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**Sabatier, Paul FRS** (1854–1941) A French chemist noted for his work on catalysts used in organic chemical reactions. He worked on the industrial applications of hydrogenation and developed the use of nickel to facilitate the addition of hydrogen to carbon compounds. Working at the University of Toulouse, he rose to become dean of the faculty of science in 1905. He was awarded the Nobel Prize for Chemistry in 1912 together with French chemist François Auguste Victor Grignard (1871–1935). The Paul Sabatier University in Toulouse is named in his honour and the *Sabatier process is named after him.

**Sabatier process** A catalytic process used for the production of methane involving the reaction of carbon dioxide and hydrogen:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

The process uses high temperature and pressure in the presence of a nickel catalyst. More efficient catalysts have subsequently been developed such as ruthenium on aluminium oxide. The process was originally developed by French chemist Paul Sabatier (1854–1941).

**Sabatier–Senderens process** A process for the hydrogenation of an organic compound such as an unsaturated fat and used to produce margarine. It uses hydrogen gas and a nickel catalyst at around 150°C. The process is named after 1912 Nobel Prize winner Paul *Sabatier (1854–1941) and Jean-Baptiste Senderens (1856–1937).

**Sachse process** A process used to convert methane to form acetylene (ethyne):

$$CH_4 \rightarrow C_2H_2 + 3H_2$$

The high temperature reaction takes place at around 1,500°C. The high temperature is obtained by burning part of the methane in air.

**sacrificial protection** *See* CATHODIC PROTECTION.

**safety** *See* PROCESS SAFETY.

**safety audit** A critical examination of all aspects of safety for a process or a defined part of an installation. The audit covers process design, management, safety culture, training, operating procedures, emergency plans, personnel protection, and accident reporting, and is carried out by qualified personnel. The report presents necessary actions for improvement to safety practices.

**safety factor** The ratio of the breaking stress of a material to the calculated maximum stress. Pressure vessels are designed with a safety factor to provide an allowance that the maximum stress is never exceeded.

**safety integrity level (SIL)** A safety management technique used to measure the performance of a process or an activity in terms of risk reduction which is numerically rated with the values of 1 to 4. SIL 1 presents a high probability of failure while SIL 4 presents a low probability of failure. The SIL is determined using methodologies such as *layers of protection analysis (LOPA) and risk matrices. SILs are useful for allowing risk of failure to be appreciated without having to understand fully all of the technical details.

**safety management system (SMS)** A systematic and comprehensive approach to identifying hazards and controlling risks while maintaining assurance that risk controls are effective. It provides goal-setting, planning, and measuring performance. An effective SMS defines how a business manages risk, identifies workplace risk and implements suitable controls, effective communications, and a process to identify and correct nonconformities. It acts as a framework to allow an organization to meet its legal obligations but is itself not a legal requirement.

**safety relief valve (SRV)** A type of automatic valve that opens to relieve pressure from both gas and liquid applications. It is used on process equipment and pipelines.

**safety report** A document that presents the justification for the safety of an installation. A **safety evaluation** is a report used in the assessment of process equipment and pipelines.

**safety valve** A generic name for a device used for the automatic release of a substance from a vessel or system when the pressure or temperature exceeds preset limits. Safety valves were first used on steam boilers during the Industrial Revolution in which boilers were prone to accidental explosion. Examples of safety valves include **pressure relief valves (PRV)**, **pressure safety valves (PSV)**, and **relief valves (RV)**. PSVs differ from PRVs by having a manual lever to open in the event of an emergency. Vacuum safety valves are used to prevent a vessel from collapsing when emptying or when a vacuum may accidentally form due to a trapped vapour that then condenses.

**salt** A compound form when one or more hydrogen atoms of an acid are replaced by a metal atom or by an electropositive ion such as ammonium. Most salts are crystalline ionic compounds. Soluble salts dissolve into ions in solution.

**sample** A small part or portion of a larger quantity of a product used to evaluate product quality. The sample is intended to be a representative part of the larger quantity. Statistical methods can be used to determine statistical variability of the sample from which judgements can be made such as for quality control purposes. Data of *process variables such as temperature, pressure, flow, and level are used in the computer control of processes. A **sample interval** is the time between the gathering of information or data. In some cases, the time interval is very small such that the flow of information is virtually instantaneous whereas in others, the time interval is much greater.

**sand filtration** A process used in *water treatment involving the removal of suspended particles of organic matter by *filtration through beds of sand to produce water of the required *quality. Sand filtration is used prior to chlorination to produce a safe supply of drinking water. Sand is the general name for particles of rock composed largely of quartz that have diameters in the range of 0.06 to 2.00 mm.

**saponification** A process used for the manufacture of soap. The process involves the hydrolysis of triglycerides using a strong base such as caustic soda to form a sodium salt of a carboxylate and glycerol. The triglycerides are esters of fatty acids obtained from vegetable

and animal fats. The process of producing common soap involves blowing steam into large pans containing a fat such as glyceryl tristearate and a solution of sodium hydroxide to form sodium stearate and glycerol:

$$C_3H_5(O\cdot OC\cdot C_{17}H_{35})_3 + 3NaOH = C_3H_5(OH)_3 + 3C_{17}H_{35}\cdot CO\cdot ONa$$

The soap is separated as a curd by adding strong brine. The lower aqueous layer is run off and processed to give glycerol. The soap is given further washes, left to reach the right condition for mixing with perfume and colouring before being run into frames for cooling. If the fat is hydrolyzed using potassium hydroxide, the resulting solution sets on cooling and yields a jelly known as soft soap containing water and glycerol.

**SARA** An abbreviation for **s**aturates, **a**romatics, **r**esins, and **a**sphaltenes, which are the four solubility classes of hydrocarbon fractions of *crude oil. The saturates are generally iso- and cyclo-paraffins whereas aromatics, resins, and asphaltenes form a continuum of molecules with increasing molecular weight, aromaticity, and heteroatom contents. Asphaltenes can also contain metals such as nickel and vanadium. A **SARA analysis** is a method used for the characterization of heavy oils based on fractionation.

**saturated 1**. A molecule that has only single bonds (i.e. no double or triple bonds) such as *octane ($C_8H_{18}$) which is a straight-chain hydrocarbon saturated with hydrogen. **2.** A solution containing the maximum possible amount of a solute at a given temperature. The solution is in equilibrium with the undissolved solute. A solution that contains more than the equilibrium amount is known as *supersaturation. A solution that contain less than the equilibrium amount is *unsaturated.

**saturated solution** A solution that is in equilibrium with an undissolved solute at a particular temperature. The solubility of a substance is defined with reference to a saturated solution of it at a stated temperature in a standard amount of solvent. For example, the solubility of a substance in water at a given temperature is the mass of the substance in grams that will saturate 100 grams of water at that temperature.

**saturated vapour pressure** The pressure exerted by a vapour that exists in equilibrium with its liquid.

**saturation temperature** The boiling point of a liquid. The liquid is deemed to be saturated with the energy required to bring about the phase change. The boiling point is the temperature at which the vapour pressure of the liquid is equal to the surrounding pressure of the liquid. The **saturation pressure** at the saturation temperature corresponds to the pressure at which the liquid boils.



**Sauter mean drop diameter** A method used to characterize the average drop size in a population of droplets in immiscible liquid–liquid dispersions. It is related to the volume fraction of the dispersed phase, $\Phi$ and the interfacial area, $a$. It is also known as the volume-to-area average drop diameter:

$$d_{SM} = \frac{6\Phi}{a} = \frac{\sum_{i=1}^{n} n_i d_i^3}{\sum_{i=1}^{n} n_i d_i^2}$$

where $n$ is the number of droplets and $d$ is the diameter.

**Saybolt viscometer** A type of instrument used to determine the viscosity of petroleum oils. It is based on the time in seconds for a given volume of oil to pass through an aperture at a controlled temperature and collect in a container with a volume of 60 millilitres. The Saybolt universal second is the unit used as a measure of the *kinematic viscosity.

**SCADA** An abbreviation for **s**upervisory **c**ontrol **a**nd **d**ata **a**cquisition, it is a computer software package used to control and monitor process plant or equipment. It displays process information, logs and stores data, and shows all the associated process control alarms. It also allows operator control of a process from a PC.

**scalar quantity** A mathematical representation of a quantity with magnitude and no direction. Examples include temperature, pressure, mass, speed, and concentration.

**scaled distance** A technique used to calculate the damage caused by an explosion at various distances from the epicentre. Also used in blasting operations, it is the actual distance from the blast to the point of concern divided by the square root of the total charge weight of explosive.

**scale-up** The translation of a process design from the laboratory or experimental scale to the larger pilot plant scale, or commercial or industrial scale. Scale-up is an important part of commercializing a process in which it is accepted that theoretical design cannot be used alone to achieve this. *Dimensionless numbers or groups are a useful way of scaling up a process since certain heat, mass, and momentum transfer phenomena are independent of scale. For example, in mixing processes, it may be necessary to ensure that the power-to-volume ratio remains the same between lab-scale and full-scale to ensure homogeneous mixing characteristics. The scaled-up equipment is also assumed to have geometric similarity. The testing of a small-scale process is therefore quick, cost-effective, and reliable such that the experimental information gained can be reliably used on a larger scale.

**scf** An abbreviation for **s**tandard **c**ubic **f**eet, it is an Imperial unit of volume used in the measurement of gas, and pronounced as 'scuf'.

**scheduled maintenance** *See* MAINTENANCE.

**schedule number** A classification for pipes in terms of their wall thickness. There are ten schedule numbers in common usage: 10, 20, 30, 40, 60, 80, 100, 120, 140, and 160.



**schematic flow diagram** *See* BLOCK FLOW DIAGRAM.

**Schmidt number** A dimensionless number, Sc, characterizing mass transfer by convection that relates viscosity and diffusion of a gas through itself. It is the ratio of the kinematic viscosity to the molecular diffusivity:

$$Sc = \frac{\mu}{\rho D}$$

where $\mu$ is viscosity, $\rho$ is density, and $D$ is diffusivity. It is named after German scientist E. W. H. Schmidt (1892–1975).

**scraped surface heat exchanger** A type of double pipe heat exchanger used for heating or cooling highly viscous, fouling, and crystallizing materials such as margarine and ice cream. It consists of two concentric pipes with agitated scrapers in the inner product

tube with the heating or cooling medium passing through the outer surrounding pipe. The scrapers consist of knives positioned in such a way that a screw effect is achieved. This ensures that the product near the wall is fully mixed with the bulk material. The product to be heated or cooled is pumped using a *positive displacement pump. Mounted either vertically or horizontally, it is relatively expensive and is only fully justified for highly viscous materials with viscosities in excess of 10 Pa s. The complex flow patterns, including *backmixing which can reduce the heat transfer rate, mean that the design is based on empirical or experimental *overall heat transfer coefficients.

**screening** A physical separation process used to separate solid particles of differing sizes. Also known as **sieving**, the separation uses a mesh with a fixed aperture allows only particle sizes below the aperture size to pass through. It is used for separating ores, grains, and many other solid–solid mixtures requiring grading or separating.

**screw pump** A type of *positive displacement pump used to transport fluids and solid materials. It consists of a helical screw that revolves within a cylinder transporting the materials along the axis of the screw. The Archimedes' screw pump is the simplest form of screw pump. More complex designs consist of multi-axis screws and the use of similarly shaped pumping casings (**stator**) trapping portions of the materials in cavities and carried along the pump. These are used for high-flow applications and noted for their suitability for handling viscous fluids, slurries, and shear-sensitive fluids. The *Mono pump is a well-known type of screw pump. Screw pumps are widely used in the *water treatment, food, paper, chemical, petrochemical, and mineral processing industries.

**scrubber** A tall cylindrical column used for gas adsorption. The separation process involves the removal of one component from a mixed gas stream by means of a selective solvent. The solvent with the adsorbed gas is sent to another column known as a *stripper, where the gas is separated again and the solvent recirculated to the scrubber for reuse. *See* ABSORPTION TOWER.

**scrubbing** The process of removing a component such as an impurity from a mixed gas stream or extract phase, by means of contacting it with a selective liquid solvent. The absorption process takes place within an *absorption tower or *scrubber. Scrubbing is used to remove sulphur dioxide from the flue gases from power stations, hydrocarbons from air, NOx from combustion gases, and hydrogen sulphide from natural gas. It is also known as **gas scrubbing**. *Compare* STRIPPING.

**SD&P** An abbreviation for **s**imultaneous **d**rilling **& p**roduction, it is a technique used to drill a new oil or gas well on a platform while continuing to produce oil or gas.

**Seaborg, Glenn Theodore** (1912–99) An American chemist noted as one of the discoverers of plutonium (plutonium-238 and plutonium-239). Gaining his doctorate in 1937 from the University of California, he was appointed professor of chemistry in 1945. He was responsible for nuclear chemical research at the Lawrence Radiation Laboratory and headed the Manhattan Project group from 1942 to 1946 that devised the chemical extraction processes used in the production of plutonium. He codiscovered nine other transuranium elements, including the element seaborgium, atomic number 106, which is named after him. He was awarded the Nobel Prize in Chemistry in 1951.

**second 1.** (Symbol s) A base SI unit of time taken as 9 192 631 770 cycles of the radiation from the transition between two hyperfine transition levels of the ground state of

caesium-133. It is equal to $1/60^{th}$ of a minute and $1/3600^{th}$ of an hour. **2.** (Symbol ″) An angle equal to $1/60^{th}$ of a minute or $1/3600^{th}$ of a degree.

**second-generation biofuel** A type of *biofuel that is produced from cellulose, hemicellulose, or lignin from plants to form cellulosic ethanol and Fischer–Tropsch fuels. They can be blended with petroleum-based fuels and combusted in modified internal combustion engines. Second-generation biofuels have been developed due to the limitations of first-generation biofuels, which have an impact on food production and biodiversity. Examples of the raw materials used include biomass from the non-food parts of crops, such as stems, leaves, and husks, as well as certain types of grass, fibre, and industry waste such as wood chips, skins, and pulp from fruit pressing.

**second law of thermodynamics** A law that states that it is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a cooler body to a hotter body. This law sets the limit on the amount of heat energy that can be converted to useful work energy.

**second-order control system** A control system in which the dynamics are determined by second-order differential equations. They mainly arise in process plants as the result of the combination of two first-order systems in series, the consequence of the addition of complex control systems, or the system may itself be intrinsically second order . This is generally uncommon where only the *continuity equations are needed for process models such as mass, component, and energy balances which are inherently first order. If continuity equations for momentum are needed, the resulting balances will be inherently second order. Such balances are used for the modelling of mechanical systems such as control valves or the behaviour of the fluid dynamics of a process.

**second-order differential equation** A differential equation involving only first and second derivatives.

**second-order reaction** *See* ORDER OF REACTION.

**sedimentation** A separation process in which particles in suspension settle under the influence of gravity into a clear liquid and a slurry that has a higher solids content. It is commonly used in *water treatment. A thickener is a type of continuously operated sedimentation device in which concentrated slurry is produced and the clear liquid overflows. A clarifier is another type of sedimentation device that is used to produce a more concentrated solid–liquid mixture. *See* THICKENING. The use of flocculating agents can assist with the settling process by causing the particles to form flocs or aggregates that have a larger size and enabling them to settle more quickly. For mixtures in which the particles do not influence one another, the rate of settling can be determined using *Stokes's law, which is dependent on the size of particle and relative density to the particular to the fluid. Where the difference in density is small, centrifugal force will hasten the separation process.

**seed crystals** Used in the process of crystallization, seed crystals are small crystals of solute used to accelerate the precipitation of crystals from supersaturated solutions by providing nuclei upon which crystal growth can continue. Nucleation is the phase transition from solute in a solution to a crystal lattice. By using small crystals, the seeding process therefore reduces the amount of time required for nucleation to occur.

**segregation coefficient** The ratio of the concentration of an impurity in a liquid to the concentration of an impurity in a solid. It is used as a measure of the ratio of the impurities in a liquid–solid interface in a *zone refining process used for producing high pure metals.

**selective medium** A *growth medium used to grow or culture selected microorganisms such as genetically modified or recombinant yeast or bacteria. The medium either contains all the necessary nutrients to sustain growth but is missing at least one component for which the necessary genes are present in the modified microorganisms or it contains genes that enable the microorganisms to grow such as provide the resistance to an antibiotic, such as ampicillin, which is supplied to the medium.

**selectivity 1.** The amount of a reactant converted to a product expressed as a ratio or percentage of the reactant converted to all products in a chemical reaction. **2.** The effectiveness of a solvent for separating a solution by comparing the ratio of one component to another in the solvent at equilibrium. The value must exceed unity for extraction to be possible. Selectivity is analogous to the *relative volatility used in distillation. **3.** The equilibrium constant of an ion exchange reaction. **4.** The ability of a *semi-permeable membrane to separate a component from a mixture of components.

**Selexol process** A process used to remove *acid gases from hydrocarbon gas streams by absorption in polyethylene glycol dimethyl ether (DMPEG). The process is used to remove or reduce the level of hydrogen sulphide, carbon dioxide and carbonyl sulphide, and other organic sulphur compounds such as mercaptans from gases such as natural gas. It involves gas absorption under pressure with the solvent in which the gas is contacted counter currently in an absorption column with the solvent. The solvent is regenerated by flashing or stripping.

**self-extinguishing** A substance that is incapable of sustained combustion in air after removal of external heat or flame.

**self-ignition** An ignition resulting from self- or spontaneous heating. *Compare* SPONTANEOUS IGNITION.

**self-regulation** The property of a body, process, or machine without closed-loop control to reach a new steady state after a sustained *disturbance.

**semi-batch process** A process that is operated on a batch basis, such as reactions taking place in a stirred tank, but where the materials can be partially added over time. This has the advantage of allowing good control of temperature and composition, while permitting efficient mixing of the materials. *See* CONTINUOUS PROCESS.

**semi-continuous process** A process whose overall operation is continuous but which features unit operations that are operated on a batch basis. For example, the conversion of sugar cane to alcohol as a biofuel is a continuous process in which sugar cane as the raw material is processed continuously to extract the fermentable sugars. A number of batch fermenters are used in varying states of operation to convert the sugar to alcohol whose collective output is then fed to a continuously operating distillation unit.

**semi-infinite** The geometry of an object in which one or two dimensions are taken to be infinite while one is finite. It is a useful way of performing calculations such as the flow of heat in a particular direction without the need to consider the influence of flow in the other directions. For example, a semi-infinite slab has a finite thickness but infinite breadth and length, while a semi-infinite cylinder has an infinite length and finite radius.

**semi-permeable membrane** A thin layer of material that permits certain molecules to pass through while being impervious to others. The process of *osmosis is the result of *diffusion across a semi-permeable membrane. The permeability of the membrane can permit small molecules such as oxygen, carbon dioxide, and glucose to pass, but not allow larger molecules such as proteins and sucrose through. The *selectivity is achieved by pore size within the membrane or by the presence of charged ions within the membrane.

