KTH ROYAL INSTITUTE
OF TECHNOLOGY

Volumetric Expander in Heavy-Duty Waste Heat Recovery (WHR)

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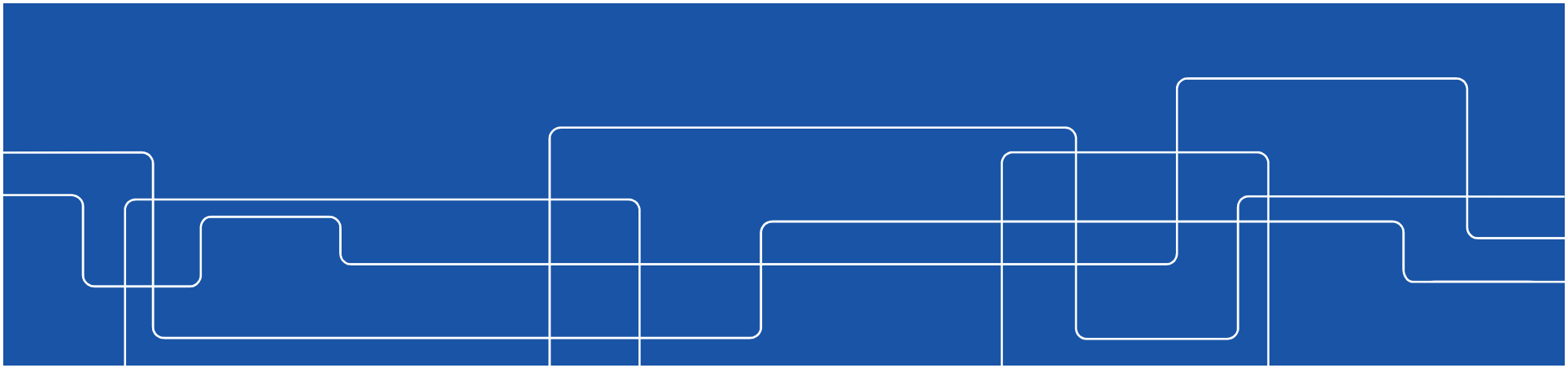
Supervisors: Prof. Anders C Erlandsson, Dr. Jens Fridh

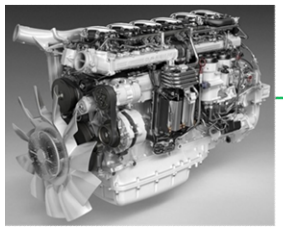
11.10.2018, CCGEx – Research Day

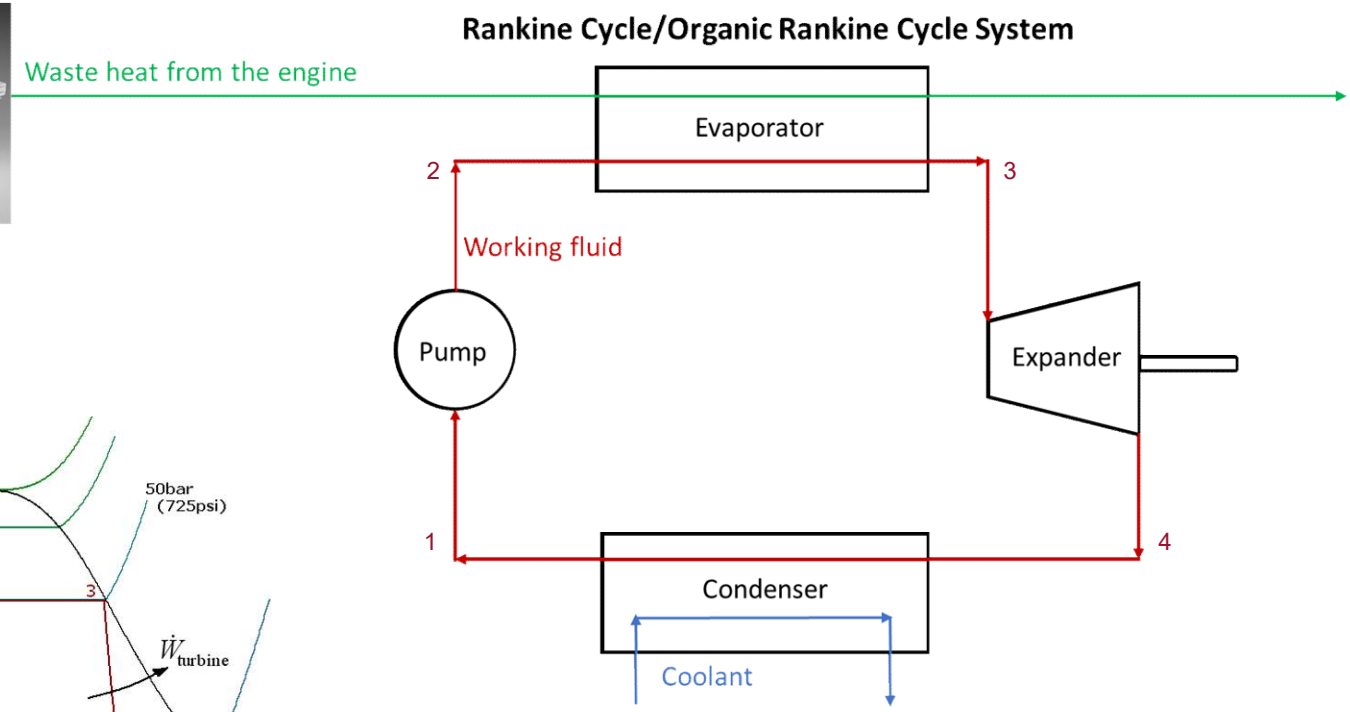


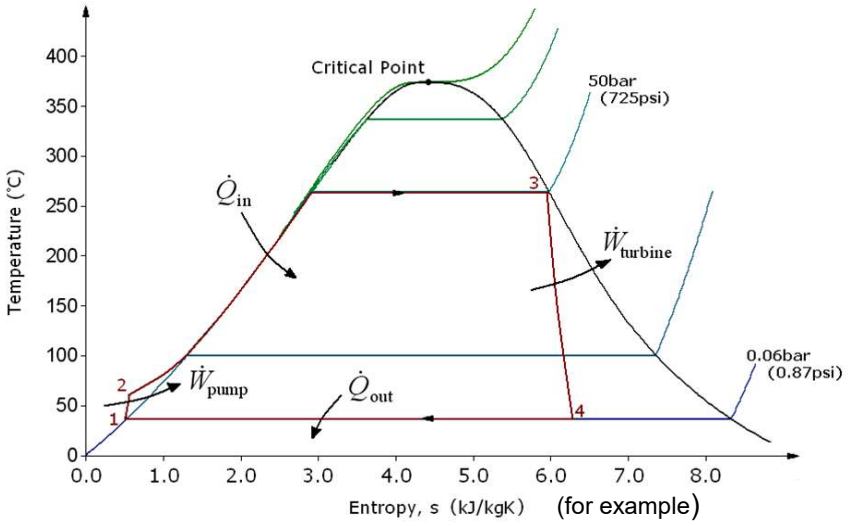
Contents

- Introduction
- Motivation
- Volumetric Expander
- Semi-empirical model
- Results
- Outcomes

