Characterization of the fluid flow phenomena in an ejector for a high temperature heat pump

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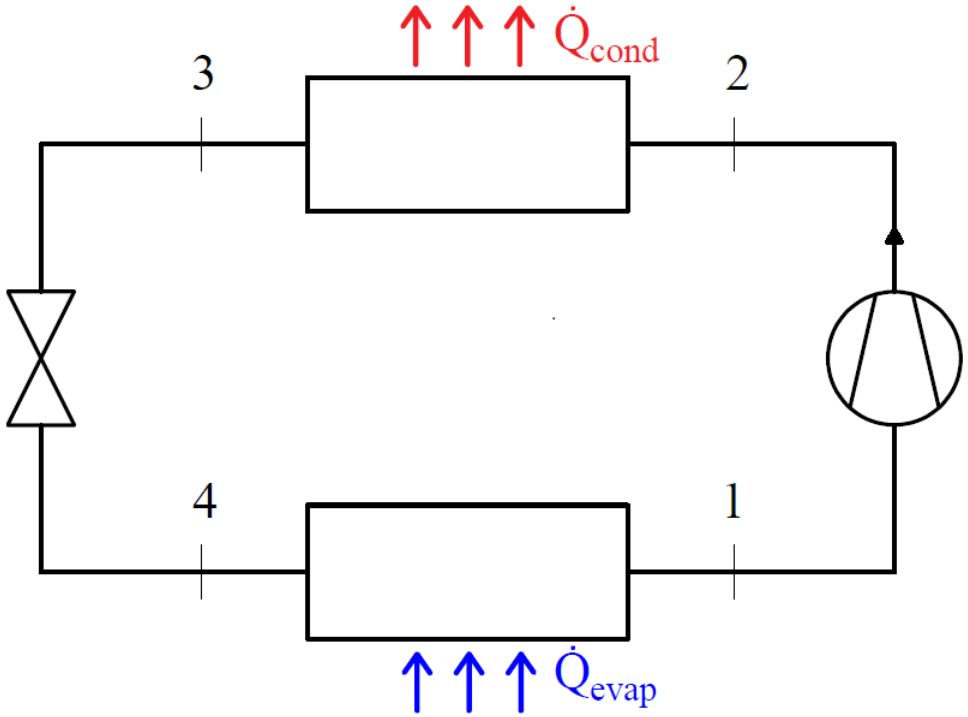
Agenda

- Introduction
- Ejector technology
- Modified heat pump cycle
- Simulation setup
- Results
- Further work
- Conclusion

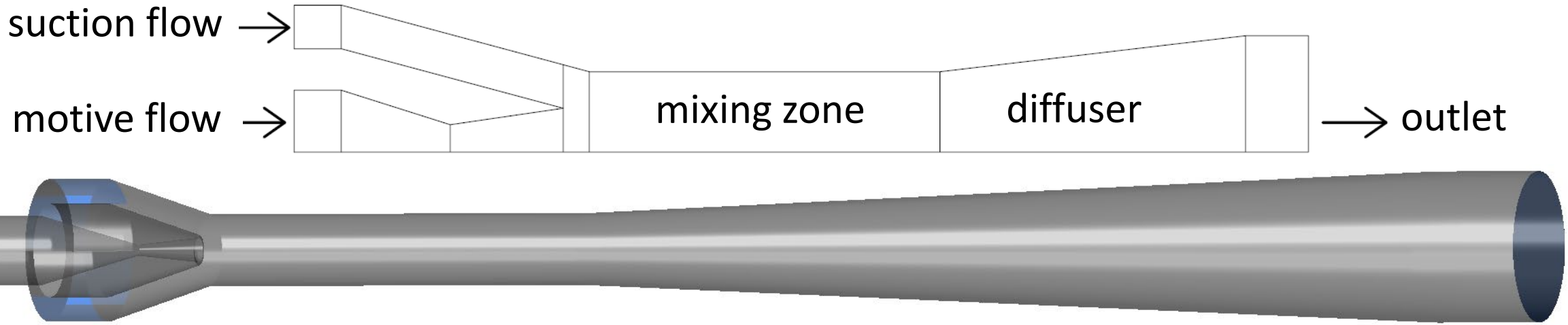
Introduction

- Heat for industrial processes mainly from fossil fuels
- High pressure differences -> high expansion losses
- Ejectors instead of expansion valve
  - Recovery of expansion work
- COP increase of up to 26%



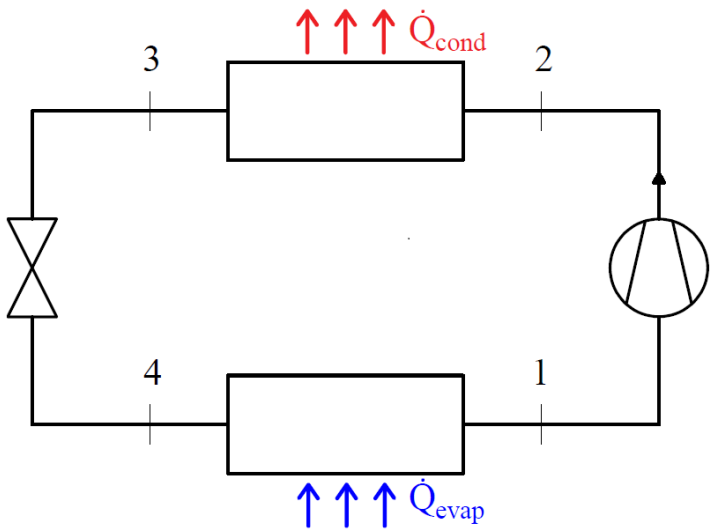
Ejector technology

- Acceleration of motive flow to supersonic speed
- Entrainment of suction flow
- Mixing
- Conversion of kinetic to potential energy

