Vacuum technology
Design and building of vacuum systems

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Design and building of vacuum systems

Consider:

- What is the purpose of the equipment?
- What kind of vacuum (pressure, purity, loadability) is needed?
- How much is the gas load?
- Anything special? Water, corrosives, extreme temperatures etc.?
- How much space is there?
- How much money is available for 1) CAPEX 2) OPEX?
- Who will use it? („fool-proofing”…)
- What is at hand?
- Consult working equipment, catalogues, web sites etc.
- 2D drawings and 3D models are usually available (CAD!)

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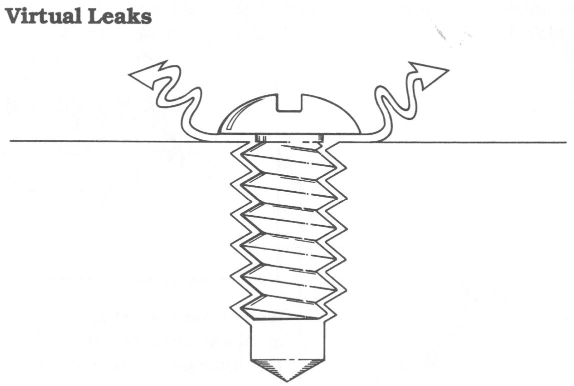
- Have a general picture on system and an understating of function
- Leave the details to experts, buy/acquire a much ready made parts as possible
- Sometimes custom made parts are unavoidable. Be careful with material (p.e. brass), purity (p.e. machining fluids), construction details (p.e. virtual leaks, closed voids as below a bolt)



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Identify critical issues: cooling water, pressurized air, electricity, critical pressure values, temperatures etc.

Proper safety equipment and warnings

Labelling, manuals, SOPs

Interlocks

Start up and shut down sequencies

Remote monitoring

Remote control

Emergency shut down

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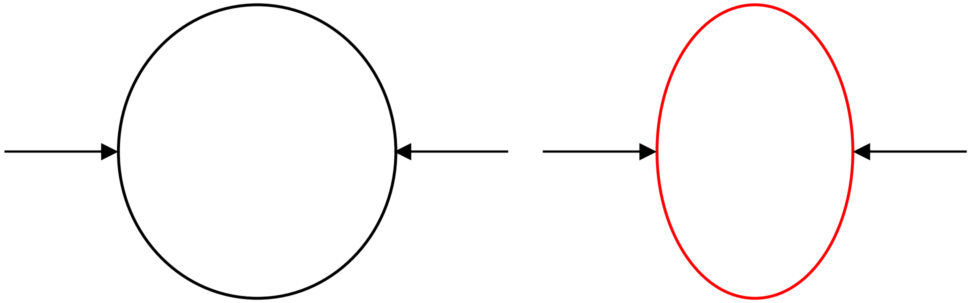
Avoid structural design! Use ready made parts.

Vacuum magnifies geometric deviations, collapsing structures.



Design and building of vacuum systems

Designing pumps to pumping speed (L/s) and capacity (mbarL/s)

- Consider pump and attached parts (piping, valves, traps etc.) together
- Highest vacuum/lowest pressure stage: designed to expected gas load (out gassing, material inlet, (pseudo leaks) and acceptable vacuuming time
- Lower vacuum/higher pressure stage(s): design to output of higher vacuum stage, to expected gas load (out gassing, material inlet, (pseudo leaks) and acceptable vacuuming time
- Demand of steady state and vacuuming phases can be different. May be separate systems.
- UHV systems may not require continuous fore vacuum supply

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Effective pumping speed of pump and attached parts:

$$1/S_{\mathrm{eff}} = 1/S_{\mathrm{pump}} + 1/C_{\mathrm{parts}}$$

Summation of serial conductances (C) :

$$1/C_{\mathrm{sum}} = 1/C_1 + 1/C_2 + \ldots$$

Summation of parallel conductances (C) :

$$C_{\mathrm{sum}} = C_1 + C_2 + \ldots$$

Pumping speeds and conductances can be found in manuals

Have uniform strength. For example a 100 L/s trap and a 100 L/s speed pump result in a 50 L/s speed system. Using a 1000 L/s pump increase total speed only to 91 L/s.

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Pumping speed of lot of pumps is given by a value, but in fact it has pressure dependency