WHR using Organic Rankine Cycle (ORC)

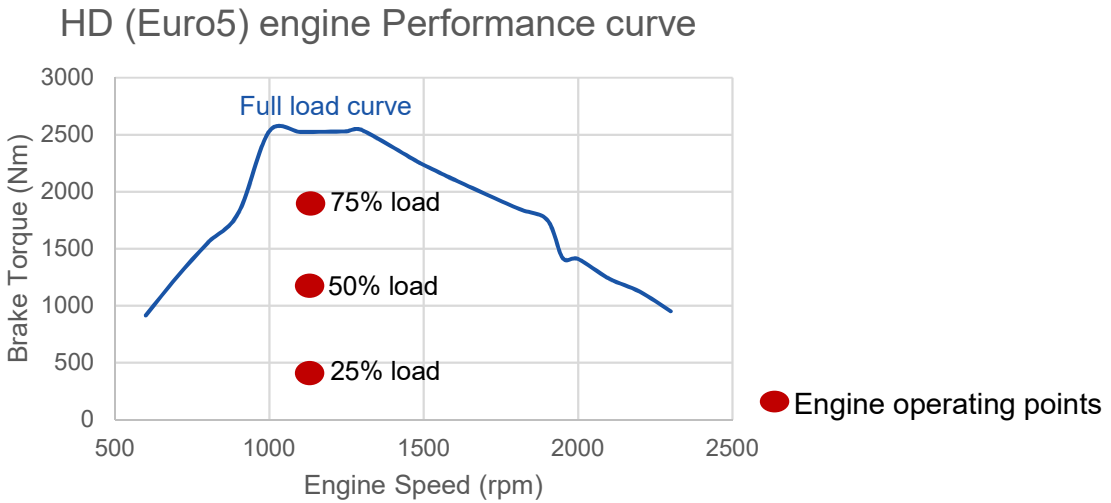






(for example)

Motivation



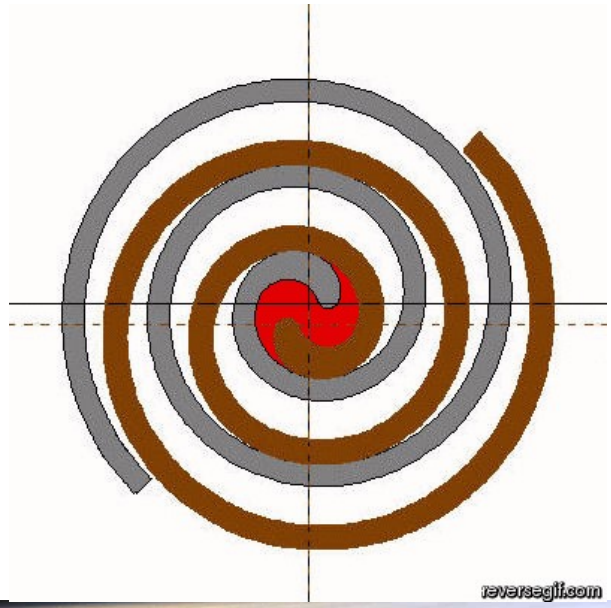
- Maximum heat recovery from the engine
  - At low- and mid-load engine operating points
  - From low temperature heat sources

- Role of Expanders is crucial
  - Identification of Expanders effective in low and medium temperature heat recovery