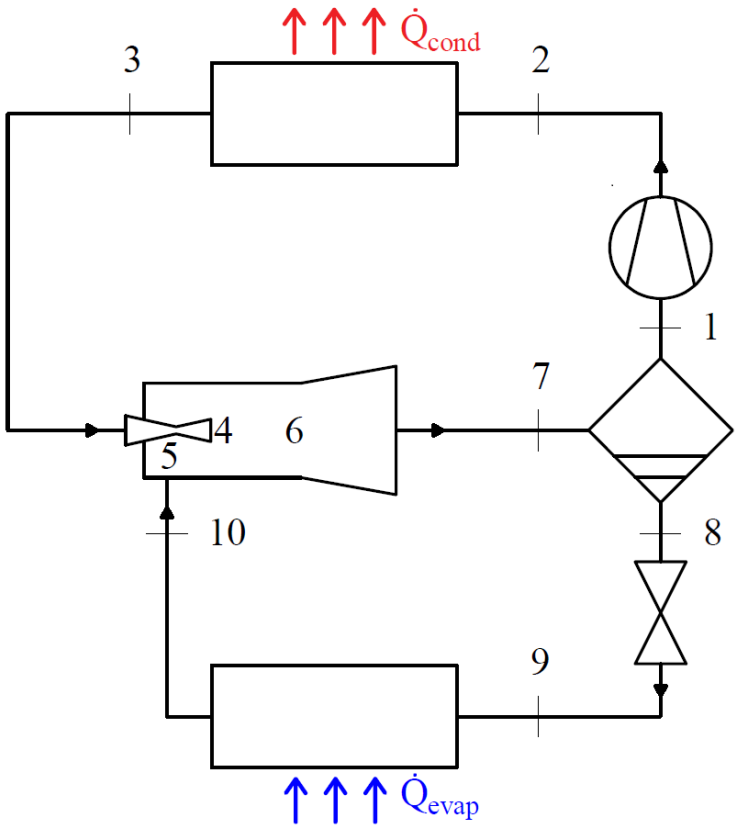


Modified heat pump cycle

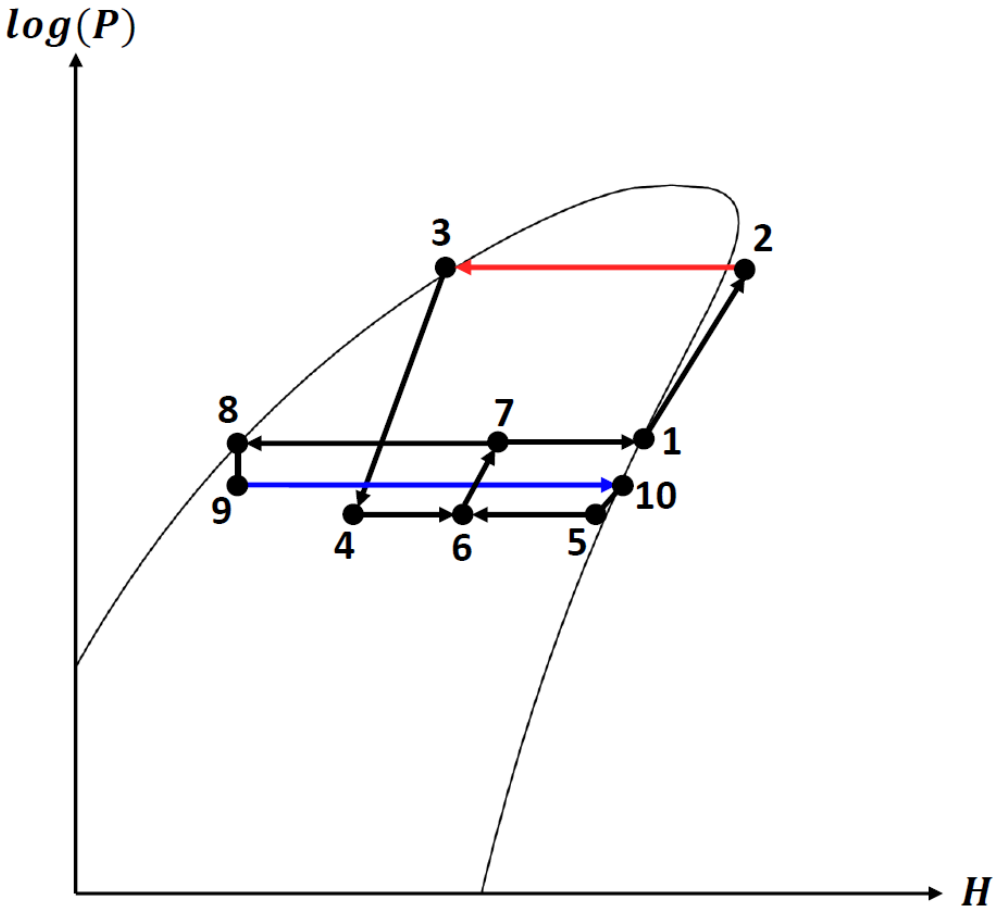
Standard HP-cycle

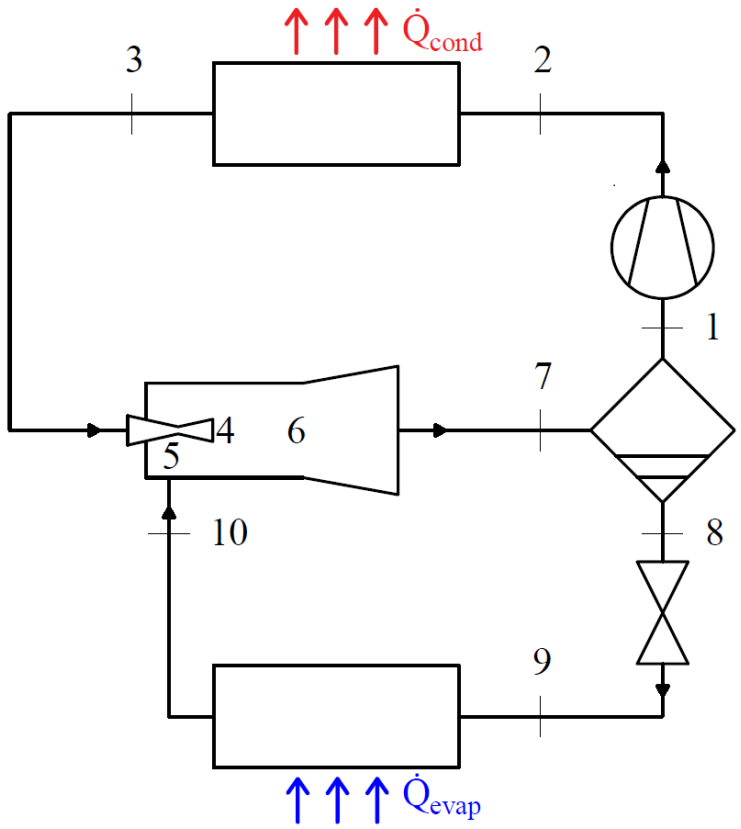


Ejector HP-cycle



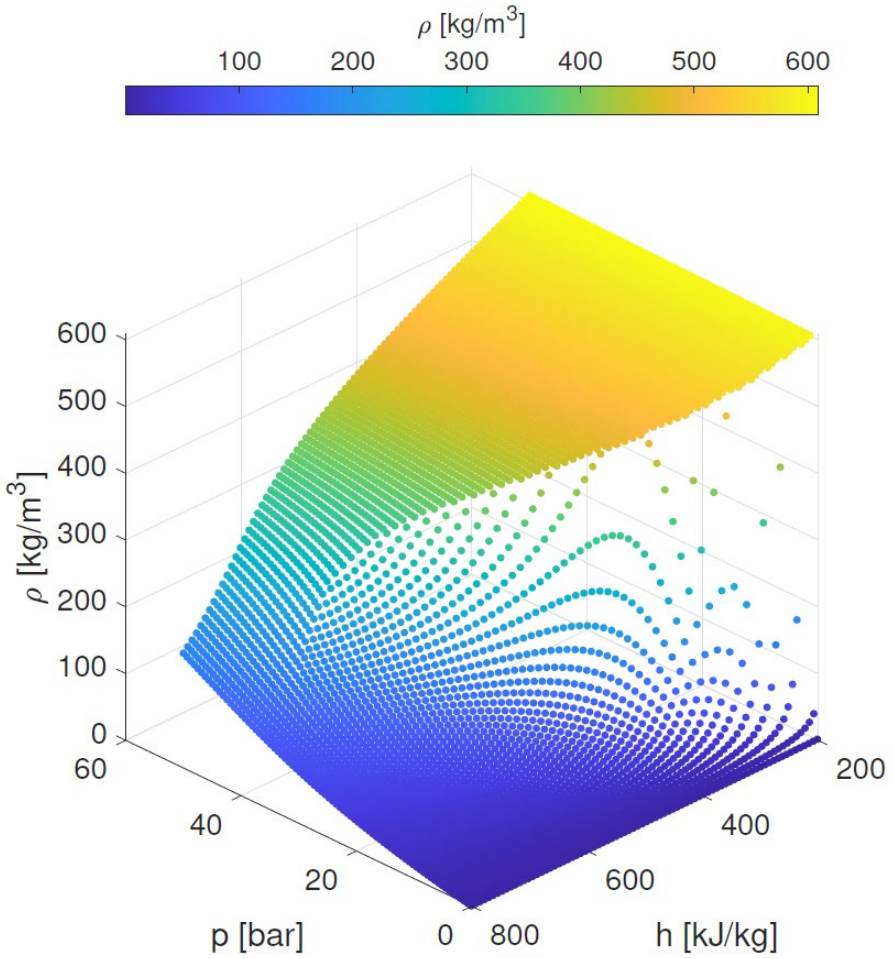
Modified heat pump cycle





Simulation setup

- 2D axisymmetric quad mesh
  - ≈170.000 cells
- k-ω SST turbulence model
- HEM – two-phase model
  - Enthalpy-based energy equation (UDF)