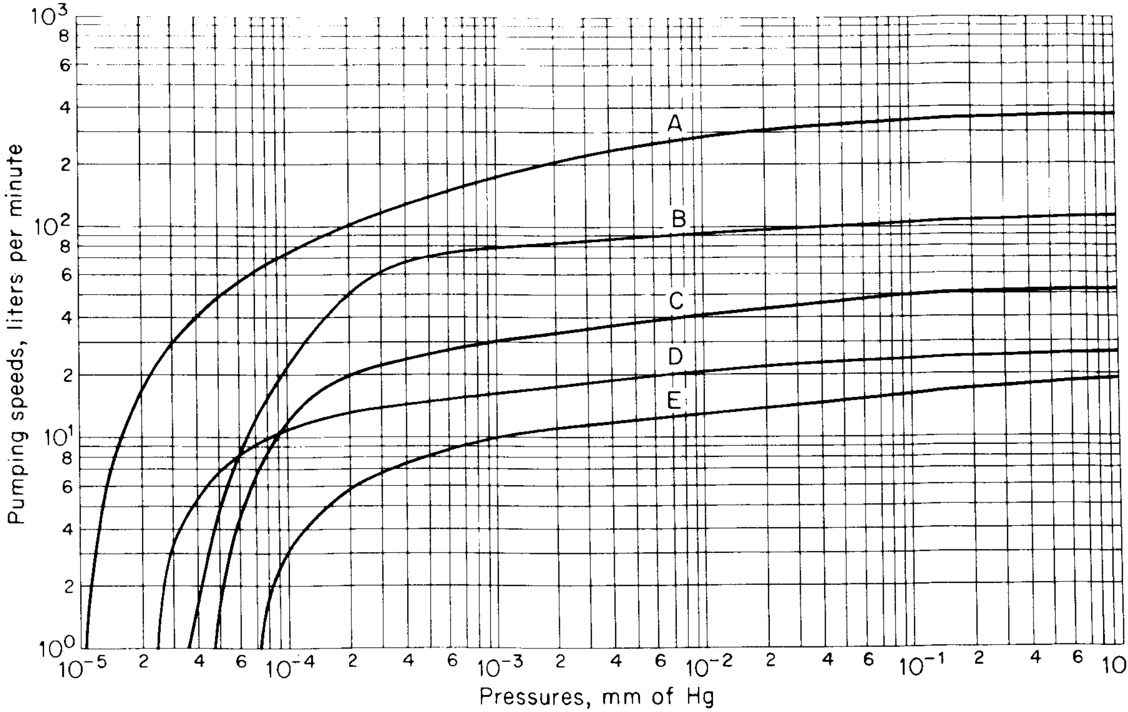

Fig. 4.2 Pumping-speed curves for various two-stage rotary vacuum pumps. (*Sargent-Welch Scientific Co., Skokie, Ill.*)

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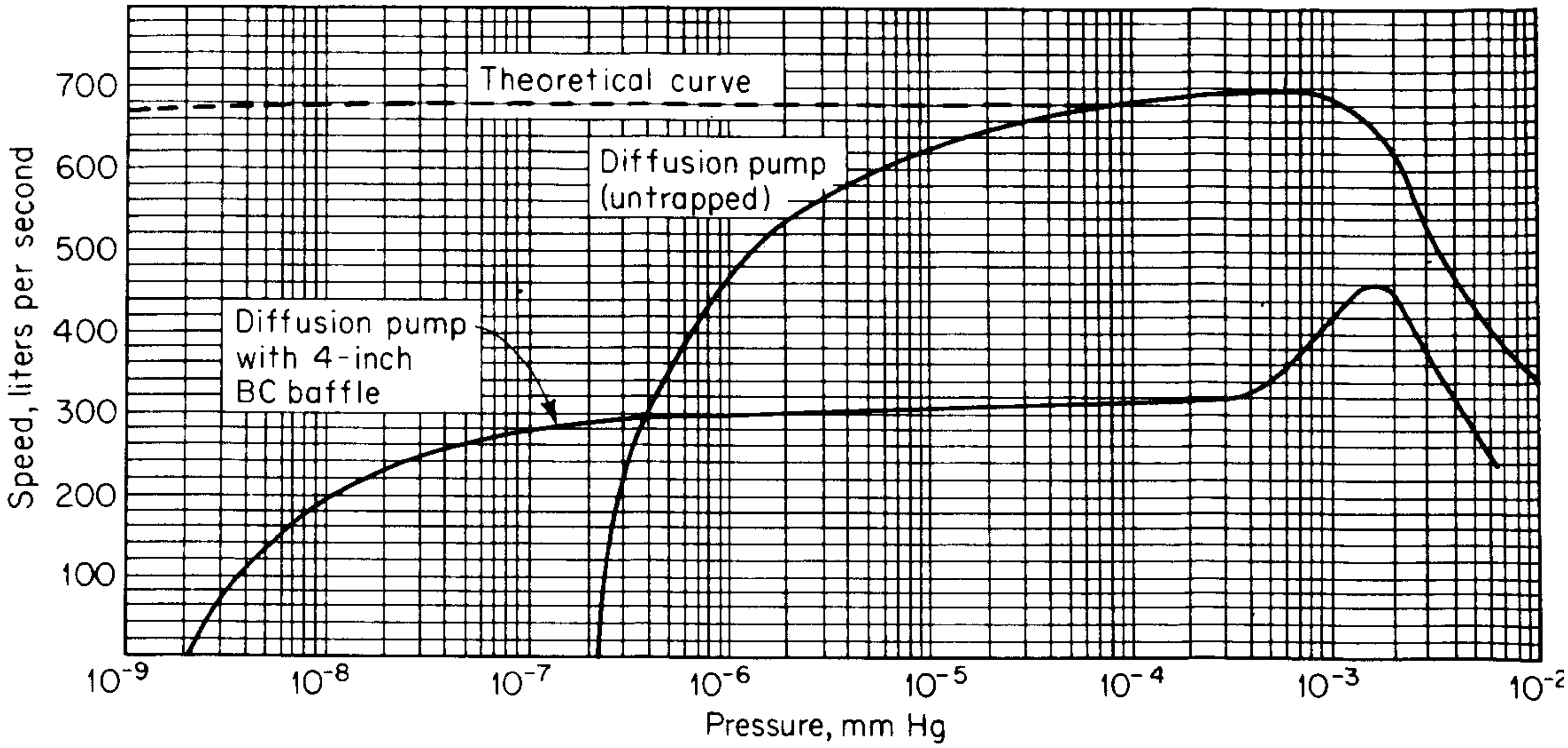

Fig. 5.4 Typical pump and baffle performance. (*Bendix Corp., Rochester, N.Y.*)

