Optimization and preliminary design of a high-temperature, low pressure-ratio sCO_2-compressor for a wide operating range

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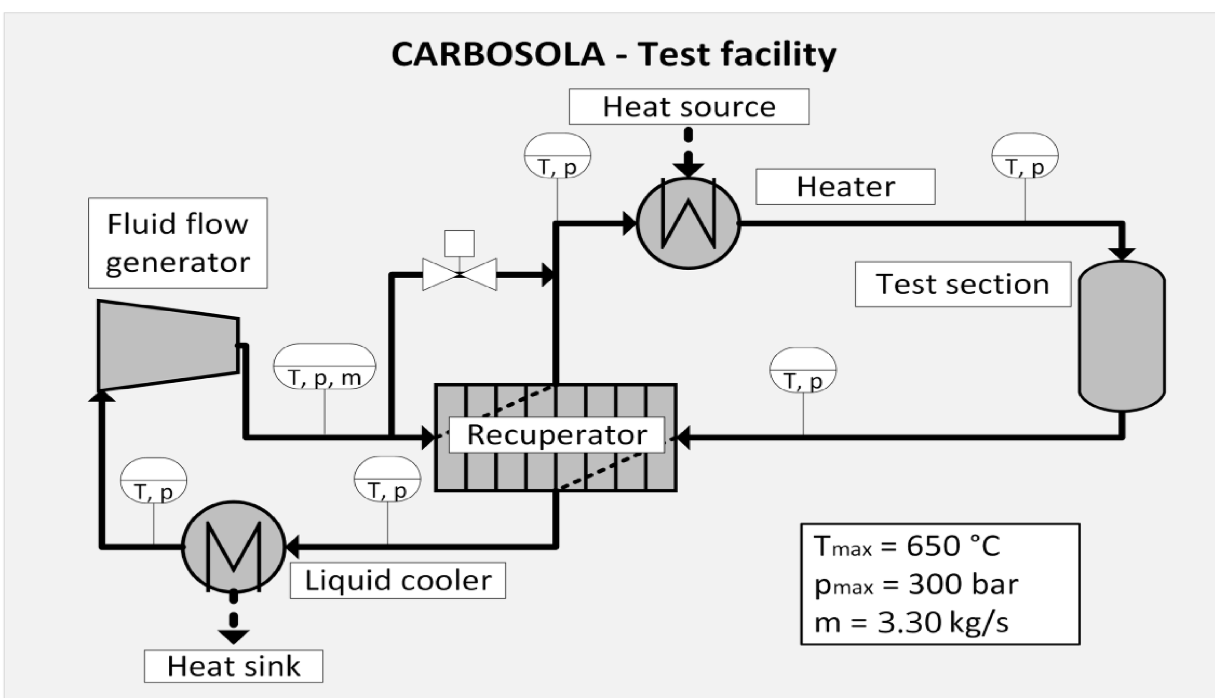
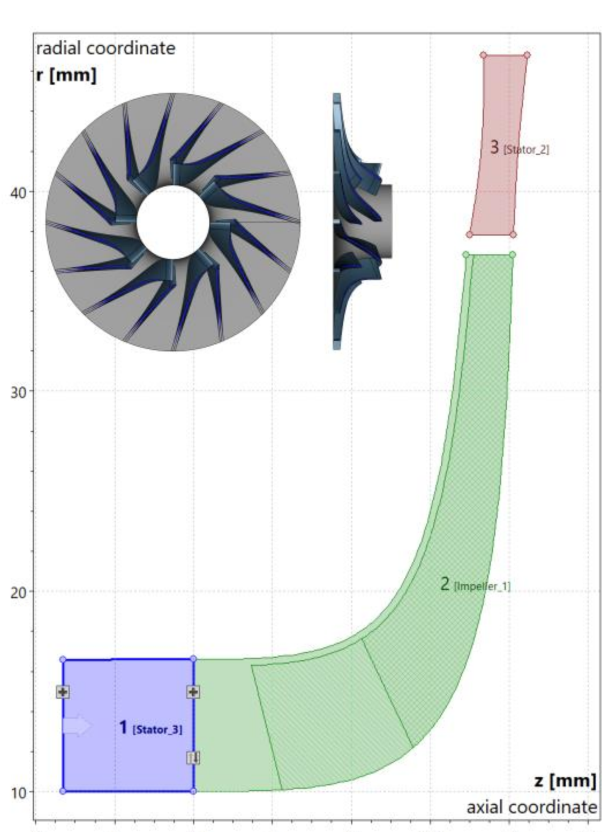
Motivation