  - Material properties via bilinear interpolation from Look-Up tables



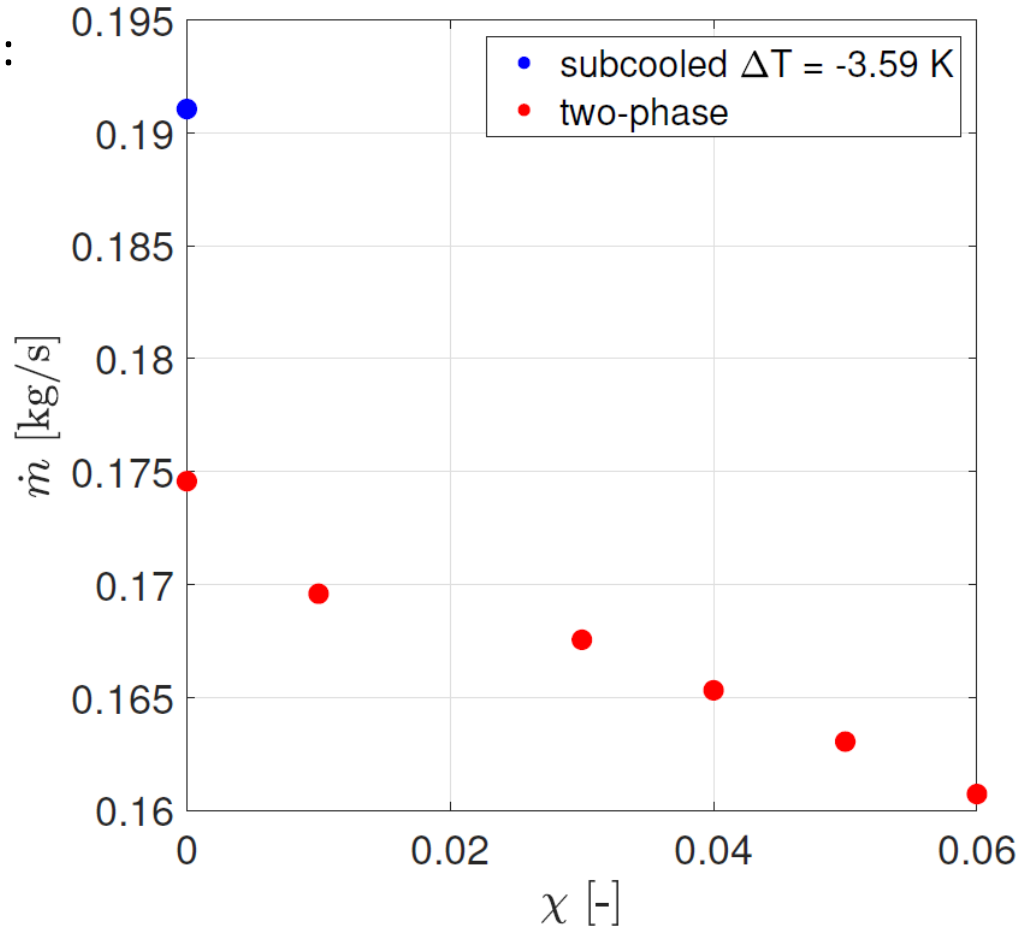
Specifications & boundary conditions

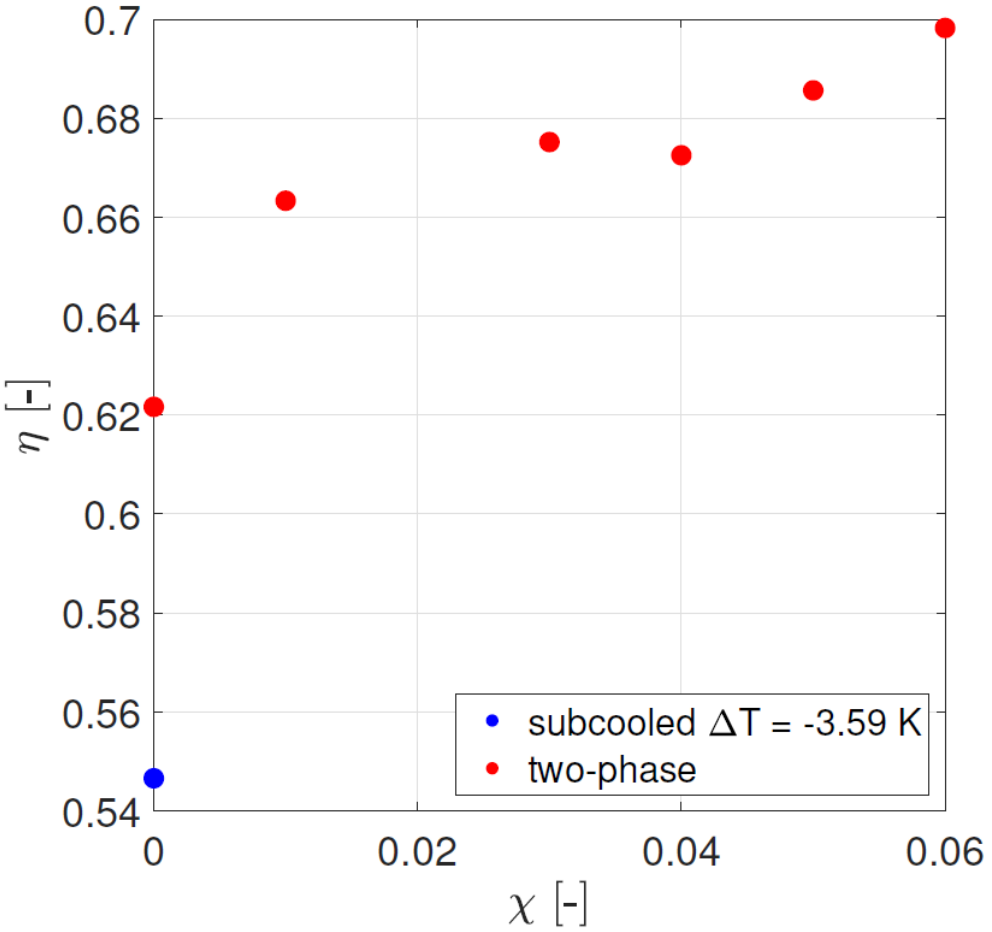
refrigerant	R600 (butane)
sink temperature (°C)	70 – 130
source temperature (°C)	50 – 60
condenser capacity (kW)	50
evaporator capacity (kW)	35

motive nozzle	pressure (Pa)	2 139 000
	vapor quality (%)	2.7
suction nozzle	pressure (Pa)	430 000
	superheating (K)	8.06
outlet	pressure (Pa)	584 500

