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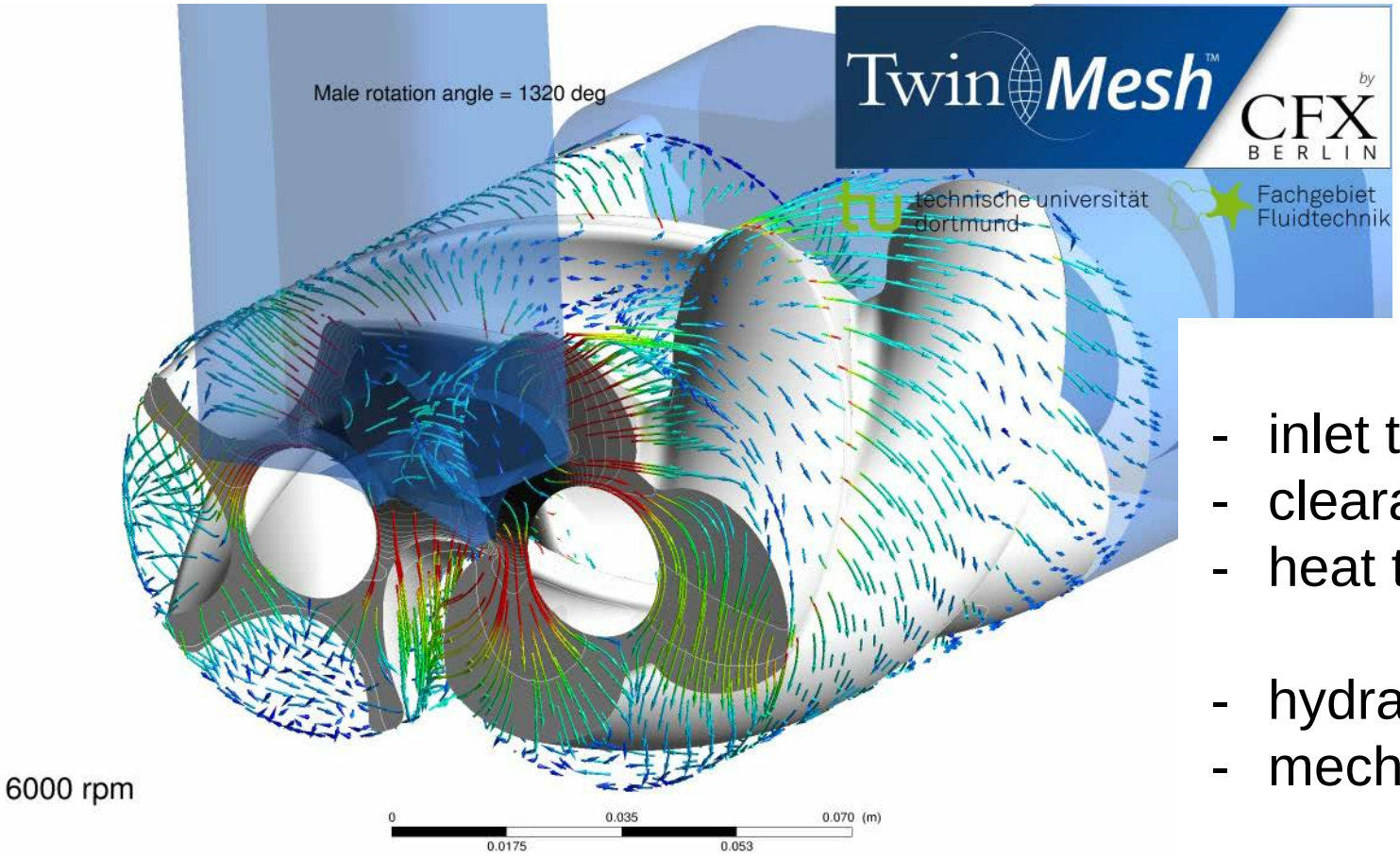
EFFECTS OF TWO-PHASE FLUIDS IN TWIN-SCREW EXPANDERS

The 9th International Conference on Compressor and Refrigeration, 2019

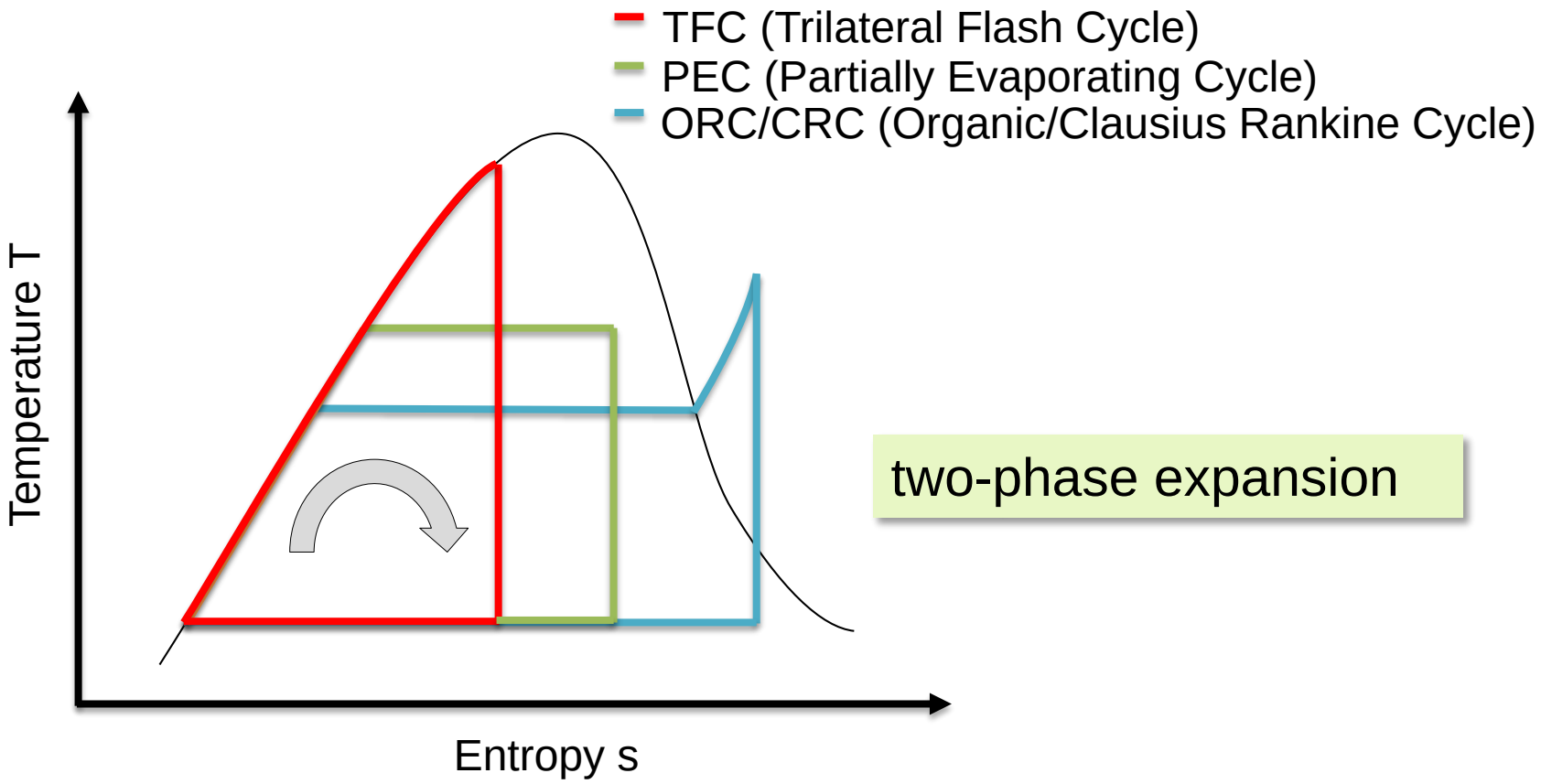
twin-screw expander (dry)



