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IMPACT OF MAJOR LEAKAGES ON CHARACTERISTICS OF A ROTARY VANE EXPANDER (RVE) FOR ORC

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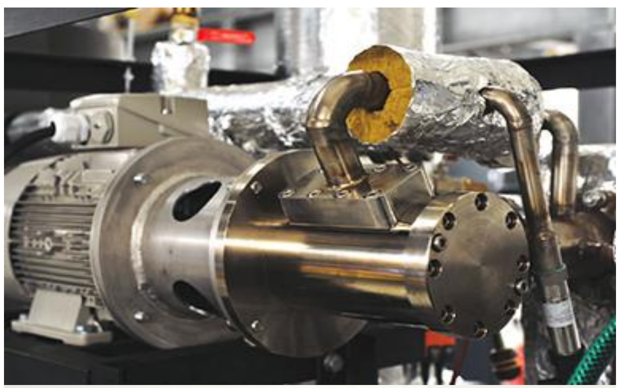
OUTLINE

- Background & motivation
- Rotary vane expander
- Losses of the expander
- Modeling
- Results
  - Current model implication
  - Relation to experimental data
- Conclusion and future work
  - Experimental
  - Detailed models perspective

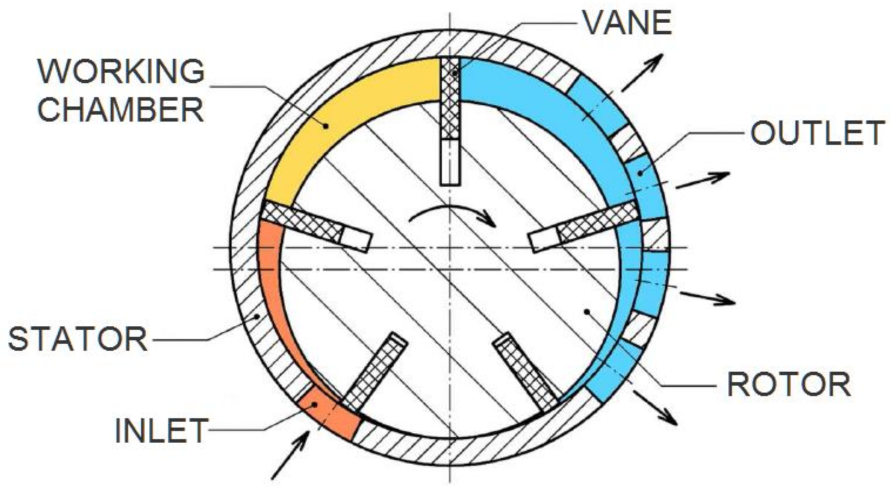
BACKGROUND & MOTIVATION

- Several experimental ORC units built and tested (WHR, CHP)
- Actually 50 kW_{th}/ 2 $kW_{e\ (nett)}$ biomass-fired CHP unit under development
- In all the cases rotary vane expander of own design was used



ROTARY VANE EXPANDERS – HOW DOES IT WORK & WHY WE USE IT

- Vanes are inserted in radial slots in the eccentrically placed rotor, creating expanding chambers for working fluid
- Selected as a potentially cost-efficient solution for 1-10 kW
- Suitable also for small series manufacturing
- Compared to scroll or screw simple machining, achievable tolerances
- Slightly lower efficiency potential due to leakages and friction losses (vane-wall)



