Performance assessment of a standard radial turbine as turbo expander for an adapted solar concentration ORC

Michaël Deligant, Quentin Danel, Farid Bakir

DynFluid laboratory, Arts et Métiers ParisTech, Paris, FRANCE

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Summury

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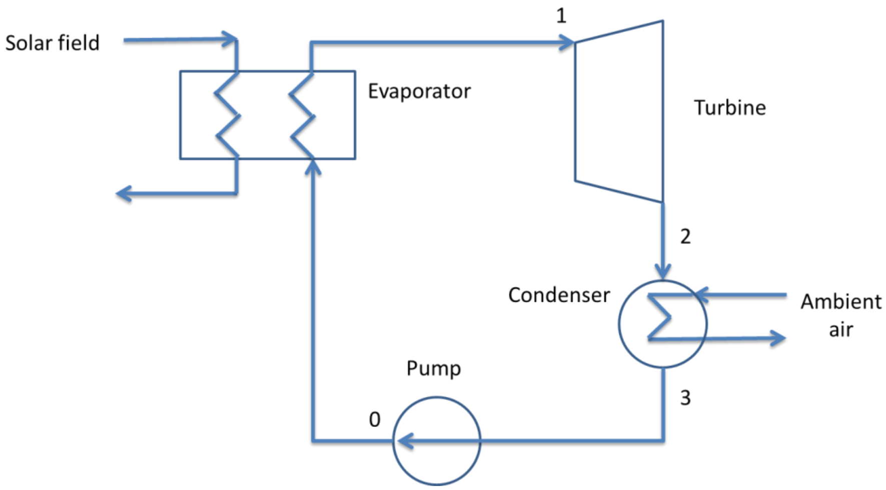
- Methodology
- Results & fluids comparison
- CFD model
- Conclusions & perspectives

Introduction

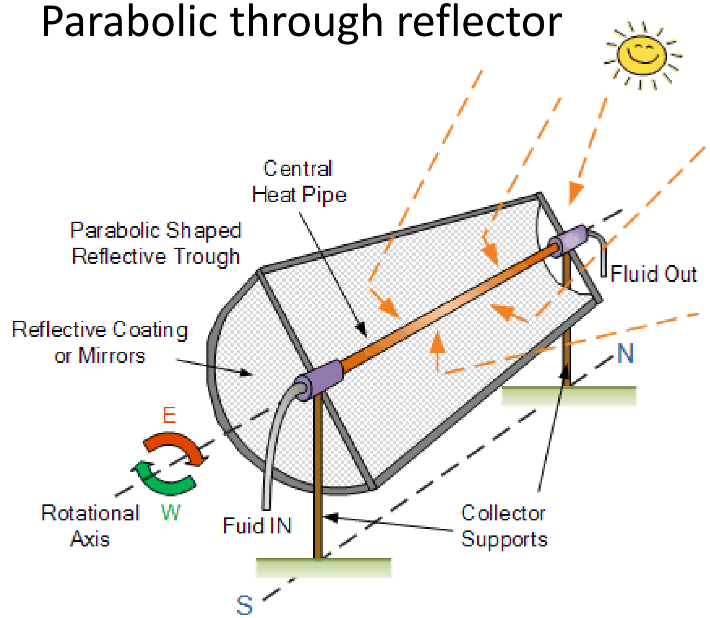
- ORC allow the conversion of low temperature thermal energy into electricity
- ORC system can be used with various heat sources (biomass, waste heat, CHP and solar)
- ORC systems are designed and adapted for each configuration of heat source and heat sink
- Expander can represent more than 50% of the cost of an ORC system
- Using standard expander might help reducing the cost of the ORC systems

Concentrated solar power

Simple solar ORC configuration



Parabolic through reflector



Source http://www.alternative-energy-tutorials.com

- Temperature depends on the concentration ratio
- Total power depends on total area of collectors

Aim of the study

For a given gas turbine with known performance map and detailed geometry

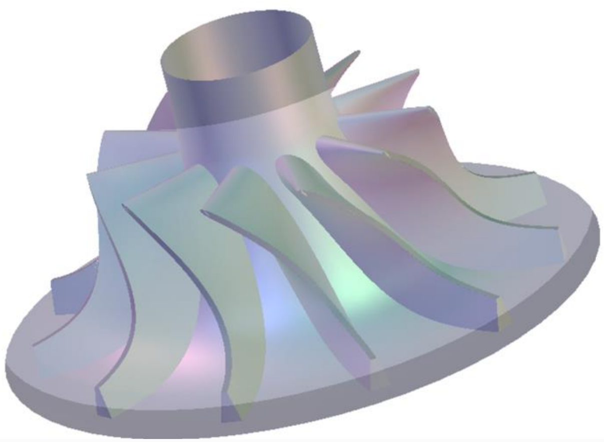
➔ What will be the operating conditions of a solar ORC system that will be adapted to use this turbine ?