- inlet throttling
- clearance losses
- heat transfer

- hydraulic losses
- mechanical friction

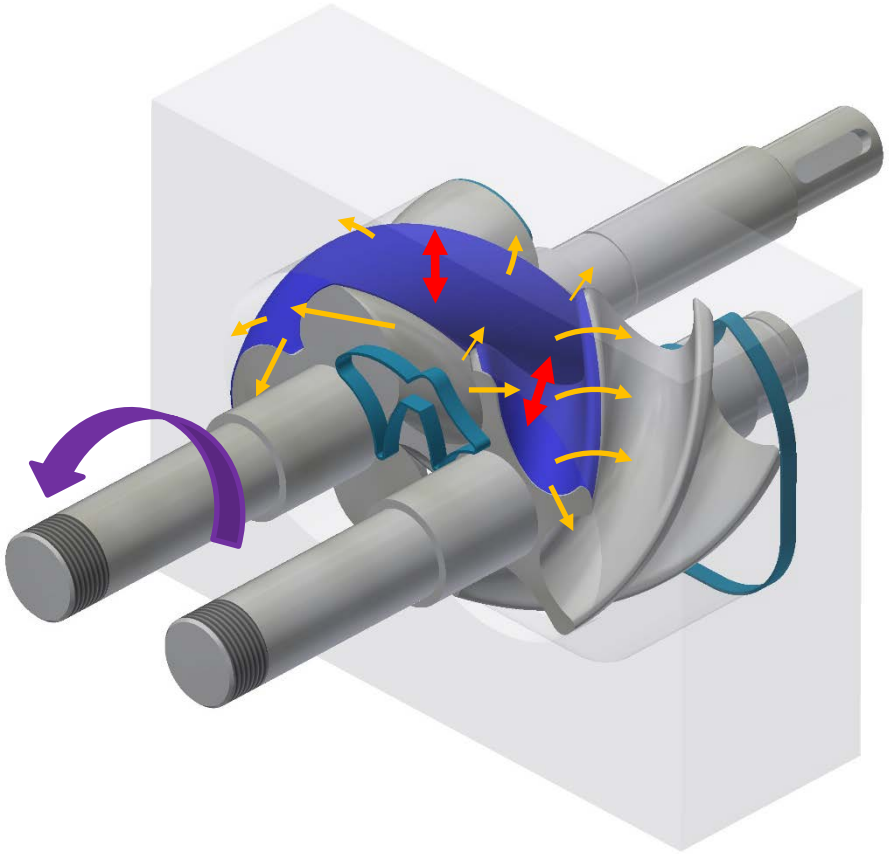
two-phase expansion processes

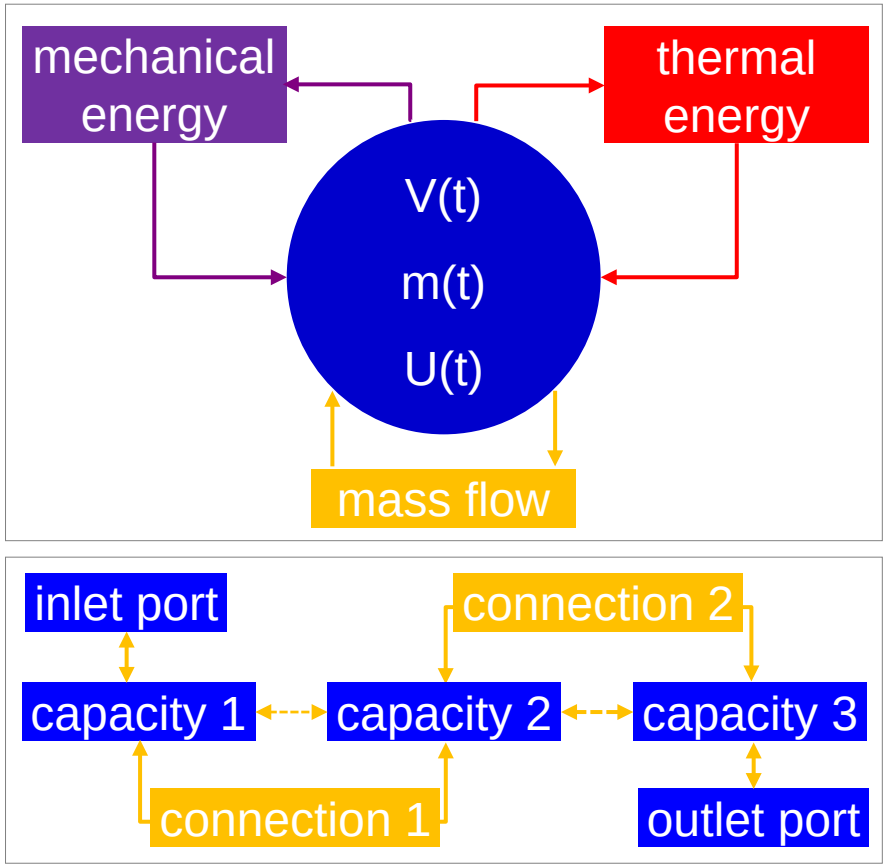


two-phase expansion

- How to design an efficient liquid-flooded twin-screw expander?

(Janicki and Kauder 2003)





3d twin-screw expander geometry

abstracted geometry

fluid capacities

- conservation of mass

$$\left(\frac{dM}{dt}\right)_i = \cdots$$

- conservation of energy

$$\left(\frac{dE}{dt}\right)_i = \cdots$$

connections

- mass flows $\dot{m} = \alpha \cdot \dot{m}_s$

  α := *flow coefficient*

  $\dot{m}_s$:= *isentropic mass flow*

- heat flows $\dot{Q} = \beta \cdot A \cdot \Delta T$

  β := *heat transfer coefficient*

- mechanical energy $dW_i = -p \cdot dV$

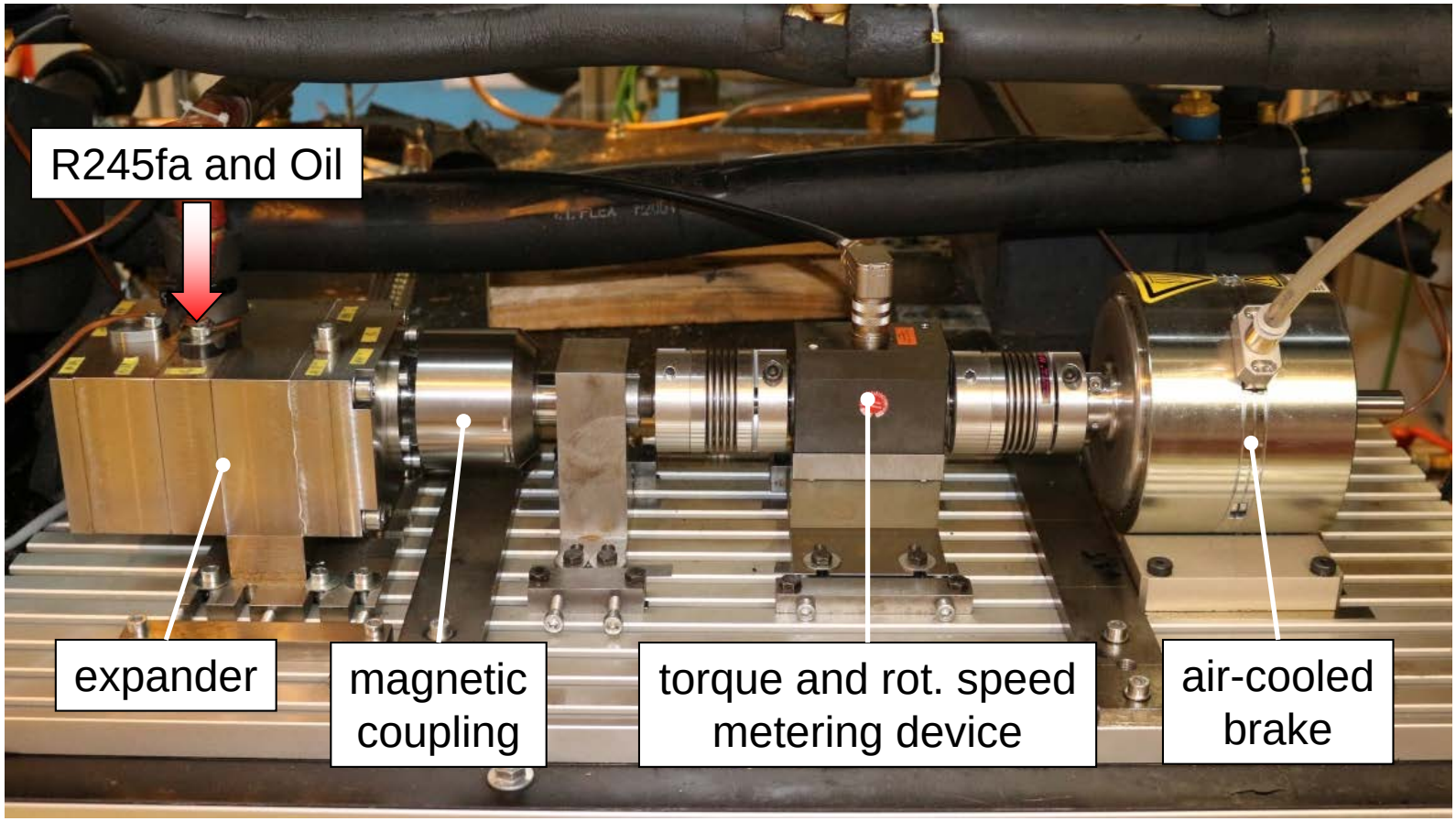
$\dot{m}_a$:= expander mass flow

P_i := expander indicated power

- First two-phase effect: Increased inlet throttling!

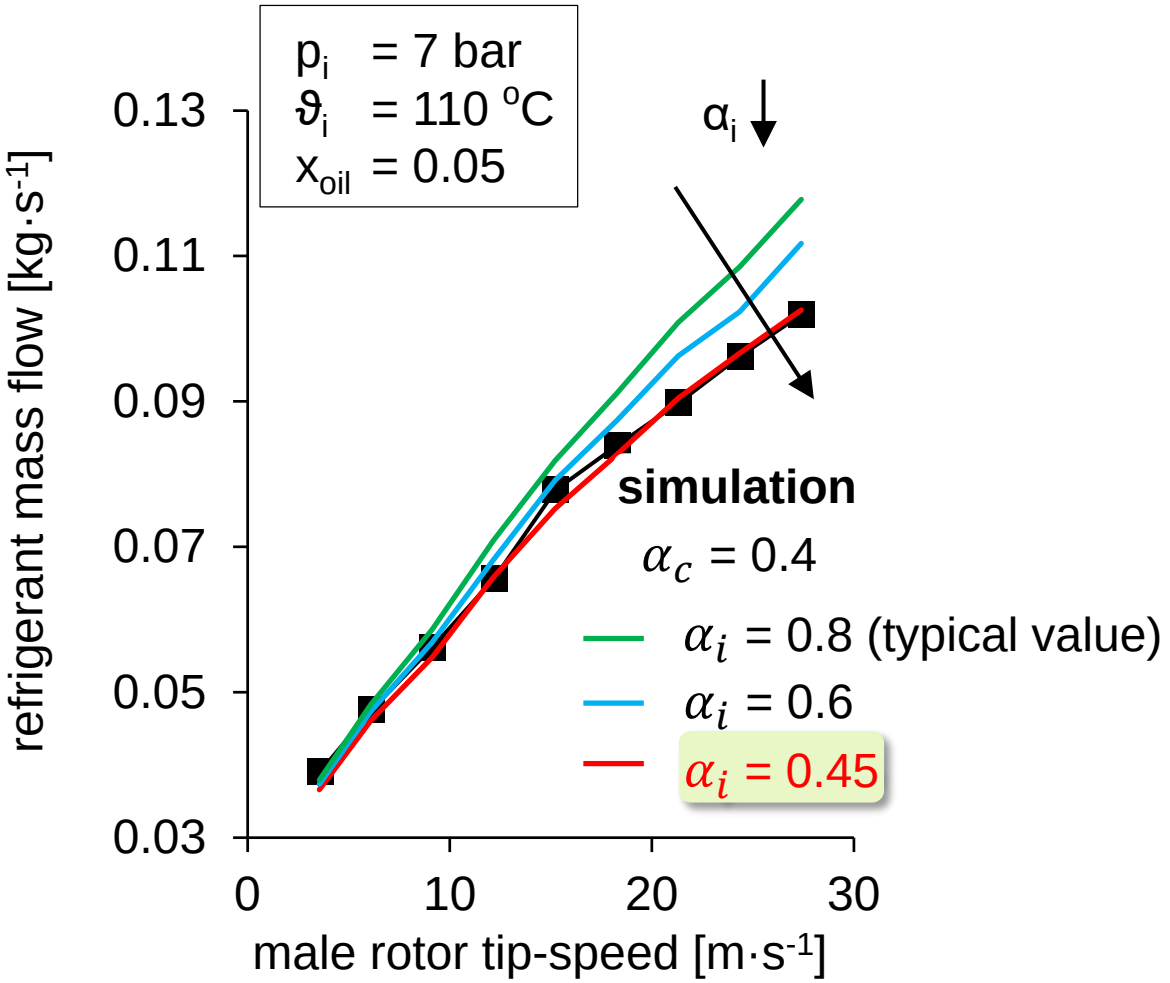
twin-screw expander in an ORC with oil

(Nikolov and Brümmer 2017)



