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DE: Department of Engineering Ferrara

Real Gas Expansion with Dynamic Mesh in Common Positive Displacement Machines

4th International seminar on
ORC Power Systems
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Outline

- Introduction
- Methodology
  - Dynamic Mesh
  - Fluids invesitgated
  - Real gas model
- Results
- Conclusion

ORC system - schematic and real 3D application

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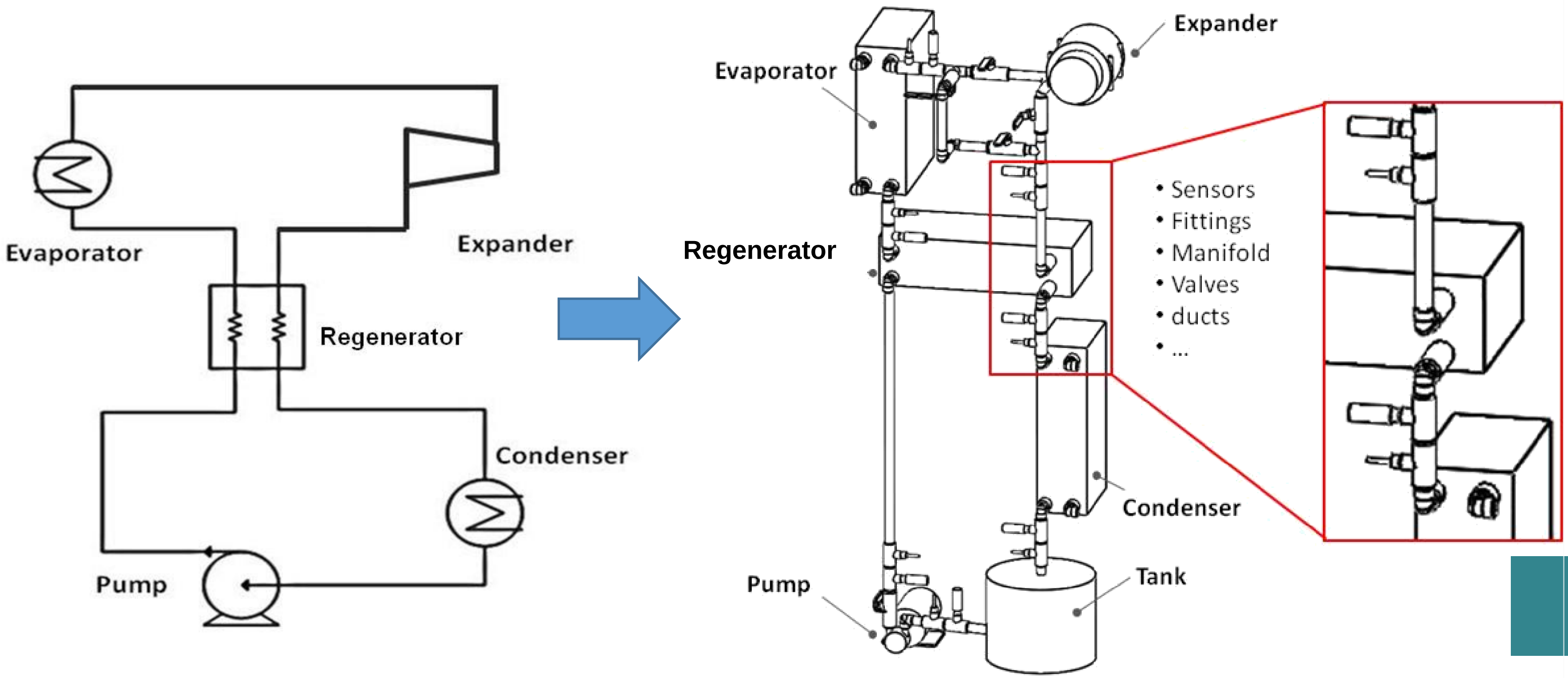
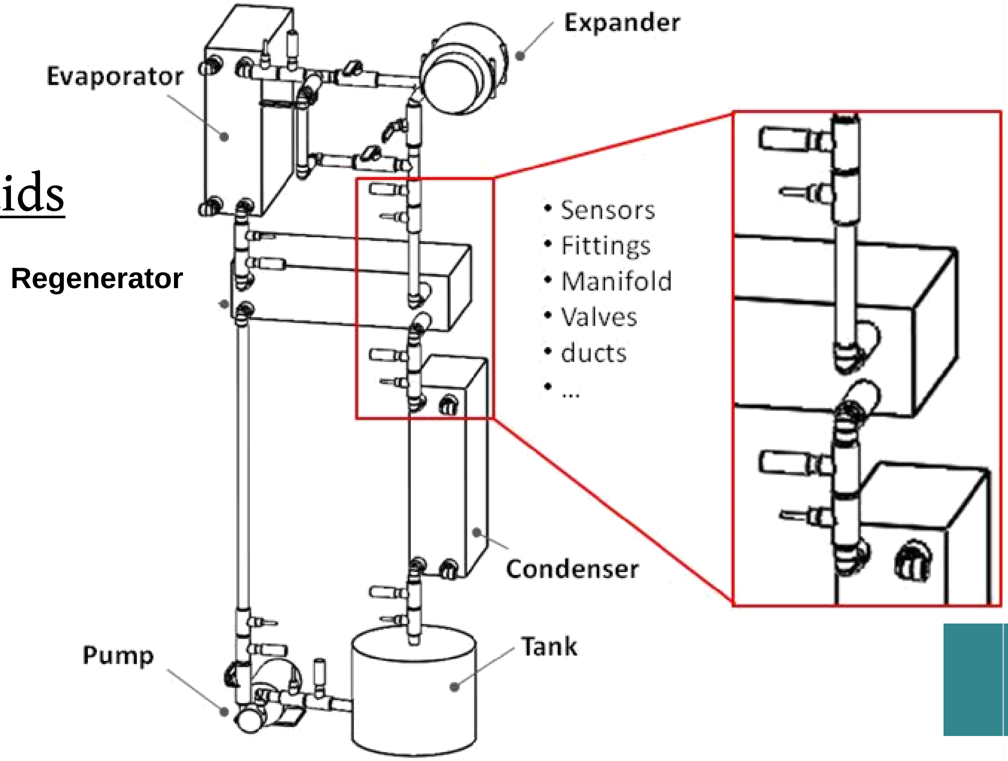


