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

Ref: High Vacuum Technology, A Practical Guide, Second Edition, M. H. Hablanian, Marcel Decker Inc., New York, 1997.

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 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 disvovery 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 Amstrom
1 cm long array of molecules = 3.3 x 10^{7} molecules
1 sq. cm = 3 x 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, $v = 146 \sqrt{(T/M)}$ m/s
H_2 = 1800 m/s
N_2 = 480 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.

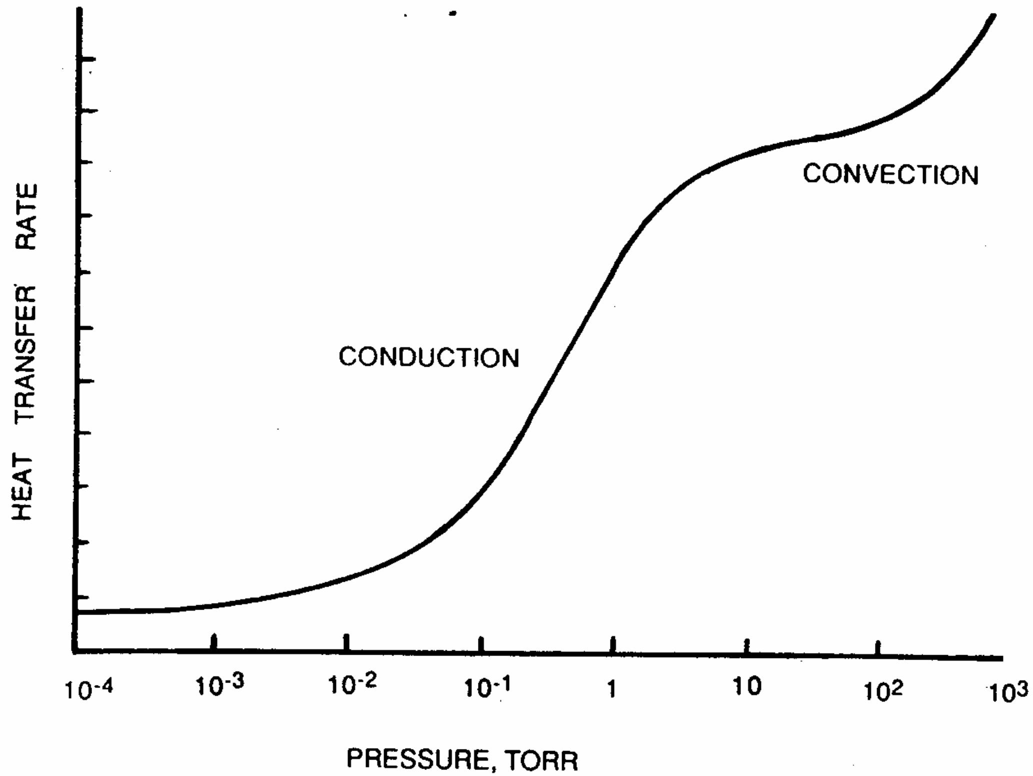

Figure 2.1 Relative heat transfer from a heated wire depending on pressure.

Vapour pressure is independent of the amount of material. Ultimate vacuum one can create is the vapour pressure of the material.