**sensible heat** The thermal energy or heat which when added to a substance increases its temperature without a change in state. *Compare* LATENT HEAT.

**sensor** An instrument or device used to detect the condition of a *process variable. Commonly used sensors include temperature, pressure, and level transmitters, and toxic gas detectors.

**SEPA** An abbreviation for **S**cottish **E**nvironment **P**rotection **A**gency, it is a non-governmental public body responsible for the protection of the environment in Scotland. Its primary role is to protect and improve the environment by regulating activities that can cause harmful pollution.

SEE WEB LINKS

- Official website of Scottish Environment Protection Agency.

**separation 1.** The division and parting of materials into their constituent parts. Separation is used for purification by removing contaminants or for enrichment. In some cases, separation may involve removing single components or groups of components from a mixture. Examples of physical and chemical **separation processes** include chromatography, distillation, evaporation, drying, electrolysis, desorption, and gravity. The petrochemical refining of crude oil is an industrial process used to separate the complex mixture of hydrocarbons into valuable components largely through distillation. The choice of separation is based on the chemical and physical properties of the materials such as chemical affinity with other components, size, shape, and density. **2.** The phenomenon of fluid streamlines changing direction due to changes in boundary shape as a result of fluid inertia or velocity distribution near the boundary surface.

**separator** A device used to separate immiscible liquids based on differences in density or for separating solids from liquids or gases. For example, in the offshore industry, oil, water, and sand, each with a different density, are separated as layers in gravitational separators. A weir is typically used to allow the top layer to overflow and separate from the layer or layers below. Centrifuge separators increase the force of the particles, increasing the rate of separation, and are used to separate cream from milk, oil, and water emulsions that are difficult to separate by gravity, and very small particles from liquids where gravitational separation would otherwise be too slow.



**sequestration 1.** The process of forming a complex of an ion in solution to prevent the chemical effect by removing it from solution. Some polymers can be used to sequester metal ions such as copper in water. **2.** The process of removing greenhouse gases and in particular carbon dioxide from the atmosphere. Trees and plants use photosynthesis to sequester the gases from the atmosphere to help reduce the greenhouse effect and control global warming. *See* CARBON SEQUESTRATION.

**set-on tee** A tee-piece in a pipe that is formed by welding one pipe over a hole made in another. It is formed by a joining weld at the junction of the tee-piece.

**set point** The desired value of a *process variable in a controlled system that is to be attained.

**settling tank** A vessel with a large capacity used to separate particles from a liquid under the influence of gravity. The design is based on a steady flow entering and leaving in which the liquid velocity is uniform at all points in the tank, allowing the particles to descend freely to the bottom. The capacity is designed such that any particle touching the base of the tank will be retained by the tank, and conversely, any other particle still in suspension will be swept out with the effluent.

**settling time** The time required for the output of a controlled process to a stimulus to enter and remain within a specified narrow band around the final steady-state value.

**settling zone** The largest section within a *sedimentation or *settling tank used to separate solid particles from a liquid. It is designed to provide a calm area in which the suspended particles are able to settle. Below is the *sludge zone in which the particles accumulate.

**Seveso incident** A major chemical disaster that occurred at a small chemical plant on 10 July 1976 near Milan, Italy. It involved a chemical runaway reaction in which the chemical 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) was released into the environment as a *side reaction caused by a kettle heater being left on overnight. The release caused the death of many animals and the evacuation of local inhabitants. Following many studies, it has led to the standardization of industrial safety regulations aimed at improving the safety of sites containing large quantities of potentially dangerous substances. The Seveso II Directive is a European Union law formed as a result of the disaster and subsequent investigation. This is known as the *COMAH regulations in the UK.

**SFE** *See* SUPERCRITICAL FLUID EXTRACTION.

**shake flask** A small glass vessel which is usually conical. It is used in preparing an inoculum of living microorganisms for a biochemical process such as fermentation. The microorganisms are first prepared by aseptically transferring colonies of the microorganism from agar plates upon which they have been stored at a chilled temperature into shake flasks containing an aqueous medium together with the necessary nutrients. The flasks are *monoseptic in that only the living microorganism is present and sealed with sterile cotton wool. They are then slowly agitated in an orbital motion and maintained at a controlled temperature desirable for growth, such as 30°C. After a period of several hours to several days, the living cells have grown to a population sufficient to be transferred or inoculated into a bioreactor.

**shale gas** Natural gas trapped within sedimentary rock.

**shape factor** A description of the geometric shape of a particle that may not necessarily be spherical. It is defined as the ratio of one characteristic length to another and is used in determining the behaviour of particles in a fluid, such as particle settling.

**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** (Symbol $\dot{\gamma}$) 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:

$$\dot{\gamma} = \frac{dv}{dz}$$

It is also known as the **velocity gradient**. The SI unit is $s^{-1}$.

**shear stress** (Symbol τ) The *shear force applied to a fluid that is applied over a surface. Where the shear stress is proportional to the *shear rate, the fluid exhibits *Newtonian behaviour and the *viscosity is constant. The SI units are $N\,m^{-2}$.

**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-pass 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 vapour and leaves as condensate from the bottom. A *kettle reboiler 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.

**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. *Compare* TUBE SIDE.

**Sherwood, Thomas Kilgore** (1903–76) An American chemical engineer and founding member of the National Academy of Engineering. After gaining his PhD at MIT, he was briefly assistant professor at Worcester Polytechnic Institute before returning to MIT in 1930 as assistant professor, eventually rising to professor and dean of engineering. On retirement from MIT in 1969 he became professor of chemical engineering at the University of California, Berkeley. He published the first text on mass transfer in 1937 entitled *Absorption and Extraction*, which was republished in 1974 as *Mass Transfer*. The Sherwood number is named after him.

**Sherwood number** A dimensionless number, Sh, 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. It is named after Thomas *Sherwood (1903–76).

**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 a wave that is travelling above the speed of sound.

**shutdown 1.** The status of a process that is not currently in operation due to scheduled or unscheduled maintenance, cleaning, or failure. **2.** A systematic sequence of actions that is needed to stop a process safely. *See* EMERGENCY SHUTDOWN.

**siccative** A material that is capable of absorbing moisture. It is used as a drying agent for certain pharmaceuticals and foods.

**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. For example, in the high-temperature cracking reaction of propane to produce propene (propylene) $C_3H_8 \rightarrow C_3H_6 + H_2$, some of the hydrogen can react with the propane to produce methane and ethane as a side reaction $C_3H_8 \rightarrow C_3H_6 + H_2$. The conditions of the reaction must therefore be controlled to reduce this unwanted reaction.

**side stream** The continuous removal of a liquid or a vapour from a process such as a distillation column that is not the main process flow. For example, drawing off vapour or liquid part-way up a distillation column can have economic advantages in terms of the physical size of column and the amount of boil-up energy required.

**sieve plate column** A type of *distillation column which uses a stack of perforated plates to aid the distribution and intimate contact between vapour and liquid. The plates allow vapour to pass up and bubble through the liquid on the plates. The rate of flow of vapour is sufficient to prevent the liquid from draining through the sieve plates. Instead, the liquid pours over a weir and down a downcomer to the sieve plate below.

**Sievert, Rolf Maximilian** (1896–1966) A Swedish physicist who specialized in the study of biological effects of ionizing radiation. He was head of physics at Sweden's Radiumhemmet before heading the department of radiation physics at the Karolinska Institute. He studied and measured the effects of radiation dosage in the diagnosis and treatment of cancer. He also invented various instruments for measuring radiation doses. The derived SI unit for ionizing radiation dose equivalent, the *sievert, is named after him.

**sievert** (Symbol Sv) The SI derived unit for the dose equivalent of ionizing radiation. Unlike the *gray, which is the SI derived unit for the absorbed radiation, the sievert is a way of quantitatively measuring the biological effects of ionizing radiation. It measures the equivalent dose of radiation as having the same damaging effect as an equal dose of gamma rays. It is named after the Swedish physicist Rolf Maximilian *Sievert (1896–1966).

**sight glass** A small window located on the side of a process vessel such as a reactor or column to allow a visual observation of the contents within.



**signal** Transmitted information about a *process variable in a controlled system in the form of a voltage, current, pneumatic, mechanical, or digital signal. The error signal in a closed-loop system is the signal formed when subtracting a particular return signal from its corresponding input signal. The input signal is the signal applied to the system, whereas the output signal is the signal delivered by the system.

**significant figures** The number of digits used to express the accuracy of a figure. For example, 1.032 is taken to be accurate to four significant figures whereas 12.3 is taken to be accurate to only three significant figures as is 0.003 24.

**SIL** *See* SAFETY INTEGRITY LEVEL.

**silo** A tall, cylindrical structure used for storing particulate materials such as grain.

**Simpson's rule** A numerical integration method used to obtain the approximate value to a definite integral. It is applied to odd numbers of data and is given by:

$$A = \frac{S}{3}(F + L + 4E + 2O)$$

where $S$ is the width of the intervals between data, $F$ and $L$ are the first and last ordinate, $E$ is the sum of the even-numbered ordinates, and $O$ is the sum of the remaining odd-numbered ordinates.

**single phase** The presence of a fluid in a system such as a vessel or pipeline as being either entirely a gas or entirely a liquid.

**sintering** A high-temperature process in which powdered materials below their melting point are compacted together to create a solid form. The process is based on atomic diffusion in which atoms in the powder particles diffuse across the boundaries of the particles, fusing the particles together, and creating one solid piece. Since the materials are not required to reach their melting points, the process is useful for materials with very high melting points such as tungsten (m.p. 3,422°C). Virtually all metals can be sintered, as can many non-metallic substances such as glass, ceramics, and organic polymers. Sintered bronze is used in bearings since its porosity allows lubricants to be retained within it. Sintered stainless steel and porous plastics are used as filter materials employed in the pharmaceutical and food industries. Sintered powders of silver and gold are used to make jewellery.

**siphon** *See* SYPHON.

**SI units** The system of base units of the international metric system. The numbers used express the ratio of a measured quantity to some fixed standard for which the unit is the name or symbol for the standard. The *Système International d'Unités is the name that was formally given in 1960 following the tenth meeting of the General Conference of Weights and Measures. There are three classes of units: base units, derived units, and supplementary units. The seven base units are metre (m), kilogram (kg), second (s), ampere (A), kelvin (K), candela (Cd), and mole (mol). Derived units are formed by combining base units such as newton (N), joule (j), pascal (Pa), and watt (W). Two supplementary units are the radian (rad) and steradian (sr), which are units for plane and solid angles, respectively.



Prefixes are used for the basic SI unit with the exception of weight, where the prefix is used with the unit gram (g), not the basic SI unit kilogram (kg). Prefixes are also not used for units of angular measurement (degrees, radians), time (seconds), or temperature (°C or K). The prefixes are used in a way that the numerical value of a unit lies between 0.1 and 1,000. For example, 56 kN rather than $5.6 \times 10^4$ N, 11.2 kPa rather than 11,200 Pa, and 6.2 mm rather than 0.0062 m.

SEE WEB LINKS

- Official website of National Institute of Standards and Technology (NIST).

**skid** A solid platform or base upon which process equipment is attached.

**slag** A material that is produced during the smelting or refining of metals by reaction of a flux such as calcium oxide with impurities in the ore. The slag, which may contain calcium silicate, phosphate, and sulphide, floats on the surface of the liquid metal and can be easily separated. It can be used as a fertilizer if the phosphorus content is sufficiently high.

**slip-plate** *See* SPADE.

**slip ratio** The ratio of the superficial velocity of a gas or vapour to liquid in a two-phase flow in a horizontal pipe. The simplest approach to estimating the gas void fraction of a flowing gas–liquid mixture is to assume that the flow is homogeneous. That is, both phases flow at the same velocity.

**slop oil** Contaminated condensate, also known as bad oil, produced on offshore oil and gas platforms. It is held in a **slop oil tank** and returned back to the production header for recirculation.

**sludge** The solid or semi-solid waste layer that is deposited below a *supernatant liquid. The sludge from industrial processes may contain harmful and toxic materials and requires careful disposal. The sludge from sewage waste treatment processes that has been both aerobically and anaerobically digested, is free from harmful pathogens, offensive smells and odours, and may be safely used as an organic fertilizer.

**sludge digestion** A process used to stabilize concentrated wastewater sludge before disposal, usually by anaerobic biological degradation. The digestion process involves converting solids to non-cellular products in which complex fats, proteins, and polysaccharides are first hydrolyzed by facultative and anaerobic bacteria, followed by the conversion to methane and carbon dioxide by anaerobic bacteria.

**sludge zone** A region at the bottom of a *sedimentation tank used to separate solid particles from a supernatant liquid. The particles are allowed to settle in the *settling zone allowing them to accumulate as a *sludge at the bottom. It therefore provides a storage area for the sludge before its removal for treatment or disposal. The zone is designed to have low velocities such that the sludge accumulates and remains undisturbed, which could otherwise lead to washout. The sludge is removed by scraper or by vacuum devices that move along the bottom.

**slug 1.** A moving bullet-shaped gas pocket formed in multiphase fluid flow. In a vertical pipe or tube the slug is axially symmetrical and occupies most of the cross-sectional area of a pipe. In horizontal flow, the shape of the pocket has a curved nose and the shape is governed by buoyancy, ratio of gas to liquid, and their relative velocities. **2.** A unit of mass in the *f.p.s. engineering system of units that will accelerate at one foot per second per second to give a one pound (lb) force.

**slug catcher** A vessel located at the end of a pipeline used to entrap and separate slugs of gas entrained with flowing liquid. It is used at the end of risers from oil and gas reservoirs in which slugs of gas rise with the crude oil as well as water and sand. The slugs of gas or surges are separated in the slug catcher, which has a sufficient capacity to cope with the largest slugs that can be expected. The separated gas and liquid are then able to be processed at a controlled rate.

**slug flow** A type of intermittent multiphase fluid flow regime that is characterized by pockets of gas in the form of high-velocity gas bubbles. In vertical flow, the gas is in the form of axially symmetrical bullets known as slugs that occupy most of the cross-sectional area of the pipe. In horizontal flow, the gas is also in the form of pockets of gas, but they are not symmetrical although they do have a curved nose in the direction of travel. In both cases, the resulting flow alternates between high-liquid and high-gas composition. *Slug catchers at the end of pipelines are used to disengage the gas. Semi-slug flow occurs where the surges do not completely fill the pipe and is often considered to be a form of *wavy flow.

**slurry 1.** A general name for a viscous liquid consisting of a concentrated suspension of solid particles. **2.** A viscous liquid suspension of manure used for fertilizing fields.

**smart pig** *See* PIG.

**smelting** A high-temperature metallurgical process in which metal is separated by fusion from impurities in minerals and ores. The metals may be chemically or physically combined or mixed in the minerals or ores. The smelting process takes place in a furnace in which the ore is mixed with a reducing agent such as carbon and a fluxing agent such as limestone. The molten metal, being of a higher density than the *slag, falls to the bottom of the furnace where it is removed.

**Smith–Brinkley shortcut method** A quick procedure used to estimate the components in a multicomponent mixture leaving the top and bottom of a distillation column operating with continuous feed. The procedure is applicable to any stage-wise separation process. For a distillation column with a single feed and a total condenser, the fractional recovery of any component in the bottom product is calculated from details that include the reflux ratio, internal flows of liquid and vapour above and below the feed point (i.e., the rectifying and stripping sections), and the relative volatilities of the components. In the calculation, the reboiler counts as stage one.

**Smith equation** A relationship representing desorption isotherms for hygroscopic products of high humidities in the order of up to 95 per cent. The Smith and *BET equations complement one another in representing desorption isotherm data from low to high humidities.

**smoke** The dispersion in air of fine particles of carbon ranging from 0.01 to 15 μm, and other solids and liquids as the result of incomplete combustion.

**smoldering** A form of combustion without flame and usually incandescent with moderate smoke.

**smother** To extinguish a fire by blocking the oxygen supply or limiting it to a point below that required for combustion.



**SNG** An abbreviation for **s**ynthetic **n**atural **g**as or **s**ubstitute **n**atural **g**as, which is a gas that is produced from coal, *petroleum coke, solid waste, or biomass. Carbon-containing coal is gasified to produce *syngas that is then converted to methane. In the *steam-oxygen gasification process, coal is gasified with steam and oxygen to produce carbon monoxide, hydrogen, carbon dioxide, methane, and higher hydrocarbons such as ethane and propane. The composition of SNG is dependent on the temperature and pressures used in the gasifier conditions.

**soap** A substance used to remove dirt, oil, and grease from surfaces. It is a salt of a long-chain fatty acid and made by boiling fats with sodium hydroxide. Manufactured in a batch process, fat or oil is heated with a slight excess of alkali in an open kettle. Salt is then added to precipitate the soap into curds, recovered, and purified. In the more common continuous process, the fat or oil is hydrolyzed by water at high temperature and pressure in the presence of a catalyst. The fatty acids and glycerol are removed and separated by distillation and the acids neutralized with an appropriate amount of alkali to make soap. Synthetic detergents now exceed the use of ordinary soaps, since soaps give a slight alkaline solution in water due to the partial hydrolysis of sodium salts, which can be harmful to fabrics. *See* SAPONIFICATION.

**Soave–Redlich–Kwong (SRK) equation of state** An equation of state widely used to predict the vapour–liquid equilibria of substances. It is a development of the *Redlich–Kwong equation of state that correlated the vapour pressure of normal fluids:

$$p = \frac{RT}{V-b} - \frac{a\alpha(T)}{V(V+b)}$$

The *a* and *b* constants are obtained from critical point data. It also involves a function which was developed to fit vapour pressure data using reduced temperature, *Tr*:

$$\alpha = \left[1+(0.480+1.574\omega-0.176\omega^2)(1-T_r^{0.5})\right]^2$$

where $\omega$ is an eccentricity coefficient.

**soft matter** A general name given to non-crystalline material and includes colloidal suspensions, surfactants, polymers, pastes, gels, and foams. They exhibit a combination of fluid and solid properties.

**software package** A professionally written computer program that is designed to perform a particular task. It is used to undertake complex and often repetitive computations. Software packages are used for a wide range of applications such as project management and flowsheeting, as well as for the study of complex flow of fluids and heat transfer termed as *Computational Fluid Dynamics or CFD, and for the study of stresses in process equipment such as pressure vessels, such as Finite Element Analysis software.

**sol** A colloidal solution in which small solid particles are dispersed in a liquid continuous phase.

**solder** An alloy used to join metal surfaces. Soft solders are made from tin and lead in varying amounts to adjust the melting point within the range 200–300°C. Hard solder additionally contains silver. Brazing solders are made from copper and zinc and melt at around 800°C.

**solenoid valve** A type of electromechanically operated valve typically used to control the flow of a fluid through a pipe. The position of the valve is controlled by an electric current through a solenoid. Solenoid valves are fast-acting and typically used to control the dosing of fluids, the release of materials, and for shut off.