ORC system –
real 3D application

- No unique layout
- <u>Gap performances</u>
- <u>Needs for testing different fluids</u>



CFD analysis of scroll expander: Geometry and numerical model

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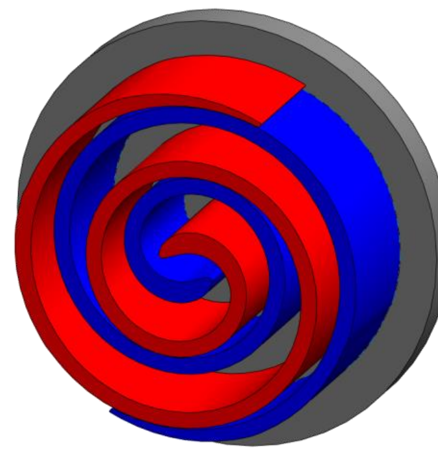
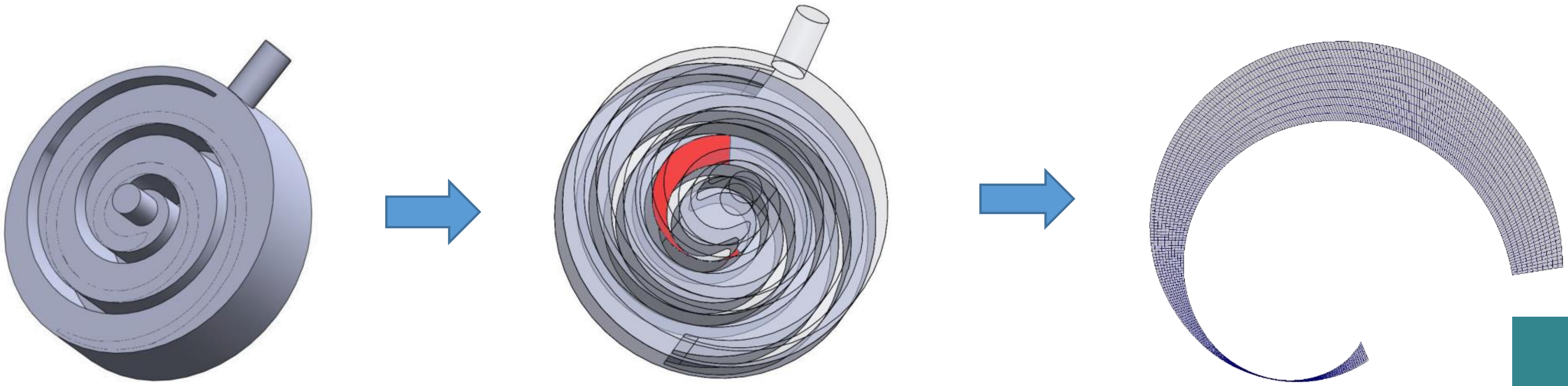
- Sanden TRSA09-3658:
  - Compressor for air-conditioning system
  - Nominal Power (as compressor) 8 kW
  - Geometry obtained via RE
  - Power output (as expander -numerical): 12 kW



Morini, M. et al. "Analysis of a scroll machine for micro ORC applications by means of a RE/CFD methodology" APPL THERM ENG

CFD analysis of scroll expander: 2D numerical model & computational grid

- Geometry representative of the flank gap (1 mm thick slice)
- 2D transient analysis (flank gap depends on crank angle!)
- Dynamic Mesh technique (w/o remeshing) → structured grid



