piston pump. 2. A pump with an up-and-down stroke or motion (See Figure 29).

Recovery: Usually refers to the fraction expressed as a percentage of a component or group of components in the feed to a distillation column that are recovered in a given product stream.

Rectification Zone: The portion of a distillation column in which heavy components are washed down the column by contact with a liquid reflux stream. In conventional distillation columns, this is the portion of the column from the tray above the feed tray to the top tray.

Recycle: A process stream that is returned to an upstream operation.

Recycled Feeds: Streams that have been processed and are fed back to the reactors for additional processing.

Reduced Crude: A residual product remaining after the removal by distillation of an appreciable quantity of the more volatile components of crude oil.

Reduced Pressure: The ratio of the absolute pressure to the critical pressure.

Reduced Temperature: The ratio of the absolute temperature to the critical temperature.

Reducing Agent: Any substance, such as base metal (iron) or the sulfide ion, that will readily donate (give up) electrons. The opposite is an oxidizing agent.

Reduction: The addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds.

Redwood Viscometer: Standard British viscometer. The number of seconds required for 50 ml of oil to flow out of a standard Redwood viscometer at a definite temperature is the Redwood viscosity.

Refinery Grade Butane (C_4H_{10}): A refinery produced stream that is composed predominantly of normal butane and/or isobutane and may also contain propane and/or natural gasoline. These streams may also contain significant levels of olefins and/or fluorides contamination.

Refinery Input, Crude Oil: Total crude oil (domestic plus foreign) input to crude oil distillation units and other refinery processing units (cokers, etc.).

Refined Products: The various hydrocarbons obtained as a result of refining process separation from crude oil. Typical refined products are LPG, naphtha, gasoline, kerosene, jet fuel, home heating oil, diesel fuel, residual fuel oil, lubricants and petroleum coke.

Refiner: A company involved in upgrading hydrocarbons to saleable products.

Refinery: 1. An installation that manufactures finished petroleum products from crude oil, unfinished oils, natural gas liquids, other hydrocarbons and oxygenates. 2. A plant used to separate the various components present in crude oil and convert them into usable fuel products or feedstock for other processes. 3. A large plant composed of many different processing units that are used to convert crude oil into finished or refined products. These processes include heating, fractionating, reforming, cracking and hydrotreating.

Refinery Gas: A non-condensable gas collected in petroleum refineries.

Refinery Input (Crude Oil): Total crude oil (domestic plus foreign) input to crude oil distillation units and other refinery processing units (cokers).

Refinery Input (Total): The raw materials and intermediate materials processed at refineries to produce finished petroleum products. They include crude oil, products of natural gas processing plants, unfinished oils, other hydrocarbons and oxygenates, motor gasoline and aviation gasoline blending components and finished petroleum products.

Refinery Margins: The difference in value between the products produced by a refinery and the value of the crude oil used to produce them. Refining margins will thus vary from refinery to refinery and depend on the price and characteristics of the crude used.

Refinery Production: Petroleum products produced at a refinery or blending plant. Published production of these products equals refinery production minus refinery input. Negative production occurs when the amount of a product produced during the month is less than the amount of that same product that is reprocessed (input) or reclassified to become another product during the same month. Refinery production of unfinished oils and motor and aviation gasoline blending components appear on a net basis under refinery input.

Refinery Yield: Represents the percentage of finished product produced from input of crude oil and net input of unfinished oils (expressed as a percentage). It is calculated by dividing the sum of crude oil and net unfinished input into the individual net production of finished products. Before calculating the yield of finished motor gasoline, the input of natural gas liquids, other hydrocarbons and oxygenates, and net input of motor gasoline blending components must be subtracted from the net production of finished motor gasoline. Before calculating the yield of finished aviation gasoline, input of aviation gasoline blending components must be subtracted from the net production of finished aviation gasoline.

Reflux: 1. Condensed liquid that is returned to the top tray of a distillation column. Reflux helps rectify the mixture being distilled by washing heavy components down the column. 2. The portion of the distillate returned to the fractionating column to assist in attaining better separation into desired fractions.

Reflux drum: A drum that receives the outlet from the overhead condenser from a distillation column. The liquid and vapor portions are separated in the reflux drum.

Reformate: An upgraded naphtha resulting from catalytic or thermal reforming.

Reforming: 1. The mild thermal cracking of naphthas to obtain more volatile products such as olefins, of higher octane values or catalytic conversion of naphthas components to produce higher octane aromatic compounds. 2. A refining process used to change the molecular structure of a naphtha feed derived from

crude oil by distillation. 3. The gasoline produced in a catalytic reforming operation.

Reformulated Fuels: Gasoline, diesel or other fuels that have been modified to reflect environmental concerns, performance standards, government regulations, customer preferences, or new technologies.

Reformed Gasoline: Gasoline made by a reformate process.

Reformulated Gasoline (RFG): 1. A gasoline whose composition has been changed (from that of gasolines sold in 1990) to (a) include oxygenates, (b) reduce the content of olefins and aromatics and volatile components, and (c) reduce the content of heavy hydrocarbons to meet performance specifications for ozone-forming tendency and for release of toxic substances (benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and polycyclic organic matter) into the air from both evaporation and tailpipe emissions. 2. Is a cleaner-burning gasoline that reduces smog and other air pollution. Federal law mandates the sale of reformulated gasoline in metropolitan areas with the worst ozone smog. 3. Finished motor gasoline formulated for use in motor vehicles, the composition and properties of which meet the requirements of the reformulated gasoline regulations promulgated by the U.S. Environmental Protection Agency under Section 211 (k) of the Clean Air Act. NB: This category includes oxygenated fuels program reformulated gasoline (OPRG), but excludes reformulated gasoline blendstock for oxygenate blending (RBOB). (4) Gasoline that meets the requirements imposed by the Clean Air Act Amendment, passed by the United States Congress on November 15, 1990. Restrictions were placed on volatile organic compounds, nitrous oxides (NO_x) from combustion, and toxins primarily related to benzene (C_6H_6) and its derivatives.

Reformulated Gasoline Blendstock for Oxygenate Blending: A motor gasoline blending component that, when blended with a specified type and percentage of oxygenate, meets the definition of reformulated gasoline.

Refrigerant: 1. In a refrigerating system, the medium of heat transfer that picks up heat by evaporating at a low temperature and pressure and gives up heat on condensing at a higher temperature and pressure. 2. It is the fluid that performs an inverse thermodynamic cycle, generating the low temperature required for natural gas cooling and liquefaction.

Refrigerant Compressor: A component of a refrigerating system that increases the pressure of a compressible refrigerant fluid and simultaneously reduces its volume while moving the fluid through the device.

Refrigerating System: A system that, in operation between a heat source (evaporator) and a heat sink (condenser), at two different temperatures, is able to absorb heat from the heat source at the lower temperature and reject heat to the heat sink at the higher temperature.

Refrigeration (or Cooling Cycle): 1. The process used to remove the natural gas liquids by cooling or refrigerating the natural gas until the liquids are condensed out. The plants use Freon or propane to cool the gas. 2. Inverse thermodynamic cycle whose purpose is to transfer heat from a medium at low temperature to a medium at higher temperature.

Regasification: The process by which LNG is heated, converting it into its gaseous state.

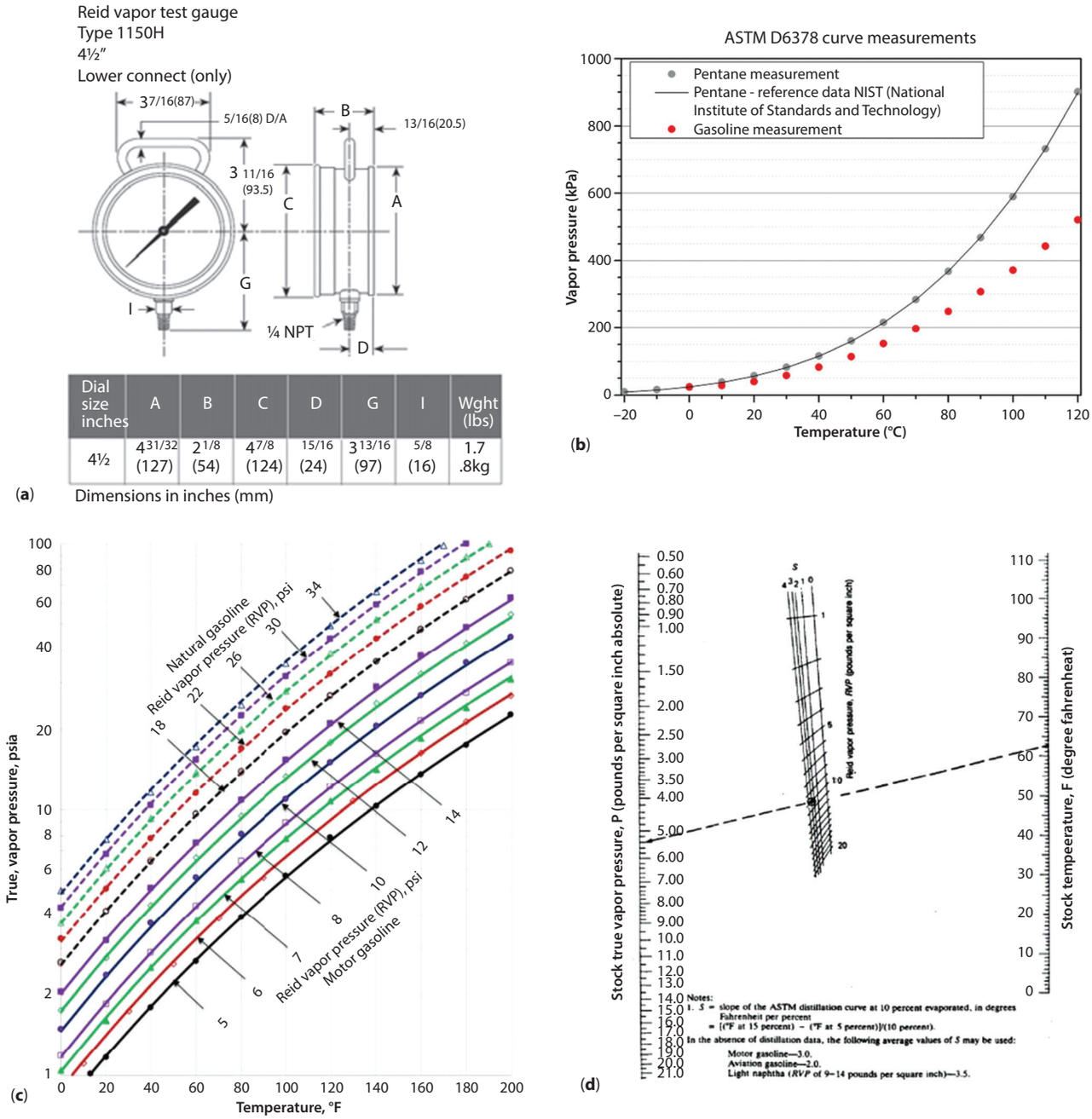
Regasification Plant: A plant that accepts deliveries of LNG and vaporizes it back to gaseous form by applying heat so that the gas can be delivered into a pipeline system.

Regenerator: The vessel in a catalytic process where a spent catalyst is cleaned up before being recycled back to the process. An example is the catalytic cracker regenerator where coke deposited on the catalyst is burned off.

Regeneration: 1. The process of burning off coke deposits on catalyst with an oxygen containing gas under carefully controlled conditions. 2. In a catalytic process the reactivation of the catalyst, sometimes done by burning off the coke deposits under carefully controlled conditions of temperature and oxygen content of the regeneration gas stream.

