4th European sCO_2 conference for energy systems

Numerical Investigation Of A Simple Regenerative Heat To Power System With Coupled Or Independent Turbomachinery Drives

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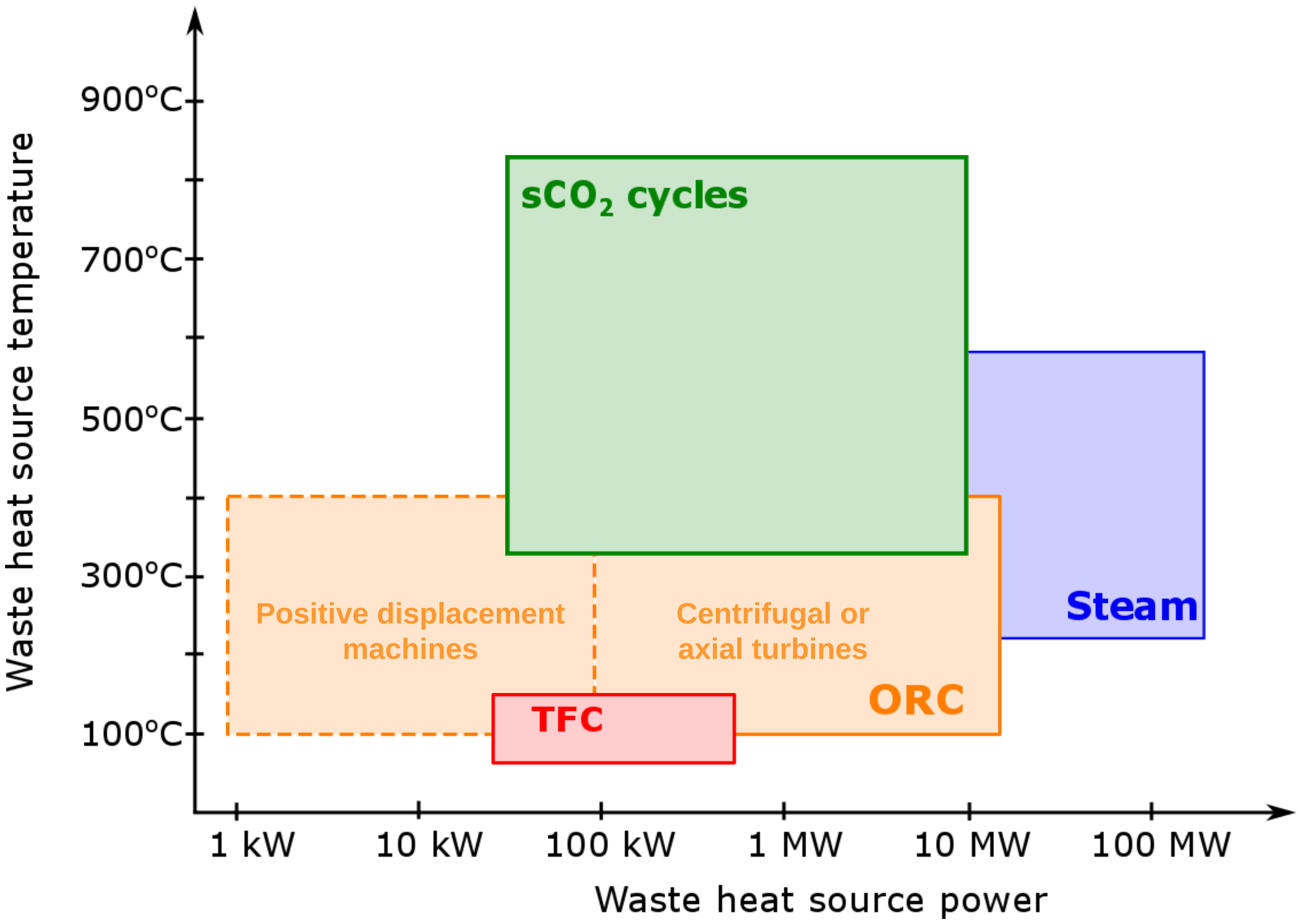
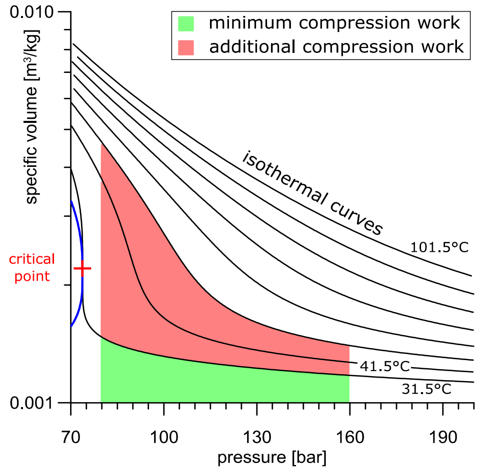
Outline

- sCO_2 power cycles for Waste Heat Recovery
- Coupled vs Independent turbomachinery drives
- Modelling methodology and calibration
- System model and optimisation analysis
- Conclusions and Future work

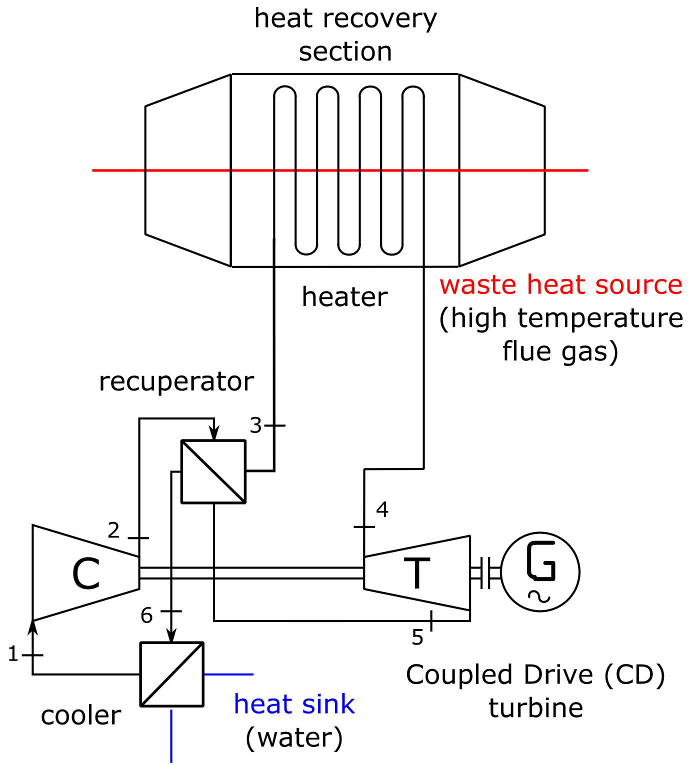
sCO_2 power cycles in Waste Heat Recovery



