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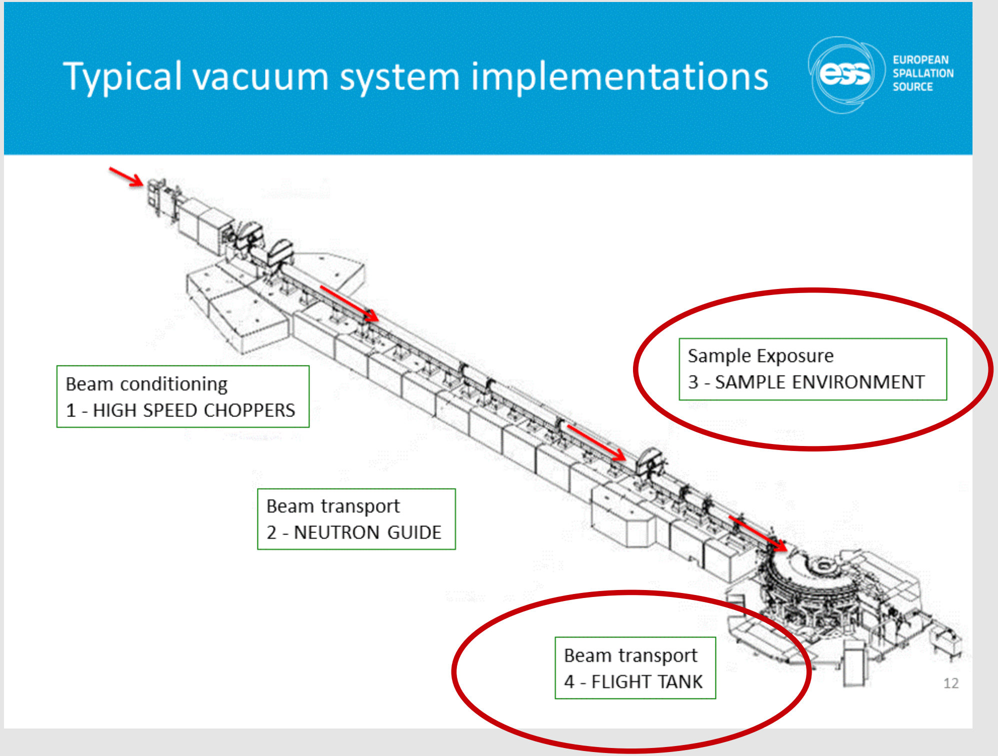
Lothar Holitzner :: Designing Engineer :: Paul Scherrer Institut

Rough Estimation of the Necessary **Pumping Time** for a Vacuum Vessel

1st ISNIE Summer School, 20-September-2018

Context


Typical vacuum system implementations
EUROPEAN
SPALLATION
SOURCE
Beam conditioning
1 - HIGH SPEED CHOPPERS
Beam transport
2 - NEUTRON GUIDE
Sample Exposure
3 - SAMPLE ENVIRONMENT
Beam transport
4 - FLIGHT TANK
12

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Context

Examples
A range of requirements and challenges for vacuum systems

EUROPEAN SPALLATION SOURCE

Criteria	HS Choppers	Neutron Guide	Detector vessel	Sample environment
Vacuum level	Good	Poor	Good	Very good
Pumped volume	Small	Moderate	V.Large	V.Small
Cycle time	V.Slow	V.Slow	Moderate	Fast
Radiation hardness	High	High/Mod	Low	High
Servicability	Low	V.Low	Moderate	High

Criterion

13

Context

Examples
A range of requirements and challenges for vacuum systems

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Criterion

13

Experiences

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Oct. 1994

Experiences

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Project: SINQ , FOCUS (Time-of-flight spectrometer)

Oct. 1994

The „FOCUS-team“

- Joël Mesot (physicist)
- Stefan Janssen (physicist)
- Lothar Holitzner (Dipl.-Ing.)

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Oct. 1994

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I saw my first neutron instruments at

- Forschungszentrum Jülich
- ILL, Grenoble

Experiences

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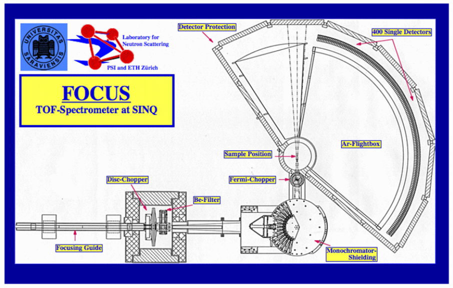
Project: SINQ , FOCUS (Time-of-flight spectrometer)

technical concept ready

assembly start



Apr. 1995 → Nov. 1996 → Dec. 1998

1st measured spectrum

Experiences

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Project: SINQ , FOCUS (Time-of-flight spectrometer)

detector housing
by IRELEC

sample chamber
by IRELEC

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Experiences

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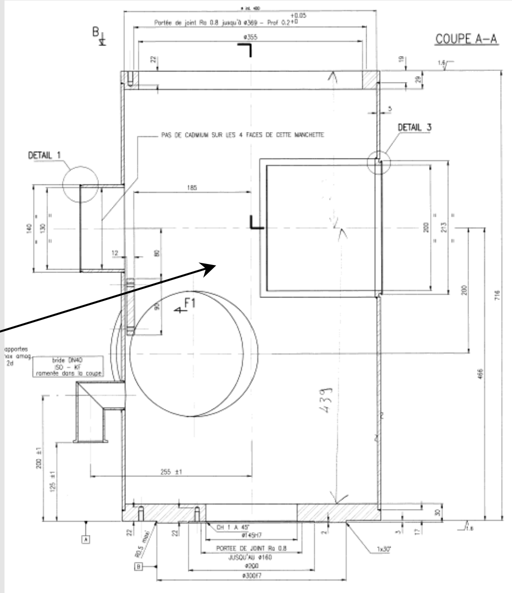
Project: **SINQ , FOCUS** (Time-of-flight spectrometer)

sample chamber
by IRELEC



it´s a
vaccum vessel

Experiences

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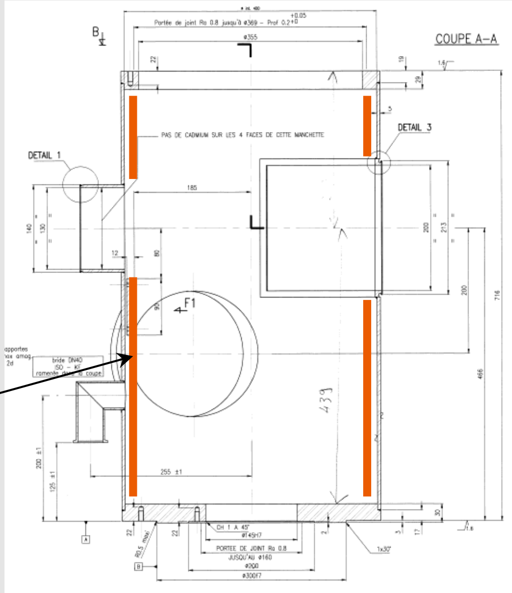
Project: **SINQ , FOCUS** (Time-of-flight spectrometer)



desired:
neutron shielding
inside the vessel

it´s a
vaccum vessel

Experiences

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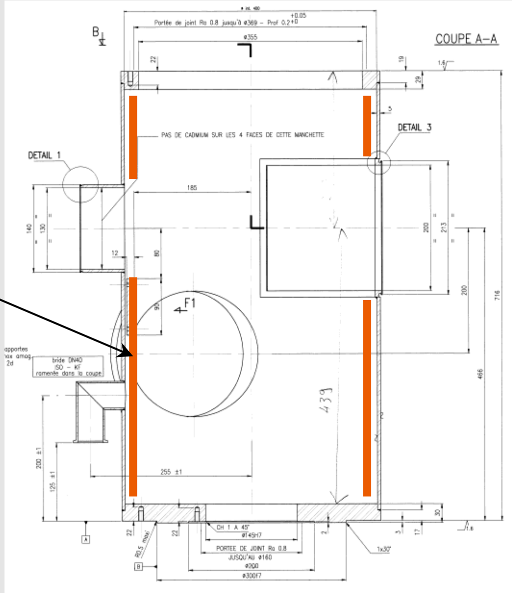
Project: SINQ , FOCUS (Time-of-flight spectrometer)

Which material?

Cadmium sheet ?

or

„Boronplastic“



it´s a

vaccum vessel

Experiences

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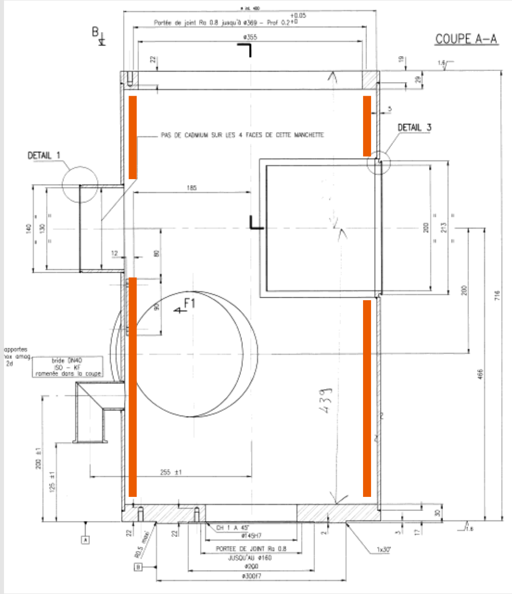
Project: **SINQ , FOCUS** (Time-of-flight spectrometer)

How to attach it?

