



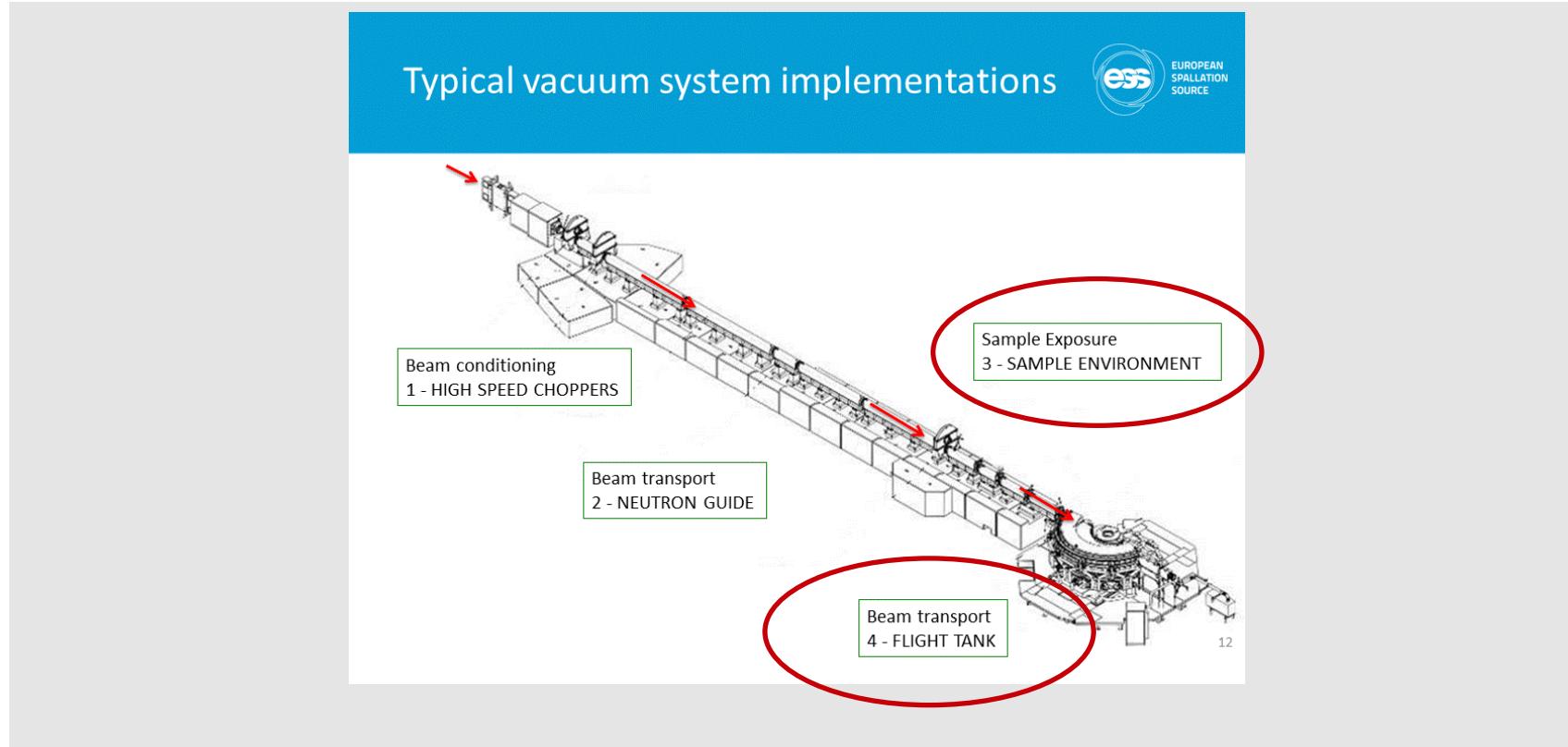
WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

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



Context

Examples

A range of requirements and challenges for vacuum systems



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

Context

Examples

A range of requirements and challenges for vacuum systems



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Radiation hardness	High	High/Mod	Low	High
Servicability	Low	V.Low	Moderate	High

Oct. 1994

Experiences

Oct. 1994

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

The „FOCUS-team“

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

Experiences

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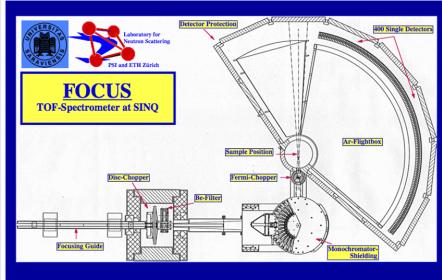
I saw my first neutron instruments at

- Forschungszentrum Jülich
- ILL, Grenoble

Experiences

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

technical concept ready



assembly start



Apr. 1995

Nov. 1996

Dec. 1998
1st measured spectrum

Experiences

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

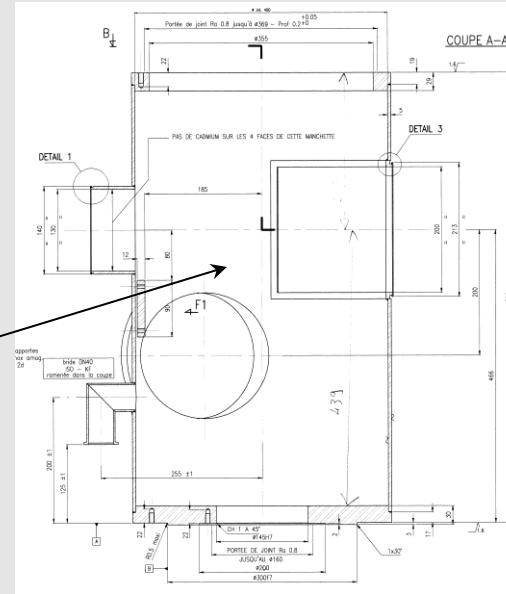
detector housing
by IRELEC



sample chamber
by IRELEC

Experiences

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

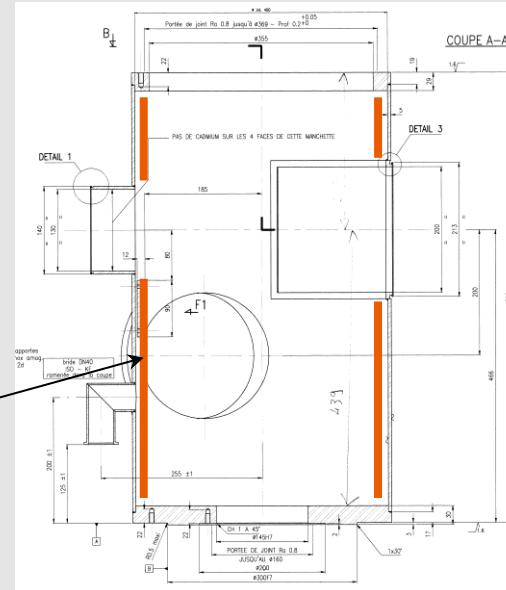


sample chamber
by IRELEC

it's a
vacuum vessel

Experiences

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



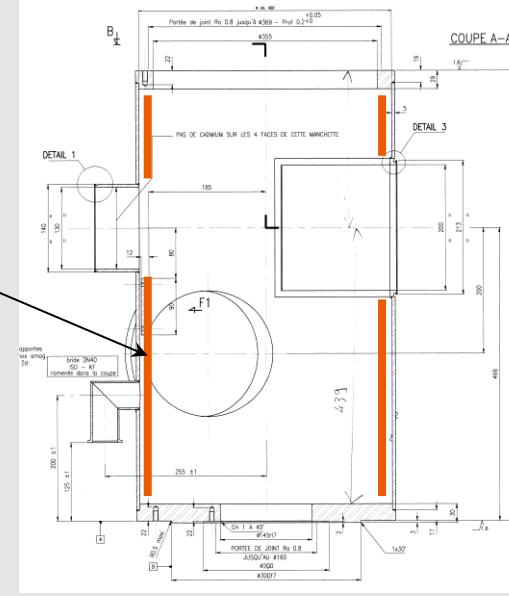
desired:
neutron shielding
inside the vessel

it's a
vacuum vessel

Experiences

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

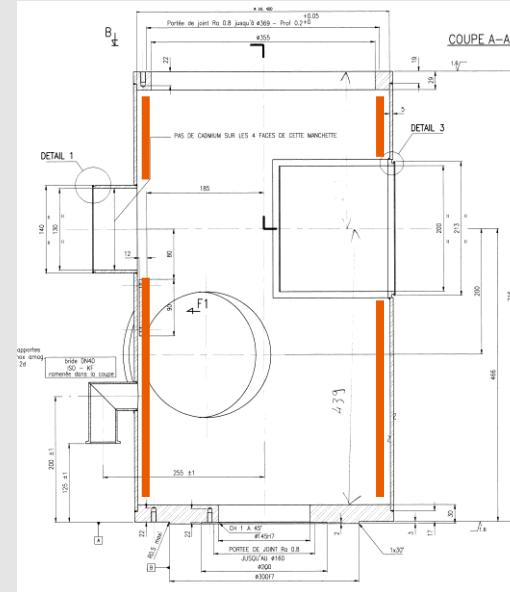
Which material?
Cadmium sheet ?
or
„Boronplastic“



it's a
vaccum vessel

Experiences

How to attach it?
They glued it to the wall.



it's a
vacuum vessel

Experiences

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

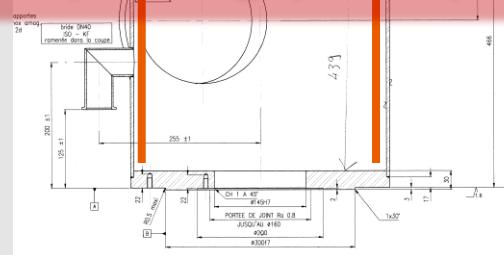
How to attach it?