inlet throttling

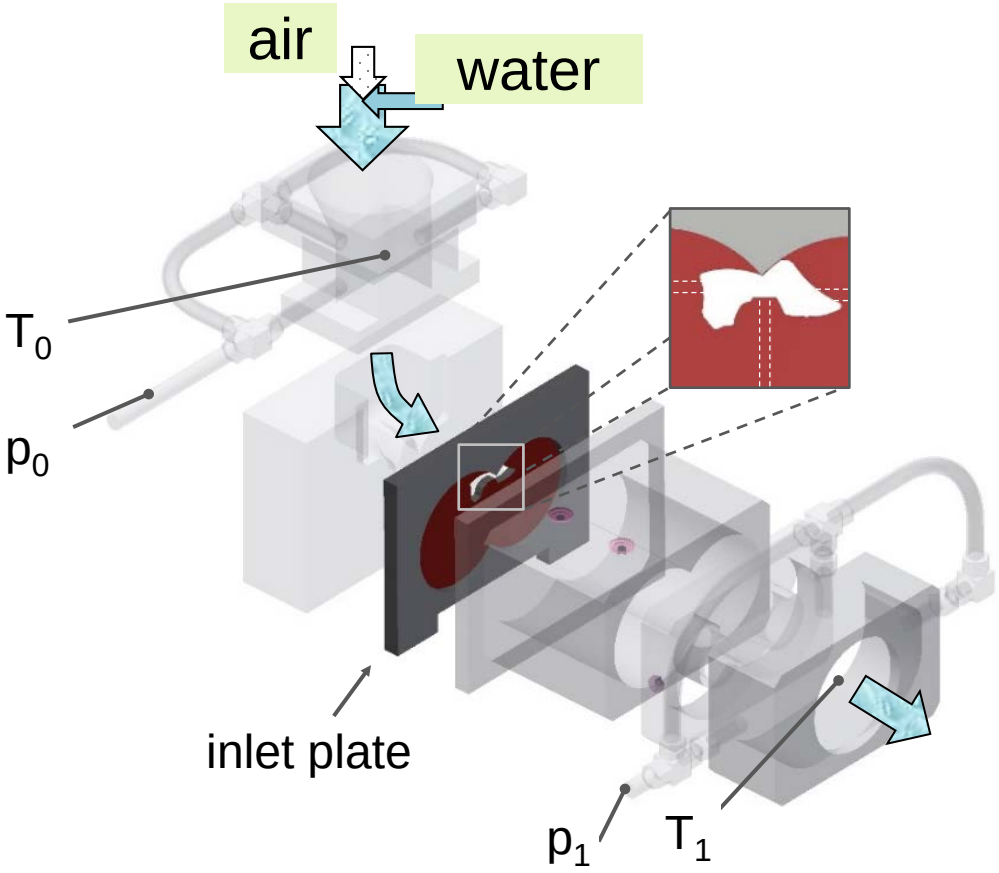
(Nikolov and Brümmer 2017)

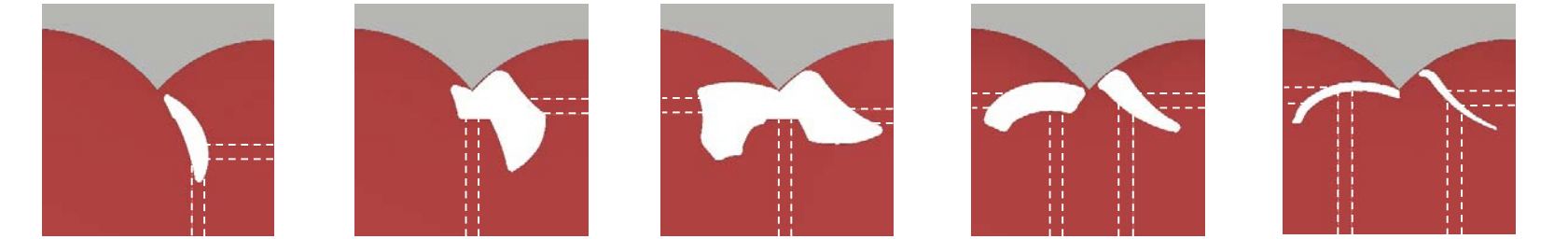


Lessons learned:

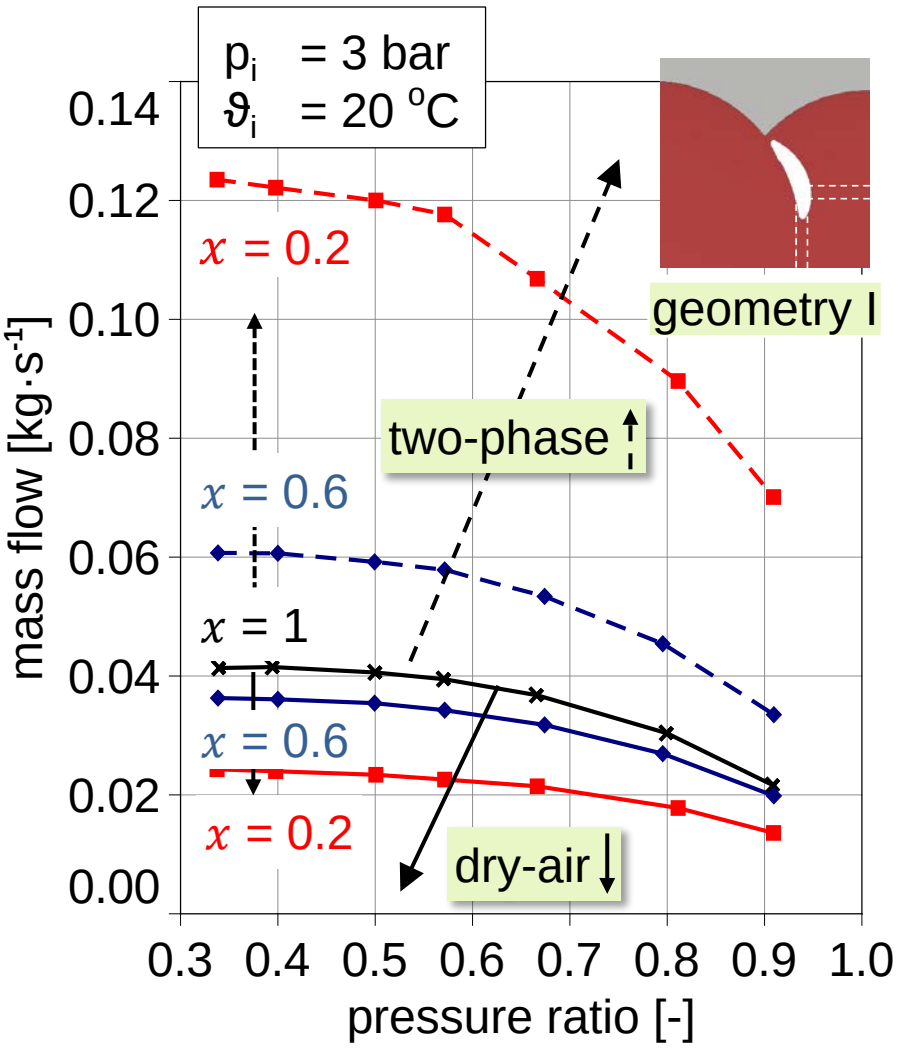
- Two-phase flow considerably increases the inlet throttling (and seals the clearances).
- Individual two-phase flow coefficients maybe extracted from the characteristic map.

- How is it possible to calculate the two-phase flow coefficient?