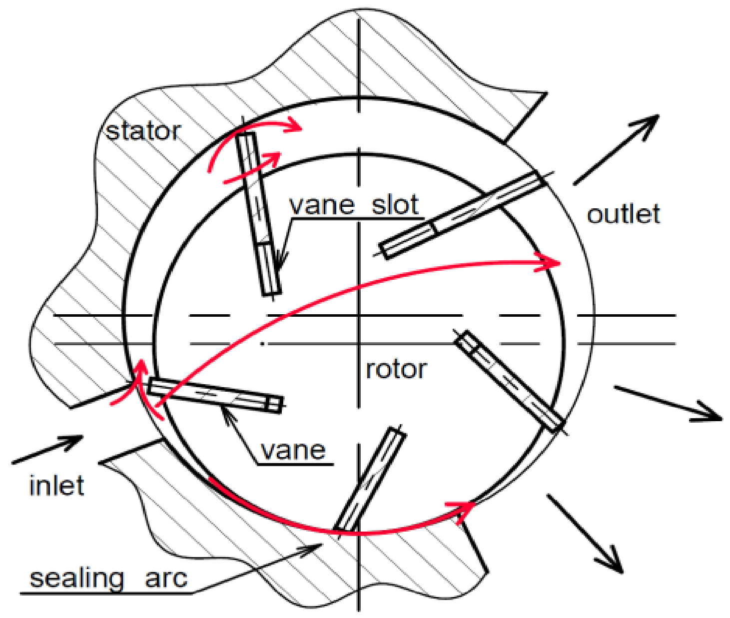
ROTARY VANE EXPANDERS – PERFORMANCE & EFFICIENCY

- Performance and isentropic efficiency affected by
  - Inbuilt volumetric ratio (under- and over-expansion losses)
  - Losses
    - Mechanical (mainly vanes friction, important but not analysed here)
    - Pressure losses (inlet and outlet ports)
    - Internal leakages
    - Electrical (common to all systems, not considered for this work)

LEAKAGES WITHIN ROTARY VANE EXPANDERS

- Strongly affect performance and overal efficiency of the RVE and a whole cycle – big issue
- Clearance between the rotor and the stator in a sealing arc area
- Clearance between the stator and the rotor faces
- Around the vane tips
- Around the vane sides
- Other negligible

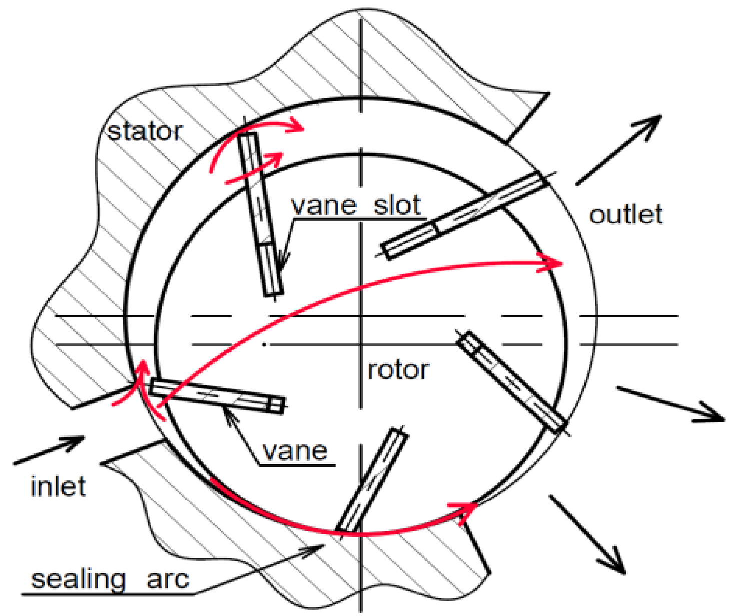
  -> similar leakage paths as in case of other volumetric expanders



LEAKAGES WITHIN ROTARY VANE EXPANDERS

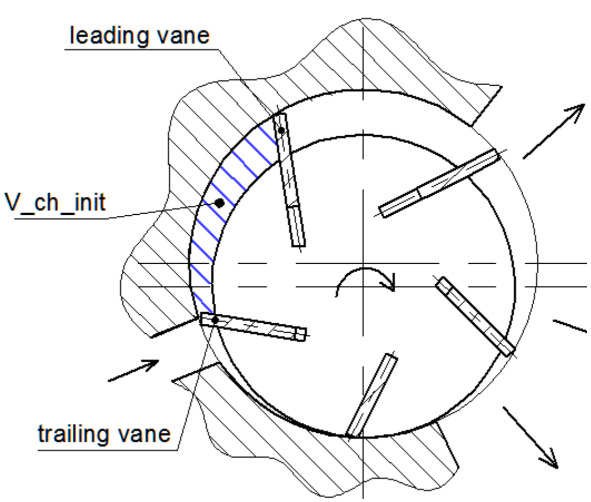
- Simple lumped leakage area model created, results compared to experimental data -> discrepancies between mass flow rate, filling factor and mechanical power output
  (large mass flow rate, large filling factor, higher power output than predicted)

Did we miss something? Probably yes..