Reid Vapor Pressure (RVP): An ASTM test method to determine the vapor pressure of a light petroleum stream. The Reid vapor pressure is very nearly equal to the true vapor pressure for gasoline streams. There is also a Reid vapor pressure test for crude oil (See Figure 30 and Table 2).

Relative volatility (α): The ratio of the vapor pressure of one liquid component to another in a heterogeneous mixture and is a measure of their separability. For a binary mixture, the relative volatility can be expressed in terms of the mole fraction of the more



Dial size inches	A	B	C	D	G	I	Wght (lbs)
4½	4 31/32 (127)	2 1/8 (54)	4 7/8 (124)	15/16 (24)	3 13/16 (97)	5/8 (16)	1.7 .8kg

Figure 30 (a) Reid vapor test gauge (b) Vapor pressure vs. temperature (c) Reid vapor pressure vs. Temperature.

volatile component in the liquid and vapor phases, x and y as:

$$\alpha = \frac{y(1-x)}{x(1-y)}$$

The greater the value of the relative volatility, the greater the degree of separation. If y =x, then no separation is possible.

Reliability: The probability that a component or system will perform its defined logic functions under the stated conditions for a defined period of time.

Research Octane Number (RON): One of two standards tests of gasoline knock, this one simulates less severe operating conditions like cruising. It is determined in a special laboratory test engine under mild "engine-severity" conditions, giving a measure of the

Table 2 RVP blending values.

RVP blending values		Vol% (aromatics)					
	rvp (pure HC)	**0**	**10**	**20**	**30**	**40**	**50**
Ethane	730.0	474.0	474.0	474.0	474.0	474.0	474.0
Propene	226.0	216.0	216.0	216.0	216.0	216.0	216.0
Propane	190.0	173.0	173.0	173.0	173.0	173.0	173.0
Isobutane	72.2	62.0	73.9	85.4	96.6	107.6	118.8
Isobutene	63.4	76.5	78.9	81.3	83.7	86.2	88.9
Butene-1	63.0	76.1	78.4	80.8	82.7	85.1	87.4
n-Butane	51.6	52.9	55.6	58.3	60.9	63.5	66.2
trans-2-Butene	49.8	62.1	64.0	66.0	68.0	70.0	72.0
cis-2-Butene	45.5	58.6	60.5	62.3	64.2	66.1	69.0
Isopentane	20.4	21.9	22.2	22.5	22.9	23.3	23.7
C_5 olefins*	16.5	17.9	18.1	18.4	18.6	18.8	19.0
n-Pentane	15.6	16.9	17.2	17.4	17.8	18.0	18.2

*C_5 olefins in FCC proportion.

low-speed knock properties of a gasoline. Contrast with Motor Octane Number.

Residence time: 1. The amount of time a hydrocarbon spends in a vessel where a reaction occurs. 2. The period of time in which a process stream will be contained within a certain volume or piece of equipment, seconds.

Residual Fuel: heavy fuel oil made from long, short or cracked residue plus whatever cutter stock is necessary to meet market specifications.

Residue: The bottoms from a crude oil distilling unit, vacuum flasher, thermal cracker or visbreaker. *See long residue and short residue.*

Residuum: Residue from crude oil after distilling off all but the heaviest components with a boiling range greater than 1000°F (538°C).

Reynolds Number (Re): A dimensionless number, Re, expressing the ratio of inertial to viscous forces in a flowing fluid, and can be used to determine the flow regime. For a fluid in a pipe of circular cross section:

$$\mathrm{Re} = \frac{\rho v d}{\mu}$$

where ρ is the density, v is the mean velocity, d is the diameter of a pipe, and μ is the viscosity. Where the value for critical pipes falls below 2,000 the flow is laminar flow, or stream line. For Reynolds number above 4,000 the flow is turbulent (See Figure 7).

Rich oil: The absorption oil leaving the bottom tray of an absorption column. The rich oil contains the absorbed light components.

Ring Compounds: Hydrocarbon molecules in which the carbon atoms form at least one closed ring such as naphthenes or aromatics. Also called cyclic.

Ring Structure: A compound in which some of the carbon atoms are linked with other carbon atoms to form a continuum. Carbon atoms attached to the ring carbon atoms are said to be "side chains".

Riser: 1. A pipe through which a fluid travels upwards. 2. Steel or flexible pipe, which transfers well fluids from the seabed to the surface.

Risk: 1. Is defined as a measure of economic loss, human injury, or environmental damage in terms of both the incident likelihood and the magnitude of the loss, injury or damage. 2. The probability of an event happening times the impact of its occurrence on operations. (Impact is the effect on conditions or people if the hazard is realized (occurs) in practice and potentials are the likelihood that the impact will occur.

Likelihood	Catastrophic	Critical	Marginal	Negligible
Certain	Class I	Class I	Class I	Class II
Possible	Class I	Class I	Class II	Class III
Occasional	Class I	Class II	Class III	Class IV
Remote	Class II	Class III	Class III	Class IV
Improbable	Class III	Class III	Class IV	Class IV
Inconceivable	Class IV	Class IV	Class IV	Class IV

Risk Analysis: A decision-making tool that allows examination of the level and significance of work place risk for humans, equipment, weather, operations or other conditions. Determines the probability of risk occurring, the impact the risk will have, and how to mitigate the risk. *See Hazard Analysis*.

Risk Assessment: The process of identifying and evaluating the technical and nontechnical risks associated with a project. It includes the amount or degree of potential danger perceived (by an assessor) when determining a course of action to accomplish a given task. Risk assessment may be qualitative or quantitative.

Risk Matrix: Is the common approach to risk assessment and hazard analysis. Its underlying idea is that acceptability of risk is a product of how likely a thing is to happen, and how bad it would be if it happened. This is shown in the following tables.

Category	Definition	Range (failures per year)
Certain	Many times in system lifetime	$>10^{-3}$
Probable	Several times in system lifetime	10^{-3} to 10^{-4}
Occasional	Once in system lifetime	10^{-4} to 10^{-5}
Remote	Unlikely in system lifetime	10^{-5} to 10^{-6}
Improbable	Very unlikely to occur	10^{-6} to 10^{-7}
Inconceivable	Cannot believe that it could occur	$< 10^{-7}$

Risk matrix categorization of severity of consequences

Category	Definition
Catastrophic	Multiple loss of life
Critical	Loss of a single life
Marginal	Major injuries to one or more person
Negligible	Minor injuries to one or more person

Risk matrix
Consequence
Key:
Class I: Unacceptable
Class II: Undesirable
Class III: Tolerable
Class IV: Acceptable

Road Oil: Any heavy petroleum oil, including residual asphaltic oil used as a dust palliative and surface treatment on roads and highways. It is generally produced in six grades from 0, the most liquid to 5, the most viscous.

Rule of Thumb: Axioms based on practical experience and/or methods to approximate calculated results using simple formulae.

Runback: The liquid returning to the flash zone of a distillation column.

Safety: A general term denoting an acceptable level of risk of, relative freedom from and low probability of harm.

Safeguard: A precautionary measure of stipulation. Usually equipment and/or procedures designed to interfere with incident propagation and/or prevent or reduce incident consequences.

Safety Integrity Level (SIL): 1. Is defined as a relative level of risk reduction provided by a safety function, or to specify a target level of risk reduction. SIL is a measure of performance required for a

safety instrumented function (SIF). 2. The degree of redundancy and independence from the effects of inherent and operational failures and external conditions that may affect system performance.

The requirements for a given SIL are not consistent among all of the functional safety standards. In the European functional safety standards based on the IEC 61508 standard, four SILs are defined, with SIL 4 the most dependable and SIL 1 the least. A SIL is determined based on a number of quantitative factors in combination with qualitative factors such as development process and safety life cycle management.

Assignment of SIL is an exercise in risk analysis where the risk associated with a specific hazard, that is intended to be protected against by a SIF, is calculated without the beneficial risk reduction effect of the SIF. That "unmitigated" risk is then compared against a tolerable risk target. The difference between the "unmitigated" risk and the tolerable risk, if the "unmitigated" risk is higher than tolerable, must be addressed through risk reduction of the SIF. This amount of required risk reduction is correlated with the SIL target. In essence, each order of magnitude of risk reduction that is required correlates with an increase in one of the required SIL numbers.

There are several methods used to assign a SIL. These are normally used in combination, and may include:

- *Risk matrices*
- *Risk graphs*
- *Layers Of Protection Analysis (LOPA)*

Of the methods presented above, LOPA is by far the most commonly used by large industrial facilities.

The assignment may be tested using both pragmatic and controllability approaches, applying guidance on SIL assignment published by the UK HSE. SIL assignment processes that use the HSE guidance to ratify assignments developed from Risk Matrices have been certified to meet IEC EN 61508.

Safety Instrumented Function (SIF): Safety function with a specific safety integrity level which is necessary to achieve functional safety and which can be either a safety instrumented protection function or a safety instrumented control function.

Salt Content: Crude oil usually contains salts in solution in water that is emulsified with the crude. The salt content is expressed as the solution of sodium chloride (NaCl) equivalent in pounds per thousand barrels (PTB) of crude oil. Typical values range from 1 to 20 PTB. Although there is no simple conversion from PTB to parts per million by weight (ppm), 1 PTB is roughly equivalent to 3 ppm.

Saturated Compounds: Hydrocarbons in which there are no double bonds between carbon atoms. Saturated compounds contain the maximum number of hydrogen atoms that are possible.

Screwed Fittings: These are used to assemble screwed connections and field instruments on pipes. They are:

- Pipe thread fittings
- Instrument or tubing fittings
- Metric fittings

None of these will screw together.

Scrub: Removal of components (gas, liquids, or solids) from the methane achieved by surface equipment (scrubbers).

Scrubber: 1. A reactor that removes various components from produced gas. 2. Equipment that causes the separation of liquid and gaseous phases in a fluid system. The separation is usually based on density, differences of the two phases and can take place using gravity force, induced centrifugal force, and so on. 3. System to reduce noxious substances from a flowing stream of air, usually filled with plates or packing, through which scrubbing fluid flows countercurrent or cross-current to the path of the contaminated air.

Scrubbing: Purification of a gas or liquid by washing it in a tower.

Secondary Absorber: The second absorber in a FCC gas plant. It is usually the last unit operation in the gas recovery plant and is also known as the sponge absorber.

Selectivity: The difference between the research octane number and the motor octane number of a given gasoline. Alkylate is an excellent low-sensitivity and reformate a high-sensitivity gasoline component. It is an indication of the sensitivity of the fuel to driving conditions (city vs. highway).

Selective Treating: Preferential removal of one acid gas component, leaving at least some of the other acid gas components in the treated stream.

Sensitivity: The difference in the research octane (F -1) and the motor octane (F -2) for a gasoline stream.

Since research octane is always larger, sensitivity is always a positive number.

Separation zone: A section of a distillation column in which a separation between two products occurs. Components which are found in both products are said to be distributed components.

Separator: Usually refers to a drum, in which the residence time is provided for a mixture of the liquid and vapor to separate into liquid and vapor streams. Also called a flash drum. The liquid and vapor leaving the separator are in phase equilibrium.

Severity: The degree of intensity of the operating conditions of a process unit. Severity may be indicated by clear research octane number of the product (reformer), percentage disappearance of the feed (catalytic cracking), or operating conditions alone (usually the temperature; the higher the temperature, the greater the severity).