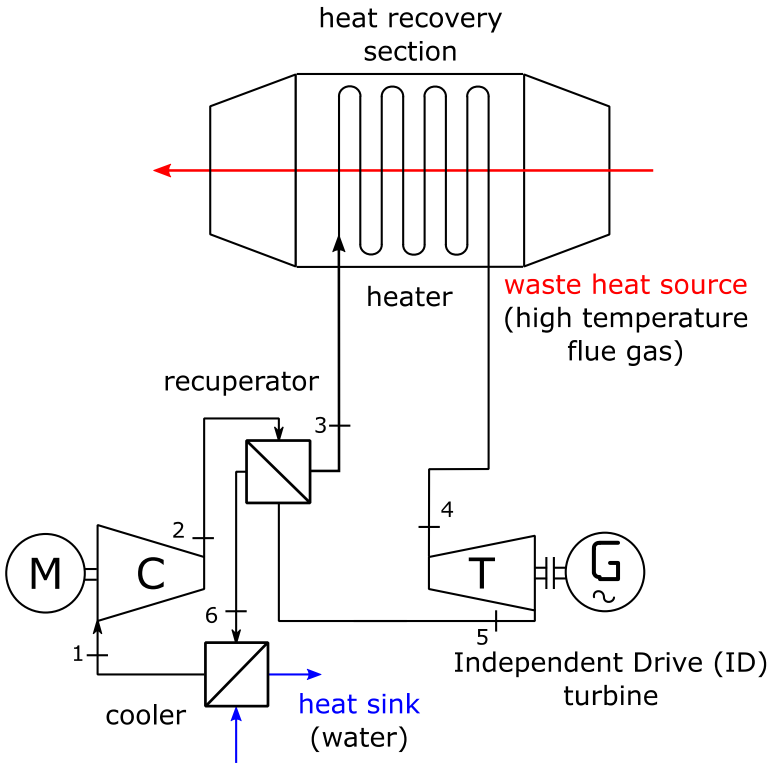
Higher efficiency



Turbomachinery drives for simple regenerative sCO_2 power cycles



Coupled Drive (CD)



Independent Drive (ID)

Research Methodology

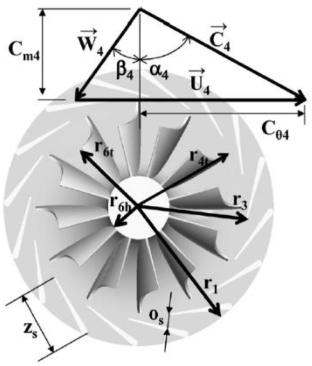
Turbine Design

1D Modelling

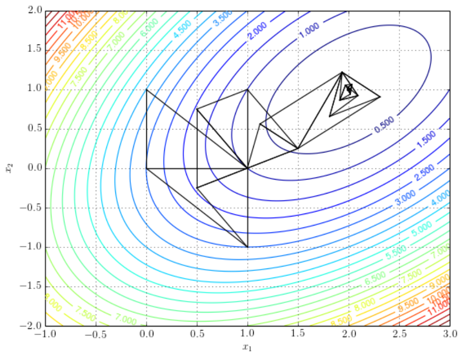
Model calibration

System analysis

Optimisation



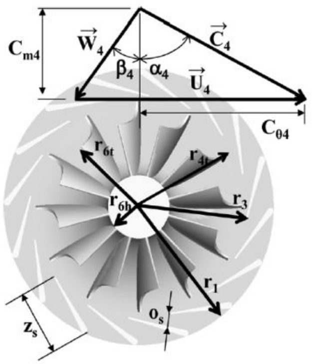
I-ThERM

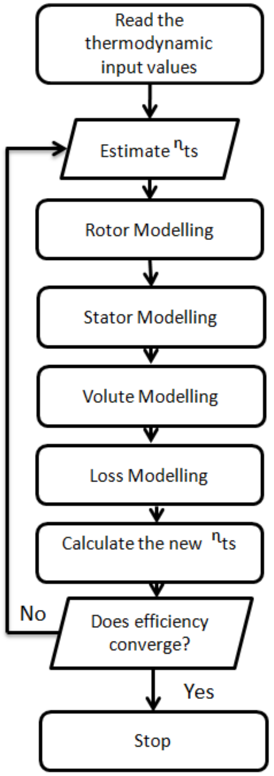


Radial Turbine Design and modelling approach

Radial Turbine Design

RTD

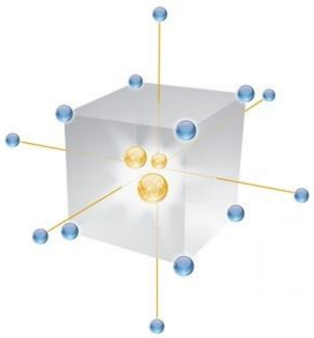




- Rotor
- Stator
- Volute
- Losses

Radial Turbine Optimisation

RTO



Advanced numerical methods for optimization:

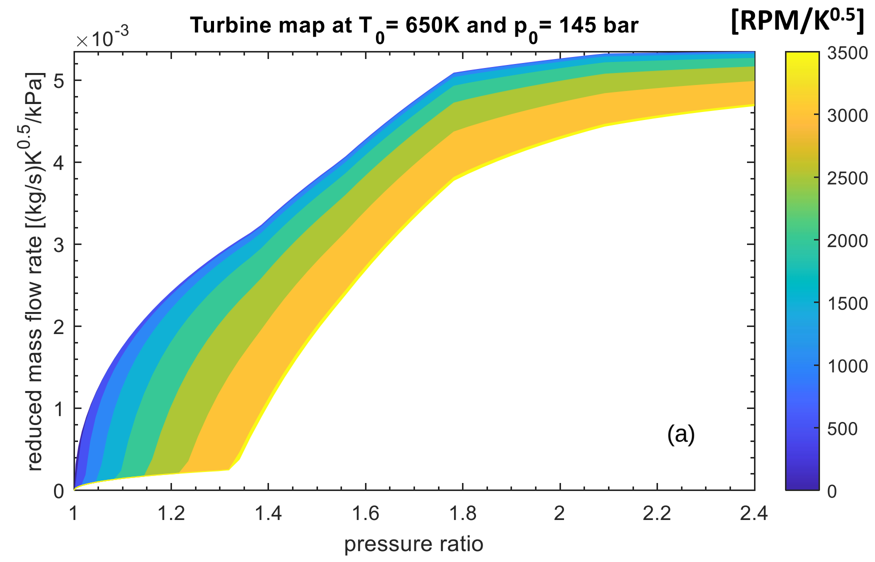
- Objective function
- DoE

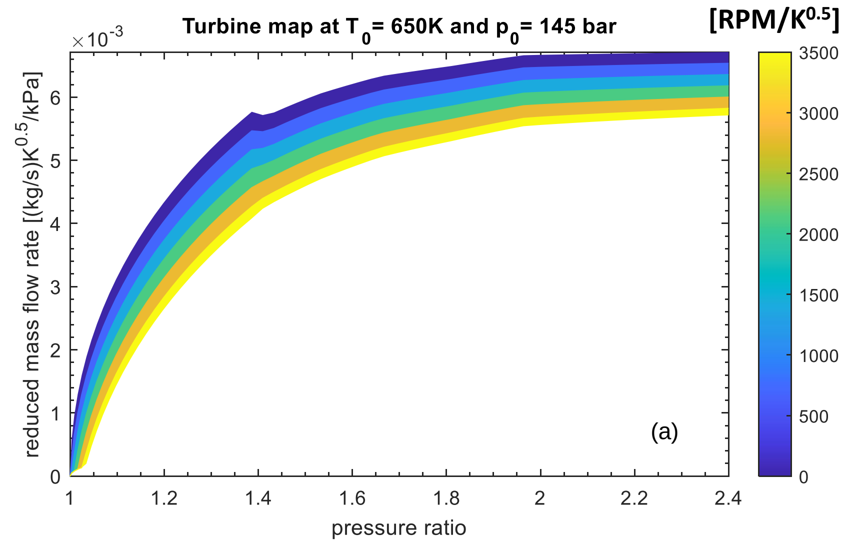
Operating Map

Coupled Drive (CD)

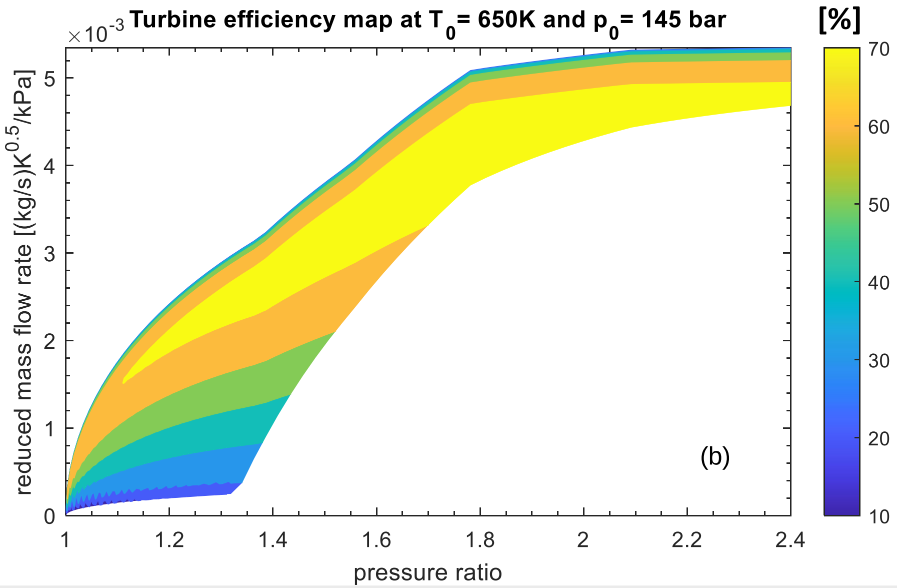
Independent Drive (ID)