Smoothing algorithm: Solves Laplace equation according to:
$\dot{\boldsymbol{x}}$ motion velocity

$$\nabla \cdot (\gamma \nabla \dot{\boldsymbol{x}}) = 0$$

Remarks on the computational grid: dynamic mesh

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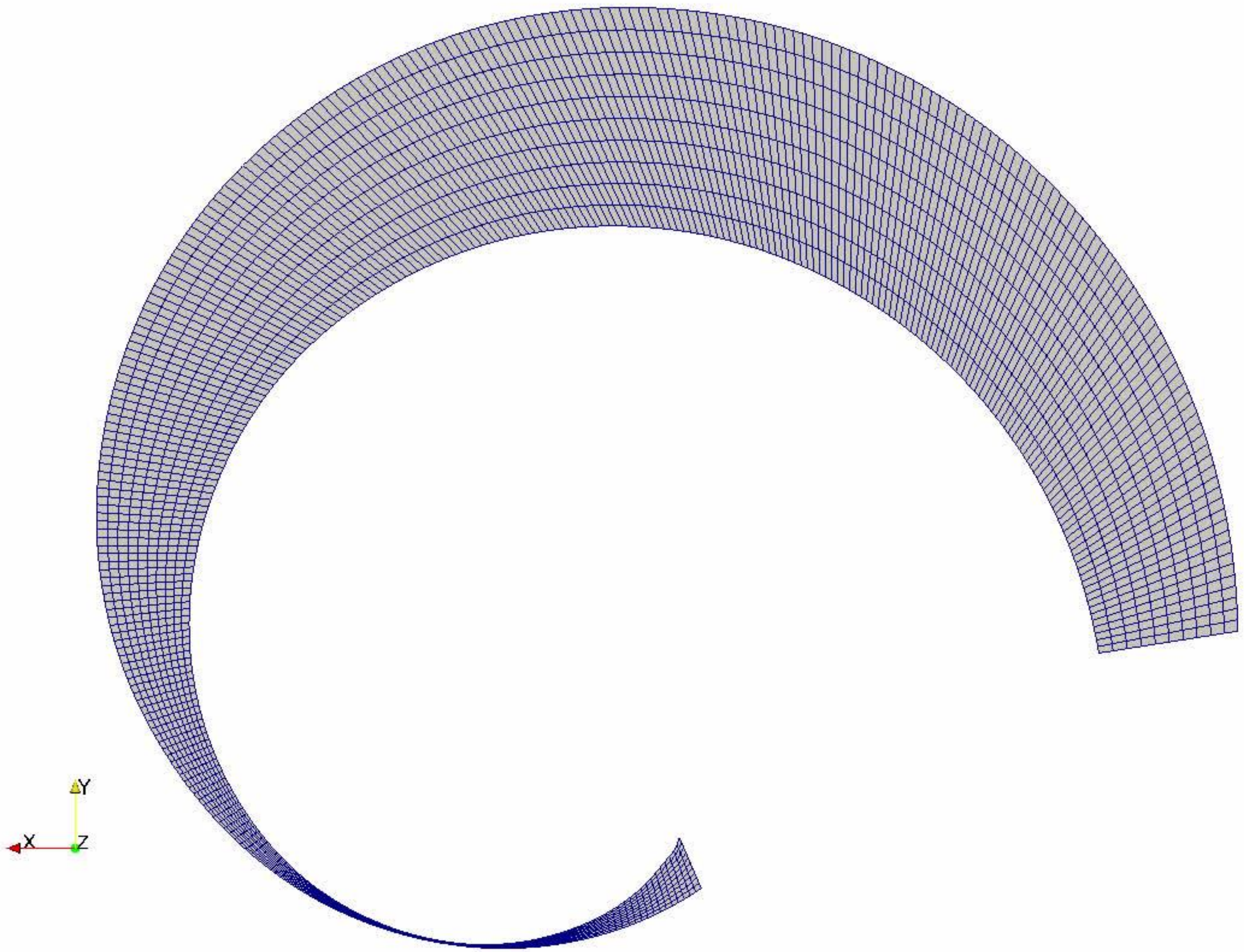

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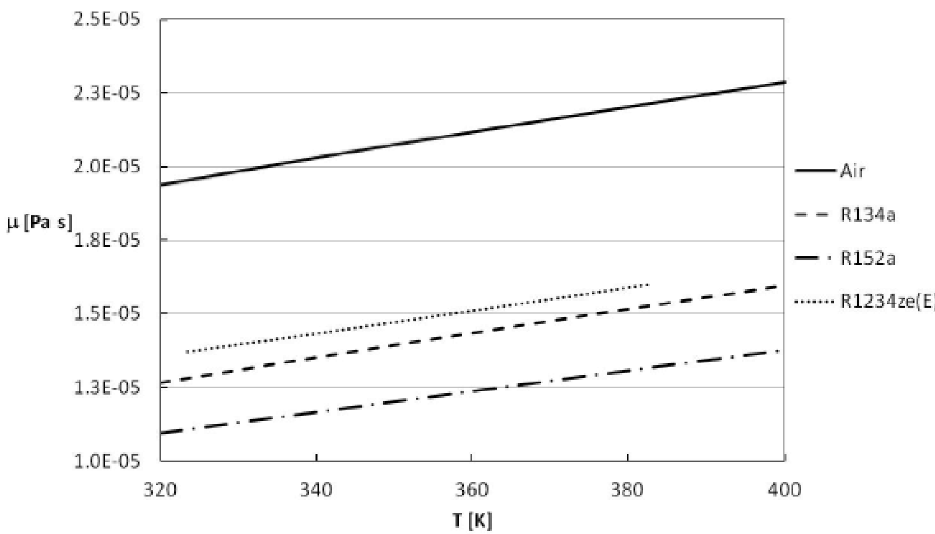
CFD analysis of scroll expander: Fluids investigated