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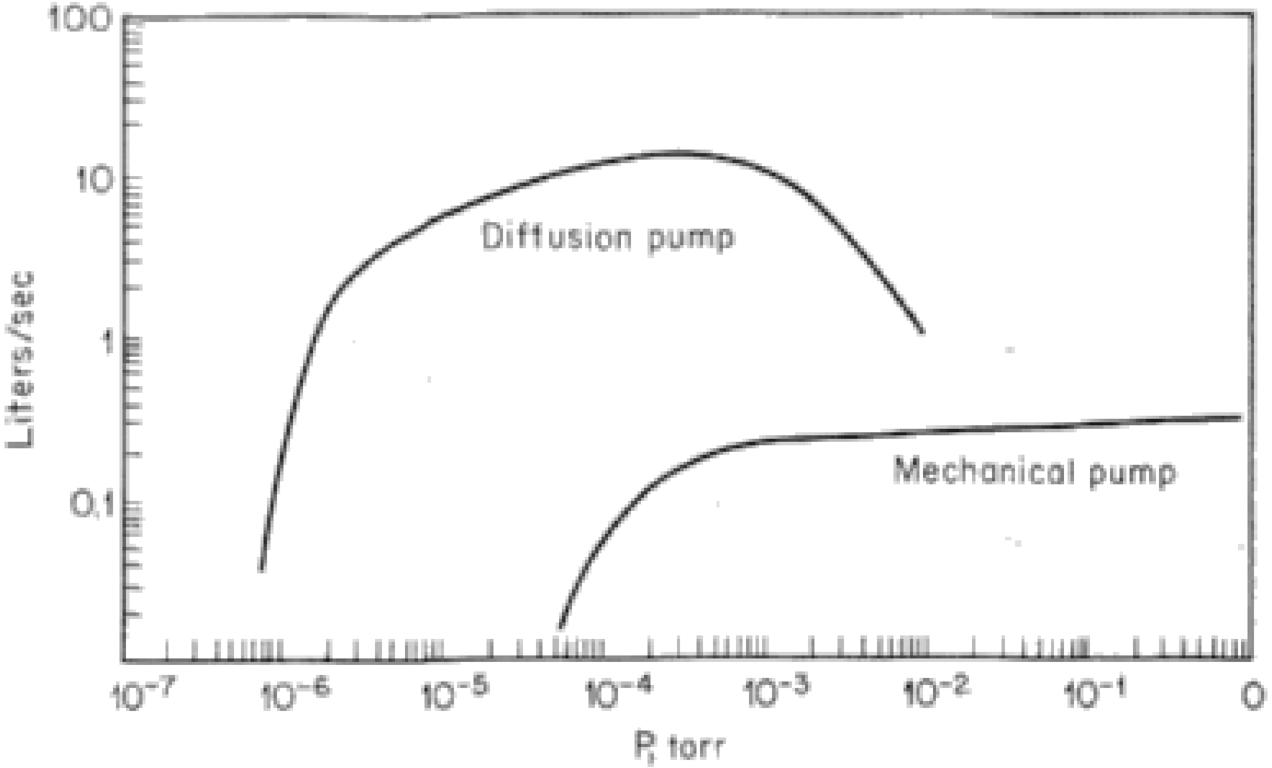

Fig. 6.3. Comparison of the pumping speed of a typical two-stage mechanical pump with a single-stage diffusion pump.

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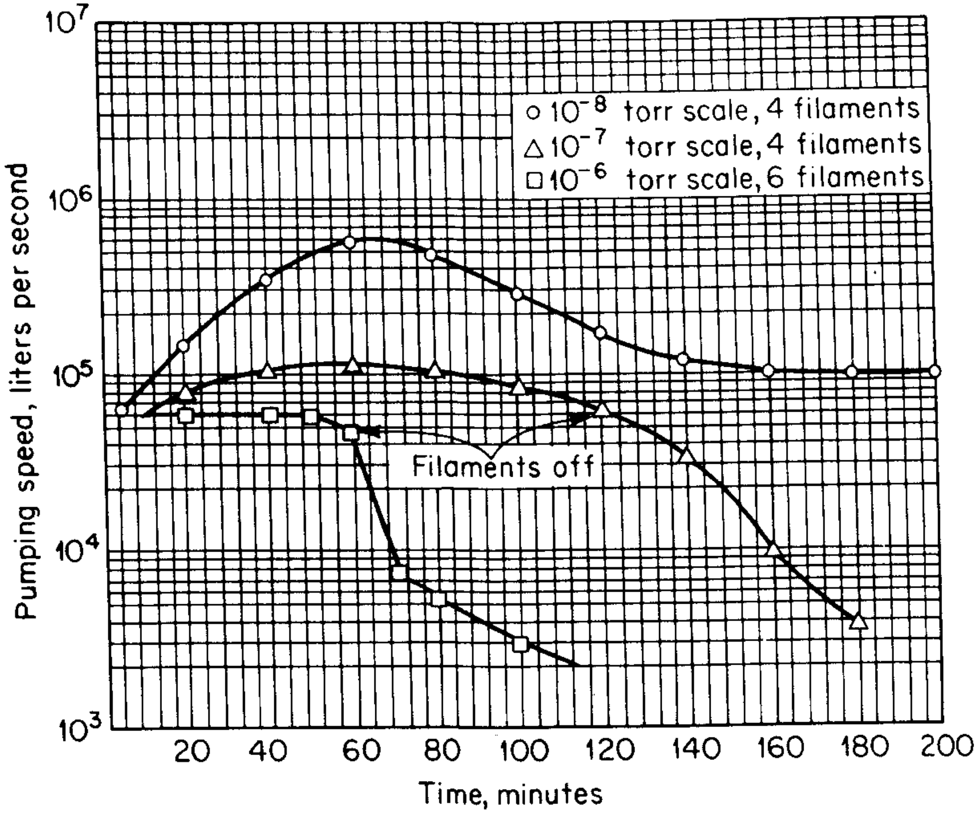