They **glued** it to the wall.



The result:

A very long pumping time !



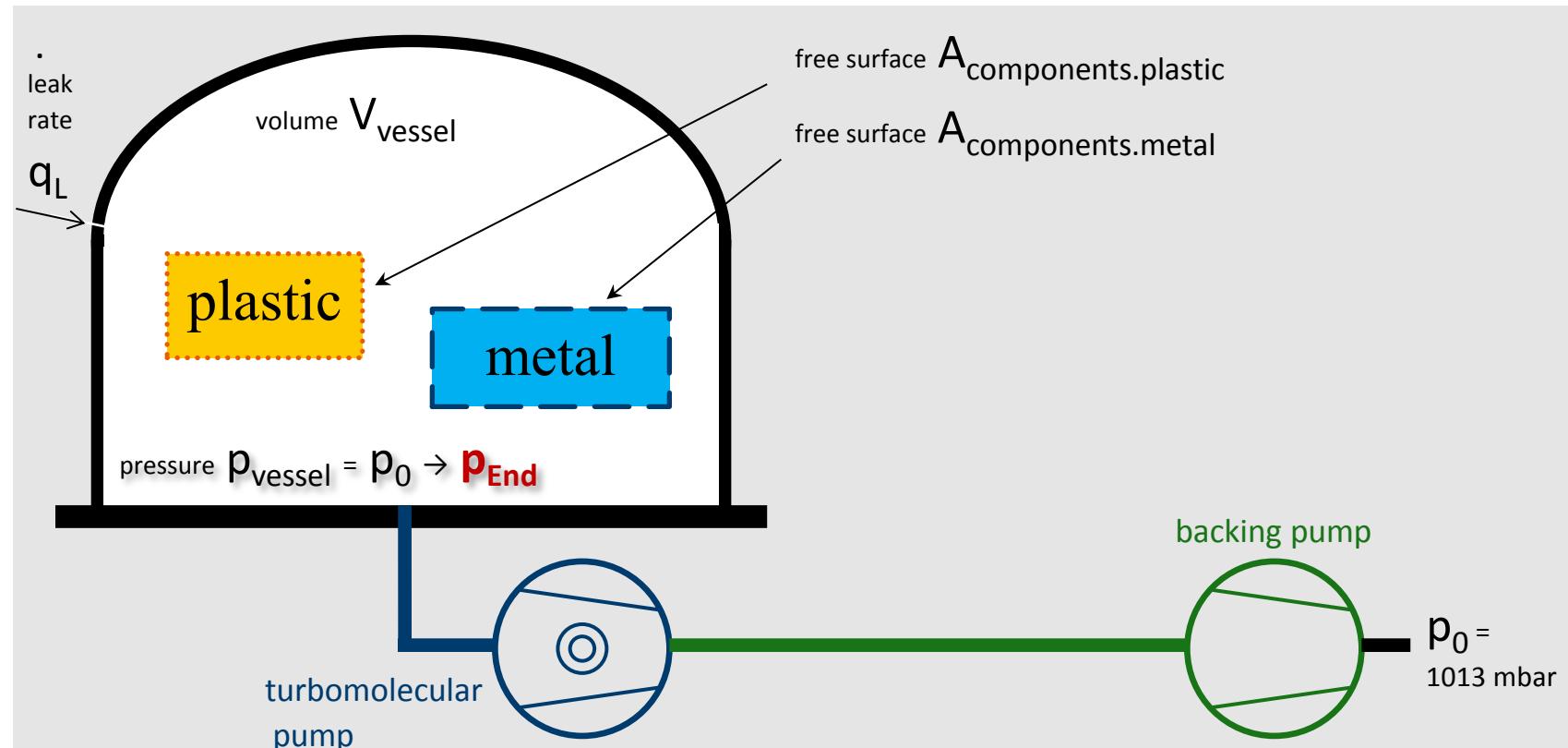
it's a
vacuum vessel

Invitation

Let's make it better

Situation

Situation



Task Formulation

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

Task Formulation

Pump down curve

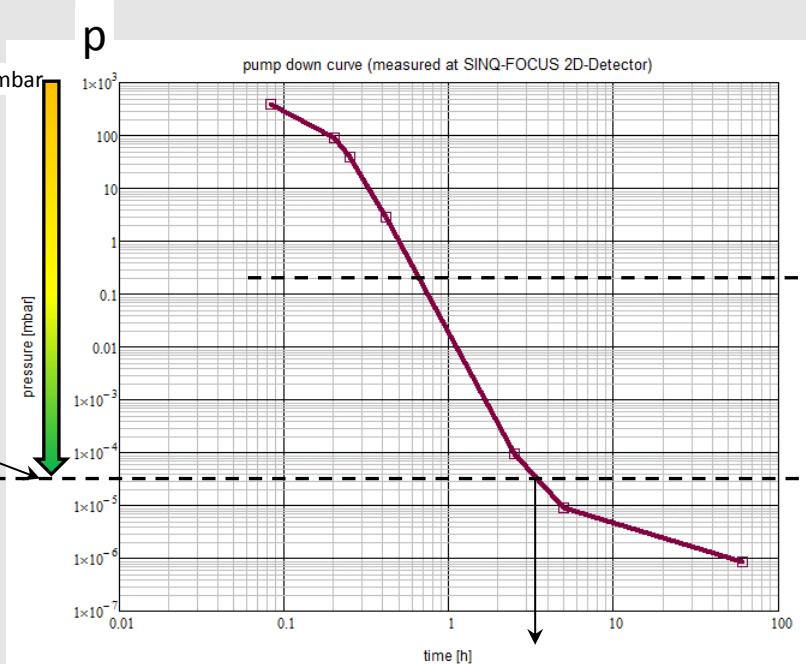
(example)

