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Materials selection, lubrication, cleaning, working discipline

10.1 GENERAL CONSIDERATIONS ON THE SELECTION OF MATERIALS

Obviously the selection of materials for application in vacuum technology must always be preconditioned by their suitability from a technical point of view: the application of the considered material in a vacuum system must give a 'proper' vacuum. What we mean with 'proper' is explained in more detail in section 10.2. Depending on the specific employment of the material, however, other more general material properties may also play an important role.

In the first place, the system must be able to mechanically withstand a pressure difference of 1 atmosphere. This means that certain requirements are imposed on the tensile strength and crushing strength of the wall materials. Particularly for bakeable and cryogenic systems, these qualities constitute an important criterion. Although the design of pressure vessels under an external pressure load (i.e. vacuum systems) is not bound to legal provisions, it is still advisable to test the construction by an informed calculation. For very large systems one can set as a condition that the design should satisfy to the international applicable Pressure Equipment Directive (PED).

Especially in the case of thin-walled vacuum systems, non-cylindrical systems, very large systems and when we have to deal with locally weakened cross-sections by the presence of flange holes and tube connections, a thorough crushing calculation is important. Other special measures, such as for instance additional ring flanges, reinforcement ribs, corner pieces etc., may also have to be considered. In practice, many incidents of collapsing vacuum systems upon first evacuation are known. In doubtful cases it is advisable to provide the system with stretching strips and perform the evacuation step by step. Particularly in the design of vacuum systems with aluminium walls one should be aware of the low collapsing strength of aluminium.

In the selection of elastomer seals, elasticity and dimensional stability are particularly important features. At low temperature elastomers usually reveal hardening with the chance of leakage. Worth mentioning however is that elastic synthetics in a cured state,

i.e. at low temperature, are more easily machinable (drilling, turning, etc.) than at room temperature. Under pressure, in particular at elevated temperatures, permanent deformation may occur (examples: Viton and Teflon), which also may result in leakage.
Finally, in certain circumstances the *wear resistance* (moving parts) and the *flexibility* (flexible hoses and bellows constructions) should be taken into account in the selection of materials.
In addition, the choice of materials can also be determined by a large number of *physical material properties*. Examples include magnetic properties, heat conductivity, thermal expansion, electric conduction in metals, electrical and thermal insulation in case of glass, ceramics and synthetics, light transmittance through viewports, light absorption in optical experiments and optical emission properties. In optical experiments surfaces with high absorption of visual light may be required. These so-called 'optically black' surfaces are usually obtained by methods such as anodizing of aluminium, chemical treatment of copper, vapour deposition of metals at high pressure (about 100 Pa) or the application of optical coatings. In cryogenic systems heat leakage and irradiation are to be countered. Hence, in this case a low heat conductivity and low radiation emission coefficient are of interest. Low radiation emission can be achieved by polishing metals. Cryogenic pipelines and vessels are sheeted with a so-called 'super insulation' (e.g. highly reflective metallized Mylar foil).
Chemical material properties must also be considered carefully. Atmospheric corrosion of metals such as steel and copper can lead to outgassing and leakage issues. Surface treatments such as nickel-plating, chrome-plating, etc. are useful if a properly adhering homogeneous layer is applied. In industry, steel vacuum plants are often internally treated with corrosion protective coatings. The internal materials must sometimes be resistant to pump liquids and manometer liquids (e.g. mercury), or to process gases (e.g. UF_6 or 'CVD' gases). Further, thermal stability (baking!) and the resistance to electromagnetic and particle radiation may be important.
Finally, factors such as cost, machinability and deliverability play an important role in addition to vulnerability, reliability and security.

10.2 VACUUM PROPERTIES OF MATERIALS

Technical vacuum features are those physical or chemical properties which are important for obtaining and maintaining the desired vacuum. This 'desired vacuum' is defined and established by imposing requirements with respect to:

1. The pressure which has to be achieved in the system before starting the process or experiment and must be maintained for the duration of the process or experiment,
2. The residual gas composition during the process or experiment.

In addition, the time needed to achieve the desired vacuum represents an important issue in many (particularly industrial) applications.

The requirements related to both the ultimate pressure and the residual gas composition are largely determined by the maximum allowable contamination of critical surfaces in the vacuum compartment and/or admitted process gases. Apart from any contaminations related to the applied pump system and/or gas production during the process to be carried out, the following contaminating gas sources can be distinguished:

a. gas release from vacuum walls, seals and components,
b. permeability of walls and seals,
c. vapour pressure of applied materials,
d. decomposition of materials,
e. leakage through walls, flange connections and seals.