They **glued** it to the wall.



it´s a vaccum vessel

Experiences

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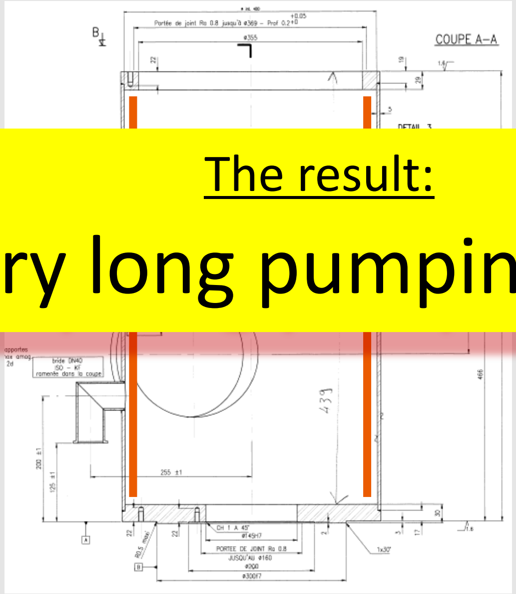

The result:

A very long pumping time !

it´s a vaccum vessel

Invitation

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Let´s make it better

Situation

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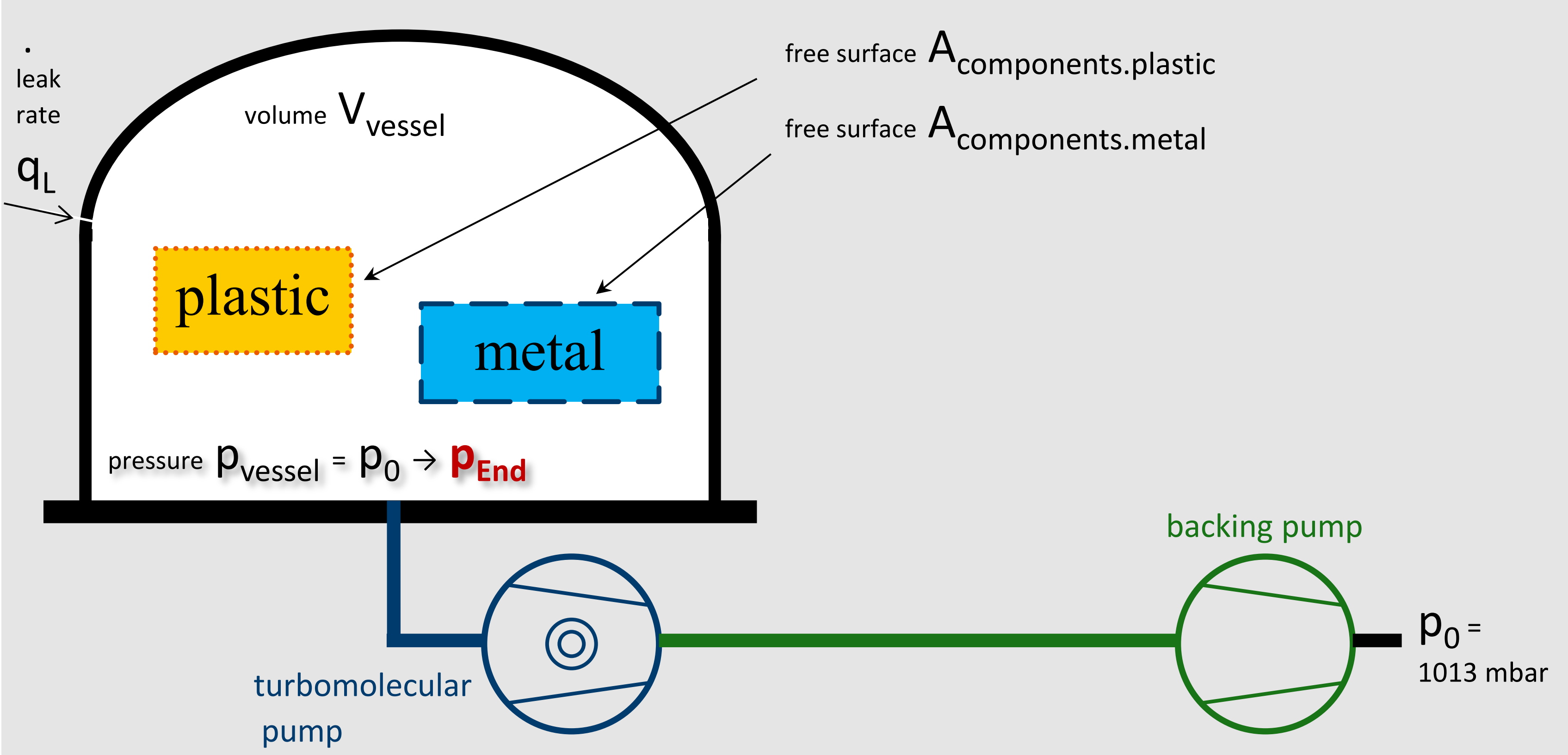
Situation



leak
rate
$\dot{q}_L$
volume V_{vessel}
free surface $A_{components.plastic}$
free surface $A_{components.metal}$
plastic
metal
pressure $p_{vessel} = p_0 \rightarrow p_{End}$
backing pump
turbomolecular
pump
$p_0 =$
1013 mbar

Task Formulation

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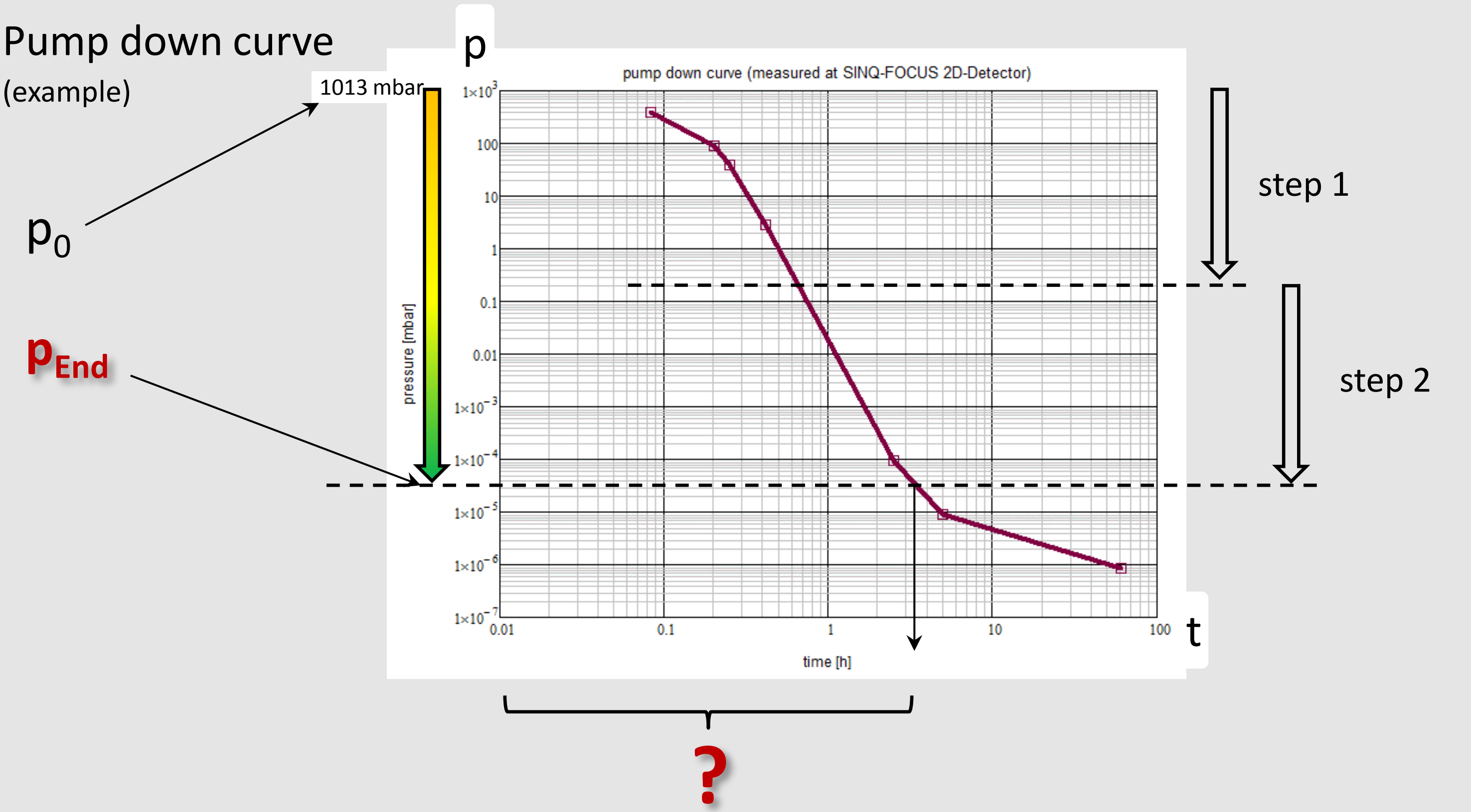
HOW LONG DOES
THE PUMP DOWN PROCEDURE
TAKE TO REACH
THE DESIRED END PRESSURE P_{END}?

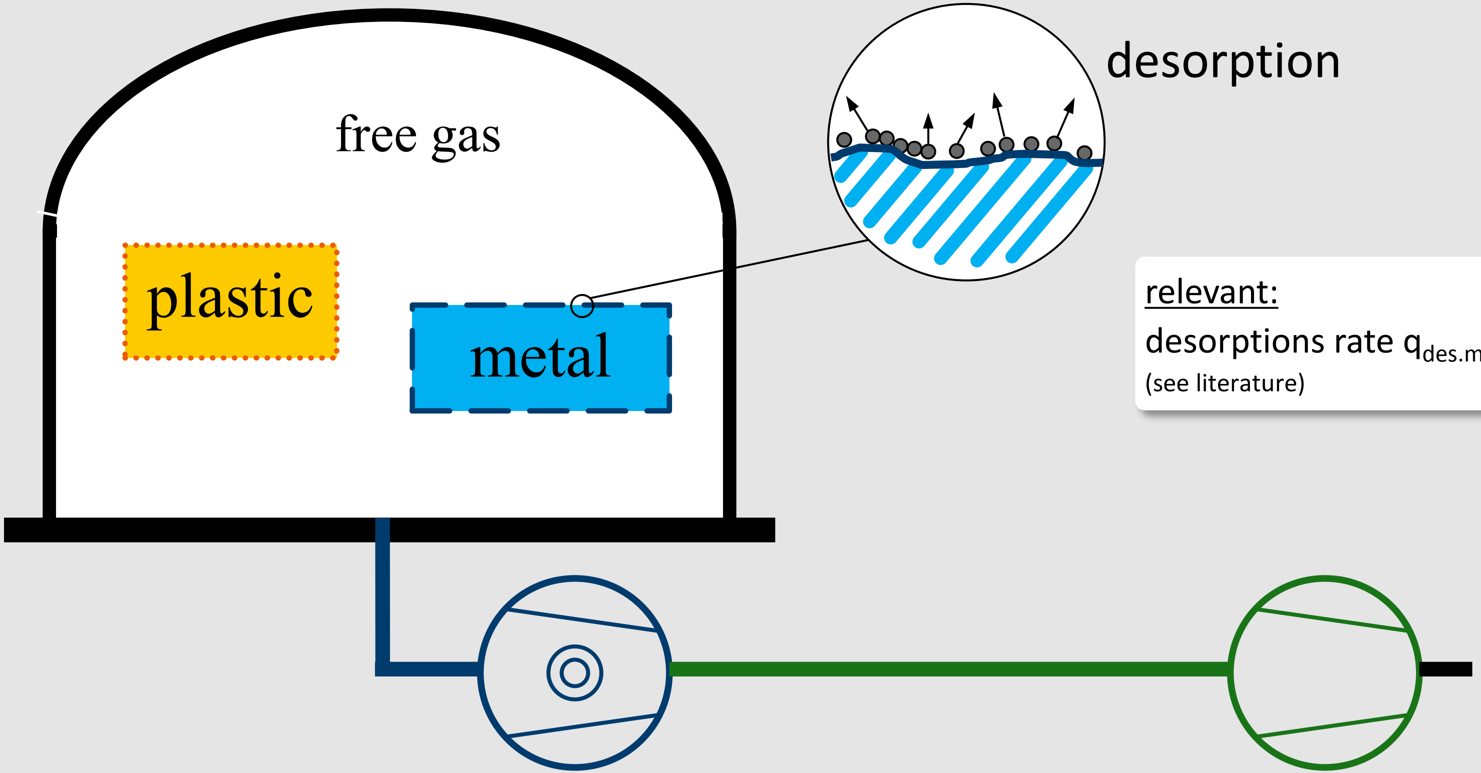
Task Formulation

Pump down curve

(example)