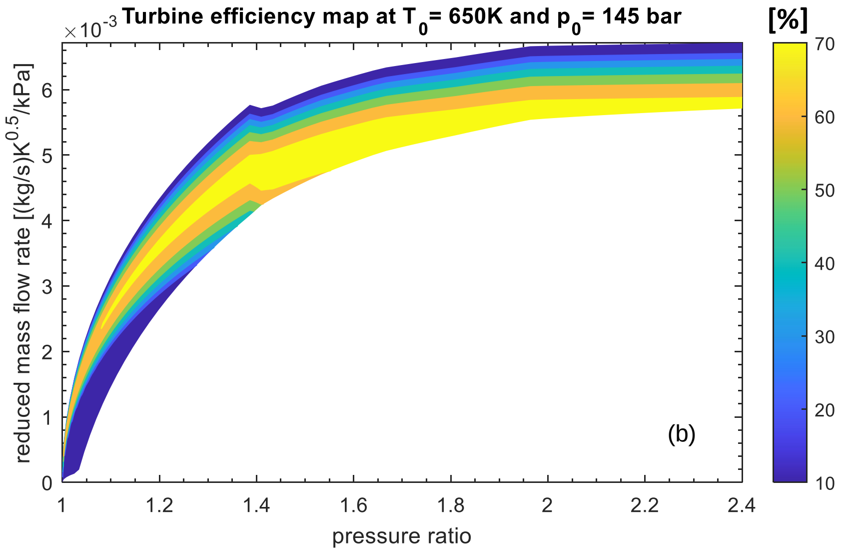
performance



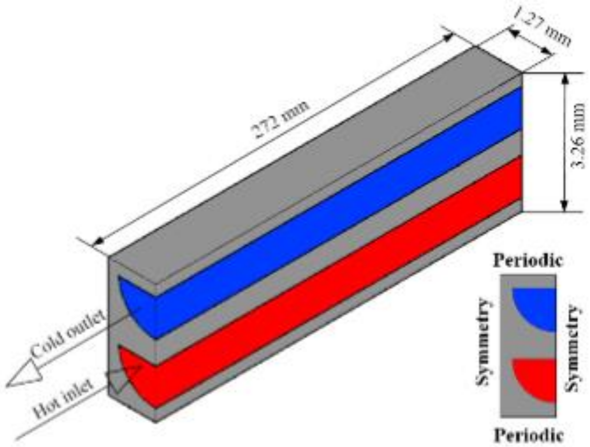


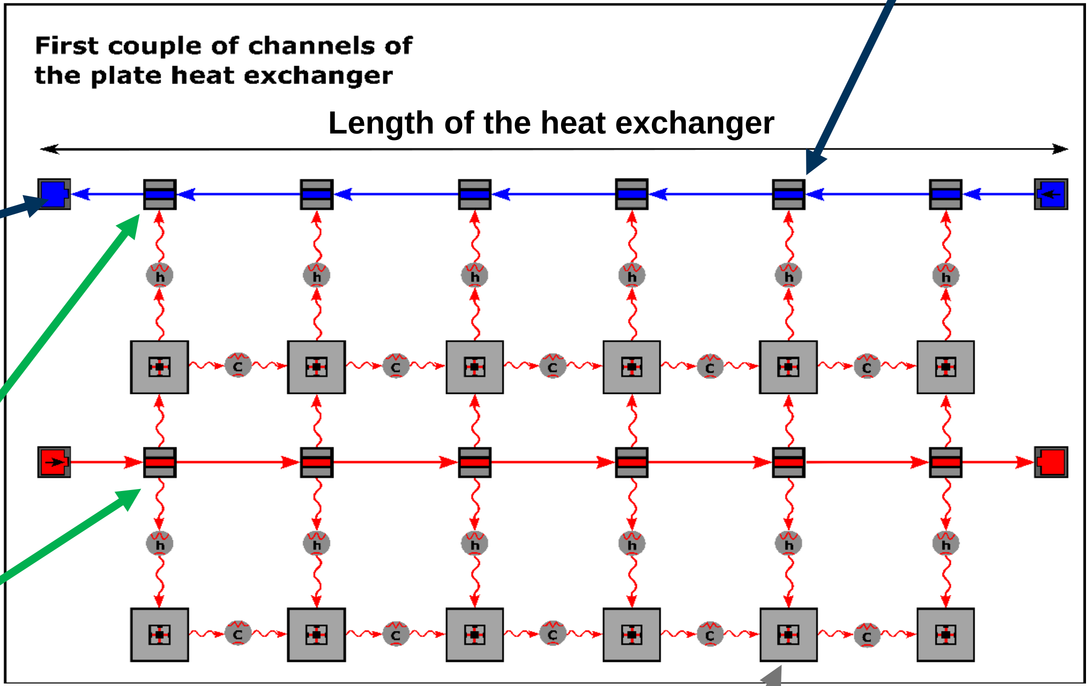
Total-static efficiency





Heat exchangers





1D channels discretized (geometry, discretization length)