- Experimental facility set up within the CARBOSOLA project (supercritical **car**bon dioxide as alternative working fluid for **bo**ttoming cycle and **sola**r thermal application)
- First rig configuration without expansion device → pure fluid circulation at low pressure difference
- Design of a centrifugal compressor to provide fluid circulation over a wide operating range

Baseline impeller design



Mass flow	$\dot{m}$	3.3	kg/s
Total inlet temperature	$T_{0,tot}$	(31) .. 200	° C
Total inlet pressure	$p_{0,tot}$	290	bar(a)
Pressure ratio	Π_{tot}	1.035	-
Estimated tot. to tot. Efficiency	η_{tt}	0.85	-
Speed	n_{RPM}	18000	rpm
Work coefficient	ψ	1.18	-
Flow coefficient	φ	0.04	-
Hub diameter	d_H	20.0	mm
Suction diameter	d_S	33.0	mm
Impeller diameter	d_2	72.0	mm
Outlet width	b_2	2.00	mm
Tip clearance	x_{tip}	0.35	mm

- First impeller design based on the rig boundary conditions
- Parametrized geometry model using the design software CFturbo providing a direct export to CFD

Optimization criteria

- Geometry optimization by varying 20 design parameters using a multi-objective genetic algorithm
- Numerical evaluation of each design in terms of a 3D, single blade passage CFD-model
- Operating range of each design estimated at the design point by the equivalent diffusion factor from 1D impeller theory:

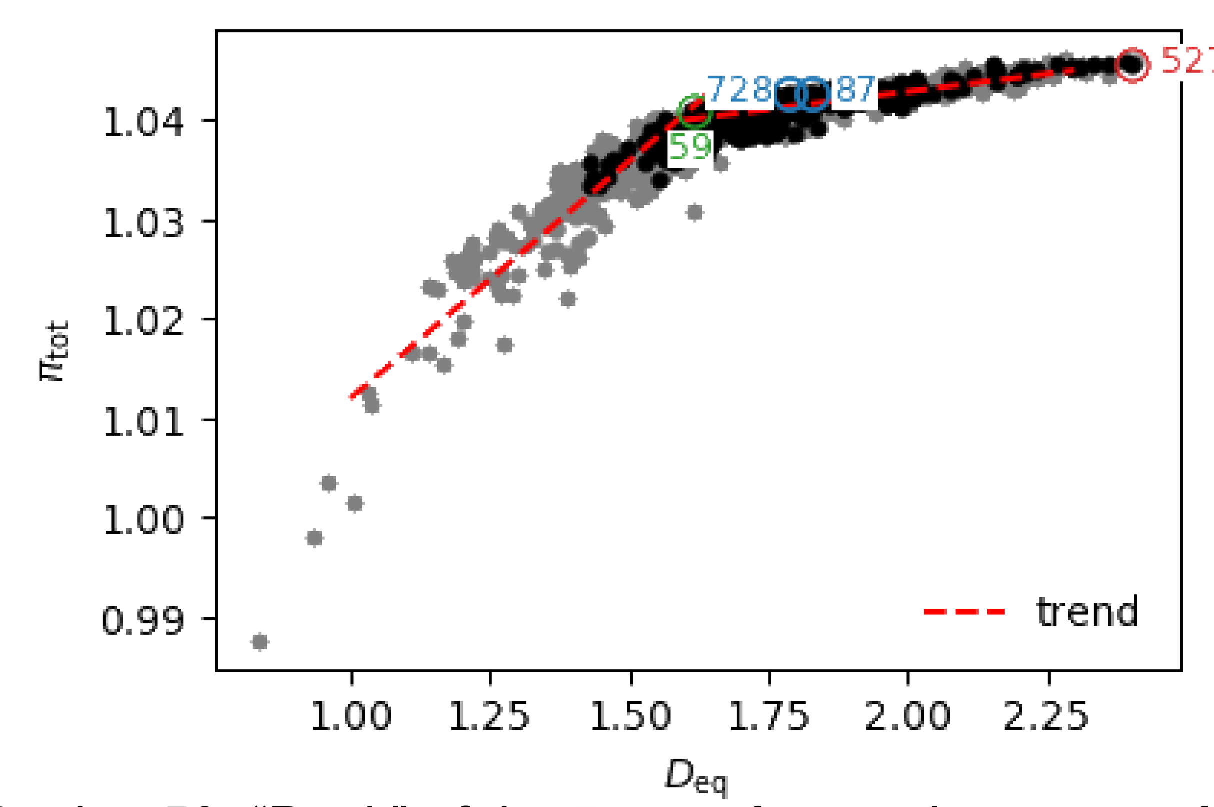
$$D_{eq} = \frac{w_{max}}{w_2} = \frac{1}{2 \cdot w_2} \cdot \left(w_1 + w_2 + \frac{2\pi \cdot d_2 \cdot u_2 \cdot I_B}{z_{eq} \cdot L_B} \right)$$