p_0

p_{End}

→

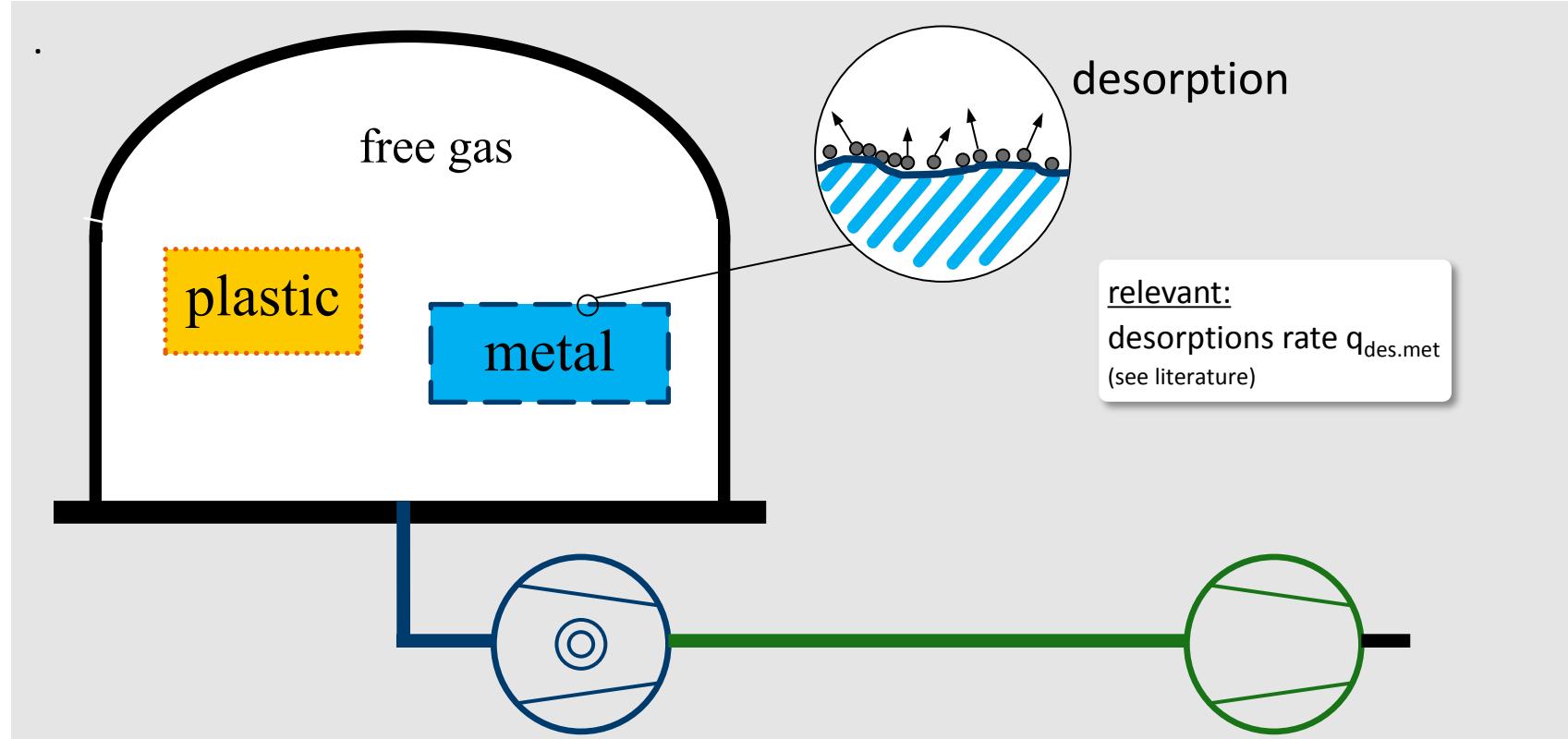
1013 mbar



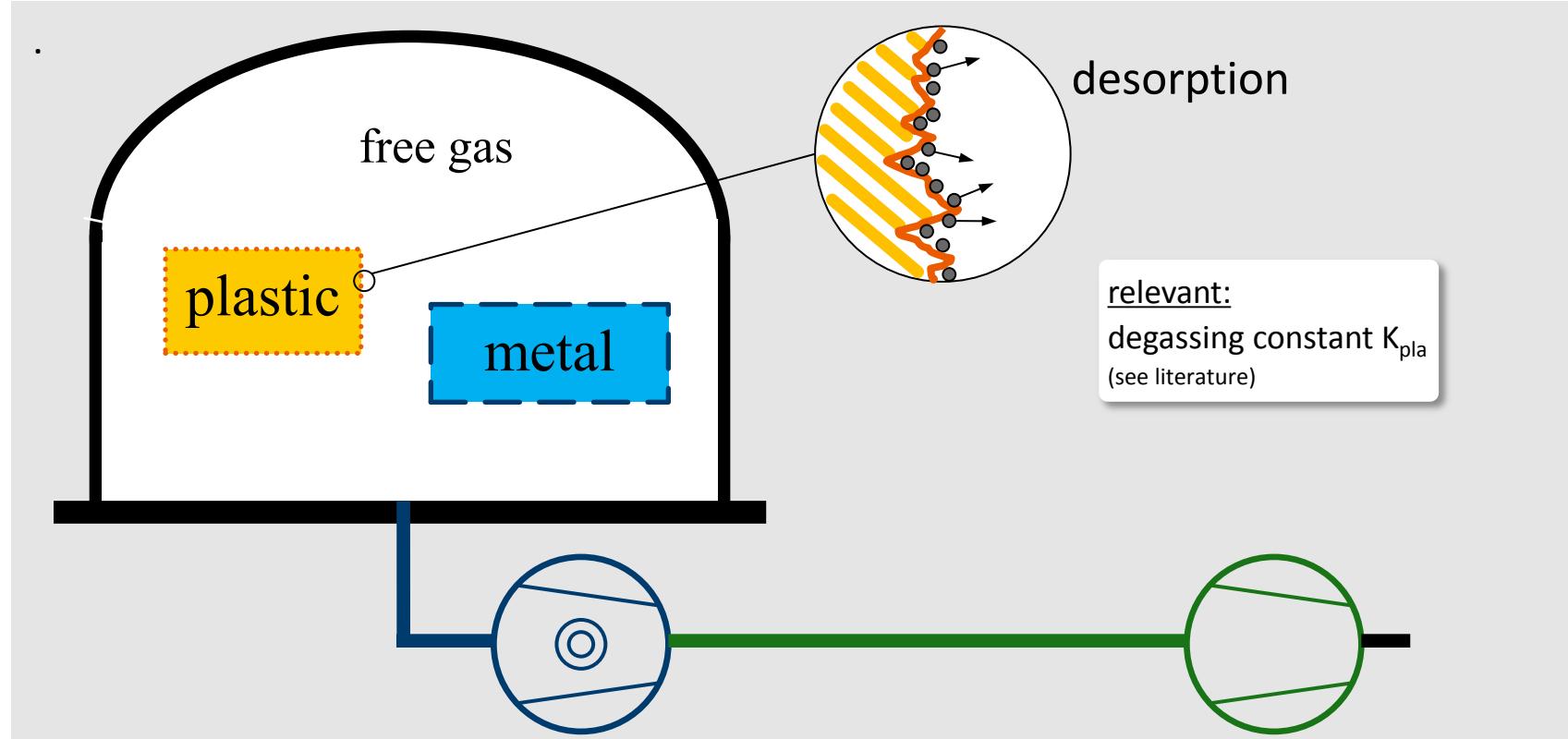
step 1

step 2

Material Choice, Outgassing from Surfaces



Material Choice, Outgassing from Surfaces



Vacuum Pumps and Connecting Tubes

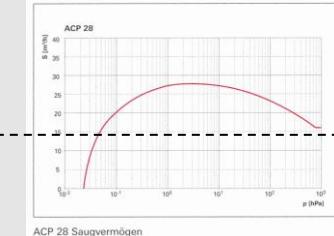
Backing pump:

relevant tube parameters:

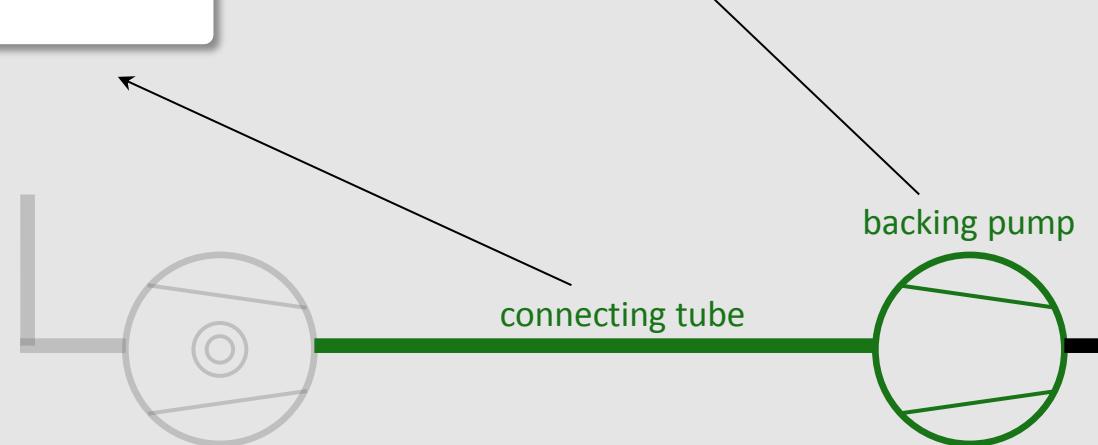
- nominal tube diameter, e. G. DN40
- tube length $l_{v,tube}$
(your choice)

relevant pump parameters:

- absorption capacity $S_V < S_{V,max}$
- theoretical ultimate pressure $P_{theo,V,end}$
(see manufacturer papers)