Shale: 1. A common sedimentary rock with porosity but little matrix permeability. Shales are one of the petroleum source rocks. Shales usually consist of particles finer than sand grade (less than 0.0625 mm) and include both silt and clay grade material. 2. A very fine-grained sedimentary rock formed by the consolidation and compression of clay, silt or mud. It has a finely laminated or layered structure. Shale breaks easily into thin parallel layers; a thinly laminated siltstone, mudstone, or claystone. Shale is soft but sufficiently hard packed (indurated), so as not to disintegrate upon becoming wet. Some shales absorb water and swell considerably causing problems in well drilling. Most shales are compacted and consequently do not contain commercial quantities of oil and gas. 3. Rock formed from clay. 4. Gas reserves found in unusually nonporous rock, requiring special drilling and completion techniques.

Shale Gas: Methane (CH_4) gas stored in shale. May be in the pore space, adsorbed to the mineral or rock surfaces, or as free gas in the natural fractures.

Shale Oil: 1. Can be either an immature oil phase, often called kerogen, or actual oil in the cracks or pores of shale. 2. The liquid obtained from the destructive distillation of oil shale. Further processing is required to convert it into products similar to petroleum oils.

Shear force: An applied force to a material that acts in a direction that is parallel to a plane rather than perpendicular. A material such as a solid or fluid is deformed by the application of a shear force over a surface known as the shear stress. The shear strain is the extent of the deformation defined as the ratio of the deformed distance with length. The shear modulus is the ratio of the shear stress to the shear strain.

Shear rate (γ): The deformation of a fluid under the influence of an applied shear force presented as the change in velocity of the fluid perpendicular to flow.

$$\gamma = \frac{dv}{dz}$$

where, dv/dz is referred to as the velocity gradient. The S.I. unit is s^{-1}.

Shear stress (τ): The shear force applied to a fluid that is applied over a surface. When the shear stress is proportional to the shear rate, the fluid exhibits

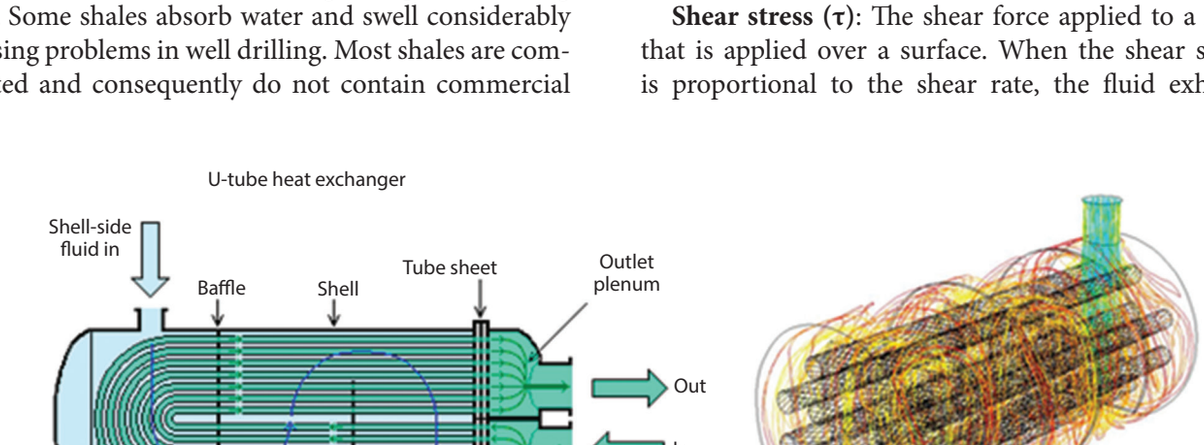


Figure 31 A shell and tube heat exchanger showing the direction of flow of fluids in the shell and tube sides.

Newtonian behavior and the viscosity is constant. The S.I. units are Nm^{-2}.

$$\tau = \mu \frac{dv}{dz}$$

where μ is the viscosity.

Shell and Tube Heat Exchanger: A device used to transfer heat from one medium to another. It consists of a shell that contains tubes. One medium is contained within the shell and the other within the tubes, and heat is transferred from one to the other across the tubes. There are many designs commonly used and the simplest is a single-phase type exchanger in which a cold liquid to be heated flows through the tubes from one side of the exchanger to the other. Steam is used as the heating medium and enters as vapor and leaves as condensate from the bottom. A kettle reboiler type is a type of shell and tube heat exchanger in which steam is admitted through the tubes. The choice of hot or cold fluid in the tubes or shell depends on the application and nature of the fluids, such as their susceptibility to fouling (See Figure 31).

Shell side: The space between the outside of the tubes and the inside of the casing or shell of a shell and tube heat exchanger.

Sherwood number (Sh): A dimensionless number that represents the relationship between mass diffusivity and molecular diffusivity.

$$Sh = \frac{kL}{D_{AB}}$$

Where k is the mass transfer coefficient, L is the characteristic dimension, and D is the diffusivity of the solute A in the solvent B. It corresponds to the Nusselt number used in heat transfer.

Shock wave: A pressure wave of very high pressure intensity and high temperature that is formed when a fluid flows supersonically or in which a projectile moves supersonically through a stationary fluid. It can be formed by a violent event such as a bomb blast or an explosion. A shock-wave compression is the non-isentropic adiabatic compression in waves that is traveling above the speed of sound.

Short Residue: Flasher bottoms or residue from the vacuum tower bottoms.

Short-Term Exposure Limit (STEL): The time-weighted average concentration of a substance over a 15 min. period thought not to be injurious to health.

Shutdown: 1. The status of a process that is not currently in operation due to schedule or unscheduled maintenance, cleaning or failure. 2. A systematic sequence of action that is needed to stop a process safely.

Side draw: *See Draw*

Side Heater (reboiler): A heat input to a distillation column that is located above the bottom tray of the column.

Side reaction: A chemical reaction that takes place at the same time as a main reaction and produces unwanted products and therefore reduces the yield of the desired product. E.g., in the high temperature cracking

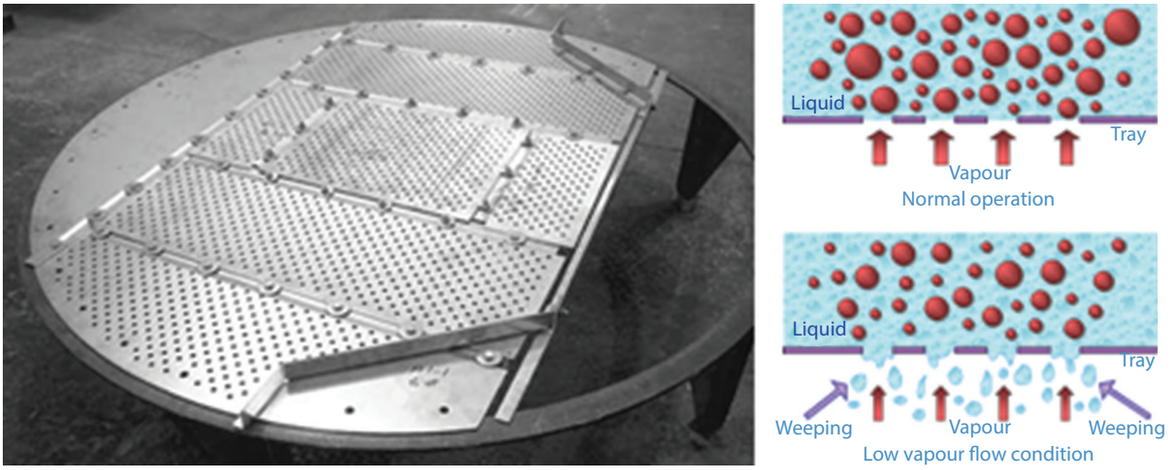


Figure 32 A sieve plate.

reaction of propane (C_3H_8) to produce propylene (C_3H_6), $C_3H_8 \rightarrow C_3H_6 + H_2$, some of the hydrogen can react with the propane to produce methane and ethane as side reactions, $C_3H_8 + H_2 \rightarrow CH_4 + C_2H_6$. The conditions for the reaction must therefore be controlled to reduce this unwanted reaction.

Side stream: The continuous removal of a liquid or a vapor from a process such as a distillation column that is not the main process flow. For example, drawing off vapor or liquid mid way up the column can have economic advantage in terms of the physical size of the column and the amount of boil-up energy required.

Side Stripper: A small auxiliary column that receives a liquid draw product from a main distillation column for stripping of light components. Light components are stripped by stripping steam or reboiling and returned to the main column. Liquid products are sometimes stripped in side strippers to raise the flash point.

Sieve plate column: 1. A type of distillation column that uses a stack of perforated plates to enhance the distribution and intimate contact between vapor and liquid. The plates allow vapor to pass up and bubble through the liquid on the plates. The rate of flow of vapor is sufficient to prevent the liquid from draining down the sieve plates. Instead, the liquid flows over a weir and down a downcomer to the sieve plate below. 2. Sieve trays are metal plates with holes; vapor passes straight through the liquid on the plate. The arrangement, number and size of the holes are design parameters (See Figure 32).

Simulated distillation (Simdist): A relatively new laboratory technique in which a petroleum stream is separated into fractions with gas phase chromatography. Carbon disulfide (C_2S) is used as the carrying agent to dissolve the petroleum stream. The component fractions elute from the chromatographic column in a time sequence, related to their boiling temperatures. Temperatures are assigned to the fractions based on the chromatographic separation of a normal paraffin standard mixture. The simulated distillation approaches a true boiling point distillation, and is reported on a mass basis for streams heavier than gasoline. Aromatic compounds elute from the column faster than paraffin of similar boiling points. Therefore, simulated distillations must be corrected for aromatic content when stocks contain significant quantities of aromatic components.

Slack Wax: Wax produced in the dewaxing of lube oil base stocks. This wax still contains some oil and must be oiled to produce finished wax product.

Slop Wax: The over flash from a vacuum column. The slop wax is usually withdrawn from the column and combined with the fresh charge to the vacuum furnace.

Slurry: The bottom stream from FCC main fractionators. It is termed slurry because it contains suspended catalyst particles.

Slurry Oil: The oil, from the bottoms of the FCC unit fractionating tower, containing FCC catalyst particles carried over by the vapor from the reactor cyclones. The remainder of the FCC bottoms is the decanted oil.

Smoke: The gaseous products of the burning of carbonaceous materials made visible by the presence of small particles of carbon; the small particles that are of liquid and solid consistencies are produced as a byproduct of insufficient air supplies to a combustion process.

Smoke Point: 1. Refers to the height of a smokeless flame of fuel in millimeters beyond which smoking takes place. It reflects the burning quality of kerosene and jet fuels. 2. A test measuring the burning quality of jet fuels, kerosene and illuminating oils. It is defined as the height of the flame in millimeters beyond which smoking takes place; ASTM D 1322.

Soaker, Soaking Drum: A soaker is a device that allows cracking time (soaking time) for heated oil in a thermal cracking operation. Furnace coils and/or drums are used for this purpose. Since some coke is deposited in the soaking device it must be periodically taken off line and cleaned. Furnace coils are much easier to clean than drums.

Soave-Redlich-Kwong (SRK) equation of state: An equation of state widely used to predict the vapor-liquid equilbria of substances. It is a development of the "Redlich-Kwong" equation of state that correlated the vapor pressure of normal fluids.

$$p = \frac{RT}{v-b} - \frac{a\,a(T)}{V(V+b)}$$

where a and b are constants and obtained from critical point data. It also involves a function that was

developed to fit vapor pressure data using reduced temperature, T_r:

$$a = \left[1 + \left(0.480 + 1.574\omega - 0.176\omega^2\right)\left(1 - T_r^{0.5}\right)\right]^2$$

where ω is the acentric factor.