**solid** A substance in a physical state that is resistant to physical change in size and shape. More correctly, it is a state of matter where the strength of the intermolecular and atomic forces is such that there is no translational motion within the substance. Held within a lattice framework, the molecules themselves do, however, vibrate about their average position.

**solid fuel** A fuel for combustion that is solid such as coke or coal rather than oil or gas.

**solid solution** A crystalline material in which two or more elements or compounds share a common lattice. Certain alloys such as gold and copper form solid solutions in which some of the copper atoms in the lattice are replaced by gold atoms. Isomorphous compounds can form solid solutions since they have the same crystal structure.

**solidus** A boundary line or curve on a *phase diagram between solid and liquid/solid at equilibrium. Below the line, the substance is solid.

**solubility** A measure of the ability of a solvent to dissolve a solid to form a solute in a solution at a given temperature and pressure. It can be expressed in terms of the mass of the solute per unit mass of solution, the mass of solute per unit mass of solvent, or the mass of solute per unit volume of solution or solvent.

**solute** The dissolved substance within a solution, the liquid part being the solvent.

**solution 1.** A homogenous mixture of a solute dissolved in a liquid. A solute can be a solid, liquid, or a gas. A solvent is the liquid that dissolves another substance. An aqueous solution is formed when water is the solvent. The solution is saturated when no more solute will dissolve at a particular temperature. Miscible liquids are liquids that dissolve completely in another liquid such as water and methanol. Conversely, an immiscible liquid is a liquid that does not dissolve completely in another liquid but forms a layer, such as oil on water. The separation of the components of a solution can be achieved by evaporation, crystallization, and distillation. **2.** A value that satisfies an algebraic equation.

**solvation** The process in which there is some chemical association between the molecules of a solvent and the molecules or ions of a solute allowing them to dissolve. For example, an aqueous solution of copper sulphate contains the complex ions of the type $[Cu(H_2O)_6]^{2+}$. **Hydration** is the process of solvation where the solvent is water. Solvation is also known as dissolution.

**Solvay, Ernest Gaston Joseph** (1838–1922) A Belgian industrial chemist who, in 1861, developed the ammonia-soda process or *Solvay process, used to manufacture soda ash (anhydrous sodium carbonate) from a solution of sodium chloride and limestone (calcium carbonate). This was noted as being a considerable improvement on the earlier *Leblanc process. Solvay worked at his uncle's chemical factory from an early age before founding his own company. Having made his fortune through his patents, he used his wealth for philanthropic purposes. Towards the end of his life, he was elected to the Belgium Senate and became Minister of State.

**Solvay process** A major industrial process used for the production of sodium carbonate known as soda ash. Also known as the **ammonia-soda process**, approximately three-quarters of all sodium carbonate is produced by this method with the remainder being mined from natural deposits. Developed by Ernest *Solvay (1838–1922) in 1861, the process is based on the fact that when excess carbon dioxide is passed into a solution of brine containing ammonia, the ammonium bicarbonate, which is first formed, interacts with the sodium chloride to give a precipitate of sodium bicarbonate as the salt is only sparingly soluble in the brine due to the common ion effect. Sodium carbonate is then readily prepared from the bicarbonate by heating at up to 230°C producing carbon dioxide that can be used again. The sodium carbonate is finally ground to a powder. The process is carried out over several stages and starts by passing concentrated brine down two towers. In the first, ammonia gas is bubbled and absorbed in the brine liquid. In the second, carbon dioxide, which is produced by the *calcination of limestone, is bubbled up through the ammoniated brine in which sodium bicarbonate precipitates out:



$$NH_4HCO_3 + NaCl \rightarrow NaHCO_3 + NH_4Cl$$

The sodium bicarbonate is the least soluble and is crystallized and filtered out from the hot ammonium chloride solution. The solution is then reacted with the quicklime (calcium oxide) remaining from the calcination of the limestone. As the ammonia is much more

costly than the sodium carbonate, it is recovered by adding calcium hydroxide and recycled back to the initial brine solution:

$$2NH_4Cl + Ca(OH)_2 \rightarrow 2NH_3 + CaCl_2 + 2H_2O$$

The Solvay process is an improvement on the earlier *Leblanc process since the materials are less costly; brine is cheaper than rock salt and no sulphuric acid is required. With no evaporation involved, less energy is required, there are no by-products produced, a purer product is obtained, and the process is continuous, and around 97 per cent of the carbon dioxide in the limestone is converted into sodium carbonate.

**solvent** The liquid part of a solution in dissolving another substance or substances. Water is a commonly used solvent. Being polar, water is capable of dissolving ionic compounds or covalent compounds that ionize. Non-polar solvents, such as benzene, do not dissolve ionic compounds but will dissolve non-polar covalent compounds. In alloys, the solvent is taken as the major component in the *solid solution.

**solvent extraction** The separation of the constituents of a liquid by contact with another insoluble liquid. If the constituents distribute themselves differently between the two liquids, a certain degree of separation will result. The separation can be enhanced further by multiple contacts. An example is the separation of plutonium and uranium isotopes dissolved in nitric acid, which can be extracted to differing extents using odourless kerosene as the solvent. Since the two liquids are immiscible in one another, the two liquids are agitated in such a way as to increase the surface area contact and to promote the rate of separation. The *extract is the solvent-rich product stream while the *raffinate is the residual liquid stream from which the solute has been removed. It is also known as **liquid-liquid extraction**.

**solvolysis** The chemical reaction between a compound and its solvent.

**sonication** An *ultrasonic technique used to disrupt the cell wall and membrane of microorganisms and release the intracellular material. The ultrasonic energy causes areas of compression and rarefaction in which cavities form, resulting in violent collapse and shock waves that are believed to be the cause of the cellular damage. Being a small-scale technique, it is largely confined to use in laboratories.

**Soret effect** A mass transfer phenomenon used in the separation of isotopes. Its effect is small in comparison with other effects that promote mass transfer and involves applying a temperature gradient. It is named after Swiss scientist Charles Soret (1854–1904), and is also known as **thermal diffusion**.



**sorption** A chemical and physical process in which a substance becomes attached to another substance. Physical sorption involves the attraction of molecules to a surface by *van der Waals' forces. *Chemisorption involves the formation of a chemical bond on the surface. Sorption is an exothermic process since the resistance of motion to a mobile molecule transmits its energy in the form of heat. *See* ABSORPTION; ADSORPTION; ION EXCHANGE.

**sour gas** Natural gas that contains hydrogen sulphide and mercaptans at a concentration in excess of 10 ppm. It is called sour on account of its sour and foul-smelling odour. It is required to be removed on account of its corrosive properties. *Compare* SWEET GAS.

**SOV** An abbreviation for **s**olenoid **o**perated **v**alve. *See* SOLENOID VALVE.

**SOx** A general term for sulphur oxide gases that are largely based on sulphur dioxide and formed during the combustion of oil and coal that contain sulphur.

**space time** (Symbol $\tau$) The holding time or mean residence time of materials in a continuous flow reactor required to process one reactor volume of feed under specified conditions to achieve a desired product composition. For a flow reactor with volume, $V$, and a total volumetric flow rate, $Q$, at the inlet:

$$\tau = \frac{V}{Q}$$

The reciprocal is the *space velocity, which is the number of reactor volumes under specified conditions that can be processed per unit time. The **space time yield** is the net yield of a product from a reactor per unit time per unit of effective reactor volume.

**space velocity** Applied to the processing of materials within a continuous flow chemical reactor, it is the reciprocal of the *space time. It can refer to the conditions in a specific location of the process materials in a reactor.

**spade** A solid plate that is inserted into a pipe to ensure isolation of material within it. It is inserted between the flanges and is made of the same material and has the same rating as the pipe. It is also known as a **slip-plate**.

**Spalding number** A dimensionless number, B, used in liquid droplet evaporation studies. It relates the sensible heat and latent heat of the evaporated material:

$$B = \frac{c_p \Delta t}{\lambda}$$

where $c_p$ is the specific heat capacity, $\Delta t$ is the temperature difference between the surrounding gas and the liquid, and $\lambda$ is the latent heat.

**span** The difference between the maximum and minimum value indicated by an instrument used to measure a process variable such as temperature, pressure, and level.

**sparger** A perforated tubular ring positioned at the bottom of a vessel containing liquid such as a bioreactor through which air or oxygen is discharged creating a swarm of bubbles that rise up through the liquid medium promoting oxygen transfer to the liquid. The size of the bubbles and their velocity determines the rate of oxygen transfer. Their size can be controlled by the number of holes, rate of flow of air or oxygen, and the location of the sparger to a rotating impeller that can disperse the bubbles.

**speciality (specialty) chemicals** Chemicals produced at the high-value end of the chemicals business that are characterized by their innovative uses such as in the development or modification of existing processes or products, or in the exploitation of new or developing technologies.

**specific** Relating to a specified or particular thing, such as being a characteristic property especially in relation to the same property of a standard reference substance expressed per unit mass. For example, the *latent specific heat of a substance is the latent heat per unit mass. The adjective is also used in relation to other terms, such as *specific speed, in which the performance of a centrifugal pump is compared to the performance of other pumps.

**specific enthalpy** (Symbol h) The enthalpy of a system defined as $h = U + pV$ where $U$ is the internal specific energy, $p$ is the pressure and $V$ is the specific volume of a substance. Like pressure, temperature, and volume, enthalpy is a property of a substance. The enthalpy is normally expressed with respect to some reference value. The specific enthalpy of water or steam, for example, is zero at 0.01°C and 101, 325 Pa.

For the freezing of foods, a value of 0 kJ $kg^{-1}$ is taken at –40°C.

**specific gravity** The ratio of the density of a substance to the density of water at 20°C. The specific gravity of water at 20°C is therefore 1.0.

**specific growth rate** (Symbol $\mu$) The rate of increase in concentration of living microbial cells per unit concentration in a growing culture such as in a bioreactor. It is a measure of the doubling time for cell division:

$$\mu = \frac{\ln\left(\frac{x}{x_o}\right)}{t}$$

where $x$ and $x_o$ are the final and initial concentration of cells in time $t$. It commonly has the unit of $h^{-1}$.

**specific heat** *See* SPECIFIC HEAT CAPACITY.

**specific heat capacity** (Symbol $c_p$, $c_v$) The amount of heat required to raise the temperature of one kilogram of a substance by a temperature of one degree K. The SI units are J $kg^{-1}$ $K^{-1}$. The *molar heat capacity is based on molar mass for which the SI units are J $mol^{-1}$ $K^{-1}$.

**specific latent heat** (Symbol L or λ) The quantity of heat absorbed or released per unit mass when a substance changes its physical phase at constant temperature and pressure. The **specific latent heat of fusion** (specific enthalpy change on fusion) of a body is the heat required to convert one kilogram of the solid at its melting point into liquid at the same temperature. The **specific latent heat of vaporization** (specific enthalpy change on vaporization) of a liquid is the heat required to convert one kilogram of the liquid at its boiling point into vapour at the same temperature. The SI units are J $kg^{-1}$.

**specific speed** A classification of centrifugal pump impellers at optimal efficiency with respect to *geometric similarity. It is useful for the scale-up and selection of centrifugal pumps and is a measure of pump pressure, head, and speed. Although the specific speed represents the numerical value for a rotational speed, and is usually expressed simply as a number, it actually has dimensions $L^{3/4}T^{-3/2}$. *See* SUCTION SPECIFIC SPEED.

**specific surface area** A measure of the total surface area of a solid per unit mass or volume. It is used in *catalysis and gas *adsorption where a chemical reaction is promoted on the surface of a *catalyst, or the rate of adsorption of a component is dependent on contact with a surface. The specific area of highly porous solids can be determined using the BET isotherm. The specific surface area of a gram of activated carbon is typically 500 $m^2$. The SI units are $m^2$ $kg^{-1}$ or $m^2$ $m^{-3}$ (or $m^{-1}$).

**specific volume** The volume occupied by a substance per unit mass. It is the reciprocal of density and has the SI units of $m^3$ $kg^{-1}$.

**speed** The rate of change of distance with time. It is a scalar quantity and has the SI units of m $s^{-1}$. Velocity is the speed of a body in a specified direction and is therefore a vector quantity.

**sphere** A body formed from the rotation of a circle about its diameter. It has a volume of $\frac{4}{3}\pi r^3$ and surface area of $4\pi r^2$ where r is the radius. Spherical vessels are commonly used to store process fluids under high pressure, such as liquefied petroleum gas (LPG), since there is an equal distribution of stress throughout the wall of the vessel. Cylindrical vessels and columns that operate under high internal pressure feature domed or hemispherical ends to distribute stresses. *See* HORTONSPHERE.

**sphericity** (Symbol Φ) The extent to which an irregularly shaped or non-spherical particle equates to being spherical. It is independent of particle size and defined as the ratio of the surface area of a particle to its actual surface area:

$$\Phi = \frac{6v_p}{d_p s_p}$$

where $d_p$ is the equivalent or nominal particle diameter, $v_p$ is the volume of a particle, and $s_p$ is its surface area. For a spherical particle, $\Phi = 1$. Tables of sphericity are used for particles of various defined geometric shapes.

**spigot 1.** A fitting at the end of a pipe that fits into another to form a joint. **2.** A type of tap to control the flow of liquid and used in wooden casks.

**splitter** A device used to divide the flow of process material into two or more streams. It can be as simple as a T-piece in a pipe or as complex as a mechanically operated diverter used to control the continuous or incremental portions of flow in particular directions. In simulation software packages, a splitter is an operation used to separate a process stream into two or more streams.

**spontaneous ignition, combustion** The initiation of combustion of a material by heating without the use of an external ignition source such as a spark or flame. The *auto-ignition temperature is the temperature at which the material is heated by its surroundings to the point that spontaneous ignition takes place.



**spray column** A simple type of liquid–gas contactor in which a liquid is sprayed into a gas contained within a column. It is typically used to absorb gases into a liquid in which the liquid is sprayed as fine droplets from the top of the column and the gas to be absorbed enters at the bottom of the column and leaves at the top.

**spray dryer** A device used to remove the moisture from a high moisture-containing fluid that contains a solid to be dried. The solid is often heat-labile, such as milk, and is continuously atomized into small droplets within a large chamber into which is fed a continuous flow of warm drying air or gas. Evaporation of the suspended droplets is rapid and the dried product is quickly carried away with the current of air or gas and separated, usually in a cyclone. Rapid drying in this way is suitable for materials that may be heat-sensitive such as certain biological and food products.

**spray dryer absorbers** *See* DRY SCRUBBING.

**spud** A term used to start the drilling of an oil or gas well. **Spudding** is used where a large drill bit forms the hole that is first lined and sealed before the main drill bit is inserted.

**sputtering** A process in which atoms from an electrode are removed from its surface by the impact of high-energy ions as in a discharge tube. It can be used to clean the surface or to deposit a uniform film of metal on an object within an evacuated chamber.

**SRV** *See* SAFETY RELIEF VALVE.

**stabilizer** A substance that is added to a colloid to prevent it from coagulating.

**stage 1.** A tray or plate in a distillation column in which equilibrium of a vapour and a liquid is reached. **2.** A part of a continuous process in which some form of separation process takes place.

The **stage efficiency** is the deviation from the equilibrium condition. In a distillation column, the stage efficiency is the composition of the mixture passing a tray divided by the composition if it were to be in equilibrium. *See* MURPHREE PLATE EFFICIENCY

**stagnant film** An assumption used in mass transfer calculations in which there is an assumed stationary film of gas or liquid surrounding an object such as a particle through which a component diffuses.

**stagnation point** A point in a flowing fluid where the fluid is stationary or brought to rest, such as in the mouth of a *Pitot tube.

**stainless steel** Alloys of iron noted for their resistance to corrosion and containing small amounts of carbon as well as chromium. Most stainless steels also contain nickel. Various other metals and non-metals are also often added to provide particular properties. They are resistant to corrosion due to a thin protective oxide coating on the surface. An example is 18:8:1 stainless steel which contains 18 per cent nickel, 8 per cent chromium, and 0.01 per cent carbon. Being of a high tensile strength and with excellent corrosion resistance, stainless steels are used extensively in the chemical and process industries for pipework and vessels.

**standard atmospheric pressure** The pressure of the atmosphere taken to be 101,325 Pa (i.e. 1013.25 mbar). Atmospheric pressure is not constant but variable and is influenced by meteorological conditions.



**standard candle** A former name for *candela, which is the unit of luminous intensity. It is no longer used due to confusion with another unit called the international candle.

**standard cell** A voltaic cell used to produce a constant and accurately known electromotive force (e.m.f.). It is used as a standard e.m.f. to calibrate voltage-measuring instruments.

**standard deviation** (Symbol $\sigma$) A statistical measure of the dispersion of a set of data from the mean and equal to the square root of the *variance. In a sample of $n$ observations, the standard deviation is:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}$$

where $\bar{x}$ is the mean of the sample. The standard deviation is therefore the square root of the mean of the sum of squared differences of the data points from the mean. A small value indicates a cluster around the mean whereas a large value indicates a wider spread of data.

**standard electrode** An electrode used in measuring electrode potential.

**standard enthalpy of combustion** *See* HEAT OF COMBUSTION.

**standard enthalpy of formation** *See* HEAT OF FORMATION.

**standard error** The estimated *standard deviation of a parameter whose value is not known exactly.

**standard solution** A solution of known concentration used in volumetric analysis.

**standard state** A state of a system used as a thermodynamic reference point. Reference points are usually taken as a temperature of 298.15K, a pressure of 101.325 kPa, and concentration of 1 M. The standard state is denoted by the superscript symbol °. For example, the standard molar heat of formation of water in the reaction:

$$H_{2(g)} + \tfrac{1}{2} O_{2(g)} \quad H_2O_l \text{ is } \Delta H_f^\circ \text{ is } -286 \text{ kJ mol}^{-1}.$$

**standard temperature and pressure** *See* S.T.P.

**Stanton number** A dimensionless number, St, used for forced convection heat transfer and relates the rate of heat transfer to the thermal capacity of a fluid:

$$St = \frac{h}{\rho v c_p} = \frac{Nu}{\text{Re Pr}}$$

where $h$ is the surface heat transfer coefficient, $\rho$ is the density, $v$ the velocity, and $c_p$ is the specific heat capacity . Nu is the *Nusselt number, Re is the *Reynolds number, and Pr is the *Prandtl number. It is named after British scientist Thomas Edward Stanton (1865–1931).

**Stanton–Pannell chart** A chart that presents the variation of friction factors for fluids across a wide range of *Reynolds numbers. It was published by British scientists Thomas Edward Stanton (1865–1931) and J. R. Pannell in 1914.

**start-up** A systematic sequence of events that is required in order to operate fully a chemical plant or item of process equipment.