Fig. 6.4 Pumping-speed curves for nominal 50,000 liter per second ion pump with various filaments. (*Ultek Division, The Perkin-Elmer Corp., Palo Alto, Calif.*)

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- Conductance of a pipe in molecular flow regime:

$C=3.81(T/M)^{1/2}d^3/L$ (l/s)   (T (K), M (g/mol), d,L (cm))

- Effective length of right angle turns:

$L_{tot} < L_{eff} < L_{tot} + 2.66nr$ (n number of turns, r pipe radius)

- Conductance of an orifice molecular flow regime :

$C=3.64(T/M)^{1/2}A$ (l/s)   (T (K), M (g/mol), A (cm^2))

- Conductance of a pipe in viscous flow regime :

$C=(\pi d^4/128\eta L)p_a$ (cm^3/s) (d,L (cm), η (poise), p_a: average pressure dyn/cm^2)

- Effective pipelines and other data can be found in chemical engineering textbooks.

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V volume vacuumed from p_1 pressure to p_2 pressure with S pumping speed in viscous flow:

$$t=(V/S)\ln(P_1/P_2)$$

10 L volume with 6 m^3/h pump from atmosphere to 0.1 mbar

$$t=(0.01m^3/6m^3/h)\ln(1000mbar/0.1mbar)=0.015 \text{ hour i.e. } 1 \text{ min}$$

Pumping speed for vacuuming 1 m^3 volume in quarter to 0.1 mbar

$$(1m^3/0.25h)\ \ln(1000mbar/0.1mbar)=37\ m^3/h$$

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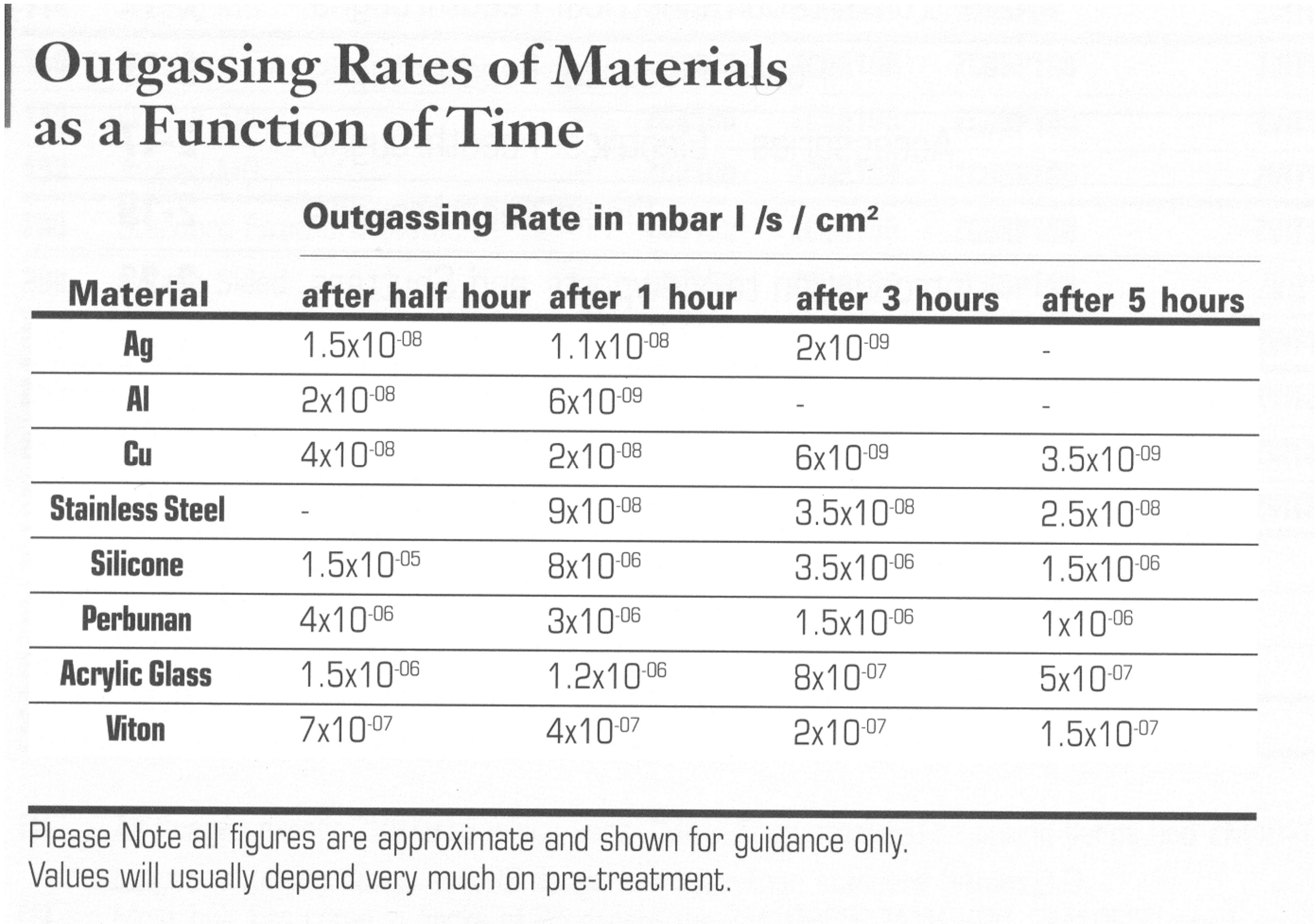
End pressure is defined by equilibrium of pumping speed with outgassing and leakages

