12.4.4 Vacuum technology

General

Accumulation leak detection technique

A leak detection technique in which tracer gas (e.g.helium) enters the part under test and is allowed to accumulate within the part, or within a system containing the part, for a period of time. The part or system is then opened to the leak detector. The system may contain the leak detector element.

Adsorption

The process by which a gas or vapour is bound on a solid or liquid surface.

Aperture impedance

The additional resistance encountered by a gas flowing through a tube with an abrupt reduction in cross-section. For *molecular flow* it is the product of the *molecular effusion* impedance of an orifice with a cross-sectional area A_2 and the aperture correction factor $(1 - A_2/A_1)$, where A_1 is the cross-sectional area of the larger tube and A_2 that of the smaller tube.

Background spectrum

A mass spectrum of residual gas species in a system. It is usually obtained before a sample of interest is analyzed in order to deduce by subtraction of spectra the true mass spectrum of the sample.

Backing space leak detection technique

A leak detection sytem in which the leak detector is connected to the forevacuum side of a pump attached to a vacuum system or an element undergoing leak test. A tracer gas is sampled at a higher pressure after compression by a *diffusion pump* or other pump operating at high speed relative to its *backing pump*.

Backstreaming

The flow of charged and/or neutral particles emanating from a pump and moving in the opposite direction to the intended flow of the gases being pumped.

Bagging

A term for a leak detection technique in which the part under test is enclosed in a bag (or other enclosure) that is filled with a tracer gas at a pressure slightly above atmospheric.

Collision frequency

The number of molecules striking a unit area of surface per unit time. Alternatively the number of collisions between molecules or atoms in a gas per unit volume and unit time. The collision frequency per molecule is equal to the probability per unit time that a molecule will collide with a surface or another molecule.

Collision rate

The collision probability per unit time for an atom or molecule travelling at a specified speed through a gas.

Conductance

The ratio of *throughput*, under steady-state conservative conditions, to the pressure differential between two specified cross-sections within a pumping system.

Critical inlet pressure

The inlet pressure of a vapour pump above which an abrupt decrease in pumping speed occurs.

Cryosorption pump

A technique of producing vacuum by physical adsorption of gases on solid adsorbents cooled to a low temperature.

Exhaust port

An opening in a vacuum punp or stage from which gases are ejected either to a preceding stage or to atmosphere.

Holding time (pump)

The time required for the forepressure of an isolated *vapour pump* or *diffusion pump* to reach the limiting forepressure.

Impedance

The reciprocal of *conductance*.

Incidence rate

The number of molecules striking a unit area of surface per unit time.

Knudsen number

The ratio of the *mean free path* of a gas molecule to a characteristic dimension of the channel through which the gas is flowing. For a cylindrical tube a characteristic dimension is the diameter.

Leakage rate

The quantity of gas passing through a leak per unit time.

Load (vapour pump)

The quantity of gas, not including pump fluid vapour, in mass units, flowing through the pump per unit time. It is also called *mass flow*.

Manometer

An instrument for measuring the pressure of gases and vapours.

Mean free path

The average distance a particle travels between successive collisions with other particles of an ensemble.

Mean path

The mean distance a particle travels between successive collisions with other particles or surfaces. When the pressure is high or the vessel dimensions are large, so that the *mean path* is small with respect to the vessel dimensions, the *mean path* and the *mean free path* are numerically equal.

Molecular effusion

The molecular flow of gas from a region at one pressure to one at a lower pressure through an orifice, in a wall of negligible thickness, with a diameter much less than the *mean free path* of the molecules.

Molecular flux

The net number of gas molecules crossing a specified surface in unit time. Those having a velocity component in the same direction as the normal to the surface are counted as positive and those with a velocity component in the opposite direction are counted as negative.

Molecular velocity distribution

The average value of the fraction of the molecules in a small volume, d$\boldsymbol{r}$, surrounding a given point, located by the radius vector $\boldsymbol{r}$ in a fluid medium, which have velocity vectors lying within an infinitesimal volume dv, surrounding the point in velocity space. The averaging process is carried out over a time long enough to smooth statistical fluctuations in the molecular populations, but short compared with the time required for significant variations in the macroscopic properties. For a gas in equilibrium at rest, the distribution of the velocity vectors with a given magnitude is uniform over a sphere about the origin in velocity space. The distribution known as Maxwell's law of velocity distribution is

$$f_v \, dv = 4\pi v^2 [m/(2\pi kT)]^{3/2} \, exp[-mv^2/(2kT)] \, dv,$$

where m is the mass of the molecule, T is the absolute temperature, k is the Boltzmann constant, and $4\pi v^2 dv$ is the volume of a spherical shell of radius equal to the magnitude of v and of thickness dv equal to the increment in this magnitude and gives the fraction of molecules having speeds between v and $v + dv$. The function fv is the Maxwellian distribution function.