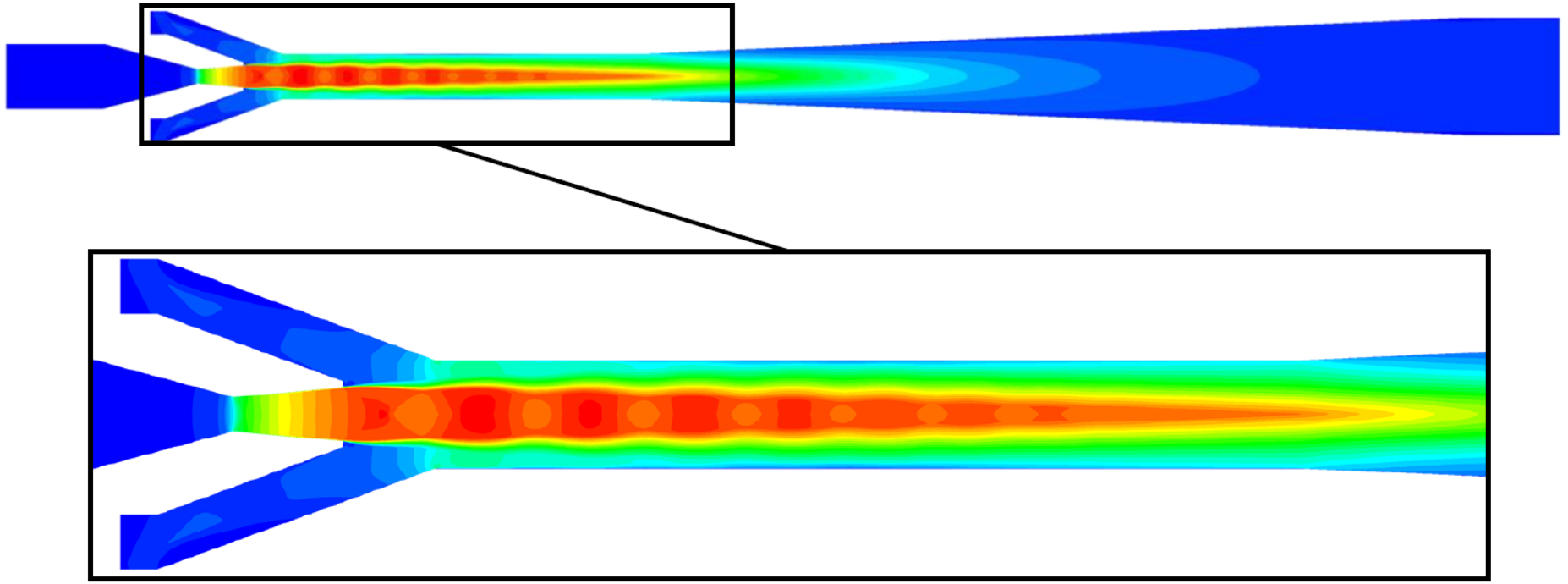
Results: Mass flow

- Entrainment ratio:
  - $\eta = \frac{\dot{m}_{suc}}{\dot{m}_{mot}}$





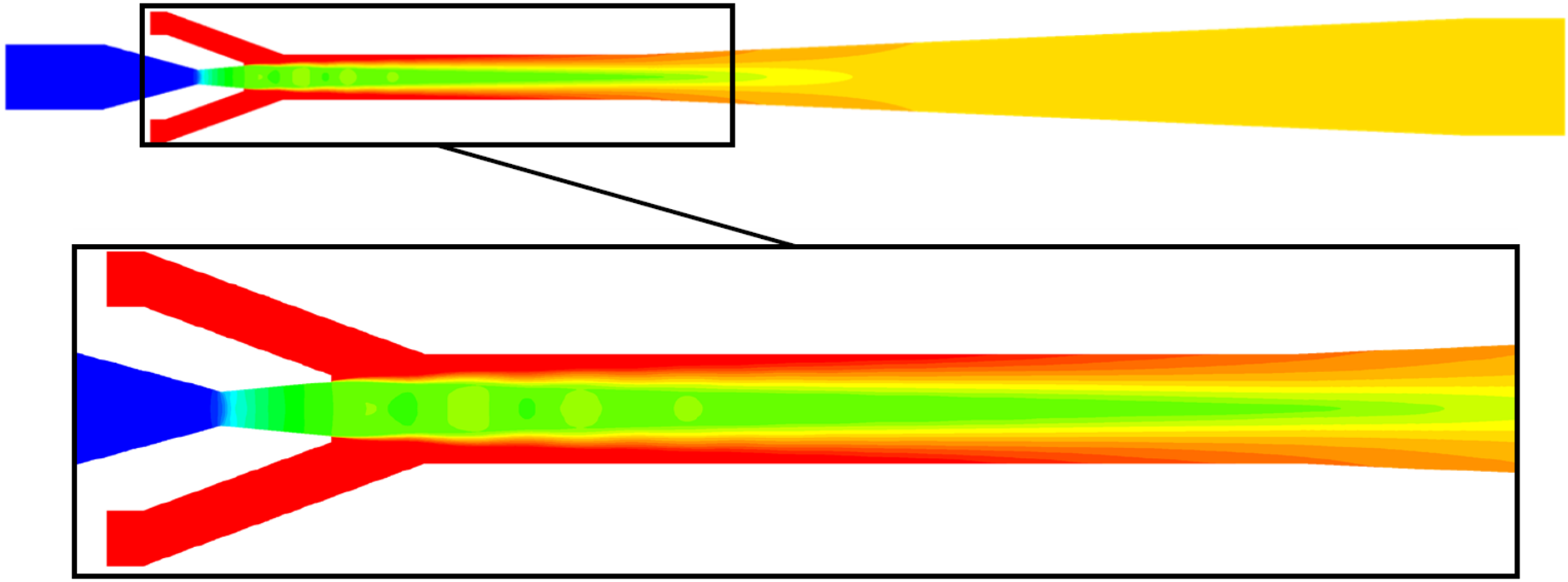