Material Choice, Qutgassing from Surfaces

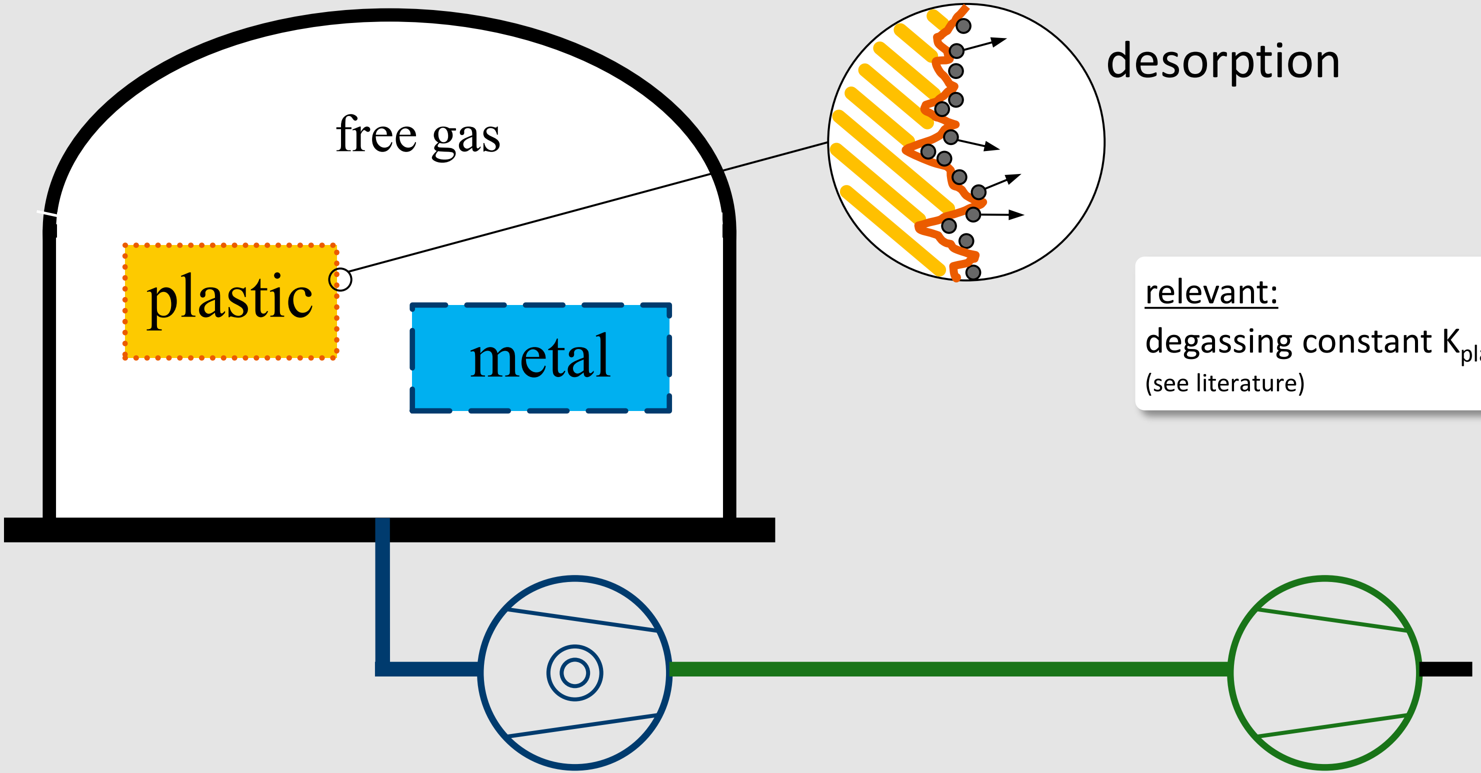


relevant:

desorptions rate $q_{des.met}$

(see literature)

Material Choice, Outgassing from Surfaces



relevant:

degassing constant K_{pla}

(see literature)

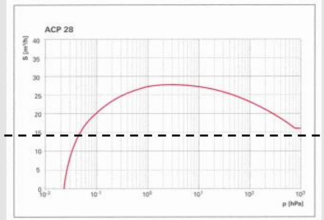
Vacuum Pumps and Connecting Tubes

Backing pump:

<u>relevant pump parameters:</u>

- absorption capacity $S_V < S_{V.max}$
- theoretical ultimate pressure $P_{theo.V.end}$

(see manufacturer papers)



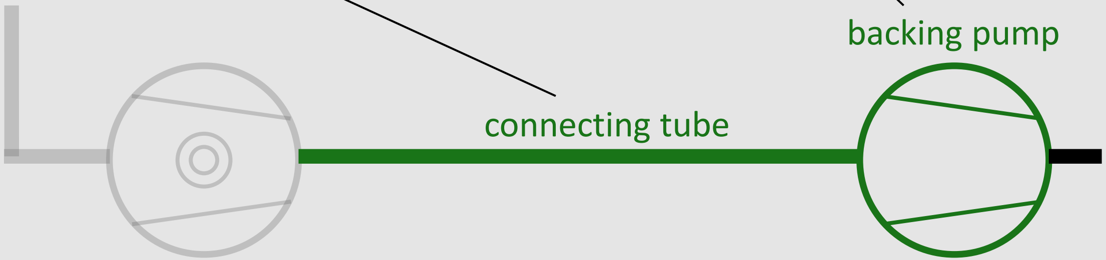
ACP 28 Saugvermögen

/1/

<u>relevant tube parameters:</u>

- nominal tube diameter, e. G. DN40
- tube length $l_{V.tube}$

(your choice)



Vacuum Pumps and Connecting Tubes

Turbomolecular pump:

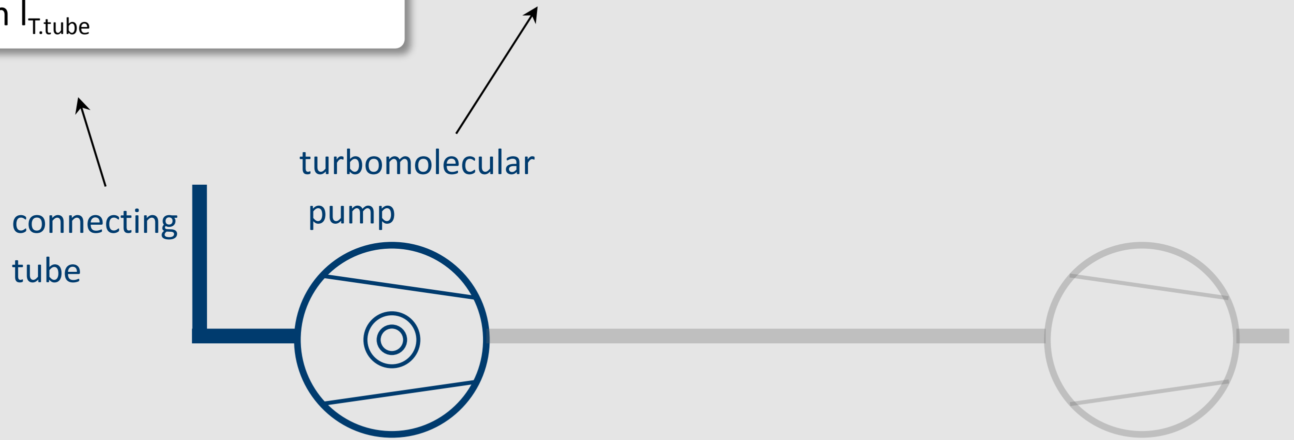
<u>relevant pump parameters:</u>

- nominal absorption capacity $S_{T.rated}$
- theoretical ultimate pressure $P_{theo.T.end}$
- start-up pressure p_1

(see manufacturer papers)

<u>relevant tube parameters:</u>

- nominal tube diameter, e. G. DN160
- inside tube diameter $d_{T.tube}$
- tube length $l_{T.tube}$



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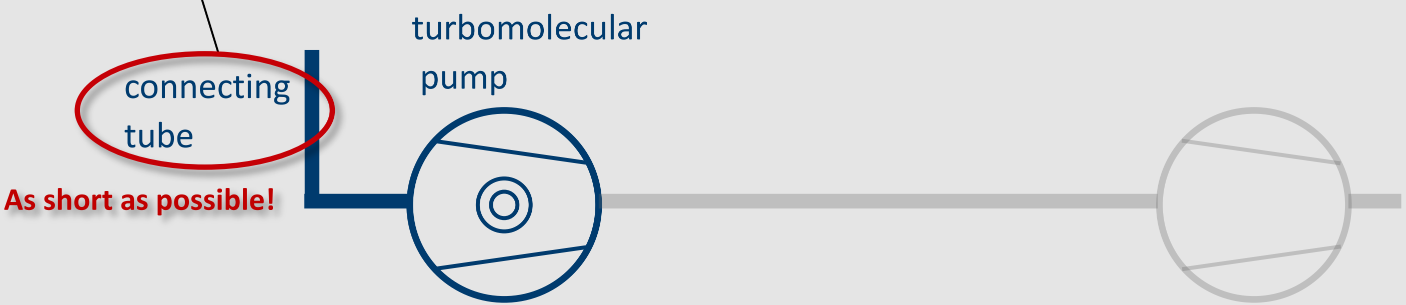

