V

vacuum A space that is devoid of matter and in which there is a very low pressure of gas. A perfect vacuum contains no atoms or molecules. However, this is not actually obtainable as the surrounding container itself has a finite vapour pressure. A soft or low vacuum has a pressure of around 10^{-2} Pa whereas a hard vacuum is around 10^{-2} to 10^{-7} Pa. An ultra-high vacuum has a pressure below 10^{-7} Pa.

vacuum breaker A method used for pumping liquids out of sealed tanks to prevent a vacuum from forming. It involves the injection of an inert gas, such as nitrogen, to maintain a slight positive pressure.

vacuum distillation A distillation process that operates at a reduced pressure. The effect of the low pressure is to reduce the boiling point temperature of the mixture being separated. This is useful where the materials may be heat-labile, such as the separation of volatiles from fruit juices, or prevent the decomposition or cracking of materials being distilled in crude oil distillation. In the vacuum distillation of petroleum fractions, residues may be used as the feedstock for cracking other products, or may be blended to produce fuel oil or asphalt. *See* MOLECULAR DISTILLATION.

vacuum drying The use of a vacuum for drying foods that are sensitive to temperature. Using a vacuum of 1 to 70 torr (133 to 9,333 Pa) lowers the temperature for vaporization of the moisture in the food. Applied to concentrating fruit juices, it differs from *freeze-drying in that heat is applied to the food material.

vacuum filtration A separation process in which a suspension of solid particles in a liquid is separated using a filter. The filter is used to trap the particles and consists of a wire or fabric mesh or cloth. The rate of filtration is increased by using a vacuum to draw the filtrate through the filter, leaving a cake on the filter. Continuously operated vacuum filters consist of either a rotating drum covered in fabric that drips into the suspension allowing a filter cake to build up and be scraped off, or consists of a slowly rotating flat filter plate in which a vacuum is drawn from the underside. The suspension is dripped onto one location and as the filter plate is rotated, the filtrate is drawn through leaving a cake that is scraped off with a fixed blade at another location. *See* ROTARY VACUUM FILTER.

vacuum pressure safety valve (VPSV) An automatic valve system that relieves the pressure of a gas. It is used for small or negative pressure differences between a vessel and atmospheric pressure.

vacuum pump A type of pump used to reduce the pressure of a gas. Rotary pumps can readily achieve pressures of 0.1 Pa. For very low pressures down to 10^{-7} Pa, a diffusion pump is required. Ion pumps and cryogenic pumps can achieve even lower pressures of 10^{-9} Pa and 10^{-13} Pa, respectively.

valency (valence) The property of atoms or radicals equal to the number of atoms of hydrogen that an atom or group can combine with or displace in forming compounds. Hydrogen therefore has a valency of 1. In ionic compounds, it is equal to the ionic charge. For example, in $MgCl_2$, magnesium has a valency of 1 while chlorine has a valency of 2. In covalent compounds, it is equal to the number of bonds formed. For example, in SO_2, sulphur has a valency of 4 and oxygen has a valency of 2.

validation A documented form of evidence that a process is capable of producing a product to a specified standard or quality. It is used for various manufacturing processes and, in particular, the production of pharmaceutical products. *See* PROCESS VALIDATION.

valve A device used to regulate and control the rate of flow of a fluid. Used in pipes, they consist of a controlled flow area, which is activated electronically, pneumatically, or manually. There are various designs and sizes including butterfly valves, diaphragm valves, ball valves, globe valves, and gate valves. In gate valves, the flow area is adjusted by the movement of a stem to increase or decrease the available area. Globe valves have a ball with a hole that sits in the passage of flow in which the available flow area is adjusted by rotation of the ball away from the axis of the pipe. *See* CONTROL VALVE.

valve tray A perforated plate within a *distillation column that is equipped with caps that lift when the pressure of rising vapour from the tray below exceeds the hydrostatic pressure of the liquid on the tray above. When the pressure falls, the valves drop and cover the perforations, preventing drainage of the liquid.

van Arkel–de Boer process A process once used to produce pure metal, such as tungsten, titanium and zirconium, by the formation of metal iodides followed by their thermal decomposition on a hot tungsten filament. It was developed by Dutch chemists Anton Eduard van Arkel (1893–1976) and Jan Hendrik de Boer (1899–1971). It is also known as the **iodide process** or **crystal bar process**. The process has been replaced by the *Kroll process.

van der Waals, Johannes Diderik (1837–1923) A Dutch physicist and professor at Amsterdam University. He completed a doctoral dissertation in 1873 at the University of Leiden entitled *On the continuity of the liquid and gaseous states*. The significance of this work was to account for many phenomena in vapours and liquids, which had already been observed by Thomas *Andrews (1813–85). Van der Waals derived a new equation of state by postulating the existence of intramolecular forces and a finite molecular volume that predicted more accurately experimental data particularly under conditions near the critical point. He was awarded the Nobel Prize for Physics in 1910 and the weak attractions between molecules called *van der Waals' forces are named after him.

van der Waals' equation A cubic *equation of state developed by *van der Waals, which was an early attempt to describe the behaviour of real gases. The equation allows for the reality of the volume occupied by the gaseous molecules (V–b) where b is a constant appropriate for each gas, and attractive forces between the gaseous molecules, a. Allowing for these two corrections, van der Waals' equation is given by:

$$\left(p-\frac{a}{V^2}\right)(V-b)=RT$$

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

van der Waals' force The weak attractive forces between atoms or molecules. Named after Johannes Diderik *van der Waals (1837–1923), the force accounts for the a/V^2 term in the *van der Waals' equation. These weak forces are inversely proportional to the seventh power of the distance between the atoms or molecules and are responsible for the non-ideal behaviour of gases and for the lattice energy of molecular crystals. Van der Waals' forces are due to dipole–dipole interactions. That is, the electrostatic attractions between molecules.

van Laar equations The equations used for the activity coefficients of the components in a liquid as a function of the composition of the mixture. Developed in 1929 by Dutch chemist Johannes van Laar (1860–1938) for liquid solutions based on the *van der Waals' equation of state, it was based on observations that strongly non-ideal solutions are associated with large heats of mixing. The van Laar equation gives good agreement for many binary mixtures. The equations can be extended to mixtures of more than two components, but the equation becomes unwieldy, and is therefore rarely used beyond binary mixtures.

van't Hoff, Jacobus Henricus (1852–1911) A Dutch professor of chemistry in Amsterdam, and then Leipzig and Berlin, who had studied in Holland, France, and Bonn. He began his research at twenty years of age and his simple theory that the four valency bonds of a carbon atom are directed to the four corners of a tetrahedron explained asymmetrical carbon compounds and established stereochemistry in 1874. In 1886 he explained osmosis, and showed the connection between osmotic and gas pressures, which led to the *Arrhenius' theory of electrolytic dissociation. He received the first Nobel Prize in Chemistry in 1901.