Solvent Extraction: A separation process based on selective solubility, where a liquid solvent is introduced at the top of a column. As it passes the feed, which enters near the bottom as a vapor, it selectively dissolves a target constituent. The solvent is then removed via the bottom of the column and put through an easy solvent/extract fractionation. From the top of the column comes a raffinate stream, the feed stripped out of the extract. Butadienes and aromatics are some products recovered by solvent extraction.

Sour Crude Oils: Crudes that contain sulfur in amounts greater than 0.5 to 1.0 wt %, or that contain 0.05 ft^3 or more hydrogen sulfide (H_2S) per 100 gal. Such oils are dangerously toxic. Even 0.05 ft^3 per 100 gal can be present before severe corrosion tends to occur. Arabian crudes are high-sulfur crudes that are not always considered sour because they do not contain highly active sulfur compounds. Original definition was for any crude oil that smelled like rotten eggs.

Sour Gas: 1. A light gas stream that contains acid gases, in particular sulfur compounds, ammonia compounds, and carbon dioxide. 2. Gas rich in hydrogen sulfide (H_2S). 3. Natural gas that contains significant amount of hydrogen sulfide (usually greater than 16 ppm) and possibly other objectionable sulfur compounds (mercaptans, carbonyl sulfide). Also called "acid gas." 4. Natural or associated gas with high sulfur content. 5. Natural gas containing chemical impurities, a notable hydrogen sulfide (H_2S) or other sulfur compounds that make it extremely harmful to breathe even small amounts; a gas with disagreeable odor resembling that of rotten eggs. 6. A gas containing sulfur-bearing compounds such as hydrogen sulfide and mercaptans and usually corrosive. 7. Raw natural gas to be processed, that is, gas received at the liquefaction plant before being subjected to any pretreatment.

Space Velocity: A unit generally used for expressing the relationship between feed rate and reactor volume in a flow process. It is defined as the volume or weight of feed per unit time per unit volume of reactor or per unit weight of catalyst. Space velocity is normally expressed on a volume basis (LHSV: liquid hourly space velocity) or a weight basis (WHSV: weight hourly space velocity). LHSV and WHSV are determined as follows:

$$\text{LHSV} = \frac{\text{total volumetric feed flow rate to the reactor}}{\text{total catalyst volume}} [=] h^{-1}$$

$$\text{WHSV} = \frac{\text{total mass feed flow rate to the reactor}}{\text{total catalyst weight}} [=] h^{-1}$$

LHSV and WHSV are related by the equation

$$\text{WHSV} = \frac{\rho_{\text{oil}}}{\rho_{\text{cat}}} \text{LHSV}$$

where ρ_{oil} and ρ_{cat} are the densities of the hydrocarbon feed and the catalyst respectively

Specific gravity: By definition is the ratio of gas density (at the temperature and pressure of the gas) to the density of dry air (at the air temperature and pressure).

Spent Catalyst: Catalyst that has been through a reaction and is no longer as active because of substances or other contaminants deposited on it (in the case of solid) or mixed with it (in the case of liquid).

Spillback: A spillback allows fluid to recycle from the discharge back to the suction of a machine. It's one way to stop a centrifugal compressor from surging.

Splitter: A distillation column that separates a feed into light and heavy products.

Sponge Absorber: *See Secondary absorber.*

Sponge Oil: The liquid used in an absorption plant to soak up the constituent to be extracted.

Stability: Is the ability of a catalyst to maintain its activity and selectivity over a reasonable period. A catalyst with good stability has a long cycle life between regeneration in a commercial unit.

Stabilization: A process for separating the gaseous and more volatile liquid hydrocarbons from crude petroleum or gasoline and leaving a stable (less-volatile) liquid so that it can be handled or stored with less change in composition.

Stabilizer: A distillation column that removes light components from a liquid product. This terminology is often used to describe debutanizer columns that remove C_4 hydrocarbons from gasoline to control the vapor pressure.

Standard cubic feet (scf): The volume of gas expressed as standard cubic feet. Standard conditions in petroleum and natural gas usage refer to a pressure

base of 14.696 psia (101.5 kPa) and a temperature base of 60°F (15°C).

Static head: The potential energy of a liquid expressed in head form:

$$h = \frac{p}{\rho g}$$

where p is the pressure, ρ is the density and g is the acceleration due to gravity. It is used directly in the Bernoulli equation for which the other two head forms are velocity head and pressure head (See Figure 3).

Steady State: Describes a process in which the mass and energy flowing both into and out the process are in perfect balance.

Steam: The gaseous form of water formed when water boils. At atmospheric pressure, steam is produced at 212°F (100°C) by boiling water. It is widely used in the chemical and process industries as a utility for heating processes such as a kettle type reboiler for distillation columns. It is also used in power generation when steam is produced or raised from a thermal process and expanded through turbines. Other uses of steam at destroying harmful pathogens and is a harmless substance once cooled. Wet steam is water vapor that contains water droplets. With further heating, the water evaporates. The ***dryness fraction*** of steam is the ratio of the amount of water in steam to the total amount of water vapor. Superheated steam is produced by heating the steam above the boiling point of water. The thermodynamic properties of steam are presented in published literature as the steam tables.

Steam (Purchased): Steam, purchased for use by a refinery that was not generated from within the refinery complex.

Steam Cracking: 1. The high temperature reduction in length or cracking of long-chain hydrocarbons in the presence of steam to produce shorter-chain products such as ethylene (C_2H_4), propylene (C_3H_6) and other small-chain alkenes (C_nH_{2n}). 2. The same as catalytic cracking, but specifically referring to the steam injected with the catalyst and feed to give the mixture lift up the riser.

Steam distillation: The separation of immiscible organic liquids by distillation using steam. In involves the injection of live steam into the bottom of the distillation column and into the heated mixture for separation. The steam reduces the partial pressure of the mixture and reduces the temperature required for vaporization. When distilled, the components operate independently of one another, with each being in equilibrium with its own vapor. Steam distillation is used in the primary separation of crude distillation in a fractionating column.

Steam injection: The use of live steam fed directly into a process to provide water and heat and to

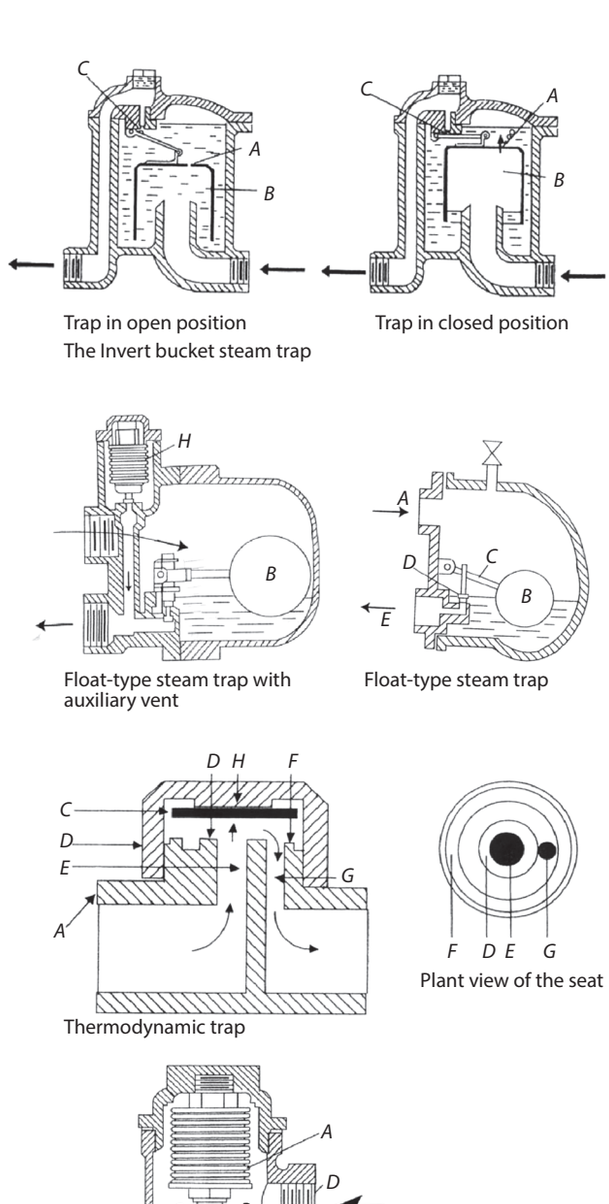


Figure 33

enhance either reaction or extraction. It is commonly used as an enhanced oil recovery method to recover oil from depleted reservoirs or from oil sands in which viscous heavy oil is recovered using steam injection to reduce the viscosity of the oil, and aid transport and recovery. Steam is also directly used in the separation of crude oil and fed to the bottom of the fractionating/distillation column. This is the primary separation of crude oil into fractions that have different boiling points. Steam cracking uses steam for thermal cracking and reforming of hydrocarbons.

Steam jet ejector: A type of fixed operating pump that uses high-pressure steam passed through a constriction to create a low pressure due to the venture effect, and to which the equipment to be evacuated is connected such as a distillation column condenser. In spite of requiring high-pressure steam, the device has no moving parts and therefore has low maintenance costs. It can handle corrosive vapors.

Steam Methane Reformer: A primary source of hydrogen in a refinery, this operating unit converts methane (CH_4) and steam (H_2O) to hydrogen (H_2) with by-products of carbon monoxide (CO) and carbon dioxide (CO_2).

Steam point: The temperature that corresponds to the maximum vapor pressure of water at standard atmospheric pressure (1.01325 bar). This corresponds to a temperature of 100°C.

Steam reforming: The conversion of methane (CH_4) from natural gas into hydrogen (H_2). It is used in production of ammonia (NH_3) in which the methane is first produced from desulfurized and scrubbed natural gas, mixed with steam and passed over nickel catalyst packed in tubes at a high temperature of round 1652 °F (990 °C)

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$

The reactions are endothermic (i.e., absorbing heat).

Steam tables: Published tables that present thermodynamic data for enthalpy, entropy and specific volume of steam at various temperatures and pressure. Steam is a commonly encountered material in chemical processes and its properties have been extensively tabulated.

Steam tracing: An internal pipe or tube used in process vessels and pipelines carrying steam to provide adequate heating to a fluid to keep it at a controlled temperature. The amount of steam or heat supplied is sufficient to overcome losses. Steam tracing is typically used in pipelines carrying molten bitumen and other fluids prone to solidification on cooling, to ensure that they remain in a liquid state.

Steam trap: A device used to automatically drain and remove condensate from steam lines to protect the steam main from condensate build-up. Various types of steam traps are used and generally consists of a valve that can be operated by a float, spring or bellows arrangement. Discharge of the hot condensate may be either to the environment or into a collection pipe and returned to the boiler for reuse (See Figure 33).

Still Gas (Refinery gas): Any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes. The principal constituents are methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), normal butane (nC_4H_{10}), butylenes (C_4H_8), propane (C_3H_8), propylene (C_3H_6), and so on. Still gas is used as a refinery fuel and a petrochemical feedstock. The conversion factor is 6 million Btu per fuel oil equivalent barrel.

Stoichiometric: Applied to reactors in which the reactants and products are defined in terms of the molar quantities reacting. E.g., in the reaction: $3H_2 + 2H_2 \Leftrightarrow 2NH_3$, the stoichiometric coefficients are -3.0, -2.0 and 2.0 for the H_2, N_2 and NH_3 respectively.

Straight Run Distillate or Natural Gasoline: 1. A fraction obtained on simple distillation of crude oil without cracking. Its octane number is usually low and thus requires upgrading by catalytic reforming. 2. A product that has been distilled from crude oil but has not been through a process in which the composition has been chemically altered. 3. Gasoline produced by the primary distillation of crude oil. It contains no cracked, polymerized, alkylated, reformed, or visbroken stock.