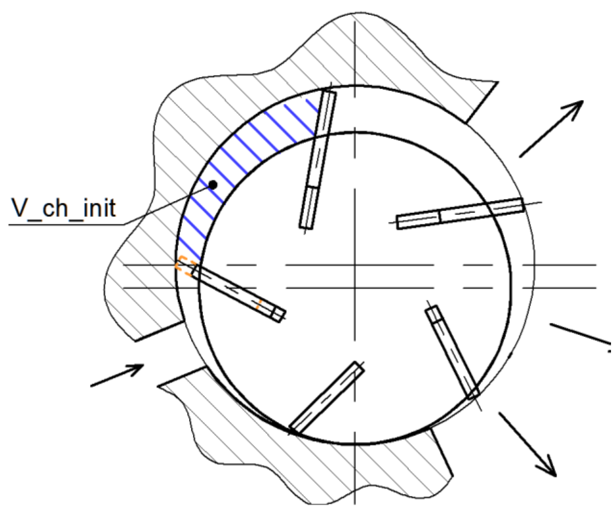


LEAKAGES WITHIN ROTARY VANE EXPANDERS

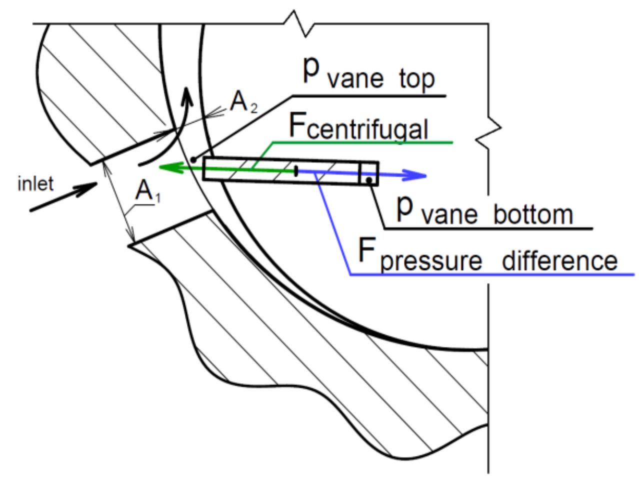
- Another „leakage“ **specific only for vane expanders** - around the tips of the vanes if there is **a poor or even no contact between the vane tip and stator surface** – at the end of the filling phase – trailing vane closes the chamber far beyond inlet port



Properly closed chamber



Later-closed chamber

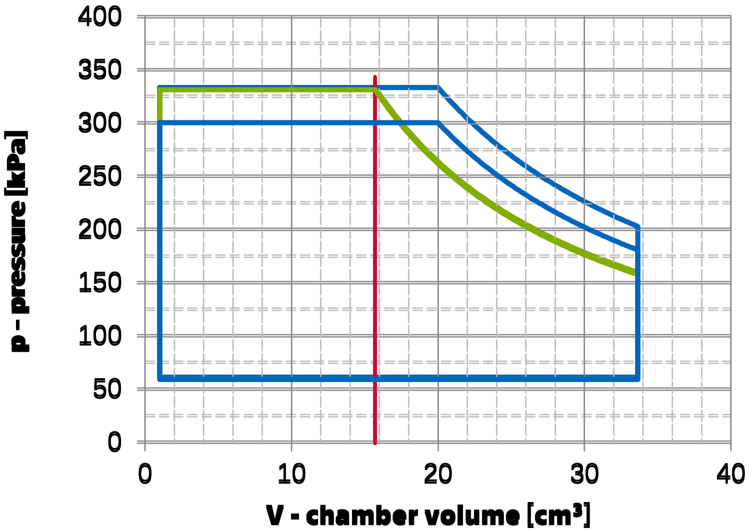


LEAKAGES WITHIN ROTARY VANE EXPANDERS

Consequences of delayed closure of a chamber (RVE only – constant inlet pressure):

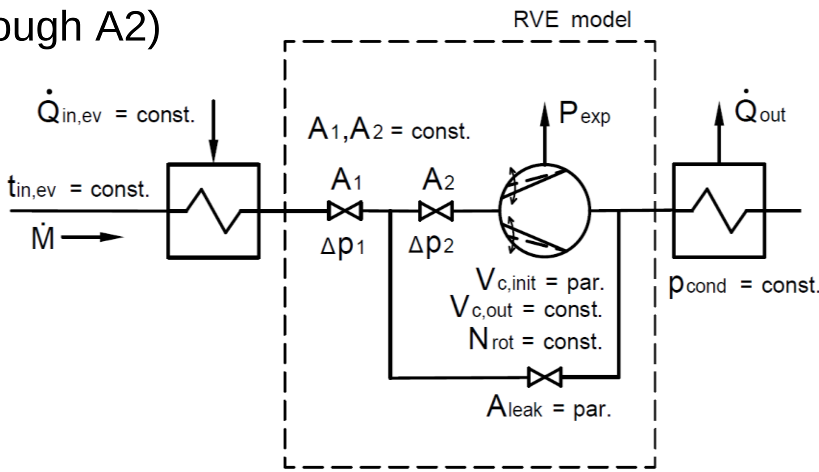
- Longer filling phase – larger initial volume of the chamber – larger mass flow rate, much larger filling factor
- Shorter expansion – „effective“ volumetric ratio (r_v) is lower than built-in r_v
- More work per revolution