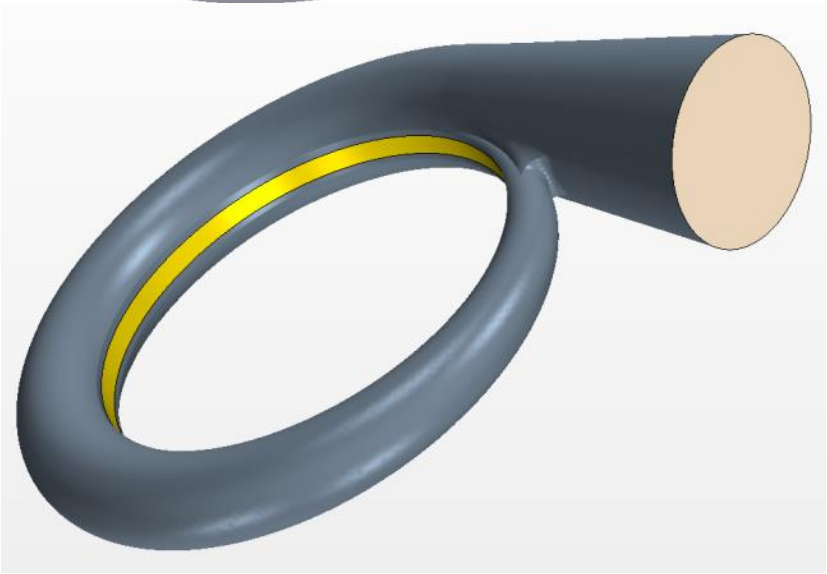
➔ For a given working fluid, what is the efficiency ?

Assumptions

- Heat sink: ambiant air 20 to 40°C
- Heat source: 90 to 250°C
- 5°C temperature difference
- 5°C subcooling

Turbine description





- Design point
  - qm=0.046 kg/s
  - P1= 3.2 bar
  - P2= 1 bar
  - T1=600°C
  - N=230,000 rpm
  - Output power 8.92 kW
  - $\eta = 78\%$
- Geometry
  - Inlet
    - radius 21.017
    - tip 2.538
  - Outlet
    - Hub radius 6.3 mm
    - Shroud radius 13.7 mm
    - tip 7.356 mm
  - 11 blades

Operating point adaptation

- Similitude parameters
  - $M_1 = 0.87$
  - Density ratio $\Gamma = \frac{\rho_0}{\rho_2} = 2.542$
  - Efficiency $\eta_{is} = 78\%$

Starting from P_{0fluid} and T_{0fluid}

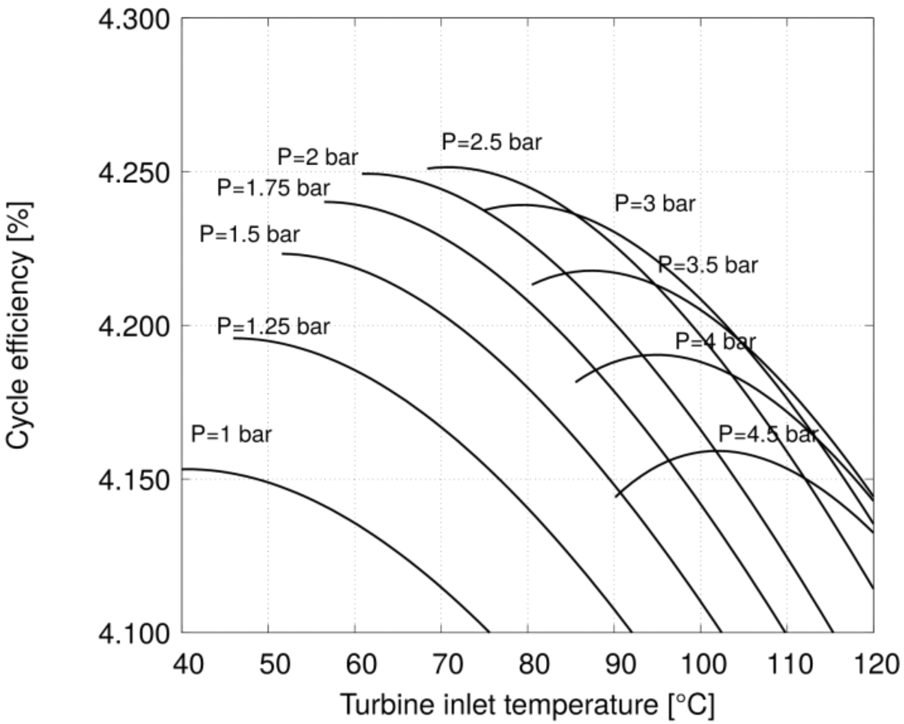
1. Compute a_{0fluid} , ρ_{0fluid} and h_{0fluid}
2. Compute $N_{fluid} = a_{0fluid}/a_{0air}\ N_{air}$
3. Compute $U_{1fluid} = R_1\ N_{fluid}\ \frac{\pi}{30}$
4. Compute $\Delta h_{is\ fluid} = -U_{1fluid}^2$
5. Compute $h_{2fluid} = h_{0fluid} + \Delta h_{is\ fluid}\ \eta_{is}$
6. Compute $\rho_{2fluid} = \rho_0/\Gamma$
7. Compute P_{2fluid} , T_{2fluid}
8. Compute $\dot{m}_{fluid} = \dot{m}_{air} \frac{\rho_{0fluid}}{\rho_{0air}} \frac{N_{fluid}}{N_{air}}$