Net speed (Vacuum pump)

The *throughput* across a section remote from the pump inlet divided by the pressure as measured at that section. The net speed can be calculated, when the *pump speed* is known, by adding, to the sum of all the *impedances* between the pump inlet and the given cross section, the reciprocal of the measured *pump speed* and then taking the reciprocal of the result.

Pascal (Symbol Pa)

The *pascal* is the SI base unit of pressure. It is equivalent to 1 newton per square cm. This term replaces the Torr. (1 mm Hg = 1.00000014 Torr = 133.3323867 **pascal**.)

Permeability coefficient

The rate of flow of gas through a unit area and a unit thickness of a solid barrier per unit differential pressure at a given temperature.

Permeation

The passage of a gas through a solid. The process always involves diffusion through the solid and may involve surface phenomena such as sorption, dissociation, migration and desorption.

Physical adsorption

An adsorption process caused by van der Waals forces between adsorbent and adsorbate.

Pump speed

The volumetric rate of gas flow across a section at the pump inlet. It can be obtained from the ratio of *throughput* of a gas to the partial pressure of that gas at a specific point.

Pumping speed

Same as *pump speed*.

Speed factor

The ratio of the speed to the product of the vacuum pump inlet cross section area and the maximum flow rate per unit area as given by the effusion law. It is also called efficiency or speed efficiency.

Speed of exhaust

The instantaneous rate of reduction of pressure in a system multiplied by its volume and divided by its pressure.

Sticking coefficient

The ratio of the number of molecules which are adsorbed on a surface for a finite period of time to the number of molecules striking the surface.

Throughput

The quantity of gas, in pressure-volume units, at a specified temperature, flowing per unit time across a specified open cross section. *Throughput* may be referred to a specific constituent of a gas in which case the partial pressure of that constituent and the associated flow rate are the relevant quantities.

Torr

See *Pascal*.

Flow

Knudsen flow

The flow of gas through a pump or system under *transition flow* conditions which are intermediate between *viscous flow* and *molecular flow*. See *Transition flow*.

Mass flow

See *Load* (vapour pump).

Molecular flow

The flow of gas through a channel under conditions such that the *mean free path* is much greater than the transverse dimensions of the channel. At these pressures the flow characteristics are determined by collisions of the gas with surfaces and not significantly with other molecules.

Transition flow

The flow of gas through a channel under conditions such that the *mean free path* is of the same order as the transverse dimensions of the channel. At these pressures the flow characteristics are determined by collisions of the gas with surfaces as well as with other molecules. Also called *Knudsen flow*.

Viscous flow

The flow of gas through a channel under conditions such that the *mean free path* is very small compared with the transverse dimensions of the channel. At these pressures the flow charecteristics are determined mainly by collisions between the gas molecules, i.e. the viscosity of the gas. The flow may be laminar or turbulent.

Gauges

Bayard-Alpert Gauge

A *hot-cathode ionization gauge* in which a fine wire ion collector is positioned on the axis of a cylindrical grid functioning as the anode. The cathode is mounted outside the grid.

Hot-cathode ionization gauge

An ionization gauge in which the pressure is measured in terms of the current of positive ions produced by electrons emitted from a heated cathode.

Knudsen Gauge

A vacuum gauge which indicates pressure by responding to the net rate of transfer of momentum by molecules moving between two surfaces maintained at different temperatures and separated by a distance smaller than the mean free path of the gas

molecules. Various types of Knudsen gauges differ mainly in the shape and method of suspension of the moveable element.

McLeod gauge

A liquid level manometer in which a known volume of the gas, whose pressure is to be measured, is compressed by the movement of a liquid column and confined in a measurable volume. Corrections need to be made for any appreciable change in gas pressure in the system caused by movement of the liquid.

Pirani gauge

See *thermal conductivity gauge*.

Thermal conductivity gauge

A vacuum gauge (also known as a *Pirani gauge*) containing two surfaces at different temperatures between which heat can be transported by gas molecules. Changes in the temperatures, or in the heating power required to maintain the temperature of one of the surfaces constant, can be correlated with the gas pressure. Thermal conductivity gauges differ in their method of indicating the temperature change. See *thermocouple gauge* and *thermistor gauge*.

Thermistor gauge

A form of *thermal conductivity gauge* in which the temperature-sensitive elements are made of semiconducting material instead of metal.