Stress Relief: Coded vessels typically have a metal stamp attached that states "Do not weld, stress relieved". That means the vessel has been postweld heat treated to remove stresses in the vessel wall created by welding during fabrication.

Stripper Column: A loose designation applied to a distillation column in which light components are stripped from a heavier liquid product.

Stripping: The removal (by steam-induced vaporization or flash evaporation) of the more volatile components from a cut or fraction.

Stripping Steam: Steam that is injected into the bottom of a side stripping column or used to strip oil from catalyst in a FCC operation.

Stripping Zone: The section of the column in which light components are stripped from a heavier liquid product. In conventional distillation columns, this is the portion of the column from the reboiler to the feed tray.

Sulfolane $(CH_2)_4SO_2$: A chemical used as a solvent in extraction and extractive distillation processes.

Sulfur: A yellowish nonmetallic element, sometimes known as "brimstone." It is present at various levels of concentration in many fossil fuels whose combustion releases sulfur compounds that are considered harmful to the environment. Some of the most commonly used fossil fuels are categorized according to their sulfur content, with lower sulfur fuels usually selling at a higher price. Note: No. 2 Distillate fuel is currently reported as having either a 0.05% or lower sulfur level for on-highway vehicle use or a greater than 0.05% sulfur level for off-highway use, home heating oil, and commercial and industrial uses. This also includes Ultra Low Sulfur Diesel (< 15 ppm sulfur). Residual fuel, regardless of use, is classified as having either no more than 1% sulfur or greater than 1% sulfur. Coal is also classified as being low-sulfur at concentration of 1% or less or high-sulfur at concentrations greater than 1%.

Sulfuric acid treating: A refining process in which unfinished petroleum products such as gasoline, kerosene, and lubricating oil stocks are treated with sulfuric acid to improve their color, odor, and other characteristics.

Sulfurization: Combining sulfur compounds with petroleum lubricants.

Sulfur content: Is expressed as a percentage of sulfur by weight, and varies from less than 0.1% to greater than 5%. Crude oils with less than 1 wt% sulfur are called low-sulfur content or sweet crude, and those with more than 1 wt% sulfur are called high-sulfur or sour crude. Sulfur-containing constituents of the crude oil include simple mercaptans (also known as thiols), sulfides and polycyclic sulfides. Mercaptan sulfur is simply an alkyl chain (R-) with SH group attached to it at the end. The simplest form of R – SH is methyl mercaptan, CH_3SH.

Surface Area: The total area that a solid catalyst exposes to the feeds in a reaction. Surface area is enhanced in some catalysts like zeolytes by extensive microscopic pores.

Supply: The components of petroleum supply are field production, refinery production, imports, and net receipts when calculated on a PADD basis.

Surge: This a terrifying sound that centrifugal compressors make when they malfunction either due to low flow or excessive discharge pressure or low molecular weight gas.

Sweet Crude: 1. Crude oil containing very little sulfur and having a good odor. 2. Crude petroleum containing little sulfur with no offensive odor. 3. Gets its name due to a pleasant and "sweet" smell. Sweet crude has sulfur content less than 1%. It is more valuable than sour crude because it costs less to process the crude into finished products. 4. Oil containing little or no sulfur, especially little or no hydrogen sulfide. Original definition was for any crude oil that did not have bad odor.

Sweetening: 1. The removal or conversion to innocuous substances of sulfur compounds in a petroleum product by any of a number of processes (doctor treating, caustic and water washing, etc.). 2. Processes that either remove obnoxious sulfur compounds (primarily hydrogen sulfide, mercaptans, and thiophens) from petroleum fractions or streams, or convert them, as in the case of mercaptans, to odorless disulfides to improve odor, color, and oxidation stability.

Sweet Gas: 1. Gas sweetened. Gas processed in the acid gas removal unit that no longer contains these gaseous pollutants. 2. Natural gas that contains small amounts of hydrogen sulfide (and other sulfur compounds), and carbon dioxide that it can be transported or used without purifying with no deleterious effect on piping and equipment. 3. A gas stream from which the sulfur compounds have been removed. 4. A gas containing no corrosive components such as hydrogen sulfide and mercaptans.

Symbols of chemical apparatus and equipment: Below are listed some symbols of chemical apparatus and equipment normally used in a P&ID, according to ISO 10628 and ISO 14617 (See Figure 34).

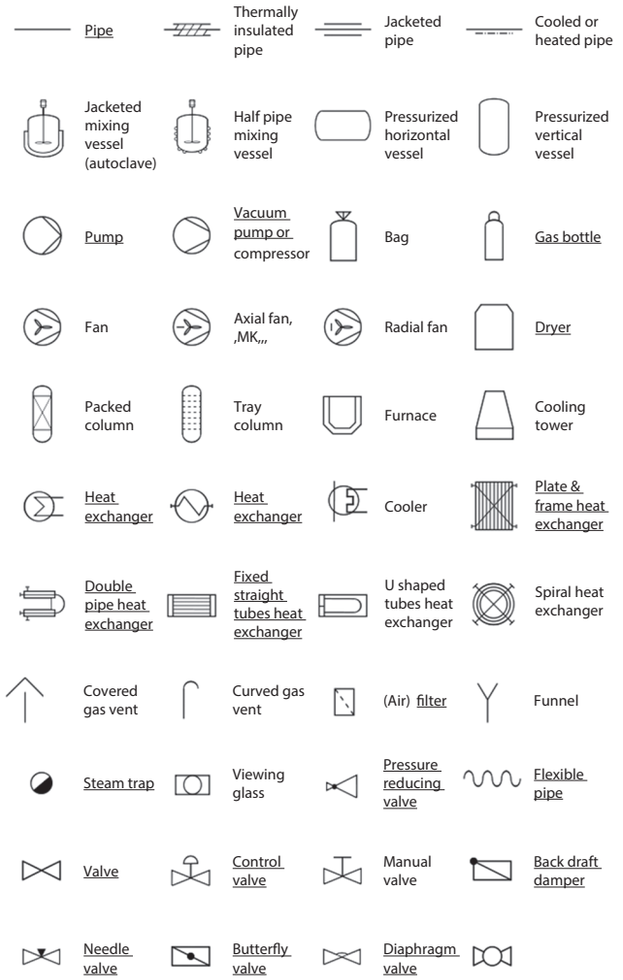


Figure 34 Symbols of chemical apparatus and equipment.

Synthetic Crude: Wide boiling range product of catalytic cracking, coking, hydrocracking, or some other chemical structure change operation.

Synthesis Gas: The product of a reforming operation in which a hydrocarbon usually methane and water are chemically rearranged to produce carbon monoxide, carbon dioxide and hydrogen. The composition of the product stream can be varied to fit the needs of hydrogen and carbon monoxide at refineries or chemical plant. Also known as syn gas.

Tail Ends: Small amounts of hydrocarbon in a cut that vaporizes slightly outside the effective initial boiling point and the effective end point.

Tail Gas: Light gases C_1 to C_3 and H_2 produced as by-products of refinery processing.

TAN: Total acid number.

Tank Farm: An installation used by gathering and trunk pipeline companies, crude oil producers and terminal operators (except refineries) to store crude oil.

Tanker and Barge: Vessels that transport crude oil or petroleum products. Data are reported for movements between PAD Districts; from a PAD District to the Panama Canal; or from the Panama Canal to a PAD District.

Tar: Complex, large molecules of predominantly carbon with some hydrogen and miscellaneous other

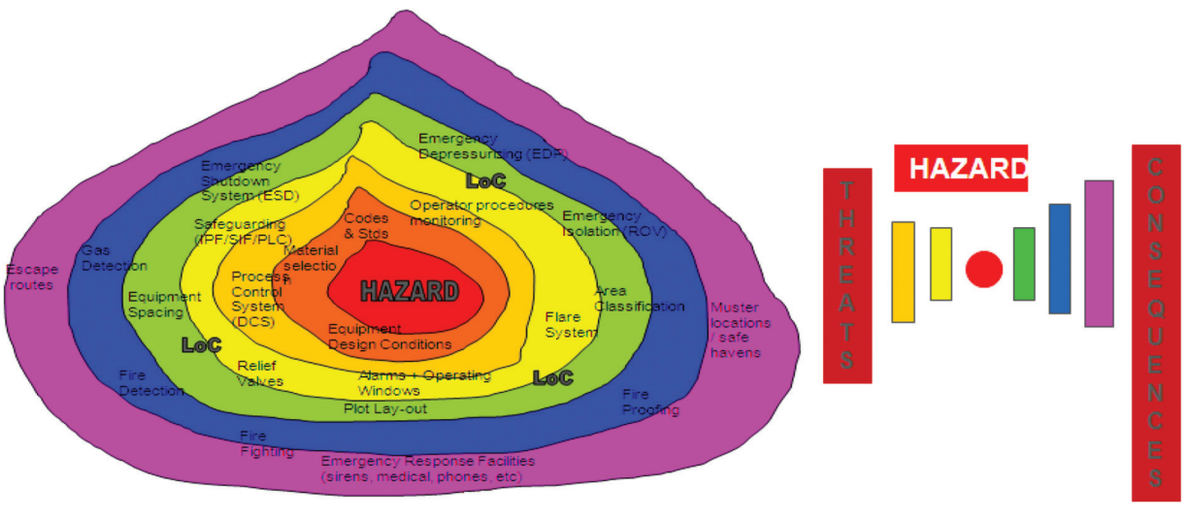


Figure 35 The Onion model (LOC = Loss of containment).

elements that generally deteriorate the quality of processes and the apparatus.

TBP distillation: *See fifteen-five distillation.*

Tertiary Amyl Methyl Ether $(CH_3)_2(C_2H_5)COCH_3$ (TAME): A high-octane oxygenate blending stock produced by reacting isoamylene (isopentylene) produced in FCC processes with methanol. Used to enhance the octane of a motor gasoline pool.

Tertiary Butyl Alcohol – $(CH_3)_3COH$ (TBA): An alcohol primarily used as a chemical feedstock, a solvent or feedstock for isobutylene production for MTBE; produced as a co-product of propylene oxide production or by direct hydration of isobutylene.

Tetra Ethyl Lead (TEL): A compound added to gasoline to increase the octane. TEL has been superseded by other octane enhancers and is no longer used by refiners for motor gasoline.

Test run: A time period during which operating data and stream samples are collected for a process. During test runs, the operation of the processing unit is held as steady as possible. For good test runs, the average conditions and streams flows approximate at steady-state operation.

The diesel engine: The diesel engine is a reciprocating internal combustion engine. It is different from the petrol engine in that the air intake in the engine cylinder is unthrottled and not premixed with the fuel. Here, the ignition takes place spontaneously without the help of a spark plug. The air taken into the cylinder at atmospheric pressure is compressed to a volume ratio somewhere near to 1:16. At the end of the compression, fuel is injected into the cylinder. The quantity injected depends on the power of the engine, and the heat of compression heats the mass of the air compressed.

The Onion Model: The onion model depicts hazards, barriers and recovery measures. It reflects the layers of protection and shows how the various measures fit together when viewed from the perspective of the hazard. The first layer is the basic containment of our feedstock, processes and products (See Figure 35).

The Saybolt Universal Viscometer: Measures the time in seconds that would be required for the total flow of 60cc of oil from a container tube at a given constant temperature through a calibrated orifice placed at the bottom of the tube. Lubricant viscosities are usually measured in Saybolt Universal seconds at 100°F (37.8°C), 130°F (54.4°C) or 210°F (98.9 °C).

E.g., the symbol SSU 100 represents the time in seconds that a fluid at 100°F (37.8°C) will take to flow through a given orifice of the Saybolt viscometer.

