Build your own vacuum system

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A basic vacuum system integrates with the following omponents:
(1) main structure – chamber, pump
(2) extended structure – mounting frame and chamber hoist
(3) service components – power, water and air supplies
(4) monitors – gauges, thermocouples

The consideration for building a vacuum system
(1) lower cost (2) pumping speed (3) vacuum level
(4) compatibility & versatility (5) reliability (6) materials used

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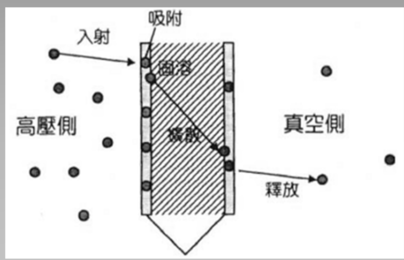
Factors that affect vacuum pressure

(1) Diffusion and permeability（擴散與滲透)
(2) Sublimation and evaporation (昇華與蒸發)
   * 飽和蒸氣壓
   * 昇華與蒸發速率
(3) Outgassing (逸氣)



How to choose a suitable material comparable to vacuum?

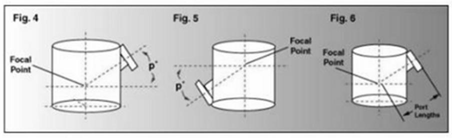
(1) It must be smooth.
(2) It has low enough vapor pressure.
(3) It doesn’t include impurities and gas.
(4) It is not easy to adsorb gas and outgas.
(5) It can be baked under high temperature and freezed under low temperature.

The material commonly use for vacuum
(1) Metal: stainless steel, aluminum
(2) Nonmetal: ceramic, artificial rubber, telfon, fused silica, sapphire, glass, MgF_2

How to design a chamber?

(1) Shape – (a) cylindrical*, (b) cubic, (c) rectangular*,

(d) spherical etc..



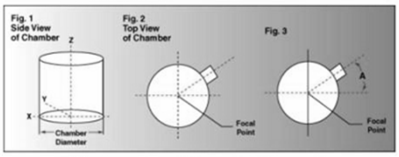
(2) Size –

(a) diameter、width、length

(b) material

(c) height from base to highest point (excluding top ports)

(d) wall thickness (the more symmetric the less thickness you need)



(3) Define the port –

(a) choose a focal point (sample location)

(b) choose the azimuthal angle

(c) pole angle

(d) port length

(e) termination (design the type of ports)

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How to calculate conductance?

(1) conductance in viscous flow

a. It depend on the pipe used.

b. It becomes 2^4 times if pipe diameter twice.

c. It becomes 0.5 times if pipe length twice.

(2) conductance in molecular flow

a. It becomes 2^3 times if pipe diameter twice.

b. It becomes 0.5 times if pipe length twice.

Conductance C_1	Conductance C_2	Total Conductance $1/(1/C_1 + 1/C_2)$
10	10	5 L/sec
10	100	9.1 L/sec
10	1000	9.9 L/sec
10	10,000	9.99 L/sec
10	100,000	9.999 L/sec
10	1,000,000	9.9999 L/sec

Series conductance $1/C_{total} = 1/C_1 + 1/C_2$ (L/sec)

Parallel conductance $C_{total} = C_1 + C_2$ (L/sec)

System conductance $1/R = 1/C + 1/S$

R : total conductance

C : the combined pipe conductance

S : the conductance of the pump

Pumping speed (L/sec) : volumetric pumping capacity, S=V/t

Throughput (torr-L/sec) : vacuum pumping capacity, Q =PS=PV/t

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Speed of gas molecules: for air (80% N_2 + 20% O_2) at 20 °C

$$\bar{v} = \sqrt{\frac{8kT}{\pi m}} = 500\, {}^{m}\!/\!{}_{s}$$

Mean Free Path: 平均自由徑

The average distance that a molecule travels between collisions

$$\lambda \cong \frac{5\times10^{-3}}{P(torr)} cm$$

for molecules of 3 Å diameter

and $\bar{v} = 500\, {}^{m}\!/\!{}_{s}$

P = 760 torr	λ = 700 Å
P = 1 torr	λ = 50 μm
P = 10^{-3} torr	λ = 5 cm
P = 10^{-6} torr	λ = 50 m

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Pumping speed

For a typical pump, its pumping speed is proportional to the ability to remove a volume of inlet gas. The pumping speed S is defined as

$$S = \frac{dV}{dt}$$ in liters per second, ℓ/s

Throughput $Q = PS$ in torr ℓ

From $PV = NRT$ ➡ $\frac{dN}{dt} \propto \frac{dPV}{dt}$ at T= const.