van't Hoff's isochore An equation formulated by *van't Hoff for the variation of the equilibrium constant in a chemical reaction with temperature:

$$\frac{d\log_e K}{dT} = \frac{\Delta H}{RT^2}$$

where K is the equilibrium constant, R is the gas constant, T is the thermodynamic temperature, and ΔH is the enthalpy of the reaction.

vaporization The process of changing a substance into a vapour or into the gaseous state.

vapour A gaseous state of matter that can be reduced to a liquid by way of condensation. A vapour is therefore a gas below its critical temperature.

vapour-absorption cycle A thermodynamic cycle used in refrigeration systems. It has no moving parts and energy is supplied as heat either by an electric heater or a gas burner. Ammonia is usually used as the refrigerant. The absorption cooling cycle has three phases: the liquid refrigerant is evaporated to a vapour thereby extracting heat from its surroundings providing the refrigeration effect; the vapour is then absorbed into another liquid; the refrigerant-containing liquid is regenerated by heating, releasing the refrigerant. The adsorption refrigerator was invented by French engineer Ferdinand Philippe Edouard Carré (1824–1900).

vapour cloud explosion (VCE) An explosion resulting from the ignition of a large cloud of flammable vapour in air. It may involve in excess of one tonne of explosive fuel. The effect of the explosion results in significant overpressure and may be more serious than the fire since it has the potential to cause fatalities more readily due to the rapid release of energy, giving little to no time for evasive action to be taken by personnel.

vapour-compression cycle A thermodynamic cycle used in refrigeration systems. It uses a volatile liquid refrigerant, which is pumped through the cooling coils of an evaporator where the latent heat used in its evaporation cools the materials requiring refrigeration. The vapour is then compressed to a high pressure by a compressor and then condensed in a condenser back to a liquid, liberating heat. The liquid refrigerant is contained in a storage vessel before finally passing through an expansion valve to reduce its pressure and being pumped back to the evaporator and the cycle repeated. In a domestic refrigeration system, the cycle is repeated until the temperature reaches the desired level of around 4°C in the cool box and –18°C in the freezer compartment. A thermostat is used to maintain a steady state by turning the compressor on and off. *See* REFRIGERATION.

vapour density The ratio of the density of a vapour or gas to hydrogen at the same temperature and pressure. The vapour ratio is therefore equal to the ratio of the mass of the vapour or gas to the mass of hydrogen occupying the same volume for the same temperature and pressure.

vapour–liquid equilibria (VLE) The relationship between a liquid and its vapour at equilibrium. At a given temperature and pressure, the composition of the vapour will be determined by the composition of the liquid. The relationship between the two is frequently expressed using K-factor values of the components involved. For binary components A and B showing ideal behaviour, the relative volatility, α_{AB}, can be used where the mole fraction of the vapour of the more volatile component y_A is related to the liquid mole fraction x_A by:

$$y_A = \frac{\alpha_{AB} x_A}{1 + x_A(\alpha_{AB} - 1)}$$

There are various liquid activity models available including Margules, van Laar, Wilson, non-random two-liquid (NRTL), and universal quasi-chemical (UNIQUAC) models. Mixing rules are used for mixtures to combine pure component parameters.

vapour–liquid separator A vessel used to separate a vapour–liquid mixture. The vessel is designed to allow the liquid to settle under the action of gravity, accumulating at the bottom of the vessel, where it is withdrawn, while the vapour travels upwards at a design velocity that minimizes the entrainment of any liquid droplets in the vapour.

vapour pressure The pressure exerted by the vapour of a solid or a liquid in which it is in contact and at equilibrium for a specified temperature. The vapour pressures of pure substances can be obtained from published data or from empirical equations such as the *Antoine equation. The *Clausius–Clapeyron equation can also be used but is less accurate. The vapour pressure can be lowered by the addition of a solute. This is related to the decrease in freezing point and increase in boiling point.

vapour recovery unit (VRU) The part of a *fluidized catalytic cracker unit in which light hydrocarbon gases are produced by the cracking process, compressed, and then separated into different product streams.

variable A mathematical expression representing either a general point taken from a specific set of values, or as a name for an unknown point to be determined from within a specified set of possible values. **Dependent variables** have values that are influenced by changes in other values, whereas **independent variables** are not influenced.

variable area flow meter A type of flow meter used for the measurement of flow of gases and liquids by virtue of the elevation of a solid float within a vertical, tapered

tube. The tube is usually made of glass while the float is made of metal, ceramic, or plastic with a float density greater than that of the fluid. The float is usually bomb-shaped having a cylindrical body with a coned bottom and short top piece, which is slightly larger in diameter and often grooved to encourage the float to spin, thereby improving stability due to a gyroscopic effect. The upwards flow of the fluid causes the float to rise and reach an equilibrium elevation. The flow is read from a calibrated scale on the tube. There is a roughly linear variation of mass flow rate with float position in the tube. In practice, a scale is marked on the tube. Calibration curves are used for a particular fluid, temperature, and float. Unlike the *venturi or *orifice type flow meters, it operates with a fixed pressure drop across the float and has a variable area around the float. The ***Rotameter** is a registered name for a type of variable area flow meter.

variable costs The costs of a process that include the cost of raw materials and all other chemicals that are consumed in the process such as catalysts, the cost of the utilities such as steam, electricity, fuel, cooling water, process water, compressed gases, etc. The variable costs also include *unscheduled maintenance costs, royalties, licence costs, transportation costs, and costs associated with quality control and other forms of monitoring. The variable costs of a process are dependent on the rate of production. The sum of the *fixed costs and variable costs is the total cost of the process. *See* PROCESS ECONOMICS.

variance A statistical measure of the dispersion of a set of data from the mean. The variance is equal to the square of the *standard deviation and is used to distinguish between probability distributions.

VCE *See* VAPOUR CLOUD EXPLOSION.

vector 1. A representation of a quantity having both magnitude and direction. Force, velocity, and acceleration are all vectors. **2.** A carrier of genetic material such as a bacteria carrying recombinant DNA fragments for another microbial species.

vector analysis A quantity with magnitude and direction. Examples include force, velocity, acceleration, and momentum. The decomposition of a vector in three dimensions may be written as:

$$v = iv_x + jv_y + kv_z$$

where i, j, and k are unit vectors in the x, y, and z direction, and v_x, v_y, and v_z are the scalar magnitudes of v's components in these directions.

velocity The speed of a body in a given direction. Velocity is thus a vector quantity, whereas speed is a scalar quantity.

velocity gradient The deformation of a fluid under the influence of a shearing force presented as the change in velocity of the fluid perpendicular to the flow.