**state function** A thermodynamic quantity whose value depends only on the state of a substance. The change in value depends only on the initial and final states of the system and is independent of the route taken to reach that state. *Enthalpy is a state function since a change in enthalpy depends only on the initial and final states, and is independent of the route between these states, and thus forms the basis of *Hess's law.

**state of matter** One of three physical forms for matter being *gas, *liquid, and *solid.

**static equilibrium** *See* EQUILIBRIUM.

**static head** The potential energy of a liquid expressed in *head form:

$$h = \frac{p}{\rho g}$$

where $p$ is the pressure, $\rho$ is the density, and $g$ is the gravitational acceleration. It is used directly in the *Bernoulli theorem for which the other two head forms are *velocity head and *pressure head.

**static mixer** *See* IN-LINE MIXER.

**static pressure** The measure of the pressure of a gas or liquid without movement. *Compare* IMPACT PRESSURE.

**statics** The study of mechanics in which balanced forces act on bodies resulting in the body remaining at rest. *Compare* DYNAMICS.

**stationary phase** The stage in the growth of a culture of microorganisms in a batch-operated bioreactor where the rate of growth ends. It occurs once all the limiting substrate has been exhausted such that no further growth is possible. The death phase then follows with the reduction of the number of viable cells.

**stationary point** *See* TURNING POINT.

**statistical error** *See* ERROR.

**statistical mechanics** The study of the properties of physical systems that can be predicted by the statistical behaviour of their constituent parts.

**statistical process control** A set of measurement techniques used to monitor a process in order to assess variability of performance and allow for predictions of when corrective action needs to be taken to prevent a problem from occurring. It uses data collected from various points within the process. Variations that may affect the quality of the end product or service are detected and corrected. The emphasis is on early detection and the prevention of problems. **Multivariable process control** is a form of statistical process control that uses a set of manipulated and control variables to control a process plant.



**statistical tables** Published tables of the values of cumulative distributions functions, probability functions, and probability density functions. They are used to determine whether or not a particular statistical result exceeds a required significance level. Examples of commonly used statistical tables include the normal distribution curve, chi-square distribution curve, Student's t-distribution curve, and F-distribution curve.

**statistics** A branch of mathematics that involves the planning of experiments, study of the classification and analysis of data using probability theories, and the application of interpretation methods such as hypothesis testing. It is used to form decisions and derive conclusions particularly where data may have a considerable degree of *error or uncertainty.

**steady state** A condition in which the net rate of change between the input and output to a process or system is zero and there is no dependence on time. For example, a steady-state material balance is where the total material entering a process and subsequently undergoing chemical reaction is equal to the total amount of material leaving the process. Where

there is an accumulation of material or where there is a loss of material, the process or system is said to be in an *unsteady state. *Compare* EQUILIBRIUM. **Steady-state flow** is the flow of a fluid into a space such that there is no loss or accumulation, and it is therefore unvarying with respect to time.

**steam** The gaseous form of water formed when water boils. At atmospheric pressure, steam is produced at 100°C by boiling water. It is widely used in the chemical and process industries as a utility for heating processes such as in *kettle reboilers for distillation columns. It is also used in power generation where steam is produced or 'raised' from a thermal or nuclear process and expanded through turbines. Scottish engineer James *Watt (1736–1819) understood the value of steam and his improvements to the Newcomen steam engine were an important contribution to the Industrial Revolution. Other uses of steam include sterilization, which is used in the food and medical industries. Steam is effective at destroying harmful pathogens and is a harmless substance once cooled. Wet steam is water vapour that contains water droplets. When heated further, the water evaporates. The **dryness fraction** of steam is the ratio of the amount of water in steam to the total amount of water vapour. *Superheated steam is produced by heating the steam above the boiling point of water. The thermodynamic properties of steam are presented in published *steam tables.

**steam cracking** 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, propylene, and other small-chain alkenes.

**steam cycle** A closed thermodynamic cycle used for power generation and involves raising steam from water in a boiler, expansion through a turbine, condensation, and return to the boiler (see Fig. 55). All steam turbine systems are based on adaptations of the *Rankine cycle. Represented on a *temperature-entropy diagram, its features include superheating, reheating, and regenerative feed heating, which are used to raise the overall cycle efficiency.

**steam distillation** The separation of immiscible organic liquids by distillation using steam. It 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



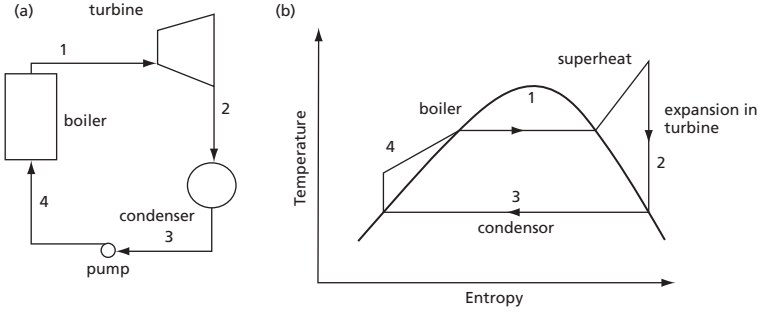


**Fig. 55a and 55b**

vapour. Steam distillation is used in the primary separation of crude distillation in a *fractionation column.

**steam injection** The use of live steam fed directly into a process to provide water and heat, and to enhance either extraction or reaction. 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, aid transport, and recovery. Steam is also directly used in the separation of crude oil and fed to the bottom of the *fractionation column. This is the primary separation of crude oil into fractions that have differing boiling points. *Steam cracking uses steam for *thermal cracking and reforming hydrocarbons.

**steam jacket** *See* JACKET.

**steam jet ejector** A type of fixed operation pump that uses high-pressure steam passed through a constriction to create a low pressure due to the *venturi 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 also handle corrosive vapours.

**steam point** The temperature that corresponds to the maximum vapour pressure of water at standard atmospheric pressure (101.325 kPa). This corresponds to a temperature of 100°C.

**steam reforming** The conversion of methane from natural gas into hydrogen. It is used in production of ammonia in which the methane is first produced from desulphurized and scrubbed natural gas, mixed with steam and passed over nickel catalyst packed in tubes at a high temperature of around 900°C:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$

The reactions are endothermic.

**steam tables** Published tables that present thermodynamic data for enthalpy, entropy, and specific volume of steam at various temperatures and pressures. Steam is a commonly encountered material in chemical processes and its properties have been extensively tabulated. Steam tables therefore provide a quick and valuable reference point.



**steam tracing** An internal pipe or tube used in process vessels and pipelines carrying steam to provide sufficient 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 typically is 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 consist 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, if appropriate.

**steam turbine** *See* TURBINE.

**steel** An alloy of iron used extensively for the fabrication of process vessels, columns, pipes, heat exchangers, ancillary equipment, and supporting structures. Steels contain up to 2.1 per cent carbon and varying amounts of other elements such as manganese, nickel, chromium, molybdenum, and silicon. There are many alloy steels with varying properties and used for specific applications. Steel with a chromium content of 11 to 12 per cent is known as stainless steel. Pipes and process vessels are often made from steel due to its high tensile strength and resistance to corrosion. Steel is also used for the support structures for process plant. It is manufactured by the *basic-oxygen process, which involves a charge of molten pig iron and scrap being blown with high-pressure oxygen on the surface through a water-cooled lance. *See* STAINLESS STEEL.

**Stefan–Boltzmann constant** (Symbol σ) A proportionality constant representing the thermal radiation heat loss by emission from a *black body. In SI units, it has a value of $5.669\,7 \times 10^{-8}\ W\,m^2\,K^{-4}$. It is named after Austrian physicists Josef Stefan (1853–93) and Ludwig Eduard Boltzmann (1844–1906).

**Stefan's law (Stefan–Boltzmann law)** A law of thermal radiation in which the radiation of all wavelengths per second per square metre from a *black body at an absolute temperature $T$ to surroundings at temperature $T_o$ is proportional to the fourth power of the absolute temperatures: $q = \sigma(T^4 - T_o^4)$. The proportionality constant, $\sigma$, is known as the *Stefan–Boltzmann constant equal to $5.669\,7 \times 10^{-8}\ W\,m^{-2}\,K^{-4}$. The law is named after Austrian physicists Josef Stefan (1853–93) and Ludwig Eduard Boltzmann (1844–1906) who theoretically derived the equation.

**STEL** An abbreviation for **s**hort **t**erm **e**xposure **l**imit. *See* WORKPLACE EXPOSURE LIMITS.

**stenching** The addition of a pungent-smelling substance to another to give a distinctive and strong odour. Substances such as diethylsulphide and mercaptans are added to odourless natural gas and LPG for safety purposes so that leakage can be readily detected. It is also known as **odourizing**.

**step** A discrete activity or stage within an overall process or chemical reaction.

**step response** The behaviour of a controlled process to adjust from one steady-state condition to another.



**steradian** (Symbol sr) A supplementary SI unit defined as the solid angle which, having its vertex in the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

**stere** A unit of volume used to measure the volume of stacked timber and equal to one cubic metre.

**stereochemistry** The branch of chemistry that is concerned with the study of the shape of molecules.

**sterility** A state of being free from microorganisms or spores. An *autoclave uses steam to kill all active microorganisms or spores in liquid media.

**still** A batch distillation vessel. It is used in the *whisky industry to distil fermented liquor known as wash. In the Scotch whisky industry, the still or pot still is made from copper and heated by steam. It has a characteristic swan neck and the distillate is condensed to

a liquid and collected before being redistilled a second or occasionally a third time. *See* WHISKY.

**still gas** A mixture of gases produced in petroleum refineries that includes methane, ethane, and ethylene as by-products of upgrading heavy petroleum fractions into more valuable and lighter products. Also known as *refinery gas, it is used as a refinery fuel or petrochemical feedstock.

**Stirling engine** A type of heat engine that involves the cyclic compression and expansion of air or any other gas as the working fluid. As a closed thermodynamic system, it uses both a hot and cold cylinder separated by a regenerator, in which the working fluid is recycled around the engine. There is a net conversion of heat energy to mechanical work. The use of the regenerator as a form of internal heat exchanger and thermal store makes the Stirling engine distinct from other types of hot air engine. It was invented in 1816 by Scottish engineer Robert Stirling (1790–1878) and is noted for its quiet operation and high efficiency. There has been much recent interest in its redevelopment particularly for use in *combined heat and power (CHP) plants.

**stirred tank** *See* AGITATED VESSEL.

**stochastic process** A statistical way of generating a series of random values of a mathematical variable and building up a particular statistical distribution from these values. Stochastic processes are used in non-equilibrium *statistical mechanics.

**Stockholm Convention on Persistent Organic Pollutants** An international environmental treaty that aims to eliminate, reduce, or restrict the production and use of chemicals described as *persistent organic pollutants (POPs). These are chemical substances capable of persisting in the environment and may pose a risk to human health and to the environment. Formed by the United Nations Environment Programme, the environmental treaty was established with cooperation of many international members and signed in 2001 in Stockholm, Sweden. The Convention includes requirements that developed countries provide resources to ensure that POP production and use are eliminated, whether intentional or unintentional, and that they are disposed in environmentally responsible ways.

SEE WEB LINKS

- Official website of the Stockholm Convention.



**stoichiometric coefficient** The coefficients used in balanced chemical reactions to show the relative number of molecules reacting. For example, in the reaction $3H_2 + N_2 \rightarrow 2NH_3$ the stoichiometric coefficients are 3, 1, and 2, respectively.

**stoichiometric combustion** The complete combustion of a fuel with oxygen, with the balanced molecular amount of fuel to oxygen. In practice, an excess of oxygen is used in the combustion of fuels. *See* COMBUSTION.

**stoichiometry** The study of the quantitative relationship between reactants and products in chemical reactions based on using the relative amounts of elements. A **stoichiometric reaction** is a chemical reaction involving the exact proportion of elements. In biochemical reactions, which tend to be more complex, a mass rather than a mole-based approach is used and is related to parameters such as the carbon content and *chemical oxygen demand.

**Stokes, Sir George Gabriel** (1819–1903) An Irish physicist and mathematician noted for his contributions to fluid mechanics. The youngest of six sons of a Protestant minister, he moved to Bristol at the age of 16 to pursue his studies, which prepared him for studying mathematics at Cambridge. Appointed as the Lucasian professor of mathematics at Cambridge in 1849, he studied the science of hydrodynamics and established his law of viscosity describing the velocity of a small sphere descending through a viscous fluid. He is best known for his work on fluid dynamics including his contribution to the *Navier–Stokes's equations. He also formulated *Stokes's law. A unit of kinematic viscosity is also named after him. A member of the Royal Society, he was first secretary and then president from 1885 to 1890.

**stokes** (Symbol St) A c.g.s. unit of measure of the *kinematic viscosity of a fluid expressed as the ratio of the viscosity, $\mu$, in poise divided by the density, $\rho$, in grams per cubic centimetre:

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

The units of centistokes, cSt, are more commonly used where 1 cSt is equal to $10^{-6}$ $m^2$ $s^{-1}$. The kinematic viscosity of water is exactly 1 cSt at 20.2°C.

**Stokes–Einstein equation** An equation used to determine the diffusion coefficient of particles through a liquid with low *Reynolds number. It was first derived by Albert *Einstein and based on a Stokes's particle undergoing Brownian motion:

$$D = \frac{k_B T}{6\pi\eta r}$$

where $k_B$ is the Boltzmann constant, $T$ is the absolute temperature, $\eta$ is the viscosity, and $r$ is the particle radius. The equation is of significance since it was first used to confirm molecular theory.

**Stokes's law** An equation based on a small particle suspended in a fluid to accelerate from stationary to achieve its terminal velocity. The equation suggests that the terminal velocity is reached after an infinite period of time but is usefully expressed as:



$$v_t = \frac{g(\rho_p - \rho)d_p^2}{18\mu}$$

where $g$ is gravitational acceleration, $\rho_p - \rho$ is the difference in density between the particle and fluid, $d_p$ is the diameter of the particle and $\mu$ is the viscosity of the fluid. The particle, which is usually solid although it also applies to small bubbles and droplets, has a maximum size of particle governed by a correlation of *Reynolds number based on the particle dimension and drag coefficient as:

$$Re_p = \frac{24}{C_d} \leq 0.4$$

as well as a minimum size for the fluid viscosity to operate (Brownian motion). The external forces on the particles may be gravity, centrifugal, electrostatic, and magnetic. Stokes's law is named after Sir George *Stokes (1819–1903).

**stonewall** The maximum stable flow and maximum head condition for a centrifugal compressor.

**storage tank** A large container or vessel used to hold liquid or powdered substances. Storage tanks may hold raw materials, intermediate products, final products, cooling water, solvents, waste products, etc. Storage tanks are usually located in a *tank farm.

**s.t.p.** An abbreviation for **s**tandard **t**emperature and **p**ressure, and is the standard conditions used as the basis for many thermodynamic calculations and tabulations involving temperature and pressure, and used for comparing the properties of gases. It is defined as $0^{o}$C (273.15 K) and one standard atmosphere (101 325 Pa).

**strain** The dimensionless change in a material produced by an applied stress divided by the original dimension. For a wire held vertically and stretched by a weight, the strain is the extended length expressed as a ratio of the original upstretched length.

**stratified flow** A two-phase flow regime that occurs in horizontal or slightly inclined pipes and channels where the liquid phase flows as a layer at the bottom of the channel with the gas phase above. This type of flow occurs at low gas velocities where separation of liquid and gas has occurred in which the liquid flows in the lower part of the pipe with the gas above it. At low gas velocities, the liquid–gas interface is smooth without ripples. At higher gas velocities, ripples and waves form on the liquid surface, eventually leading to the breakdown of this flow regime.

**stream** The flow of process materials to or from a process, plant unit, or within a pipeline. They are indicated on *process flow diagrams in which the direction of flow is shown by an arrow. The details of the stream are presented in a *stream table, which includes the components, their mass or molar flows, phase, temperature, and pressure. In *process integration studies, the hot and cold streams correspond to the relative temperatures and are distinguished by their function for either heating or cooling.

**streamline flow** An imaginary line in a flowing fluid such that the tangent to it at every point gives the direction of flow, and its velocity at any instant. It is also known as *laminar flow.

**stream table** Usually accompanying a *process flow sheet, a stream table presents the complete material accountancy throughout a process. It shows each process *stream, its composition, individual and total flows, as well as process conditions of temperature, pressure, and phase (solid, liquid, gas, or mixed). The flows are typically presented on a mass or molar basis per unit time such as kmol $h^{-1}$. The stream table data is usually given as the design *steady-state values. Maximum design values may also be indicated.

**stress** An applied force over a given area of a material that produces a strain. The SI units for stress are N $m^{-2}$.

**stress corrosion cracking** A cracking effect of a material held under tension due to the action of chemicals leading to its failure. The cracks formed are either intercrystalline or transcrystalline, in that they either form between and around crystals, or across and through them. Examples of chemicals capable of leading to stress corrosion cracking include chlorides on stainless steels, nitrates and hydroxides on mild steels, and ammonia on brass.

**string** The full length of tubing or a drill pipe that is used in an offshore drilling operation.

**stripper** A separation vessel used to reduce the amount of a volatile component in a liquid mixture. This is usually a column containing a packing material in which liquid material is fed at the top and cascades down, intimately contacting another fluid stream flowing up through which mass transfer takes place. For example, ammonia can be stripped out of water, where ammonia gas leaves at the top of the column and water with a low ammonia content from the bottom.

**stripping** A separation process in which chemicals are removed from one phase and transferred to another by absorption using a stripping agent. **Gas stripping** is the process of removing a component from a gas by contact with a liquid. For example, volatile organics and hydrogen sulphide can be removed from wastewater by contacting it with steam or air within a **stripper**. The chemicals are therefore stripped out of the wastewater and recovered from the steam or air from the top of the column. *Compare* SCRUBBING.

**stripping section** The section in a distillation column located below the feed point, in which the less volatile component or components in the mixture undergoing separation increase in concentration towards the bottom of the column as the more volatile component or components are stripped out. The upper section is the *rectification section.

**structured packing** A type of packing material used within vessels to increase the contact area between two phases to enhance a chemical reaction or separation. It consists of many arranged sheets of corrugated metal which cause the phases to make good contact with one another. They are used in distillation and absorption columns as well as some types of chemical reactor. *See* PACKED BED.

**Stubs' Wire Gauge** *See* BIRMINGHAM WIRE GAUGE.

**subcritical** A condition in a nuclear reactor in which the rate of nuclear fission is not sufficient to sustain a chain reaction. *See* CRITICAL MASS.

**sublimate** The solid that is formed through the process of *sublimation.

**sublimation** A direct change of state from the solid to the gaseous state without the appearance of the liquid state. The principle of sublimation is used in *freeze drying. **Desublimation** is sometimes used to describe the condensation of a gas to a solid and **ablimation** is used to describe the condensation of water vapour to ice.



**subnatant** A layer of liquid, particles, or sediment that lies beneath an upper layer of liquid, known as the *supernatant.