- Full optimization target:

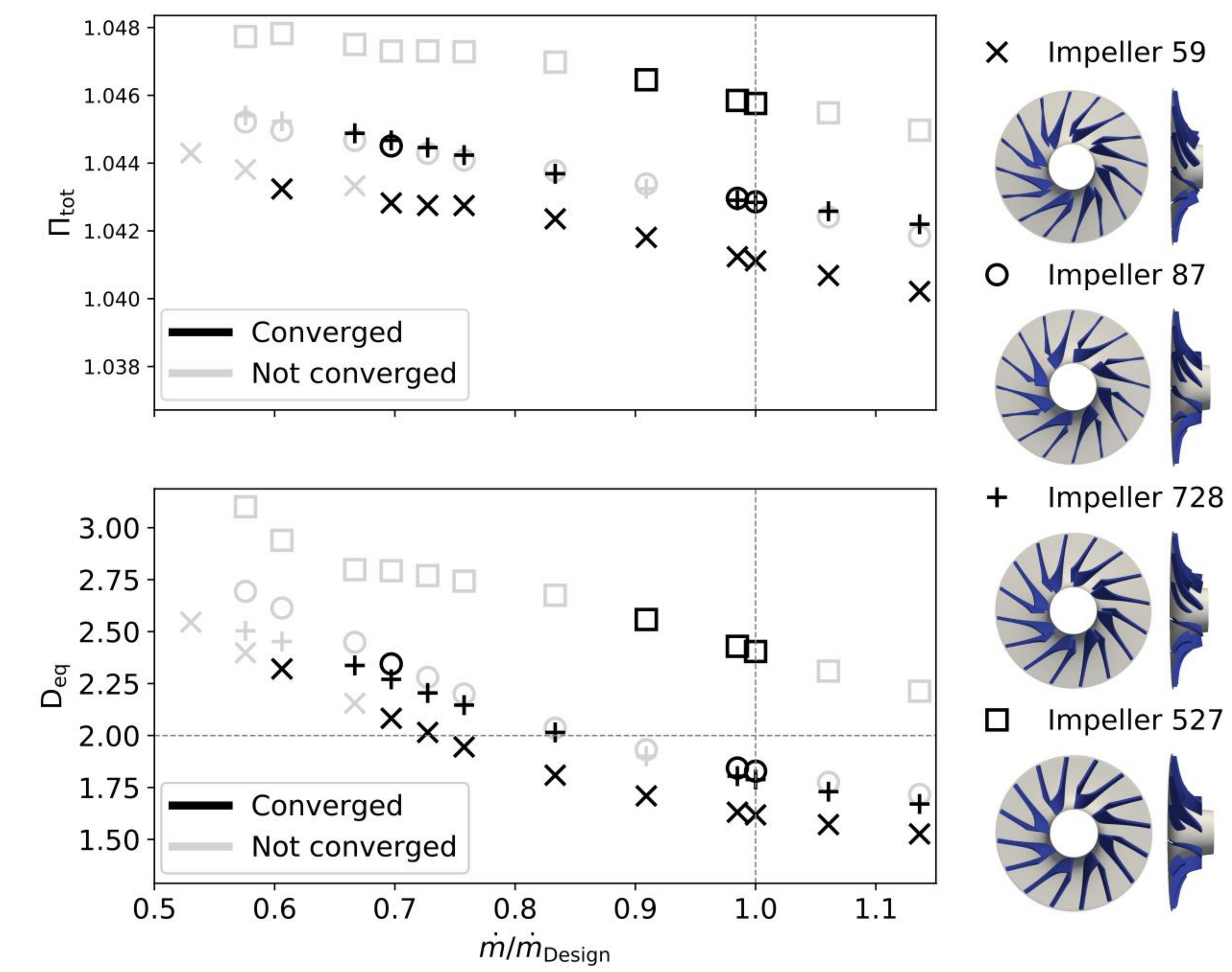
$$\min(D_{eq}) \wedge \min(w_2) | \, \pi_{tot} \geq 1.036$$