Results: Contour of mach number

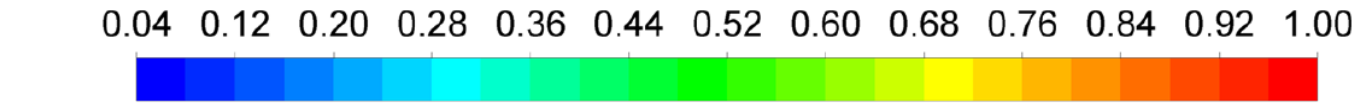


contour
Mach Number

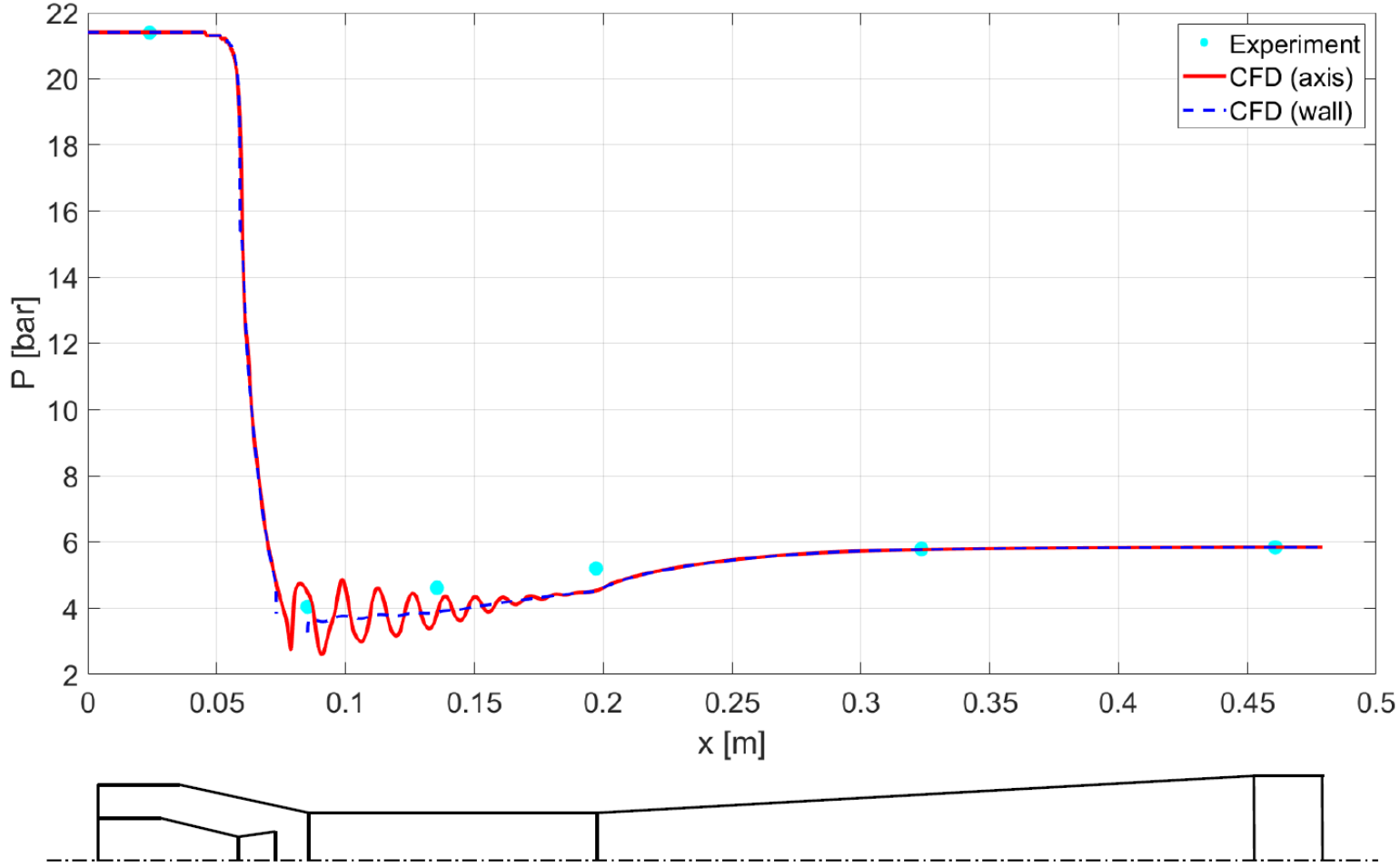
0.00 0.14 0.28 0.42 0.56 0.70 0.85 0.99 1.13 1.27 1.41 1.55 1.69