- R134a, R152a and R1234ze(E)

Fluid	Chemical Formula	Molar Mass [kg/kmol]	Global Warming Potential [GWP]	Critical Pressure [MPa]	Critical Temperature [K]	Critical Density [kg/m^3]	Acentric Factor [-]
R134a	$C_2F_4H_2$	102	1430	4.06	374.2	511.9	0.327
R152a	$C_2F_2H_4$	66	140	4.52	386.4	368.0	0.275
R1234ze(E)	$C_3F_4H_2$	114	4	3.64	382.5	489.2	0.313

- Viscosity @ 7 bar (REFPROP)
    - Air
    - R1234ze(E)
    - R134a
    - R152a

μ



CFD analysis ofscroll expander: Numerical set-up

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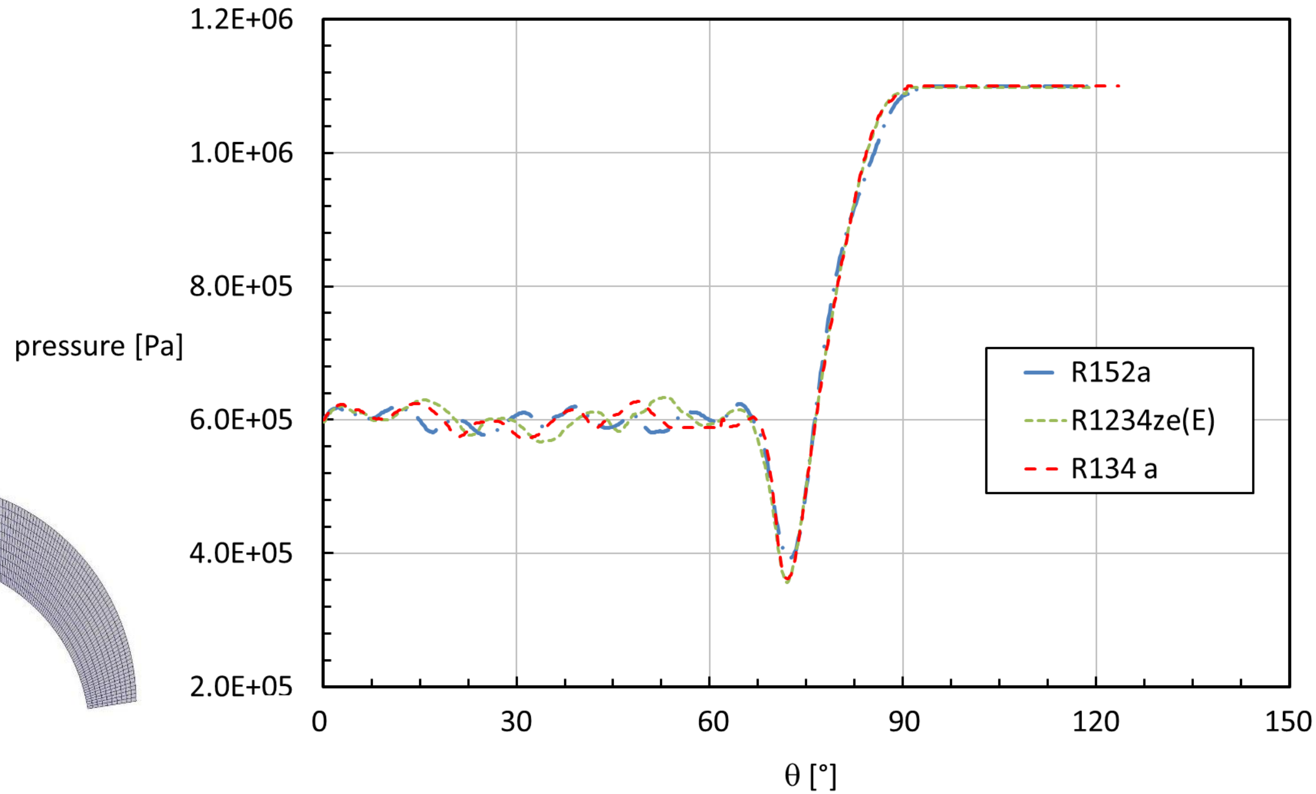
- Compressible 2d Finite Volume Solver (with Dynamic Mesh support)
- Software: OpenFOAM – v1606+ ( )
- Real Gas model: Peng-Robinson
- $c_p(T)$ and $\mu(T)$ implemented via 8^{th} degree polynomials