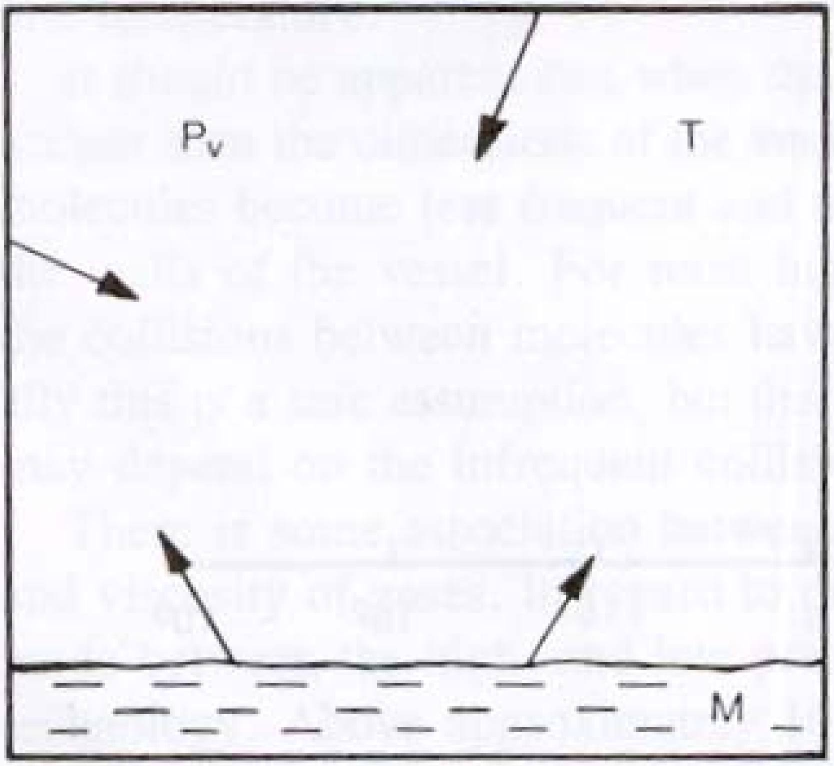

Figure 2.2 Concept of vapor pressure.

Amount of gas adsorbed depend on the pressure

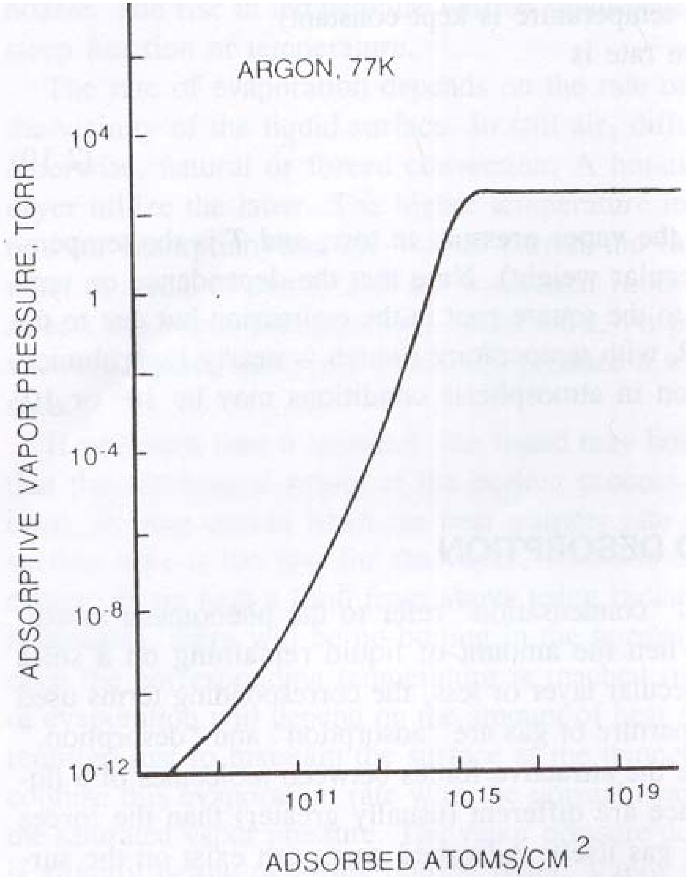

Figure 2.3 Adsorption isotherm relating the pressure of vapor to its adsorbed amount.