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

It is also known as the *shear rate.

velocity head The kinetic energy of a moving fluid expressed in head form:

$$h = \frac{v^2}{2g}$$

It is therefore seen as the equivalent height of a column of the fluid if it were brought to rest. The velocity head can be used directly in the *Bernoulli theorem. The SI unit is m.

vena contracta The minimum flow area formed downstream by a fluid flowing through a sharp-edged opening. It literally means 'contracting veins'. It is seen in a freely discharging jet of liquid just beyond the opening where the flow lines converge.

vent An opening from a vessel. It usually consists of a short tube and opens to the atmosphere to allow the pressure of the vessel to attain atmospheric pressure within. It is required to be of adequate capacity and free from blockage. Appropriate safeguards are often used in vessel design and operation, such as multiple vents, flame arresters, and the addition of inert gas.

venturi effect The phenomenon in which a fluid flowing through a restriction increases in velocity with a corresponding decrease in pressure. It is named after Italian physicist Giovanni Battista Venturi (1746–1822).

venturi meter A fluid flow-measuring device that consists of a tapered tube to form a throat such that the increase in velocity results in a decrease in pressure, known as the *venturi effect. The differential pressure produced by the flowing fluid through the throat gives a measure of the rate of flow. The pressure differential can be measured using manometers or other types of pressure measurement devices attached both upstream and at the throat. In practice, the theoretical rate of flow through the device is not achieved as friction in the device is ignored. To allow for this difference, a correction factor known as a coefficient of discharge is used. For a well-designed venturi, the coefficient lies between a value of 0.95 and 0.98. It is named after Italian physicist Giovanni Battista Venturi (1746–1822).

venturi scrubber A device used for gas cleaning in which a liquid is injected at the throat of the venturi, and due to the high velocity of the gas to be cleaned, it disintegrates into droplets. These droplets then collide with smaller droplets, particles, or gases to be absorbed, which are then collected in a cyclone or demister device downstream.

Verneuil process A process used to produce synthetic gemstones that was developed in 1902 by French chemist Auguste Victor Louis Verneuil (1856–1913). It involves melting finely powdered materials using an oxy-hydrogen flame and crystallizing the droplets on a seed crystal. It is used to make ruby, sapphire, and forms of corundum.

vertical tube evaporator A device used to concentrate a solution by boiling and evaporation, and consists of vertical tubes that are heated by steam. In short tube evaporators, steam used as the heating medium is contained within the tubes, whereas in long tube evaporators, the product is contained within the tubes and external heating by steam is used.

vessel A general name for a receptacle used to contain a liquid, solid, or gas.

vibromixer A type of low shear mixer used to mix shear-sensitive biological reactions and polymer solutions. It consists of a disc with a conical perforation, perpendicularly

attached to a shaft that moves up and down with a controlled frequency. The turbulence is increased by adjusting the amplitude and frequency of the translatory movement.

view factor The fraction of thermal radiation leaving a surface that is intercepted by another surface. The view factor depends only upon the geometric arrangement of the surfaces, and satisfies the reciprocity relation:

$$A_i F_{ij} = A_j F_{ji}$$

where A_i is surface i and F_{ij} refers to the fraction of radiation that leaves surface i and is directly intercepted by surface j. The view factor has a numerical value of between 0 and 1. Tables and equations are available for calculating the view factors of some simple and most commonly encountered geometries. It is also known as the configuration factor or shape factor.

virial equation of state A power-series expansion of the compressibility for a substance expressed in terms of molar density:

$$Z = 1 + B\rho + C\rho^2 + D\rho^3 + \ldots$$

The equation assumes that the compressibility is unity for zero density. The coefficients B, C, and D are known as the second, third, and fourth **virial coefficients**, and are functions of temperature. It is used to fit experimental PVT data of compressed real gases. The equation was originally known as the Kammerlingh–Onnes equation.

visbreaking A *thermal cracking process that involves reducing the viscosity of petroleum residues from heavy atmospheric or vacuum still bottoms. The purpose is to produce distillate products that can reduce the viscosities of hydrocarbon distillation residues used for producing fuel oil blends. It involves a high temperature, non-catalytic process in the presence of steam.

viscoelasticity The property of certain materials to exhibit both viscous and elastic behaviour when deformed under an applied shear stress. Some complex polymer solutions exhibit viscoelasticity.

viscometer An instrument used to measure the viscosity of a liquid. Rotational type viscometers include concentric cylinders, and cone and plate instruments. They operate at constant speed, which defines the shear rate. The liquid forms a continuous film between the rotating element and the stationary element. The torque to resist the motion defines the shear rate. The Ostwald viscometer, which is used to measure the viscosity of liquids, consists of a bulb into which the liquid is filled and is allowed to flow under gravity through a capillary tube. It is the time taken for the meniscus to reach a mark on the capillary from which the viscosity can be calculated. A falling-sphere viscometer is based on *Stokes's law, which consists of timing a steel sphere at its terminal velocity under the influence of gravity through the liquid.

viscometry The study of the deformation and flow of fluids that considers only shearing stresses. *Compare* RHEOMETRY.

viscose process A process that is used in the production of regenerated cellulose fibres in a product known as rayon. Cellulose is obtained from wood or cotton and reacted with sodium hydroxide. The alkali cellulose is then dissolved in carbon disulphide to produce cellulose xanthate, which is dissolved in a solution of sodium hydroxide. The injection of

this solution into an acid bath produces the regenerated cellulose product. It is known as viscose on account of its high viscosity. The process was invented in 1882.

viscosity A measure of the flow transport behaviour of a fluid. It is the phenomenon in which a fluid will withstand a slight amount of molecular tension between particles, which will cause an apparent shear resistance between two adjacent layers. The term 'viscosity' is used to describe the fact that certain fluids flow easily, such as gases, water, and mercury, while others do not, such as tar, treacle, and glycerine. These fluids are broadly classified as thin and thick fluids. Sir Isaac *Newton (1642–1727) proposed that the shear stress is proportional to the velocity gradient or shear rate. By considering a fluid sandwiched between two parallel plates set at a distance dz apart in which the upper plate moves with some small velocity dv in comparison with the lower plate, there will be a small resisting force over the plate area due to viscous frictional effects in the fluid. This force per unit area of plate (F/A) is known as the shear stress, τ. Newton's law of viscosity is therefore given as:

$$\tau = \mu \frac{dv_x}{dz} \text{ which is sometimes written as } \tau = \mu\dot{\gamma}$$

The proportionality constant, μ, is known as the coefficient of dynamic viscosity and is also known as the absolute or dynamic viscosity of the fluid; it is influenced by process conditions such as temperature. In the case of Newtonian fluids, μ is a constant. Examples of Newtonian fluids include water, ethanol, and benzene. The viscosity of a fluid may, however, not always be constant for certain fluids for different applied shear stresses. These fluids are known collectively as non-Newtonian fluids. In such cases, the term 'apparent viscosity' is conveniently used. Examples of non-Newtonian fluids include paint, polymers, most slurries, and many foodstuffs. The calculation remains the same and is the ratio of shear stress to shear rate. In SI units, it has examples of non-Newtonian fluids include paint, polymers, most slurries, and many foodstuffs. the units $kgm^{-1}s^{-1}$ or using derived SI units Nsm^{-2} or Pa.s. In the c.g.s. system it is measured in poise (P) or centipoise (cP), where 1 cP is equivalent to 10^{-3} Nsm^{-2}. The viscosities of gases are significantly less than for liquids. Oils, such as olive oil, are an order of magnitude higher than liquids such as water. In general, high-viscosity fluids can be considered in the order of 10 Nsm^{-2} and above. *See* KINEMATIC VISCOSITY.

viscous force The drag effect that occurs on a body when placed in a viscous fluid. For two parallel plates sandwiching a viscous fluid, the viscous force is proportional to the difference in velocity between the two plates.