**substance** Any material that has a definite chemical composition. It may be a chemical element, a compound, or an alloy. Ores and minerals are naturally occurring substances and comprise mixtures of elements and compounds. A **substance hazardous to health** is any substance that can cause harm to human health by being toxic, irritant, corrosive, harmful, sensitizing, carcinogenic, mutagenic, or toxic to reproduction. *See* LETHAL DOSE.

**substituted mechanism** A reaction involving an enzyme ($E$) and a substrate ($S_1$) to produce a product ($P_1$) and a modified enzyme ($E^*$). The modified enzyme then reacts with another substrate ($S_2$) to form another product ($P_2$) with the regeneration of the enzyme:

$$E + S_1 \rightarrow E^* + P_1$$

$$E^* + S_2 \rightarrow E + P_2$$

**substitute natural gas** *See* SNG.

**substitution** The process of solving mathematical problems by replacing one variable with another. For example, for the simultaneous equations: $x-y=1$ and $2x-y=3$, in the first equation $y=x-1$ can be substituted into the second as $2x-(x-1)=3$ and be readily solved to show $x=2$ and so $y=1$.

**substitution reaction** A chemical reaction in which an atom or a molecule is substituted for another atom or molecule. An example is the reaction of zinc with hydrochloric acid to produce zinc chloride and hydrogen:

$$Zn+2HCl \rightarrow ZnCl_2+H_2$$

**substrate 1.** A substance upon which an enzyme acts. For example, starch is the substrate of the enzyme amylase that is hydrolyzed to maltose. **2.** The medium on which microorganisms grow in a *bioreactor. **3.** The substance on which some other substance is absorbed or in which it is absorbed.

**suction boot** A vertical leg that extends downwards from the suction or inlet pipe to a gas compressor. The purpose is to catch and collect moisture during the ascent of the gas into the compressor such that it can be removed safely without harm to the compressor. A valve is used to periodically drain the accumulated liquid.

**suction pressure** The pressure entering a duct or pump at a pressure below the system pressure.

**suction specific speed** A dimensionless number used as a measure of centrifugal pump performance for a particular application. Evaluated at the *best efficiency point, which corresponds to the maximum efficiency of the pump, the suction specific speed refers to the suction side of the pump and is used to identify issues of cavitation and the type of pump appropriate for a particular application, such as multi- or single stage, mixed or axial flow. It is calculated from:

$$S_n=\frac{NQ^{\frac{1}{2}}}{gH^{\frac{3}{4}}}$$

where $N$ is the rotational speed of the impeller, $Q$ is the flow rate, $g$ is the gravitational acceleration, and $H$ is the delivered head. *Compare* SPECIFIC SPEED.

**suffocation** Interference with the entrance of air into the lungs with resultant asphyxia. It can be the result of the release of gas or vapour in a *confined space in which oxygen is depleted.

**sulfate process** *See* KRAFT PROCESS.

**Sulfinol process** A regenerative process used to remove or reduce the level of hydrogen sulphide, carbon dioxide, carbonyl sulphide, and other organic sulphur compounds such as mercaptans from natural gas. It involves gas *absorption with solvents in which the gas is contacted countercurrently in an absorption column with the solvent. The *scrubbing process uses di-isopropanolamine dissolved in a mixture of sulfolane ($C_4H_8SO_2$) and water. Regenerated solvent is introduced at the top of the absorber. The solvent in which

the sulphur compounds are absorbed is heated in a heat exchanger with the regenerated solvent and is fed back to the regenerator where it is further heated to release the dissolved gases using steam. The gas is passed to a *Claus process to recover elemental sulphur. The process was developed in the 1960s.

**summing point** Used in process control, it is any point in which the process signal is added algebraically.

**sump** A vessel located at a low place with a capacity sufficient to collect or retain liquids. It is often located at the bottom of a process or a machine to collect waste liquids such as oil.

**supercooling** A *metastable state in which a liquid is cooled to below its normal freezing point without a change of phase. The particles of the liquid lose their energy but do not form a lattice structure of the solid crystal. By seeding with a small crystal, crystallization of the liquid then occurs and the temperature returns to the freezing point. Supercooling in the air occurs in which supercooled water droplets in the absence of freezing nuclei may exist at temperatures as low as -40°C.

**supercritical** The thermodynamic state of a substance that is above its *critical temperature and *critical pressure. The substance has a density greater than that of a gas but less than that of a liquid. The viscosity is also greater than that of a gas but less than that of a liquid. Supercritical fluids such as carbon dioxide are used as solvents in many extraction processes involving organic materials.

**supercritical fluid extraction (SFE)** An extraction process that uses pressures and temperatures above the critical point of the extracting solvent. Carbon dioxide is a popular solvent on account of its low critical point (31.4°C and 72 bar). The extraction process involves compressing the carbon dioxide and heating it. The supercritical carbon dioxide has the density of a liquid but properties of a gas, which aids diffusion and helps solubility. The solvent and dissolved extract is then transferred to a separator tank and the pressure reduced precipitating the extract. The carbon dioxide is recycled into the extractor via a condenser. A small amount of *make-up is required to allow for losses. Examples of SFE using carbon dioxide include the decaffeination of tea and coffee, flavour extraction from hops, the removal of pesticides from rice, and the dry cleaning of cloths. Other solvents used in supercritical fluid extraction include nitrous oxide, propane, and water.



**superficial velocity** The velocity of a fluid through a pipe that also contains another fluid of another state expressed in terms of the overall cross-section area as if no other fluid were present.

**superfluid** A fluid in a state being characterized by a very low viscosity and therefore possessing frictionless flow. It also has a high thermal conductivity. The only known fluid is cryogenically cooled liquid helium at a temperature close to absolute zero. **Superfluidity** is the state of being, or property of becoming, a superfluid.

**superfractionation** The separation of liquid mixtures by distillation that have close boiling points. Due to the relative volatility between two components being close to unity, the separation therefore requires a large number of theoretical plates and high reflux ratios.

**superheat** The heat added to a saturated vapour such as steam to raise the temperature above the saturation point at a given pressure. The **degrees of superheat** correspond to the temperature to which the vapour is heated above the normal boiling point.

**superheated steam** Steam produced in a boiler that has been heated to a temperature above that of the boiling point of water at a given pressure. It is produced by heating saturated steam in a boiler and passing it through a **superheater**, which further heats the steam. The number of degrees of superheat refers to the temperature of steam above the saturation temperature. Superheated steam is used to prevent harmful and wasteful condensation in steam turbines.

**supernatant (supernate)** A liquid that lies above the surface of another liquid or layer of sediment. *Subnatant means lying under, whereas **infranatant** means lying below.

**supersaturation** An unstable solution that contains more of a solute in solution than it can hold, at a particular temperature, in the presence of crystals of that solute. It is prepared by cooling an unsaturated solution and by isothermal evaporation of a solvent. Used in the process of *crystallization, supersaturation is more common with organic solvents than aqueous solvents.

**supersonic flow** The velocity of a fluid greater than the speed of sound i.e. greater than Mach 1.

**supervisory control** A form of automatic process control in which control loops operate independently subject to intermittent corrective action such as *set point changes arising from an external source.

**supply pressure** The pressure at the entry port to an item of process equipment.

**surface finish** The degree of roughness of a vessel or pipe surface, important for its durability. A clean surface is essential for providing maximum resistance to corrosion.

**surface flux** The amount of thermal radiation per unit area emitted from a flame or some other hot body. It is also known as the **surface emissive power**.

**surface roughness** The surface finish of pipes and vessels. There are various ways it is measured: The parameter Ra is the mean of the absolute values of height difference measured along the surface. Rt is the total roughness and describes the peak-to-valley height in a profile. Rz is the average roughness based on the successive measuring points or an individual peak and valley height. A profilometer is commonly used to measure a surface profile and uses a diamond stylus, which moves vertically in response to the roughness as it is guided over the surface. Other techniques include visual methods and scanning electron microscopy.



**surface tension** (Symbol $\sigma$) The force that acts on the surface of a liquid tending to minimize the surface area. The effect is caused by the attraction of molecules of the liquid to produce a film of tension over the surface. The SI unit is N $m^{-1}$. The c.g.s. unit of dyne per cm is still in common usage where 1 dyne $cm^{-1}$ = 0.001 N $m^{-1}$.The surface tension of a liquid can be measured from the *contact angle of a drop of a liquid on a surface. Other methods include a Du Nouy tensiometer, which consists of a ring of wire placed on the surface of a liquid and measuring the force to remove it from the surface. The drop weight method involves a drop of liquid hanging from the end of a capillary tube. The downward force is supported by the surface tension just before detachment. The weight and radius of the drop can be measured, from which the surface tension can be determined.

**surfactant** A molecule that contains both polar and non-polar parts causing the molecule to act at the surface where different substances meet. Soaps are surfactants. Their

structure allows them to detach grease and oil particles from a surface being cleaned and to emulsify them so that they can be washed away.

**surge** An unstable operating condition when the flow through a compressor is decreased to the point that momentary flow reversals can occur. This can lead to major damage of the compressor. **Surge control** is therefore used to prevent this and uses a **surge tank** which is a storage vessel, drum, or reservoir used to absorb unexpected rises in flow or pressure. It can also be used to provide additional fluid in the event of a drop in pressure or flow. Surge tanks are used in hydroelectric power stations to provide additional capacity and used to mitigate pressure variations due to rapid changes in the velocity of water.

**suspension** A mixture of particles suspended in a fluid and independent from one another. The particles may be either solid or liquid.

**sustainability** A process, business, or activity that is capable of being maintained at a steady level without exhausting natural resources or causing adverse ecological damage. Founded on the three elements of economics, effects on society, and the environment, it considers the wider effects and longer-term implications on the planet. The concept of sustainability has developed over the decades and can be traced back to United Nations Conference on the Human Environment held in 1972 that added the effect of the environment to the list of problems facing the existence of humankind. The UN Conference also led to the creation of the United Nations Environment Programme, which provides leadership and partnership in caring for the environment and enables nations to improve the quality of life without compromising future generations.

SEE WEB LINKS

- Official website of the United Nations Environment Programme.

**sustainable development** The development of businesses, processes, and products that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is based on the three elements of environment, economics, and society. A sustainable process requires all three. The 1992 Earth Summit held in Rio de Janeiro, Brazil, was the first global conference to address the issues of the environment being integrated into the issues of the global economy. An outcome from the conference was Agenda 21, which was a non-binding agenda that set goals and recommendations related to environmental, economic, and social issues. World leaders reaffirmed the principles of sustainable development at the 2002 World Summit held in Johannesburg, South Africa, and set an agenda for reducing world poverty and improving the lives of humans through responsible use of limited resources, while respecting the environment for future generations.



**sweet gas** Natural gas that contains very small amounts of hydrogen sulphide and carbon dioxide. North Sea gas is considered to be naturally sweet. *Compare* SOUR GAS.

**Swiss cheese model** A safety management tool used to explain how different but connected systems are related in achieving process safety. The barriers that prevent, detect, control, and mitigate accidents are depicted as slices of the cheese with each having a number of holes of differing sizes. The size and number of holes in each slice represents the imperfections in the barrier and are defined as specific performance standards. Well-managed processes have few or small holes. When two or more slices are put together, protection can be achieved and represented as the coverage of holes.

**symbol** A letter or a character used to present a quantity of something, a chemical reaction, a physical constant or variable, a mathematical operation, or relation.

**syneresis** The consolidation of a gel by the reduction in volume or contraction by forcing out interstitial water. It is used in the drying of solids.

**syngas** *See* SYNTHESIS GAS.

**synthesis** The formation of complex chemical compounds from simple compounds.

**synthesis gas** Also known as **syngas**, it is a mixture of carbon monoxide and hydrogen, made by steam reforming natural gas:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

A principal use of hydrogen is in the *Haber process. Before the Second World War, *water gas was previously used.

**synthetic** A substance that has been created artificially by chemical reaction and does not come from a natural source.

**synthetic fibres** Used in textiles, they are made from various raw materials. Those derived from petroleum, coal, and natural gas include polyesters, acrylics, nylon, polyethylene, polypropylene, polyvinylchloride, polyurethane, and synthetic rubbers. Fibres derived from cellulose include rayon, acetate, and triacetate. Inorganic fibres include glass and metal. Synthetic fibres such as nylon are produced by extruding the molten thermoplastic through extrusion dies called spinnerets into air that cools the fibres. The most widely used polyester fibre is PET (polyethylene terephthalate), which is used in carpeting.

**synthetic hydrocarbons** Hydrocarbon products that resemble petroleum products formed in high-temperature and pressure catalytic processes. The first products developed included methanol manufactured in the 1920s in Germany in a process operated at 400°C and 200 atmospheres using zinc and chromium oxide catalysts. The *Fischer–Tropsch process is used to produce saturated hydrocarbons of different molecular weight.

**synthetic medium** *See* DEFINED MEDIUM.

**synthetic natural gas** *See* SNG.

**syphon** The transfer of liquid from one vessel to another at a lower elevation by means of a pipe or flexible tube whose highest point is above the surface of the liquid in the upper vessel. It is a useful technique when the original (or upper liquid) has a layer of sediment, which must not be disturbed as in racking homemade wine.

**system** Refers to a quantity of a substance, or a group of substances, or energy under consideration contained within a space or transferred across a boundary. A system may be a mass of material or an energy contained within a boundary such as a vessel and isolated from the surroundings. Within an *isolated system the mass remains constant and the system is entirely uninfluenced by changes in its environment. In an *open system, it is possible to exchange energy and matter with its surroundings, whereas in a *closed system, energy can be transferred across the boundary but not matter, such as heating a vessel. This is an idealized system since there will be some exchange of energy and possibly material.

In a *steady-state flow system there is a transfer of energy or matter in and out such that the system remains constant. In a **cyclic system**, the final state is identical to the initial state. That is, the heat absorbed is equal to the work done by the system. In an **adiabatic process**, there is no heat exchange with the surroundings. The process is therefore thermally isolated or the process is very rapid such that heat has no time to enter or leave the system. This is an idealized process since insulation is not perfect and there will be some transfer of heat. In an **isothermal process**, there is no exchange of temperature with the surroundings. The type of system may depend on the timeframe of interest. For example, a vessel containing volatile liquid can be considered to be closed for a very short period after which the system can be considered to be open.

**systematic error** *See* ERROR.

**Système International d'Unités** Known more commonly as *SI units, it is a system comprising seven base units of the international metric system. The units are metre (m) for length, kilogram (kg) for mass, ampere (A) for electrical current, second (s) for time, kelvin (K) for temperature, candela (cd) for luminosity, and mole (mol). Derived units are the newton, joule, pascal, and watt.

# T

**tail end** The final stage in the reprocessing of *nuclear fuel. The end products are uranyl and plutonium nitrate solutions. These can then be converted into new nuclear fuel.

**tail gas** The gas arising from the *Claus process that contains sulphur and sulphur dioxide. The gas is treated to remove sulphur vapour, sulphur dioxide, and traces of other sulphur compounds for release to the atmosphere. The recovered sulphur is returned to the process. The treatment involves reducing the sulphur compounds to hydrogen sulphide by passing through a bed of cobalt-molybdenum catalyst. The gases are cooled to remove excess water vapour.

**tailings** The largely uneconomic and non-metallic minerals separated from ores in mining processes known as *gangue.

**tailrace** A channel used for carrying away tailings from mining processes in water.

**tails** The heavy products recovered from the bottom of a fractional distillation column.

**tangent 1.** A straight line that has a contact point with a curve at which point it has the same slope as the curve. **2.** A trigonometric function. The tan of the angle, $\alpha$, is the ratio of the side opposite to the angle to the side adjacent to the right-angled triangle.

**tank** A vessel used to contain liquids usually at atmospheric pressure. For closed tanks that are likely to become pressurized, such as due to pumping operations, a pressure relief system and vacuum breaker for pumping out may be fitted. A **tank farm** is a dedicated area of a chemical plant that is used for storage tanks. The tanks are used for storing liquids that may be feed, product, or reagents used in the plant. The location is generally near the process according to needs and safety issues.

**tapping** A point on a process vessel or pipe used to gain access to the material within. On a furnace, the tapping is used for drawing off molten metal. In a pipeline, it can be used to extract a small sample for analysis, or can be connected to a pressure-measuring device such as a manometer involving two tapping points across an *orifice plate meter.

**tar** A dark viscid substance obtained by the destructive distillation of organic matter such as coal, wood, or by petroleum refining. Coal tar fuels are produced by tar distillation and consist of either batch stills or pipe stills for continuous distillation. Tar oil is the product obtained from the distillation of coal tar.

**tatoray process** A catalytic process used for the transalkylation of toluene to a mixture of benzene and *xylene. The vapour phase process involves a fixed bed of zeolite catalyst and hydrogen. It is an abbreviation of **t**ransalkylation **a**romatics **Toray** developed by Toray Industries Inc. *Compare* XYLENE-PLUS PROCESS.

**Taylor bubble** *See* PLUG FLOW.

**Taylor series** An infinite power series used to determine the development of a given function. Obtained from Taylor's theorem, a function $f(x)$ can be expanded to the nth degree as:

$$f(x)=f(a)+\frac{f'(a)}{1!}(a-x)+\frac{f''(a)}{2!}(x-a)^2+\ldots$$

Taylor's formula gives $f(x)$ with increasing accuracy, the larger the series used. The Taylor series can be used to develop a given function $f(x)$ in powers of $(x–a)$. It was developed by Brook Taylor (1685–1731).

**Taylor vortices** A secondary fluid flow pattern that can occur in the gap or annulus of a concentric cylinder, or cup and bob system known as a Couette. For a rotating bob and stationary cup, a shear rate may reach a critical value such that a series of rolling toroidal flow patterns occur in the annulus of the Couette. In a cup and bob-type rheometer, this gives rise to inaccurate measurements of viscosity.

***TCE*** Formerly known as *The Chemical Engineer*, it is the official monthly magazine of the *Institution of Chemical Engineers covering news, current affairs, and events in the chemical and process engineering industry worldwide. It also includes updates on industrial developments, chemical engineering education, recruitment, and advertising.

SEE WEB LINKS

- Official website of the magazine *TCE*.

**tellerette** A ring-shaped spiral used as a packing material in adsorption columns. It has a high specific surface area and is used to provide effective contact between a gas and liquid. Having a high voidage, the pressure drop across the packing is low.

**Temkin isotherm** An empirical adsorption isotherm that relates the quantity of gas molecules absorbed onto a surface with pressure: $\theta=k\ln(np)$ where $\theta$ is the measure of the sites occupied per unit area of surface measured as the ratio of the mass of absorbate to the mass of absorbent, $p$ is pressure, $k$ and $n$ are empirical constants for a particular temperature.

