PHYSICS OF LOW PRESSURE

Production and Measurement of Low Pressure

The production and measurement of low pressure without error is a challenging task. For production of low pressure, exhaust pumps like rotary oil pump, molecular pump, and diffusion pump are very common. Many techniques have been developed for the measurement of pressure and vacume. Instruments employed are called pressure gauge or vacuum gauges. A manometer is usually referred to a pressure measuring instrument but limited to measuring pressure near to atmospheric. The term manometer is often used to refer specially to liquid column hydrostatic instruments. A vaccume gauge is used to measure the pressure in vacum which is further divided into subcategories: high and low vacuum. Adaption of most of the common types of pressure transducer can be used for absolute pressure measurement in the vacuum range, special forms of bourdon tubes measure pressure down to 10 mbar, manometers and belows-type instruments measure pressure down to 0.1 mbar, and diaphragms can be designed to measure pressure down to 0.001 mbar. Other more specialized instruments are also used to measure vacuum pressures. These instruments include the thermo-couple gauge, the pirani gauge, the termistor gauge, the Mcleodgauge and the ionization gauge. The construction of a baurdon tube gauge, the construction elements are made of brass. The applicable pressure ranges of many of the techniques used to measure vacuums have an overlap. Hence, by combining several differal different types of gauge, it is possible to measure system pressure continuously from 10 mbar to $(10)^{-11}$ mbar.

Rotary Pump

The main parts of the pump are as shown in fig. Where S is a hollow steel chamber inside which rotates eccentrically a strong electrically driven shift S, called the rotor, such that it is always in contact with a certain peripheral point of the stator, such as P. On either side and close to the point of contact P lie the inlet I and outlet 0 for the gas or vapour to enter and leave the stator,‘ with the outlet fitted with a spring operated value V.

A slot, cut diametrically across the rotor, carries two sliding, cut diametrically across the rotor, carries two sliding rods or discs called the vanes V1, V2 with one or more springs between them which keep them pressed against the wall of the stator. This is further ensured by the centrifugal force on the vanes due to the high-speed rotation of the rotor. The space between the rotor and the stator is thus divided into tW0 separate and air or gas proof compartments.

The pump is kept immersed in a special type of oil, called vacuum oil, which (i) provides atomic lubrication, (ii) prevents leakage of gas vapour into the high vacuum created (iii) ensure efficient cooling 0f the pump

As the electric motor is switched on and the rotor starts rotating in the direction indicated, the space on the inlet side of the chamber goes on increasing and that on the outlet side decreasing correspondingly. The gas or vapour from the vessel connected to the inlet is thus continually drawn into the former and that in the latter goes on getting compressed. When the pressure of this compressed gas or vapour is high enough, it forces open the outlet value and escapes out into the atmosphere. All this operation is completed in one full rotation of the rotor and goes on repeating itself as the rotor continues to rotate, until the pressure in the vessel is reduced to 10-3 mm. A special self-sealing oil-valve prevents the gas or vapour being sucked back into the evacuated vessel when the pump stops working.

Advantages

1. It is driven by a electric motor and the whole operation is thus quick and automatic, with no man power needed.
2. Due to much higher speed of rotation of the rotor than is possible manually, it can produce a much higher degree of vacuum.
3. Its being kept immersed in oil automatically ensures its efficient cooling and lubrication as also prevents leakage of the gas or vapour into the vacuum produced.
4. It can operate directly from the atmospheric pressure and no force-vacuum is thus necessary.
5. It is small and compact in size and occupies much less space.
6. It can also be used as a compression pump. For, if a vessel be connected to the outlet 0 of the pump, the out-coming gas or vapour can be compressed into it.