$$Q_o+Q_L=S_{eff}*p_{end}$$

Plastics and elastomers has much higher outgassing than metals



Outgassing Rates of Materials as a Function of Time

Material	Outgassing Rate in mbar l /s / cm²			
	after half hour	after 1 hour	after 3 hours	after 5 hours
Ag	1.5×10^{-08}	1.1×10^{-08}	2×10^{-09}	-
Al	2×10^{-08}	6×10^{-09}	-	-
Cu	4×10^{-08}	2×10^{-08}	6×10^{-09}	3.5×10^{-09}
Stainless Steel	-	9×10^{-08}	3.5×10^{-08}	2.5×10^{-08}
Silicone	1.5×10^{-05}	8×10^{-06}	3.5×10^{-06}	1.5×10^{-06}
Perbunan	4×10^{-06}	3×10^{-06}	1.5×10^{-06}	1×10^{-06}
Acrylic Glass	1.5×10^{-06}	1.2×10^{-06}	8×10^{-07}	5×10^{-07}
Viton	7×10^{-07}	4×10^{-07}	2×10^{-07}	1.5×10^{-07}

Please Note all figures are approximate and shown for guidance only.
Values will usually depend very much on pre-treatment.

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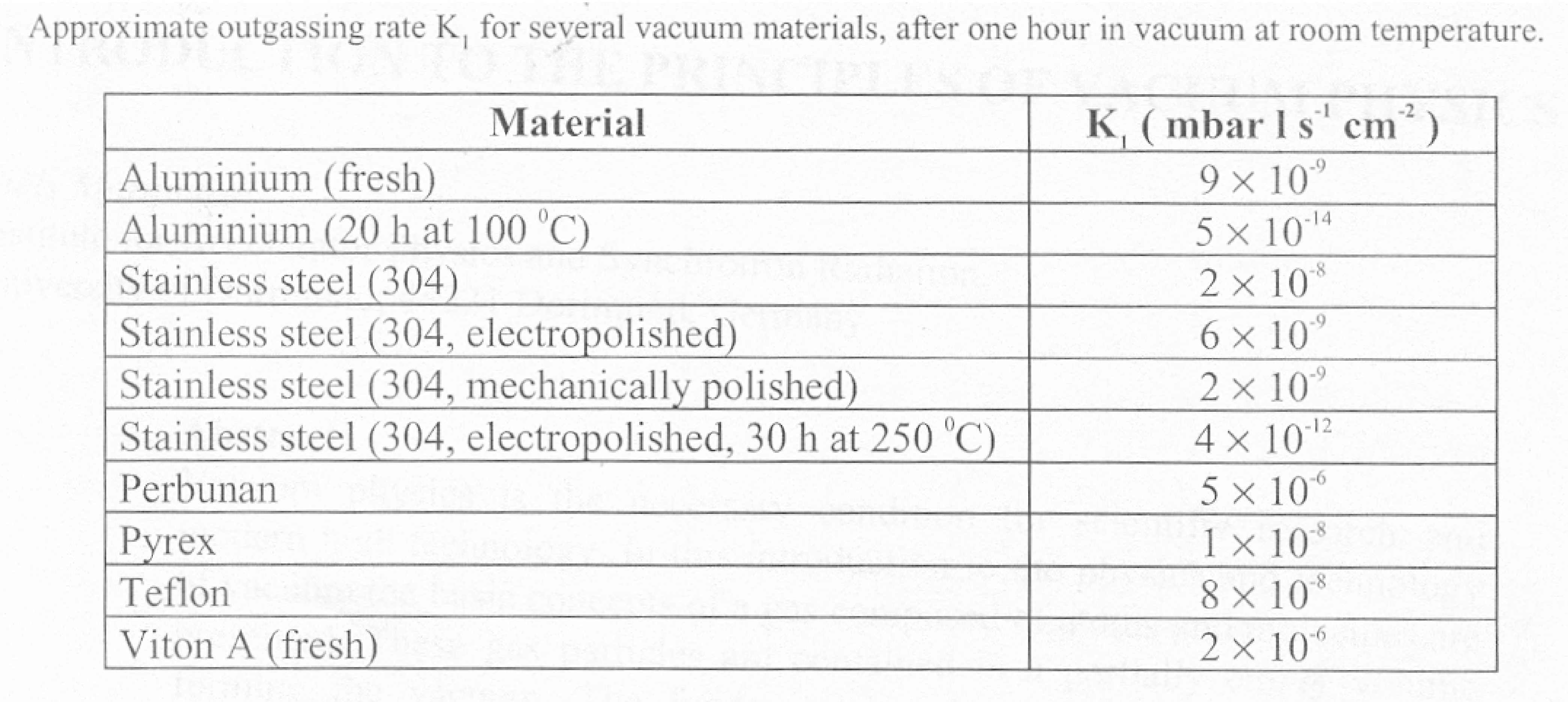

Approximate outgassing rate K_1 for several vacuum materials, after one hour in vacuum at room temperature.

Material	K_1 (mbar l s^{-1} cm^{-2})
Aluminium (fresh)	9×10^{-9}
Aluminium (20 h at 100 ^{0}C)	5×10^{-14}
Stainless steel (304)	2×10^{-8}
Stainless steel (304, electropolished)	6×10^{-9}
Stainless steel (304, mechanically polished)	2×10^{-9}
Stainless steel (304, electropolished, 30 h at 250 ^{0}C)	4×10^{-12}
Perbunan	5×10^{-6}
Pyrex	1×10^{-8}
Teflon	8×10^{-8}
Viton A (fresh)	2×10^{-6}

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1 L ss cube with 100 l/s pumping speed

$$(600\ \mathrm{cm}^2 * 2*10^{-9}\ \mathrm{mbar\ l/s\ cm}^2)/(100\ \mathrm{l/s}) = 1.2*10^{-8}\ \mathrm{mbar}$$

Pumping capacity is the same across the system, so needed fore vacuum speed is

$$(1.2*10^{-8}\ \mathrm{mbar}*100\ \mathrm{l/s})/0.01\ \mathrm{mbar} = 1.2*10^{-4}\ \mathrm{l/s}$$

Which is $4.3*10^{-4}\ \mathrm{m}^3/\mathrm{h}$

Other parameter for fore vacuum speed is vacuuming. If HV start at 0.01 mbar, and temporarily 0.5 mbar fore vacuum is accepted, then needed fore vacuum speed is

$$(0.01\ \mathrm{mbar}*100\ \mathrm{l/s})/0.5\ \mathrm{mbar} = 2\ \mathrm{l/s}$$

Equals to $7.2\ \mathrm{m}^3/\mathrm{h}$.