Kinematic viscosity can be converted to Saybolt viscosity SSU by the formula:

$$\text{Kinematic viscosity, } \nu = \frac{\mu}{\rho} = 0.219t - \frac{149.7}{t}$$

where

μ = viscosity of fluid in centipoises, cP
ρ = density of fluid, g/cc
t = Saybolt Universal viscosity, sec.

Theoretical Plate: 1. A theoretical contacting unit useful in distillation, absorption, and extraction calculations. Vapor and liquid leaving any such unit are required to be in equilibrium under the conditions of temperature and pressure that apply. An actual fractionator tray or plate is generally less effective than a theoretical plate. The ratio of a number of theoretical plates required to perform a given distillation separation to the number of actual plates used given the overall tray efficiency of the fractionator. 2. Refers to vapor/liquid contact device (e.g., distillation column) in which the liquid and vapor leaving the device are in perfect vapor/liquid phase equilibrium. There are also

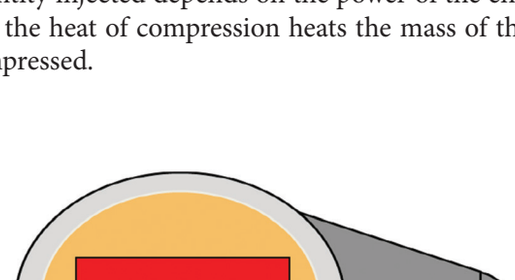


Figure 36 A threat.

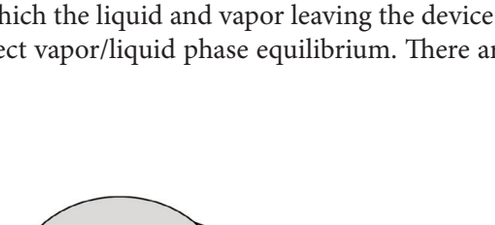


Figure 37 Top event.

perfect energy and mass balances for a theoretical tray (See Figure 5).

Thermal Cracking: 1. A refining process in which heat and pressure are used to break down, rearrange, or combine hydrocarbon molecules. Thermal cracking includes gas oil, visbreaking, fluid coking, delayed coking and other thermal cracking processes (e.g., Flexicoking). 2. The first cracking process, in which the oil was cracked by heating only. Thermal cracking produces lower octane gasoline than catalytic processes.

Thermal Cracked Distillate: Is formed when a distillate heavier than gasoline is heated under pressure in order to break the heavy molecules into lighter ones that boil in the gasoline range. This is superseded by catalytic cracking which gives better distillate.

Thermal Conductivity: The ability of a material to let heat pass. Metals, water and materials that are good conductors of electricity have a high thermal conductivity. Air, rubber, and materials that are bad conductors of electricity have a low thermal conductivity. High viscosity hydrocarbons are bad conductors of heat.

Thermal expansion: Railroad tracks grow longer in the heat of the sun. The hot tubes in an exchanger grow more than the cold shell. Hence, we have a floating head in the tube bundle to accommodate differential rates of thermal expansion between the tube bundle and the shell.

Threat: A threat is something that can cause the release of a hazard and lead to a top event (See Figure 36).

Three phase: A mixture consisting of one vapor in equilibrium with two mutually insoluble liquid phases.

Threshold Limit Value: The amount of a contaminant to which a person can have repeated exposure for an eight-hour day without adverse effects.

Tolerable: Minimum requirements/criteria that have to be met for managing a risk.

Toluene ($C_6H_5CH_3$): 1. Colorless liquid of the aromatic group of petroleum hydrocarbons, made by the catalytic reforming of petroleum naphthas containing methyl cyclohexane ($CH_3C_6H_{11}$). A high- octane gasoline blending agent, solvent and chemical intermediate, base for TNT. 2. One of the aromatic compounds used as a chemical feedstock most notoriously for the manufacture of TNT, trinitrotoluene.

Top Event: A top event is the 'release' of the hazard, i.e., the first consequence, typically a loss of containment, a loss of control, or an exposure to something that may cause harm, such as the release of hydrocarbons, toxic substances or energy (See Figure 37).

Top Product: For columns with condensers, the liquid and/or vapor streams from the reflux drum that exit the process.

Topping: Removal by distillation of the light products and transportation fuel products from crude oil, leaving in the still bottoms all of the components with boiling ranges greater than diesel fuel.

Topped Crude Oil: 1. Crude that has been run through a distilling unit to remove the gas oil and lighter streams. The long residue is sold as residual fuel. 2. The bottom product from a crude distillation column.

Toxic Compounds: NO_x, VOCs and SO_x are toxic compounds such as formaldehyde, oxides of nitrogen, volatile organic compounds such as pentene and oxides of sulfur.

Tray: A liquid/vapor contact device in a distillation column (See Figure 5).

Tray Efficiency: See overall tray efficiency

Treat Gas: Light gases, usually high in hydrogen content, which are required for refinery hydrotreating processes such as hydrodesulfurization. The treat gas for hydrodesulfurization is usually the tail gas from catalytic reforming or the product from a hydrogen unit.

Trip: 1. The fast shutdown of an item of chemical plant or process equipment such as a pump or compressor. The shutdown is the result of a process condition being exceeded such as an abnormal flow, pressure, temperature or concentration, etc. 2. This a safety device that automatically shuts down a piece of equipment. It's a fail-safe mechanism often activated by unlatching a spring operated valve, which then closes.

Troubleshooting: A form of problem-solving methodology used to identify, solve and eliminate problems within a process that has failed or has the potential to fail. It is a logical and systematic search for the source or cause of the problem and solutions presented to ensure that the process is restored back to its full operability. Troubleshooting is applied once a problem has occurred and the process stops functioning. It can take the form of a systematic checklist and

requires critical thinking. Computer techniques are employed for more complex systems where a sequential approach is either too lengthy or not practical or where the interaction between the elements in the system is not obvious.

True Boiling Point distillation (TBP): 1. Of a crude oil or petroleum fractions results from using the U.S. Bureau of Mines Hempel method and the ASTM D – 285 test procedure. Neither of these methods specifies the number of theoretical stages or the molar reflux ratio used in the distillation. Consequently, there is a trend toward applying a 15:5 distillation according to ASTM D2892, instead of the TBP. The 15:5 distillation uses 15 theoretical stages and a molar reflux ratio of 5. 2. A laboratory test in which petroleum oil is distilled in a column having at least 15 theoretical trays and a reflux ratio of 5.0. The distillate is continually removed and further analyzed. The separation corresponds somewhat to a component by component separation and is a good measure of the true composition for the sample being distilled. As the temperatures in the still increase, the pressure of the still is lowered to suppress thermal cracking of the sample.

The minimum pressure for most TBP stills is about 38 mm Hg. This allows distillation of petroleum components boiling up to about 900–950°F (483–510°C) at a pressure of one atmosphere. Surprisingly, the TBP test has never been standardized and several different apparatuses are used for the test.

A key result from a distillation test is the boiling point curve, i.e., the boiling point of the oil fraction versus the fraction of oil vaporized. The initial boiling point (IBP) is defined as the temperature at which the first drop of liquid leaves the condenser tube of the distillation apparatus. The final boiling point or the end point (EP) is the highest temperature recorded in the test.

Additionally, oil fractions tend to decompose or crack at a temperature of approximately 650°F (344°C) at one atmosphere. Thus, the pressure of TBP distillation is gradually reduced to as low as 40 mmHg, as this temperature is approached to avoid cracking the sample and distorting measurements of true components in the oil (See Figure 12).

Tube bundle: Pipes in a shell and tube heat exchanger that are packed into an arrangement to ensure effective heat transfer from the outer surface and good transport for fluids through the tubes. The tubes in the tube bundle are spaced and typically set with a rectangular or triangular pitch, and held and sealed with a tube plate. Baffles also provide rigidity and encourage turbulent flow of fluids through the shell side. The tubes can be a straight single-pass or hairpin double-pass arrangement. The tube bundle can be removed from the shell for periodic cleaning. Lugs are welded to the baffles for lifting purposes (See Figure 31).

Tube size: Tubing sizes are entirely different from pipe sizes. Tubing is often used in heat exchangers and fired equipment.

Tube still: *See pipe still.*

Turbine: 1. A machine used to generate electricity by the expansion of a gas or vapor at high pressure through a set of blades attached to a rotor. The blades rotate as the result of the expansion and conversion of energy. Gas turbines and steam turbines are commonly used to generate electricity. A nozzle is used to direct the high-speed gas or steam over a row of turbine blades. The fluid pushes the blades forwards causing them to rotate due to change in momentum. A row of stationary blades within the turbine redirects the fluid in the correct direction again before it passes through another set of nozzles and expands to a lower pressure. A steam turbine may have several pressure sections and

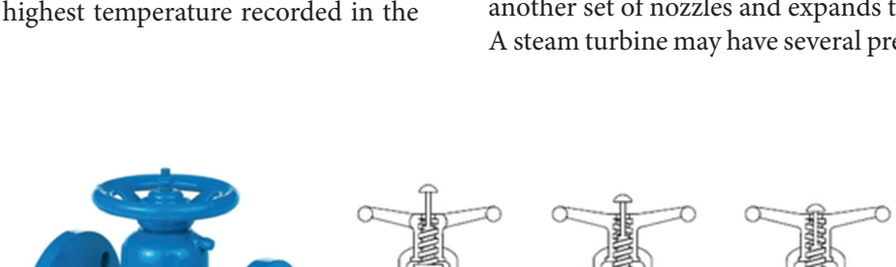


Figure 38 A diaphragm valve.

operate at high pressure, medium pressure, and as the steam expands, a low-pressure section all linked to the same shaft. The steam in the medium-pressure section may be returned to a boiler and reheated before doing further work to prevent the formation of water in the turbine. 2. A turbine uses steam pressure or burning gas to drive pumps and compressors at variable speeds. Motor drives are usually fixed-speed machines. Variable speed is an energy efficient way to control flows by eliminating the downstream control valve.

Turbulent flow: A fluid flow regime characterized by the fluctuating motion and erratic paths of particles. In pipes of circular cross-section, this occurs at Reynolds number in excess of 4000. Turbulent flow occurs when inertial forces predominate resulting macroscopic mixing of the fluid.

Turnaround: A planned complete shutdown of an entire process or section of a refinery, or of an entire refinery to perform major maintenance, overhaul, and repair operations and to inspect, test, and replace process materials and equipment.

Two phase: A mixture consisting of one vapor in equilibrium with one homogeneous liquid phase.

ULSD: Ultra-Low-sulfur diesel. Diesel fuel with < 15 ppm sulfur.

Unaccounted for Crude Oil: Represents the arithmetic difference between the calculated supply and the calculated disposition of crude oil. The calculated supply is the sum of crude oil production plus imports minus changes in crude oil stocks. The calculated disposition of crude oil is the sum of crude oil input to refineries, crude oil exports, crude oil burned as fuel, and crude oil losses.

Undistributed Component: A component in a distillation column separation zone that is totally recovered in only one of the products.

Unfinished Oils: All oils requiring further processing, except those requiring only mechanical blending. Unfinished oils are produced by partial refining of crude oil and include naphthas and lighter oils, kerosene and light gas oils, heavy gas oils, and residuum.

Unfractionated Streams: Mixtures of unsegregated natural gas liquid components excluding, those plant condensate. This product is extracted from natural gas.

Unsaturated Compounds: Hydrocarbon compounds in which some of the carbon atoms have multiple bonds with other carbon atoms because of the lack of hydrogen atoms to satisfy the carbon atoms valences.

Upper Explosive Limit (UEL): The maximum concentration of vapor in air above which the propagation of flame will not occur in the presence of an ignition source. Also referred to as the upper flammable limit or the upper explosion limit.