The obtained parameters are then used to compute the cycle thermal efficiency

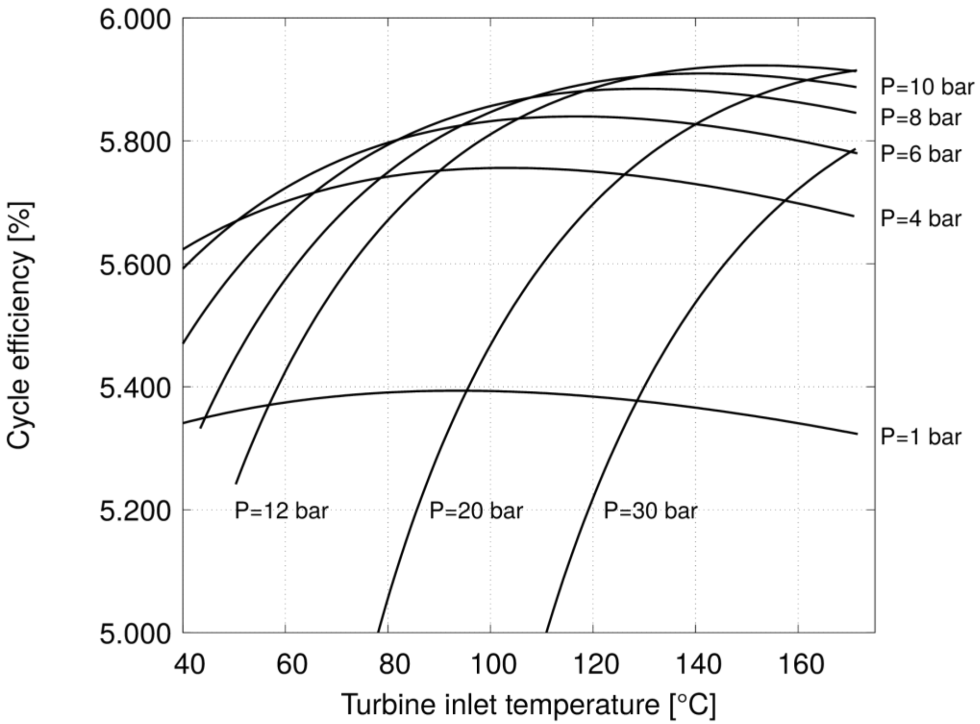
$$\eta_{cycle} = \frac{\mathscr{P}_{turbine\ fluid} - \mathscr{P}_{pump\ fluid}}{\mathscr{P}_{thermal\ fluid}} = \frac{\dot{m}_{fluid}(h_{0fluid} - h_{2fluid}) - \dot{m}_{fluid}/\rho_{0fluid}(P_{4fluid} - P_{3fluid})}{\dot{m}_{fluid}(h_{0fluid} - h_{4fluid})}$$