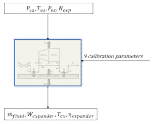
Volumetric Expander - Scroll Type

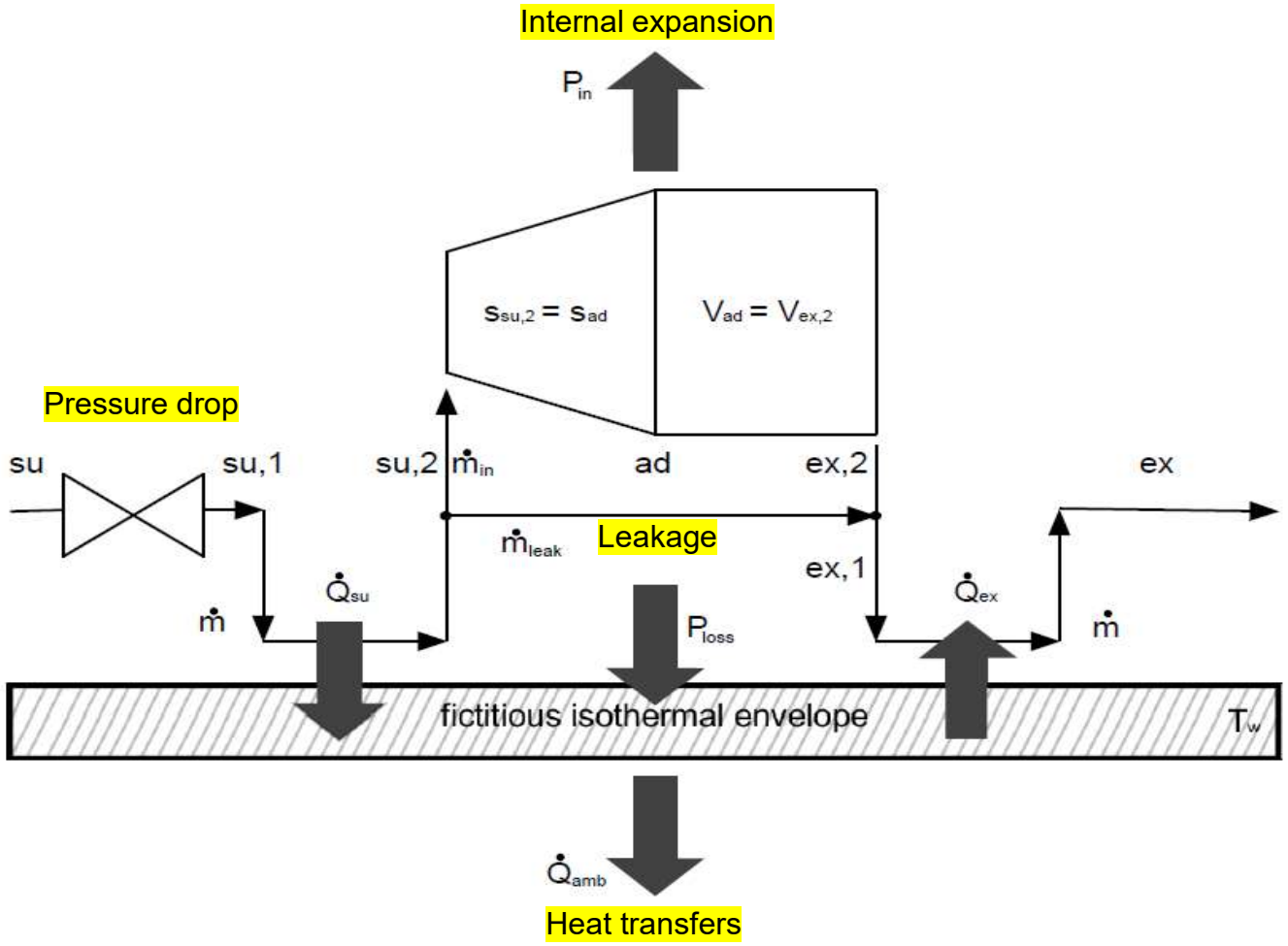
❑ Advantages

- Reduced number of moving parts
- Wide output Power range (1 – 10kW)
- Can tolerate wet expansion
- Can operate with/without lubrication
- Low rotational speeds
- Availability
- Not very heavy



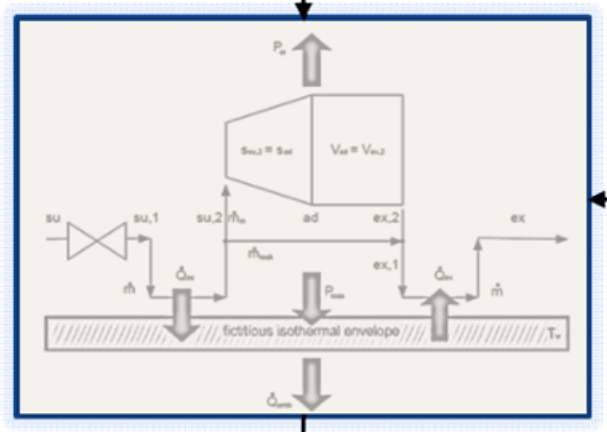
Semi-empirical Expander model (conceptual scheme)