**temperature** A measure of the intensity of heat that will flow into or out of a body or medium from another body or medium, and in which direction the heat flows. As a physical property of a body, it is proportional to the kinetic energy of the atoms or molecules. Where there is no heat flow, the body or medium is in thermodynamic equilibrium and at the same temperature as the other body or medium. Where they are not in equilibrium, the heat flows in the direction of the higher to the lower temperature body. There are various *temperature scales used to quantify the property of temperature including *kelvin, *centigrade or *Celsius, and *Fahrenheit scales.

**temperature-entropy diagram** A graphical representation of experimental thermodynamic properties for a substance in which absolute temperature, $T$, is presented on the y-axis and entropy, $S$, as the x-axis. The T–S diagram shows lines of constant pressure and distinguishes between saturated liquid, vapour, and superheated vapour. They are convenient to show the optimum efficiencies in various thermodynamic cycles such as *refrigeration.

**temperature gradient** The difference in temperature between two points of a known distance apart and is a measure of the direction of heat flow. The flow of heat is from the body or surface with the higher temperature to the lower temperature. It is the *driving force for heat flow.

**temperature scales** An empirical scale used to represent the physical property of temperature of a body. There are a number of scales in use and each is calibrated with fixed points to represent zero degrees, such as the freezing point of water and another temperature, such as the boiling point of water at standard atmospheric pressure, with a division between them to permit interpolation. In the case of the *Celsius this is 100 degrees. For scientific purposes, the *kelvin scale is used, which has absolute zero as a fixed point and other fixed points with divisions used to interpolate between them. They commonly are related as:

Fahrenheit to Celsius: $T_{(^{o}C)} = 5/9(T_{(^{o}F)} - 32)$
Celsius to Fahrenheit: $T_{(^{o}F)} = 9/5(T_{(^{o}C)} + 32)$
Celcius to kelvin: $T_{(K)} = T_{(^{o}C)} + 273.16$

**tempering** A process used to harden alloys by heating to a particular temperature, holding for a given period of time, and then cooling at a controlled rate to room temperature. Steel is tempered to allow excess carbide to precipitate out of a supersaturated solution of *solid solution of martensite and then rapidly cooled by quenching in cold water to prevent further precipitation or grain growth.

**temporary refuge** A safe place on an offshore oil and gas platform where process operators and other personnel can take temporary shelter during emergency situations such as fire and gas leaks. This is usually within the accommodation block.

**tensile strength** A mechanical property of a material as a measure of the resistance to tensile stress. This is the force per unit area required to break the material. Steel is commonly used in chemical plants for pipework, vessels, and support structures on account of its high tensile strength and resistance to corrosion.

**tensor** A mathematical entity that is the general equivalent in any n-dimensional coordinate system. A *vector in a two- or three-dimensional coordinate system is a special case of a tensor. Tensors are used to describe how all the components of a quantity behave under certain transformations.

**terminal velocity** The velocity of a moving body that has attained a constant maximum velocity in which the forces on the body such as those due to gravity are balanced by the resistive drag forces. Particles can be separated from liquids in settling tanks such as lagoons under the influence of gravity. Where the terminal velocity is very slow and a more rapid separation is required, centrifugal separators can sometimes be used where much higher centrifugal forces on the particles increase the terminal velocity and therefore reduce the time for separation. *See* STOKES'S LAW.

**ternary** Composed of three parts. For example, a ternary mixture has three compounds or components; a ternary *alloy has three elements.

**tesla** (Symbol T) The derived SI unit for magnetic flux density and is equal to the flux of one weber in an area of one square metre. It is named after the Croatian-born US electrical engineer Nikola Tesla (1857–1943) who invented transformers, generators, and dynamos.

**test separator** A horizontal cylindrical vessel used on offshore platforms for the separation of gas and water from crude oil and is identical to a *production separator except that it is used to process the contents of a single well. The oil enters the separator through a manifold. The reduction of pressure causes the release of dissolved gases, which are removed from the top of the vessel. The water and oil separate by virtue of being immiscible and having different densities. The oil and condensate is separated from the water by overflowing a weir. The results from the well test separator are used to provide information on the performance of the well.

**textile** Fabric and other material made from combinations of fibres that are woven, knitted, braided, and tufted. The fibres are long, thread-like materials from natural sources such as animal, plant, or mineral, or chemically synthesized. They occur or are made into different forms, such as filaments, which are long continuous fibres; tow, which is a bundle of untwisted continuous fibres; and yarn, which is a bundle of twisted fibres.

**TFR** *See* TUBULAR FLOW REACTOR.

**theorem** A conclusion from a mathematical argument that has been proved based on certain assumptions. A **corollary** is a result that follows on from a theorem such that a separate theorem is not required.

**theoretical air** The amount of air that is required to burn completely a given amount of fuel. The amount is determined from the chemical composition of the fuel. In practice, excess air is required for complete combustion.

**theoretical stage** A part of a process in which two fluids are in equilibrium. Such an equilibrium stage may also be referred to as a **theoretical tray, equilibrium stage**, or **ideal stage**. In a *distillation column, a liquid and a vapour are close to being in equilibrium in the reboiler and partial condenser. On each of the trays within the column, the enrichment of vapour of the *more volatile component is less than one theoretical stage. This means that more stages or trays are required in practice to achieve a desired separation. In absorption columns, the amount of a gas absorbed is a fraction of the amount absorbed in a theoretical stage. In a liquid–liquid solvent extraction process, a *mixer-settler is close to one theoretical stage. *See* MURPHREE PLATE EFFICIENCY.

**theory** A description of a mathematical, physical, or chemical principle that does not fully cover all of the circumstances and has not fully achieved the incontrovertible status of a law.



**therm** The former non-SI unit of thermal energy equal to $10^5$ British thermal units (Btu) equal to 105,505,600 joules.

**thermal analysis** A technique used to determine the chemical analysis of a substance by heating it. *Differential scanning calorimetry is an example in which a sample under investigation is heated or cooled under controlled conditions to allow the enthalpy change due to thermal decomposition to be studied.

**thermal capacitance** Another name for the *thermal mass of a material, which is the ability of a body to store thermal energy, and is expressed as the heat required to raise the temperature of a body by 1°C. It is the product of the mass of the body and the heat capacity. The SI units are $J\,K^{-1}$.

**thermal conductivity** (Symbol $k$ or $\lambda$) The measure of the movement of heat through a body by kinetic molecular activity. It is used in *Fourier's law, which states that the thermal conductivity is independent of the temperature gradient but not necessarily of temperature itself. The thermal conductivity is the proportionality constant between heat flux and temperature gradient. That is, the rate of flow of heat ($dQ/dt$) through a surface of area $A$ in a medium is given by:

$$\frac{dQ}{dt} = -kA\frac{dT}{dt}$$

where $dT/dt$ is the temperature gradient measured in the direction normal to the surface. Values for the thermal conductivity vary widely for substances, with metals having the highest and finely powdered materials the lowest. The SI units are $W\,m^{-1}\,K^{-1}$.

**thermal cracking** A process that uses heat and pressure to break down and chemically alter heavy petroleum hydrocarbon molecules into smaller, lighter molecules. Typical pressures range from 7 bar to 70 bar and temperatures range from 450°C to 540°C. It is less frequently used than catalytic cracking since the yields of high-octane products are lower.

**thermal death time** (Symbol $t_D$) Used in the thermal sterilization process of foods that may be contaminated with harmful microorganisms, it is the time in minutes to bring about complete sterilization at a particular temperature, $T$. It is calculated using the *F-value and *z-value:

$$t_D = F_{121}10^{\frac{T-121}{z}}$$

**thermal diffusion** *See* SORET EFFECT.

**thermal diffusivity** (Symbol $\alpha$) The rate at which thermal energy moves through a body due to a change in temperature. It is used in unsteady-state heat transfer calculations in which a body with a non-uniform temperature approaches equilibrium:

$$\alpha = \frac{k}{c_p\rho}$$

where $k$ is the thermal conductivity, $c_p$ is the specific heat capacity, and $\rho$ is the density. Materials that have a high thermal diffusivity, such as metals, diffuse heat more quickly than materials with a low thermal diffusivity. When the temperature around the material changes, heat flows in or out of the material until thermal equilibrium is reached, assuming the environment around the material remains unchanged. Materials that have a high thermal diffusivity reach thermal equilibrium more quickly than materials with a low thermal diffusivity. The SI units are $m^2\,s^{-1}$.

**thermal efficiency** The ratio of heat output from a thermal device to the heat input expressed as a decimal or percentage. Examples include heat exchangers, furnaces, and dryers.

**thermal expansion** The increase in volume of a substance with temperature. Most substances increase in volume with increasing temperature. The coefficient of expansion, $\alpha$, is the ratio of the change in length of a substance with temperature to the length at 0°C. The

coefficient of volumetric expansion, $\beta$, is approximately three times the value of $\alpha$. Water is a notable exception in which above 0°C, the volume decreases with temperature to approximately 4°C and increases in volume thereafter. The SI unit is $K^{-1}$.

**thermal hysteresis** When a body is heated and then cooled through the same temperature range, the temperature path taken is different.

**thermal mass** The ability of thermal materials, particularly those used for building and construction purposes, to moderate internal temperatures and to regulate heat release, and therefore to delay the time at which peak temperatures occur. It is the product of the mass and heat capacity of the material and has the SI units of $J\,K^{-1}$. A high thermal mass can store and later release large quantities of heat without a large temperature rise on the surface, whereas a low thermal mass can release its heat quickly. See THERMAL CAPACITANCE.

**thermal oxidation process 1.** A process used to produce a thin layer of silicon dioxide on the surface of a semi-conductor wafer of silicon. The high-temperature process causes the oxidizing agent to diffuse into the wafer. Using temperatures of up to 1,200°C, water or oxygen reacts with the silicon to form silicon dioxide as either **wet oxidation** or **dry oxidation**, respectively. **2.** A high-temperature process involving the oxidizing of combustible materials by above the auto-ignition temperature in the presence of oxygen, reducing them to carbon dioxide and water.

**thermal radiation** The energy emitted by all bodies above absolute zero temperature due to the excitation by molecular vibration. Energy is transmitted between bodies without heating the space in between unless the medium is capable of absorbing energy. The *Stefan–Boltzmann constant, σ, is used in thermal radiation calculations in which the rate of heat loss from a *black body is:

$$q = \varepsilon\sigma A\left(T_1^4 - T_2^4\right)$$

where $\varepsilon$ is the emissivity, $\sigma$ the Stefan–Boltzmann constant, $A$ is the area, and $T$ is the absolute temperature. The SI units are $J\,s^{-1}$.

**thermal resistance** (Symbol R) The resistance of a body to transmit thermal energy. It is the ratio of the driving force to the rate of heat transfer. A lagged pipe carrying a hot fluid has thermal resistances that include convective resistance on the inside of the pipe, resistance due to conductivity of the pipe wall material, resistance due to the lagging material, convective resistance on the outside of the pipe, and possibly the resistance to heat transfer due to fouling on the inner pipe wall surface. It has SI units $m^2\,K\,W^{-1}$.

**thermal runaway** *See* RUNAWAY REACTION.

**thermite process** A highly exothermic process used to produce molten iron for in-situ welding such as railway lines. The reaction involves igniting a mixing iron oxide with aluminium to form aluminium oxide and molten iron:

$$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$$

It is also known as aluminothermy.

**thermochemistry** A branch of chemistry involving the study of the heat energy from a process and includes chemical reactions and physical changes of state.

**thermocouple** A temperature-sensing instrument that consists of a pair of dissimilar metal wires joined together. One pair of wires operates as a reference junction and the other as the sensing junction. Where a temperature difference exists, an e.m.f. difference is measured and a current flows from which the temperature is determined.

**thermodynamic cycles** Heat engines, refrigeration cycles, and steam cycles can all be represented using ideal thermodynamic cycles. Heat engines are usually represented on pressure-volume or *temperature-entropy diagrams. Refrigeration and steam cycles are usually represented on temperature-entropy diagrams. Reciprocating machines and simple air compressors are usually shown on pressure-volume diagrams.

**thermodynamic diagrams** Charts used to present complex thermodynamic data for materials over a wide range of conditions. They are used to simplify thermodynamic calculations. Commonly used diagrams include enthalpy-concentration, pressure-enthalpy, temperature-entropy, enthalpy-entropy (*Mollier), and *psychrometric charts. The reference conditions are the pure compounds at some specified condition such as pressure.

**thermodynamic equilibrium** The condition of a system in which the quantities that specify the system, such as temperature and pressure, remain unchanged. It is often abbreviated to *equilibrium.

**thermodynamics** The study of the relationship between properties of matter, changes in these properties, and transfers of energy between matter and its surroundings that bring about these changes. These changes may be both physical and chemical. There are four laws of thermodynamics that define the relationships in terms of temperature, energy, and entropy. The *zeroth law of thermodynamics states that for two bodies being in thermal equilibrium with a third body, then they must all be in thermal equilibrium with each other. The *first law of thermodynamics refers to the conservation of energy in which the change in internal energy of a system is equal to the difference in the heat added to the system and the work done by the system. The *second law of thermodynamics states that it is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a cooler body to a hotter body. The law sets the limit on the amount of heat energy that can be converted to useful work energy. The *third law of thermodynamics enables absolute values to be stated for entropies by stating that the entropy of a system approaches a constant value as the temperature approaches absolute zero. It therefore provides an absolute scale of values for entropy by stating that for changes involving only a pure crystalline substance at absolute zero, the change of the total entropy is zero.

**thermodynamic temperature** The temperature defined in terms of the laws of thermodynamics and therefore independent of the properties of the body being measured. It is usually expressed using the *kelvin scale. It is not measured directly but is usually inferred from measurements with a gas thermometer that contains a nearly ideal gas. The thermodynamic method to specify temperature was proposed by Lord *Kelvin.

**thermolysis** The decomposition of a substance as the result of heating. It is used in the process of thermal *cracking of hydrocarbons to produce smaller hydrocarbons of lower molecular weight.

**thermometer** An instrument used to measure temperature based on the thermal expansion of a gas or liquid. Commonly used liquid-in-glass thermometers consist of a bulb containing a liquid such as mercury or some other liquid such as alcohol coloured with a dye, and a long graduated capillary. As the temperature of the liquid rises, the liquid expands

out of the bulb and moves along the graduated scale. The temperature is read directly. Other principles of operation include the expansion of metal and bi-metallic materials, the change in resistance to the flow of electricity and semi-conductors (thermistors). Copper, platinum, and nickel are the most commonly used metals in resistance thermometers.

**thermonuclear reactor** A type of reactor in which nuclear fusion takes place with the controlled release of a considerable amount of energy. While such reactors are still at the experimental stage, the main challenges are the ability to reach the very high temperatures needed that are in excess of a million degrees Celsius, and containing the reacting nuclides for a sufficient period of time to achieve the required ignition temperature. In a *tokamak, powerful magnets are used to guide the charged plasma around the toroidal-shaped reactor and to prevent collisions with the walls.

**thermophilic bacteria** A type of bacteria that is tolerant of heat or temperature. They can survive at temperatures in excess of most other bacteria and have been found in sulphur-rich thermal volcanic vents such as geysers and fumaroles. Their resistance has been exploited in some biotechnological processes. For example, heat-resistant **thermophilic enzymes** are used in products such as washing powders.

**thermostat** A type of on–off device used to automatically control the temperature of a system, a piece of equipment such as a domestic boiler in which heat is applied when the temperature falls below a desired value. The heat is applied to the point that a maximum allowable temperature is reached, at which point the application of heat is halted.

**thermo-syphon reboiler** A type of *reboiler heat exchanger used to boil up the liquid from the bottom of a distillation column. It consists of vertical tubes heated with condensing steam in which natural circulation of the liquid is caused by the reduced density of the heated liquid in the tubes drawing in more liquid. No pump is therefore required. They are also known as *calandrias.

**thickening** A separation process used to remove liquid from a suspension of particles in a solution, usually under the influence of gravity. The settling of the particles gives rise to an increase in the concentration of particles in a solution as a sludge or slurry in which clear liquid above overflows and is removed. In a thickener, which consists of wide tank with a slightly conical base, a revolving rake moves the sludge towards the centre of the base for removal. *Compare* CLARIFICATION.

**Thiele–Geddes** A procedure used for stage-wise calculations for multicomponent distillation problems. The procedure involves computations from both ends of the column and works towards the middle. Numerical instabilities occur when stage-wise calculations cross a feed stage. The procedure is not suitable for multiple-feed or draw-off columns. *Compare* LEWIS–MATHESON.

**third law of thermodynamics** The law which states that the entropy of a perfect crystal is zero at a temperature of absolute zero.

**thixotropic fluids** Fluids such as certain gels, paints, and lubricants that have a viscosity that decreases when a stress is applied, as in stirring, and is also dependent on the time that the stress has been applied. *Compare* ANTITHIXOTROPIC FLUIDS.

**Thomson, James** (1822–92) A Scottish engineer who studied civil engineering at the University of Glasgow where his younger brother William (later Lord *Kelvin) was also a

student. He worked on water-power engineering and thermodynamics, and invented various water wheels and turbines. He became professor of civil engineering. He calculated the effect of pressure on the melting point of ice, which was shown by experiment to be correct by the work of Lord Kelvin.

**Thomson, Sir William** *See* KELVIN, LORD.

**Three Mile Island accident** A major nuclear accident that occurred on 28 March 1979 at the Three Mile Island Generating Station in Pennsylvania, USA, involving a *core meltdown and release of radioactive material into the environment. The cause was attributed to a *pilot-operated relief valve that had become stuck open allowing reactor coolant to the pressurized water reactor to escape. Human factors were also attributed to the accident including inadequate training and an operator manually overriding the automatic emergency cooling.

**three-term control** *See* PID CONTROL.

**threshold limit value (TLV)** The airborne concentration of a particular substance used to define conditions under which nearly all people may be repeatedly exposed for a working lifetime without causing adverse effects. The time weighted average or TWA is the time concentration of a particular substance for an eight-hour day or 40-hour working week to which nearly all workers may be exposed. The ceiling TLV is the airborne concentration that should not be exceeded at any time.

**throttling** A way of controlling the rate of flow of a fluid in a pipe by means of a regulating valve. For example, it is used to control the rate of vaporized fuel to an internal combustion engine. Throttling is used in the suction line to a compressor in which a pressure regulator adjusts a control valve, normally a butterfly valve.

**throughput** The total amount of material fed to or produced as a product from a process per unit time. It can be expressed as either a mass or a volumetric rate. In oil refineries, the throughput refers to the stream of feedstock supplied.

**tie-in** The joining of two sections of pipeline. Tie-ins may be used in modifications to an existing pipeline to make it join a new pipeline, or in the joining of various sections of a newly laid pipeline constructed in sections.

**tie line** A horizontal line used in a liquid–vapour phase diagram for two substances. The line extends from the point that a liquid can coexist with its vapour to the point where only vapour exists as the pressure is reduced. A tie line is perpendicular to an *isopleth.