Results

SES36

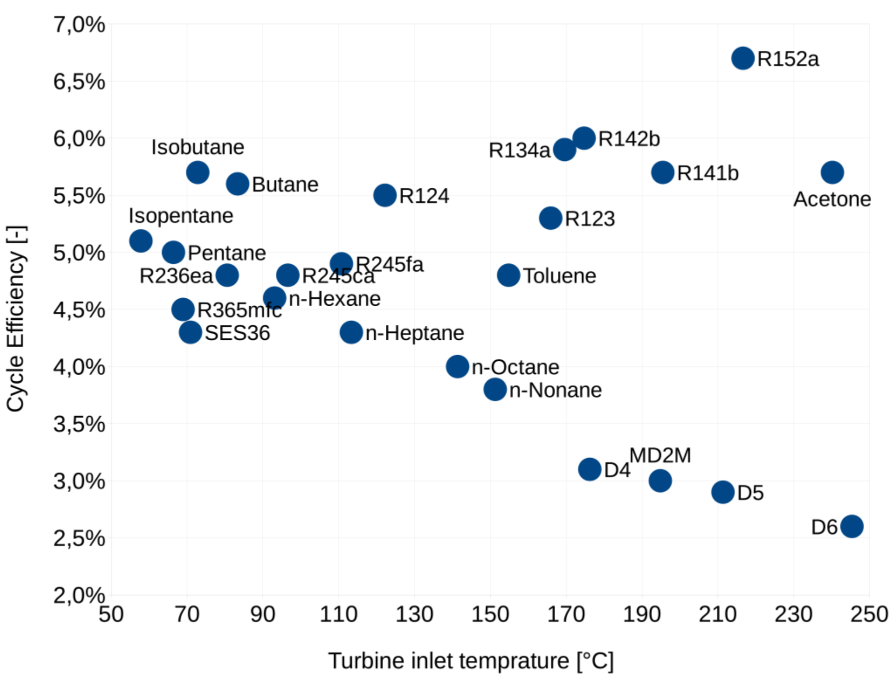


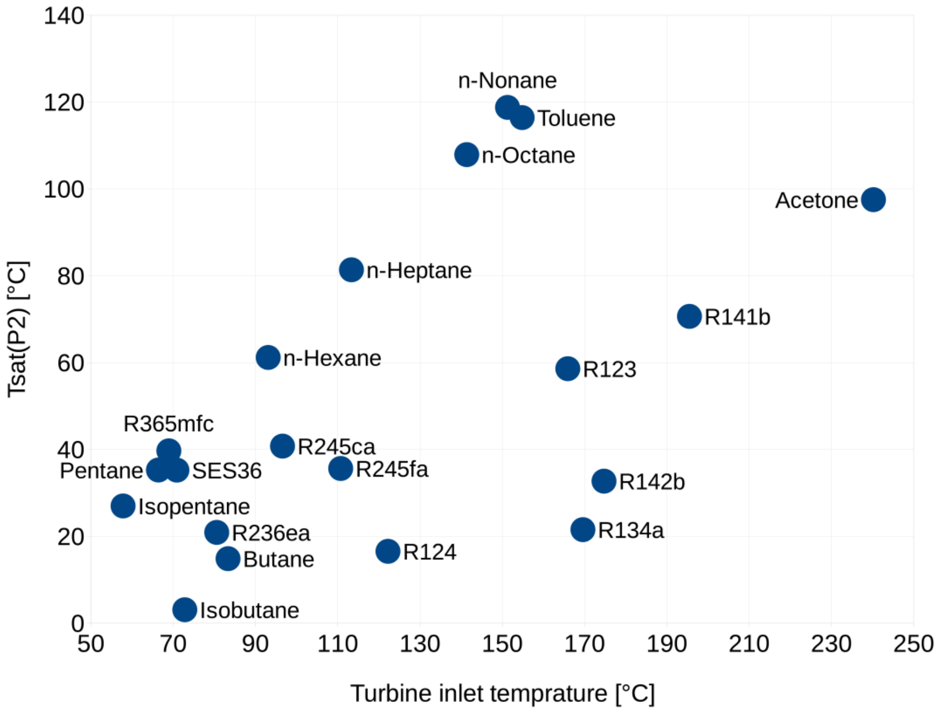
R134a



Comparison of fluids

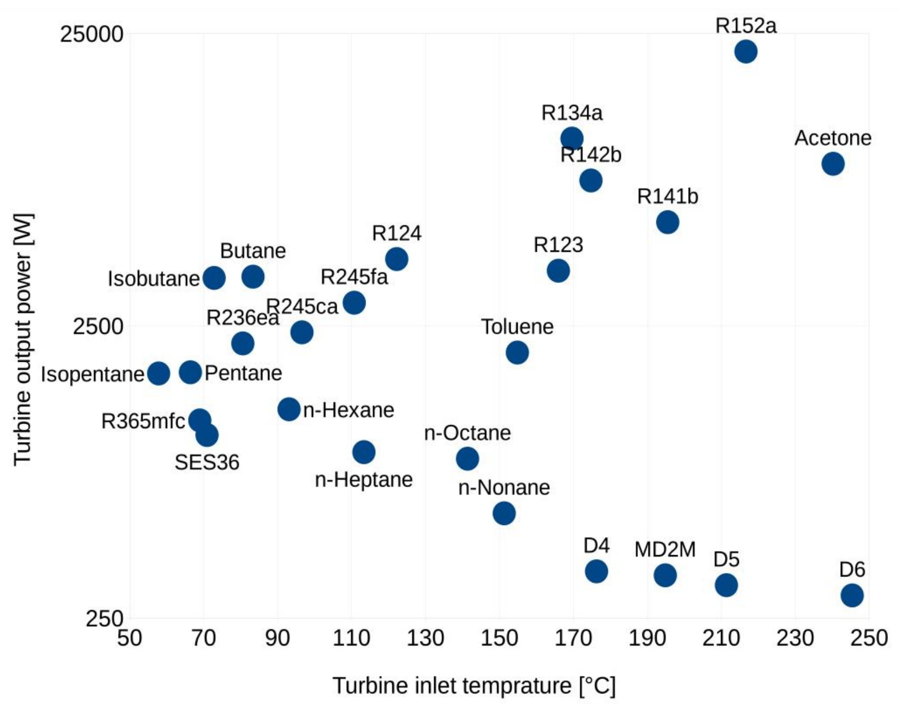
- Best efficiency vs. temperature
- Tsat(P2) vs. temperature