BUT: generally, leakages can affect also the rest of the cycle, especially evaporator



TWO LEAKAGE PATHWAYS MODEL

- Needs to be considered including affecting of evaporator pressure
  - Constant heat input
  - Inlet steam controlled to constant 15 K superheat
  - Filling factor (leaks) affects mass flow rate and pressure
  - Condenser pressure kept constant
- Common inlet pressure drop (flow through A1)
- Constriction at chamber inlet (flow through A2)
- Bypass corresponds to lumped leakages (sealing arc, faces,...)
- Delayed chamber closure affects initial volume of the chamber and r_v respectively

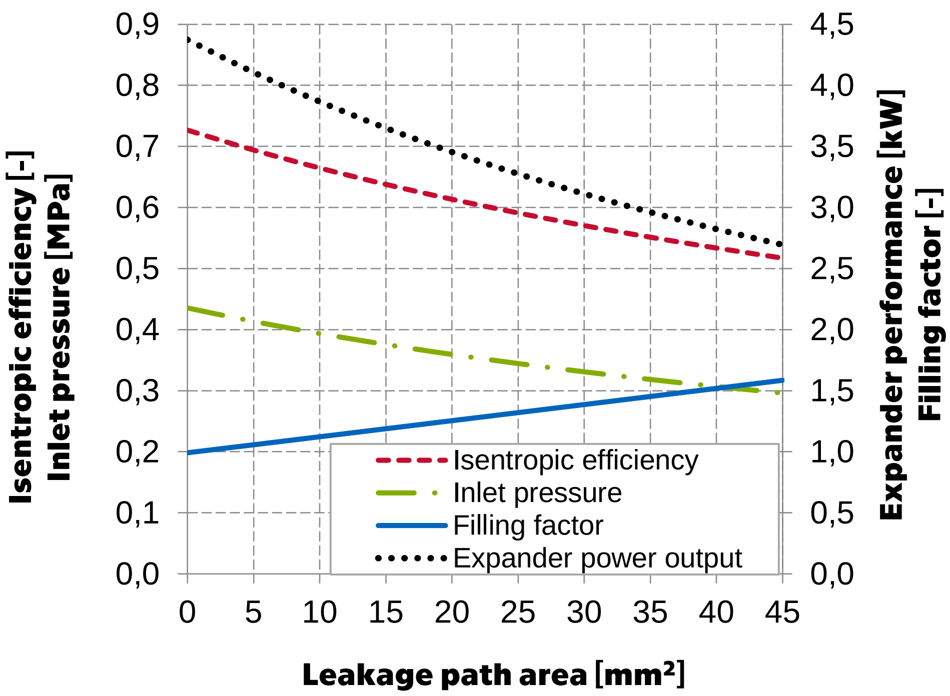


MODEL PARAMETERS

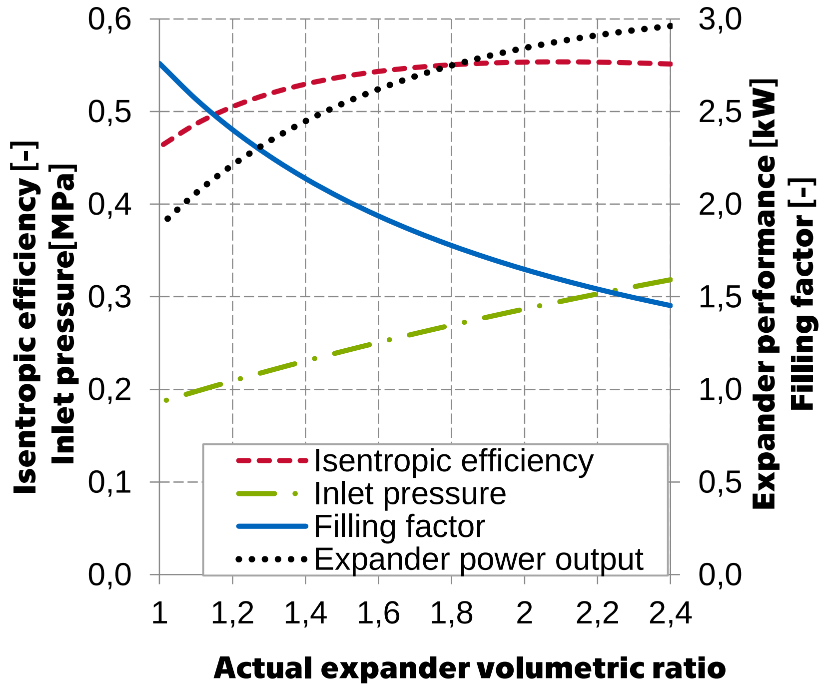
- Correspond to the experimental micro-ORC CHP unit
  - 50 kW evaporator input
  - Expander:

Parameter	Symbol	Value
Nominal initial chamber volume (cm^3)	$V_{c, init}$	15.7
Final chamber volume (cm^3)	$V_{c, out}$	37.7
Nominal volumetric ratio (-)	r_v	2.4
Number of vanes / working chambers (-)	c	8
Rotational speed (min^{-1})	N_{rot}	3000
Inlet manifold flow area (mm^2)	A_1	785
Chamber inlet flow area (mm^2)	A_2	375

MODEL RESULTS



Properly closed chambers,
leakage path area = variable



Later-closed chambers -
volumetric ratio = variable
Leakage path = 35mm^2 (const.)

MODEL RESULTS

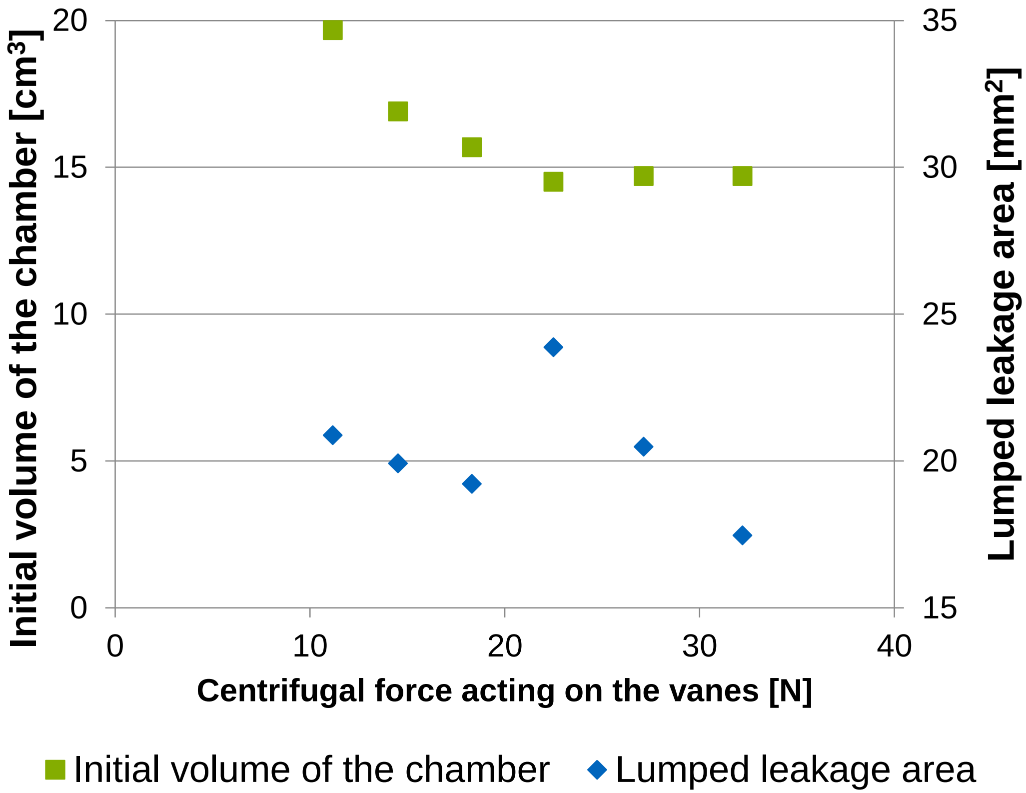
- Specific interesting cases
  - 1:ideal – without leakages
  - 2 - 3: same FF and ev. pressure, different power output
  - 3 - 4: same isentropic eff., different ev. pressure and power output!