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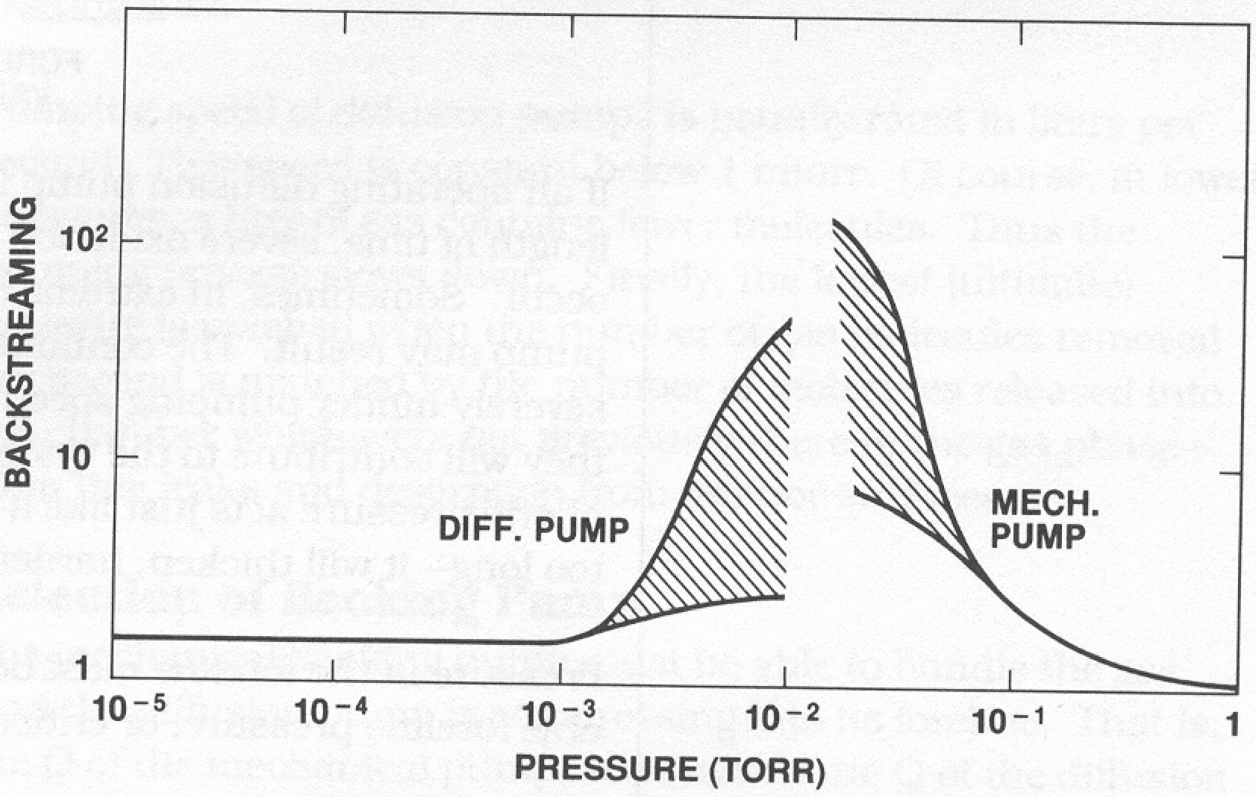
In a combination of a rotary vane and a diffusion pump the „cross-over” pressure is in fact typically 0.01 mbar.



PUMPING AND LUBRICATION FLUID BACKSTREAMING
IN THE TRANSITION ZONE
BETWEEN DIFFUSION AND MECHANICAL PUMPS

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Some things to keep in mind:

- Material no-no-s (carbon steel, brass, cadmium, general plastics etc.).
- Welding from inside with TIG,
- Soldering with silver solder
- Sticking with proved epoxy-resin
- Avoid closed volumes (bolts and nuts, imperfect fitting of parts, weldings etc.).
- Surface treatment and contamination (sanding, machining oils etc.)