/1/



Vacuum Pumps and Connecting Tubes

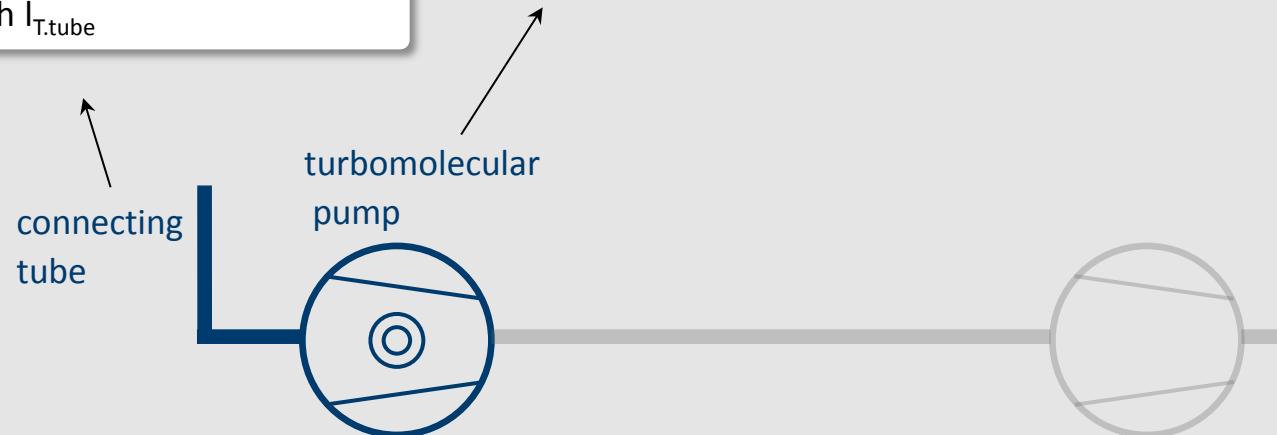
Turbomolecular pump:

relevant tube parameters:

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

relevant pump parameters:

- nominal absorption capacity $S_{T,rated}$
- theoretical ultimate pressure $P_{theo,T,end}$
- start-up pressure p_1
(see manufacturer papers)



Vacuum Pumps and Connecting Tubes

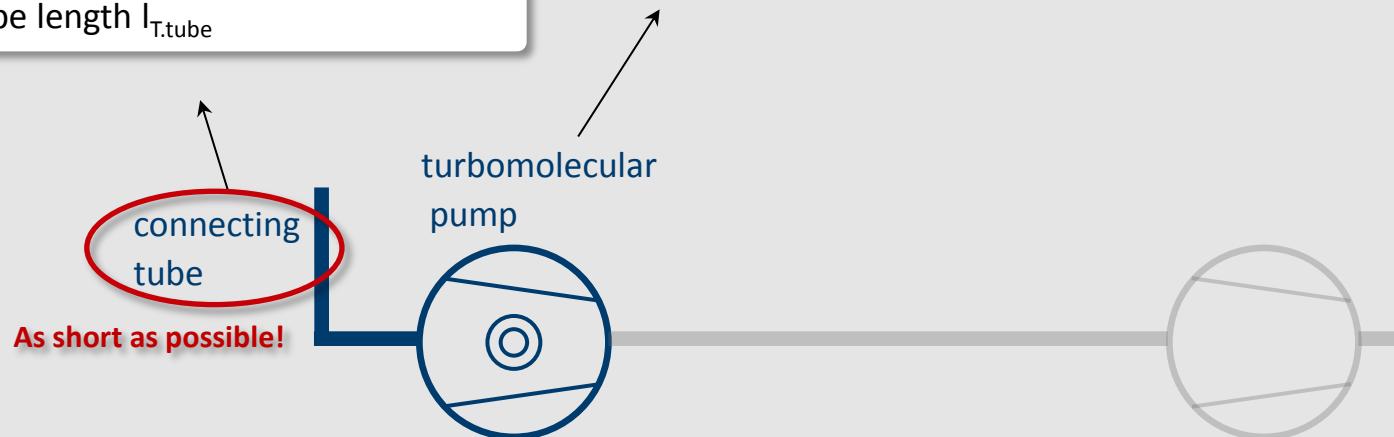
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- start-up pressure p_1
(see manufacturer papers)



Rough Estimation of the Pumping Time

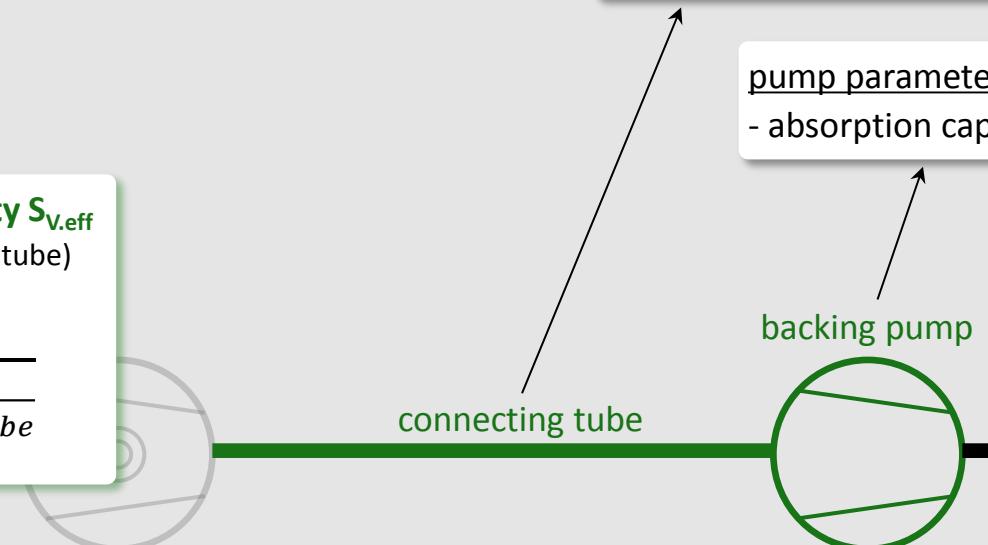
CALCULATIONS

Effective Absorption Capacities

Backing pump:

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:

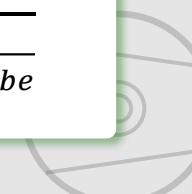
conductivity for laminar flow $L_{V.tube}$



effective absorption capacity $S_{V.eff}$

(Backing pump with connecting tube)

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



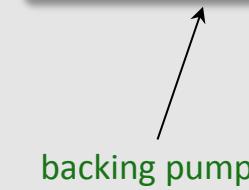
connecting tube

tube parameters:

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

pump parameter:

- absorption capacity S_V



Effective Absorption Capacities

Backing pump:

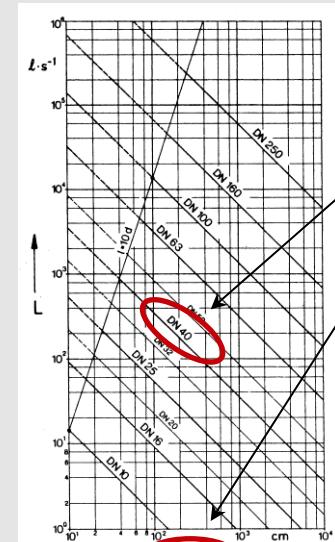
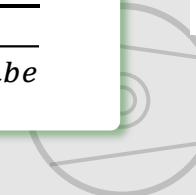
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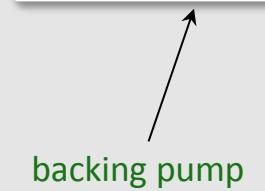
connecting tube

tube parameters:

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

pump parameter:

- absorption capacity S_V

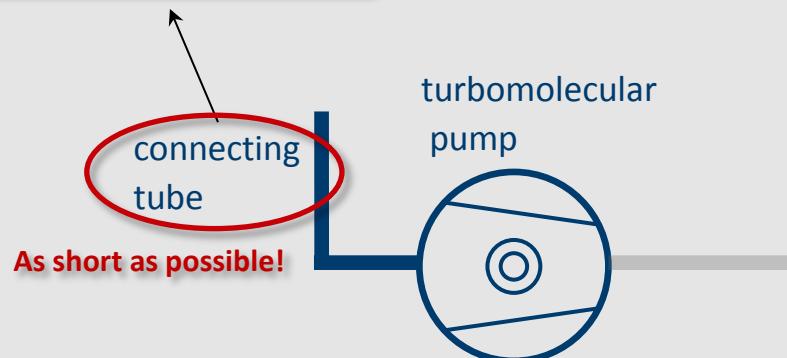


Effective Absorption Capacities

Turbomolecular pump:

tube parameters:

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

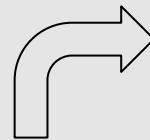


short tube conductivity $L_{T.tube}$
(in case of a short connecting tube)

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

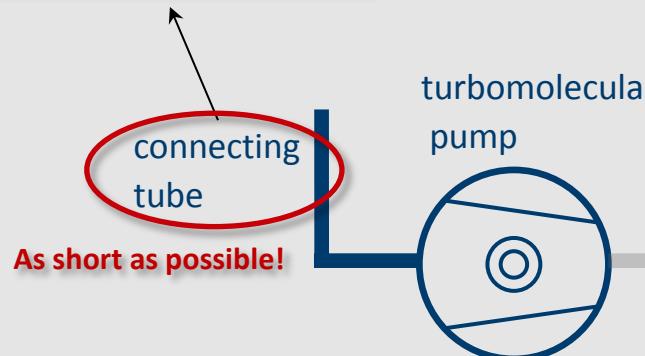
Effective Absorption Capacities

Turbomolecular pump:



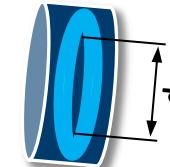
tube parameters:

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



aperture mask conductivity L_{aperture}

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

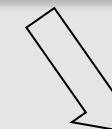


c_{gas} - average gas particle speed

&

long tube conductivity L_{longtube}

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



short tube conductivity $L_{T.tube}$

(in case of a short connecting tube)

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

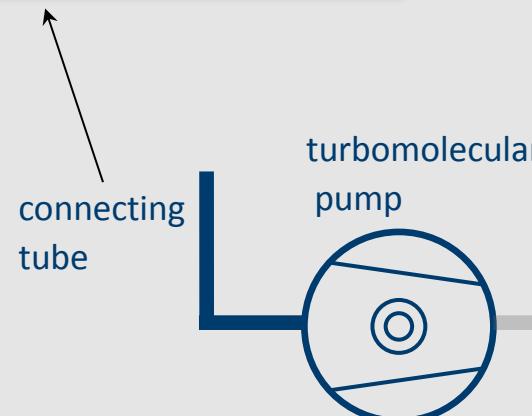


Effective Absorption Capacities

Turbomolecular pump:

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

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



pump parameter:
- nominal absorption capacity $S_{T.rated}$

Effective Absorption Capacities

Turbomolecular pump:

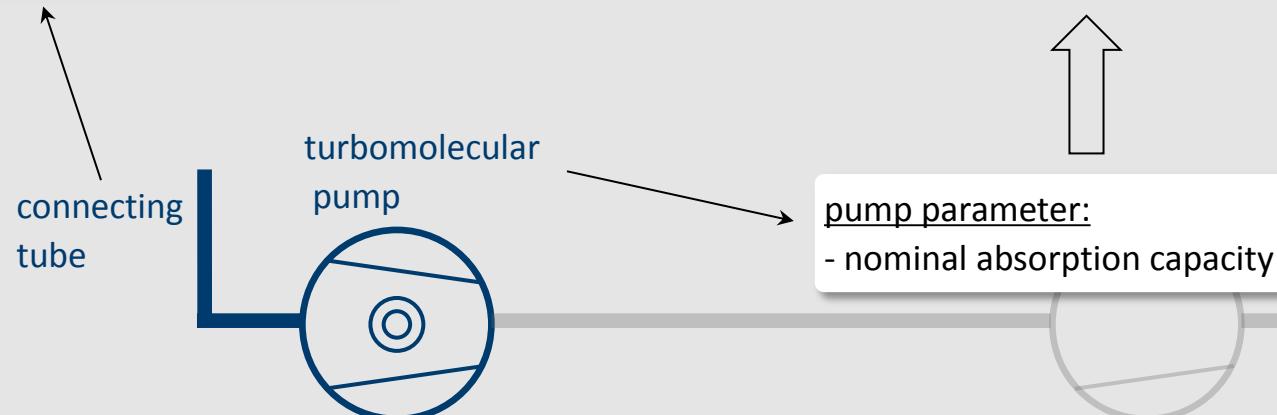
conductivity for molecular flow $L_{T.tube}$

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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 $S_{T.rated}$

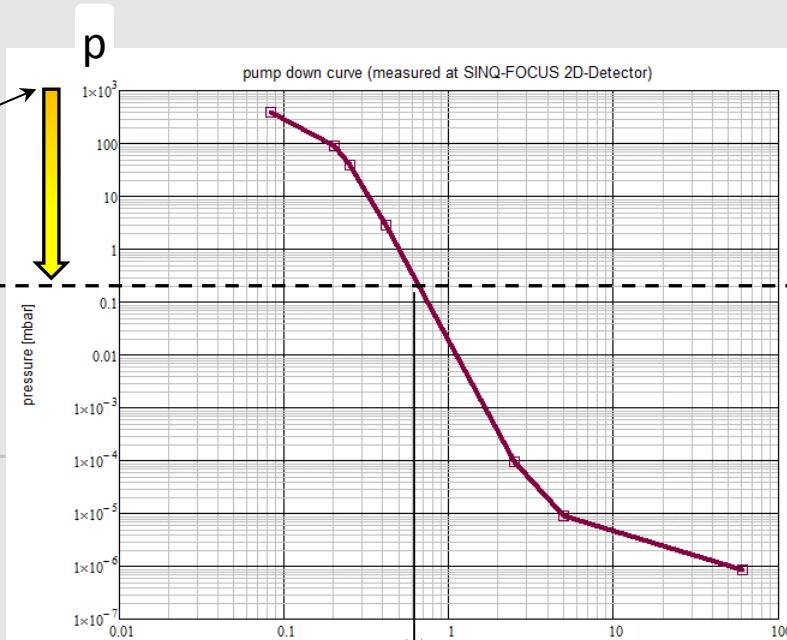
Rough Evacuation

Pump down curve
(example)