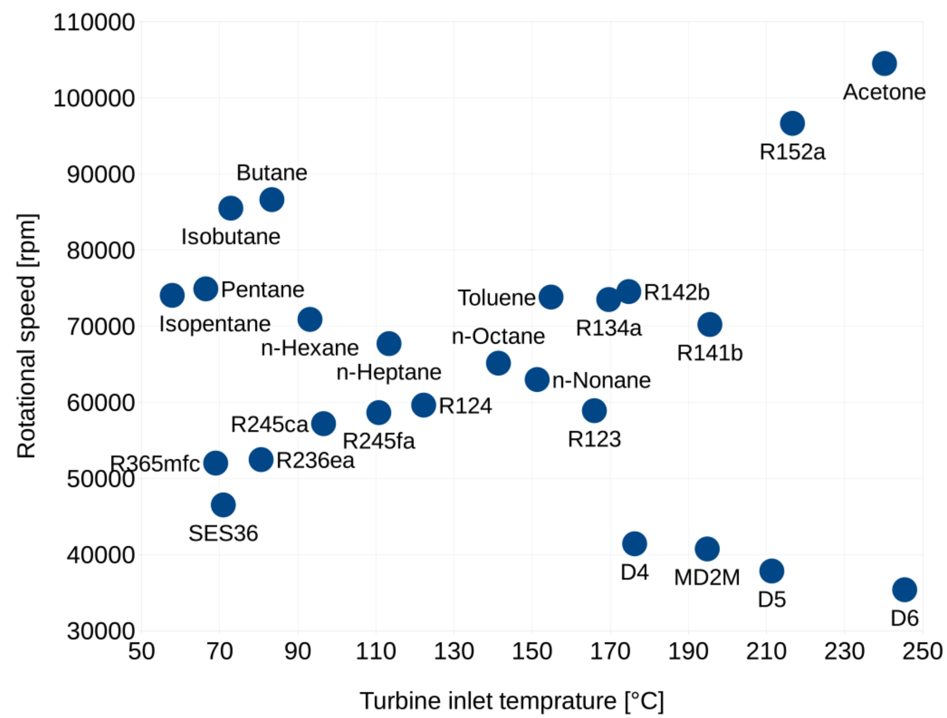


Comparison of fluids

- Output power vs. temperature

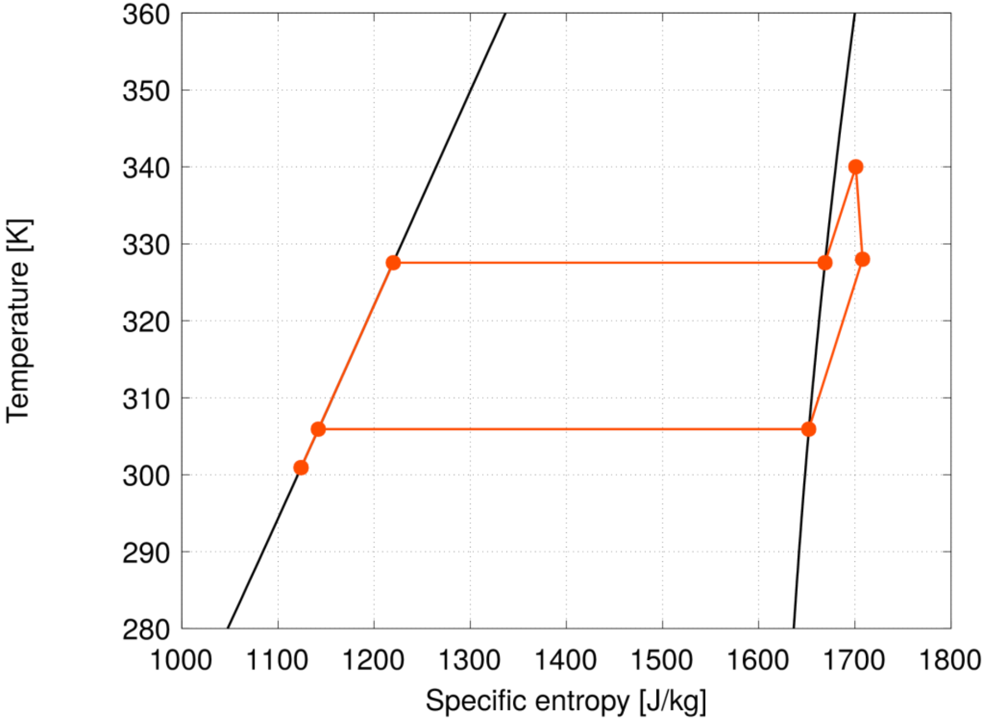


- Rotational speed rate vs. temperature