VITOX process A process used in sewage treatment and other microbiological processes in which oxygen is added through the throat of a *venturi to form fine bubbles to aid oxygen transfer. Unlike the *UNOX process, the VITOX process uses open tanks.

vitrification A high-temperature process used to convert highly radioactive liquid waste into glass form for long-term storage purposes. The process heats the material to 1,100°C, evaporating the liquid either to the glass transition temperature to form an amorphous solid that is free from a crystalline structure, or is added to molten glass. In both processes, the molten glass is loaded into steel containers. The hardened glass material is therefore free from leakage and can be stored in safe and secure underground repositories.

VLE *See* VAPOUR–LIQUID EQUILIBRIA.

voidage The space between solid particles expressed as a percentage or fraction of the total volume. The voidage of a *packed bed is used to indicate the available space for the

flow of gas or liquid for chemical reaction. For spherical particles packed in face-square arrangement in which each particle touches six others, the voidage is 0.46. *Compare* POROSITY.

volatility The tendency and measure of the ability of a liquid to go into the vapour phase expressed as the ratio of the mole fraction in the gas phase (y_A) to that in the liquid phase (x_A):

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

The *relative volatility is a comparison of the lightness of two components and can be found by taking a ratio of the vapour phases of the two components.

volt (Symbol V) The derived SI unit of electrical potential defined as the potential difference between two points on a conductor carrying a current of one ampere when the power dissipated between the points is equal to one watt. It is named after Italian physicist Count Alessandro Volta (1745–1827).

voltaic cell A device that produces an e.m.f. as the result of a chemical reaction that takes place within it. The reaction takes place at the surface of two electrodes, each of which is immersed in an electrolyte. It was devised by Italian physicist Count Alessandro Volta (1745–1827). It is also known as a *galvanic cell.

voltaic pile An early form of battery that consists of a number of dissimilar metals such as copper and zinc with each pair being joined in series by paper pads moistened with an electrolyte. It was devised by Italian physicist Count Alessandro Volta (1745–1827).

volume The three-dimensional space enclosed within or occupied by a body. For example, the volume occupied by a cylindrical vessel is equal to the cross-sectional area multiplied by the length. The volume occupied by a liquid can be determined from its mass divided by its density. The SI unit is m^3.

volumetric analysis A method of chemical analysis that involves measuring volumes of liquids or gases, such as titration.

volumetric efficiency (Symbol η) Used to quantify the efficiency of fans, blowers, compressors, and pumps. It is ratio of the volume of a fluid discharged divided by the volume displaced by the moving part during the same time.

volumetric flow rate The volume of a fluid that passes a given surface per unit time. SI units are $m^3 s^{-1}$.

volumetric flux The volumetric flow rate of a fluid per unit area. It is also known as the *superficial velocity and used in multiphase flow systems, such as gas and liquid flow through pipelines. The SI units are $m\ s^{-1}$. The integration of the volumetric flux over a flow area gives the *volumetric flow rate.

volumetric oxygen transfer coefficient (Symbol k_La) A measure of the capacity of a bioreactor, or any other aeration reactor or system, to transfer oxygen from air into a liquid phase. It is the product of the oxygen transfer coefficient k_L and the interfacial area, a, between the air bubbles and the liquid, per unit volume of the liquid.

volute chamber A spiral-shaped casing around the impeller of a centrifugal pump. It is used to convert kinetic energy of the moving fluid into pressure energy at the point of discharge.

von Kármán, Theodore (1881–1963) A Hungarian-American mathematician and physicist noted for his significant contribution to advances in aerodynamics, and in particular on supersonic and hypersonic airflow behaviour. Born Szőllőskislaki Kármán Tódor, he studied engineering in Budapest before moving to Germany to join *Prandtl at the University of Göttingen. He emigrated to the US in 1930 to become director of the Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT). At the age of 81, he was the recipient of the first National Medal of Science, presented by President John F. Kennedy.

vortex A rotating fluid. *See* FREE VORTEX; FORCED VORTEX.

vortex breaker A device used in tanks and vessels to prevent the formation of a vortex when discharging through an orifice. It typically consists of a cross of vertical plates or baffles on the outlet from a vessel.

vortex flow meter An instrument used to measure the volumetric rate of flow of a fluid and is based on the principle that the velocity is directly proportional to the frequency at which vortices are shed from a body in a flow stream. One design relies on a body that lies in the direction of flow to generate vortices that are detected with the aid of a capacitive transducer, which consists of two electrodes separated from two welded diaphragms by a dielectric of fluid. When the fluid flows, vortices cause asymmetric movement of the diaphragms varying the capacitances generating a current output.

vortex shedding An unsteady and oscillatory flow behaviour of a moving fluid around a body in which vortices are formed at certain velocities. The vortices are formed on the downstream side of the body and become detached from either side of the body known as a **von Kármán vortex street**. The body will tend to move towards the region of low pressure and forms the basis of a vortex-shedding flow meter. The vibrating oscillations are also responsible for the whistling sound of overhead power lines. Tall stacks and chimneys are protected from the potentially destructive oscillatory effects by the use of helical fences known as strakes or spoilers.

VPSV *See* VACUUM PRESSURE SAFETY VALVE.

VRU *See* VAPOUR RECOVERY UNIT.

vulcanization A process for hardening rubber and improving its elasticity by heating it with sulphur or sulphur compounds such as sulphur monochloride. The process involves cross-linking the polymer chains, adding strength to the rubber, and acting as a form of 'memory' that allows the polymer to recover to its original shape after stretching. The process was invented in 1839 by the American Charles Goodyear (1800–60).

W

Wacker process 1. A catalytic process used to oxidize aliphatic hydrocarbons such as ethylene to ethanol, aldehydes, and ketones using oxygen. The process uses an aqueous solution of mixed palladium and copper chlorides either in solution or on a support of activated carbon through which the ethylene is bubbled. The process was invented in 1957 and is named after the chemical company. **2.** A process used for the production of sodium salicylate through the reaction of sodium phenate and carbon dioxide.