Model Inputs and Outputs

$$P_{su}, T_{su}, P_{ex}, N_{exp}$$



9 calibration parameters

$$\dot{m}_{fluid}, \dot{W}_{expander}, T_{ex}, \eta_{expander}$$

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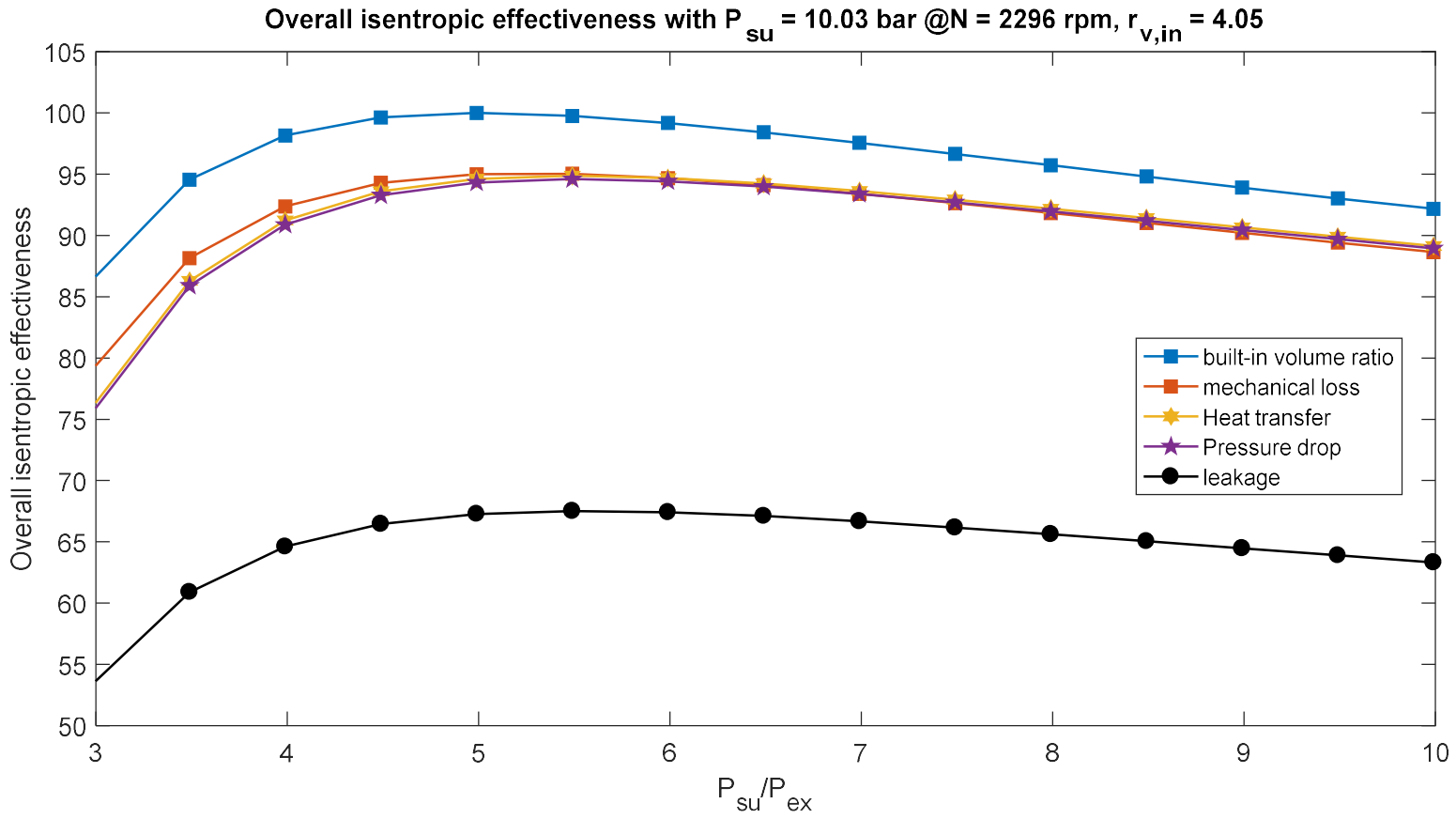
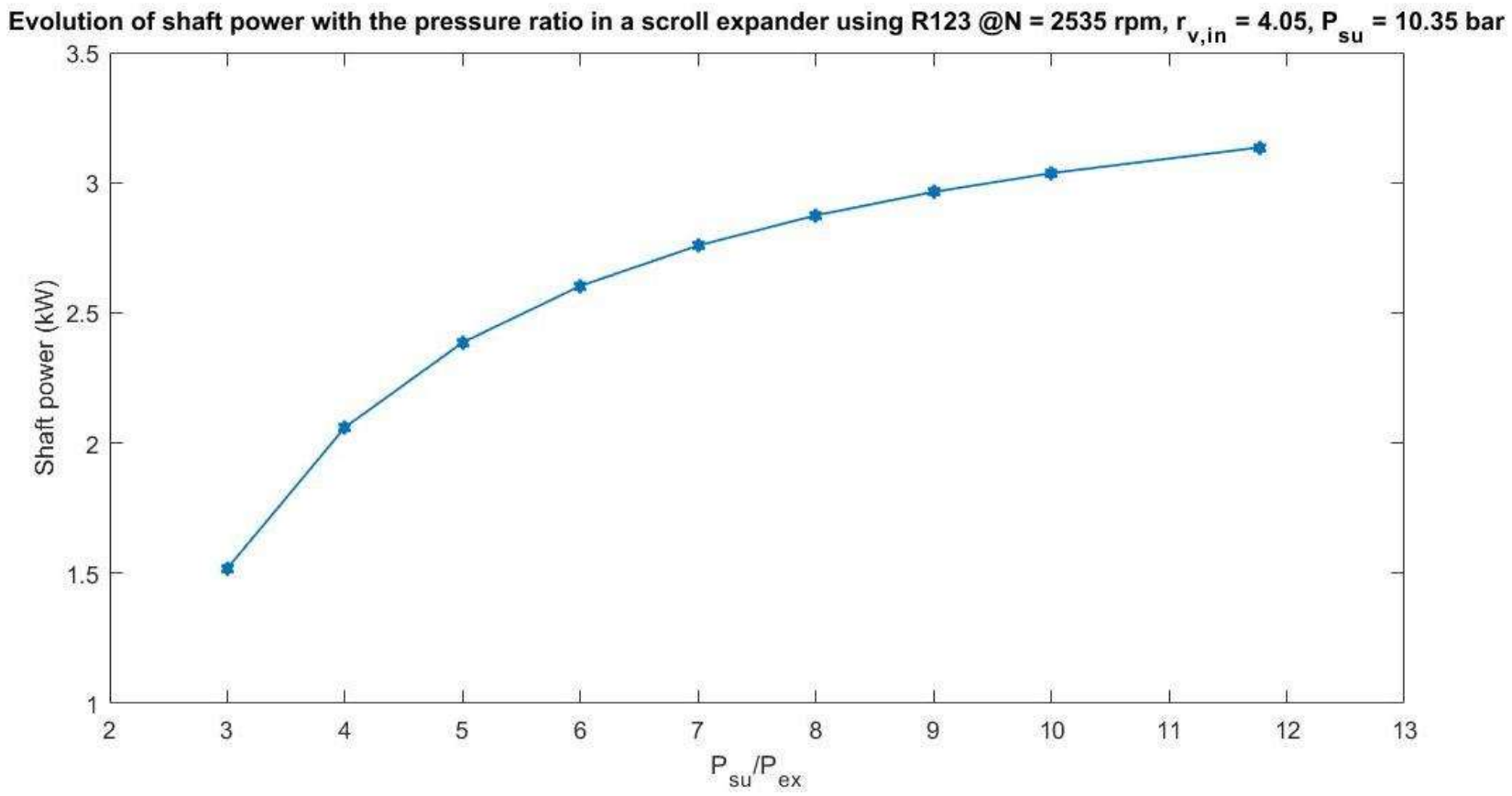
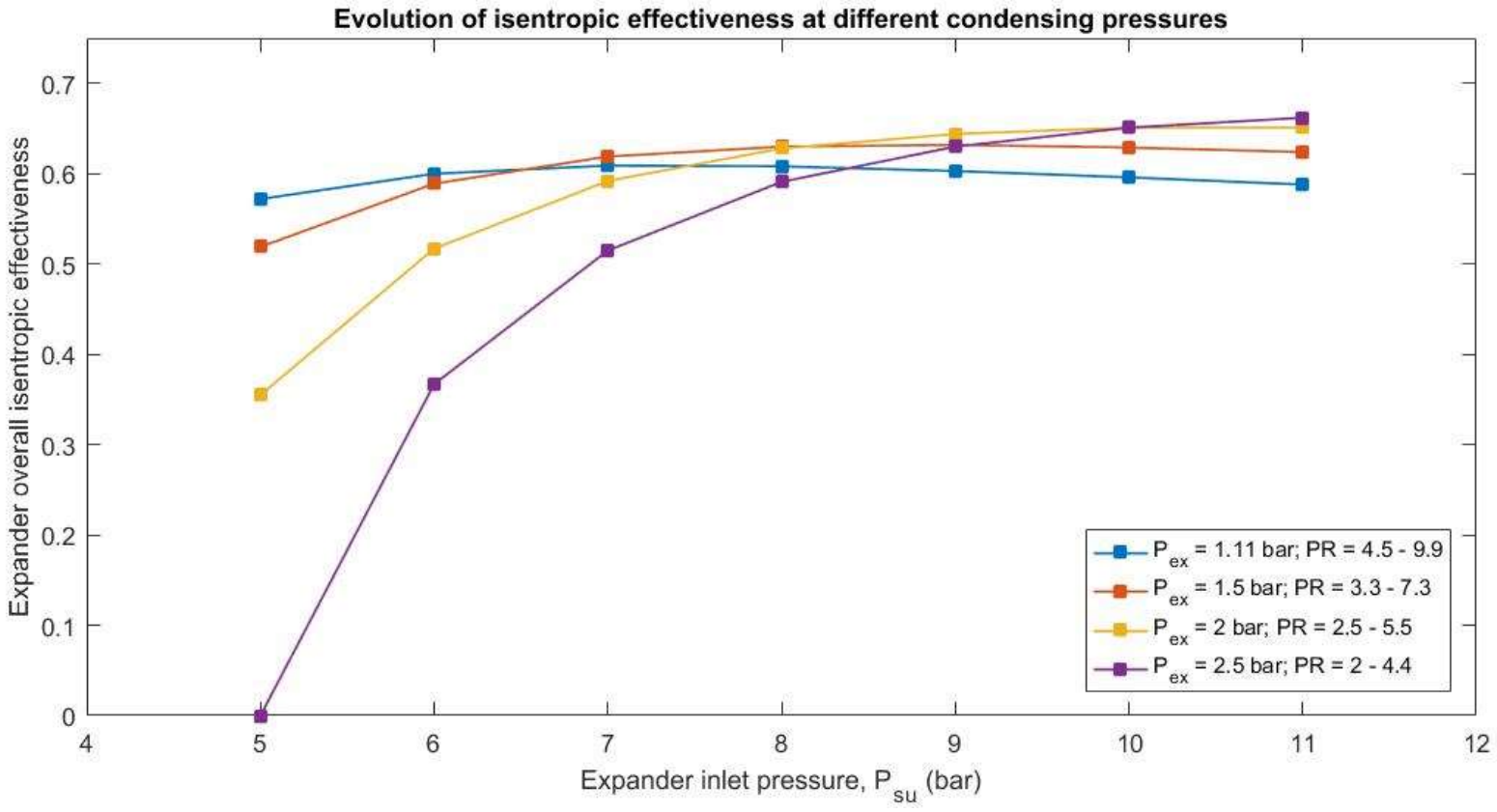
Performance of the Scroll Expander with R123