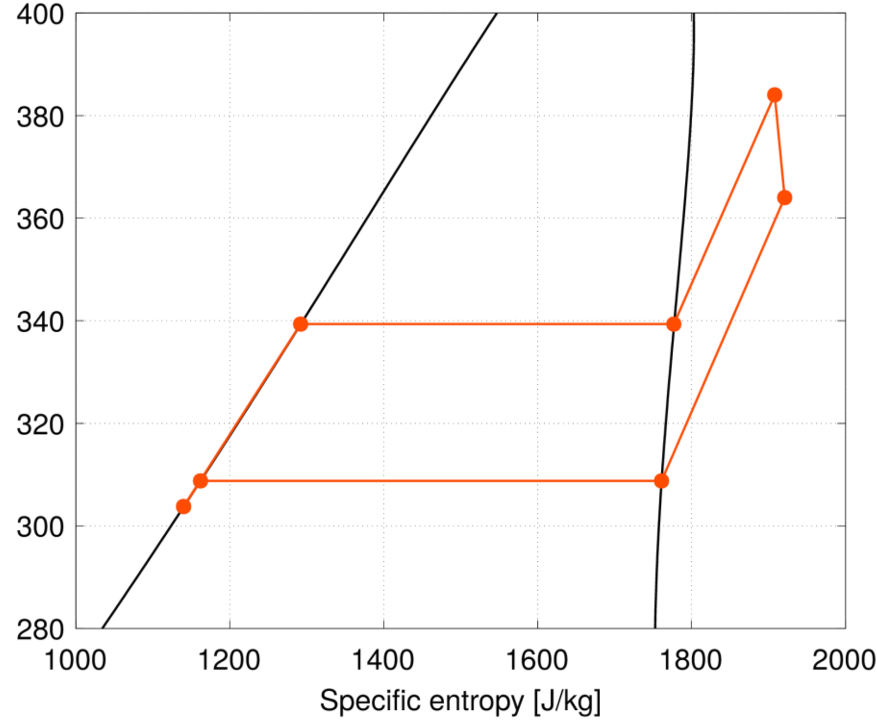
Results

SES36



- Thermal efficiency 4.3%
- Inlet temperature 70.9°C
- Output power 1.0 kW
- Rotational speed 46,519 rpm.