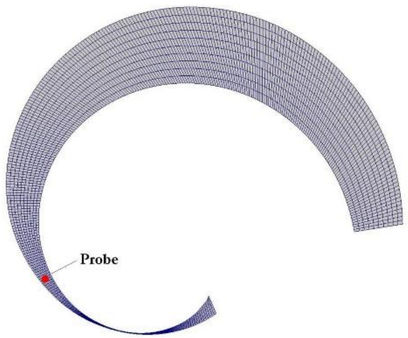
Fluid	Critical Pressure [MPa]	Critical Temperature [K]	Critical Density [kg/m^3]	Acentric Factor [-]
R134a	4.06	374.2	511.9	0.327
R152a	4.52	386.4	368.0	0.275
R1234ze(E)	3.64	382.5	489.2	0.313

Quantity		Inlet	Outlet	Walls
Pressure		11 bar	6 bar	noGradient
Temperature		390 K	noGradient	adiabatic
Turbulent Quanties	k	Turbulent intensity: 10%	noGradient	Standard Wall function
	ε	Mixing length: 2 x 10^{-4} m	noGradient	Standard Wall function

Results: variation of static pressure

- All the fluids have a very similar behaviour
- Lower pressure drop: R152a (probably due to lower viscosity)





Results: Mass flow rate variation with the crank angle

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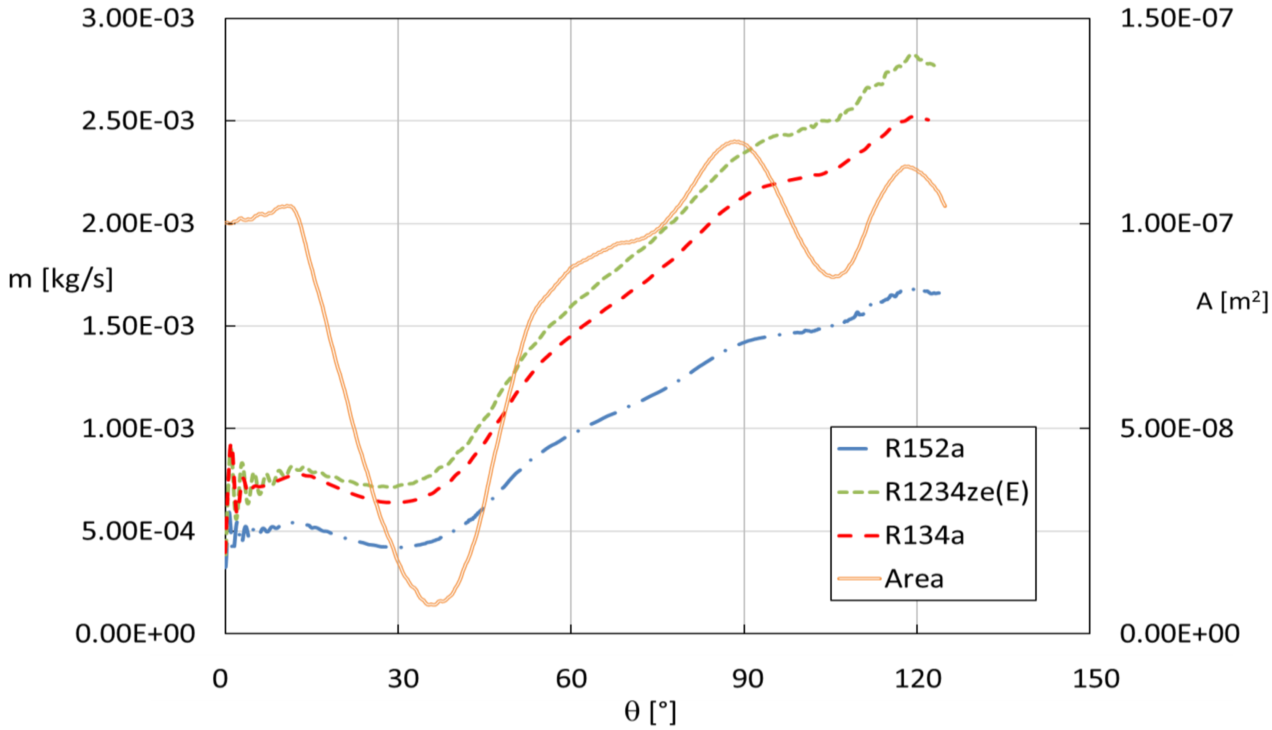
- Similar trend for all the tested fluids
- Mass flow rate of R134a and R1234ze(E) almost twice than R152a
- Flank gap variation: from 7 μm to above 100 μm