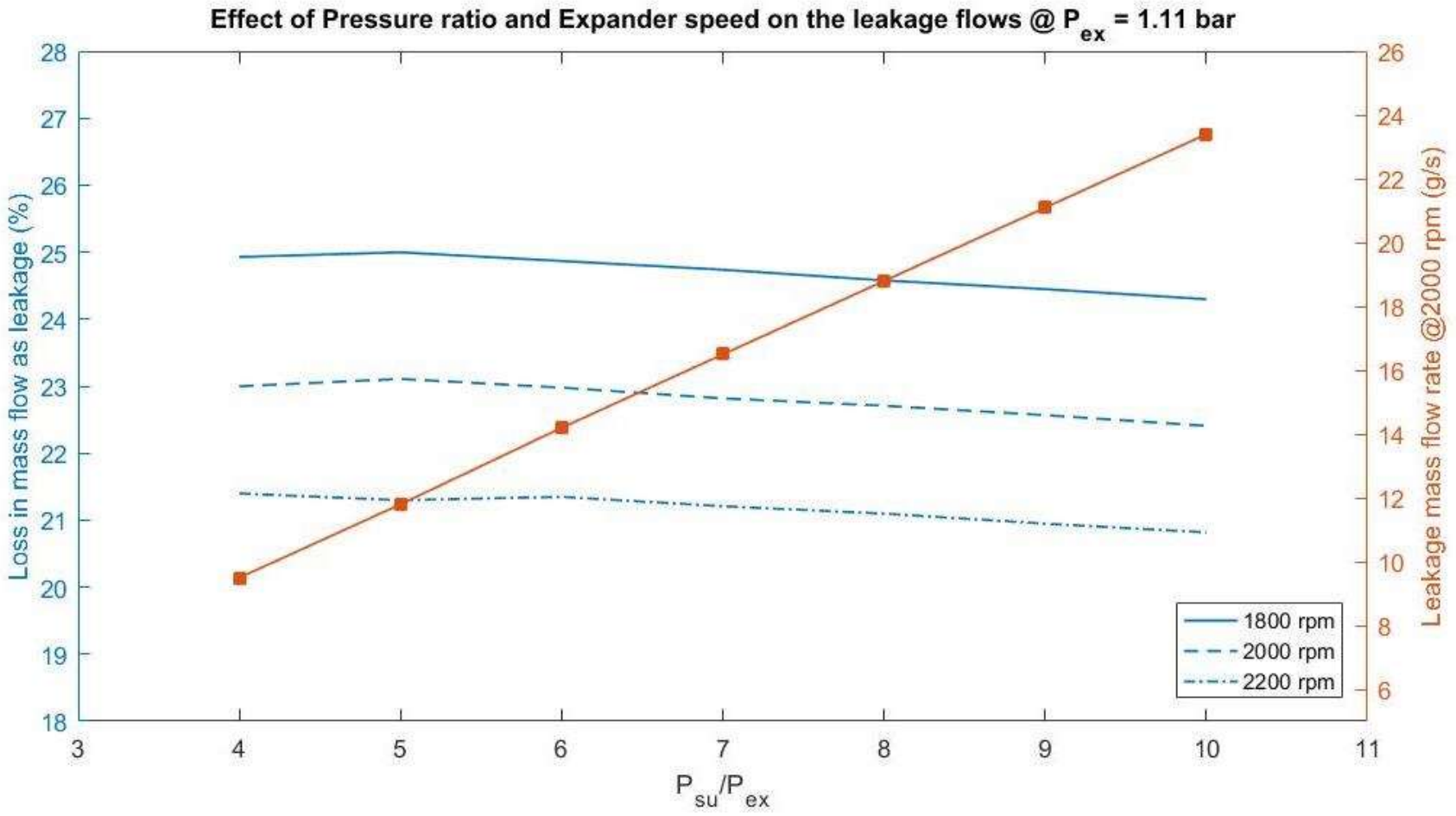
Power output from the Expander with R123



Expander efficiency at different condensing pressures



Leakage flows in the Scroll Expander



Outcomes

- Performance analysis of a Scroll Expander with working fluid R123
  - Semi-empirical model implemented in Matlab
  - Large leakage losses

- Challenges of implementation in Heavy-Duty Trucks
  - Scroll expander can be a potential choice
  - Waste heat to pre-heat, vaporise, superheat the working fluid
  - Very low condenser coolant temperatures required
  - Recuperator can improve the ORC system efficiency
  - R123 may not be suitable due to challenging condenser cooling requirements