R245fa

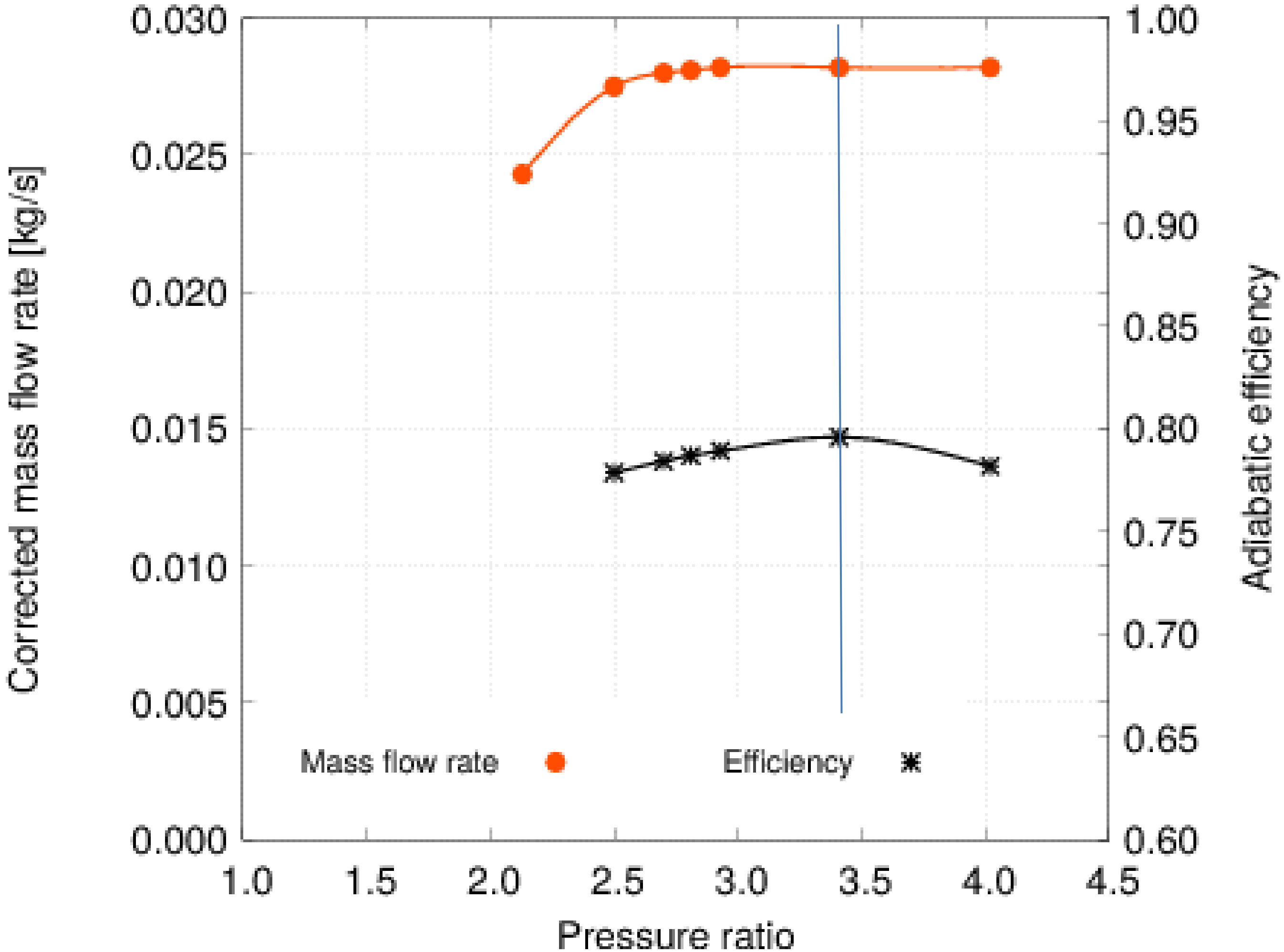


- Thermal efficiency 4.9%
- Inlet temperature 110.7°C
- Output power 3.0 kW
- Rotational speed 58,645 rpm

CFD model

- CD-Adapco StarCCM+
- Steady state
- Frozen rotor
- Mixing plane interface
- Standard k-ε model
- Mesh
  - 202,736 polyhedral cells
  - 735,095 polyhedral cells
- Boundary conditions
  - Mass flow inlet
  - Pressure outlet (fixed)
- EOS
  - Ideal gas for air
  - Peng-Robinson for SES36 and R245fa