Utilities: Most plants have some of the following utility systems connected to process units.

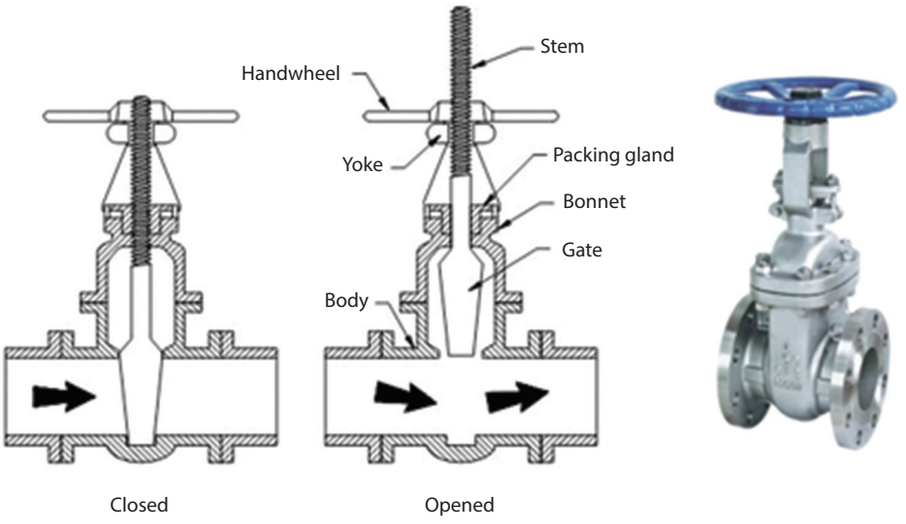


Figure 39 A gate valve.

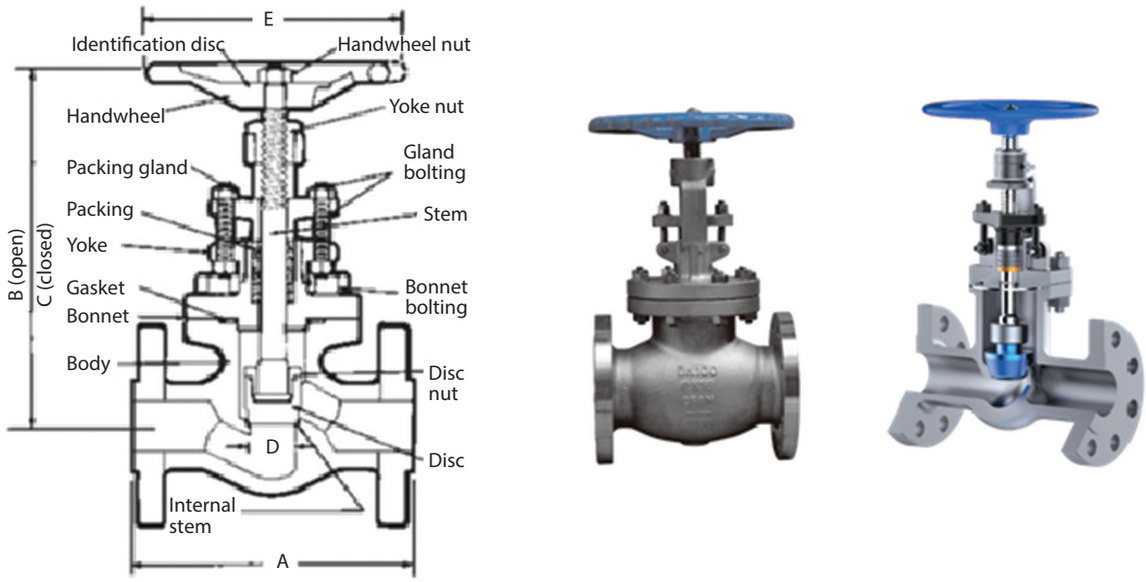


Figure 40 A globe valve away section of a globe valve.

Figure 41 Plug valves Cutaway section of a plug valve.

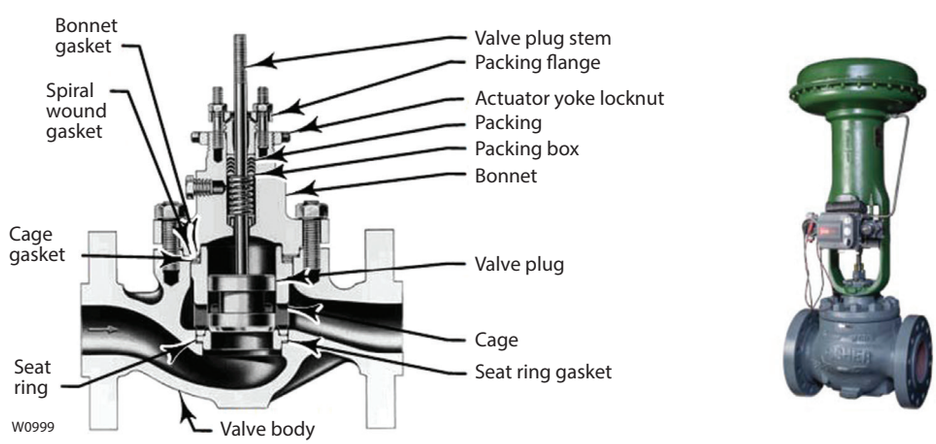


Figure 42 A Control valve.

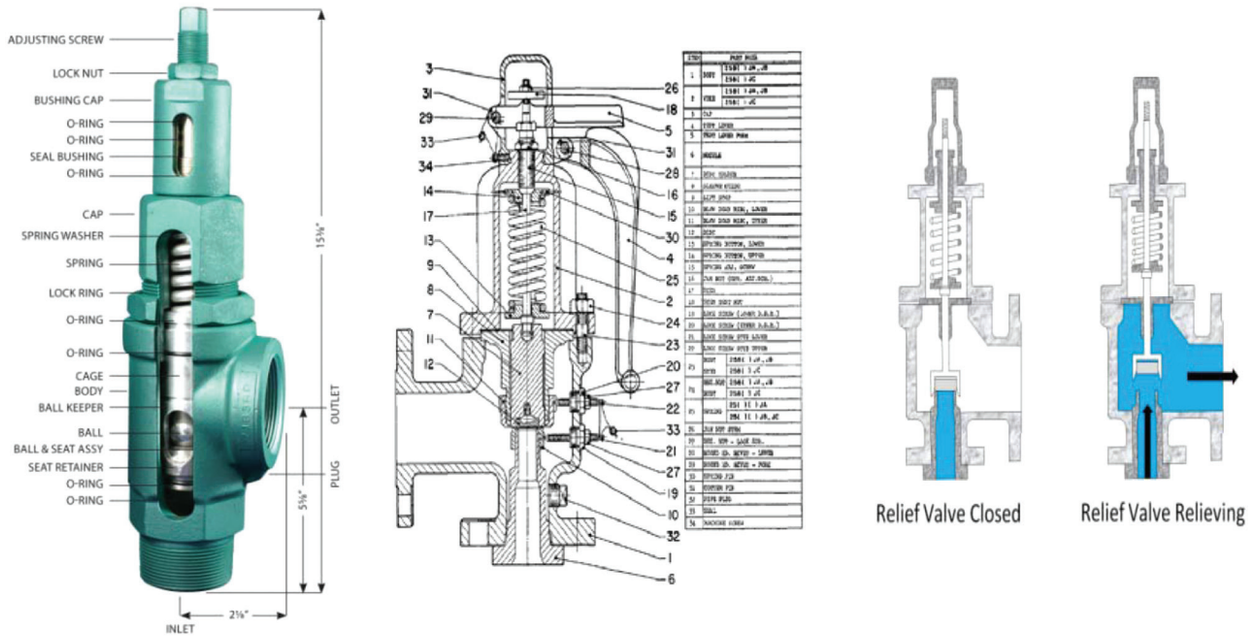


Figure 43 Relief valves.

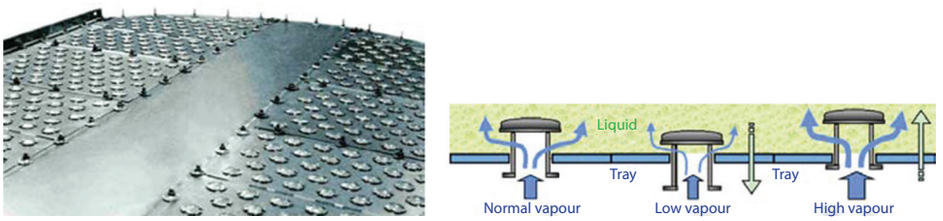


Figure 44 A valve tray.

- Natural gas
- Nitrogen
- Plant air
- Instrument air
- Steam of various pressures
- Cooling water
- Service water
- Boiler feed water
- Fire water
- Fuel gas
- City water

Your company safety policy does not permit you to cross-connect these systems. Connecting natural gas to plant air killed 17 workers at a Louisiana refinery.

Vacuum Distillation: 1. Distillation under reduced pressure (less than atmospheric), which lowers the boiling temperature of the liquid being distilled. This technique prevents cracking or decomposition of the charge stock which occurs above 1000°F (538°C). 2. A distillation column that operates at sub-atmospheric pressure. Vacuum distillation permits the further distillation of heavy feed stocks at reduced temperatures that minimize cracking reactions.

Vacuum Gas Oil (VGO): A side stream from the vacuum distillation tower.

Vacuum Residuum: The heaviest product from a vacuum distillation column.

Valves: A valve is a device that regulates, directs or controls the flow of a fluid (gases, liquids, fluidized solids, or slurries) by opening, closing or partially obstructing various passageways.

Diaphragm valve: A type of device in which a flexible membrane is used to restrict the rate of flow. The membrane is usually made from a flexible natural or synthetic rubber. Diaphragm valves are typically used for fluids that contain suspended solids (See Figure 38).

Gate valve. This valve closes by sliding a plate or gate down between two grooves. Used to isolate different portions of the process equipment not used to control flow. The valve closes clockwise and takes about a dozen turns to close. Ninety percent of the valves used in process plants are gate valves (See Figure 39).

Globe valve: A device that regulates the flow of a fluid in a pipe and consists of a flat disc that sits on a fixed ring seat. The disc is movable and allows flow through the valve (See Figure 40).

Plug valve: This valve goes from 100% open to shut by turning a valve 90°. The natural gas supply to your house is shut off with a plug valve (See Figure 41).

Control valve: This valve is used to alter flows remotely. Normally it is moved by air pressure. A gate valve is sometimes used to control flows locally, but this wears out the valve and is best avoided (See Figure 42).

Relief valves: These valves open to relieve excess pressure to protect a vessel from failure. Also called safeties or pop valves (See Figure 43).

Valve Trays: 1. Fractionator trays that have perforations covered by discs that operate as valves and allow the upward passage of vapor. 2. In valve trays, perforations are covered by lift-able caps. Vapor flows lift the caps, thus self-creating a flow area for the passage of vapor. The lifting caps direct the vapor to flow horizontally into the liquid, thus providing better mixing than is possible in sieve trays (See Figure 44).

Vapor: The gaseous phase of a substance that is a liquid at normal temperature and pressure.

Vapor/Liquid Ratio (V/L): The vapor/liquid ratio (V/L) is the ratio of the volume of vapor formed at atmospheric pressure to the volume of gasoline in a standard test apparatus. The vapor-lock tendency of the gasoline sample can be measured more reliably in terms of its V/L ratio than in terms of its vapor pressure. The V/L ratio also increases with rise in temperature.