**tie substance** An inert and unreactive substance, such as nitrogen, which passes through a system or process in a completely unchanged form. It enters in an input stream and leaves via an output stream. It therefore forms a tie between the input and output streams and as a result is useful for undertaking material balance calculations such as for combustion processes.

**time constant** (Symbol $\tau$) A parameter that determines the dynamic path of a process to respond to a disturbance and approach a new steady state. It is a product of both capacity and resistance. A low resistance means that the final steady-state condition is reached quickly. 63.5 per cent of the final change corresponds to one time constant after the input change.

**titration** A laboratory technique used to find the exact volume of acid of unknown concentration that is needed to neutralize a certain volume of alkali of known concentration. It uses a burette to carefully administer the acid and a colour indicator, such as phenolphthalein, to indicate the end point in the technique.

**TLV** *See* THRESHOLD LIMIT VALUE.

**TNT** An abbreviation for **t**ri**n**itro**t**oluene, it is a pale yellow material used as a high explosive first prepared by German chemist Julius Wilbrand (1839–1906). The **TNT equivalent** is a convenient way of expressing the magnitude of an explosion by calculating the amount of TNT which, when detonated at a particular point, would cause the same level of *blast wave damage. The ton of TNT is a unit of energy equal to 4.184 gigajoules of energy, and is the approximate amount of energy released on the detonation of one ton of TNT.

**tokamak** A toroidal *thermonuclear reactor used in thermonuclear fusion experiments originally developed in Russia in the 1960s. It has a strong axial magnetic field that keeps the plasma inside the ring-shaped vacuum from touching the external walls—a hot plasma that hits the walls will rapidly cool, ending the fusion process. The name comes from the Russian for 'toroidal chamber with magnetic coils'. *See* JET.

**tolerance** A range of physical dimensions of an object within which the true dimensions lie. It is used in machining components such as the meshing gears where clearance must be controlled.

**tomography** A non-destructive imaging technique used to examine the internals of process pipes and equipment. It uses penetrating waves such as X-rays and produces a sectional image known as a tomogram. Invented by electrical engineer Sir Godfrey Newbold Hounsfield (1919–2004), it uses a computed tomographic or CT scanner. The scanner rotates around the object under investigation and takes a series of X-ray measurements. The accumulated data is then used to construct a three-dimensional image. Tomography has made a substantial contribution to medicine as well as many other areas of science and engineering.

**tonne** A metric unit of weight equal to 1,000 kg. The long or gross ton of 2,240 lb (1,016.05 kg) was removed from official UK measures in 1985, whereas the short ton is still used in the US and is equal to 2,000 lb (907 kg).

**tons refrigeration** A unit signifying the capacity of a refrigeration plant or air-conditioning system using the Imperial system of measurement in which 1 ton of refrigerant will freeze 1 ton of water at 32°F (0°C) in 24 hours. A one-ton unit is equivalent to 3.52 kW.

**topping** The separation of *crude oil to remove light fractions by distillation. A **topping refinery** separates crude oil into light components with no further refining being involved. The components are used as fuel.

**top product** The vapour or liquid drawn from the top of a distillation column. In a continuous distillation process, a portion is returned to the column for further enrichment known as *reflux. In a batch distillation process, the composition of the top product changes with time as volatile components are progressively drawn off.

**topsides** The oil and gas processing equipment installed in an offshore platform located above the splash zone. These include drilling, gas and liquid processing, accommodation,

utilities, services, and safety equipment. On floating production systems, the topsides equipment is normally pre-assembled into skids, which are located above the deck to provide some protection against large breaking waves.

**torque** (Symbol $\tau$) The ability of a mechanism to do work, usually by rotation, such as a bolt or a rotating shaft on a pump or compressor, or viscometer, which takes into account the distance through which force is applied:

$$\tau = FL$$

where $F$ is the force and $L$ is the length from the axis of the shaft. The SI units are N m.

**torr** A unit of pressure used in high vacuum applications and equal to one millimetre of mercury or 133.322 Pa. The unit is named after Evangelista *Torricelli (1608–47) who discovered the principle of the barometer.

**Torricelli, Evangelista** (1608–47) An Italian scientist and mathematician who was professor of mathematics in Pisa, and did work on the thermal expansion of liquids. For a short time he was an assistant to *Galileo and started building telescopes after the death of his teacher. He discovered the attraction between the Earth and air molecules that results in pressure and concluded by saying 'We live submerged at the bottom of an ocean of the element air.' He wrote on a number of subjects in applied mathematics, including the movement of a stream of water through a small hole in the side of a container. The **Torricelli theorem**, which he proposed in 1643, is named in honour of him: $v = \sqrt{2gh}$, where $v$ is the velocity of the discharging jet of liquid and is proportional to the square root of the supplied head, $h$. The equation was derived from a balance between potential and kinetic energies for which energy losses are neglected. His most important development was the mercury barometer in 1643 with the help of his pupil Vincenzo Viviani (1622–1703) who demonstrated the existence of a vacuum. He was able to show that the pressure of the atmosphere varied with weather conditions. This important work led to the development of meteorology for weather prediction. Pascal's siphon, Samuel Morland's diagonal barometer, and Robert Hooke's quadrant barometer are all variations and improvements on Torricelli's instrument.

**Torricellian vacuum** The vacuum formed in a vertical glass tube filled with mercury and closed at the upper end. The level of mercury in the tube is used to measure atmospheric pressure as a barometer. The pressure of the Torricellian vacuum formed above the level of the mercury is equal to its vapour pressure, which is about $10^{-3}$ torr. It is named after Evangelista *Torricelli (1608–47) who discovered the principle of the barometer.

**total acid number (TAN)** A measure of the potential corrosivity of crude oils. It is expressed as the number of milligrams of potassium hydroxide that are required to neutralize one gram of crude oil. Values of greater than 1 mg are considered corrosive and labelled as High-TAN crudes.

**total annual costs** The costs incurred on a process on an annual basis. It is the sum of the *fixed costs, *variable costs, and taxes. Along with the *economic potential, it is a useful economic indicator of a process when considering the preliminary design of a process.

**total condenser** A type of heat exchanger used in a distillation process in which all the vapour from the top of the column is condensed and part of it is drawn off as the top product. *Compare* PARTIAL CONDENSER.

**total dissolved solids (TDS)** The total amount of organic and inorganic substances dissolved in water. The principal constituents in fresh water are sodium, potassium, calcium, and magnesium, sodium, and potassium cations, and carbonate and hydrogen carbonate, chloride, sulphate, and nitrate anions. It is a measure of the quality of water for drinking and for rivers. The main source of total dissolved solids is from sewers, urban sources, and agricultural surface runoff. The total dissolved solids are measured in parts per million (ppm). The World Health Organization considers drinking water to be unacceptable if the total dissolved solids content is in excess of 1,200 ppm. *Compare* TOTAL SUSPENDED SOLIDS.

SEE WEB LINKS

- Official website of the World Health Organization information on water sanitation.

**total heat** The sum of the sensible heat, latent heat, and superheat (if any) of a substance. As the temperature and pressure rise in a substance, the amount of sensible heat increases, while the latent heat decreases.

**total moisture** The total amount of water that is retained within the pores of a solid substance. The inherent moisture is the moisture that is stored within the pores of particles and which can only be removed by heating.

**total pressure** The sum of the partial pressures of all the constituents in a mixture of gases and vapours. *See* DALTON'S LAW.

**total reflux** A condition in which all the overhead product from a distillation column is returned back to the column as reflux. On a *McCabe–Thiele diagram, increasing the *reflux ratio moves the operating lines of both stripping and rectifying sections away from the equilibrium line reducing the number of theoretical plates required to bring about a desired separation until they follow the 45° diagonal. This corresponds to the minimum number of trays required in the column for the separation.

**total solids** The solids remaining in a liquid solution after evaporation and may include colloidal, soluble, and suspended solids.

**total suspended solids** The amount of suspended material in water. It is a measure of the quality of water for drinking and for rivers, and is determined by filtering a volume of water through a glass fibre filter and drying it. The total suspended solids is expressed as the collected dry weight per volume of water filtered. *Compare* TOTAL DISSOLVED SOLIDS.



**tower** Another name for a column, which is a tall, cylindrical vessel used for carrying out processes such as distillation, absorption, or extraction.

**town gas** A manufactured fuel gas for domestic and industrial use such as coal gas, substitute natural gas (SNG), and natural gas. It is typically composed of about 50 per cent hydrogen, 25 per cent methane gas, between 7 and 17 per cent carbon monoxide, and lesser amounts of carbon dioxide, nitrogen, and hydrocarbons. It is toxic and its characteristic unpleasant smell is due to its sulphur content.

**toxic** The harmful properties of a chemical substance or some physical agent on humans. The harmful effects are the result of absorption, inhalation, or digestion and result in illness, injury, or death. A **toxic hazard** is a type of atmospheric hazard that may be poisonous, toxic, or harmful if inhaled.

**trace heating** The heating of a fluid in a pipe by means of steam or electrical heating elements. The fluid may have a relatively low melting point such as bitumen and is required to remain in the liquid state to prevent it from solidifying and blocking the pipe. The trace heating consists of an internal pipe carrying the steam, which runs down the centre of the pipe carrying the fluid to provide sufficient heat transfer that prevents solidification.

**tracer** A radioactive isotope used to follow a chemical or biochemical reaction.

**train** A group of similar process units that are operated in series. A *distillation train is a series of distillation columns used to progressively remove or cut components from multicomponent feed mixtures.

**transducer** A device used to convert a signal from a sensed process variable into another form of signal. Sensed variables may be temperature and pressure, and converted to pneumatic pressure, voltage, or current. These signals are then used either directly to control valves or used by computers where the signals are digitized and used with other signals to control a process or system. An **I/P transducer** is a type of transducer that converts an electrical input signal to a pneumatic output signal while a **P/I transducer** converts a pneumatic output signal to an electrical input signal. The electrical signal is in the range 4 to 20 milliamps, while the pneumatic signal is 3 to 15 psig (20–100 kPa).

**transfer function** Used in process control to represent the relationship between the output to input signal from and to a process in which the differential equations used to describe the signals as functions of time have been transformed using Laplace transforms. Laplace transforms are used to simplify the calculations since differential equations do not readily enable the relationship between the output to the input to be discerned. The transformation is said to be from the time domain to the s-domain. If the input is $y(t)$ and the output is $y(t)$ then the transformed function $G(s)$ is:

$$G(s)=\frac{Y(s)}{X(s)}$$

Capital letters are used for variables in the s-domain and lower-case letters for the time domain.

**transformation 1.** The conversion of reactants to products irrespective of the chemical, physical, or biochemical process route involved. **2.** The change in a mathematical expression or equation resulting from the substitution of one set of variables by another. **3.** The change in an atomic nucleus to a different nuclide as the result of the emission of either an *alpha particle or a *beta particle.

**transient response** A short, brief, or temporary change in the state of a system when there has been a disturbance. The transient effects in a well-controlled system tend to die away with time, allowing the system to settle to a steady-state condition. For example, a thermometer initially reading a temperature $T_1$ immersed in a hot oil of temperature $T_o$ will read a new temperature of $T_2$:

$$T_2 = T_o - (T_o - T_1)e^{\frac{-t}{\tau}}$$

where $\tau$ is the *time constant. The exponential term will eventually die away with time to give the steady-state value of the thermometer reading the oil temperature.

**transition 1.** The change from one state to another. **2.** The period of time during which a change takes place, passing from one state to another.

**transition flow** A flow regime that exists between laminar or streamline flow and turbulent flow. Velocity fluctuations may be present and impossible to predict.

**transition point 1.** The point at which a moving fluid increases in velocity and changes from laminar flow to turbulent flow. **2.** The temperature at which a substance changes phase such as from liquid to solid. **3.** The temperature at which a crystalline substance changes into another crystalline form.

**transition temperature** The temperature at which an immediate change of physical properties occurs, such as a change of phase, crystalline structure, or conductivity.

**transmissivity** The portion of radiant energy falling on a surface that is transmitted through the body. *Compare* ABSORPTIVITY, REFLECTIVITY.

**transmitter** A transducer that responds to a measured *process variable by way of a sensing element and converting it to a signal that is a function only of the measurement.

**transuranic element** An element whose atomic number is greater than that of uranium (i.e. exceeds 92). These elements do not occur in nature. Neptunium, with an atomic number of 93, is the first.

**trapezium rule** A form of *numerical integration used to find the approximate area under a curve by dividing it into parts of trapezium-shaped sections that form columns of equal width with bases that lie on the horizontal axis. Also known as the trapezoidal rule, it is calculated from:

$$\int_b^a f(x) \approx (b-a)\frac{f(a)+f(b)}{2}$$

**trays** Perforated plates used in distillation columns that permit vapour to rise up through a layer of liquid as bubbles and designed in such a way that the liquid is unable to flow down at the same time. There are various designs such as sieve trays, which are located both above and below the feed tray. Stripping trays are located below the feed tray in which the concentration of the less volatile component in the liquid increases as the liquid flows down the column. The purity of the bottom product is increased by increasing the number of trays. Rectifying trays are located above the feed tray in which the concentration of the more volatile component is enriched as the vapour rises from tray to tray up the column. Again, the purity is increased by increasing the number of trays.

**trenched piping** The organized routing of pipework within a wide, open trench to transport fluids such as raw materials, products, and utilities such as water and steam to and from process equipment. The trench is usually trapezoidal in cross section. Being open and at ground level, leaks from pipes into the trench are easy to detect. In the event of leakage, liquids and heavy gases are contained in the bottom of the trench. *Compare* PIPETRACK.

**trial and error** A problem-solving technique used to obtain a solution to a problem by using reasoning. The method is useful when there is insufficient knowledge or information within a problem to reach a solution by analytical means. A reasoned judgement is therefore made and further adjustments are made based on the effects. *Compare* GUESS AND CHECK.

**triangular diagrams** A graphical presentation of the interaction of three components in a mixture known as a *ternary liquid system. The diagram (see Fig. 56) uses equilateral triangular coordinates, with each liquid being presented as either a mass fraction or percentage in terms of the other two. Any point on the side of the diagram represents a binary mixture. Where one pair of liquids is partially soluble in each other and both are fully soluble in the third at a particular temperature, the diagram is known as an isotherm. An example is benzene, water, and acetic acid with benzene dissolving completely in the other two. For example, in Fig. 56a, any *ternary liquid outside the solubility curve at P is a homogenous solution of one liquid. Any ternary liquid below at Q will form two insoluble, saturated liquid phases of equilibrium compositions R and S. The line RS is the tie line, which passes through Q. The plait point T is the last tie line and the point where A- and B-rich solubility curves merge. Where the two pairs of liquids are partially soluble, such as chlorobenzene (A) and water (B), and water and methyl ethyl ketone (C), the isotherm appears as Fig. 56b. Homogeneous ternary solutions are formed at P while two liquids phases at equilibrium appear with R and S corresponding to tie lines in the heterogeneous area.

**triboelectrification** The generation of static electricity caused by friction in flowing fluids and solids.

**tribology** The study of friction, lubrication, and wear between moving surfaces.

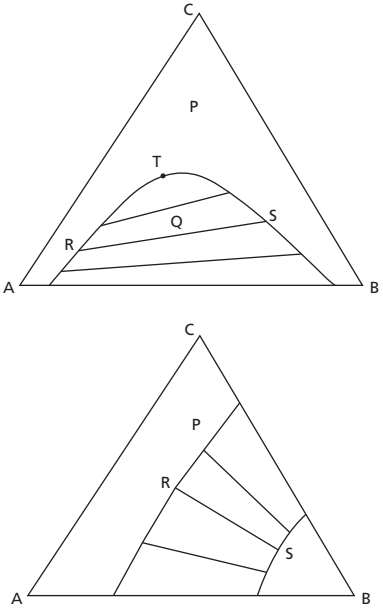


**Fig. 56a and 56b**

**trigonometric functions** The representation of relationships between the sides and angles of a right-angled triangle, such that for an angle θ:

sine θ = opposite side/hypotenuse
cosine θ = adjacent side/hypotenuse
tangent θ = opposite side/adjacent side
secant θ = hypotenuse/adjacent side
cosecant θ = hypotenuse/opposite side

**trigonometric series** An expression for the sine and cosine trigonometric functions as convergent power series:

$$\sin x = \frac{x}{1!} - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \ldots$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \ldots$$

**trip** The fast shutdown of an item of chemical plant or process equipment such as a pump. The shutdown is the result of a process condition being exceeded such as an abnormal flow, pressure, temperature, or concentration, etc. In a nuclear power plant, a trip can lead to the fast shutdown of a nuclear reactor by rapid insertion of the neutron-absorbing *control rods.

**triple point** The temperature and pressure at which the gas, liquid, and solid phases (or states) of a substance are in equilibrium. The triple point of water, in which vapour, liquid, and ice phases exist in equilibrium, is 0.01°C and 611.2 Pa. The triple point of water forms the basis of the *thermodynamic temperature scale proposed by Lord *Kelvin.

**triplex pump** A type of reciprocating pump that has three cylinders. The pistons or plungers operate out of phase with one another such that the outflow is continuous and is the sum of the discharging cylinders. They are commonly used in offshore drilling operations and can handle a wide range of fluids including slurries and abrasive and corrosive fluids.

**trouble-shooting** A form of problem-solving 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. Trouble-shooting is often applied once a problem has arisen and the process stops functioning. In its simplest form, it can take the form of a systematic checklist and requires critical thinking. Computer techniques are used 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 are not obvious.

**Trouton's rule** A method used to determine the approximate latent heat of vaporization of a substance based on its normal boiling point as:

$$\frac{\lambda}{T_{BP}} = \Delta s \approx 90\ Jmol^{-1}K^{-1}$$

It is used where no heat of transformation data exists or can be readily found. For polar liquids, the value increases while for non-polar liquids, the value decreases. It should not be used for highly polar or non-polar molecules. It is named after Irish physicist Frederick Thomas Trouton (1863–1922).

**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.

**tube sheet** A mounting plate used for the support and spacing of tubes in heat exchangers, boilers, coolers, and filters.

**tube side** A reference to the inside of the tubes of a shell and tube heat exchanger through which a heat transfer medium flows. *Compare* SHELL SIDE.

**tubing** A conduit with a circular cross section used for the transportation of fluids. Available in a wide variety of materials such as metals, glass, and plastic, there is no clear-cut distinction between tubing and pipes. In general, tubing is thin-walled and comes in coils with long lengths. Sizing is usually indicated by the outside diameter. The wall thickness is given by the BWG (*Birmingham Wire Gauge) number.

**tubular flow reactor (TFR)** A commonly used chemical reactor consisting of parallel pipes or tubes contained within a cylindrical vessel. Reactants are fed to one end and the reacted product is withdrawn from the other. A heat transfer medium can be circulated between the tubes making them useful for the conversion of raw materials to products in chemical reactions that require heat exchange.

**tundish** A vessel with a broad opening or funnel at the top with one or several holes at the bottom. It is used in plumbing and metal-founding.