Results: Volumetric flow rate variation with the crank angle

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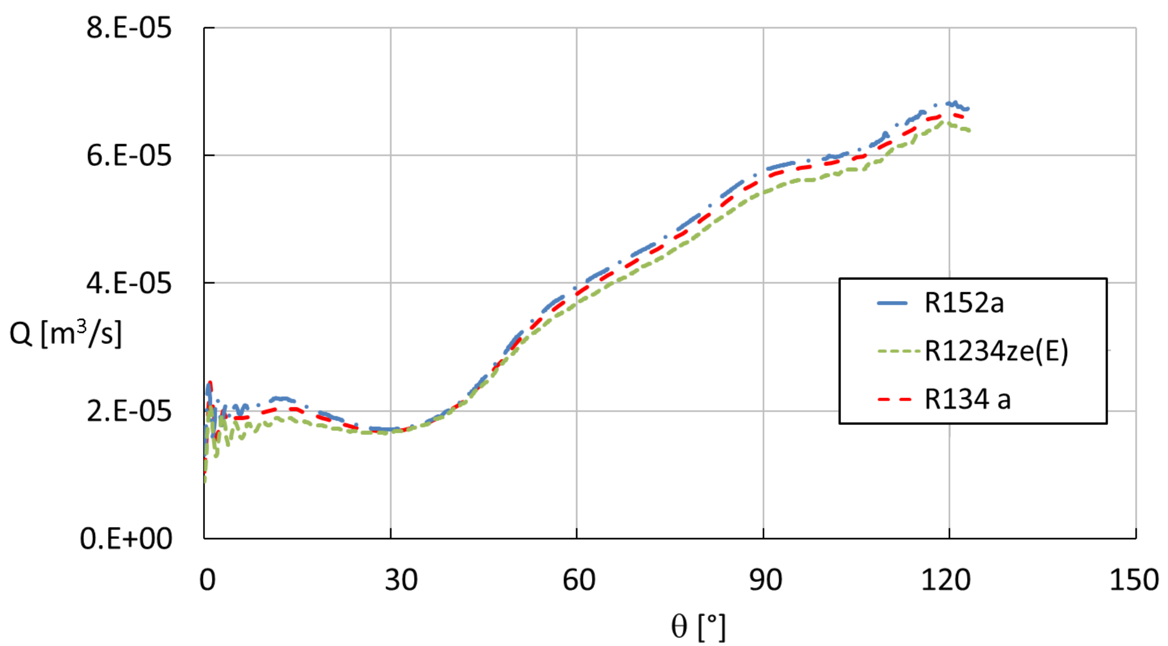
- Relative position opposite to the viscosity ones
- R152a density roughly one half of the other two fluids investigated



Results: Mach variation with the crank angle

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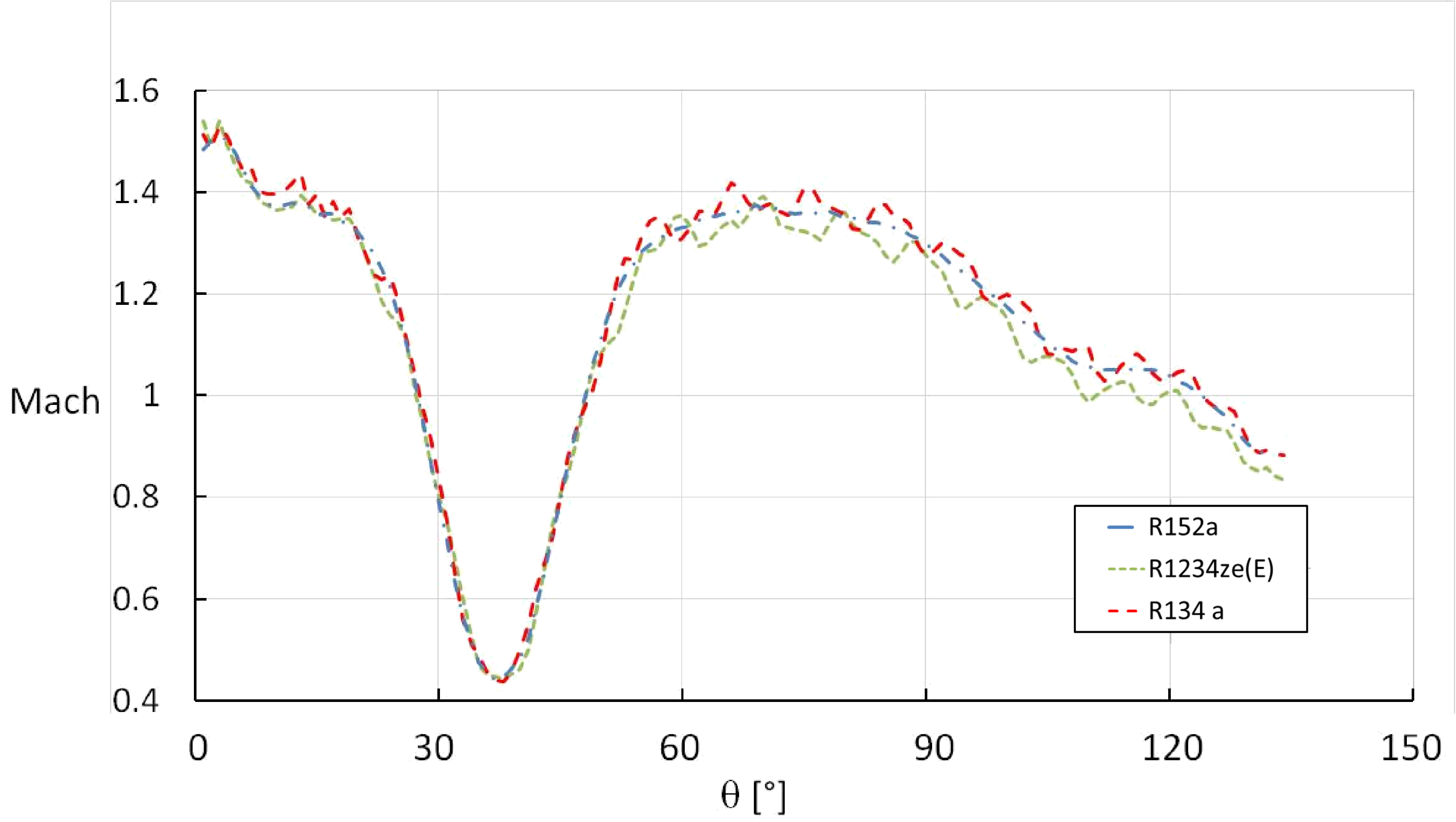