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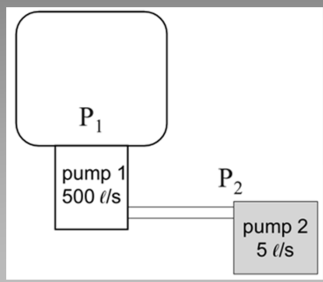
Normally, throughput, Q, is conserved.

$$Q = P_1S_1 = P_2S_2$$

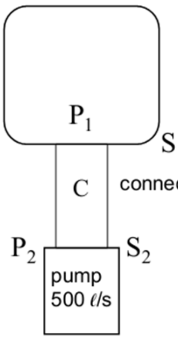
Ex: $P_2 = 100\,P_1$



Tube

$$\frac{1}{S_1} = \frac{1}{C} + \frac{1}{S_2}$$

D = diameter, in cm
L = length, in cm
C = conductance, in ℓ/s



connecting tube, conductance $C = 12\dfrac{D^3}{L}$ @ molecular flow

example 1	example 2
D = 15 cm	D = 10 cm
L = 20 cm	L = 20 cm
C = 2025 ℓ/s	C = 600 ℓ/s
S_1= 401 ℓ/s	**S_1= 273 ℓ/s**

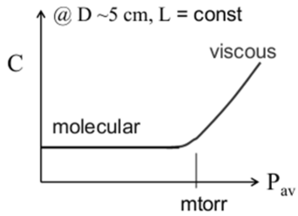
Pump is expensive. Tube is cheap.

For tube

$$C = 12\frac{D^3}{L}$$ @ molecular flow, D ~ 5 cm, P < mtorr

λ = 5 cm @ 1 mtorr

$$C = 180\frac{D^4}{L}P_{av}$$ @ viscous flow, P > mtorr



D = diameter, in cm
L = length, in cm
C = conductance, in ℓ/s
P_{av} = average pressure, in torr

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Pump down time

$$\frac{dPV}{dt} = SP$$ equation for the throughput

$$\frac{dP}{dt} = -\frac{S}{V}P$$

$$P = P_0\, e^{-t/\tau}$$

$$\tau = \frac{V}{S}$$

example
V = 1000 ℓ
S = 500 ℓ /s
τ = 2 s
every 2.3 τ, 10 x pressure drop

Why it takes much longer from 10^{-6} Torr to 10^{-7} Torr?
Ans.: Surface outgas

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Surface Concern

example: 10^{-3}mol H_2O, 18 mg, liquid 1.8×10^{-2}cm^3; gas $2.4\times10^{-2}\ell$ at 1atm

If 10^{-3}mol H_2O in chamber surface and if the outgas pressure is 10^{-7} Torr, how long it takes to pump down to 10^{-8} Torr when the pumping speed is 1000ℓ/s?

Initial pumping throughput, Q, is

10^{-7}torr * 1000ℓ/s = 10^{-4}torr ℓ/s

Total amount of water is

1 atm* $2.4\times10^{-2}\ell$= 760Torr * $2.4\times10^{-2}\ell$= 1.8×10^{1}Torr ℓ

Assume:
outgas rate ∝ water amount ∝ P ∝ pump out throughput
i.e. first order rate equation

$$\frac{dP}{dt} = -\frac{1}{\tau}P \qquad P = P_0 e^{-t/\tau}$$

Pump out time constant = τ

$$\tau = \frac{\text{total amount}}{\text{initial rate}} = \frac{1.8\times10^{1}\ \text{torr}\ \ell}{10^{-4}\ \text{torr}\ \ell/\text{s}} = 1.8\times10^{5}\text{s} = 50\,\text{hr}$$

2.3 τ = 115 hr to reduce 10x pressure

Often for a chamber with big surface area

How to minimize surface area?

Oxide could be porous
- Remove thick surface oxide:
  - electro polish SUS chamber and parts
  - basic wash (NaOHsolution) Al alloy
  - acid wash copper/brass parts
  - sand blast

Dirty surface is thicker.
Cleaning -- Strong detergent is much more efficient than solvent.

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Estimate the effect of Baking

When temperature rises by 100°C, outgas rate rises by roughly two orders of magnitude.

Initial pumping throughput is 10^{-5} Torr * 1000ℓ/s = 10^{-2} Torr ℓ

$$\tau = \frac{1.8\times10^{1}\,\text{torr}\,\ell}{10^{-2}\,\text{torr}\,\ell/\text{s}} = 1.8\times10^{3}\,\text{s} = 0.5\,\text{hr}$$

to P = 10^{-10} torr, $P_0/P = 10^5$ $$\Delta t = \tau \ln\frac{P_0}{P} = 11.5\,\text{hr}$$

Practically, it takes a little bit longer (≲100 hrs). ∵Single exponential delay is only an approximation. Deeper water has smaller outgas rate, thus longer τ.

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Bake uniformly is important to avoid distortion.
- Aluminum foil on SUS chamber, heating tape on the aluminum foil, another layer of aluminum foil to reduce heat loss

Degas ion gauge during baking
- Clean ion gauge and its surrounding by excess heating

Don't bake oily surface. Oil ➔ tar

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