**turbidity** The clarity of water as a way of determining its quality. An optical measure of the turbidity of a fermenting broth in a bioreactor can be used to determine the rate of growth of microorganisms. Within limits, there is usually a direct relationship between *cell dry weight and turbidity.

**turbidostat cultivation** *See* CONTINUOUS CULTIVATION.

**turbine** A machine used to generate electricity by the expansion of a gas or vapour 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 the 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 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.

**turbulent flame** The propagation of a flame under turbulent flow conditions such as a jet engine flame.

**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 numbers in excess of 4,000. Turbulent flow occurs when inertial forces predominate resulting in macroscopic mixing of the fluid. *Compare* LAMINAR FLOW.

**turnaround** A term used for a planned downtime of a process plant for maintenance. The **turnaround time** is the time required to prepare and restore a process or an item of equipment back into operation. It may include cooling, emptying and cleaning, charging, and reheating to bring the process or equipment back on stream.

**turning point** A point on a graph at which the gradient of a tangent of a mathematical function changes sign. Where a gradient changes from a positive to a negative, the point represents a maximum point; where a gradient changes from a negative to a positive, the point represents a minimum. Turning points are also known as **stationary points**. Where the mathematical function $y = f(x)$ is known, the turning point can be obtained from the first derivative:

$$\frac{dy}{dx} = 0$$

A maximum or minimum can be identified from the sign of its second derivative.

**turn-key** A process or system that has been designed and built by a contractor that is ready for immediate use and for a fixed fee.

**TWA** An abbreviation for **t**ime **w**eighted **a**verage, it is an occupational exposure limit used to protect the health of employees against exposure to harmful airborne substances. It is averaged over a defined period of time to which workers may be exposed by inhalation. *See* WORKPLACE EXPOSURE LIMITS.

**12-D process** *See* BOTULINUM COOK.

**two-dimensional flow** An approach used to determine the flow of a fluid in which all velocities are parallel to a given plane. The flow between two parallel flat plates is considered to be two-dimensional. Either rectangular (x,y) or polar (r,θ) coordinates are used to describe the flow characteristics.

**two-phase multiplier** A factor used in the determination of pressure drop in two-phase flow. It is determined from the superficial velocities of both the gas and liquid phases for which the respective pressure drops can be determined and then combined to determine the overall pressure drop using the two-phase multipliers for both phases. They are obtained from charts, graphs, and mathematical correlations.

**two-property rule** A rule used to uniquely define a system and requires specification of two independent properties such as specific internal energy, specific volume, specific enthalpy, absolute temperature, and specific entropy. All of the other properties can be found if the two independent properties are known. The properties are independent if one can be varied while the other does not change. *See* PROPERTY DIAGRAM.

# U

**Uchatius process** A process used in the nineteenth century to make cheap steel that involves pouring molten cast iron into water. The iron granules are then mixed with fresh iron containing manganese and fireclay, and heated. The molten product is then poured into moulds. It was named after Austrian engineer Franz von Uchatius (1811–81), an officer in the Austrian army who invented the process in England in 1855.

**UFD** *See* UTILITY FLOW DIAGRAM.

**Ufer process** A process once used for refining light oil produced from the carbonization of coal. The oil is first washed with sulphuric acid before adding water. The resulting mixture of resins passes into the oil phase. The dilute sulphuric acid was then used to make ammonium sulphate. The process, named after its German inventor A. Ufer, was used in the 1920s and 1930s.

**UFL** *See* UPPER FLAMMABLE LIMIT.

**UHT** *See* ULTRA HIGH TEMPERATURE.

**ultimate analysis** A type of compositional analysis of fuels expressed in percentages for carbon, hydrogen, oxygen, nitrogen, sulphur, and ash. The mnemonic 'no cash' is an easy way to remember the elements. The *proximate analysis is the analysis of fuels in terms of moisture content, volatile matter, ash, and fixed carbon content.

**ultimate-cycle tuning method** An empirical procedure used to tune a controller using *PID control with optimum controller settings. Developed by J. G. Ziegler and N. B. Nichols in 1942, it assumes that open loop transfer functions can be approximated by a first order system with a time delay. The settings for the tuned controller result in an underdamped transient response with a *decay ratio of a quarter.

**ultimate oxygen demand (UOD)** A method used to determine the demand for oxygen in wastewater and is a measure of the conversion of all the carbon being converted to carbon dioxide and nitrogen to nitrates ions. It is less widely used than the *biochemical oxygen demand (BOD) and *chemical oxygen demand (COD) tests, which are used to measure the effects of pollution in water.

**ultimate tensile strength** The maximum strength that a material can withstand before fracture and failure. It is therefore the maximum stress, which is the applied load divided by the cross-sectional area of a test piece of material. The SI unit is the pascal and is more commonly expressed as MPa. For materials that don't deform under an applied load, this is the nominal stress at the point the material breaks. For materials that deform, this is the point that necking forms before breakage.

**ultracentrifugation** A high-speed centrifugation process used to separate very small particles such as colloids from liquids, and macromolecules such as proteins and nucleic acids from solutions. It uses speeds of up to 60,000 rpm and can generate a force on a particle of up to two million times greater than the force of gravity.

**ultrafiltration** The separation of very fine particles and molecules by filtration through a microporous or *semi-permeable membrane. It is used to separate molecules with a molecular weight in the range of 3,000 to 100,000. Ultrafiltration therefore can separate out macromolecules such as proteins, polysaccharides, and fat globules while allowing smaller water and lactose molecules to pass through the membrane as permeate.

**ultraforming process** A catalytic reforming process of naphtha used in the petroleum industry that uses platinum and rhenium catalyst in a swing reactor. The reactor can periodically be taken off-line so that the catalyst can be regenerated.

**ultra high-pressure processing** *See* HIGH-PRESSURE PROCESSING.

**ultra high temperature (UHT)** A process used in the food industry to sterilize liquid beverages such as fresh fruit drinks and milk. It involves heating the liquid to a temperature of 140°C using a *plate heat exchanger and holding the temperature for a couple of seconds. This is sufficient to destroy all potentially harmful pathogenic microorganisms and spores. The effect of the process on milk, however, is to caramelize the sugars giving a sweeter taste. It also denatures some of the proteins making processed milk unusable for making cheese. The process is also known as **ultra heat treatment**.

**ultra orthoflow process** A fluid catalytic cracking process used to convert petroleum distillates and heavier fractions to components of lower molecular weight.

**ultrasonic cleaning** The use of ultrasonic pressure waves to vibrate an object to be cleaned while the object is immersed in a cleaning fluid. The process is used to produce a very clean surface and is used for medical equipment and jewellery.

**ultrasonic flow meter** A type of non-intrusive flow meter used to measure the velocity of a fluid flowing in pipes and open channels. It uses the principle of ultrasound in which an ultrasonic signal is passed through the fluid, which is detected by another sensor located a short distance away. The time is measured between the pulses of emitted and detected ultrasound. The delay between sending and receiving the signal is related to the velocity of the fluid. While inexpensive to operate and with no moving parts, ultrasonic flow meters are sensitive to changes in fluid density and to distortions of flow profile.



**ultrasonics** The study of ultrasonic pressure waves for the purposes of testing metals for faults, flaws, and thickness, as well as for surface cleaning. It uses frequencies above audio frequencies and cannot be detected by the human ear. **Ultrasonic testing** is a non-destructive technique used to identify the thickness of metal such as vessels and pipework, and the presence of corrosion. It uses short pulses of ultrasound with frequencies typically of around 2 MHz.

**ultraviolet radiation** Electromagnetic radiation with a wavelength shorter than that of visible light. It lies just beyond the visible spectrum and has typical wavelengths in the order of $10^{-7}$ m.

**unbound moisture** A liquid that is held by a solid, which is in excess of the equilibrium moisture content corresponding to the saturation humidity.

**unconfined vapour cloud explosion** A loose term used to describe a *vapour cloud explosion, which is an explosion due to the ignition of a cloud of flammable vapour in air.

**underdamped** *See* DAMPING.

**underflow** A liquid that leaves a continuously fed mixer-settler or some other solvent extraction device. The liquid outflow is divided into two streams by a weir arrangement based on density difference. The liquid with the highest density or heavy phase leaves as the underflow. The light phase leaves as the *overflow.

**underground storage** The storage of gas such as methane or ethylene in vast underground reservoirs and natural rock strata instead of using above-ground gas holders.

**Underwood equation** A shortcut method used to estimate the minimum reflux ratio in a multicomponent distillation process. It was proposed by A. J. V. Underwood in 1948.

**unicracking** A *hydrocracking process used to produce hydrocarbon fuels by simultaneous hydrogenating and cracking of liquid petroleum fractions to form hydrocarbon mixtures of low molecular weight. It uses an aluminosilicate catalyst either contained within a *zeolite or in an amorphous state.

**unidak process** A catalytic process used in petroleum refining to extract naphthalene from reformer residues. It involves a dealkylation stage to form naphthalene. The catalyst is based on cobalt and molybdenum and the process is operated at 600°C.

**UNIFAC** A semi-empirical thermodynamic model used to predict the behaviour of components in complex mixtures, which uses structural groups to estimate component interactions. It is an abbreviation for **UNI**QUAC **F**unctional-group **A**ctivity **C**oefficients and is used to predict non-electrolyte activity in non-ideal mixtures. It is used to predict the activity coefficients as a function of composition and temperature. It is useful when experimental data is not available.

**uniform flow** A fluid flow condition in which there is no change in fluid velocity at a given time with respect to distance.

**unimolecular reaction** A chemical reaction involving only one molecule as the reactant. An example is the decomposition of ammonia to nitrogen and hydrogen on a metal surface. Unimolecular reactions are always first order.

**union** A ring-like device used to couple or link together pipes and tubes.



**unionfining processes** One of a number of petroleum *hydrodesulphurization and hydrodenitrogenation processes used to produce a high-quality diesel fuel.

SEE WEB LINKS

- Website of Honeywell UOP Company.

**UNIPOL process** A process used for polymerizing ethylene to polyethylene and also for polymerizing propylene to polypropylene. Unlike the *Ziegler–Natta process, it uses a gas phase process at low pressure. The catalyst is continuously added to the process and the granular product withdrawn. A co-monomer is also usually used in the process.

SEE WEB LINKS
- Website for Dow Company's UNIPOL process.

**UNIQUAC** *See* UNIVERSAL QUASI-CHEMICAL.

**unit 1.** The fundamental measure of a physical quantity such as length, mass, and time. Derived units include area, velocity, density, etc. SI units have replaced previous systems for scientific and engineering purposes. **2.** An item of process equipment or plant designed to carry out a specific task.

**unit operation** A basic step in a process or operation carried out in a chemical plant. A unit operation involves the study of physical, chemical, or biochemical changes that occur during the processing of materials. The design of equipment and systems is based on these operations and includes mixing, reaction, and separation. Unit operations may be classified as:

1 Fluid flow processes including filtration and fluidization.
2 Heat transfer including evaporation and condensation.
3 Thermodynamic processes including heat pumps.
4 Mechanical processes such as solids and particle handling.
5 Mass transfer including distillation, drying, solvent extraction, and adsorption.

Arthur D. *Little is credited with coining the concept of unit operation.

**universal constants** The parameters that do not change such as gravitational constant, the speed of light, the Planck constant, and the charge on an electron, etc.

**universal gas constant** (Symbol R) The constant or proportionality in the law of ideal gases:

$$pV = nRT$$

where p is pressure, V is volume, n is the number of moles, and T is absolute temperature. The SI units are 8.314 kJ $kmol^{-1}$ $K^{-1}$.

**universal quasi-chemical (UNIQUAC)** A thermodynamic model tested against experimental data used to obtain vapour liquid equilibria data. It is used in computer simulation software packages particularly for carrying out complex distillation calculations.

**UNOX process** An activated sludge sewage treatment process used for treating domestic effluents. It uses oxygen aeration in closed tanks rather than air.



**unsaturated 1.** A chemical compound having double or triple bonds within its structure. Unsaturated compounds can undergo addition as well as substitution reactions, such as the hydrogenation of vegetable fatty acids. **2.** A solution containing less than the maximum equilibrium amount of a solute at a given temperature. *Compare* SATURATED; SUPERSATURATED.

**unscheduled maintenance** *See* MAINTENANCE.

**unstable 1.** A chemical compound that readily decomposes. **2.** The spontaneous decomposition of a radionuclide by nuclear decay. **3.** A process or mechanical or electrical

system that has the tendency of self-oscillation. Process control is used to ensure that the dynamics of a process are controlled.

**unsteady state** A condition in which the transport of material or energy in and out of a process is not balanced; instead there is either a loss or an accumulation over time. An **unsteady-state mass balance** involves the flow of materials into a process together balanced with the flow of materials out with any accumulation or loss. For example, the flow of a liquid into a tank, $Q_{in}$, with an open drain valve that has a flow out, $Q_{out}$, resulting in a change in capacity dV/dt, can be expressed mathematically as:

$$Q_{in} = Q_{out} + \frac{dV}{dt}$$

In an **unsteady-state energy balance** the same principle applies. The accumulation of energy within a process where all the energy forms are considered including kinetic, potential, heat flow rates, enthalpies, and stirrer works may result in an increase in the thermal energy and a rise in temperature. **Unsteady-state heat transfer** involves the transfer of heat under conditions where the temperature changes with time. For the simple case of one-dimensional conduction in a solid slab, the accumulation of heat is a product of the mass and specific heat of the material and the increase in temperature where:

$$\frac{\partial T}{\partial t} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial x^2} = \alpha\frac{\partial^2 T}{\partial x^2}$$

where $\alpha$ is the thermal diffusivity of the material. General solutions of unsteady-state conduction for simple geometries are available such as for slabs, infinitely long cylinders, and spheres. For a semi-infinite slab, the integration for the heating or cooling from both sides by a medium of constant surface temperature is:

$$\frac{T_S - T_1}{T_S - T_2} = \frac{8}{\pi^2}\left(e^{-aFo} + \frac{1}{9}e^{-9aFo} + \frac{1}{25}e^{-25aFo} + \ldots\right)$$

where $T_S$ is the average temperature of the surface, $T_1$ is the initial temperature, $T_2$ is the temperature at time t, Fo is the Fourier number, and a is $(\pi/2)^2$. **Unsteady-state heat transfer** occurs where there is a change of material within a space with time. Similar one-dimensional mathematical principles apply.

**unstructured model** A simple mathematical description of the rate of growth of microorganisms based on the cells being represented by a single variable such as cell concentration, X. The rate of cell growth is proportional to the cell concentration:

$$r_X = \frac{dX}{dt} = \mu X$$

A widely used expression that relates the specific growth rate $\mu$ to the amount of substrate in a fermenting medium is the *Monod equation.

**unstructured packing** Small objects that are randomly arranged in distillation and absorption columns to provide a high surface area thereby allowing intimate contact between a rising vapour or gas with a descending liquid to allow effective mass transfer to take place. Many types are commonly used such as Berl saddles, Raschid rings, Intalox saddles, and Pall rings amongst others, and are made from a variety of materials such as

plastic, metal, and ceramic, which are inert to the substances in which they are in contact. *Compare* STRUCTURED PACKING.

**UOD** *See* ULTIMATE OXYGEN DEMAND.

**updraft** The upward movement of air or a gas in a structure or through a product. It is used to designate the direction in a dryer or fluidized bed. The opposite is called downdraft.

**upper flammable limit** The highest concentration of a flammable vapour or gas mixed with an oxidant such as air that will propagate a flame at a specified temperature and pressure. *See* FLAMMABILITY LIMITS.

**upset** An unscheduled alteration to the operation of a process. *See* PROCESS UPSET.

**upstream** A stream of material for processing that has not yet entered the process for chemical transformation in reactors, etc. In the oil and gas industry, it includes production facilities, pipelines, and receiving terminals. *See* DOWNSTREAM.

**upthrust** *See* ARCHIMEDES' PRINCIPLE.

**uranium enrichment** The process of purifying uranium. The difference in mass between uranium-235 and uranium-238 allows the isotopes to be separated and to increase or enrich the percentage of uranium-235. All enrichment processes, either directly or indirectly, make use of this small mass difference enabling the uranium-235 to be used as a nuclear reactor fuel. *See* FLUORINATION.

**uranium series** *See* RADIOACTIVE SERIES.

**Urbain process** A process used to produce activated charcoal by pulverizing a precarbonized material such as peat or lignite, then heating with phosphoric acid, followed by washing with hydrochloric acid. The process, developed in the 1920s, is named after its inventor Edouard Urbain, who patented many gas treatment processes by carbonaceous materials.

**USGPD** An abbreviation for **US g**allons of oil **p**er **d**ay, it is an Imperial unit of volumetric flow used in the oil industry. *See* GALLON.

**utilities** The services used to support a process such as fuel, heating, cooling, steam, electricity, refrigeration, compressed air, fire water, power generation, instrument tool air, and process water. After the raw materials consumed in a process, they make up the most significant *variable costs in a process. *See* PROCESS ECONOMICS.



**utility flow diagram (UFD)** A type of *engineering flow diagram showing the layout of utility services that connect process equipment. These include steam and condensate lines, water supply and return, air, fuel gas, refrigeration, and flare systems as well as various flush and priming lines for pumps and instruments.

**utility waste** *See* WASTE.

**U-tube manometer** An instrument used to determine the differential pressure between two points such as across an orifice plate in a pipeline. It consists of a U-tube of glass or clear plastic with the top of each vertical leg being attached to the *tapping points across the flow

meter. The U-tube contains a manometric fluid that is opaque, unreactive, has a low volatility, and has a higher density than the process fluid. The difference in levels between the two vertical legs of the manometer provides a measure of the differential pressure. It is also known as a **differential manometer**.

**U-value** The *overall heat transfer coefficient for a heating or cooling system, such as a heat changer, and is a measure of the thermal efficiency of the heat transfer device. It is dependent on the tube and shell side film coefficients as well as the thermal conductivity of the material of the heat exchanger. The SI units are $W\,m^{-2}\,K^{-1}$.

**UV disinfection** A *water-treatment process used to eradicate harmful bacteria and viruses by exposing potentially contaminated water to *ultraviolet radiation. At a certain level of intensity, ultraviolet light is fatal to all microorganisms that inhabit water. Mercury arc lamps are used to generate the ultraviolet radiation with low-pressure lamps being the most common and effective. The lamp is made of fused silica or quartz to allow transmission of the ultraviolet light. The efficiency of UV disinfection is diminished by turbidity and by the build-up of scale on the tubes.

**UVOX process** A process used to purify water using air and *ultraviolet radiation. The ultraviolet radiation converts the oxygen in the air to ozone, which kills the pathogenic organisms in the water as well as other parasitic dissolved matter. It is used for purifying water in swimming pools and other water systems.

SEE WEB LINKS

- Website of UVOX Redox Systems, with page describing UV disinfection and ozone oxidation with UVOX Redox Systems.