Waelz process A process used for the extraction of zinc and lead from ores using a rotary kiln. Zinc is still largely extracted from ores although around 40 per cent of zinc is recycled from galvanized steels and other scrap metals. A high-temperature rotary Waelz kiln is used to convert zinc dust from electric arc furnaces into zinc oxide, which is then converted to zinc metal. The process of zinc volatilization was first proposed in 1881.

Walker process A catalytic oxidation process used to partially oxidize natural gas or LPG to form a mixture of methanol, formaldehyde, and acetaldehyde. The process uses oxygen in the form of air and aluminium phosphate as the catalyst. It was developed in the 1920s and is named after its inventor J. C. Walker.

wall shear stress (Symbol τ_w) The shear force applied to a flowing fluid at the point of contact with a surface. Where it is assumed that the wall shear stress is proportional to the kinetic energy of the moving fluid per unit volume, the proportionality constant is known as the *Fanning friction factor, f. That is $\tau_w = f\rho v^2/2$ where ρ is the density of the fluid and v is the velocity. The SI units are N m^{-2}.

washback *See* FERMENTATION.

washings The liquid waste stream leaving a process in which a liquid has been in contact with a solid for the purposes of extraction and leaching. In a multistage washing process operated with countercurrent flow in which the liquid flows in the opposite direction to the flow of process stream, the liquid becomes progressively more dilute.

Washoe process A process used to extract silver from sulphide ores. It involves heating the ores with a solution of sodium chloride in an iron vessel. The sodium chloride dissolves the silver while the iron reduces it. It was invented in 1860 and is named after the district in Nevada in the US where the ore was originally mined.

waste The material left over from a process that no longer has an economic value nor has potential as a valuable resource. Its lack of value may be the result of difficulties in recovery that may be otherwise uneconomic, expensive to transport, or possess hazardous properties. **Process waste** is waste generated from within a process such as from by-products in reactors or loss of solvents from separations and recycle systems, whereas **utility waste** is

waste generated through the provision utility services to the main process such as waste from steam boiler *blowdown or heat loss from a heat exchanger network.

waste heat The generation of low grade heat from a process discharged into the environment. The excess heat is produced due to the low efficiencies of thermodynamic cycles used in nuclear and thermal power stations. The efficiency of power generation is the electrical energy generated to the heat generated. The waste heat can be partly recovered and reused such as by using *waste heat boilers.

waste heat boiler A type of boiler used to produce very hot water or to raise steam using hot by-product gases or hot liquids from a chemical process. By recovering the waste thermal energy, the thermal efficiency of a process is improved. The hot water and steam can be used for other useful purposes elsewhere, such as for heat transfer.

waste management The methods and procedures used to dispose of waste materials arising from chemical processes. All chemical processes produce waste in various forms and at the various stages of production and materials transportation. The objectives of the management of waste materials are to minimize responsibly the impact on the environment and human health, and to conserve scarce resources, as well as to maximize waste reuse, reclamation, and recycling. In the case of nuclear waste, the material is categorized in terms of its radioactivity and the waste managed accordingly. Low radioactive waste may go to landfill, medium radioactive waste can be recycled, and highly radioactive waste, which poses a serious risk to the environment and human health over very long periods of time (tens of thousands of years for some isotopes), is stored in deep caverns in geologically stable rock.

water A colourless, odourless, tasteless, and non-flammable liquid with the chemical formula H_2O that covers two-thirds of the surface of the planet. With a freezing point of 0°C and boiling point of 100°C at atmospheric pressure, it is used in huge quantities in the chemical industry. It is the most commonly used solvent and has the ability to dissolve a wide range of materials. It is also extensively used as a heat transfer medium for both heating and cooling purposes. It can be converted to ice or to steam, and in some cases a supercritical state is used as a solvent. It is also used as a transport medium in conveying other materials, and widely used in cleaning process plant equipment and process materials. Depending on the application, water quality is an important consideration and there is increasing pressure to reduce the amount of water that is used. The cost of transportation and scarcity are also increasingly important considerations.

water activity (Symbol a_w) A measure of the amount of water in a substance such as food and expressed as an equilibrium relative humidity. That is, it is the vapour pressure of water in the substance or in a solution divided by the vapour pressure of pure water at a particular temperature. Distilled water therefore has a water activity of unity. Since contaminating microorganisms in foods are dependent on the amount of available water, water activity is a useful parameter in controlling the growth of microorganisms.

water gas A mixture of carbon monoxide and hydrogen gas produced by the exothermic reaction of steam on heated carbon:

$$C + H_2O_{(steam)} \rightarrow CO + H_2$$

Water gas burns with a non-luminous bluish flame and is also known as **blue water gas**. Water gas was once produced from coke, and was in turn produced from coal. Prior to the use of steam reforming of natural gas, the main use before the Second World War was for

the production of hydrogen in the *Haber process and was combined with the *water-gas shift reaction to increase the amount of hydrogen produced.

water-gas shift A catalytic process used to convert carbon monoxide gas to carbon dioxide and hydrogen using steam:

$$CO + H_2O_{(steam)} \rightarrow CO_2 + H_2$$

The reaction takes place in a fixed bed reactor known as a **water-gas shift reactor**. It uses a mixed catalyst of iron and chromium oxides. The reaction is exothermic and is completed either before or after the acid gas removal. The products are known as *synthesis gas or **syngas**, for short.

water hammer A violent and potentially damaging shock wave in a pipeline caused by the sudden change in flow rate, such as by the rapid closure of a valve. The effect is avoided by controlling the speed of valve closure, lowering the pressure of the fluid, or lowering the fluid flow rate.

water pollution The presence of harmful or objectionable material in water in sufficient quantity so as to cause a change in its chemical, physical, biological, or radiological quality that may be injurious to its existing or intended potential use. This includes use for human consumption and general domestic use for washing, cooking, etc., industrial use, aquatic organism health such as fish, and ecosystem health such as rivers, lakes, and sea.

water treatment A process used to improve the quality of water by removing or reducing the presence of pollutants so that the water is fit for purpose, such as being potable and fit for human consumption, for industrial use, or for release into the aquatic ecosystem. A water-treatment plant involves the separation of solids from wastewater by sedimentation and flocculation, and reducing the *BOD.

water vapour The gaseous state of water dispersed with air at a temperature below the boiling point of the water. The amount present in air is designated by the humidity. The *relative humidity is the amount of water vapour in a mixture of dry air. A relative humidity of 100 per cent corresponds to the partial pressure of water vapour being equal to the equilibrium vapour pressure, and depends on the temperature and pressure.