Diffusion Pump

Diffusion pump deceived by Gaedein 1915, this pump has, with some modifications, proved to be the very best among mechanical pumps and has atmost completely replaced all the rest. If cannot, however, operate directly from the atmospheric pressure but requires a fore-vacuum ranging from 20 mm to 10-2 mm. The principle underlying the pump is that in a mixture of gases, the Diffusion of a gas occurs from a region where its partial pressure ie higher to that where it is lower, irrespective of the total pressure in the two regions. The vessel F to be exhausted is connected up as shown in fig, to a wide tube AB through a narrow connecting tube CD, having a cylindrical slit at D. The necessary fore-vacuum is created by means of rotary oil Pump connected to the side tube T and a stream of easily condensable vapour is passed through AB in the upward direction as indicated by the arrow.

The partial pressure of the gas being greater at the end C of the tube than at the end D diffusion of the gas occurs from C into AB, where it is swept away by the Vapour stream. Again, therefore, the partial pressure of the gas is less at D than at C, so that more of the gas diffuses into AB and is carried at C than at D, With the result that the pressure in vessel F goes on falling progressively. Since the partial pressure of the vapour is higher in tube AB than in CD, it tends to diffuse along DC, thus driving the gas diffusing from C into AB backwards. This back diffusion of the vapour and the gas not only reduces the speed of the pump but also set a limit to the attainable vacuum in vessel F. It is, therefore, prevented by (i) making the aperture at C very narrow (about 0.1 mm in width) and (ii) cooling tube CD by circulating cold water around it, as shown, so as to condense the vapour into its liquid before it can reach the vessel. The liquid is then transferred back to the boiler.

Gaede showed theoretically and later continued experimentally that the speed of the pump is the maximum when the width of the aperture at C is of the same order of magnitude as the mean free path of the molecules in the back-streaming vapour. Since diffusion as well as condensation play their parts in the working of the pump, such pumps are also referred as diffusion-condensation pumps or even condensation pumps.

Molecular Pump

A molecular pump works on the principle that if the linear dimensions of the annular gap between a rapidly rotating surface and the surrounding stationary surface be smaller than the mean free path of the gas molecules, there are much fewer collisions amongst the molecules themselves than those between the molecules and the walls of the gap. Under such conditions, as shown by Knudsen, the molecules acquire the drift velocity of the rotating surface and this velocity then remains unaffected by any subsequent collisions among the molecules.

A molecular pump, however, cannot operate directly from the atmosphere and the necessary fore-vacuum has therefore to be created by means of a backing pump, which is usually a rotatory oil pump, connected to the exhaust port or the outlet. Shows the essential parts of the pump, Where A is cylinder called the rotor, revolving about its own axis at a high speed of at least 5000 revolutions per minute inside and close to the wall of a hermetically sealed shell or stator C. The annular gap between the stator and the rotor is small as 0.03 min. Inlet and outlet ports P and Q respectively are provided, as shown in fig. for the gas or vapour to enter and leave the annular gap respectively. A slot in the stator between P and Q, makes the annular gap a little larger there than elsewhere. The inlet port P is connected to the vessel to be exhausted and a backing rotary oil pump to the exhaust port Q. The necessary fore-vacuum is created by working the oil pump and the rotor set in motion by means of an induction motor. As the rotor rotates at a high speed in the direction shown the gas

molecules in the annular space, rebounding from the walls of the gap and falling into the wide part between P and Q are dragged along with the rotor from P to Q, where they are ejected out. A pressure difference is thus created between P and Q, as indicated by the manometer M. More molecules therefore enter the gap through P, are dragged along from P to Q and then escape out. In this manner, a vacume 0f the order 10-6 nm is created in the vessel in the course of just a few minutes.

Drawbacks

1. There are recurring mechanical troubles on account of the very small clearance between the rotor and the stator.
2. While there is no problem in the case of gases and vapours, slowly vapourising substances like mercury or any traces of grease present make the working of the pump difficult.

Pressure Gauges

A pressure gauge is a device to measure the pressure produced by a pump.

Knudsen Gauge

This is perhaps the simplest and most efficient' gauge developed up to date and has been successfully used to measure the lowest pressure yet produced.