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Welding do-s and don’t-s

to avoid closed volumes and dirty points

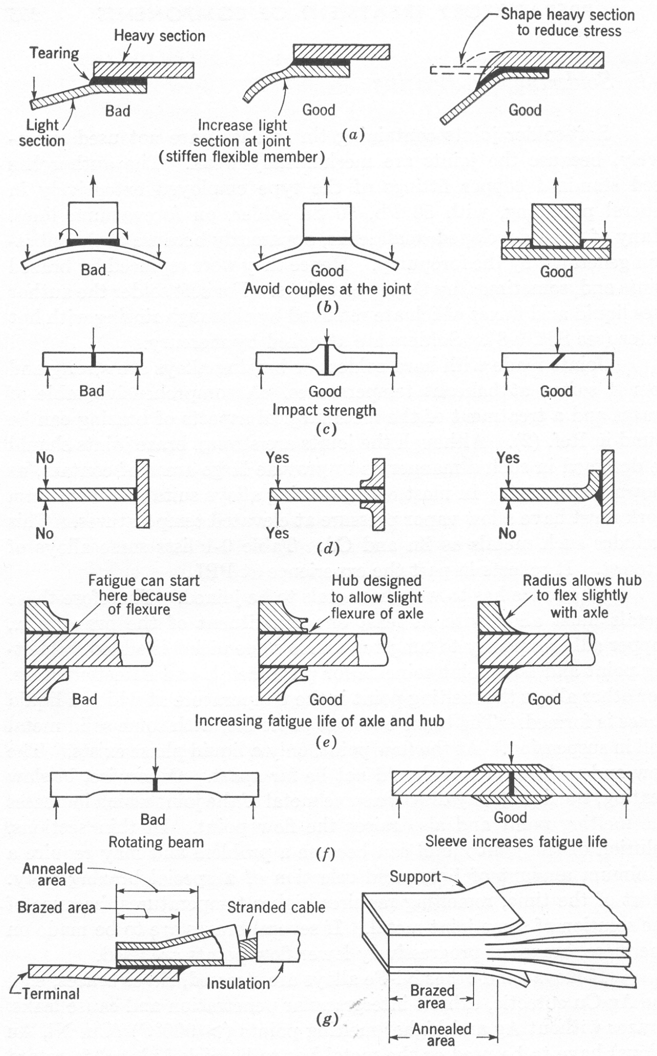

Fig. 9-1 Examples of good and bad designs of brazed joints. (From “Brazing Manual,” Committee on Brazing and Soldering of American Welding Society, Reinhold Publishing Corporation, New York, 1955.)

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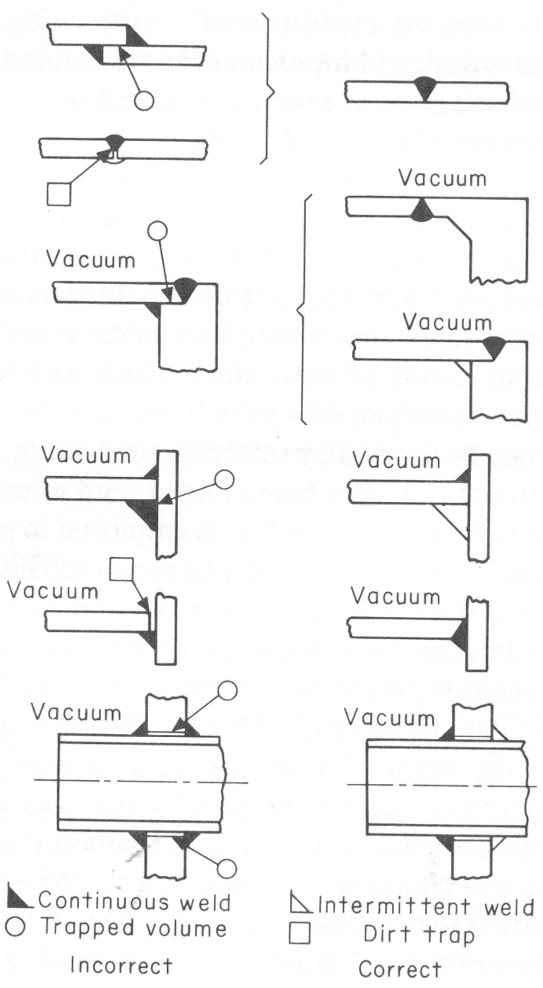

Fig. IV.1. Welding practice for vacuum apparatus. Note that the general approach is to weld on the inside and avoid dead spaces which may present leaks that are extremely hard to locate.

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Test piece for vacuum welding. A good welder can learn the tricks in three days