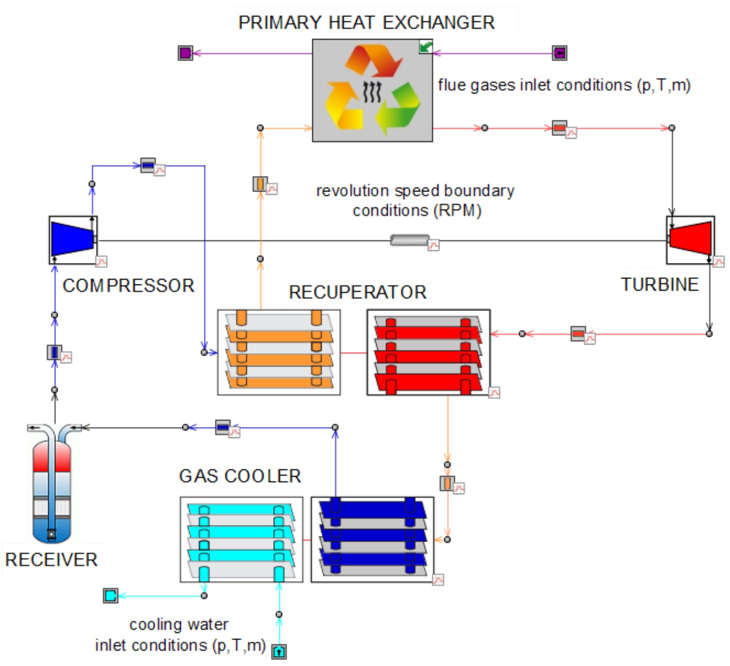
Boundary conditions

1D Navier-Stokes equation solution in each sub-volume

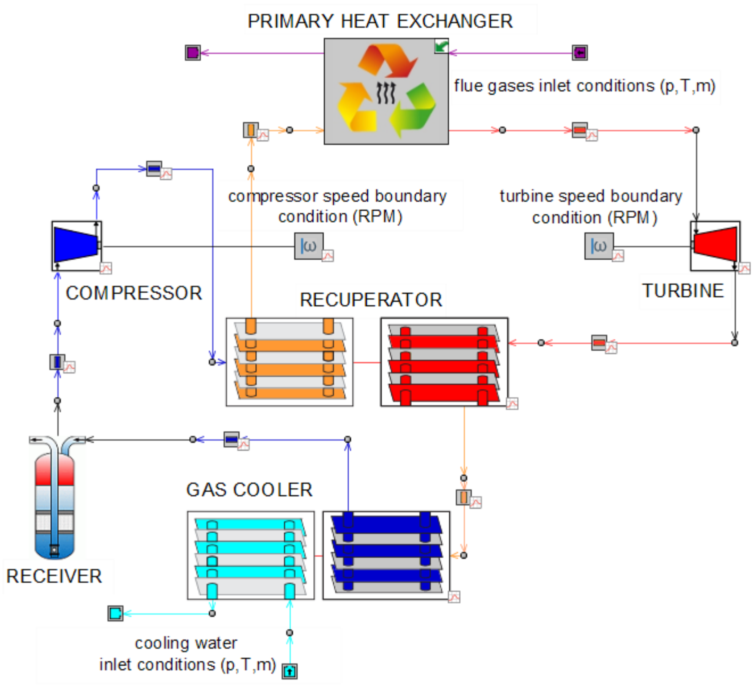
Heat exchanger thermal inertia (geometry, material properties)

System models

Coupled Drive (CD)



Independent Drive (ID)



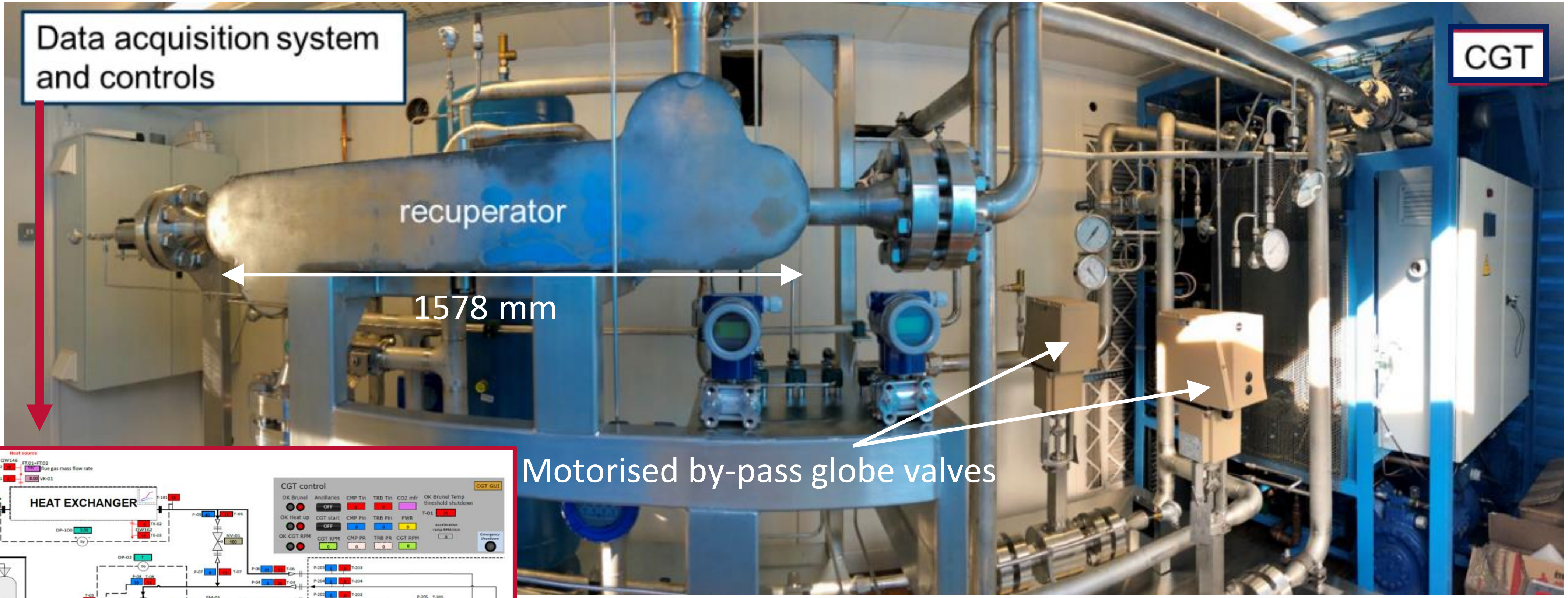
- Boundary conditions (CD & ID)
  - heat sink/source mass flow rate
  - Heat sink/source inlet temperature
  - Revolution speed of the shaft (CD only)
  - Revolution speed for turbine and compressor (ID only)
- Assumptions (CD & ID)
  - Heat and pressure losses neglected in pipes
  - Refprop for the fluid thermo-physical properties
  - Power quantities purely mechanical

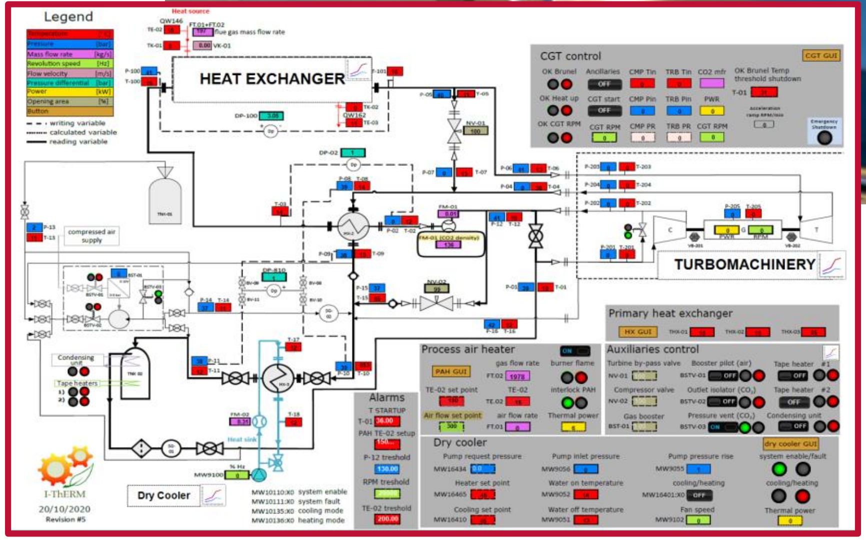
Calibration against I-ThERM sCO_2 demonstrator equipment