Watt, James (1736–1819) A Scottish engineer who made a significant improvement to the Newcomen steam engine. The Watt engine proved so effective that he is credited with the invention of the steam engine, since it may be argued that the Newcomen engine is essentially only a pump. He was therefore instrumental in the Industrial Revolution in Great Britain and around the world, since factories no longer needed to be tied to locations where there was a strong source of water power. Massive machines could therefore be built and housed in factories which proved to be the dawn of mass production.

watt (Symbol W) An SI unit of power defined as the rate of energy output or consumption of one joule per second. The power consumed over a period of time is measured in watt-hours. The watt is named after Scottish engineer James *Watt (1736–1819) who developed a steam engine to replace horses in coal pits. The term *horsepower was used by Watt to demonstrate the equivalent power of his new machine, where one horsepower (hp) is equal to 746 watts.

watt-hour A unit of energy expressing the power in watts used over a period of time of one hour. The consumption of electricity is often expressed in kilowatt-hours or kWh.

wavelength (Symbol λ) The distance between each crest or trough of a wave. It is related to frequency, *f*, by the velocity of the wave, *v*, as:

$$\lambda = \frac{v}{f}$$

wavy flow A type of stratified two-phase fluid flow in a horizontal pipe in which waves form at the surface between a liquid and gas or vapour. This type of fluid occurs where there is a notable difference between the superficial velocities of the vapour or gas and the liquid sufficient to cause waves to form. It is also known as the **stratified-wavy flow regime**.

wax A solid or semi-solid substance with may be either a monoester of fatty acids or a mixture of hydrocarbons of high molecular weight. As a monoester, such as beeswax, the acid and alcohol proportions both have long saturated carbon chains:

$$C_{25-27}H_{51-55}COOC_{30-32}H_{61-65}$$

Waxes are used to make polishes, cosmetics, pharmaceutical preparations, ointments, and candles. In nature, waxes coat leaves and stems in plants that grow in arid conditions and have a protective effect.

WCEC *See* WORLD CHEMICAL ENGINEERING COUNCIL.

Weber number A dimensionless number, We, used in thin film gas–liquid flows where surface tension has a major effect on the strongly curved interface between two fluids such as in the formation of droplets and bubbles. It is a measure of the relation between surface tension and gravity forces:

$$We = \frac{\rho v^2 l}{\sigma}$$

where ρ is the density of the fluid, v is the velocity, l is the characteristic dimension such as droplet diameter, and σ is the surface tension. It is named after German engineer Moritz Weber (1871–1951).

weeping A phenomenon that occurs in a distillation column in which liquid on a sieve plate passes down through the perforations intended for the vapour to pass up. Weeping occurs when the velocity of the upward vapour is too low. This may be caused by insufficient boil-up.

weight The property of a body to exert a force due to the influence of gravity $F = mg$. The SI unit is the newton (N). *Compare* MASS.

weir A vertical obstruction across a channel carrying a liquid over which the liquid discharges. In a distillation column, a weir is used to retain an amount of liquid on a sieve tray or plate. While the vapour enriched with the more volatile component rises up through the perforations on the sieve tray or plate, the liquid cascades over the weir into the *downcomer to the tray below. The **weir crest** is the top of the weir over which the liquid flows.

Weissenberg effect A phenomenon that occurs when a spinning rod is placed into a liquid polymer solution. Molecular entanglements within the polymer cause the polymer chains to be drawn towards the rod and appear to climb up the rod instead of being thrown

outwards and away from the rod. It is named after Austrian physicist Karl Weissenberg (1893–1976).

Weizmann process A fermentation process used to produce acetone, butanol, and ethanol using the acid-resistant bacterium *Clostridium acetobutylicum*. The bacteria derived from soil and cereals is able to convert whey, sugar, and starch. The process was developed by Russian-born chemist Chaim Weizmann (1874–1952) and was used in the UK in the First World War for the production of acetone, which was used in the production of cordite. He became a UK citizen in 1910 and then the first president of Israel in 1949. The process is also known as the **ABE fermentation**.

weld The attachment of two metal surfaces by the use of heat to melt and fuse the metals.

well A natural oil or gas reservoir that exists below a layer of sedimentary rock. *Wildcat wells are the first wells to be drilled in a particular geographic location. **Appraisal wells** are drilled after hydrocarbon has been identified. **Development wells** are drilled according to a predetermined pattern to maximize the amount of oil hydrocarbon that can be recovered. This is based on available seismic surveys and other geological data. **Injection wells** are used for the injection of fluids into the reservoir for enhanced oil hydrocarbon recovery. The **wellhead** is the top of the oil or gas well.

Wellman–Lord process A process used for flue gas desulphurization. Sulphur dioxide in the flue gas is absorbed in sodium sulphite in a wet spray scrubber column forming sodium bisulphite:

$$Na_2SO_3 + H_2O + SO_2 \rightarrow 2NaHSO_3$$

The solution is regenerated by heating the solution to release the sulphur dioxide and then either collected or used in the production of sulphuric acid. The sodium sulphite is returned to the process.

Welsh process A copper smelting process used in South Wales that originates from the early eighteenth century and was used through to the end of the nineteenth century. It used a furnace in which roasting, fusing, and refining were carried out. The process was superseded by bigger furnaces.

SEE WEB LINKS

- Official website of the Copper Development Association Inc., Education pages.

West Texas Intermediate A grade of crude oil used as a benchmark in oil pricing. Also known as Texas light sweet, it has a relatively low density and low sulphur content. Other price benchmarks include Brent crude and Dubai crude.

wet and dry bulb hygrometer *See* HYGROMETER.

W

wet basis A method of representing the moisture content of a substance in which the amount of water is taken as a ratio of the combined amount of substance and water. The moisture content of a very wet substance on a wet basis will approach but not equal 100 per cent. *Compare* DRY BASIS.

wet bulb temperature The temperature indicated by a glass bulb thermometer whose surface is kept wet by a thin film of liquid, usually water, and which is exposed to a current of

air. It is therefore the dynamic equilibrium temperature attained by a liquid surface subject to the action of a rapid stream of gas. The use of both wet and dry bulb temperature is used to determine the *humidity of a gas such as water vapour in air for a particular temperature and pressure. The difference between the wet and dry bulb temperatures is known as the **wet bulb depression**.

wet gas 1. A term used to describe light hydrocarbon gas dissolved in heavier hydrocarbons. Wet gas is an important source of LPG. **2.** Water that is present in natural gas in offshore platforms. It is necessary to remove the water from the gas for export through subsea pipelines. The pipeline is dosed with corrosion inhibitors to prevent hydrate formation.

wet process 1. A process used to remove the skin of coffee cherries before they are dried. The cherries are immersed in water to separate unripe fruit before pressing. The pulp is fermented to digest the cellulose using large amounts of water. The **dry process** uses only the juices from the cherries. **2**. A process used to produce phosphoric acid from phosphate rock using a strong acid such as sulphuric, nitric, or hydrochloric acid. Sulphuric acid is used to digest tricalcium phosphate mineral rock, apatite, to produce a solution of phosphoric acid and insoluble calcium sulphate. This is then concentrated by evaporation.