Results: Vapor quality

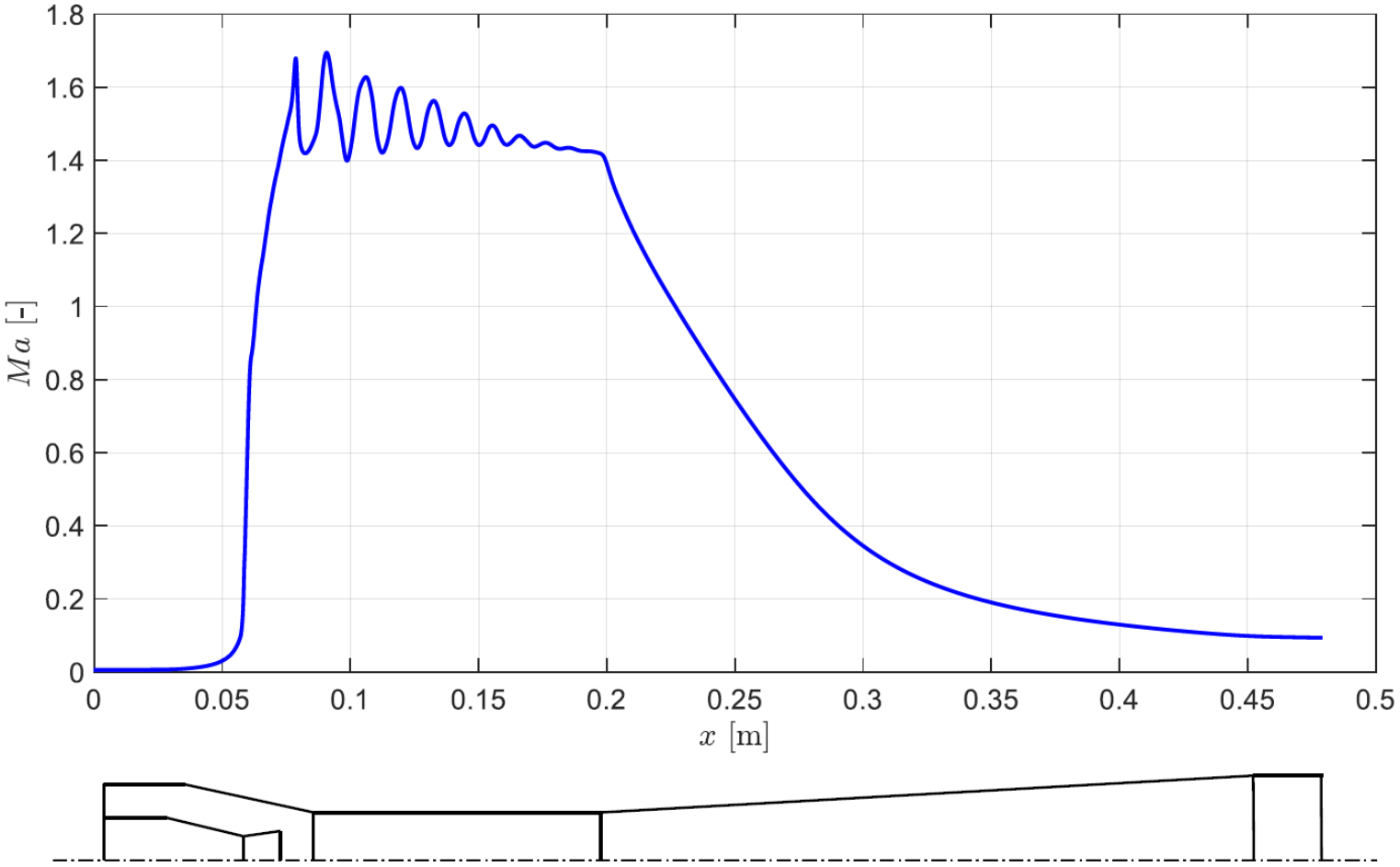




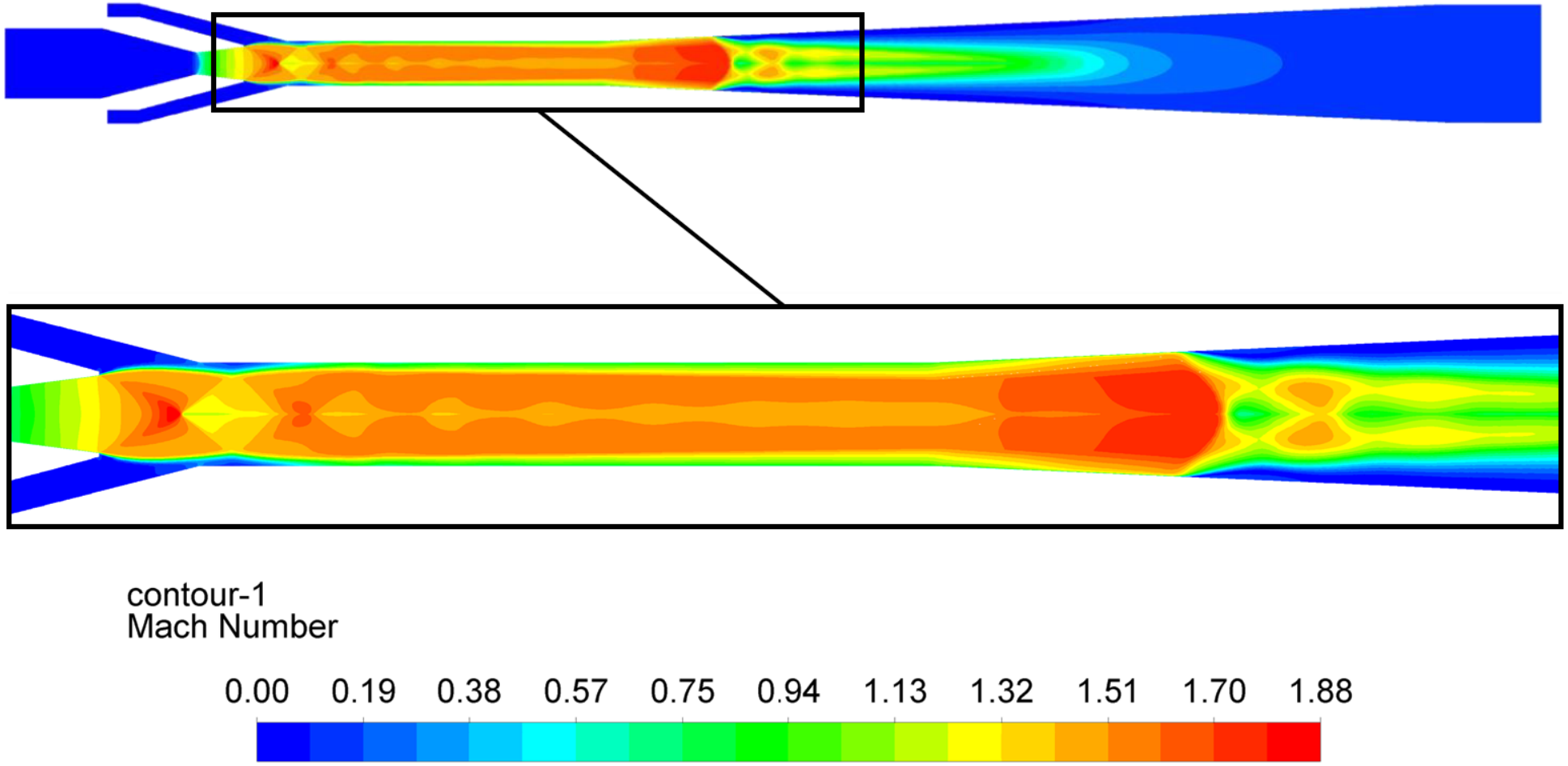
Results: Pressure



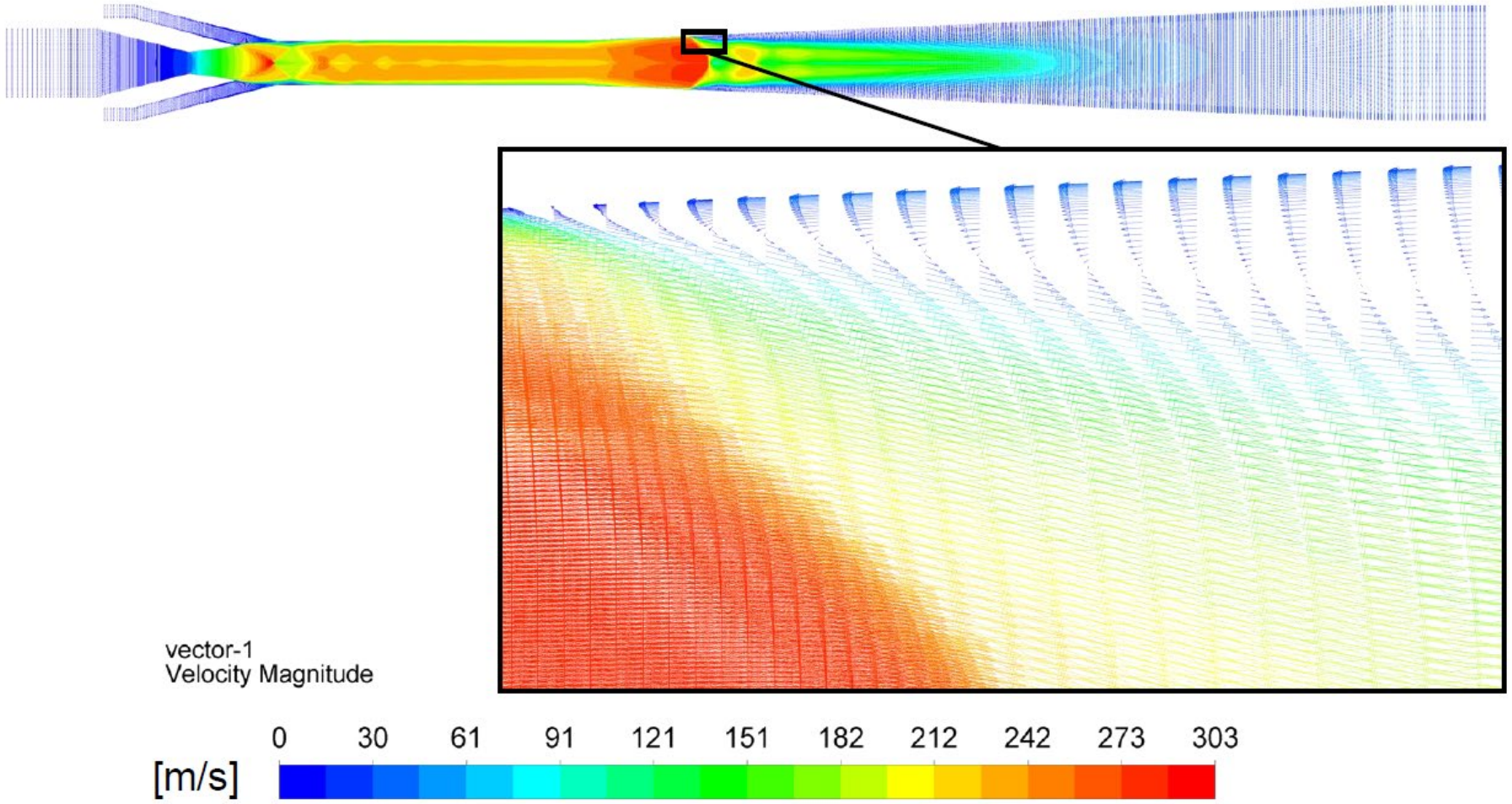
Results: Mach number