Results: Detailed fluid dynamics Mach number, effect of the gap variation

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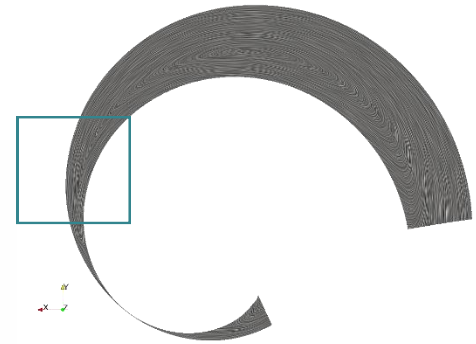
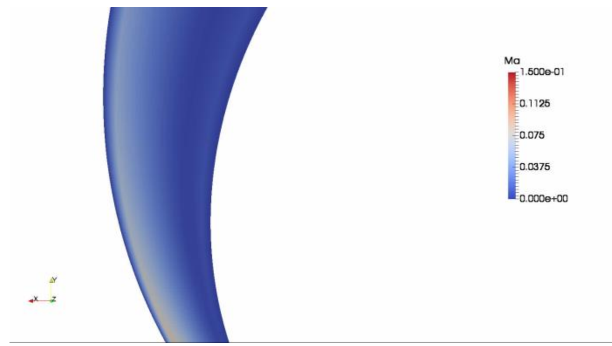
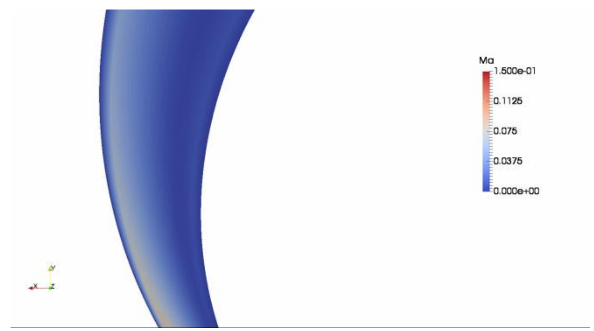


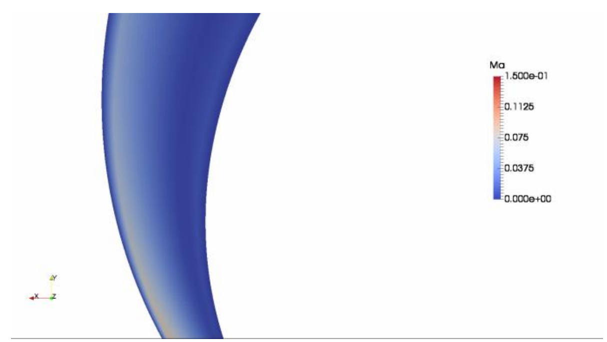
- R1234ze E



- R152a



- R134a



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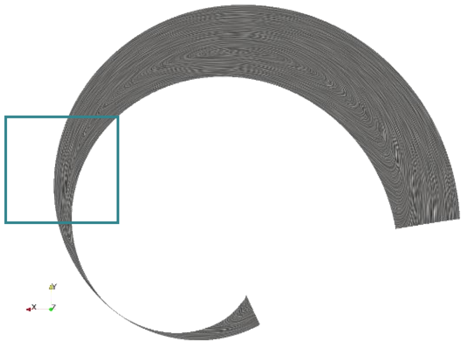
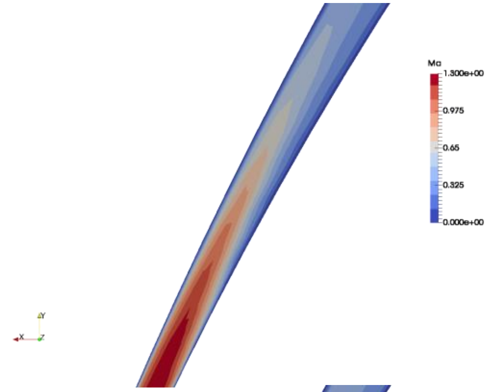
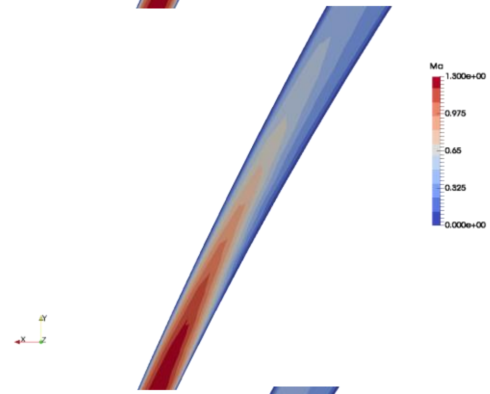