Turbine performance map with air

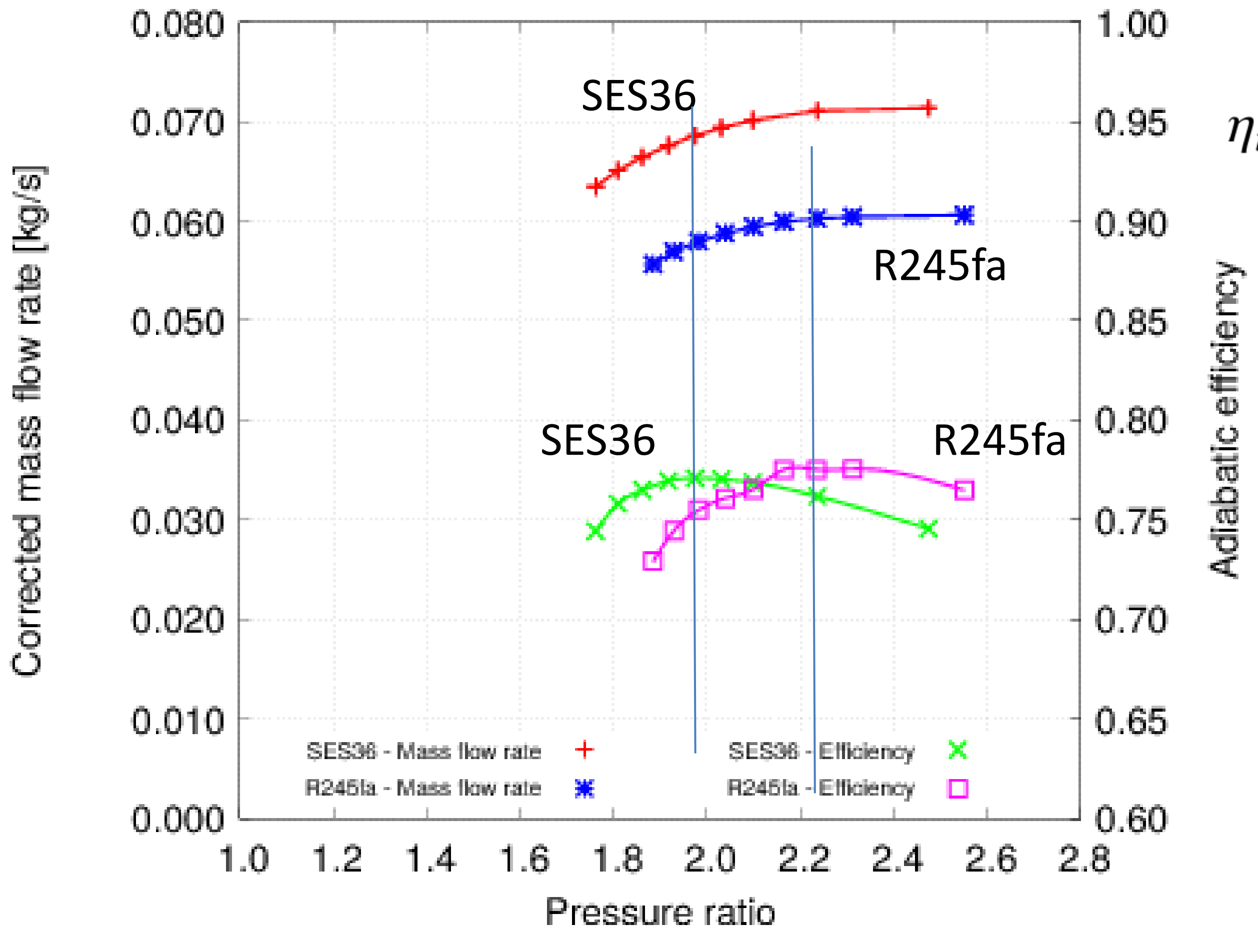


$$\eta_{turbine} = \frac{T_0 - T_{2is}}{T_0 - T_2}$$

$$T_{2is} = T_1 \left(\frac{P_2}{P_0}\right)^{\frac{\gamma-1}{\gamma-1}}$$

Max efficiency: 79.6 %

Turbine performance map with organic fluids



$$\eta_{turbine} = \frac{\mathscr{P}_{shaft}}{\mathscr{P}_{is}} = \frac{C_{shaft}\,\omega}{\dot{m}\Delta h_{is}}$$

Max efficiency

- 77.1 % with SES36
- 77.5 % with R245fa

Conclusions & perspectives

- A simple model has been proposed to determine the best operating point of an adapted ORC to use a given radial turbine as an expander
- Given a set of assumptions it allow the comparison of working fluids
- CFD simulations for two common working fluids confirmed the high efficiency of the turbine on the operating point

- Reproduce this work with other turbines including VNT
- Implementation of more detailed models for each component (pump, fan, scroll housing)
- Investigate off-design operation and economics outcome
- Adapt the turbine and the test facility to perform measurements

Thank you for your attention

michael.deligant@ensam.eu

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