Rough Estimation of the Pumping Time

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CALCULATIONS

Effective Absorption Capacities

Backing pump:

<u>tube parameters:</u>

- nominal tube diameter, e. G. DN40
- tube length $l_{V.tube}$

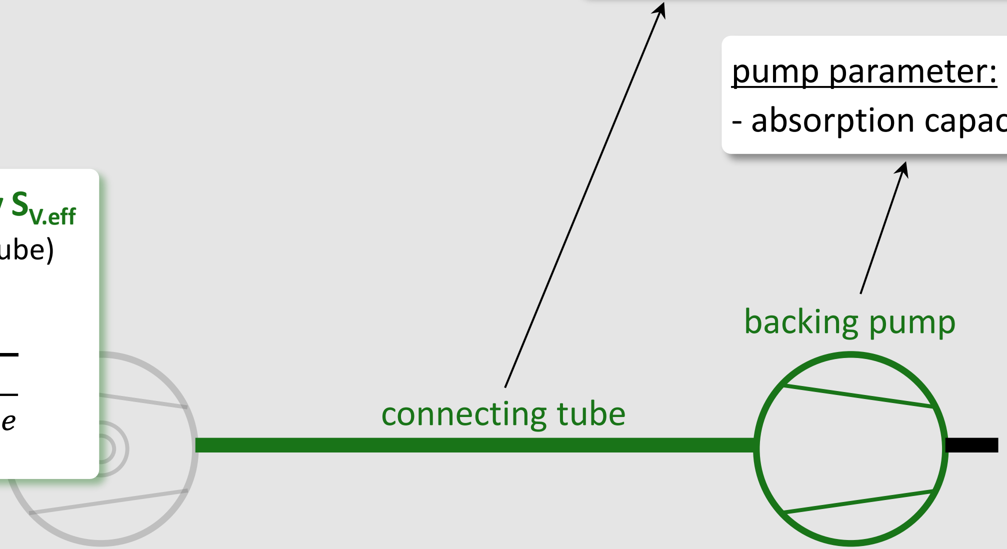
<u>pump parameter:</u>

- absorption capacity S_V

effective absorption capacity $S_{V.eff}$

(backing pump with connecting tube)

$$S_{V.eff} = \frac{1}{\frac{1}{S_V} + \frac{1}{L_{V.tube}}}$$



Effective Absorption Capacities

Backing pump:

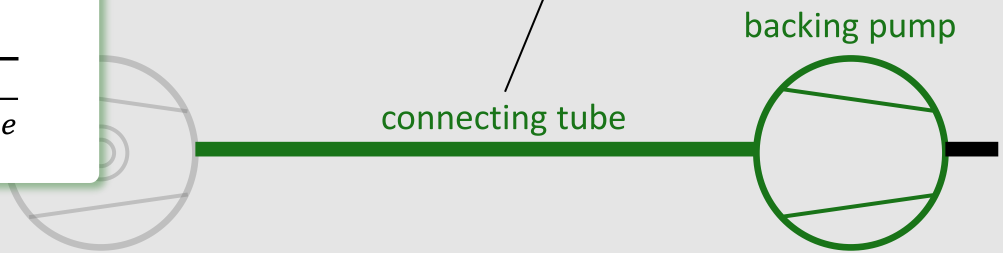
conductivity for laminar flow $L_{V.tube}$

effective absorption capacity $S_{V.eff}$
(backing pump with connecting tube)

$$S_{V.eff} = \frac{1}{\frac{1}{S_V} + \frac{1}{L_{V.tube}}}$$

tube parameters:
- nominal tube diameter, e. G. DN40
- tube length $l_{V.tube}$

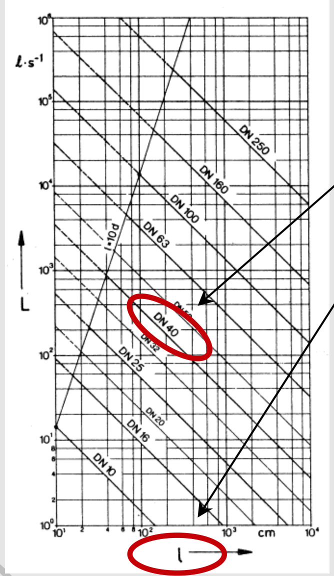
pump parameter:
- absorption capacity S_V



Effective Absorption Capacities

Backing pump:

conductivity for laminar flow $L_{V.tube}$



tube parameters:

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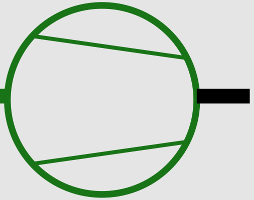
connecting tube

backing pump

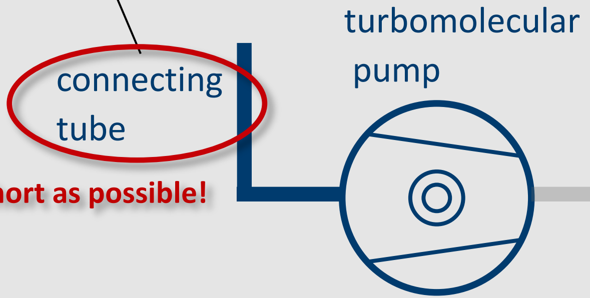


Effective Absorption Capacities

Turbomolecular pump:

<u>tube parameters:</u>

- inside tube diameter $d_{T.tube}$
- tube length $l_{T.tube}$



As short as possible!

short tube conductivity $L_{T.tube}$
(in case of a short connecting tube)

$$L_{T.tube} = \frac{1}{\frac{1}{L_{aperture}} + \frac{1}{L_{longtube}}}$$

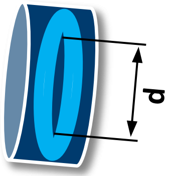
Effective Absorption Capacities

Turbomolecular pump:

tube parameters:
- inside tube diameter $d_{T.tube}$
- tube length $l_{T.tube}$

aperture mask conductivity $L_{aperture}$

$$L_{aperture} = \frac{\pi}{16} \cdot d_{T.tube}^{\ 2} \cdot c_{gas}$$

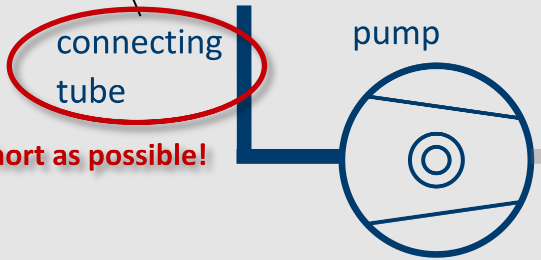


&

long tube conductivity $L_{longtube}$

$$L_{longtube} = \frac{\pi}{12} \cdot \frac{d_{T.tube}^{\ 3}}{l_{T.tube}} \cdot c_{gas}$$

c_{gas} - average gas particle speed



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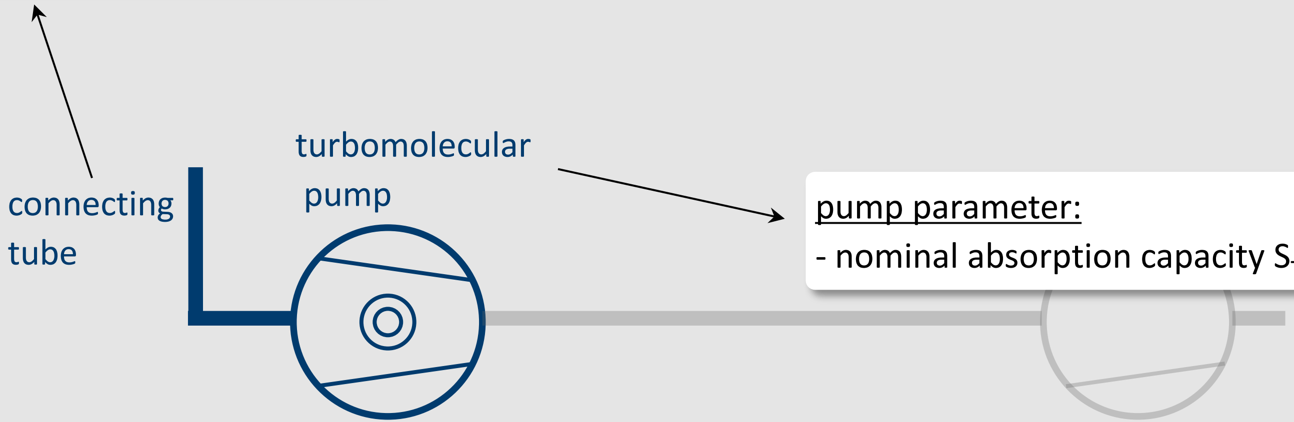
Effective Absorption Capacities

Turbomolecular pump:

conductivity for <u>molecular flow</u> $L_{T.tube}$

$$L_{T.tube} = \frac{1}{\frac{1}{L_{aperture}} + \frac{1}{L_{longtube}}}$$



<u>pump parameter:</u>

- nominal absorption capacity $S_{T.rated}$

Effective Absorption Capacities

Turbomolecular pump:

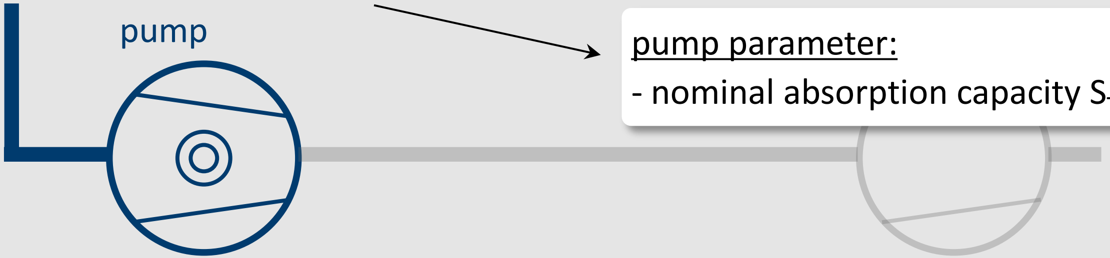
conductivity for molecular flow $L_{T.tube}$

$$L_{T.tube} = \frac{1}{\frac{1}{L_{aperture}} + \frac{1}{L_{longtube}}}$$

effective absorption capacity $S_{T.eff}$

(turbomolecular pump with connecting tube)

$$S_{T.eff} = \frac{1}{\frac{1}{S_{T.rated}} + \frac{1}{L_{T.tube}}}$$

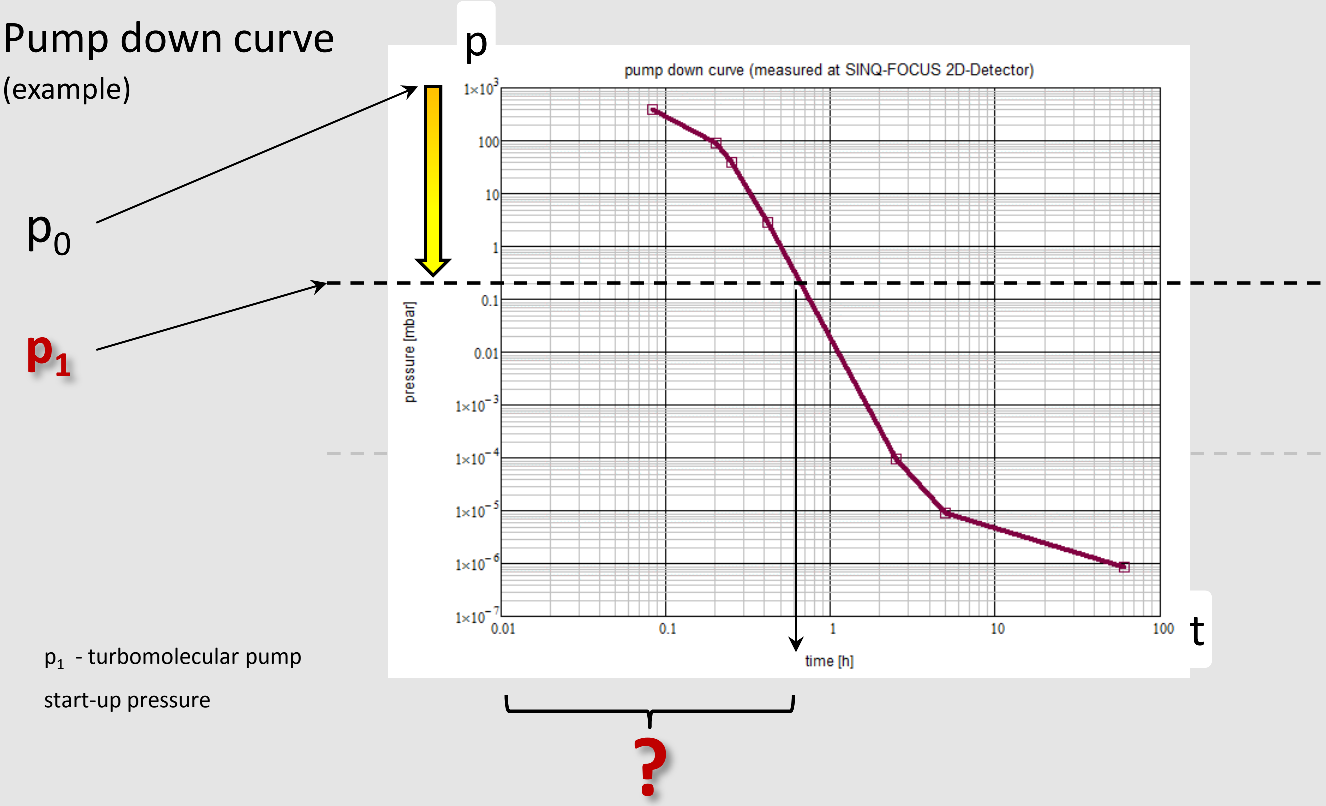


pump parameter:

- nominal absorption capacity $S_{T.rated}$

Rough Evacuation

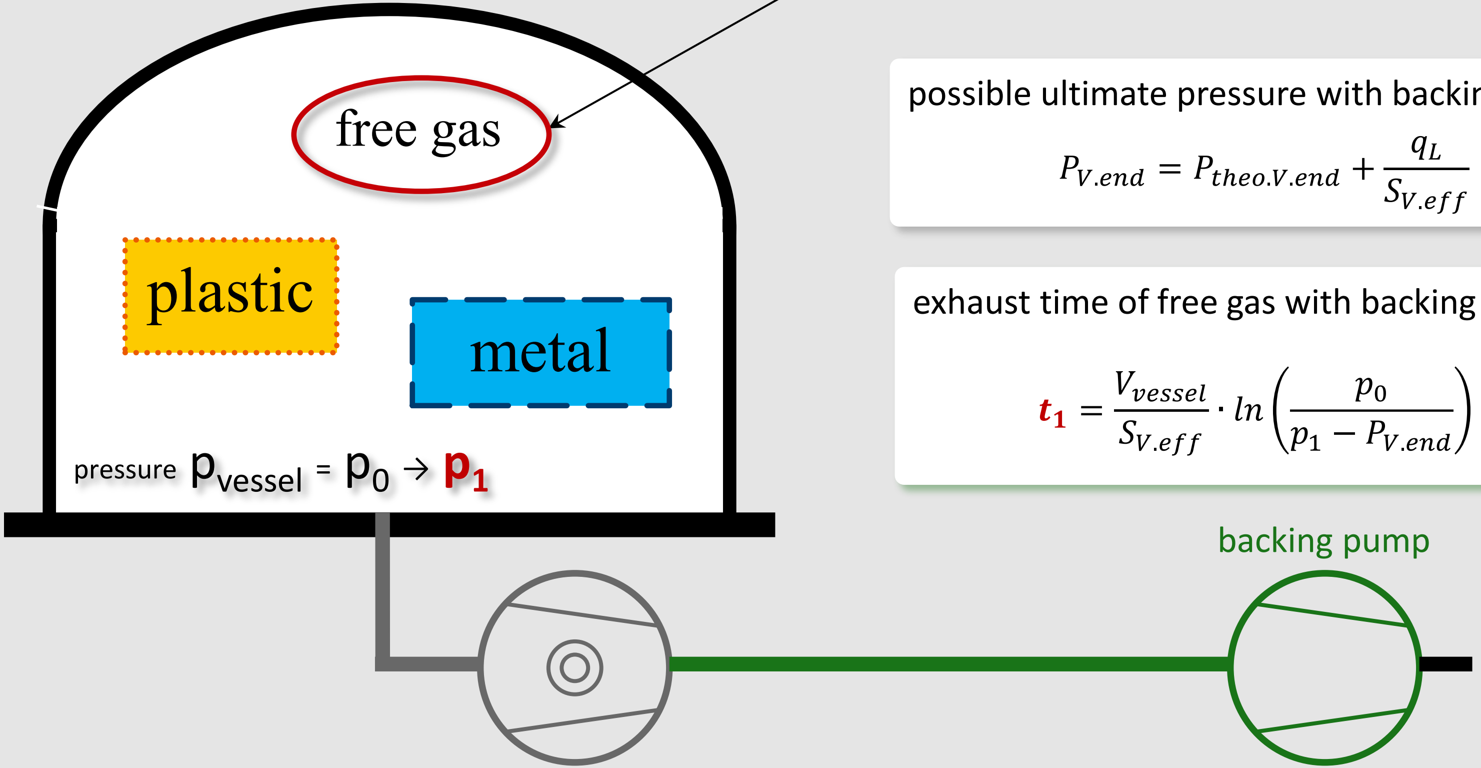
Pump down curve
(example)



p_1 - turbomolecular pump start-up pressure

Rough Evacuation

Pumping out of the free gas



possible ultimate pressure with backing pump

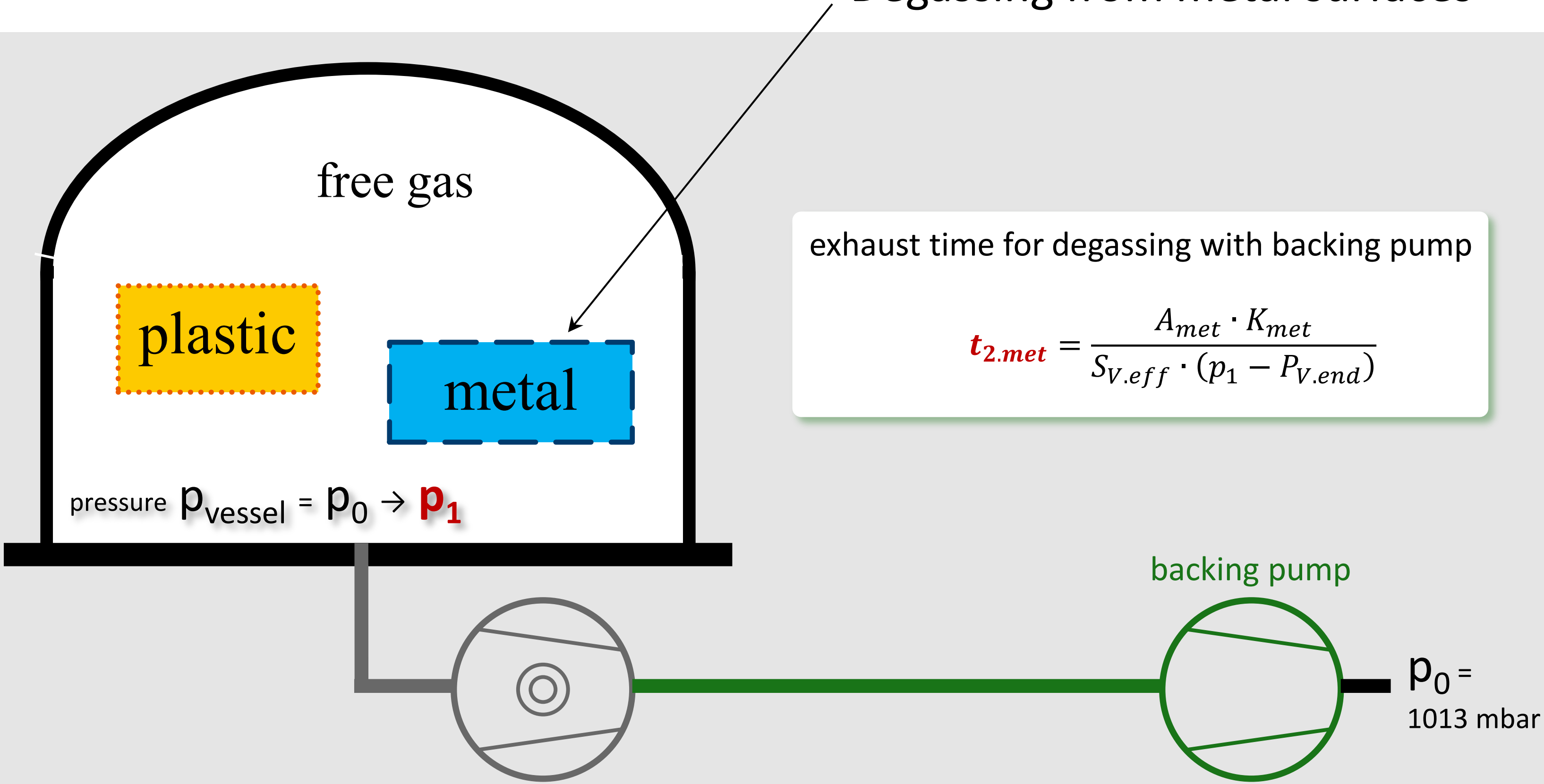
$$P_{V.end} = P_{theo.V.end} + \frac{q_L}{S_{V.eff}}$$

exhaust time of free gas with backing pump

$$t_1 = \frac{V_{vessel}}{S_{V.eff}} \cdot ln\left(\frac{p_0}{p_1 - P_{V.end}}\right)$$