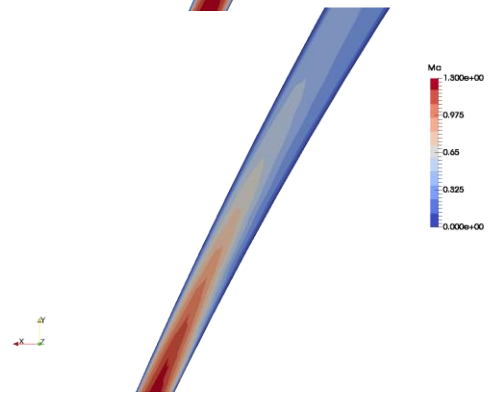
- R1234ze E



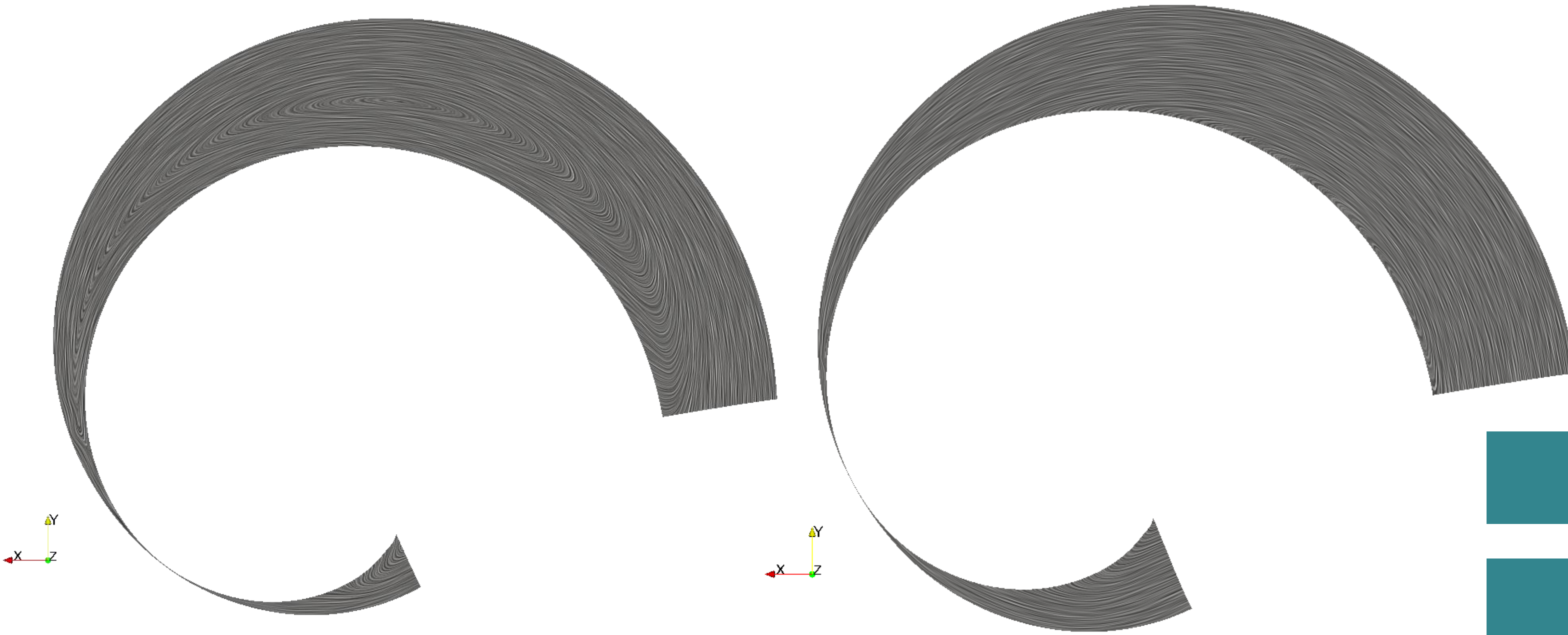
- R152a



- R134a



Results: Detailed fluid dynamics
Separation downstream the gap



Conclusions

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- Leakage flow has an inverse behavior with respect of the viscosity if the volumetric flow rate through the gap is kept into account
- The great differences in the density forbid a generalization of this statement to the mass flow rate, where the opposite results have been obtained
- The complex fluid dynamics reported in this work shows how inadequate could be the steady analyses for the determination of the coefficient of discharge
- It is very important to keep into account the variation of the flank gap with the crank angle evolution

Future works

- Extension of the crank angle investigated to simulate the full revolution of the inner spiral
- Extension to full-span 3D analysis, keeping into account the axial gaps
- Comparison of the results obtained in the current work (using the Peng-Robinson model for the real gas) with the one obtained implementing the Helmholtz equation (via COOLPROP)

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