More a moderate desorption energy, the gas spends significant time at a surface

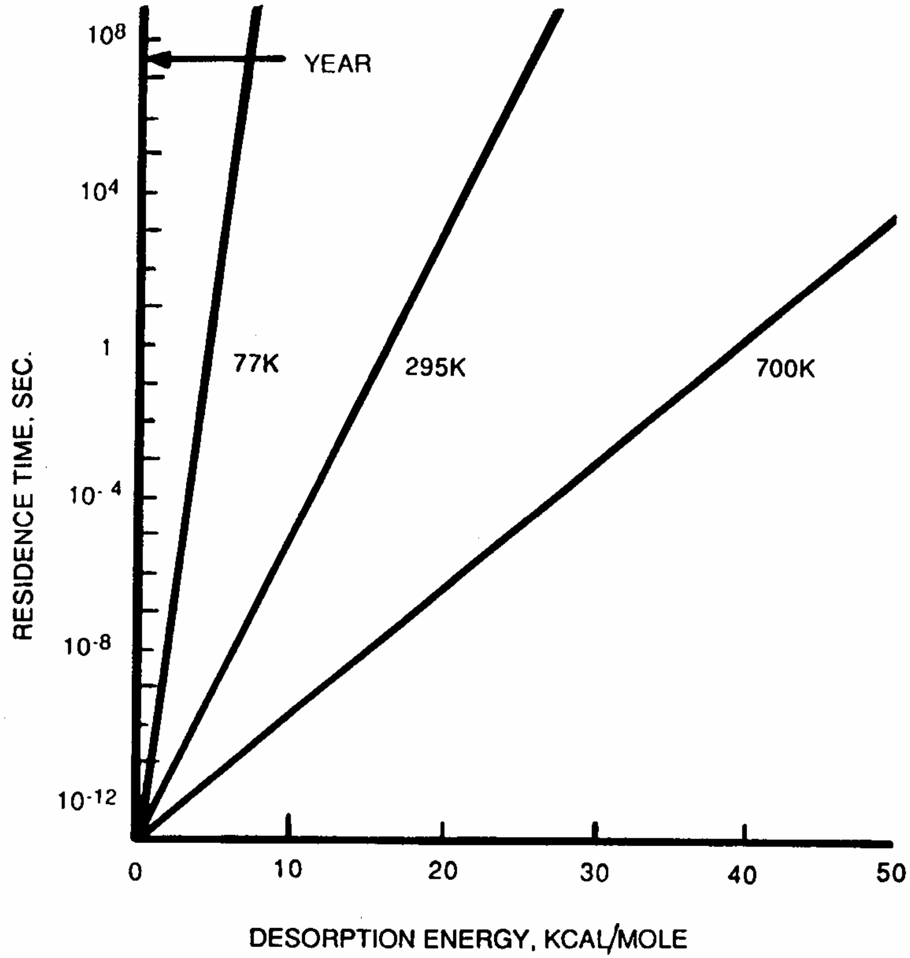

Figure 2.4 Residence time of gas molecules on a surface depending on the heat of adsorption and temperature.

Outgassing rates of materials

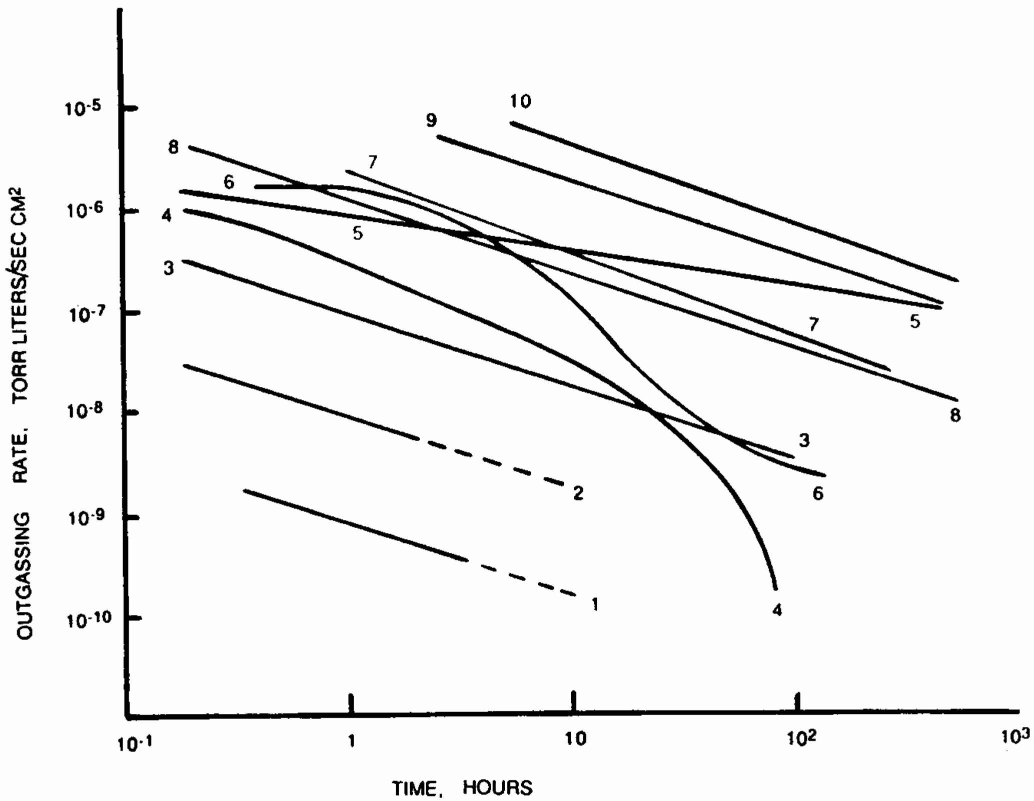

Figure 2.7 Examples of outgassing rates: 1 and 2 stainless steel; 3, cold-rolled 1020 steel; 4, aluminum; 5, 6, and 7, epoxy resins; 8, Teflon; 9, neoprene; and 10, Hycar.