Optimization results

- Evaluation of 1067 designs in total
- Selection of 4 designs with various D_{eq} to verify the optimization target

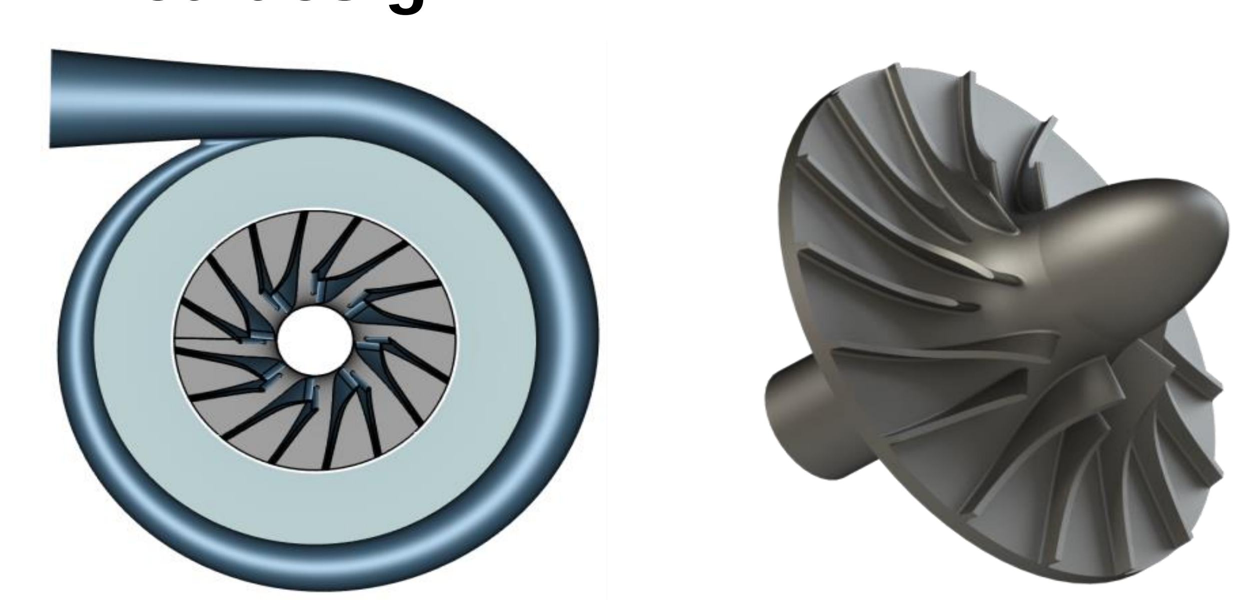


- Design 59: "Peak" of the Pareto front at lowest D_{eq} from which only small changes in π_{tot} occur for higher D_{eq}
- Designs 728, 87: Compromise between higher π_{tot} and low D_{eq}
- Design 527: Highest D_{eq}



- Comparison of performance lines validates suitability of D_{eq} to be used as an indicator for a wide operating range
- Differences for impeller 728 and 87 shows that D_{eq} is an indicator but not a guarantee for a wide and stable range
- Impeller design 728 shows the best compromise of a wide operating range and high values for π_{tot}

Optimized design



- Based on the selected impeller a solid model and a stage design were created for further evaluation

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