wet scrubbing A process used to remove polluting or harmful gases and particles from a gas stream. For example, carbon dioxide can be removed from a flue gas stream by solvent extraction using an amine solution such as methyl diethanolamine to form a stable salt. The rate of absorption increases with the amine concentration. The amine solution can be regenerated by heating. *Compare* DRY SCRUBBING.

wet steam A mixture of droplets of water and steam that are both at the saturated temperature. If additional heat is added at constant pressure, the temperature remains constant until the point where all the water has evaporated and converted into saturated steam. Beyond this saturation temperature, the steam becomes superheated. The *quality of the steam is the amount of water in the steam.

wetted perimeter The part of the cross section of a pipe or channel that is in contact with a liquid.

wetting agent A surface active agent that reduces the surface tension of a liquid. It has the effect that small amounts of a wetting agent cause the liquid to spread out over a flat surface.

whisky (whiskey) A distilled spirit made from a fermented mash of sugars derived from cereal. Scotch malt whisky and Irish whiskey are made from malted barley from which the starch is converted to sugars through germination. Bourbon whiskey is made from a grain mixture containing at least 51 per cent corn. Rye whiskey is made from at least 51 per cent rye grain. The malting process releases enzymes used to convert the starch to sugars. It is then roasted and mashed as a fermentation that converts the sugars into alcohol. The fermented wort liquid is distilled and the distillate collected. Maturation takes place in wooden casks. For Scotch whisky, this must be for a minimum of three years. Single malt whisky is from a single distillery. Most whiskies are blended.

Whitman two-film theory A theory used in gas adsorption to describe the mass transfer of a solute from a gas into a liquid in which either side of the interface exists a stagnant gas film and a similar stagnant liquid film (see Fig. 57). The two films are assumed to offer the only resistance to mass transfer. In the bulk gas and liquid, the solution partial pressure

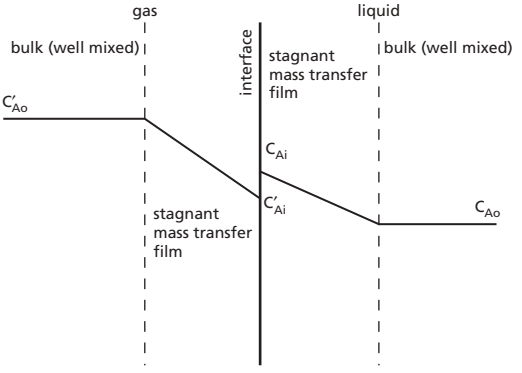

Fig. 57

and concentration are considered to be constant. At the interface, they are assumed to be in equilibrium. It was developed by W. K. Lewis and W. G. Whitman in 1924.

whole numbers The set of integers {1, 2, 3 . . . } excluding zero.

Wien's displacement law A law that states that the most strongly emitted wavelength in the continuous spectrum from a full radiator is inversely proportional to the absolute temperature of that body (see Fig. 58). $\lambda T = b$ where b is Wien's constant equal to 2.898×10^{-3} m K. The maximum temperature in the spectral distribution from a *black body is therefore displaced towards the shorter wavelengths with increasing temperature. For example, an electric bar heater emits no colour when cold and on heating initially glows red and is white (i.e. a mixture of all coloured light) when very hot. The law was stated by German physicist Wilhelm Wien (1864–1928).

wildcat well An oil and gas exploration test *well. Not all drilling operations are successful. Where oil or gas is found in the wildcat, a series of appraisal wells are drilled at locations to represent the boundaries of the field before a permanent installation is located in position.

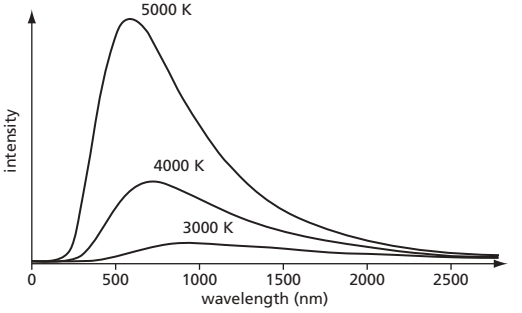

Fig. 58

Wilke–Chang correlation A semi-empirical correlation used for the estimation of the diffusion coefficient of a substance present in infinite dilution in a solvent.

Windscale nuclear accident The UK's worst nuclear accident, which occurred on 10 October 1957 at the Windscale nuclear power station at Sellafield. The first of two *atomic piles, built in 1950 and 1951 as part of Britain's atomic weapons project, caught fire releasing radioactive material into the environment. The 120-metre-high piles were solid graphite moderated and air cooled with horizontal channels within which uranium cartridges could be passed and exposed to neutron radiation to produce plutonium. After the accident, pile one was sealed and pile two was permanently shut down shortly after.

wine A fermented product made from fermented sugar derived from grapes. The process involves harvesting grapes, from which the juice is extracted using roller or rotary paddle crushers. White wine involves filtration and centrifugation of the skins and pulp whereas red wine does not. Fermentation takes place in vessels that were traditionally made of wood but large-scale processes now use stainless steel. Water and yeast are added to convert the sugar to alcohol. Sulphur dioxide is added to control potential contamination by bacteria. The fermentation is maintained at a controlled temperature and may last several days to two weeks, at the end of which yeast and any other solid material is removed by racking. The wine is clarified by filtration and fining using bentonite clay or some other absorbing material. The wine is stored at a controlled temperature for several months and bottled.

Winkler process An early coal gasification process that uses air and steam in a fluidized bed operated at atmospheric pressure. The air provides the oxygen in the process. The process is named after its inventor Fritz Winkler who developed it in the 1920s.

wiped film evaporator A type of evaporator used for concentrating heat-labile solutions. It consists of a vertical cylindrical column or cylinder surrounded by a steam jacket. The solution to be evaporated enters the top of the vessel and is allowed to descend the inner walls under the influence of gravity. A rotating assembly of blades with a close clearance to the wall ensures a short hold-up and corresponding residence time, where longer residence times at the boiling temperature would otherwise damage the solution.

wispy annular flow A two-phase flow regime in a pipe or tube characterized by a continuous gas core and wall film of liquid. The flow regime occurs at high gas velocities. At very high liquid flow rates, liquid concentrations in the gas core are sufficiently high that droplets coalescence in the gas core leading to streaks or wisps to occur instead of droplets.

Wobbe index A number used to compare the combustion energy of different fuels such as natural gas, *SNG, and *LPG, and used for comparative purposes of gas burners. Fuel gases with the same Wobbe index can be used interchangeably without a change in the air-to-fuel ratio. It is calculated from the calorific value of the gas divided by the square root of the specific gravity. The SI units are MJ m^{-3}. It is also often still expressed in Imperial units of BTU per standard cubic foot.

Wöhler's synthesis The synthesis of urea from the evaporation of a solution of ammonium isocyanate. First carried out by Friedrich Wöhler in 1828, the synthesis was significant at the time as organic substances were thought to be produced only by living organisms.