Rough Evacuation

Degassing from metal surfaces

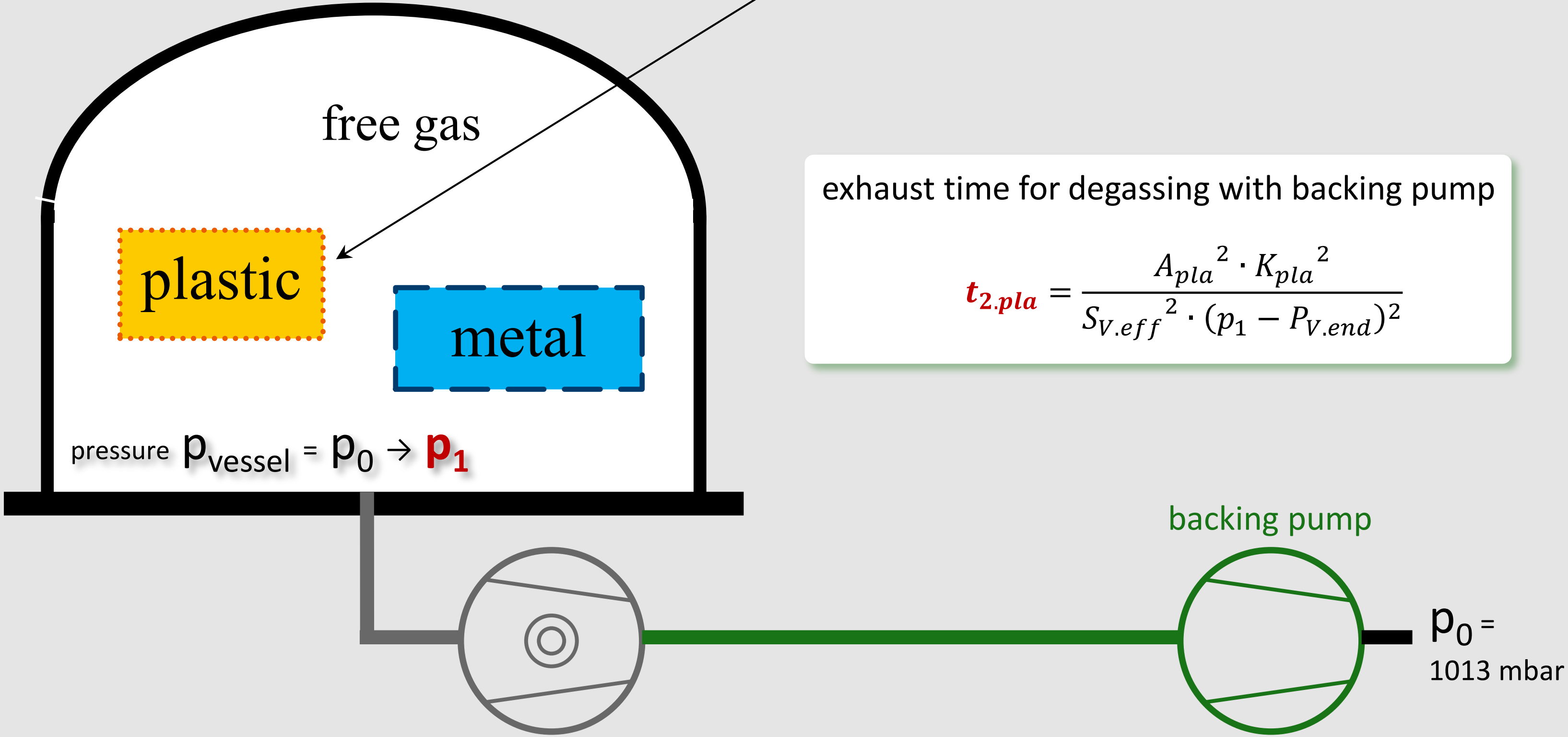


exhaust time for degassing with backing pump

$$t_{2.met} = \frac{A_{met} \cdot K_{met}}{S_{V.eff} \cdot (p_1 - P_{V.end})}$$

Rough Evacuation

Degassing from plastic surfaces



exhaust time for degassing with backing pump

$$t_{2.pla} = \frac{{A_{pla}}^2 \cdot {K_{pla}}^2}{{S_{V.eff}}^2 \cdot (p_1 - P_{V.end})^2}$$

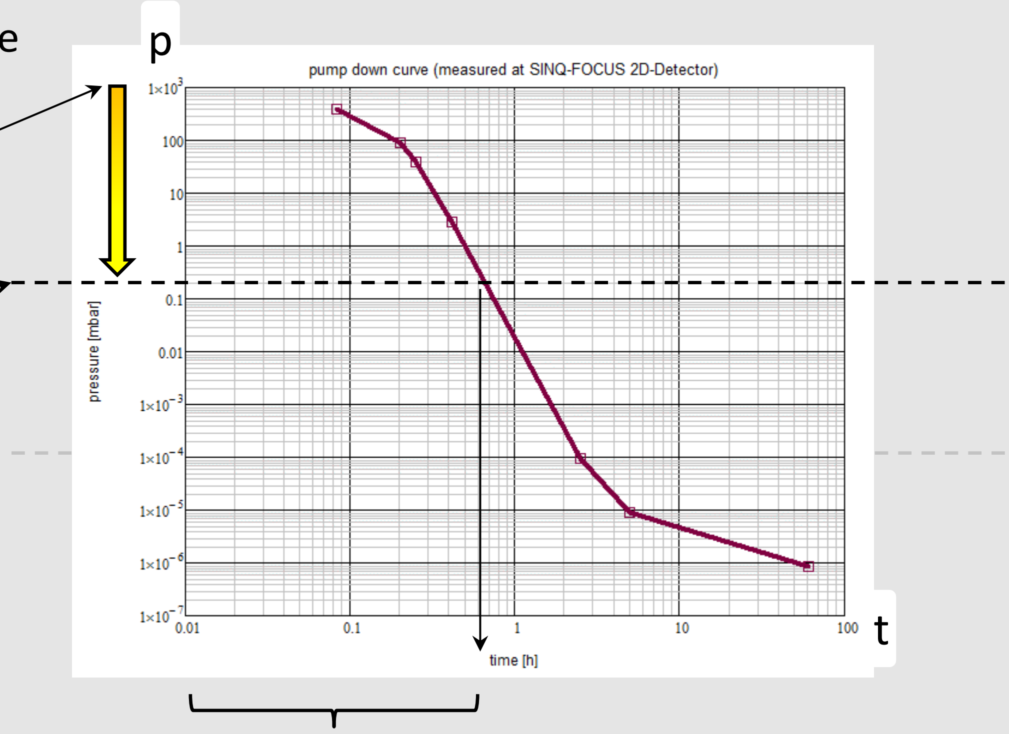
Rough Evacuation

Pump down curve

(example)

p_0

p_1



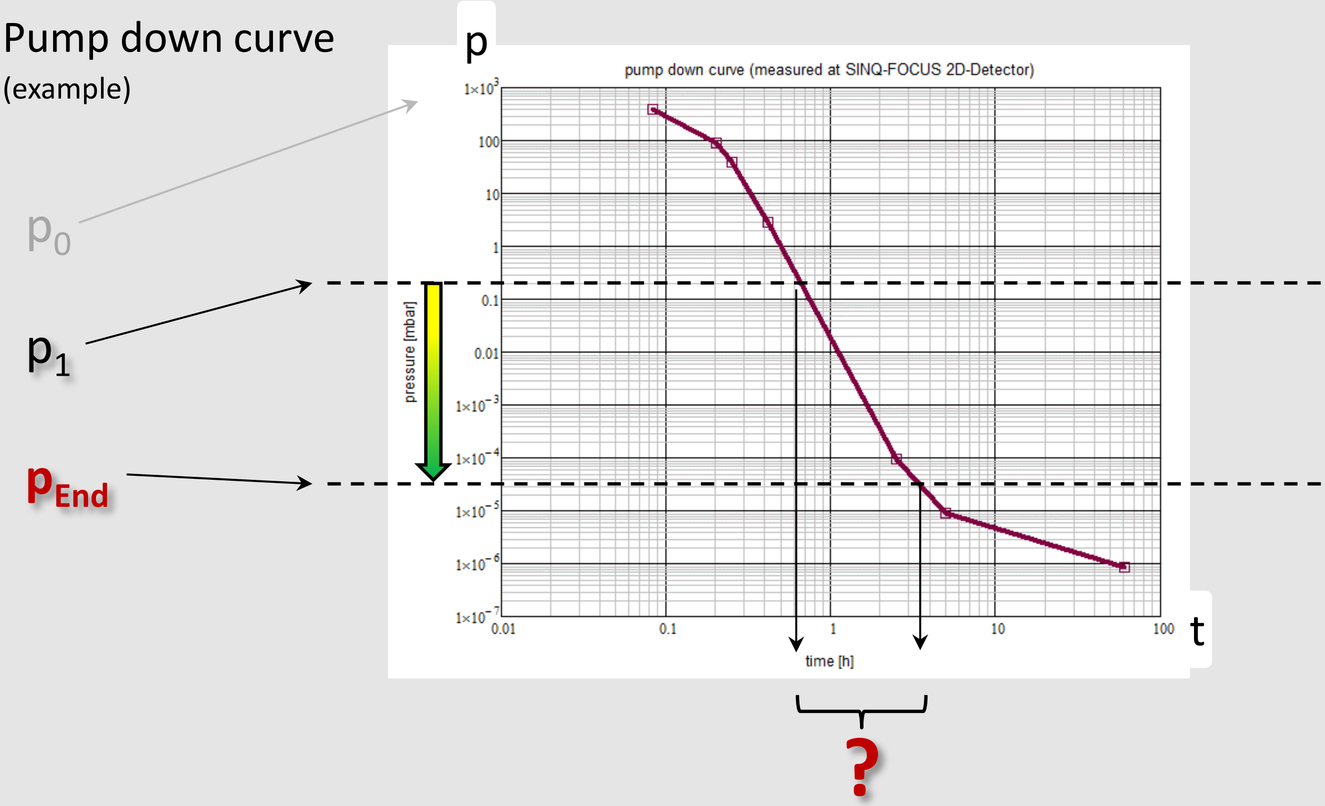
p_1 - turbomolecular pump start-up pressure