	Case	A_{leak} [mm^2]	Effect. r_v [-]	$p_{in,exp}$ [kPa]	$\dot{M}$ [kg/s]	η_{is} [-]	FF [-]	P_{out} [kW]
	1	0	2.40	435.4	0.139	0.727	0.992	4.37
DCC	**2**	0	1.62	**318.3**	0,149	0.658	**1.453**	3.53
	3	35	2.40	**318.3**	0,149	**0.551**	**1.453**	2.96
DCC	**4**	35	1.82	271.1	0,155	**0.551**	1.763	2.76

DCC - Delayed chamber closure

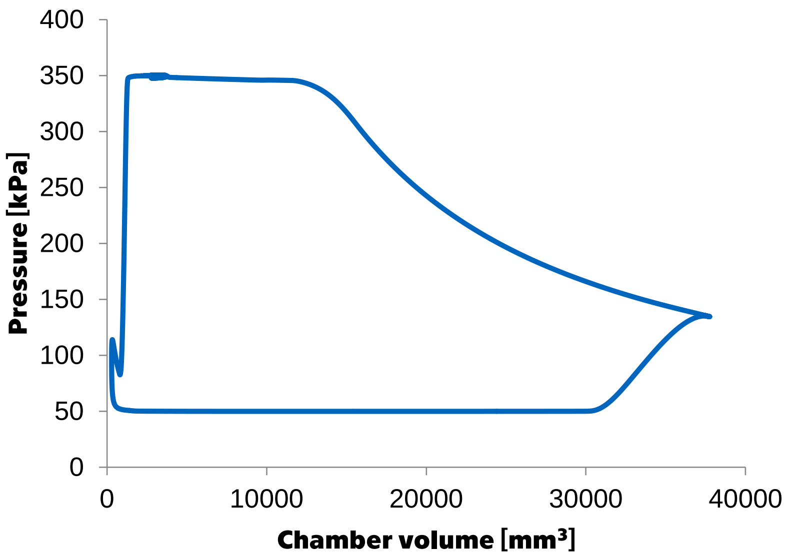
RELATION TO EXPERIMENTAL DATA – PRELIMINARY MODEL VERIFICATION

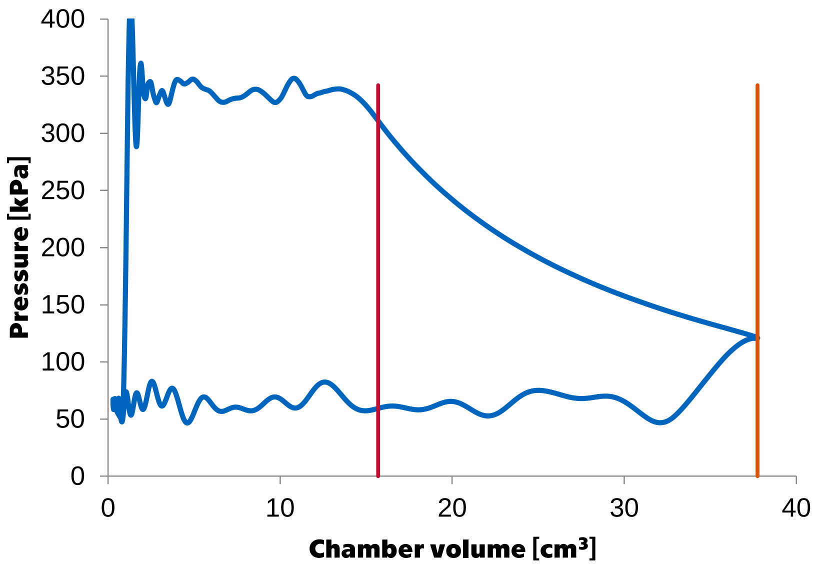
- Friction model had to be added, better chamber discharge model



FUTURE AND ONGOING WORK

- p-V diagram prediction, **separate leakage paths**, further validation with experimental data
- own model vs. GT Suite ® comparison





CONCLUSION

- Internal leakages within RVE can highly affect evaporation pressure -> isentropic efficiency only is not sufficient
- Potential vane-stator loss of contact need to be considered
  - Especially if: high filling factor, power output higher than expected
- Preliminary experimental data evaluation confirmed model suitability and problem with vane-stator loss of contact

Thank you for your attention!

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