Results: Geometry variation



Results: Geometry variation

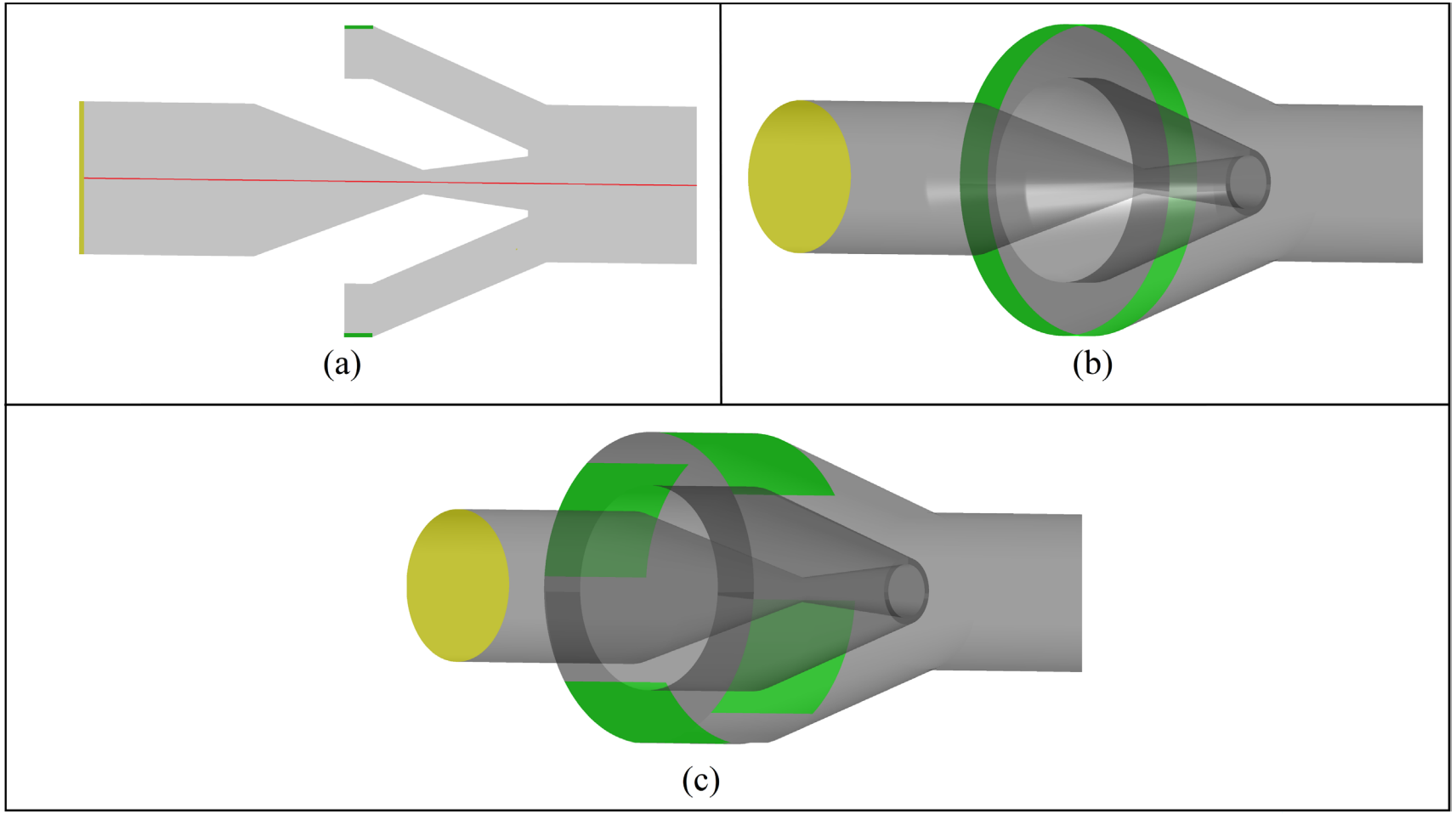


Further work

- Measurement campaign
- New project
  - R1233zd(E)
  - ≈ 100 kW condenser capacity