Vapor Pressure: 1. As a liquid is heated, the molecules in the liquid try to escape into the vapor phase. The hotter the liquid, the harder they try to escape. The pressure that the molecules of liquid create as they push out into the vapor space is the liquid vapor pressure. More volatile liquids such as LPG have a higher vapor pressure than less volatile diesel oil. 2. The pressure exerted by a volatile liquid as determined by ASTM D-323, Standard Method of Test for Vapor Pressure of Petroleum Products (Reid Method). 3. Is a measure of the surface pressure necessary to keep a liquid from vaporizing. The vaporizing tendency of gasoline is measured in terms of its vapor pressure. It is related to vapor lock and engine starting. Vapor lock arises due to the vaporization of the fuel in fuel lines, fuel pump, carburetor, etc, making bubbles of vapor, which prevent the normal flow of fuel. This occurs if the gasoline contains too high a percentage of low-boiling components as observed by a very high vapor pressure. Alternatively, if the gasoline contains only too few low boiling components as indicated by a low vapor pressure, then the fuel will not vaporize readily making it difficult in starting. *(See Reid Vapor Pressure, RVP)*

Vapor Lock: Is the phenomenon of insufficient gasoline flow from a fuel pump due to its inability to pump the mixture that results from low pressure or high temperature, which has high volatility.

Vapor Lock Index: A measure of the tendency of a gasoline to generate excessive vapors in the fuel line, thus causing displacement of a liquid fuel and subsequent interruption of normal engine operation. The vapor-lock index generally is related to RVP and percentage distilled at 158°F (70°C).

Virgin Material, Gas Oil, etc: Virgin material is material distilled from crude oil but not subjected to processes that chemically alter its composition.

Virgin Stocks: Petroleum oils that have not been cracked or otherwise subjected to any treatment that would produce appreciable chemical change in their components.

Visbreaking: 1. A thermal cracking process in which heavy atmospheric or vacuum-still bottoms are cracked at moderate temperatures to increase production of distillate products and reduce viscosity of the distillation residues. 2. A process in which heavy oil is thermally cracked just enough to lower or break the viscosity. A small quantity of gas oil and lighter products are formed in the process.

Viscosity ASTM D445: Internal resistance to the flow of liquids is expressed as viscosity. The property of liquids under flow conditions that causes them to resist instantaneous change of shape or instantaneous rearrangement of their parts due to internal friction.

Viscosity is generally measured in seconds, at a definite temperature, required for a standard quantity of oil to flow through a standard apparatus. Common viscosity scales in use are Saybolt Universal, Saybolt Furol, poises, kinematic [stokes, or centistokes (cSt)]. Usually, the viscosity measurements are carried out at 100°F (38°C) and 210°F (99°C).

Viscosity is a very important property for the heavy products obtained from the crude oil. The viscosity acts as an important characterization property in the blending units associated to heavy products such as bunker fuel. Typically, the viscosity of these products is specified to be within a specified range and this is achieved by adjusting the viscosities of the streams entering the blending unit.

Viscosity Index (VI): This index is a series of numbers ranging from 0 to 100 which indicate the rate of change of viscosity with temperature. A Viscosity Index of 100 indicates an oil that does not tend to become viscous at low temperatures or become thin at elevated temperatures.

Typically paraffin-base lubricating oils exhibit a Viscosity Index of nearly 100, whereas naphthenes-base oils on the market show about 40 Viscosity Index, and some naphthenic oils have a Viscosity Index of zero or lower. Paraffin wax has a V.I. of about 200, and hence its removal reduces the V.I. of raw lube stocks. By solvent extraction processes, lubricating oils of Viscosity Index higher than 100 can be produced.

Volatile: A hydrocarbon is volatile if it has a sufficient amount of butanes and higher material to noticeably give off vapors at atmospheric conditions.

Volatile Organic Compounds (VOCs): Organic chemicals that have a high vapor pressure at ordinary room temperature. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air. E.g., formaldehyde (HCHO), which evaporates from paint, has a boiling point of only -19°C (-2°F).

One VOC that is a known human carcinogen is benzene, which is a chemical found in environmental tobacco smoke, stored fuels, and exhaust from cars. Benzene also has natural sources such as volcanoes and forest fires. It is frequently used to make other chemicals in the production of plastics, resins, and synthetic fibers. Benzene evaporates into the air quickly and the vapor of benzene is heavier than air allowing the compound to sink into low-lying areas. Benzene has also been known to contaminate food and water and if digested can lead to vomiting, dizziness, sleepiness, rapid heartbeat, and at high levels, even death may occur.

VOCs are many and varied, are dangerous to human health or cause harm to the environment. Harmful VOCs typically are not acutely toxic, but have compounding long-term health effects. Because the concentrations are usually low and the symptoms slow to develop, research into VOCs and their effects is difficult.

Volatility: As measured by the distillation characteristics, helps to determine the relative proportion of the various hydrocarbons throughout the boiling range of a gasoline. It is the distillation characteristics along with vapor pressure and vapor/liquid ratio that help to control the performance of the fuel with respect to starting, warm-up, acceleration, vapor-lock, evaporation losses, crankcase dilution, fuel economy and carburetor icing.

Volatility Factor: An empirical quantity that indicates good gasoline performance with respect to volatility. It involves actual automobile operating conditions and climatic factors. The volatility factor is generally defined as a function of RVP (Reid vapor pressure), percentage distilled at 158°F (70°C) and percentage distilled at 212°F (100°C). This factor is an attempt to predict the vapor-lock tendency of a gasoline.

vppm: Parts per million by volume.

VRC: Vacuum reduced crude; vacuum tower bottoms.

WABP: Weight average boiling point:

$$\text{WABP} = \sum_{i=1}^{n} X_{wi}\, T_{bi}$$

where

X_{wi} = weight fraction of component i.

T_{bi} = average boiling point of component i.

Wash Zone: A section in a column where the column vapor is washed of entrained heavy materials by contact with a cooler injected liquid. A section of packed material is often used to promote good mixing of the liquid and vapor in the wash zone. All vacuum distillation columns have wash zones to remove heavy residual material that is carried up the column from the flash zone. If washing is inadequate, the heavy residual material forms petroleum coke and plugs the column above the flash zone.

Water hammer: A violent and potentially damaging shock wave in a pipeline caused by the sudden change in flow rate, such as by the rapid closure of a valve. The effect is avoided by controlling the speed of valve closure, lowering the pressure of the fluid, or lowering the fluid flow rate.

Water vapor: The gaseous state of water dispersed with air at a temperature below the boiling point of the water. The amount present in air is designated by the humidity. The "relative humidity" is the amount of water vapor in a mixture of dry air. A relative humidity of 100% corresponds to the partial pressure of water vapor being equal to the equilibrium vapor pressure and depends on the temperature and pressure.

Watson Characterization factor (K_w): *see Characterization factor*

Wax: A solid or semi-solid material consisting of a mixture of hydrocarbons obtained or derived from petroleum fractions, or through a Fischer-Tropsch type process, in which the straight-chained paraffins series predominate. This includes all marketable wax, whether crude or refined, with a congealing point (ASTM D 938) between 100–200°F (37.8–93°C) and a maximum oil content (ASTM D 3235) of 50 weight percent.

Weeping: A phenomenon that occurs in a distillation column in which liquid on a sieve plate passes down through the perforations intended for the vapor to pass up. Weeping occurs when the velocity of the upward vapor is too low. This may be caused by insufficient boil-up.

Weir: A vertical obstruction across a channel carrying a liquid over which the liquid discharges. In a distillation column, a weir is used to retain an amount of liquid on a sieve tray or plate. While the vapor enriched with the more volatile component rises up through the perforations on the sieve tray or plate, the liquid cascades over the weir into the downcomer to the tray below. The weir crest is the top of the weir over which the liquid flows.

Weighted average inlet temperature (WAIT): [Weight of catalyst in reactor 1 × inlet temperature in reactor 1 + weight of catalyst in reactor 2 × inlet temperature in reactor 2 + weight of catalyst in reactor 3 × inlet temperature in reactor 3]/total weight of catalyst, i.e. $[WCR_1 \times R_{1IT} + WCR_2 \times R_{2IT} + WCR_3 \times R_{3IT}]/(WCR_1 + WCR_2 + WCR_3)$, where WCR_1, WCR_2, WCR_3 are the weights of catalysts in reactors 1, 2, 3 and R_{1IT}, R_{2IT}, R_{3IT} are the inlet temperatures for reactors, 1, 2 and 3 respectively.

Weighted average bed temperature (WABT): $[WCR_1 (R_{1IT} + R_{1OT})/2 + WCR_2 (R_{2IT} + R_{2OT})/2 + WCR_3 (R_{3IT} + R_{3OT})/2]$/total Weight of catalyst, where WCR_1, WCR_2, WCR_3 are the weights of catalysts in reactors 1, 2, 3; R_{1IT}, R_{2IT}, R_{3IT} are the inlet temperatures for reactors 1, 2, 3 and R_{1OT}, R_{2OT}, R_{3OT} are the outlet temperatures for reactors 1, 2, and 3 respectively.

Well: 1. A natural oil or gas reservoir that exists below a layer of sedimentary rock. 2. A hole bored or drilled into the earth for the purpose of obtaining water, oil, gas or other natural resources.

West Texas Intermediate (WTI): A type of crude oil commonly used as a price benchmark.

Wet Gas: 1. Natural gas that has not had the butane, C_4 and natural gasoline removed. Also the equivalent refinery gas stream. 2. A term used to describe light hydrocarbon gas dissolved in heavier hydrocarbons. Wet gas is an important source of LPG. 3. Water that is present in natural gas in offshore platforms. It is necessary to remove the water from the gas for export through subsea pipelines. The pipeline is dosed with corrosion inhibitors to prevent hydrate formation.

White Oil: Sometimes kerosene, sometimes treated kerosene used for pharmaceutical purposes, and in the food industry.

WHSV: Weight hour space velocity; weight of feed per hour per weight of catalyst.

Wick Char: A test used as an indication of the burning quality of a kerosene or illuminating oil. It is defined as the weight of deposits remaining on the wick after a specified amount of sample is burned.

What-If Analysis (WIA): A safety review method, by which "What If" investigative questions (i.e., brainstorming and/or checklist approach) are asked by an experienced and knowledgeable team of the system or component under review where there are concerns about possible undesired events. Recommendations

for the mitigation of identified hazards are provided. (See Process Safety Management/Hazid/Hazop)

wppm: Parts per million by weight.

Xylene, $C_6H_4(CH_3)_2$: 1. Colorless liquid of the aromatic group of hydrocarbons made from the catalytic reforming of certain naphthenic petroleum fractions. Used as high-octane motor and aviation gasoline blending agents, solvents chemical intermediates. 2. One of the aromatic compounds. Xylene has a benzene ring and two methyl radicals attached and three isomers namely: ortho, para and metaxylene. Used as a gasoline blending compound or chemical feedstock for making phthalic acids and resins.

Yield: Either the percent of a desired product or all the products resulting from a process involving chemical changes to the feed.

Zeolites: 1. Compounds used extensively as catalysts, made of silica or aluminum as well as sodium or calcium and other compounds. Zeolites come in a variety of forms – porous and sand like or celatinous and provide the platform for numerous catalysts. The solid zeolites have extensive pores that give very large surface areas. The precise control during fabrication of the pores sizes enables selected access to different size molecules during reactions. 2. A class of minerals that are hydrated aluminosilicates. An aluminosilicate is where some of the Si atoms in silica (SiO_4) are replaced with aluminum giving an excess negative charge. Hydrated means that water is strongly associated with these materials by hydrogen bonding. A positively charged counter ion is required to balance the negative charge on the zeolite. Zeolites are extremely porous materials, with a regular internal structure of cavities of defined size and shape.