Process Air Heater (800 kW) and sCO_2/gas heater

- 50 kW simple regenerative layout
- High temperature flue gas as heat source and water as heat sink
- Micro-tube sCO_2 heater
- Single shaft turbomachinery

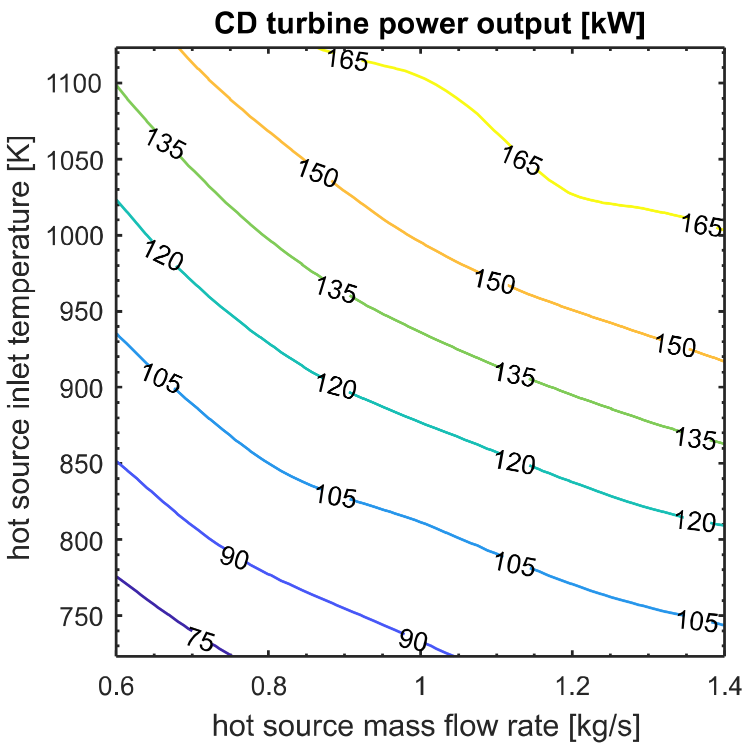
Calibration against I-ThERM sCO_2 demonstrator equipment

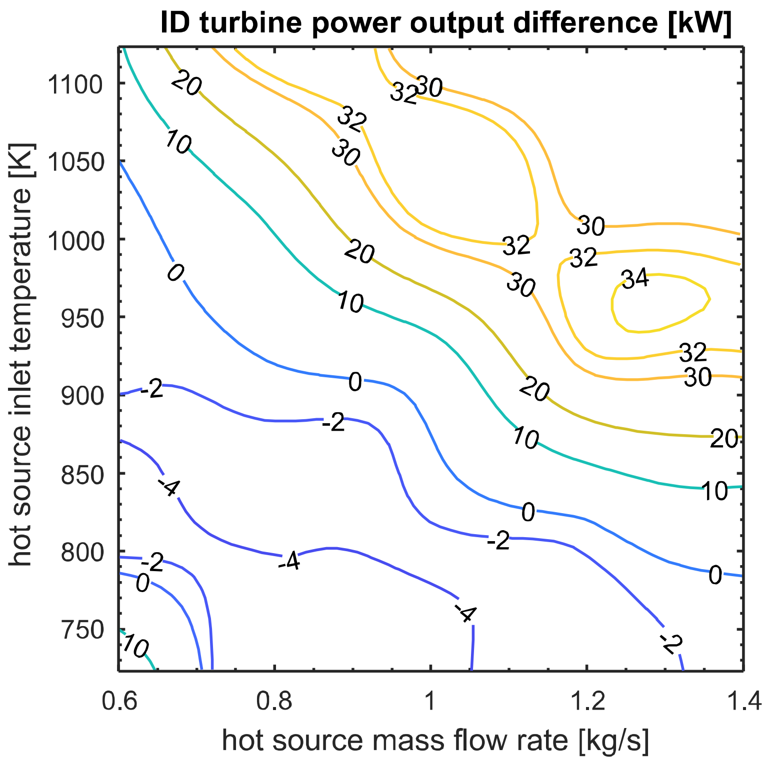




- Printed circuit recuperator
- Plate heat exchanger as gas cooler
- Supervisory control system IEC 61499 standard

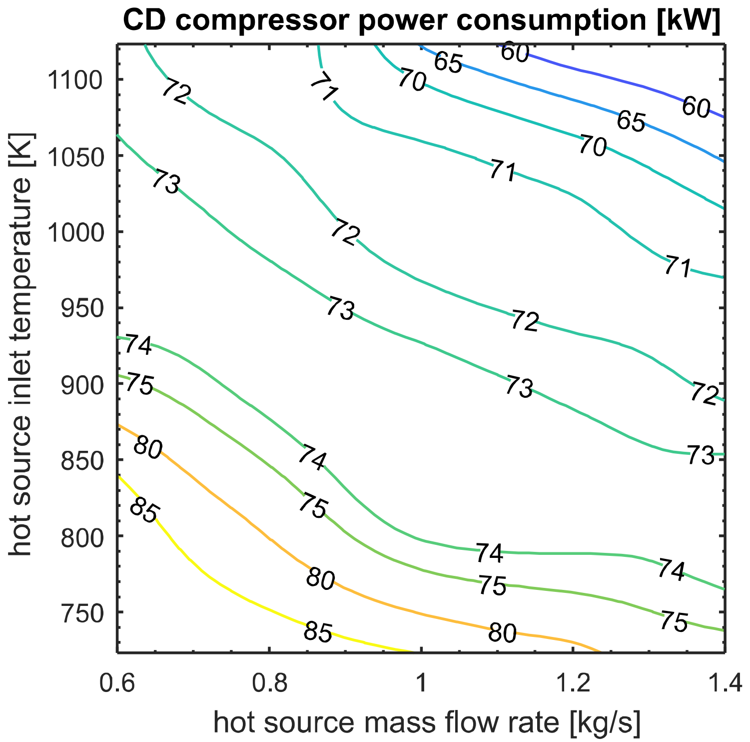
Turbine performance in CD and ID configurations