Competence Center for Gas Exchange

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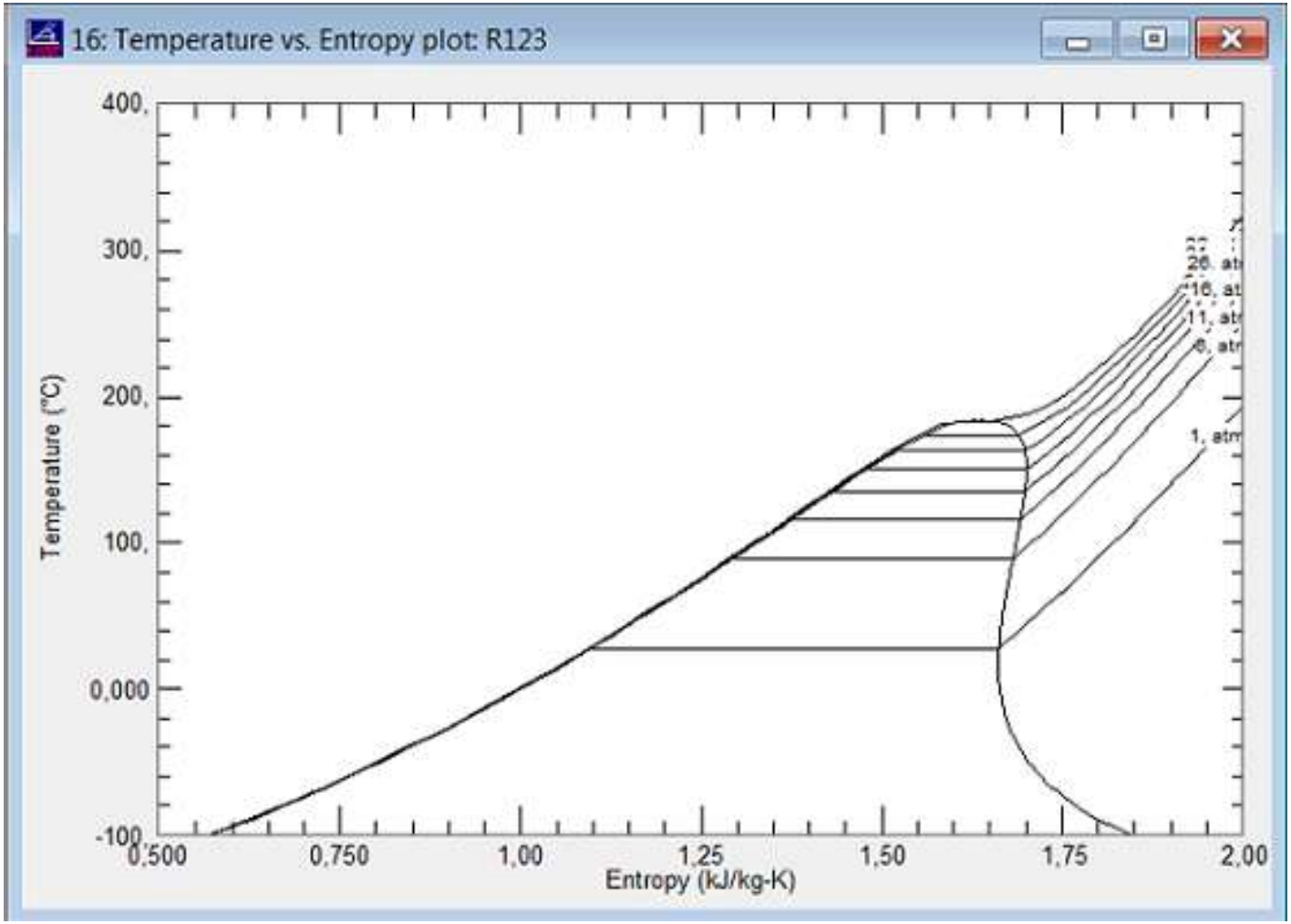
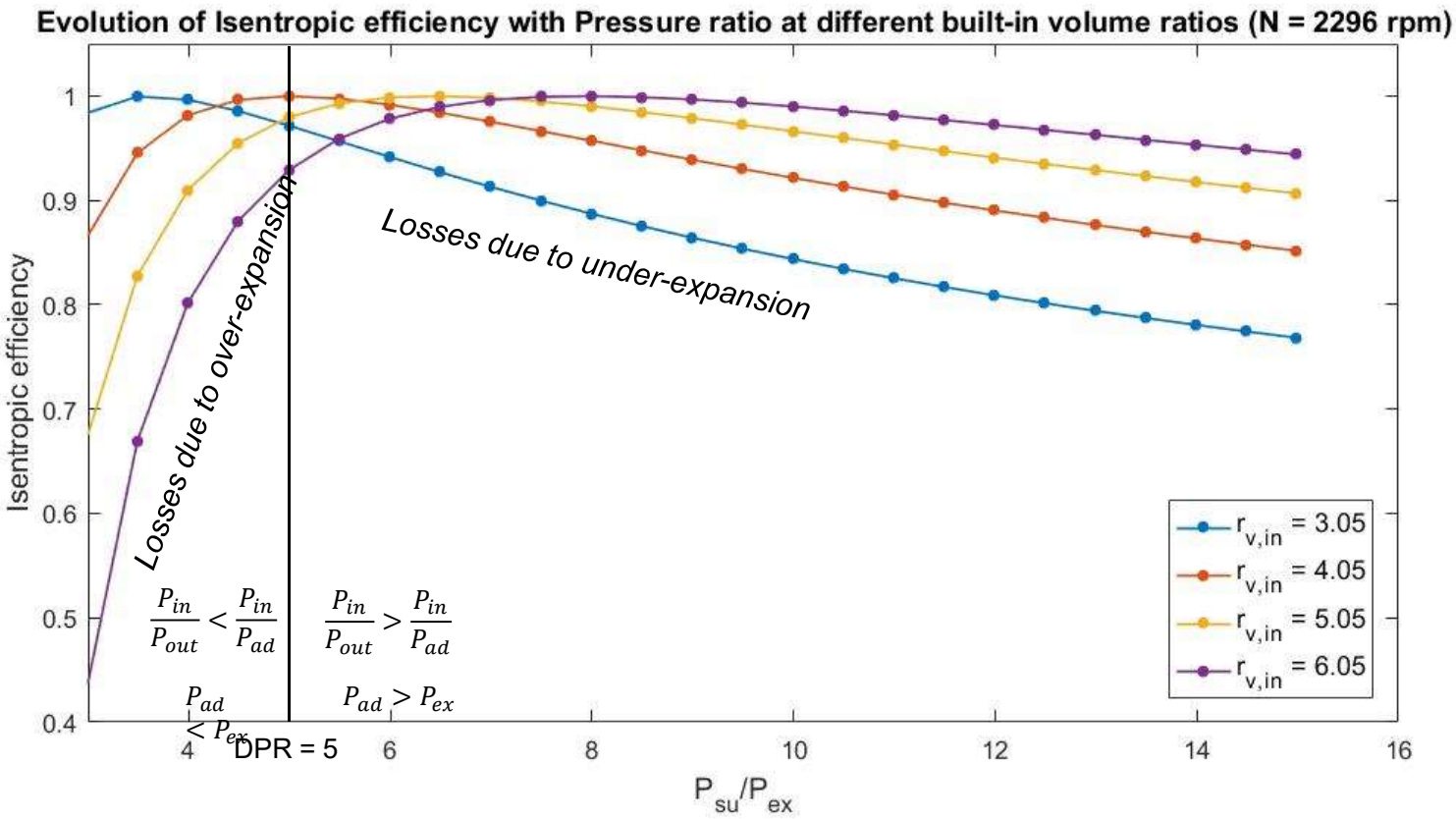
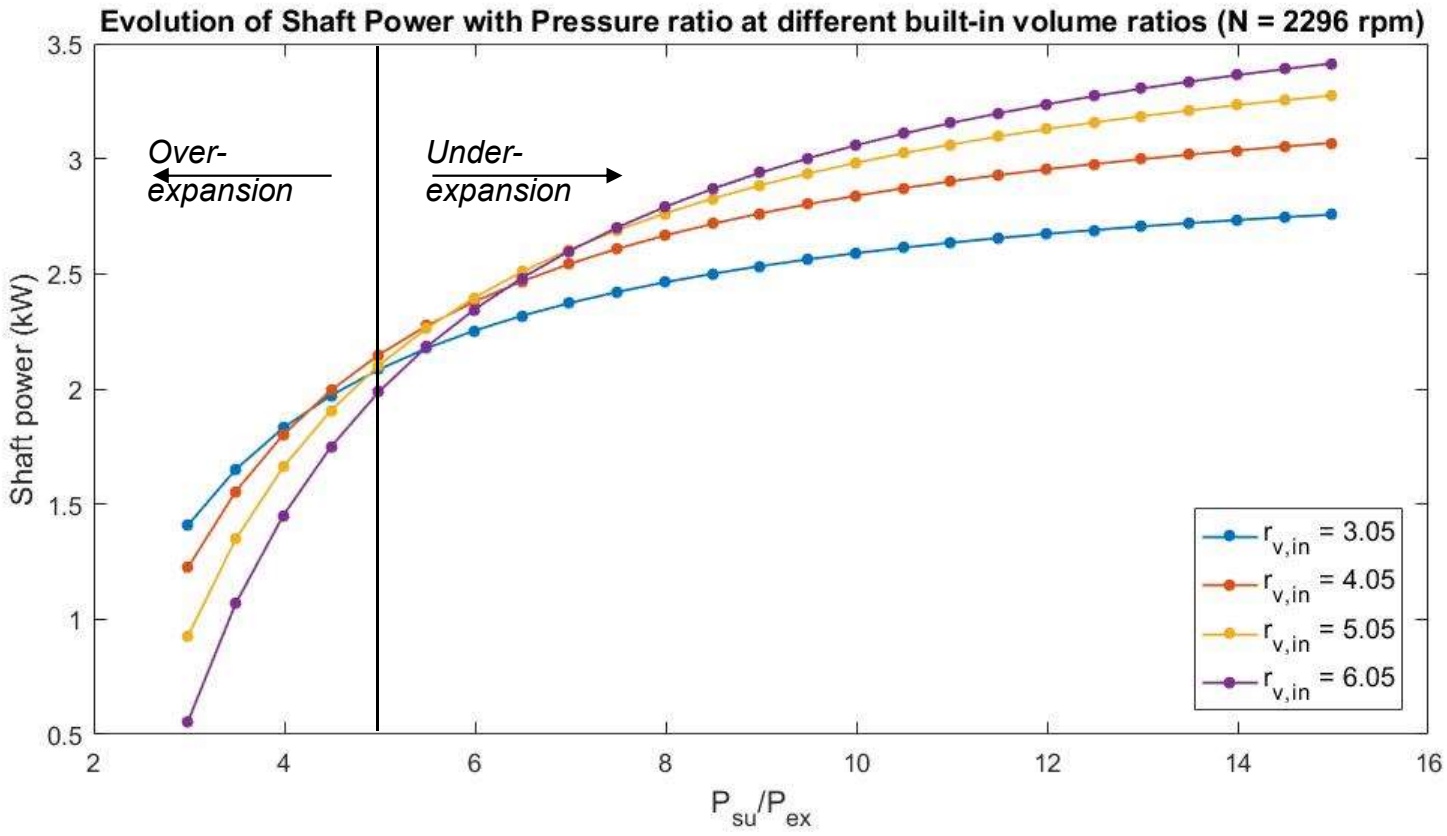
”Charging for the future”