The influence of the gas sources in points b to e can usually be reduced sufficiently through good design, the use of appropriate materials and manufacturing techniques, and an expert assembly. However, the outgassing mentioned under point a sets fundamental limits on the achievable ultimate pressure.

In order to be able to understand this, we consider figure 10.1 with guiding curves for the outgassing rates of metal surfaces as a function of time. In practice, during the first tens of hours after starting the evacuation this outgassing rate appears to be inversely proportional to time.

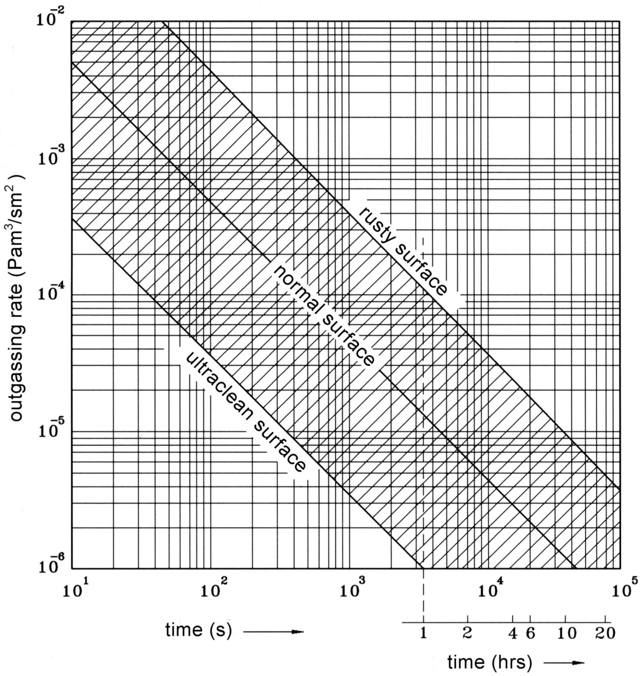

Figure 10.1
Guiding curves for the outgassing rate of metal surfaces as a function of time after starting the evacuation.

The level of outgassing depends greatly on the surface roughness and pretreatment. The cleaner and smoother the surface, the lower the gas release will usually be. Via the well-known expression $Q = pS$, the pressure p which can be attained after a certain pumping time is determined by the available pumping speed S. Consequently, this pressure initially also decreases linearly with time.

As an example we consider a vacuum chamber having an internal metal surface area of 1 m^2. From figure 10.1 it can be deduced that this surface, under the assumption that it is reasonably cleaned in advance, reveals an outgassing rate in the order of 10^{-5} Pam^3/s about 1 hour after evacuation start-up. Table 10.1 shows the relation between the pumping speed required for processing this gas flow in relation to the desired system pressure.

We conclude that for pressures down to about 10^{-2} Pa, outgassing, as a rule, plays a minor role in the sense that the required (additional) pumping speed to remove the outgassing products is negligibly small. In contrast, in closed systems such as cryogenic pipelines and cryogenic storage containers the outgassing of the applied materials is very critical. For pressures below 10^{-2} Pa outgassing becomes increasingly important with decreasing pressure, so much so that in high and ultra-high vacuum systems the required pumping speed is (almost) completely determined by the material outgassing. Table 10.1 shows, that in order to attain pressures below about 10^{-6} Pa within a reasonable time, extremely high pumping speeds are required. Such pumps would, if they were on the market, not only be very expensive but also unmanageable in view of their disproportionally large dimensions.

Table 10.1 Required pumping speed S to pump 10^{-5} Pam^3/s (originating from 1 m^2 normally cleaned surface after about 1 hour of pumping; see figure 10.1) in relation to the desired system pressure p

Desired system pressure p (Pa)	Required pumping speed S (m^3/s) per m^2 wall surface
10	10^{-6}
10^{-2}	10^{-3}
10^{-5}	1 (!)
10^{-8}	10^{3} (!)

In the next sections the first four gas sources in points a to d will be further elucidated. Machining methods and procedures by which their impact on the desired ultimate pressure and residual gas composition can be reduced are indicated. The possible causes of leakage (gas source point e) and methods to detect leaks are already addressed in chapter 8.