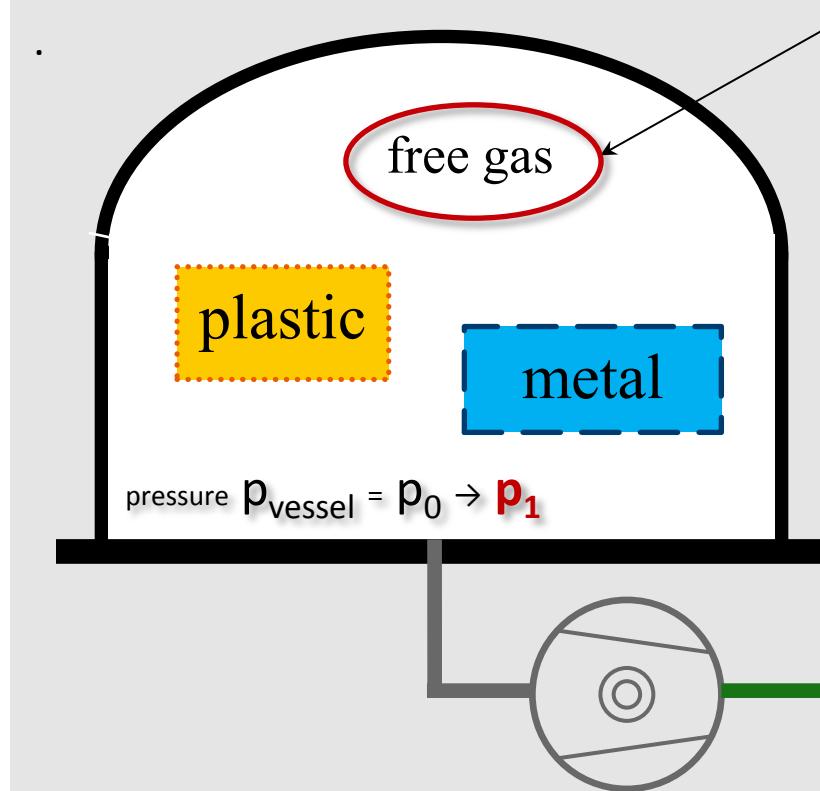
 p_0 p_1

p_1 - turbomolecular pump

start-up pressure



Rough Evacuation



Pumping out of the free gas

possible ultimate pressure with backing pump

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

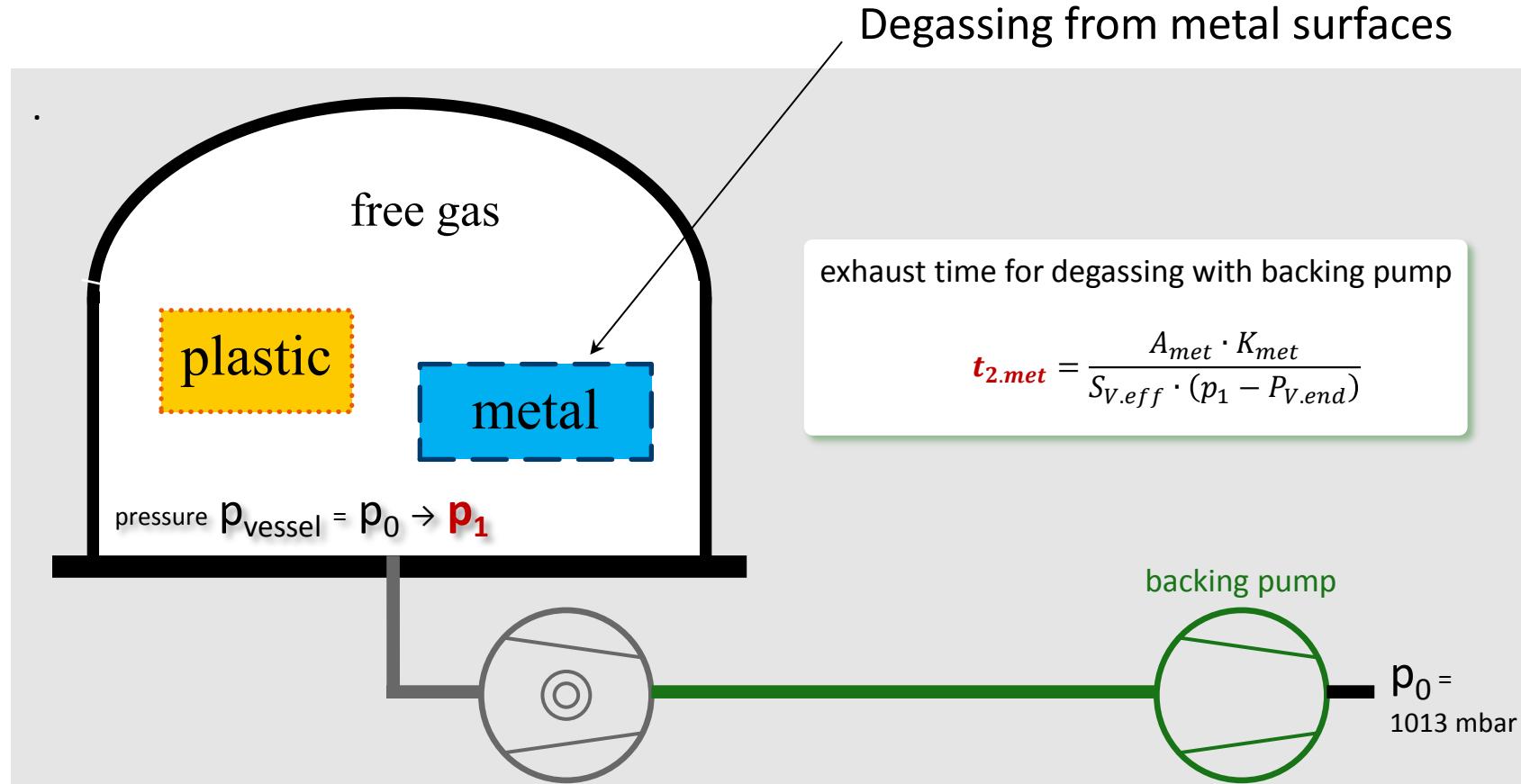
exhaust time of free gas with backing pump

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

backing pump

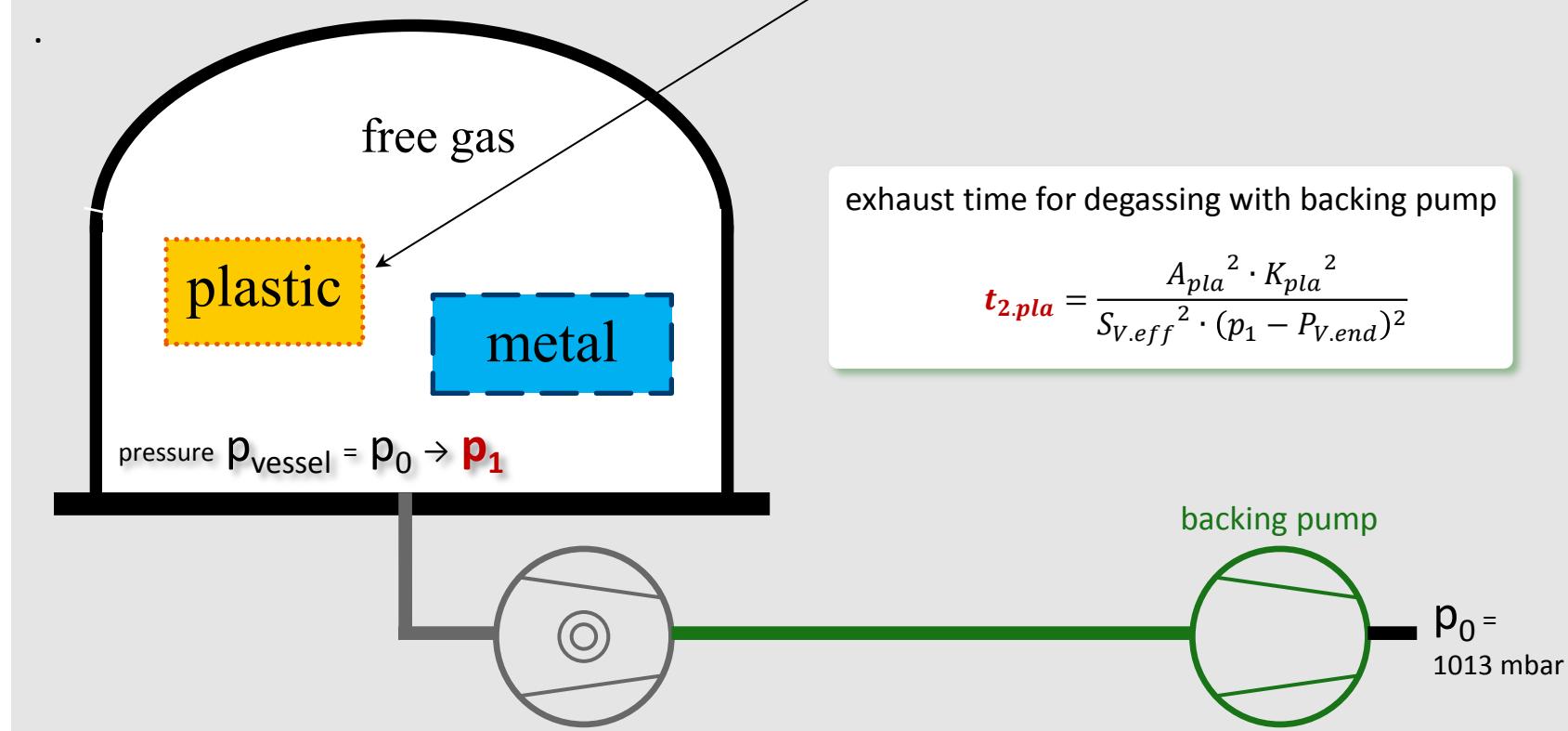
$p_0 =$
1013 mbar

Rough Evacuation



Rough Evacuation

Degassing from plastic surfaces



Rough Evacuation

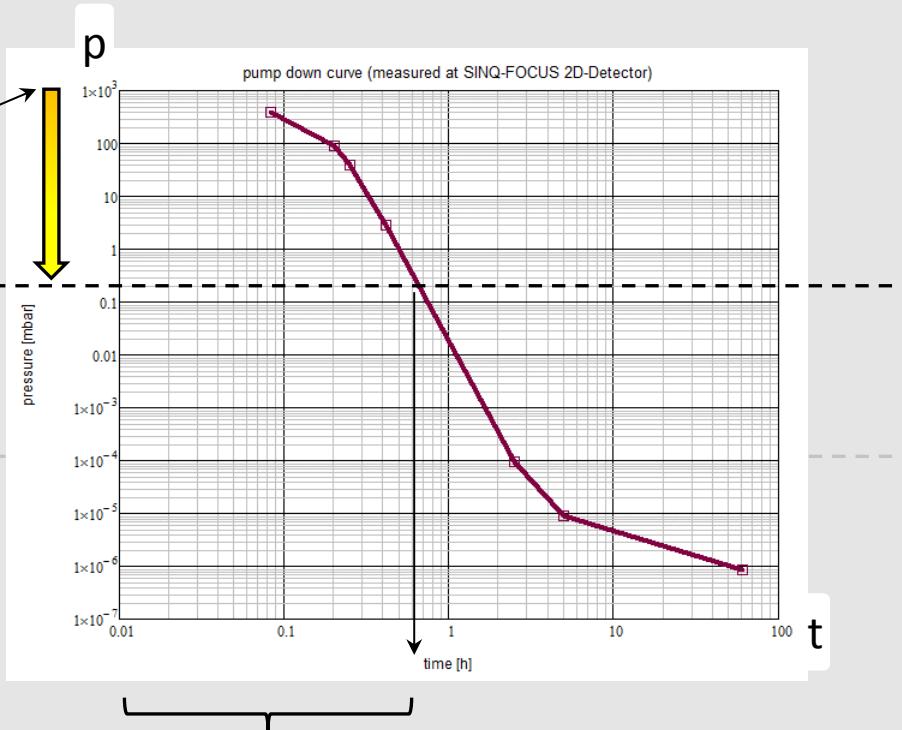
Pump down curve
(example)