$t_1 + t_{2.met} + t_{2.pla}$

Final Evacuation

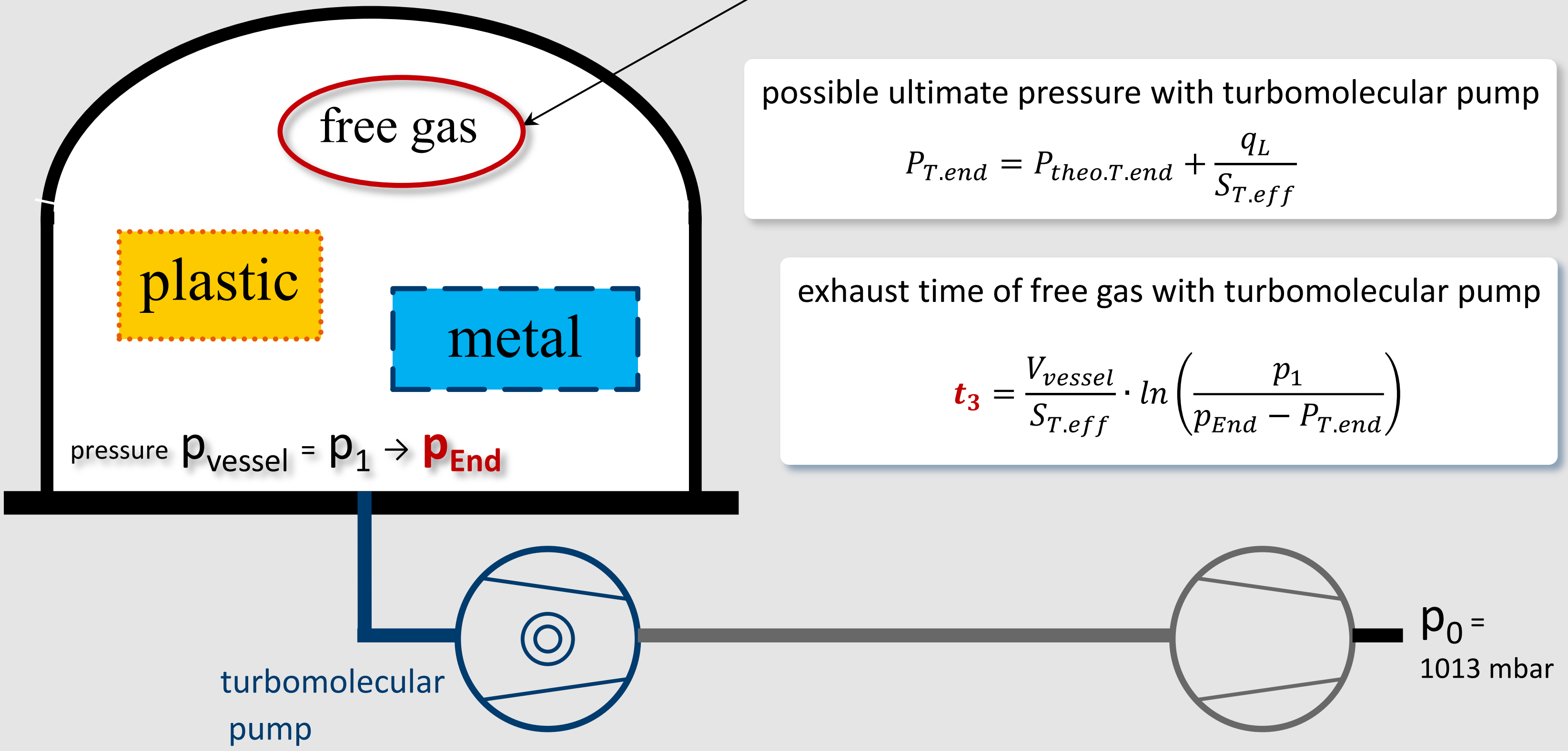
Pump down curve

(example)



Final Evacuation

Pumping out of the free gas



possible ultimate pressure with turbomolecular pump

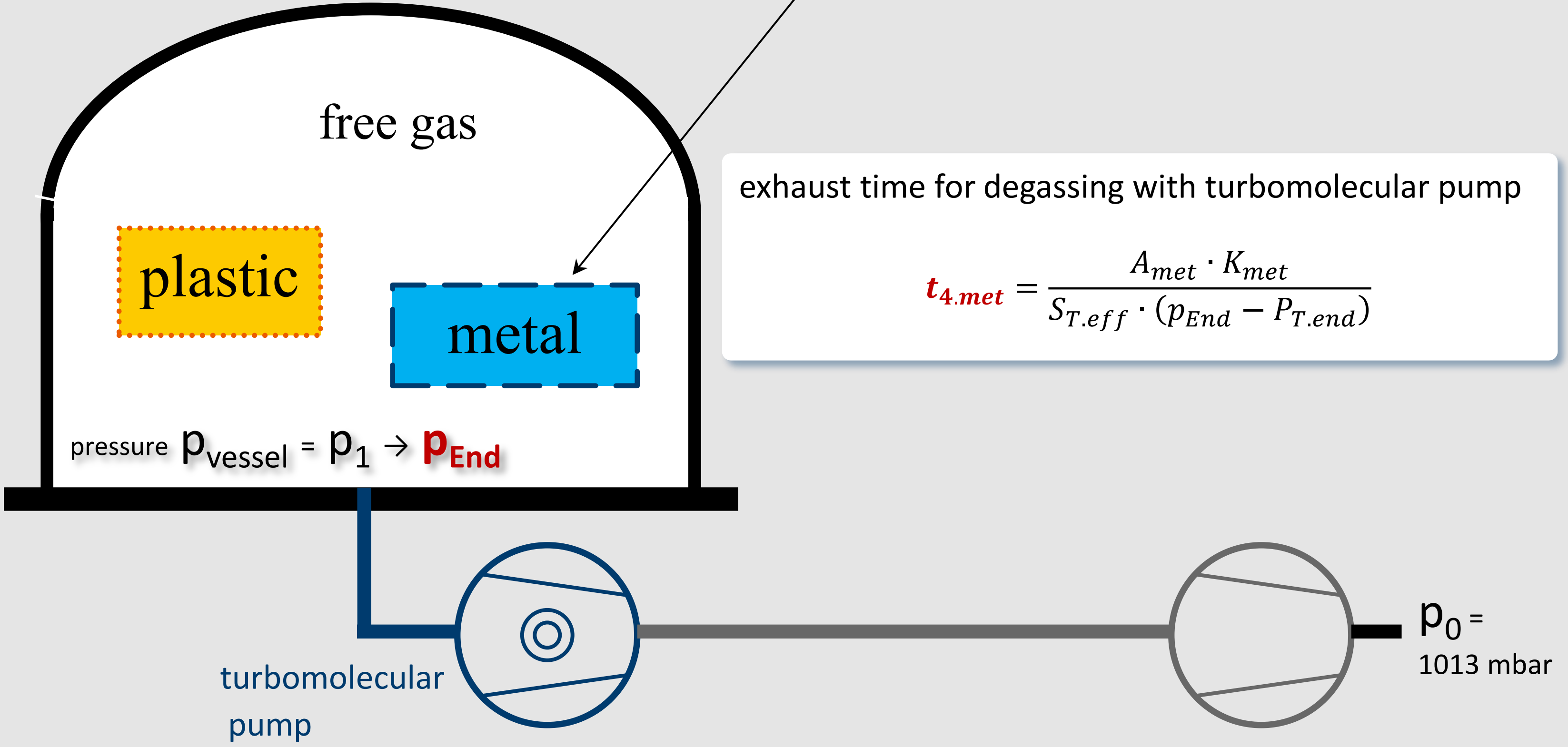
$$P_{T.end} = P_{theo.T.end} + \frac{q_L}{S_{T.eff}}$$

exhaust time of free gas with turbomolecular pump

$$t_3 = \frac{V_{vessel}}{S_{T.eff}} \cdot ln\left(\frac{p_1}{p_{End} - P_{T.end}}\right)$$