Thermocouple gauge

A *thermal conductivity gauge* which contains a heated filament and a thermocouple for measuring the filament temperature as a function of gas pressure.

Leak

Calibrated Leak

A leak which has a known leakage rate for a specific gas under specific conditions.

Capillary leak

A leak having a small cross-section and a length many times greater than its cross section dimension.

Diffusion leakage

A leakage resulting from the temperature-dependent diffusion of a specific gas through a membrane. Examples include the diffusion of hydrogen through palladium and helium through glass or Teflon (PTFE).

Membrane leak

A leak which permits gas flow by permeation through a thin non-porous wall.

Molecular leak

A leak of such a size that the flow of gas through it is predominantly molecular for a given pressure. See *molecular flow*.

Variable leak

A leak with an adjustable leakage rate.

Virtual leak

An apparent leak caused by the presence of contaminants which outgas slowly within a vacuum system.

Viscous leak

A leak of such a size that the flow through it is mainly viscous. See *viscous flow*.

Pressure

Forepressure

The pressure measured downstream from the outlet or foreline of a vacuum pump.

Inlet pressure

The gas pressure at the entrance to a pump.

Interstage pressure

The gas pressure at any point between the exhaust port of the low-pressure stage and the high-pressure or roughing stage of a compound pump.

Limiting forepressure

The pressure at the discharge side of a vacuum pump, at a stated throughput, above which the pumping action of the pump rapidly deteriorates, as evidenced by sudden increase of *inlet pressure*.

Maximum pressure ratio (of a vacuum pump)

The maximum value of the ratio of forepressure to inlet pressure which a pump can maintain at zero gas flow.

(Saturated) vapour pressure

The pressure of a vapour in thermodynamic equilibrium with a condensed phase at a fixed temperature. The definition applies to single components as well as to multicomponent systems. In the latter case it is necessary to distinguish between the total pressure over the condensed phase and the partial pressure of a given component.

Ultimate pressure

The limiting low pressure approached in a vacuum system after sufficient pumping time has elapsed to establish that further reduction in pressure will be negligible.

Ultimate partial pressure

The part of the ultimate pressure in a vacuum system caused by the partial pressure of a specific gas.

Pumps

Cryopump

A vacuum pump which operates by the condensation and/or sorption of a gas at surfaces maintained at a temperature sufficiently low for the vapour pressure of the condensed gases to be negligible.

Differential sputter pump

A *sputter-ion pump* having two cathodes for which materials and sputter rates are different.

Diffusion pump

A vapour pump in which the pumped gas flows into a vapour stream under conditions in which molecular flow predominates. Momentum is transferred from the vapour to the gas carrying it along in the direction of the stream. Pump fluid is heated in vacuum to generate the vapour which is directed through a nozzle. It expands freely in the stream before it reaches a cool wall where it condenses and is returned to the boiler to begin a new cycle.

Diode pump

An *ion pump* containing two uniquely shaped electrodes, *viz*. an anode and a cathode; two-electrode ion pumps are also referred to as diode getter pumps and diode sputter pumps.

Ejector pump

A vapour pump in which the pumped gas enters the pump and the vapour stream under predominantly conditions of viscous flow.

Electrostatic pump

An *ion pump* having only electrostatic fields rather than both electrostatic and magnetic fields to generate the ionizing discharge.

Electrostatic getter pump

An electrostatic ion pump in which a getter material is made to sublime and react with the gas molecules being pumped.

Evaporation pump

A *getter-ion pump* in which the getter is evaporated from a molten surface rather than sublimed or sputtered from a solid source.

Fore pump

A vacuum pump for maintaining the *forepressure* of another pump below its critical value.

Fractionating pump

A diffusion pump whose design allows the more volatile impurities in the pump fluid, resulting from decomposition or contamination of pumping fluid, to be ejected out of the foreline or trapped within the pump in such a manner as to reduce their chance of backstreaming through the pump inlet.

Getter-ion pump

A pump which combines the pumping mechanism used in the *ion pump* and the *getter pump*.

Ion pump

An electronic device in which ionization produces a significant rate of gas removal by reaction of the ions with the cathode material.

Magnetic pump

An *ion pump*, usually with multiple anode cells immersed in a magnetic field parallel to the cell axes and with two cathode end plates of reactive material spaced from the ends of the anode cells which terminate the discharge space.

Mechanical pump

A device with moving parts, such as rotating vanes, a piston or eccentric rotary members, used for pumping gas or vapour.

Noble gas pump

A magnetic ion pump with novel cathode geometries to enhance the pumping of noble gases.

Positive displacement pump

A mechanical vacuum pump in which the pumping action is provided by displacement of a trapped volume of gases, typically by a rotating or reciprocating piston, a sliding vane or intermeshing lobes.