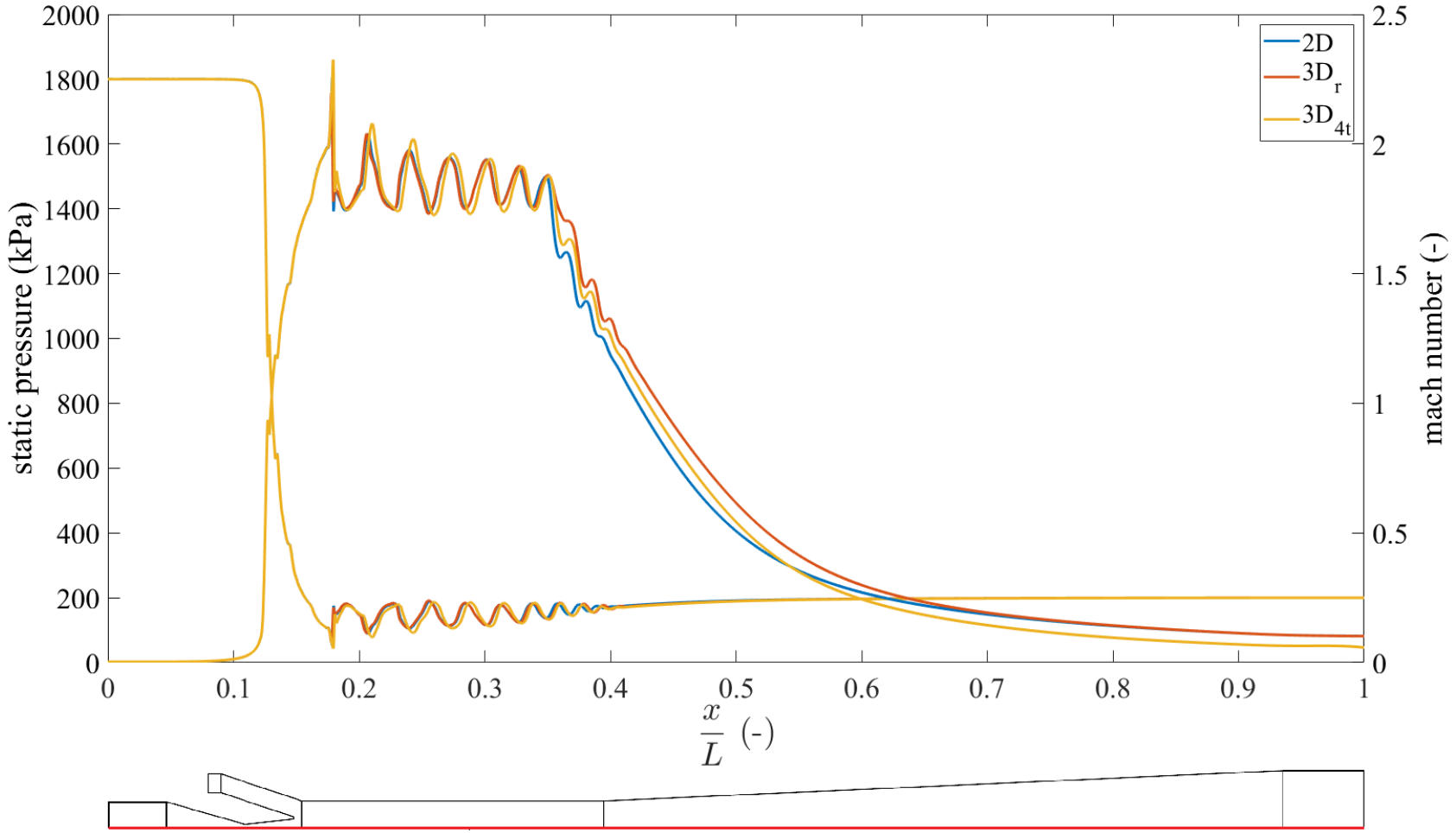
Further work: Comparison 2D / 3D

a) 2D axisymmetric
b) 3D radial
c) 3D tangential 4x



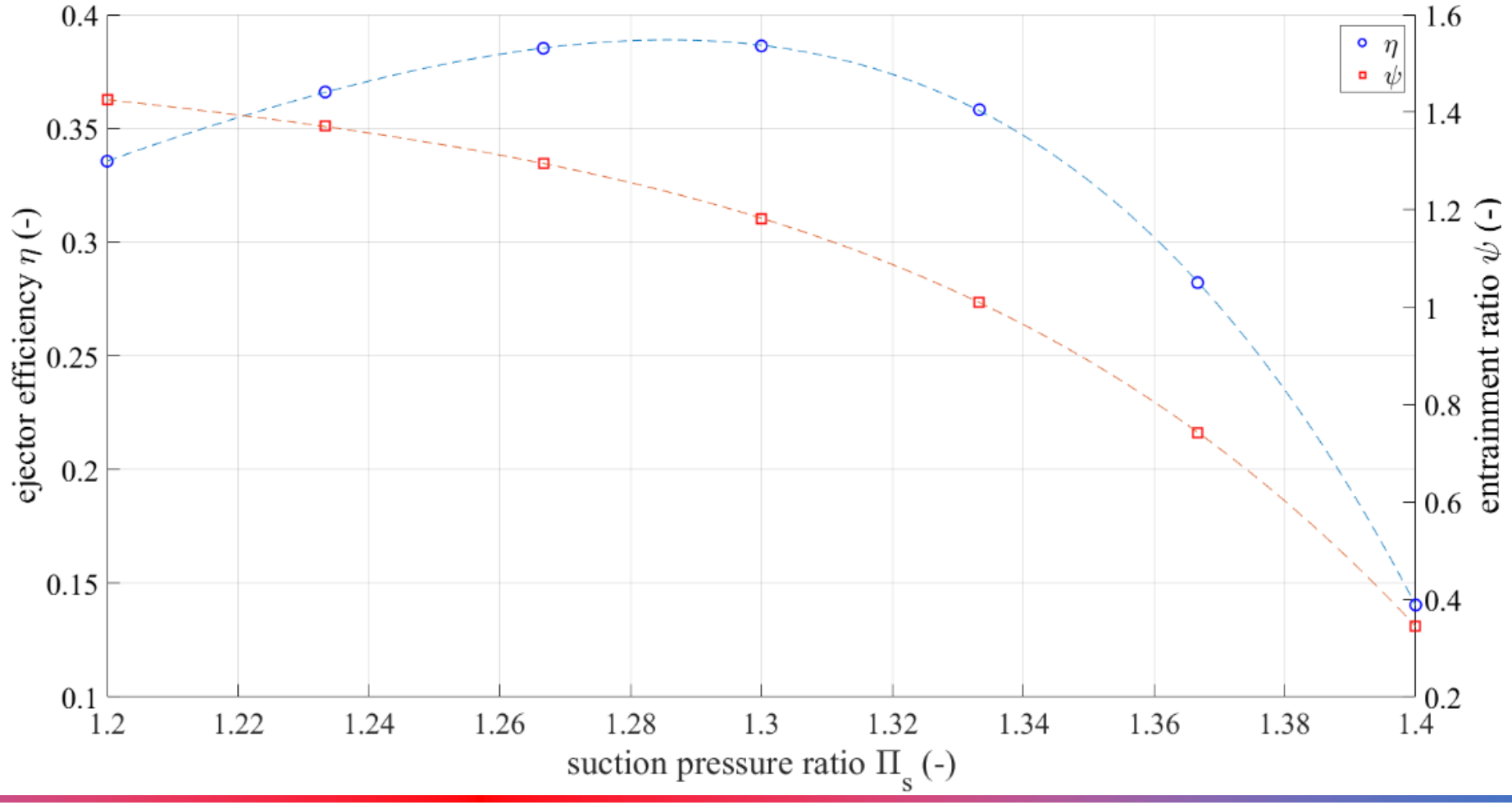
Further work: Comparison 2D / 3D

- 2D axisymmetric
- 3D with a radial suction inlet (equivalent to 2D)
- 3D with 4 tangential suction inlets



Further work: Ejector efficiency

- Entrainment ratio:
  - $\psi = \frac{\dot{m}_{suc}}{\dot{m}_{mot}}$
- Suction pressure ratio:
  - $\Pi_s = \frac{p_{out}}{p_{suc}}$
- Ejector efficiency:
  - $\eta = \frac{\dot{W}_{rec}}{\dot{W}_{rec,max}}$



Conclusion

- Ejectors have a great potential for industrial processes
- Complex design process
  - Sensitive to geometry variations
- 2D simulations sufficient for the design process
  - 3D recommended
- Highest ejector perfomance ≠ highest COP
- Depending on operating conditions different models needed

Thank you!

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Further work: Models

Homogeneous equilibrium model HEM

- Mechanical & thermal equlibrium
- Enthalpy-based energy equation (UDF)
- Material properties via bilinear interpolation from Look-Up tables

Homogeneous relaxation model HRM

- Relaxation time for phase change
- Enthalpy-based energy equation (UDF)
- Material properties via bilinear interpolation from Look-Up tables