Final Evacuation

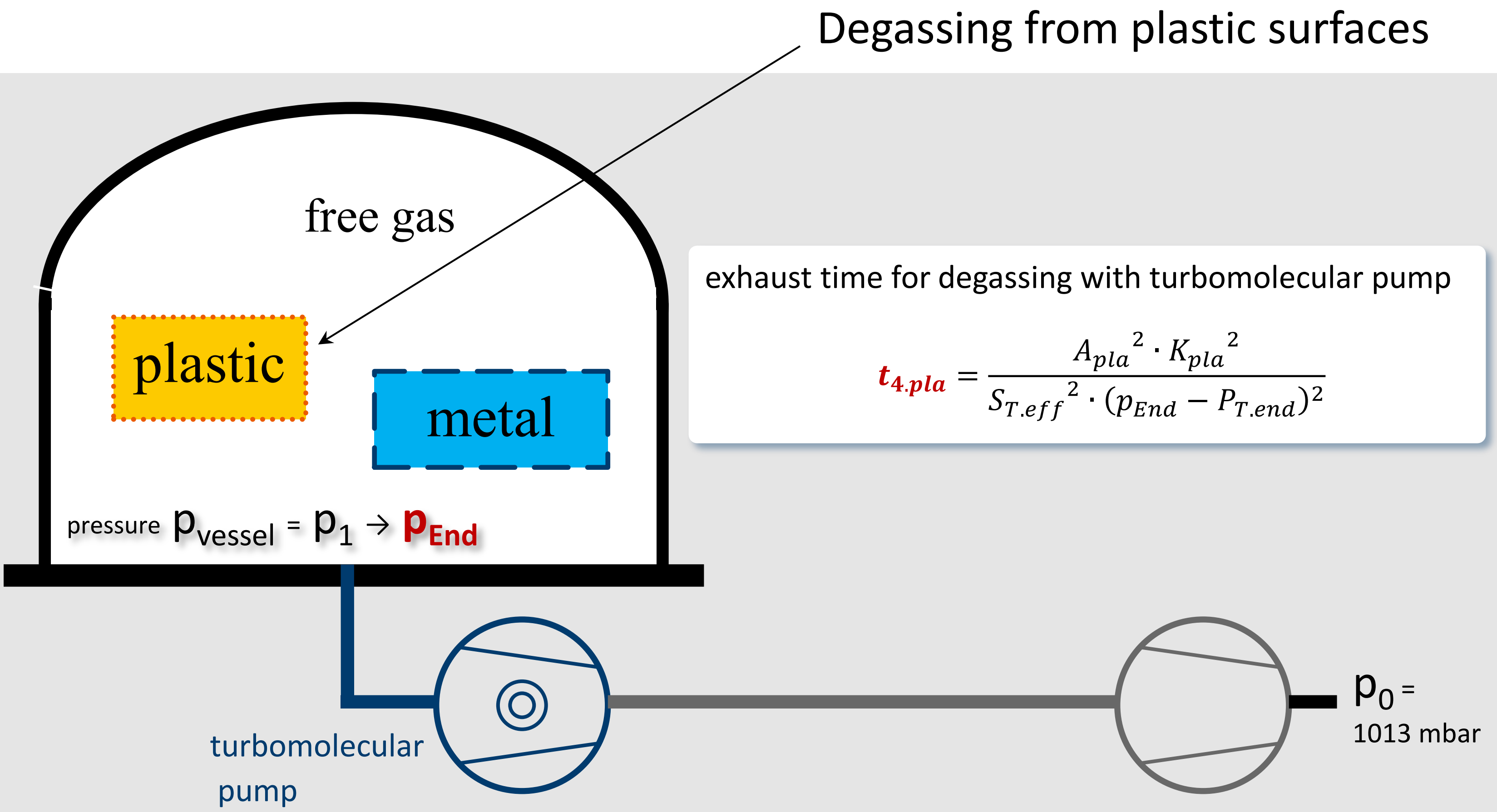
Degassing from metal surfaces



exhaust time for degassing with turbomolecular pump

$$t_{4.met} = \frac{A_{met} \cdot K_{met}}{S_{T.eff} \cdot (p_{End} - P_{T.end})}$$

Final Evacuation



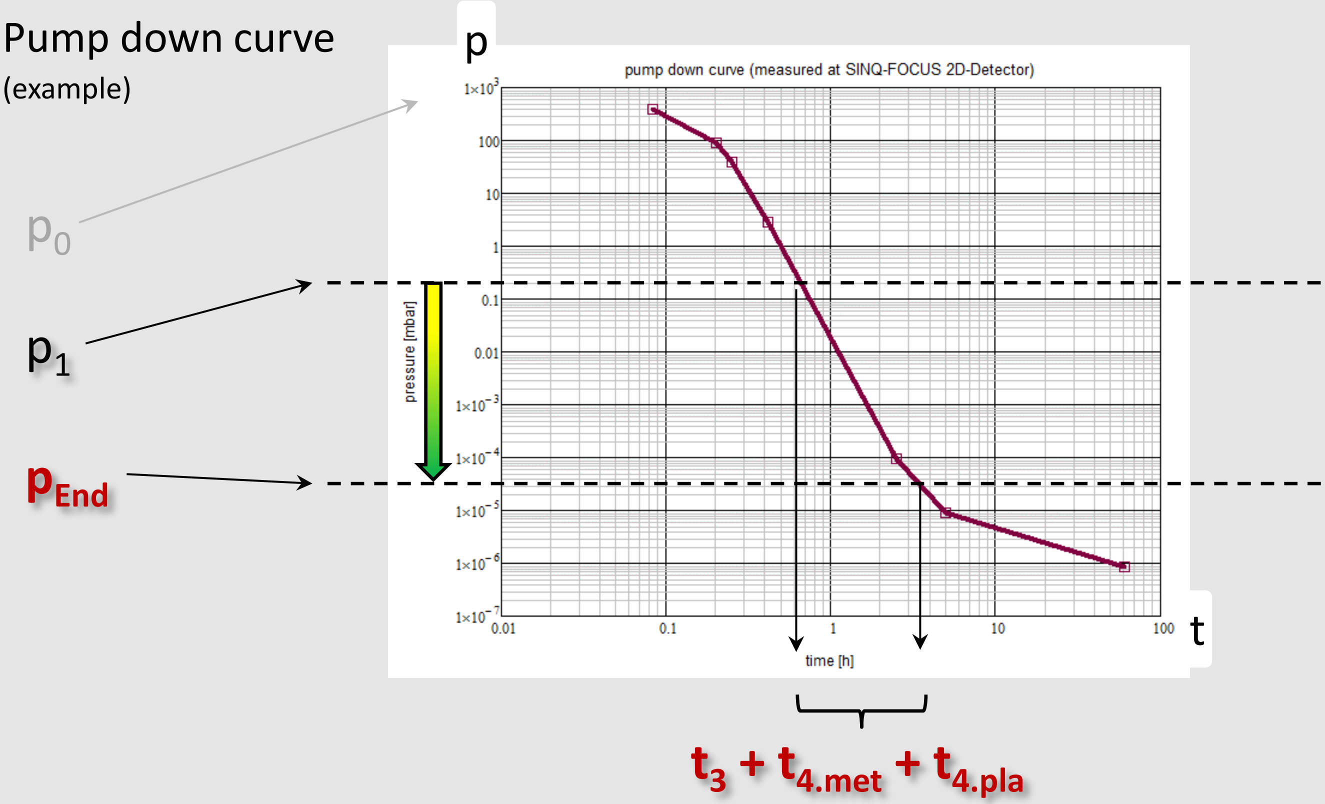
exhaust time for degassing with turbomolecular pump

$$t_{4.pla} = \frac{{A_{pla}}^2 \cdot {K_{pla}}^2}{{S_{T.eff}}^2 \cdot (p_{End} - P_{T.end})^2}$$

Final Evacuation

Pump down curve

(example)

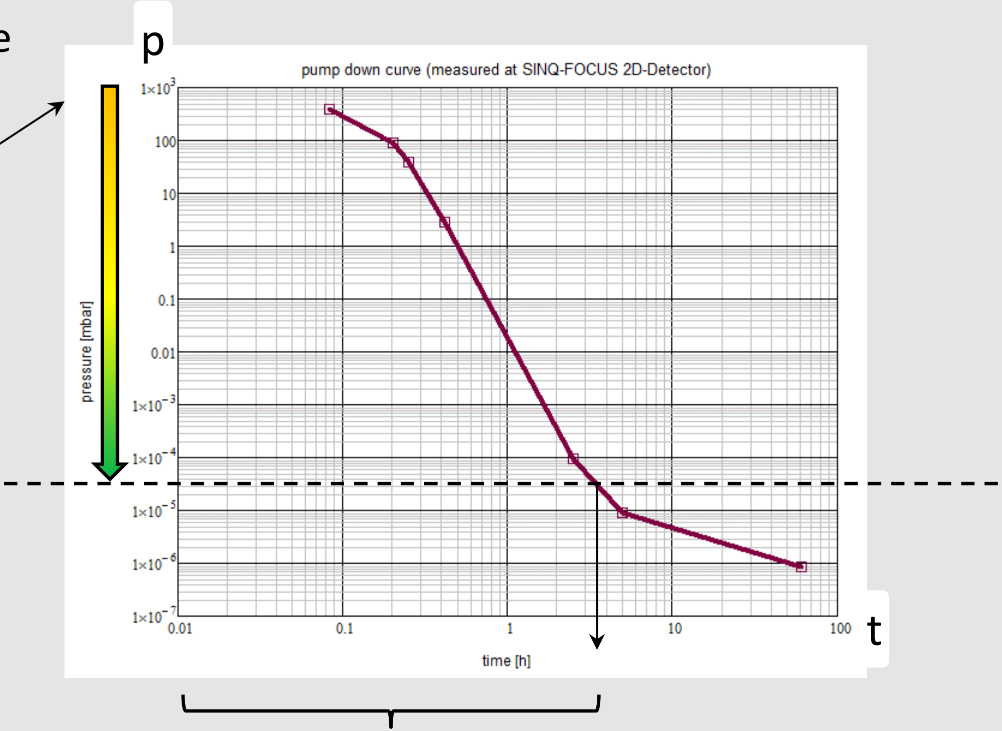


Result

Pump down curve (example)

p_0 = 1013 mbar

p_{End}



$$t_{result} = t_1 + t_{2.met} + t_{2.pla} + t_3 + t_{4.met} + t_{4.pla}$$

An Example with Values

An extreme example:

	Free Gas in the vessel	Metal (comp.s & vessel)	Plastic components
Volume	1500 L		
free Surface		10 m^2	10 m^2
Material	air	stainless steel	according Lit. /2/, p. 685
Rough Evacuation	59 min	25 sec	327 min
Final Evacuation	24 sec	1 min	944 min

} exhaust resp. pump out times

<u>Choice:</u>

backing pump = Alcatel ACP 28 with DN40 x 150cm , turbomolecular pump = Pfeiffer Compact Turbo TMH 521 YP with DN160 x 20cm , q_L = 1 x 10^{-5} mbar·L/sec , p_1 = 0.1 mbar , p_{End} = **5 x 10^{-4} mbar**

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Literature

- /1/ Pfeiffer, The Vacuum Technology, Book Volume II, Band 3.1, Vakuumerzeugung (https://www.pfeiffer-vacuum.com/de/info-center/download-center/)
- /2/ Wutz, Handbuch Vakuumtechnik, Theorie und Praxis, Vieweg Verlag, Wiesbaden, 2004

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Wir schaffen Wissen – heute für morgen

This is an example, how to roughly estimate the pumping time for a vaccum vessel,

in order to …

… understand, how the material choice affects the pump out time

… choose the components for a successful evacuation.