Sputter-ion pump

A *getter-ion pump* in which the getter surfaces are contiuously removed by sputtering.

Triode pump

An ion pump, usually of the sputter-ion type, containing three uniquely shaped electrodes, an anode, a sputter cathode and an ion collector electrode.

Triode getter pump

A *triode pump* in which gettering plays a significant role in the pumping.

Turbomolecular pump

An axial flow turbine for operation in the molecular flow range consisting of a series of alternate circular rotor and stator disks both of which have inclined blades designed to impart momentum change to gas molecules in a preferential direction from pump inlet to the outlet.

Seals

Bakeable seal

A seal that can be baked at elevated temperatures.

Break seal

A seal between two sections of a vacuum system that can be broken to connect them.

Demountable seal

A seal between two elements designed for dis- assembly without resort to cutting, fracturing or melting.

Gasket seal

A *demountable seal* in which the seal is made by pressing a gasket of deformable material between two members of harder material. The gasket may be of metal or elastomers etc.

O-ring seal

A *gasket seal* in which the gasket is a toroidal ring of circular cross section.

Vacuum seal

A joint between two elements of a vacuum system which can maintain leakage at or below the required level.

Traps (vacuum)

Anti-migration trap

A trap that includes a chilled surface or other means to prevent surface migration of oil from a source into the vacuum system.

Cold trap

A trap with a refrigerated surface used to condense vapours present in a vacuum system.

Molecular sieve trap

A trap containing molecular sieve material that has a high specific surface area and that adsorbs hydrocarbon and water vapours at or below room temperature.

Trap

A device used in a vacuum pumping line to reduce vapour pressure in a vacuum system or prevent backstreaming and migration of vacuum pump fluids such as oil or mercury.

U-tube trap

A trap in the form of a U-shaped tube immersed in a coolant.

Vacuum

Extreme ultrahigh vacuum

A vacuum in which the pressure is less than 10^{-10} Pa (7.5×10^{-13} Torr).

High vacuum

A vacuum in which the pressure is less than or equal to 10^{-1} Pa (7.5×10^{-4} Torr) and greater than 10^{-4} Pa (7.5×10^{-7} Torr).

Low Vacuum

A vacuum in which the the pressure is less than 10^{5} Pa (750 Torr) and greater than 3.3×10^{3} Pa (25 Torr).

Medium Vacuum

A vacuum in which the pressure is less than or equal to 3.3 X 10^{3} Pa (25 Torr) and greater than 10^{-1} Pa (7.5 x 10^{-4} Torr).

Ultrahigh vacuum

A vacuum in which the pressure is less than or equal to 10^{-7} Pa (7.5 x 10^{-10} Torr) and more than 10^{-10} Pa (7.5 x 10^{-13} Torr).

Vacuum

The condition of a gaseous environment in which the gas pressure is less than atmospheric.

Very high vacuum

A vacuum in which the pressure is less than or equal to 10^{-4} Pa (7.5 x 10^{-7} Torr) and greater than 10^{-7} Pa (7.5 x 10^{-10} Torr).

Valves

Angle valve

A valve in which the ports are not in line, as, for example, a right angle valve.

Butterfly valve

A valve which is opened or closed by rotating a disc 90° about an axis through the centre of the disc.

Diaphragm valve

A valve in which the valve stem is mounted in bonnet that is isolated from the rest of the valve by using a diaphragm to divide the space inside the valve body.

Flapper valve

A thin spring steel plate, fastened at one end to the pump housing, which seals the exhaust port of a mechanical pump from the oil reservoir. During the exhaust cycle, gas pressure is sufficient to deflect the plate from its seat and gas is discharged from the pump.

Leak valve

A valve for admitting air or gas at a precisely determined rate into a vacuum system.

Needle valve

A valve in which a tapered needle is moved along its axis against a seat that may also be tapered.

Relief valve

A valve which will automatically open when the pressure on the seat side rises above a specific preset value.

Sealed bellows valve

A valve, usually for high vacuum applications, in which the stem is sealed by a flexible metal bellows. One end of the bellows is attached to the valve body and the other end to the disk part of the valve stem.

Solenoid valve

A valve in which the moveable member is actuated electrically by an electromagnet.

Straight through valve

A valve in which the parts are in line, or coaxial, and for which the internal construction is such that line-of-sight flow occurs when the valve is open.

Vacuum valve

A mechanical device by which the flow of gas or vapour may be started, stopped or regulated by a moving part that opens or obstructs a passage.

Vacuum baffle

A valve containing a shield, which remains in line with the valve port and can thus act as a baffle.