Vacuum Technology: Introduction

Vacuum: State of emptiness, space without matter
Common vacuum spreads 15 orders of magnitude in terms of real numbers
Evolution in vacuum technology is also evolution in science

Uses: Reduction in boiling point, engineering production, science, space exploration, electronics

History

Aristotle 384-322 BC, vacuum was not possible as empty space would mean motion without resistance.

Similar view by Roger Bacon (1214-1299) and Rene Decartes (1596-1650).

Galileo (1564-1642) made some of the early studies. Some of the early studies were used with pumps made for displacing water from mines. Galileo’s associate, Torricelli (1608-1647) did studies with Mercury as working fluid. He made the barometer, said that air pressure is 760 mm mercury. The unit torr was introduced in honour of him. The unit today is Pascal, in honour of Blaise Pascal (1623-1662).
Otto von Guericke (1602-1686) did the experiments at Magdeburg (1654), horses pulling an evacuated vessel. Boyle (1627-1691) made improved vacuum pumps. Vacuum resulted in the discovery of electrical discharges of gases (1895), discovery of electron (1897), subatomic particles, isotopes, etc. Modern experiments and discoveries happened as a result of developments in vacuum technology.
Oil diffusion pumps of Langmuir
Turbomolecular pumps
Basic Units

Old units
Psig, pounds per square inch (gauge) or psia, pounds per square inch (absolute)
760 torr = 1 atmosphere
101,000 Pa = 1 atmosphere
Pa = Newton per sq. meter
1 torr = 133 Pa
1 bar = 760 torr
Dimensions

1 atom/molecule = 3 Å
1 cm long array of molecules = $3.3 \times 10^7$ molecules
1 sq. cm = $3 \times 10^{22}$ molecules

Ratio of solid to gas density is about 1000. So the number of molecules in gas = $10^{19}$ per cubic cm.
Thus even at $10^{-12}$ torr, we have 30,000 molecules per cubic cm.

At atmospheric pressure, over a billion molecular collisions happen on sq. cm area. At $10^{-10}$ torr, one can avoid collisions for several minutes. In vacuum, most of the collisions happen between the molecules and chamber walls and not between molecules.
Basic equations

Average gas velocity, $v = 146 \sqrt{(T/M)} \text{ m/s}$
$H_2 = 1800 \text{ m/s}$
$N_2 = 480 \text{ m/s}$
Independent of pressure, greater than the speed of sound in air (330 m/s).

Mean free path $= 1/\sqrt{2} (\pi d^2 n)$
For air at RT, mean free path (MFP) $= 5 \times 10^{-3}/P$, $P$ is in torr and MFP is in cm.
Aspects of pressure and making vacuum

Vapour pressure
Evaporation
Adsorption and desorption
Gas content of materials
  Even if one molecule out of 1000 solid atoms is a gas, we will have one atmospheric pressure due to that gas.
Outgassing
Heat transfer depends on pressure. This can be used for pressure measurements.

Figure 2.1 Relative heat transfer from a heated wire depending on pressure.
Vapour pressure is independent of the amount of material. Ultimate vacuum one can create is the vapour pressure of the material.
Amount of gas adsorbed depend on the pressure

Figure 2.3  Adsorption isotherm relating the pressure of vapor to its adsorbed amount.
More a moderate desorption energy, the gas spends significant time at a surface.

Figure 2.4 Residence time of gas molecules on a surface depending on the heat of adsorption and temperature.
Outgassing rates of materials

Figure 2.7 Examples of outgassing rates: 1 and 2 stainless steel; 3, cold-rolled 1020 steel; 4, aluminum; 5, 6, and 7, epoxy resins; 8, Teflon; 9, neoprene; and 10, Hycar.