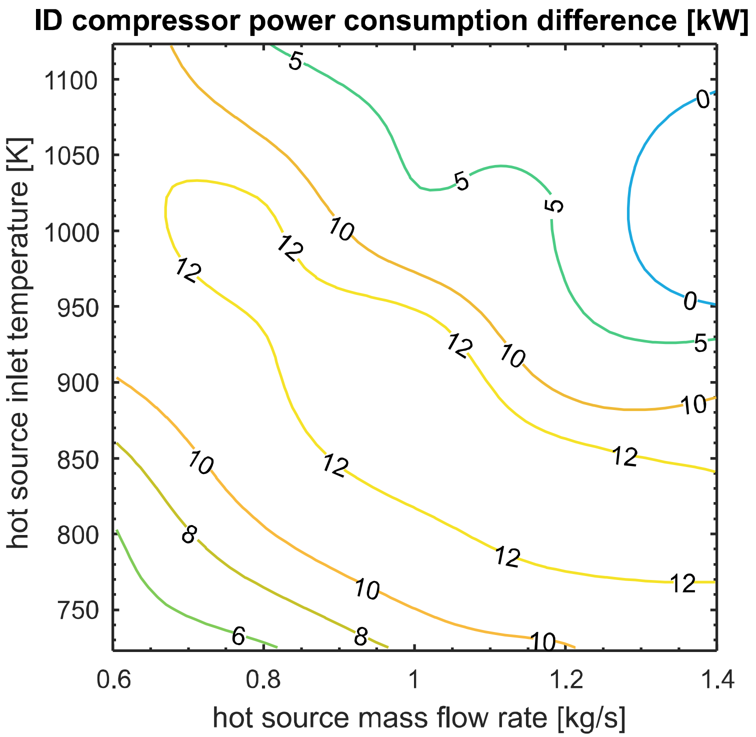




- At nominal conditions (HS mass flow rate and temperature of 1 kg/s and 923.15K) the two turbine generate same power output (120 kW);
- Independent drive (ID) configuration allows to improve the generated turbine output by 36.4% at higher heat loads;
- Performance increase due to the higher CO_2 mass flow rate processed by the turbine in ID case

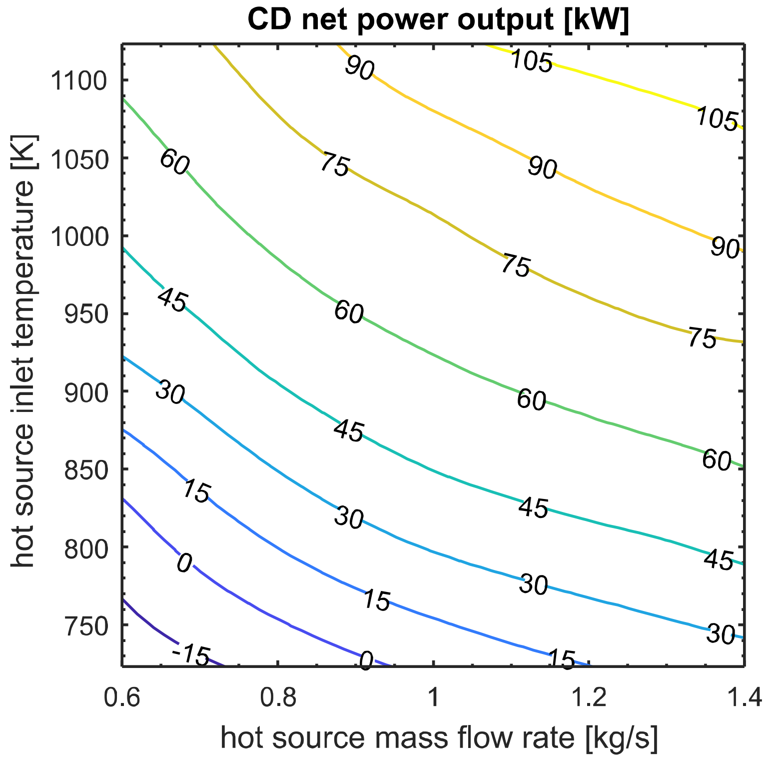
Compressor performance in CD and ID configurations

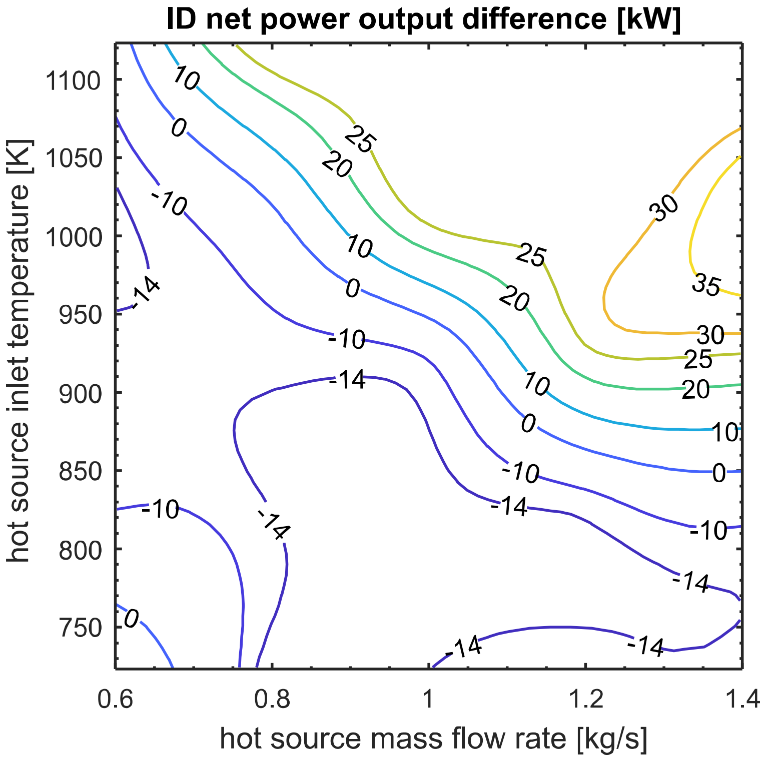




- Higher mass flow rate processed in the ID configuration leads to slightly lower compressor performance at nominal conditions (10 kW increase in power consumption);
- In general, compressor power consumptions do not change consistently with the configuration selected;