Energimyndigheten SCANIA VOLVO VOLVO BorgWarner

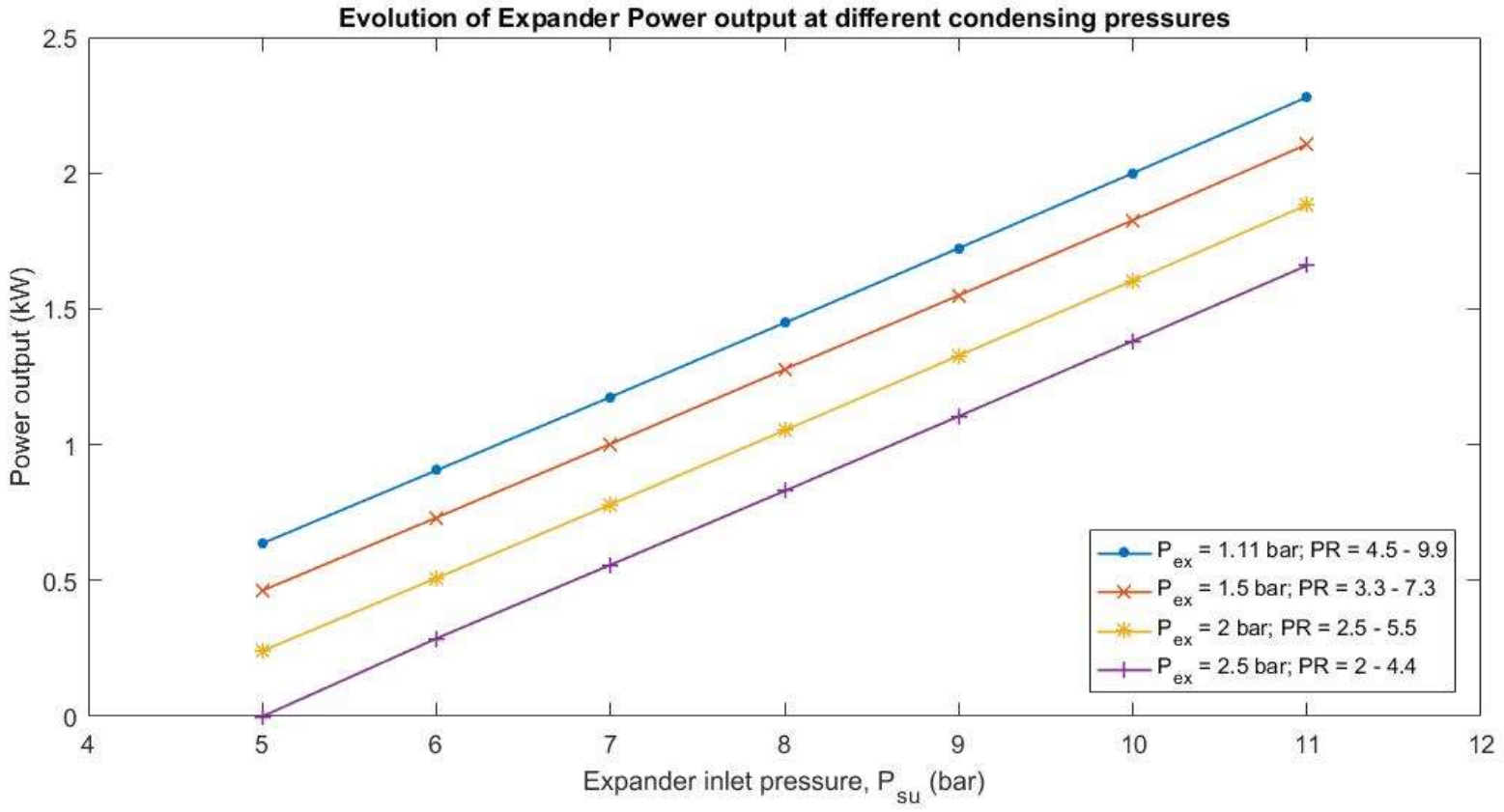
Temperature - Entropy diagram for R123



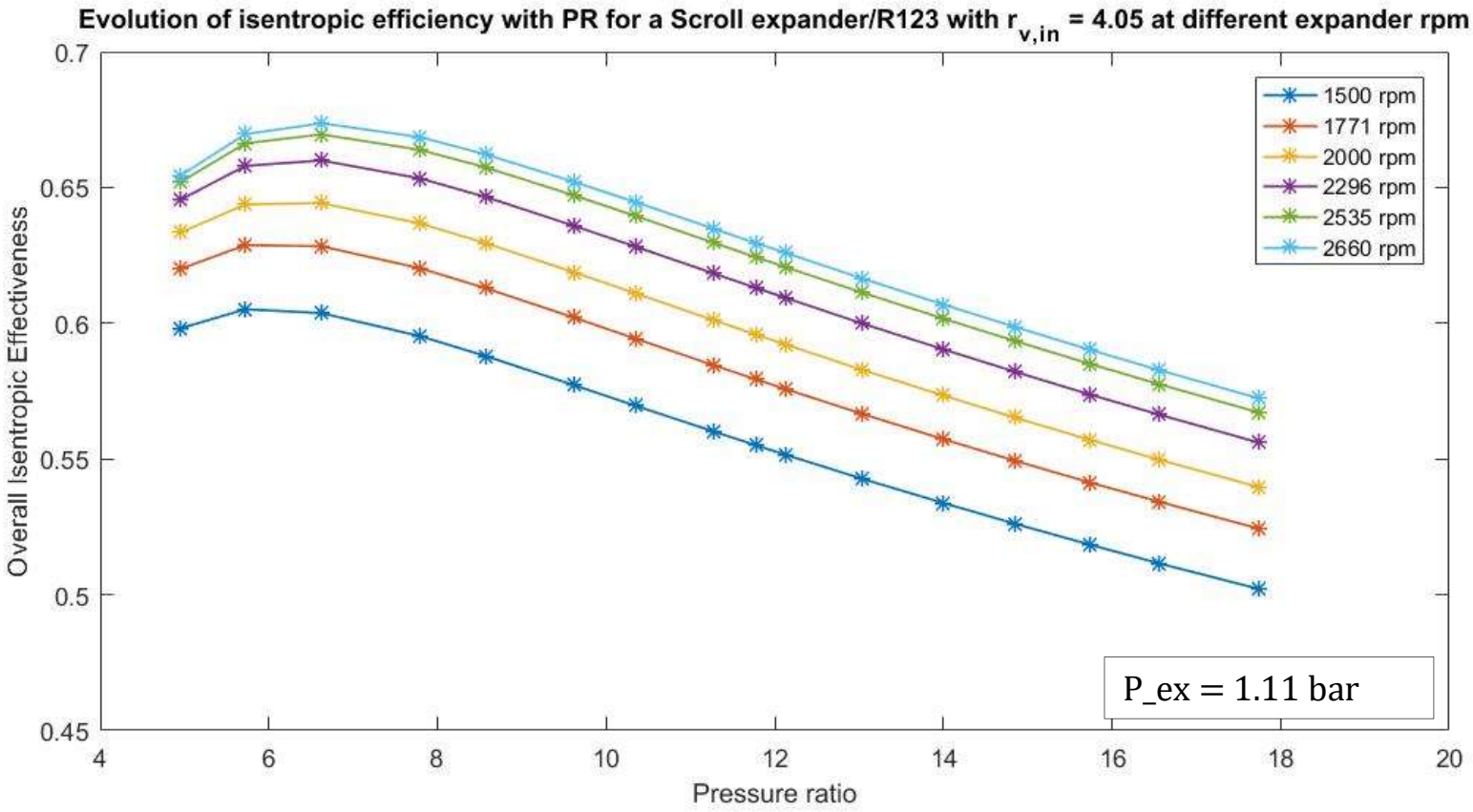

Evolution of Isentropic efficiency with Pressure ratio at different built-in volume ratios (N = 2296 rpm)
Isentropic efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
4
6
8
10
12
14
16
P_{su}/P_{ex}
Losses due to over-expansion
Losses due to under-expansion
$\frac{P_{in}}{P_{out}} < \frac{P_{in}}{P_{ad}}$
$\frac{P_{in}}{P_{out}} > \frac{P_{in}}{P_{ad}}$
$P_{ad} < P_{ex}$
$P_{ad} > P_{ex}$
DPR = 5
$r_{v,in}$ = 3.05
$r_{v,in}$ = 4.05
$r_{v,in}$ = 5.05
$r_{v,in}$ = 6.05


Evolution of Shaft Power with Pressure ratio at different built-in volume ratios (N = 2296 rpm)
Shaft power (kW)
3.5
3
2.5
2
1.5
1
0.5
2
4
6
8
10
12
14
16
P_{su}/P_{ex}
Over-expansion
Under-expansion
$r_{v,in}$ = 3.05
$r_{v,in}$ = 4.05
$r_{v,in}$ = 5.05
$r_{v,in}$ = 6.05

Power output at different condensing pressures



Efficiency at different Expander speeds



Expander efficiency & Power Output