p_0

p_1

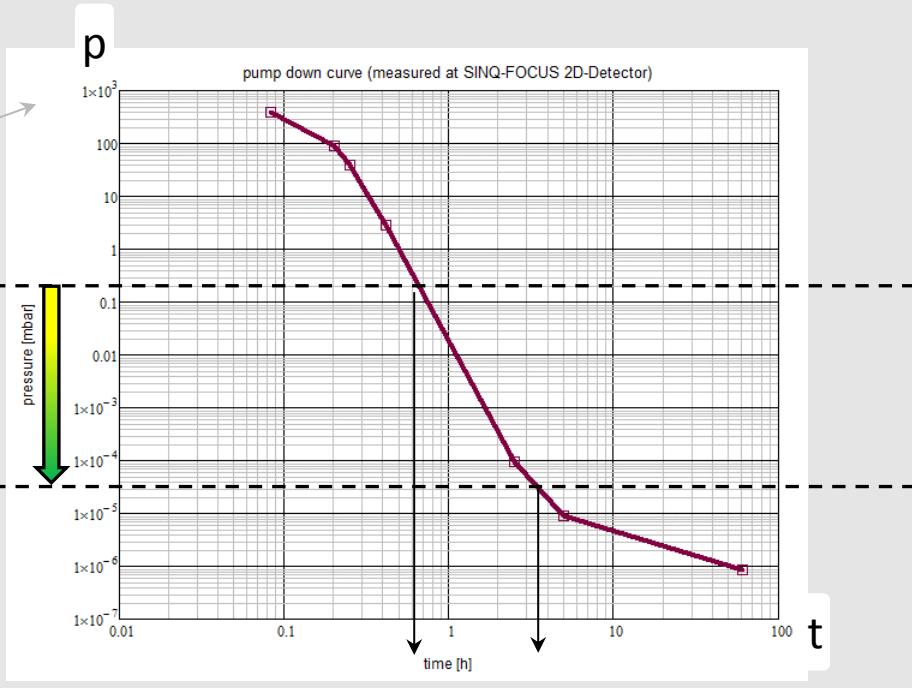
p_1 - turbomolecular pump

start-up pressure

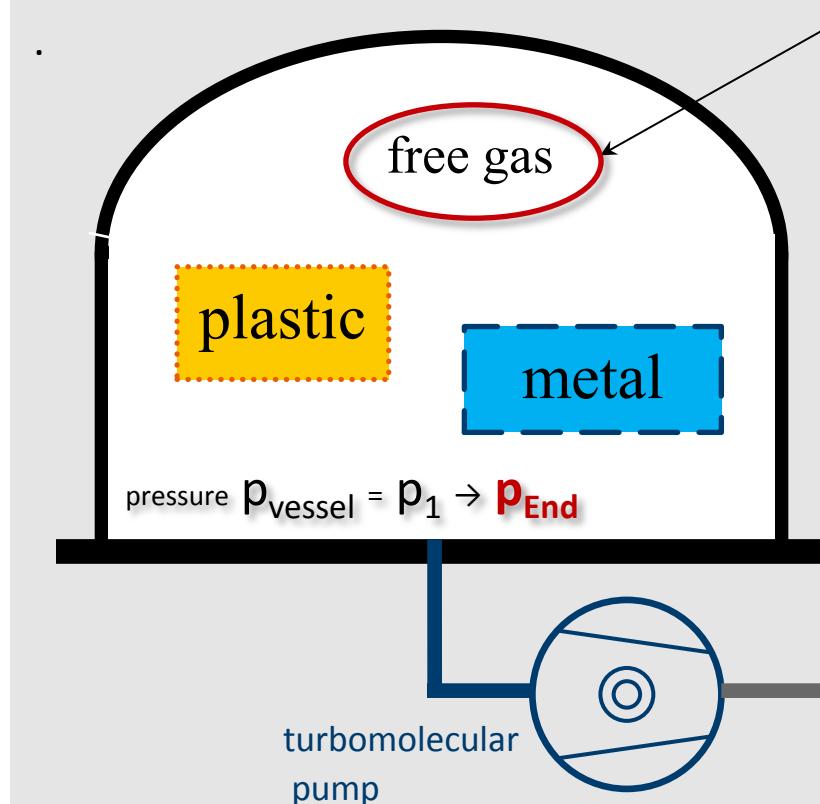


Final Evacuation

Pump down curve
(example)

 p_0 p_1 p_{End} 

Final Evacuation



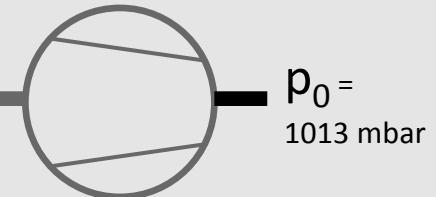
Pumping out of the free gas

possible ultimate pressure with turbomolecular pump

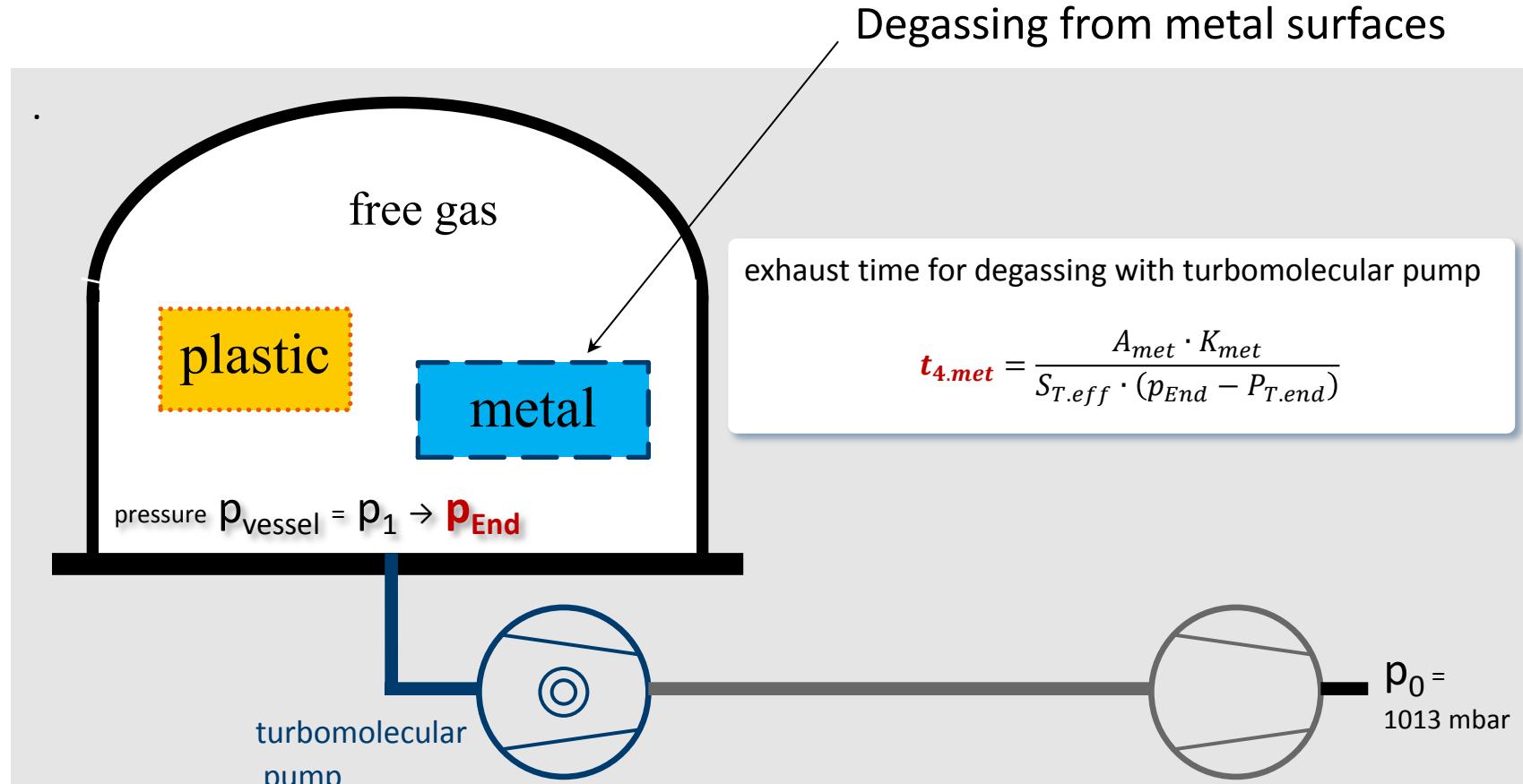
$$P_{T.end} = P_{theo.T.end} + \frac{q_L}{S_{T.eff}}$$