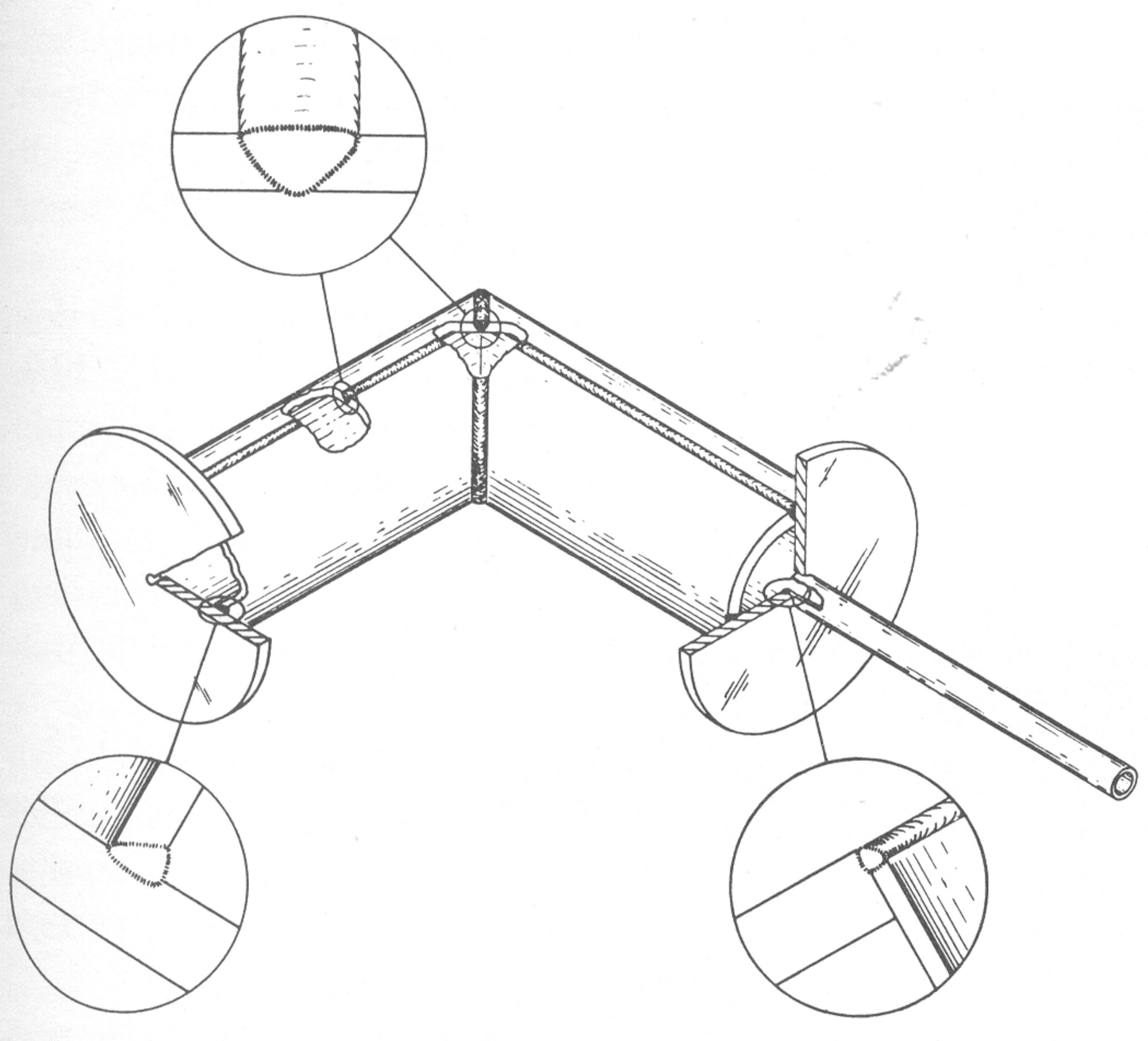

Fig. 13.4 High-vacuum-qualification welding test assembly.

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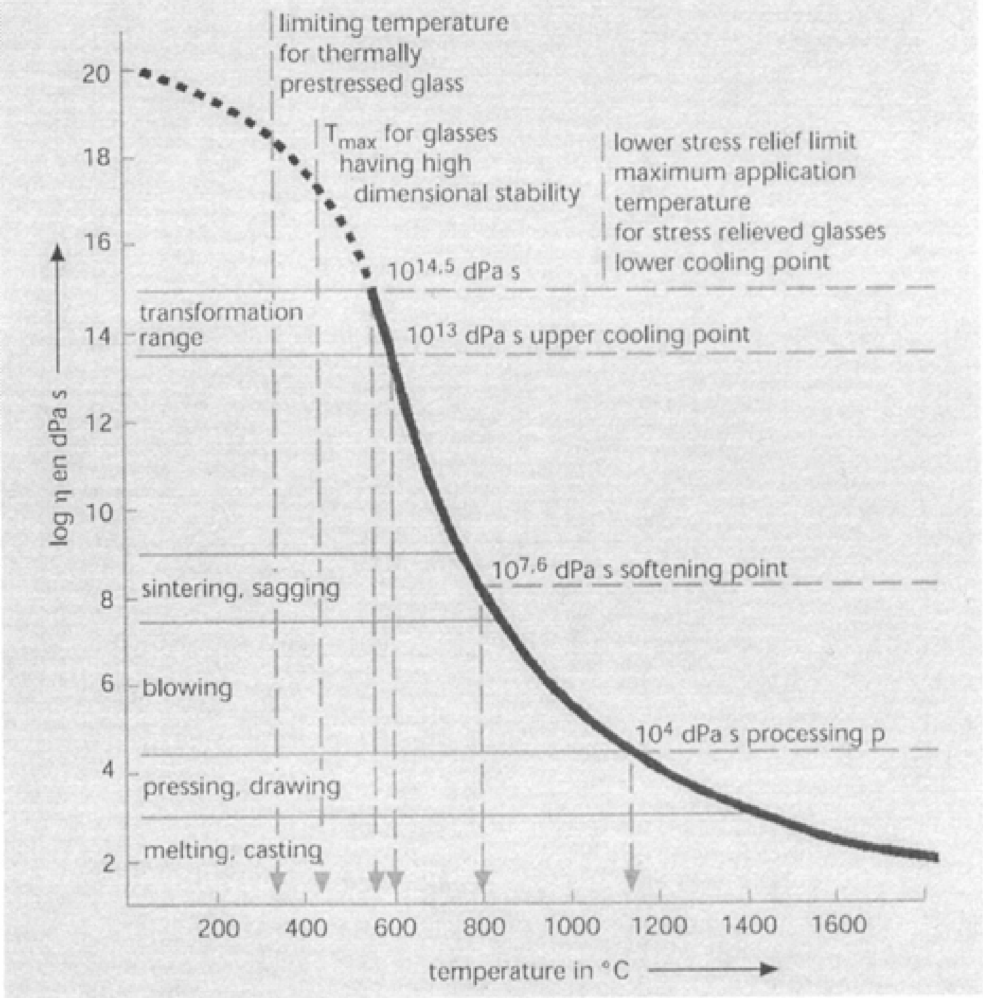
Pyrex equipment can be stress relieved at 550-600 °C (i.e. 12 heating in furnace with 8 hours controlled cooling, see manufacturers data). Check for stress between two polar filters (stressed glass polarize light and rotates polarization plane), be very cautious at first vacuuming



Normal temperature dependence/viscosity curve of, for example, DURAN®; viscosity ranges of important processing techniques, position of fixed points of viscosity and various limiting temperatures.