It is based on the principle of radiometric effect, which may be defined as the mechanical force exerted between two surfaces very close to each other and maintained at a difference of temperature. The effect manifests itself only when the mean free path of the gas molecules is longer than the distance between the two heated surfaces or a heated surface and a wall. This means, obviously that the effect is possible only at very low pressures.

Knudsan showed that if a cold plate be suspended close and parallel to a hot plate in a vessel in which the pressure is below 10^{-3} mm, the cold plate gets deflected due to the bombardment by the molecules rebounding from the hot plate. If the dimensions of the plates be very much larger than the distance between them and if this distance be smaller than the mean free path of the gas molecules, the deflecting repulsive force on the cold plate is proportional t0 the gas Pressure right upto 10^{-7}mm.

The gauge consists of two fixed metal plates P_1 and P_2 arranged close and parallel to the vertical strips of a metal framework in the picture frame A, such that one Strip lies infront of P_1 and the other behind plate P_2. The frame A is suspended by a fine quartz fiber S in the chamber or the Vessel in which the pressure is to be determine , and carries a small mirror M, to enable the deflection of A to be Observed by the lamp and scale method.

Advantages:

1. It is an absolute gauge.
2. It gives a continuous indication of pressure in the vessel.
3, It is unaffected by outside influence.
4. It is compact and stable and yet sensitive at low pressure down to 10^{-7} mm.
5. It can be used with all kinds of vapours and gases.
6. It does not require the use of objectionable liquids like mercury.

Penning gauge (cold cathode ionization gauge)

This is the latest form of an ionization gauge, in which the ionization of the gas is brought about by means of a-particles from a radioactive substance. And, since it is not necessary to heat the cathode here, it may be called a cold cathode ionization gauge.

It is designed by downing and Mellen in 1946. It consist of a closed ionization chamber C fig. inside an outer protective shell and perforated at its top and bottom to allow free access to the gas inside it. At the bottom of the chamber is securely held in position a small saucer-shaped plaque P, 1 $\underline{cm^2}$ in area and with its upper surface made of an alloy of gold and radium, which is in equilibrium with its products of decay ex : radon, radium A and radium B, if which the first one is a gas. To prevent any of this gas escaping out, the upper surface of the plaque is electrolytically coated with a layer of nickel which also serves the additional purpose of preventing contamination by mercury vapour. The losses from the plaque are so small that the instrument needs to be tested only once in a number of years. This plaque thus forms a highly efficient alpha-ray emitter, though with a slow emanating power.

The inner electrode, on the grid G, consists of four wires spread or stretched out, as shown. This limits distance to be covered by the positive ions produced by the ionization of the gas, thus facilitating their 'capture' before they have time to cover longer distances. For in the latter case, the ions may re-unit and thus the linear relation between the ionization current and pressure may no longer remain valid, with the whole basis of the gauge knocked out. The small ionization current produced is first amplified and then read on the micro ammeter, the gauge otherwise functioning just like the hot cathode one.

Although the relationship between ionization current and pressure of the gas no longer remains valid beyond a pressure of 10 mm of mercury, the gauge may be used to measure pressures within a wide range from 10-3 mm to 1000 mm. Further, the gauge is a continuous reading one.

Draw back

The one serious drawback of the gauge is that extra precautions are necessary to work with it, if one is to save oneself from the hazards of exposure to the radio-active substance used.

Pirani gauge

It is a well known fact that whereas at high and ordinary pressures, the thermal conductivity of a gas (K) is quite independent of pressure, at pressures below 10^{-2} m, it is directly proportional to pressure, i.e.,K is a linear function of P. This fact was first used by Warburg in 1907, for the measurement of low pressures and forms the basis of the pirani gauge.

Construction

It is very much like the cage-type incandescent lamp. The essential requirements are

1. The filament should have a high coefficient of increase of resistance with temperature, so that even a small change in its temperature may result in an appreciable change in its resistance.