Wohlwill process An early electrolytic process used to refine gold. It used crude gold as the anode and pure gold as the cathode with a solution of gold chloride in hydrochloric acid as the electrolyte. By applying an electrical current across the electrodes, pure gold

accumulates at the cathode. Silver present deposits as silver chloride. The process was developed in 1874 and is named after its German inventor Emil Wohlwill.

work (Symbol W) The forms of energy transfer that can be accounted for in terms of changes in the external macroscopic-scale physical constraints on a system. The work done is the product of a force and the distance moved by its application. Displacement work is the energy that goes into expanding the volume of a system against an external pressure such as by driving a piston out of a cylinder against an external force or driving a piston into a cylinder of a given volume and pressure. Work done can also be achieved by a paddle acting upon a fluid or by a fluid, propeller, or turbine blade. Frictional work is the work done overcoming friction. The SI unit is the joule.

work-hardening The process of increasing the hardness or strength of metals by working using a mechanical process such as compression, tension, or torsion. The process causes a permanent change in the crystal structure. Iron, copper, and aluminium can all be work-hardened, whereas metals such as zinc and lead are not capable of being work-hardened as they have the capacity to recrystallize at room temperature.

working capital The current assets of an organization minus the current liabilities. It is the part of the capital that is available for operations.

working drawing A scale drawing of a part of a process or assembly that is used as a guide for fabrication, manufacture, or construction.

working pressure The normal operating pressure of a process.

workover A major form of maintenance or remedial operation on an operating oil or gas well to either restore or increase the rate of production.

work permit An authority written by a responsible person specifying work that can be carried out, the precautions which have to be taken to ensure it is carried out safely, any particular procedures to be followed or particular equipment to be used, and the period for which the permit is valid. Work permits are usually required by law before any work is done. *See* PERMIT TO WORK.

workplace exposure limits (WEL) The UK occupational exposure limits used to protect the health of employees. The exposure limits are defined as the maximum concentration of an airborne hazardous substance averaged over a defined period of time to which workers may be exposed by inhalation and that should not cause adverse health effects. The **short-term exposure limit** (STEL) is averaged over fifteen minutes while the **time weighted average** (TWA) is averaged over eight hours. STELs are aimed to help prevent effects such as eye irritation that may occur following exposure for only a few minutes.

works A place, such as a factory, chemical plant, or refinery, where a number of people are employed.

World Chemical Engineering Council (WCEC) An association of leading professional and learned chemical engineering bodies from around the world. It was formally launched in 2001 at the closing ceremony of the Sixth World Congress of Chemical Engineering in Melbourne, Australia, with the aim of raising public awareness of the work and contribution of chemical engineering and chemical engineers. It comprises prominent chemical engineers who influence the scientific structure of the World Congress of

Chemical Engineering. The Executive Committee comprises representatives from leading societies of chemical engineering, including IChemE, AIChE, DECHEMA, and the regional federations from Europe (EFCE), Asia Pacific (APCChE), and the Americas (IACChE).

SEE WEB LINKS

- Official website of the World Chemical Engineering Council.

World Congress of Chemical Engineering (WCCE) A four-yearly international conference organized under the auspices of the *World Chemical Engineering Council. The conference rotates amongst the major regions of the world and is hosted by one of the professional societies for the subject. The 2009 conference was held in Montreal, Canada, the 2013 conference in Seoul, South Korea, and the 2017 conference is due to be held in Barcelona, Spain.

wrought iron An iron alloy with a very low carbon content containing fibrous inclusions, known as slag. The fibrous structure gives a graining effect. Wrought iron is noted as being tough, malleable, ductile, and easily welded. Before the development of effective methods of steelmaking, wrought iron was the most common form of malleable iron. A modest amount of wrought iron was used as a raw material for the manufacturing of steel, which was mainly to produce swords, cutlery, and other blades. Demand for wrought iron reached its peak in the 1860s with the adaptation of ironclad warships and railways, but then declined as mild steel became more available. Wrought iron rusts less readily than other forms of metallic iron and used to be used for rivets, nails, wire, chains, railway couplings, water and steam pipes, nuts, bolts, horseshoes, handrails, straps for timber roof trusses, and ornamental ironwork. Wrought iron is no longer produced on a commercial scale.

Wulff process A process used for the production of acetylene (ethyne) by the cracking of a saturated aliphatic hydrocarbon gas with superheated steam in a high-temperature furnace. The gas is first heated to around 1,300°C and then passed to a refractory brick reactor operating at 400°C. It is named after its American inventor R. G. Wulff who developed it in 1927.

X

xenobiotic Any substance foreign to living systems. Xenobiotic substances include drugs, pesticides, and carcinogens. Detoxification of such substances occurs mainly in the liver.

Xmas tree *See* CHRISTMAS TREE.

X-ray A penetrating short-wavelength electromagnetic radiation (10^{-10} m) that is produced when a stream of cathode rays (i.e. electrons) strikes a target surface. On impact, the target may emit secondary X-rays which are characteristic of the elements in it. The ability of X-rays to penetrate many types of materials makes them useful for inspecting cracks and flaws such as in *welds. *See* RADIOGRAPHY.

X-ray crystallography The use of diffraction of X-rays for the determination of the structure of crystals or molecules. It uses a beam of X-rays directed onto the target sample that is diffracted and captured on a photographic plate as a pattern of light and dark spots of differing intensities. These are analysed, and from which, the structure of the crystal or molecule is deduced. Since the wavelength of X-rays is comparable to the distance between the atoms in most crystals, the repeating structure acts like a diffraction grating for X-rays.

X-ray fluorescence The emission of X-rays from excited atoms that are produced by the impact of high-energy electrons, or other particles, or a primary beam of other X-rays. The wavelengths of the fluorescence X-rays can be measured by an X-ray spectrometer as a means of chemical analysis.

xylene A mixture of three closely related aromatic hydrocarbons of the benzene group having isomeric forms of orthoxylene (o-xylene), metaxylene (m-xylene), and paraxylene (p-xylene). They each have the formula $C_6H_4(CH_3)_2$ and have close boiling points. They can be separated by crystallization and by distillation. They are important members of the *BTX group of petrochemical feedstocks and used in small amounts in aircraft fuel. They are widely used to produce plastics, vitamins, synthetic fibres, dyes, and pharmaceutical products. The non-technical name for xylenes is xylol.

xylene-plus process A catalytic process used for the isomerization of toluene to a mixture of benzene and *xylene. The process involves a moving bed of silica-alumina catalyst. It differs from the *tatoray process in that no hydrogen is used in the process.

xylofining process A catalytic process used for the isomerization of petrochemicals that contain ethyl benzene and *xylenes. The process developed in India is operated in the vapour phase with an iron-based zeolite at a temperature of around 360°C. The reaction converts the ethyl benzene to ethylene and benzene. It is an abbreviation of **xylol** re**fining**. **Xylol** is a non-technical name for xylene.