exhaust time of free gas with turbomolecular pump

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

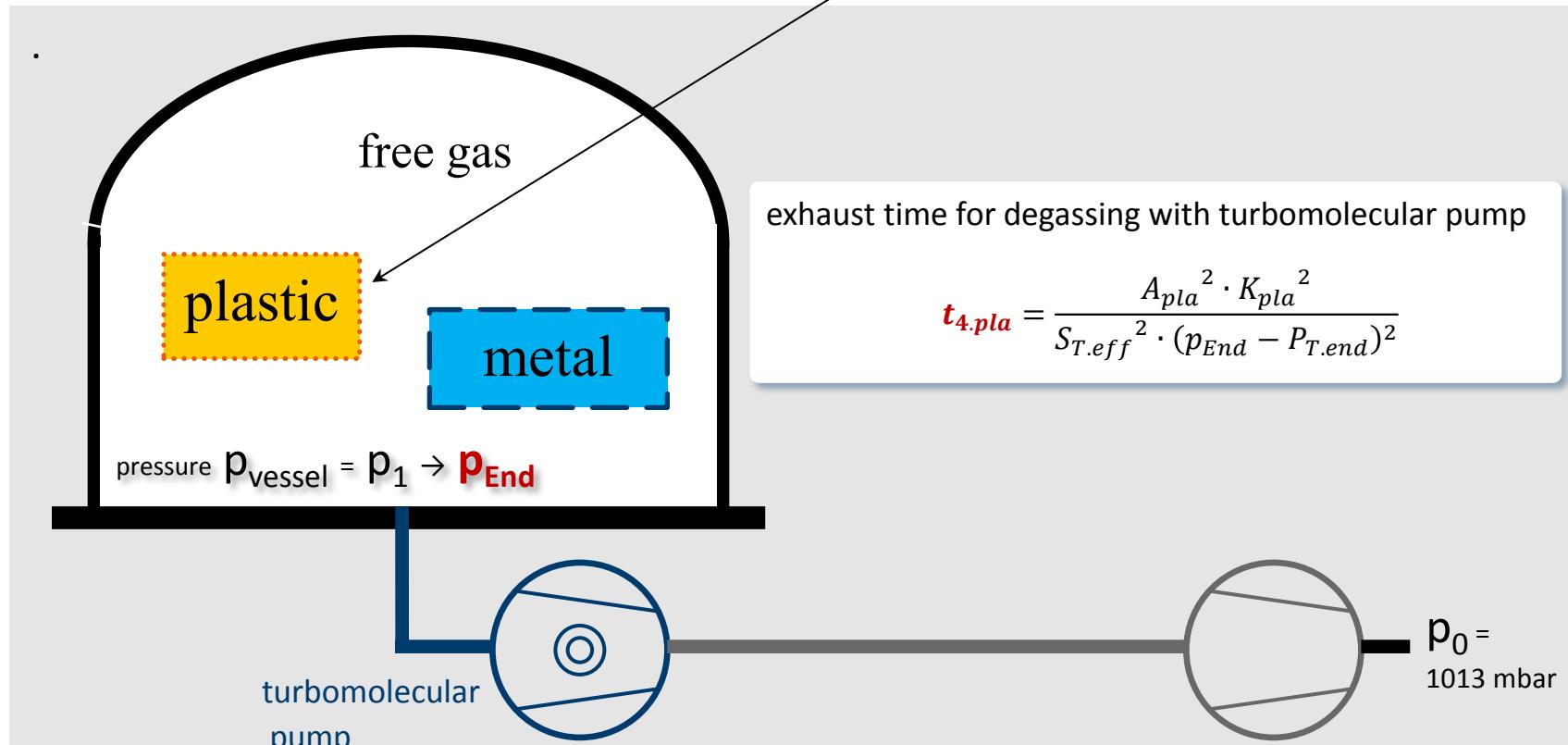


Final Evacuation



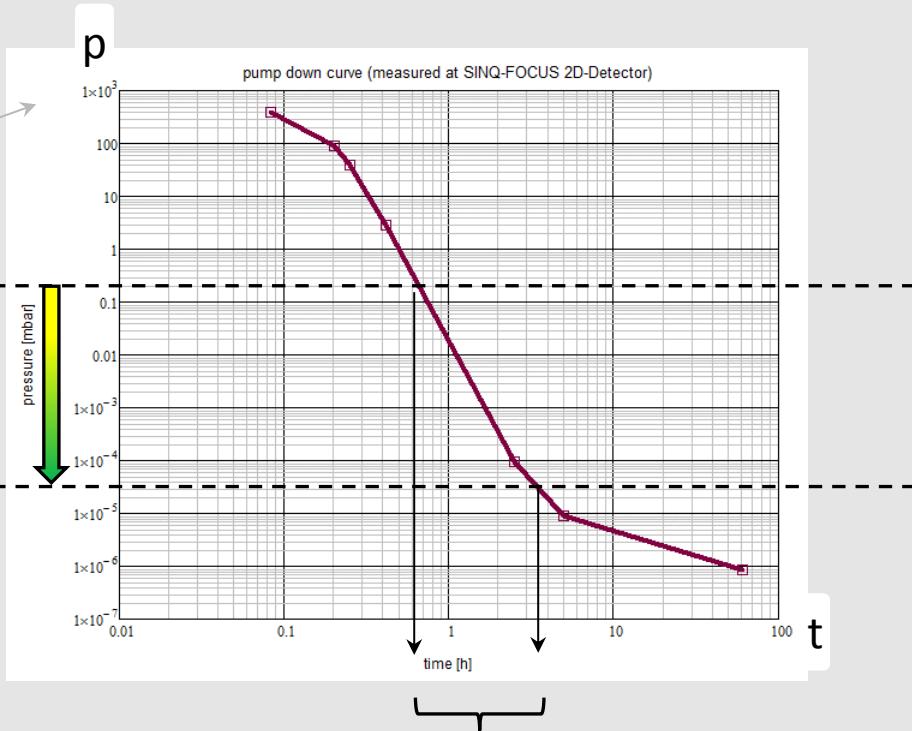
Final Evacuation

Degassing from plastic surfaces



Final Evacuation

Pump down curve
(example)

 p_0 p_1 p_{End} 

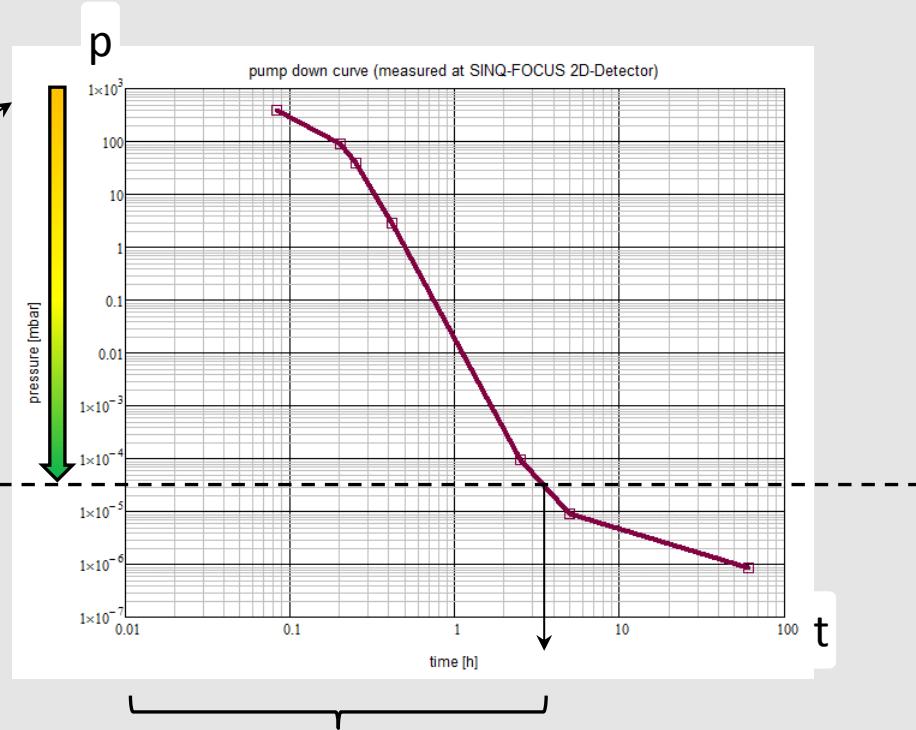
$$t_3 + t_{4.\text{met}} + t_{4.\text{pla}}$$

Result

Pump down curve
(example)

$$p_0 = \\text{1013 mbar}$$

$$p_{\\text{End}}$$



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

Choice:

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

Wir schaffen Wissen – heute für morgen

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

in order to ...

- ... understand, how the material choice affects the pump out time
- ... choose the components for a successful evacuation.

