APPLICATION NOTE

EDWARDS

OUTGASSING

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There are several contributions to the gas load of a system. At pressures below ~0.1 mbar, the most dominant is often 'outgassing'. Outgassing is the result of desorption of previously adsorbed molecules, bulk diffusion, permeation and vapourisation. Adsorption occurs via two main processes, physisorption and chemisorption, and can be described using five (or six) classifying isotherms.

Looking at the desorption rate, pumping speed and readsorption on surfaces, the net outgassing of the system can be calculated.

As seen in Diagram 1, contributions to the gas load of a system can come from:

1 Initial or the 'bulk' gas in the system
2 Process load
3 Back-streaming
4 Leaks
5 Outgassing

For a leak-tight system in **High Vacuum (HV)** with no process load, outgassing could contribute up to **100%** of the gas load.

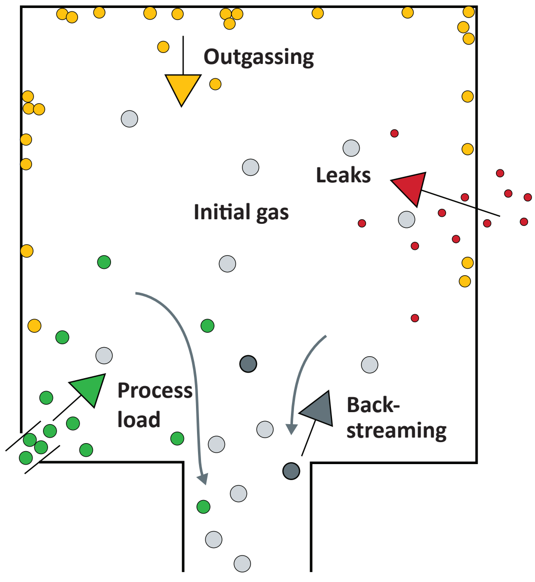

Diagram 1: Gas loads in a vacuum system

The relative contribution of different species to the gas load varies with pressure. For many HV applications water vapour is the major concern in terms of outgassing. However, for achieving UHV in all metal systems, H_2 outgassing is critical.

The table below shares typical major gas loads at various pressures.

Pressure (mbar)	Major Gas Load
Atmosphere	Air (N_2, O_2, H_2O, Ar, CO_2)
10^{-3}	Water vapour (75-95%), N_2, O_2
10^{-6}	H_2O, CO, CO_2, N_2
10^{-9}	CO, H_2, CO_2, H_2O
10^{-10}	H_2, CO
10^{-11}	H_2, CO

Table 1: Contributions to outgassing

There are 4 main mechanisms which contribute to outgassing (shown in the diagram below):

1 Vapourisation of the actual surface material itself (in metals this is negligible at typical operating temperatures)
2 Desorption — this is the reverse process of adsorption; the release of molecules bound at the surfaces of the chamber and internal fixtures
3 Diffusion — this is the movement of molecules from the inner structure of the material to the surface
4 Permeation — this is the movement of molecules from the external atmosphere through the bulk to the vacuum surface

The extent to which each of these affects outgassing depends on the composition of both the gas and the surface material (and its history). Outgassing rates are a sum of these contributions.

VACUUM

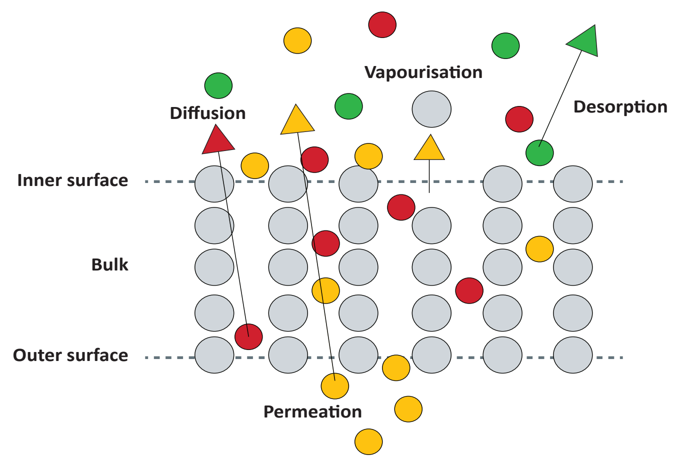

Diagram 2: Mechanisms contributing to outgassing

CALCULATING USING THE OUTGASSING RATE EQUATION

The approach below shows how to calculate gas loads using the outgassing rate equation.

A thorough treatment considering:

- gas removed from the system by pump
- gas desorbing from the surfaces
- gas re-adsorbed

Leads to the differential equation: [1]

$$\frac{d_2 n_v}{dt^2} + \left(\frac{\bar{v}}{4V} (aA_s + A_P) + \frac{1}{\tau} \right) \frac{dn_V}{dt} + \frac{\bar{a}}{4V} \frac{A_P}{\tau} n_V = 0$$

But a reasonable approximation of is given by: [2]

$$\dot{Q} = \sum \frac{a_{1h} . A}{\left(\frac{t}{1h}\right)^{\alpha}}$$

Outgassing flow rate ($\dot{Q}$); Outgassing rate at 1 hour (a_{1h}); Decay constant (α)

Keep in mind that the value of the decay constant gives an indication of the material and outgassing mechanism. For example:

- α ≈ 1.1-1.2 ultra-clean metal surfaces
- α ≈ 1 metals, glasses and ceramics
- α ≈ 0.4-0.8 polymers
- α ≈ 0.5-0.7 highly porous surfaces
- α ≈ 0.5 diffusion-controlled outgassing from the bulk

TYPICAL OUTGASSING VALUES

In the table below, we share typical outgassing values, where t = 1 hour.

Material	Average ($mbarls^{-1}cm^{-2}$)
Aluminium	3.0×10^{-7}
Iron	2.7×10^{-7}
Brass	1.5×10^{-6}
Copper	2.3×10^{-8}
Gold	1.1×10^{-7}
Mild steel	6.2×10^{-7}
Stainless Steel	1.9×10^{-7}
Zinc	2.6×10^{-7}
Titanium	1.0×10^{-8}
Pyrex	9.9×10^{-9}
Neoprene	4.0×10^{-5}
Viton A	1.1×10^{-6}
PVC	3.2×10^{-6}
PTFE	1.4×10^{-6}

Table 2: outgassing values, where t = 1 hour

SUMMARY

Outgassing is often the largest contributor to a system's gas load (especially below Medium Vacuum) and limits the achievable ultimate pressure. It occurs via several processes including vapourisation, desorption, diffusion and permeation. The major contributions to outgassing depend on the vacuum level but in HV it stems mainly from water vapour, whilst hydrogen is most common when working with metals at UHV.

There are many outgassing rates available in the literature, however there is significant variation in these. While variations in outgassing rates can primarily be attributed to the measurement method used and sample preparation; the development of a standard for rate measurement techniques would be valuable.

1 *K. Jousten, Thermal Outgassing, No. OPEN-2000-274, CERN (1999)*

2 *J. M. Lafferty, Foundations of Vacuum Science and Technology John Wiley & Sons, Inc (1998)*

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Edwards Ltd, registered in England and Wales
No. 6124750, registered office: Innovation Drive,
Burgess Hill, West Sussex, RH15 9TW, UK.