Air leakage in vacuum vessels

- How airtight is a vacuum plant?
- Is the suction capacity of the vacuum pump large enough?
- Why does it take so long for the plant to reach the vacuum?
- Must the vacuum pump extract leak air as well as gases from the product?

You can answer all these questions if you know the air leakage in the vacuum tank.

It is determined as follows:

- Evacuate the vessel to a vacuum under 500 mbar, e.g. 60 mbar.
- Isolate the vacuum pump from the vessel and completely seal off the vessel.
- Measure the pressure increase in the vessel and determine the corresponding time.
- The pressure increase in mbar divided by the time in minutes gives the vacuum loss in mbar/minute.

With this value and the volume of the vessel under vacuum the air leakage rate in kg/h can be found in the chart, **fig. 1**.
The chart, **fig. 1**, is calculated from the formula:

$$\dot{M}_A = 0.071^* \cdot \frac{\Delta p}{t} \cdot V$$

Whereby:

$\dot{M}_A$	Air leakage in $\frac{kg}{h}$
Δp	Change of pressure in mbar
t	Corresponing time in min
V	Plant volume in m^3

* The exact value is **0.071289977**, based on:

Universal gas constant	8.31441 $\frac{J}{mol\ K}$
Absolute temperature	293.15 K
Mol mass for air	28.96 $\frac{kg}{kmol}$

EXAMPLE FOR AIR LEAKAGE

A vessel of 20 m^3 volume is evacuated to 60 mbar and isolated. Within 10 minutes there is a vacuum loss to 120 mbar. The pressure change thus amounts to 60 mbar.
Therefore, the vacuum loss is

$$60 : 10 = 6 \ \frac{mbar}{min}$$

With this value, the formula results in an air leakage of

$$0.071 \cdot 6 \cdot 20 = 8.5 \ \frac{kg}{h}$$

In the high-vacuum range the air leakage rate or the quantities of gases and vapours are measured in mbar · liter/s.

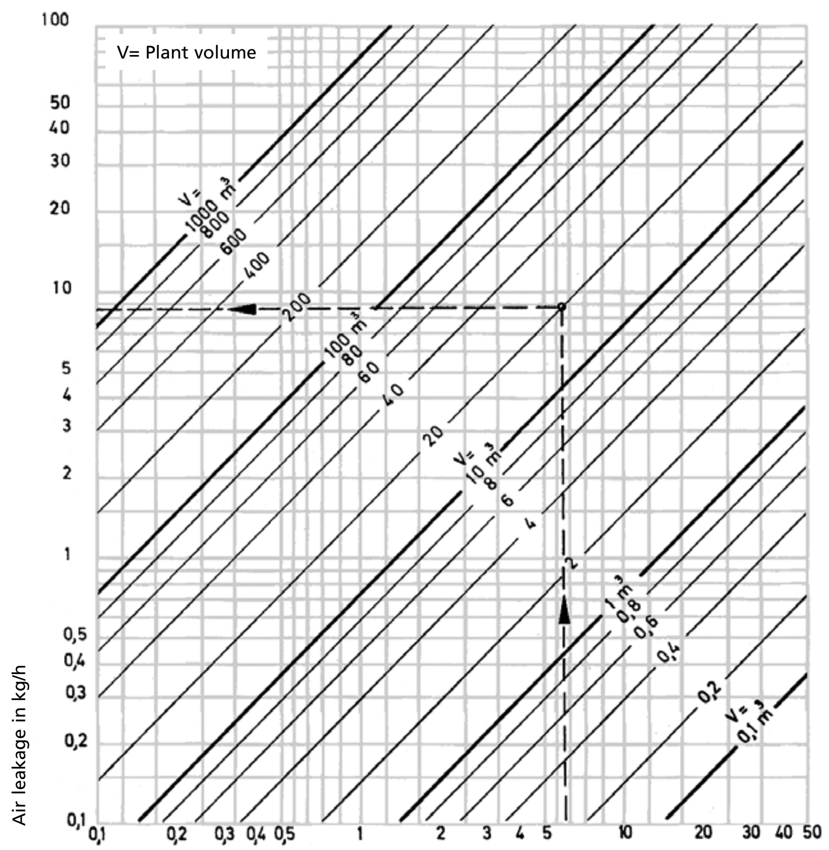
$$1\,mbar \ \frac{liter}{s} \cong 0.0043 \ \frac{kg}{h} \quad \text{Air of 20 °C}$$

BUDGET VALUES REGARDING AIR LEAKAGE IN VACUUM UNITS AND PLANTS

The following shall apply regarding the requirement to the tightness of a plant under vacuum: The lower the pressure to be maintained in the plant, the higher the requirement to the tightness of the plant, because the expenditure for generating and maintaining vacuum increases with decreasing pressure.
Through an opening of 1 mm^2 approx. 0.83 kg/h of air flow into a vacuum unit, independent of the amount of vacuum, if it is only < 530 mbar. In this case, just critical conditions are prevailing.

In case of normal flanged connections with large nominal diameter the assumed air leakage amounts to 200 to 400 g per hour and meter of seal length. With specially designed flanged connections, e.g. with groove and tongue or fine machined sealing surfaces and with the use of special seals the value can be reduced to 50 to 100 g/hm.
The tightness of vacuum plant can vary, depending on whether mainly welded units are concerned or whether units are concerned in which flanged connections, sight glasses, valves, gate valves, glands etc. have to be taken into consideration. The table on page 20 shows values which are based on experience. Depending on the overall volume of the unit and of the type of connections of units and ducts it shows the leakage air flow to be expected in kg/h.