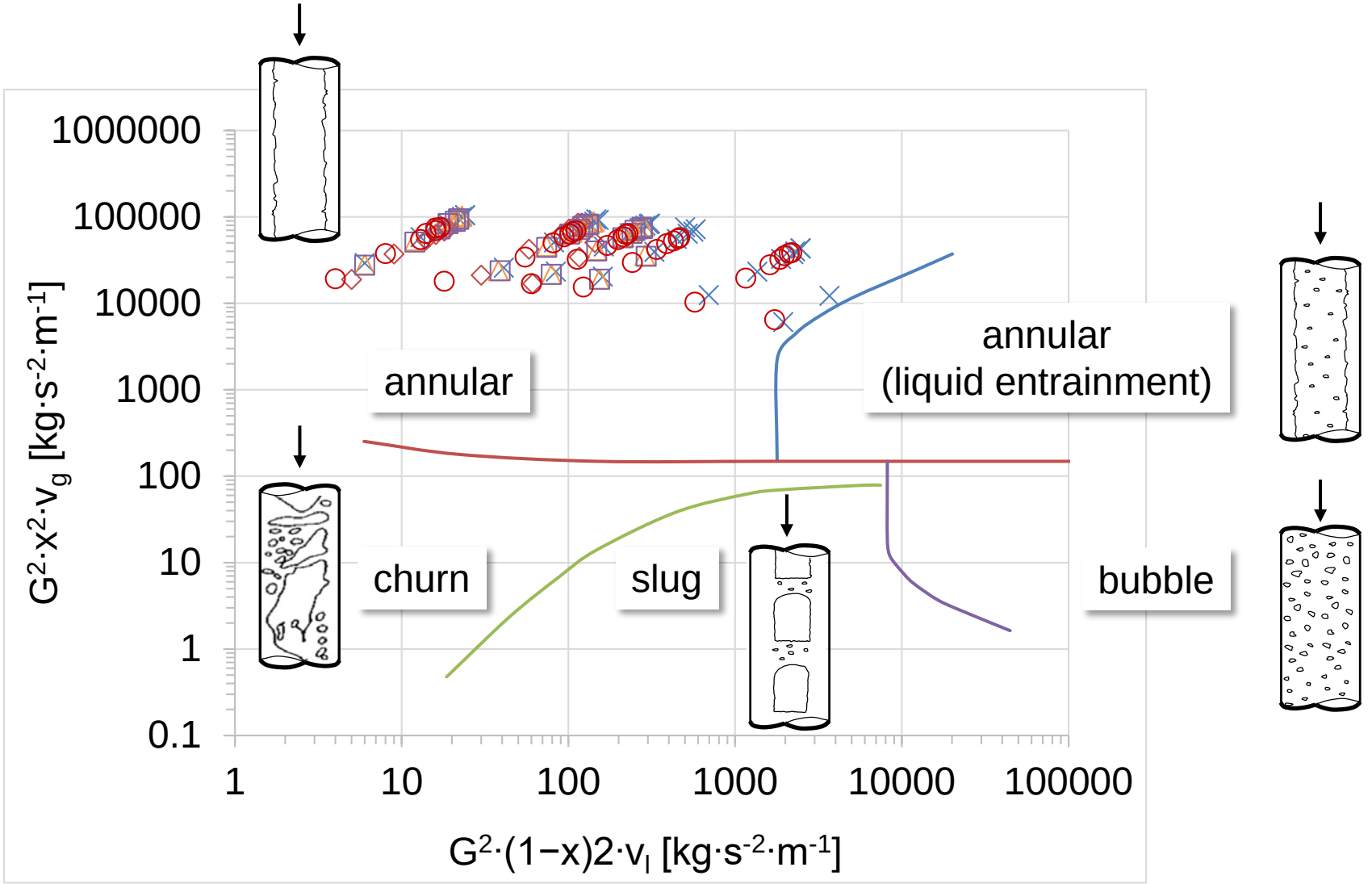

air
water
T_0
p_0
inlet plate
p_1
T_1


I
II
III
IV
V

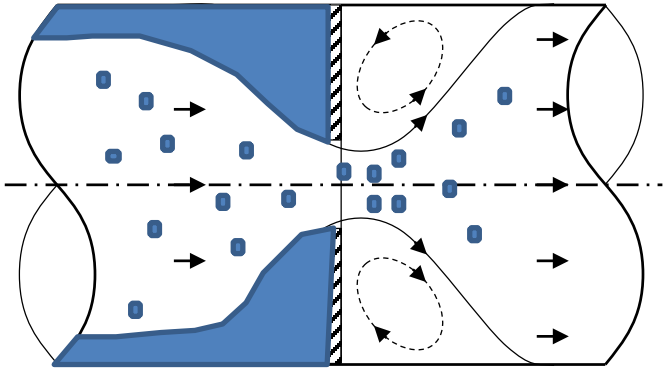
$$x = \frac{\text{dry-air mass flow}}{\text{dry-air mass flow + water mass flow}}$$



two-phase flow pattern map (vertical flow)



slip-flow model
(gas – liquid)



slip ratio

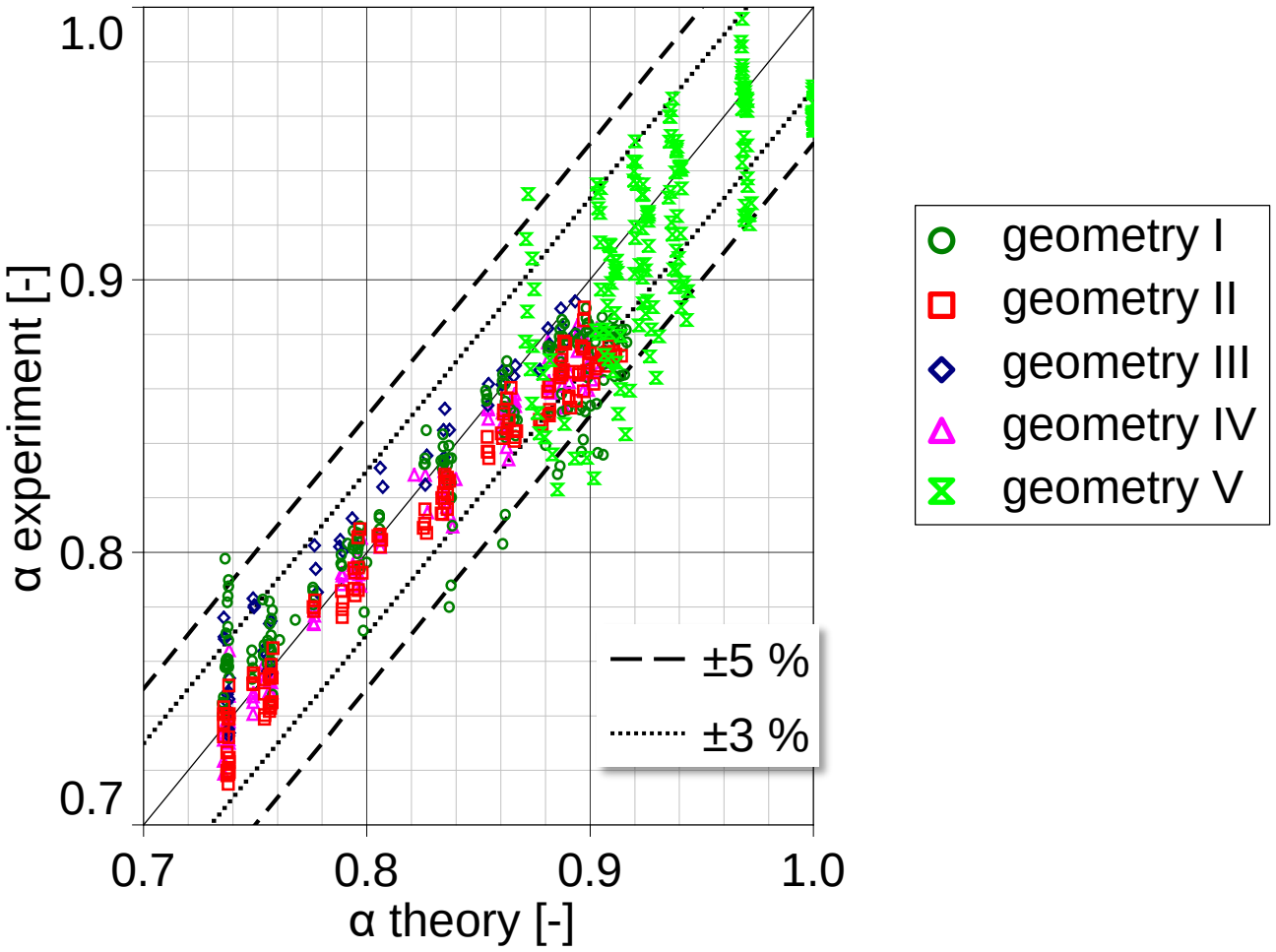
$$S = \frac{gas\ velocity}{liquid\ velocity}$$

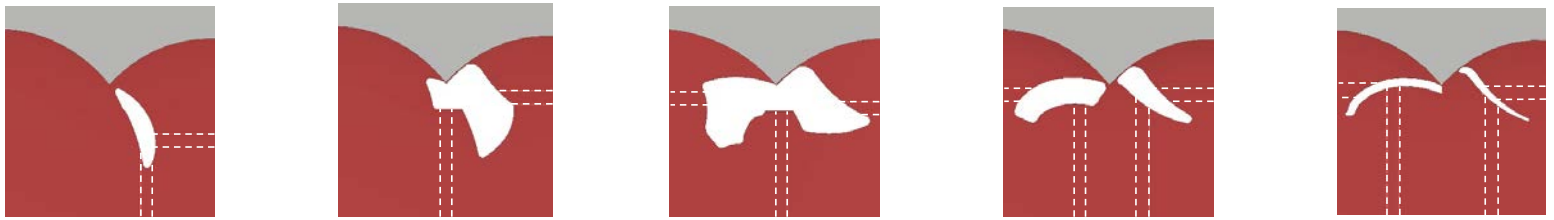
experiment:

$$\alpha := \frac{\dot{m}_e}{\dot{m}_{th}}$$

theory:

$$\alpha := \frac{\dot{m}}{\dot{m}_{th}} = f\left(\Pi, \kappa, v_g, v_w, S\right)$$


1.0
0.9
0.8
0.7
α experiment [-]
0.7
0.8
0.9
1.0
α theory [-]
±5 %
±3 %
geometry I
geometry II
geometry III
geometry IV
geometry V


I
II
III
IV
V

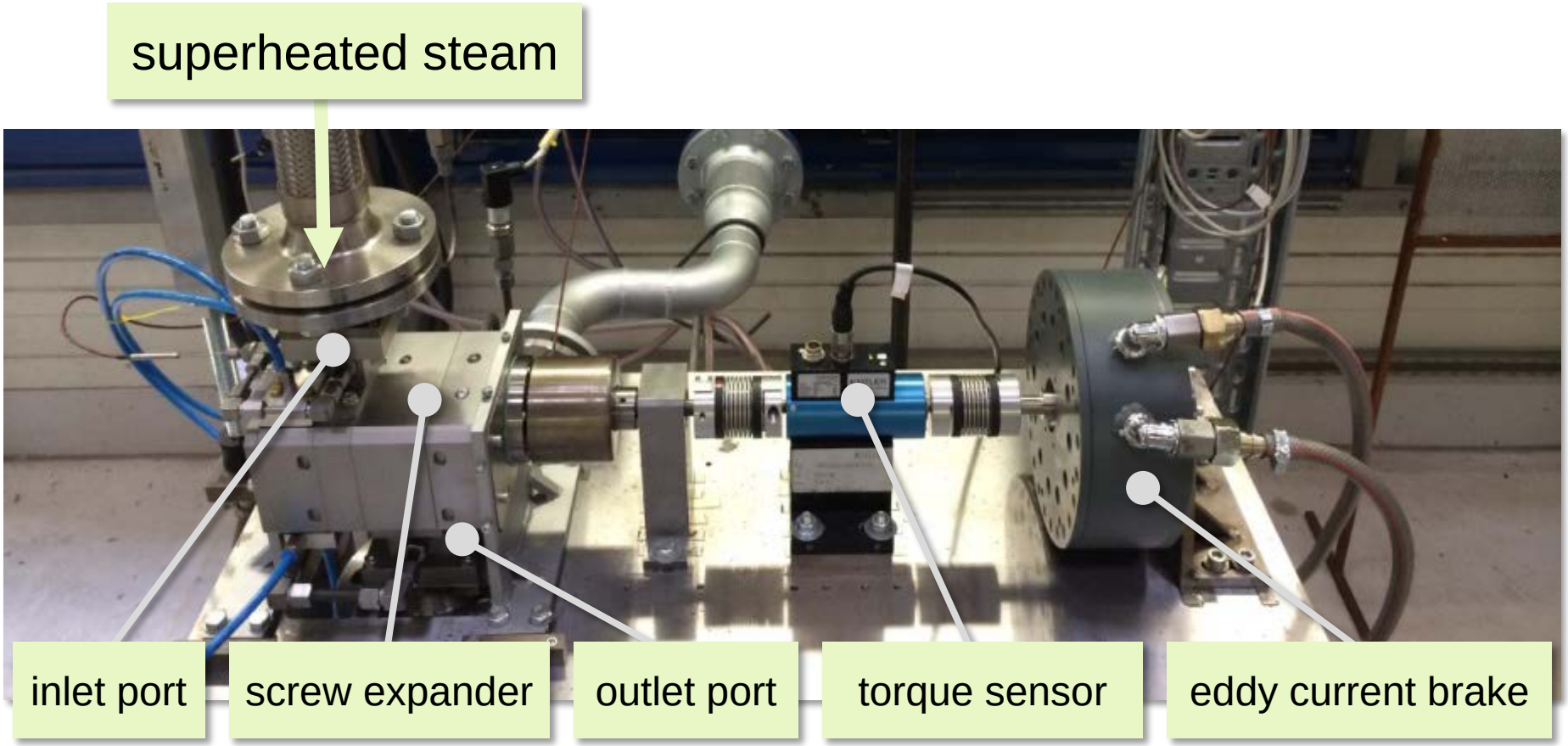
Lessons learned:

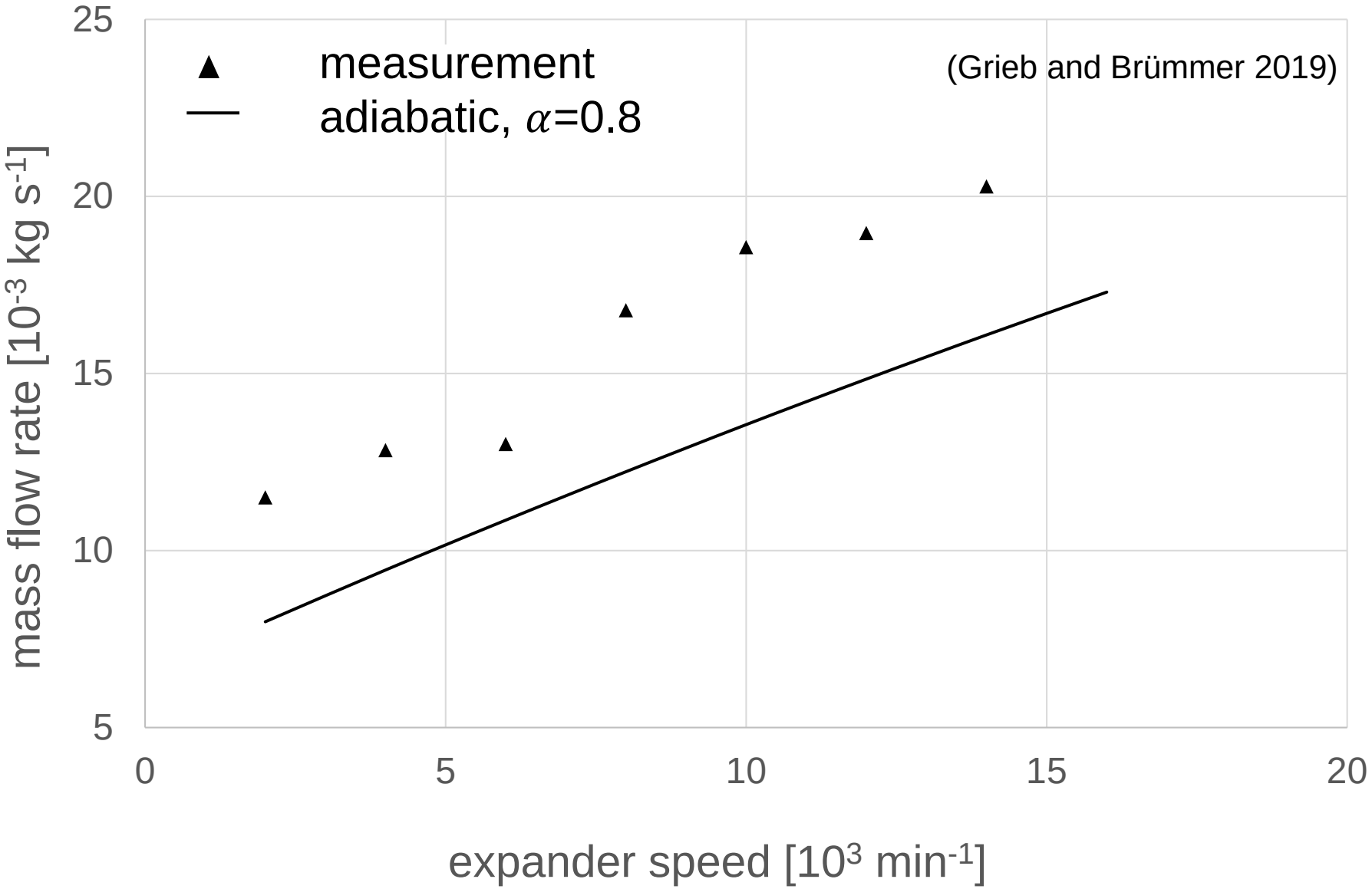
- The flow coefficients for a two-phase inlet flow can be calculated knowing the flow pattern and taking slip between gas and liquid into account.

- Second two-phase effect: Condensation.

twin-screw expander in an steam cycle

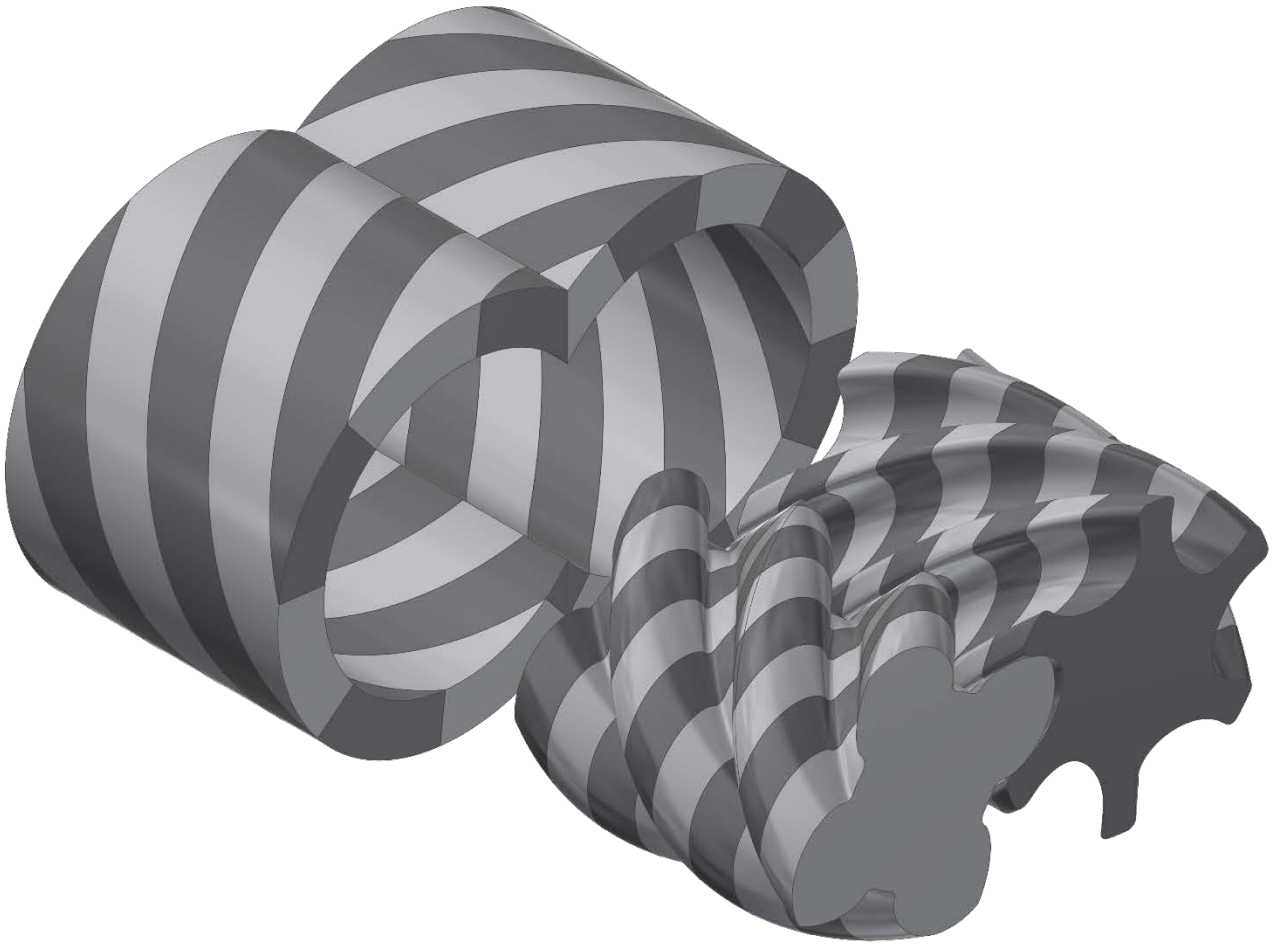
(Grieb and Brümmer 2014)



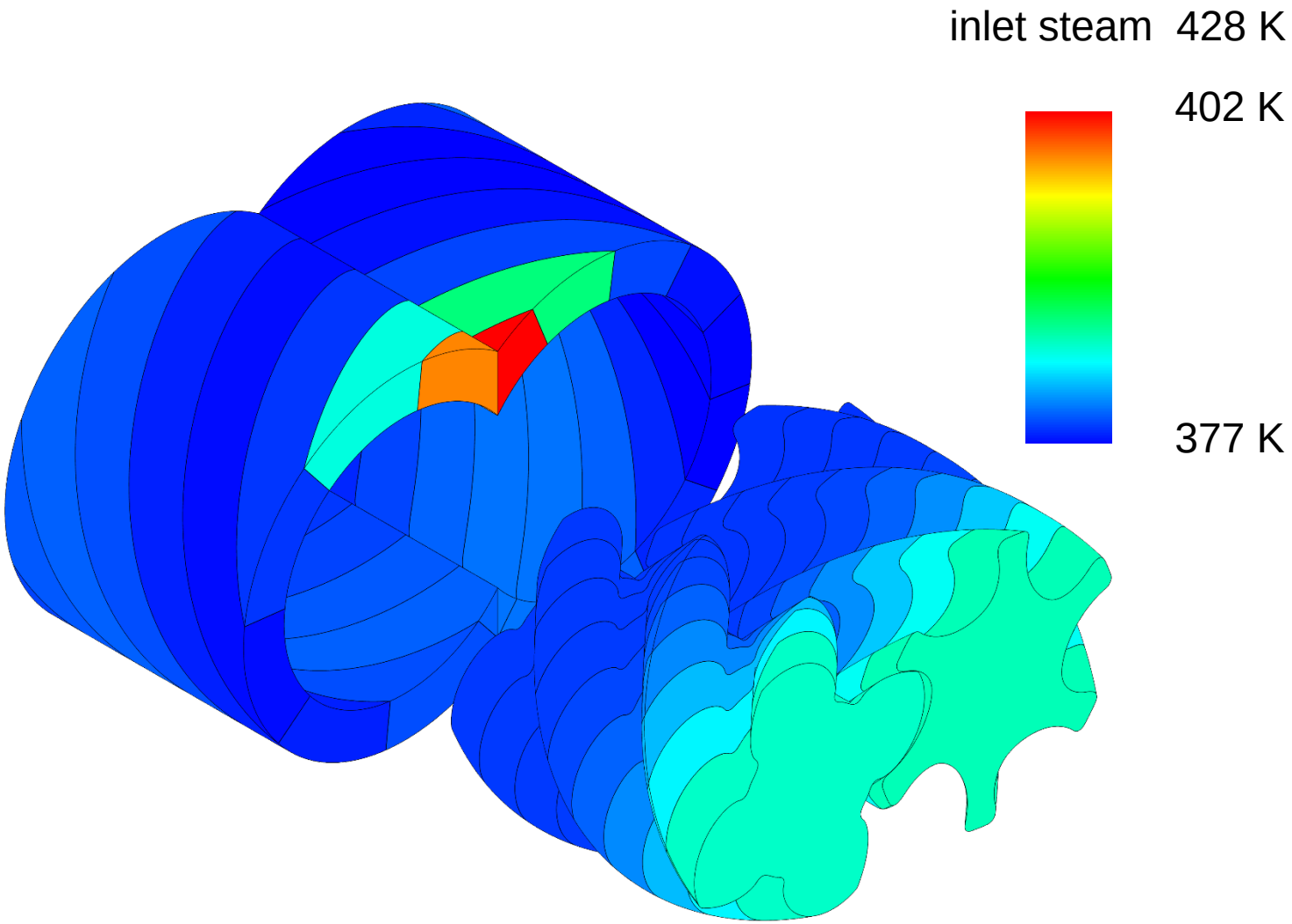

measurement
adiabatic, α=0.8
(Grieb and Brümmer 2019)
mass flow rate [10^{-3} kg s^{-1}]
25
20
15
10
5
0
5
10
15
20
expander speed [10^3 min^{-1}]