2. The heat-loss along the filament-support should be as small as possible.
3. The distance between the filament and the wall of enclosing glass bulb must remain unaltered. The filament is therefore. Filament of tungsten or platinum wire, of a diameter of about 0.06mm, a glass rod is used as the support and the filament is kept taut by taking it round glass beads as shown in fig So that the longer portions of the filament are equidistant from the wall of the bulb. The bulb is Open at the low which can be connected to the vessel in which the pressure is to be measured.

with change in pressure of the gas between the filament and the wall of the bulb, the rate of conduction of heat across the gas changes. the results in a change in the temperature of the filament and hence a change in its resistance. The charge in the resistance of the filament is measured. It gives the change in conductivity of the gas and hence, indirectly, the pressure of the gas.

A calibration curve is drawn between resistance of the filament and the pressure of the gas. The pressure corresponding to any resistance of the filament can then be read off directly from the curve, which is a straight line. The method of drawing the calibration, curve suggested by Campbell is however, a very complicated one. The procedure usually adopted therefore, is the following.

The bridge is first balanced with the gauge exhausted as completely as possible and surrounded with melting, the voltage across the bridge being just sufficient to raise the temperature of the filament to about 120°C. Maintaining the voltage constant, the gas from the vessel is gradually allowed to enter the gauge. The pressure in the gauge increases and is measured by a Mcleod Gauge. The balance of the bridge is naturally upset and a current corresponding to the want of balance thus passes through the galvanometer. The deflection in the galvanometer in terms of scale divisions is noted. This is repeated for each small increase of pressure due to more and more gas entering the gauge. A graph is plotted between pressure and the deflection in the galvanometer. It is found that straight line. From this graph, the pressure corresponding to any deflection in the galvanometer can be read straightaway.

Draw backs.

1. It is quit unsuitable for use with organic vapours, for they ‘poison’ the filament.
2. It is not an absolute gauge and has to be calibrating against a Mcleod or any absolute gauge.
3. It is not suitable for measurement of pressures below 10^{-3} mm.

4. In the range of 10^{-3} to 10^{-5} m, it requires some manual adjustments, which obviously cannot be made reliably.

Detection of leakage

1. In case of an all-glass system, a spark discharge from a small induction will may be used. One terminal of the induction coil may be connected to a metal piece in direct communication with the system and the other may be connected to a long copper wire attached to a glass rod. Holding the rod, the wire may be moved all over the portion suspected of a leak. In case of a pinhole leak anywhere, a small spark passes through the hole and the general intensity of the discharge in a system increases.

2. In the case of a glass-metal or an all-metal system, the above procedure cannot be adopted, instead some form of a discharge tube is attached to the system and its parts suspected of a leak painted with alcohol or acetone. Its vapour enters the system through the leak and the colour of the discharge from pink to pale blue, this being the color associated with the presence of carbon compounds, in the region of the discharge. The trouble with these vapors is that they may pass into the backing pump and later reappear in the system when the pump is in action and the coil gets hot.

It is therefore, advisable to use carbon dioxide instead, which can later be easily removed. A jet or CO2 is, therefore, directed over the suspected of the system. In case of a leak, the gas enters the system and its presence and hence that of the leak, directed by the change in the colour of discharge as before.

3. In case the leak be so small that a discharge cannot be maintained one of the way, mentioned hereunder is adopted.

(a) An ionization gauge may be attached to the system, which will show at once the entry of any vapors into the system through a leak. '

(b) A jet of hydrogen may be directed over the parts under test which will diffuse much more
readily into the system than air. A Pirani gauge attached to the system will thus show a sudden and a marked change in its readings.

(c) In case of pressure be very low, in the range 10^{-6} to 10^{-7} mm, a mass spectrograph may be
included in the system and a helium steam passed over the suspected part. The presence of a helium line in the spectrograph will be clear indication of a leak.