FIG. 1



Vacuum loss in mbar/min
(The diagram is valid for pressures ≤ 500 mbar and for air of 20 °C)

Some measurements were compared with recommended values according to "HEI standards for steam jet ejectors", and it was determined that the measurements are according to those standards. Shaft throughputs are not considered in the table values. Mark-ups of 1 to 2 kg/h of air leakage per shaft throughput are required with normal gland seals.

Unit volume to be maintained under vacuum in m³	0.2	1	3	5	10	25	50	100	200	500
	Leakage air flow in kg/h									
Unit and duct connections										
with normal seals, mainly flanged	0.15-0.3	0.5-1	1-2	1.5-3	2-4	4-8	6-12	10-20	16-32	30-60
partly flanged, partly welded	0.1-0.2	0.25-0.5	0.5-1	0.7-1.5	1-2	2-4	3-6	5-10	8-16	15-30
mainly welded or designed with special seals	< 0.1	0.15-0.25	0.25-0.5	0.35-0.7	0.6-1.2	1-2	1.5-3	2.5-5	4-8	8-15

Admissible flow velocity in vacuum ducts

The admissible velocity of flow in a vacuum pipeline depends on how high the pressure loss of this pipeline is allowed to be. Higher pressure loss implies increased energy requirements for the vacuum pump. A pressure loss of up to 10 % of the total pressure can generally be accepted. This is shown in graph Fig. 1 and valid for air at 20 °C. It is calculated according to the formula:

$$w_{adm.} = \sqrt{\frac{2\left(\frac{\Delta p}{p}\right)_{adm.} \cdot R \cdot T}{1 + 40 \cdot \frac{l}{d}}}$$

$w_{adm.}$	Admissible flow velocity in m/s
$\left(\frac{\Delta p}{p}\right)_{adm.}$	Admissible pressure loss as portion of the total pressure
$R = \frac{\tilde{R}}{\tilde{M}}$	Individual gas constant in J/kg K
$\tilde{R} = 8314.3 \frac{J}{kmol} K$	Universal gas constant
$\tilde{M}$	Molecular mass in kg/mol
T	Temperature in K
l	Duct length in m
d	Duct diameter in mm

For reasons of simplification, the calculation is based on an average pipe friction coefficient of $\lambda = 0.04$ (this is max.) and on a free-of-loss acceleration from 0 to w m/s, i. e. with a well rounded duct inlet.

Range of application:

$2 \text{ mbar} \leq p \leq 1000 \text{ mbar}$

Furthermore, the graph contains lines for constant volume flow in m³/h. The graph is meant for rapid, rough dimensioning of a vacuum duct. An exact pressure loss calculation can be made with the help of sheet ↗ I abl 9.

EXAMPLE 1

CALCULATION OF THE MASS FLOW

GIVEN:

Duct	DN 100
Duct length	l = 10 m
Flow medium	Air, 20 °C
Total pressure	p = 10 mbar
Adm. pressure loss	Δp = 1 mbar

PARAMETERS TO BE FOUND:

1) Admissible velocity — $w_{adm.}$ in $\frac{m}{s}$

2) Volume flow — $\dot{V}$ in $\frac{m^3}{h}$

3) Mass flow — $\dot{M}$ in $\frac{kg}{h}$

SOLUTION:

With $\frac{\Delta p}{p} = 0.1$ the equation results in:

1) $w_{adm.} \approx 58 \frac{m}{s}$

2) $\dot{V} \approx 1650 \frac{m^3}{h}$

3) Formula $\dot{M} = \frac{\dot{V}}{v} \frac{kg}{h}$ and $v_A = \frac{840}{p} \frac{m^3}{kg}$

with v_A = Spec. volume of air at 20°C and p = Pressure in mbar:

$$\dot{M} = \frac{1650 \cdot 10}{840} \approx 20 \frac{kg}{h}$$

EXAMPLE 2

EQUIVALENT DUCT LENGTH IF PIPE BENDS AND GATE VALVES ARE INSTALLED IN THE DUCT:

$$l_E = l + \frac{d}{40} \cdot \Sigma \zeta$$

l_E	Equivalent duct length in m	
l	Duct length in m	
d	Pipe diameter in mm	
ζ	Resistance coefficients:	
	Pipe bend D/d = 3.90°	ζ = 0.16
	Gate valve with restriction	ζ = 1.0

GIVEN:

Duct	DN 600
Pipe length	l = 100 m
Flowing medium	air, 20 °C
Total pressure	p = 10 mbar
Adm. pressure loss	Δp = 1 mbar

4 tube bends 90°, 1 gate valve

PARAMETERS TO BE FOUND:

1) Equivalent pipe length — l_E in m

2) Admissible flow velocity — $w_{adm.}$ in $\frac{m}{s}$

3) Volume flow — $\dot{V}$ in $\frac{m^3}{h}$

4) Mass flow — $\dot{M}$ in $\frac{kg}{h}$

SOLUTION: The following results by way of calculation:

1) $l_E = 100 + \frac{600}{40}(4 \cdot 0.16 + 1) = 124.6 \text{ m}$

With $\frac{\Delta p}{p} = 0.1$ the equation results in:

2) $w_{adm.} \approx 44 \frac{m}{s}$

3) $\dot{V} \approx 45000 \frac{m^3}{s}$

4) $\dot{M} = \frac{45000 \cdot 10}{840} \approx 535 \frac{kg}{h}$

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