thermal capacities for diabatic chamber model simulation

(Grieb and Brümmer 2019)



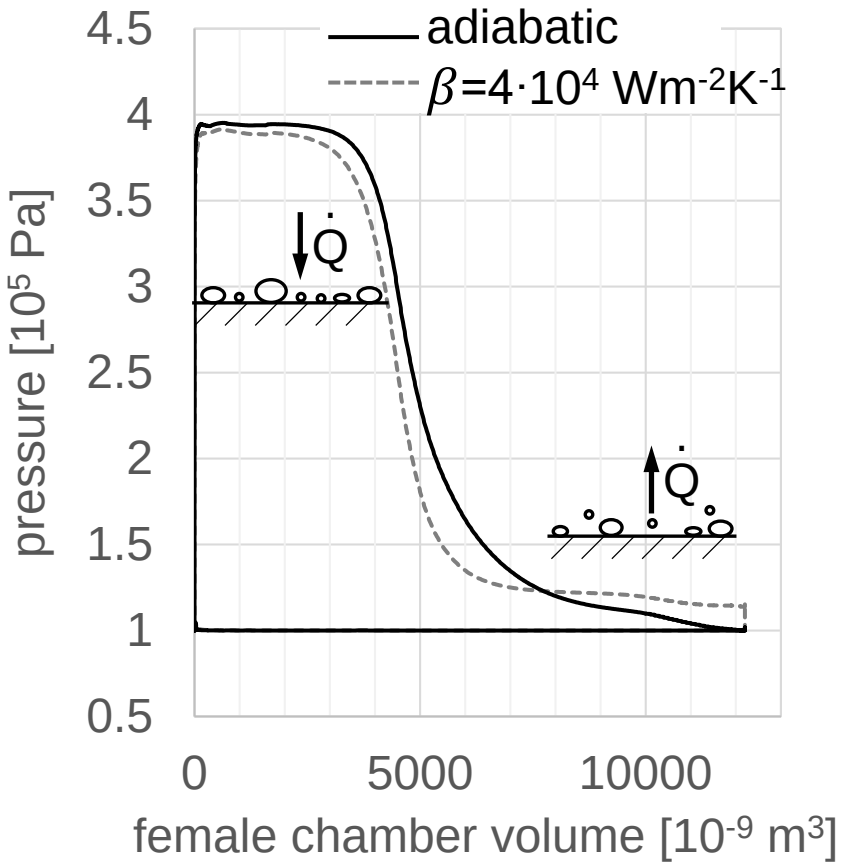
temperature distributions in housing and rotors

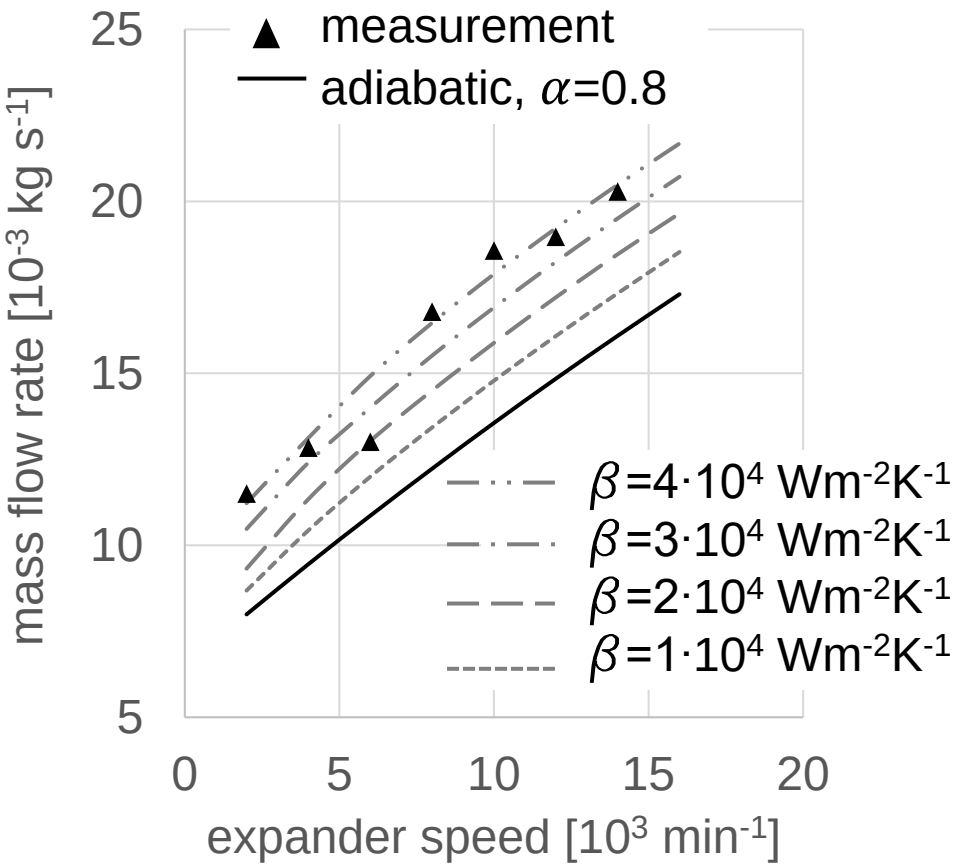


(Grieb and Brümmer 2019)

diabatic simulation

(Grieb and Brümmer 2019)





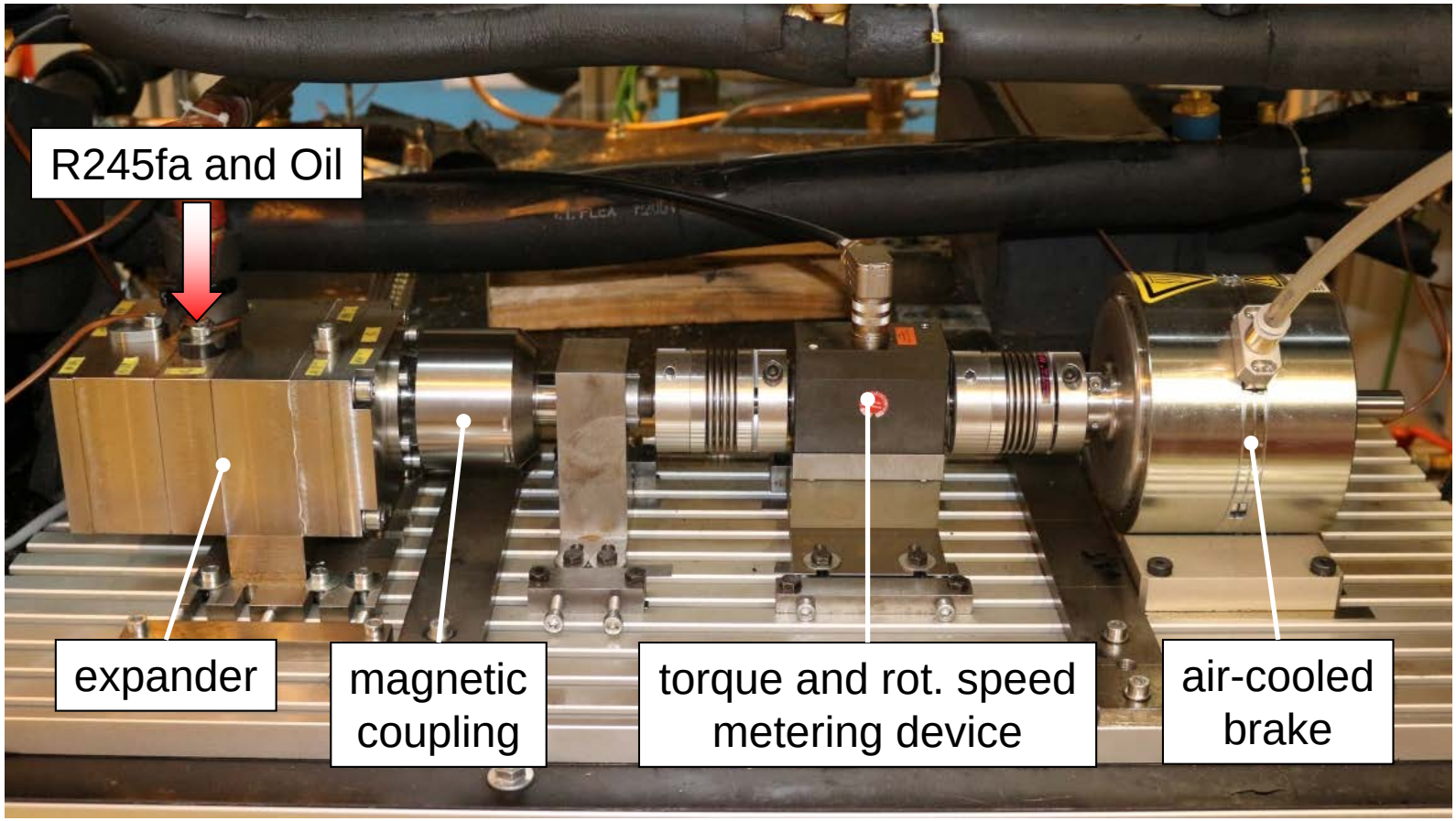
Lessons learned:

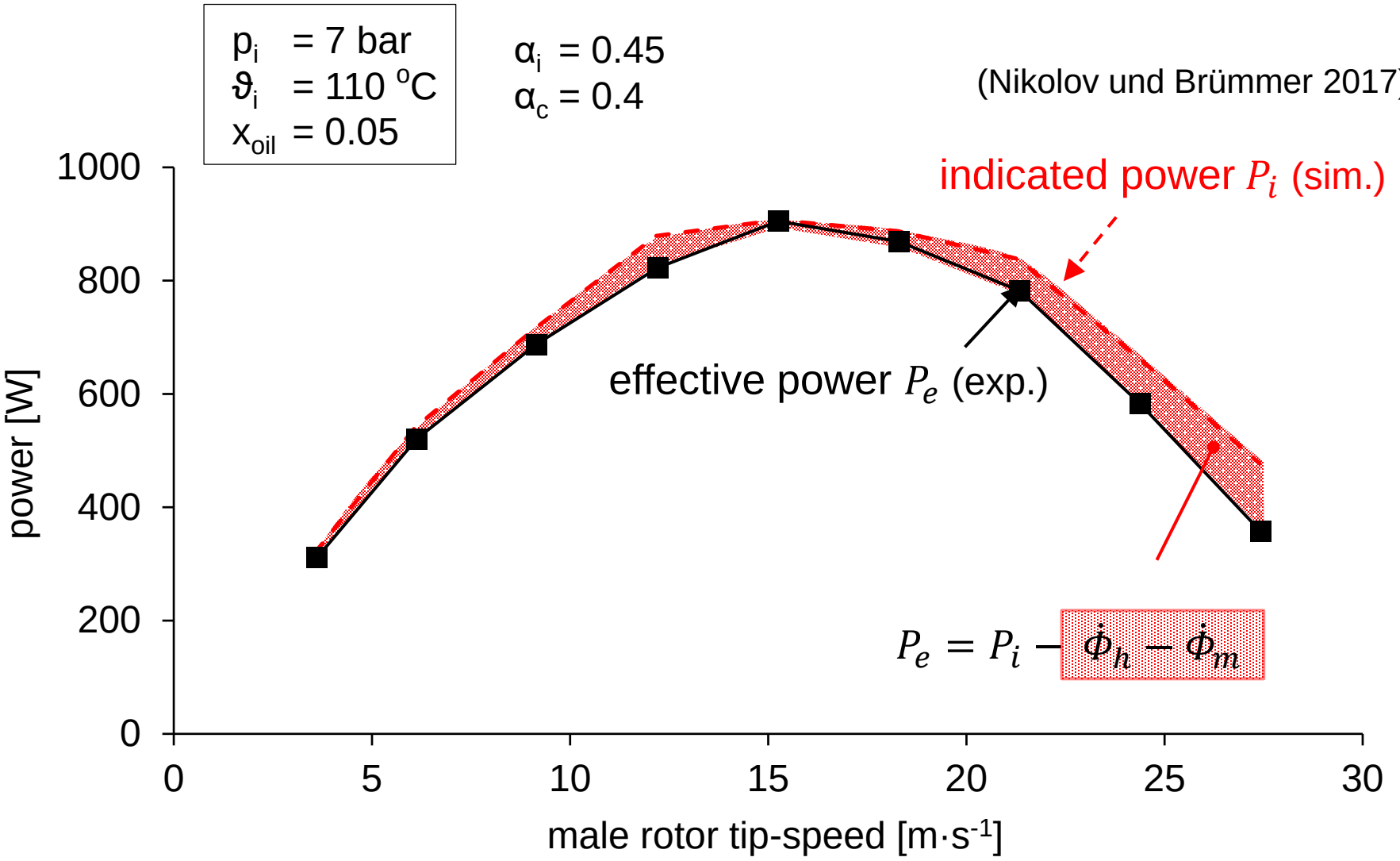
- Condensation during chamber filling primarily takes place at the rotors and increases the expander mass flow rate.
- Condensed liquid reduces indicated power.
- Condensed liquid does not result in significant sealing of gaps (not shown).

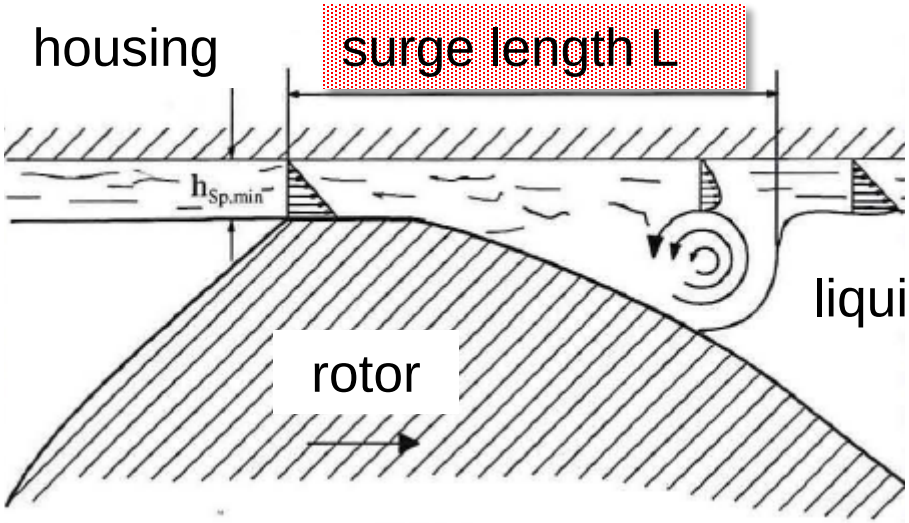
- Third two-phase effect: Hydraulic losses!

twin-screw expander in an ORC with oil

(Nikolov und Brümmer 2017)



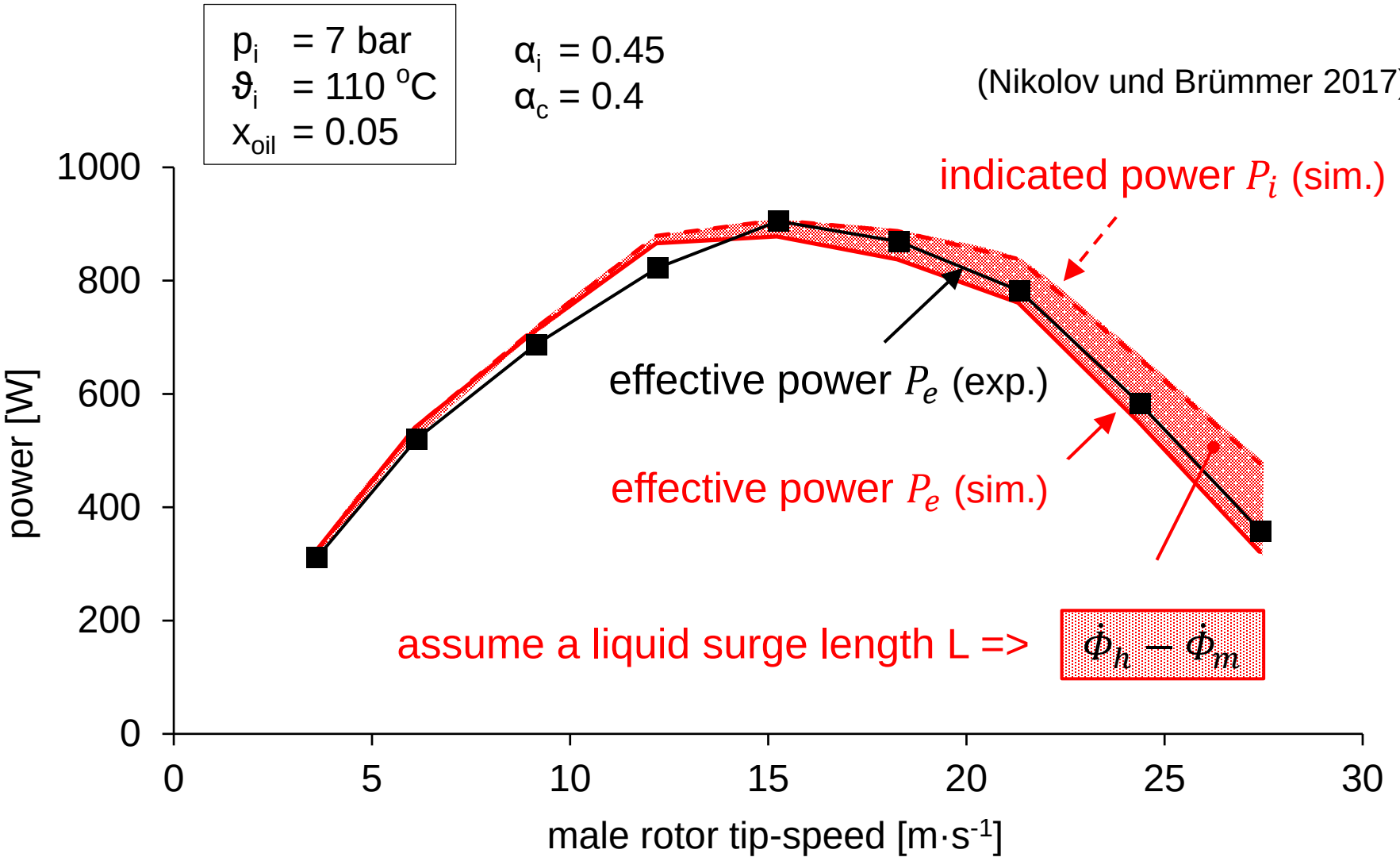

p_i = 7 bar
ϑ_i = 110 °C
x_{oil} = 0.05
α_i = 0.45
α_c = 0.4
(Nikolov und Brümmer 2017)
indicated power P_i (sim.)
effective power P_e (exp.)
$P_e = P_i - \dot{\Phi}_h - \dot{\Phi}_m$
power [W]
1000
800
600
400
200
0
0
5
10
15
20
25
30
male rotor tip-speed [m·s^{-1}]



(Kauder 1987)
(Deipenwisch 2000)