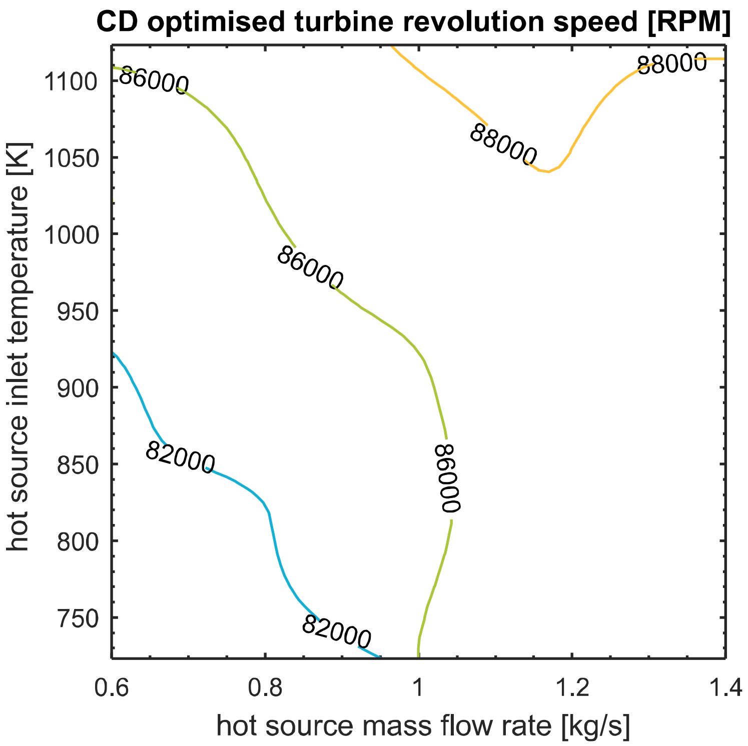
System net power output in CD and ID configurations

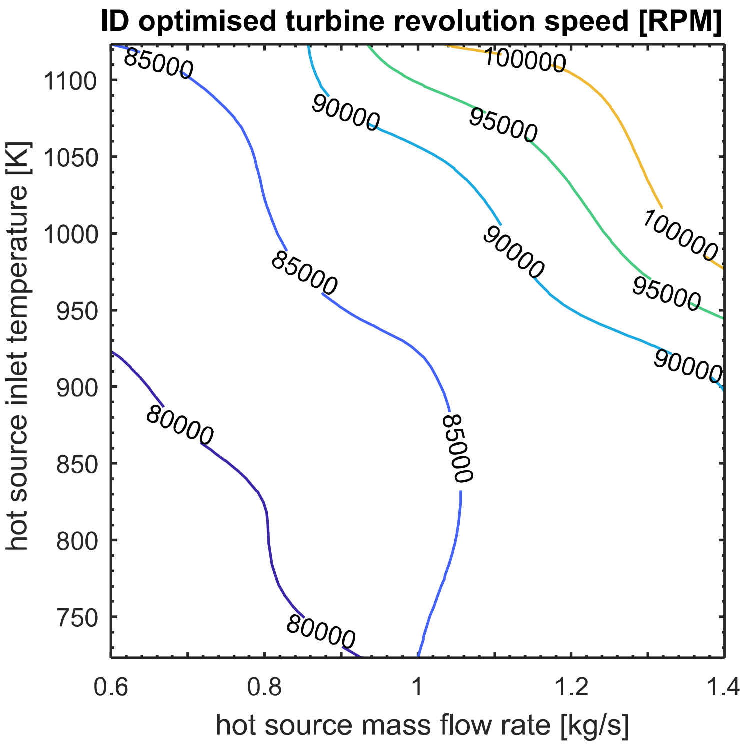




- Adoption of ID configuration allows to increase the system net power output up to 140 kW for waste heat source temperatures higher than 950K;
- At lower heat loads system net power output shows -10 kW decrease compared to CD case.
- Independent drive solution only beneficial for part-load operating conditions exceeding the design point.

Optimised turbomachinery revolution speeds





- In CD configuration the optimised revolution speed does not change consistently with heat load variations;
- In ID case increasing the turbine revolution speed at higher heat loads allows to slightly increase the CO_2 mass flow rate in the sCO_2 loop with positive impact for system net power output.

Conclusions

- Simple regenerative sCO_2 system model developed with component data obtained from the construction of a 50 kW sCO_2 demonstrator at Brunel University London (Couple and Independent drive configurations)

- ID configuration allows better performance at higher heat loads thanks to the turbine design unconstrained by compressor one

- At lower heat loads the ID configuration does not allow any significant improvement of the system performance (compressor design must be considered)

- Future work will consider
  - ✓ Cost and scale aspects for optimal techno-economic design of simple regenerative sCO2 power units
  - ✓ Aerothermal compressor design optimisation
  - ✓ Scalability for large sCO2 power applications by considering axial turbomachines rather than radial ones

Acknowledgement

I-ThERM

The Industrial Thermal Energy Recovery Conversion and Management project aims to

investigate, design, build and demonstrate innovative plug and play waste heat recovery solutions to facilitate optimum utilisation of energy in selected applications with high replicability and energy recovery potential in the temperature range 70°C – 1000°C

www.itherm-project.eu

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