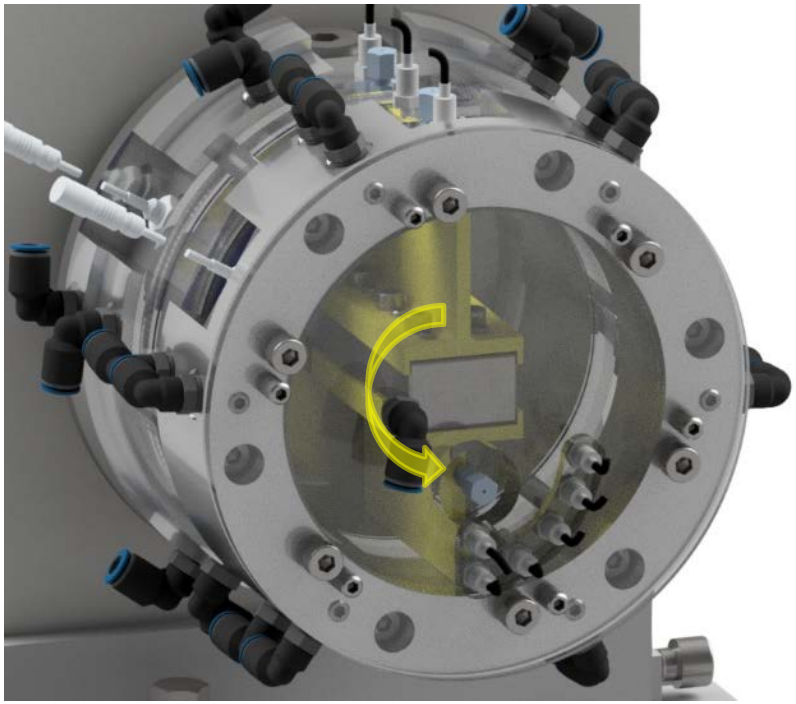
$\dot{\Phi}_{friction}(L,..)$:= friction losses

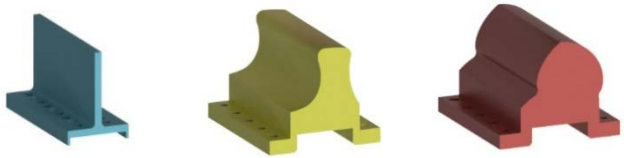
$\dot{E}_{kin}(L,..)$:= kinetic energy


p_i = 7 bar
ϑ_i = 110 °C
x_{oil} = 0.05
α_i = 0.45
α_c = 0.4
(Nikolov und Brümmer 2017)
indicated power P_i (sim.)
effective power P_e (exp.)
effective power P_e (sim.)
assume a liquid surge length L => $\dot{\Phi}_h - \dot{\Phi}_m$
power [W]
1000
800
600
400
200
0
0
5
10
15
20
25
30
male rotor tip-speed [m·s-1]

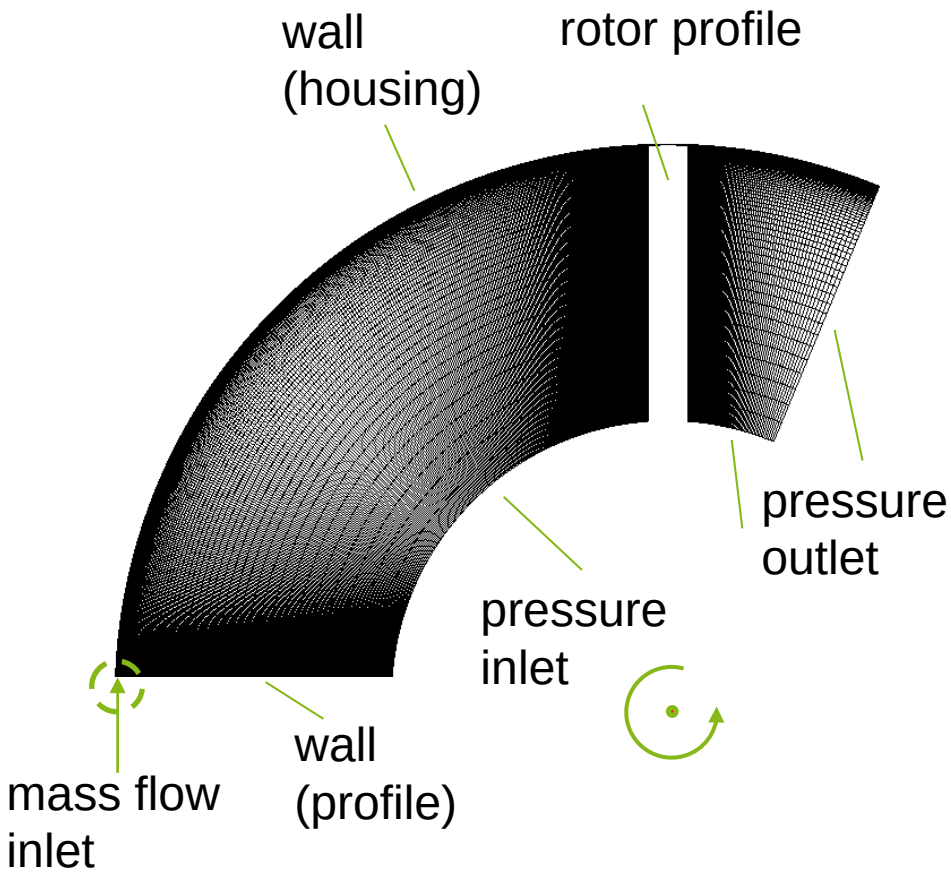
- Is it possible to avoid the assumption of a liquid surge length L ?

fundamental experiment



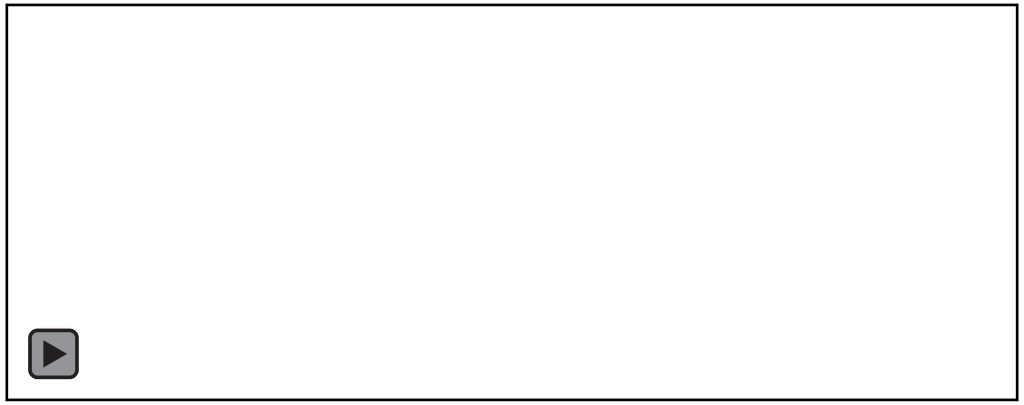


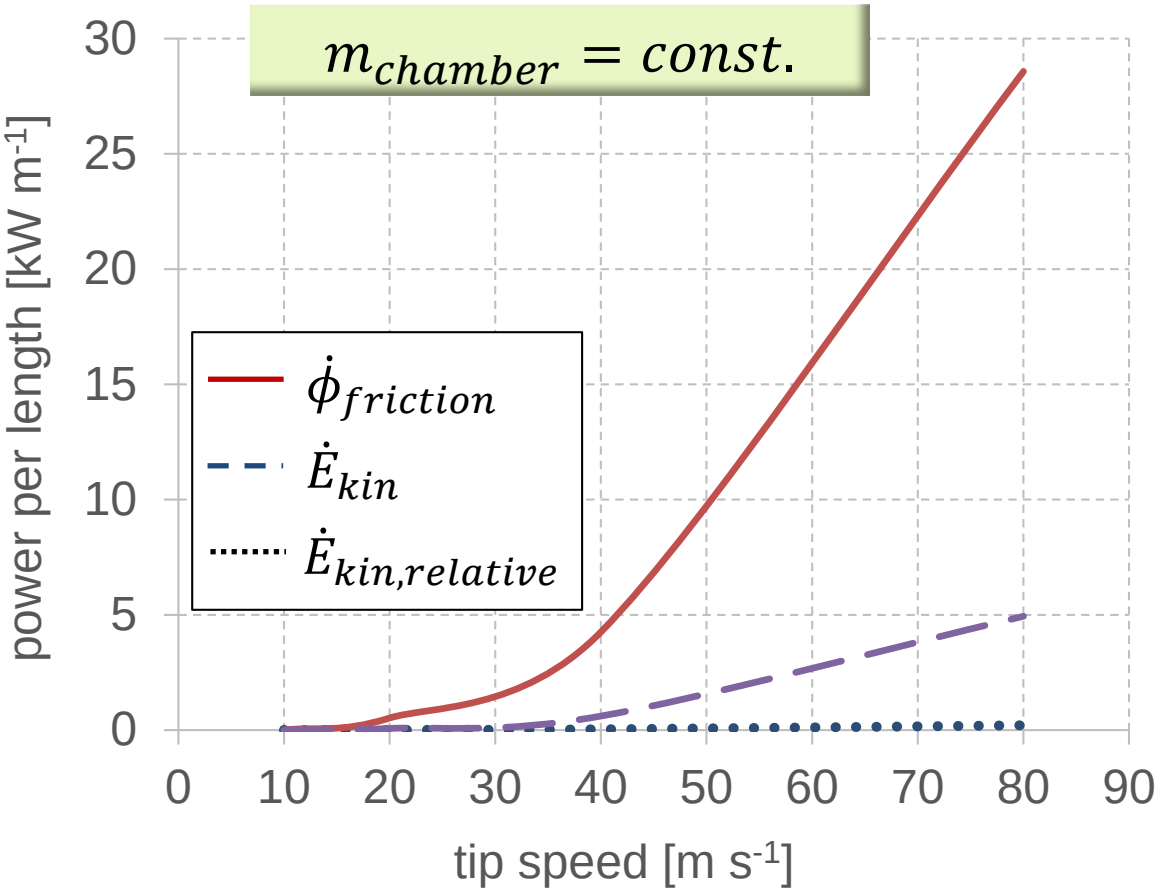
CFD simulation (relative system)



measurement

CFD simulation





ongoing research: developing a new analytical model for hydraulic losses

Lessons learned:

- Mainly responsible for hydraulic losses are friction losses and rotational kinetic energy losses.
- A semi-analytical model to calculate the hydraulic losses is known.
- Developing a new analytical model for hydraulic losses is ongoing research.

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THANK YOU FOR YOUR ATTENTION!

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references (1)

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Grieb, Manuel, Brümmer, Andreas (2014): Design and examination of a small-scale screw expander for waste heat recovery. In: International Conference on Screw Machines, VDI Bericht 2228 , 2014.

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Kauder, Knut (1987): Das Öl im Schraubenkompressor - ein Faktor für optimale Betriebsverhaeltnisse. In: Pumpen Vakuumpumpen Kompressoren, Nürnberg: Harnisch, 38–44.

Nikolov, Alexander; Brümmer, Andreas (2017): Investigating a Small Oil-Flooded Twin-Screw Expander for Waste-Heat Utilisation in Organic Rankine Cycle Systems. In: Energies 10 (7), S. 869. DOI: 10.3390/en10070869.