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# Two-phase chamber modelling of a twin-screw expander for Trilateral Flash Cycle applications

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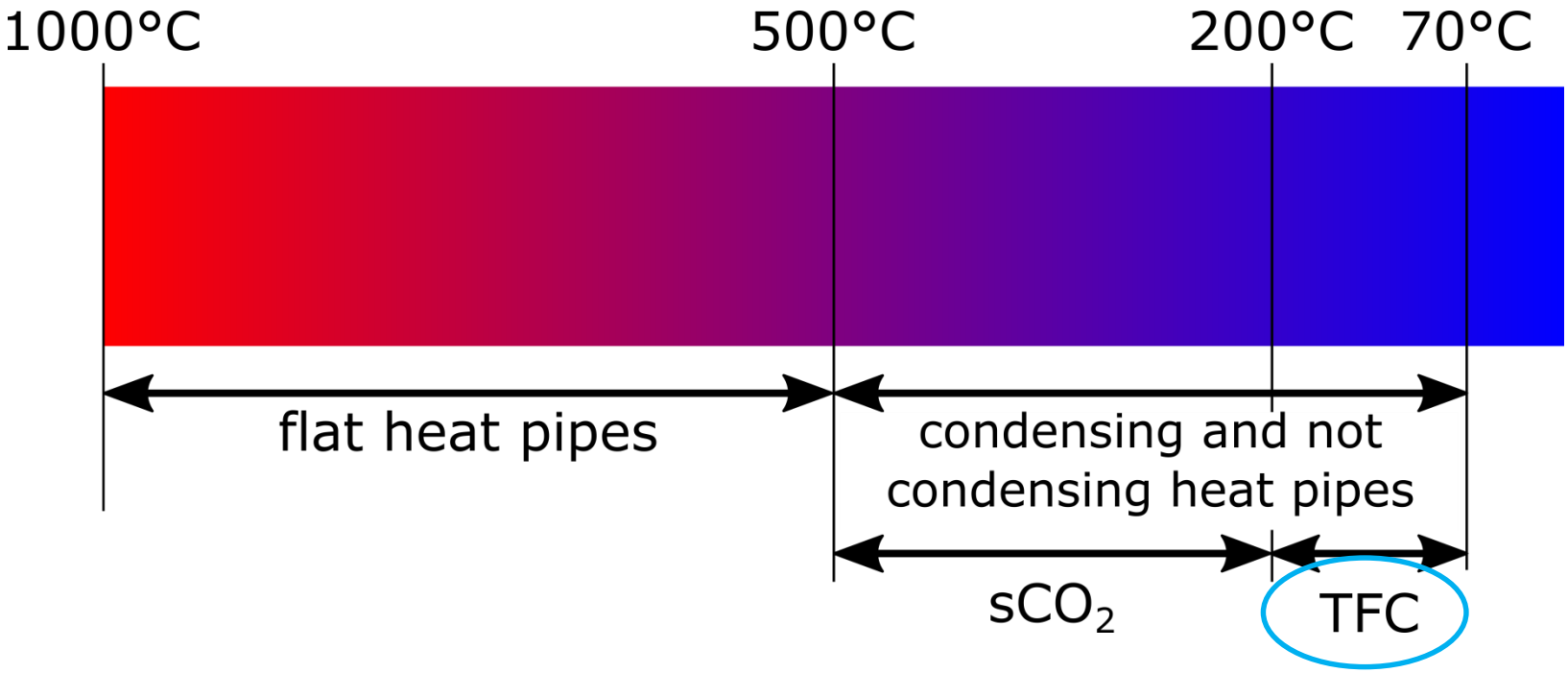
spirax sarco
Howden

# **I-ThERM** Project aim is 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℃ – 1000℃*

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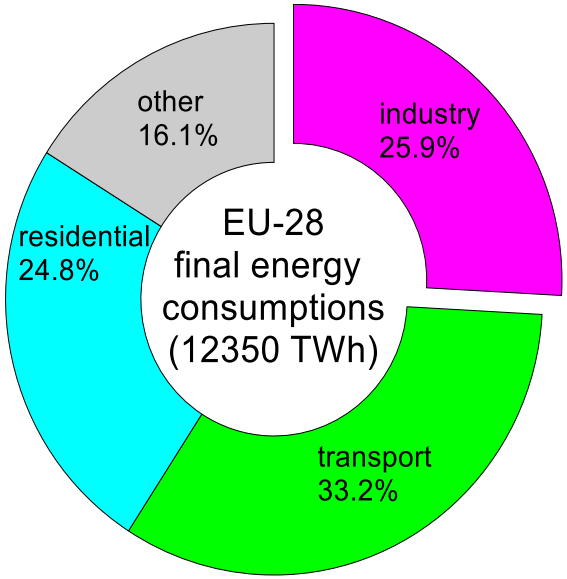
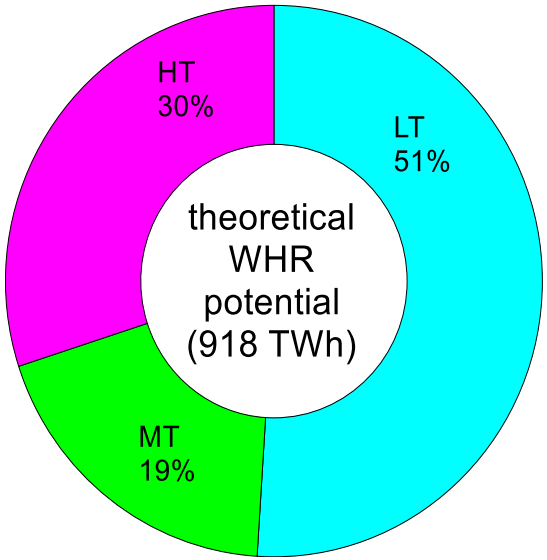
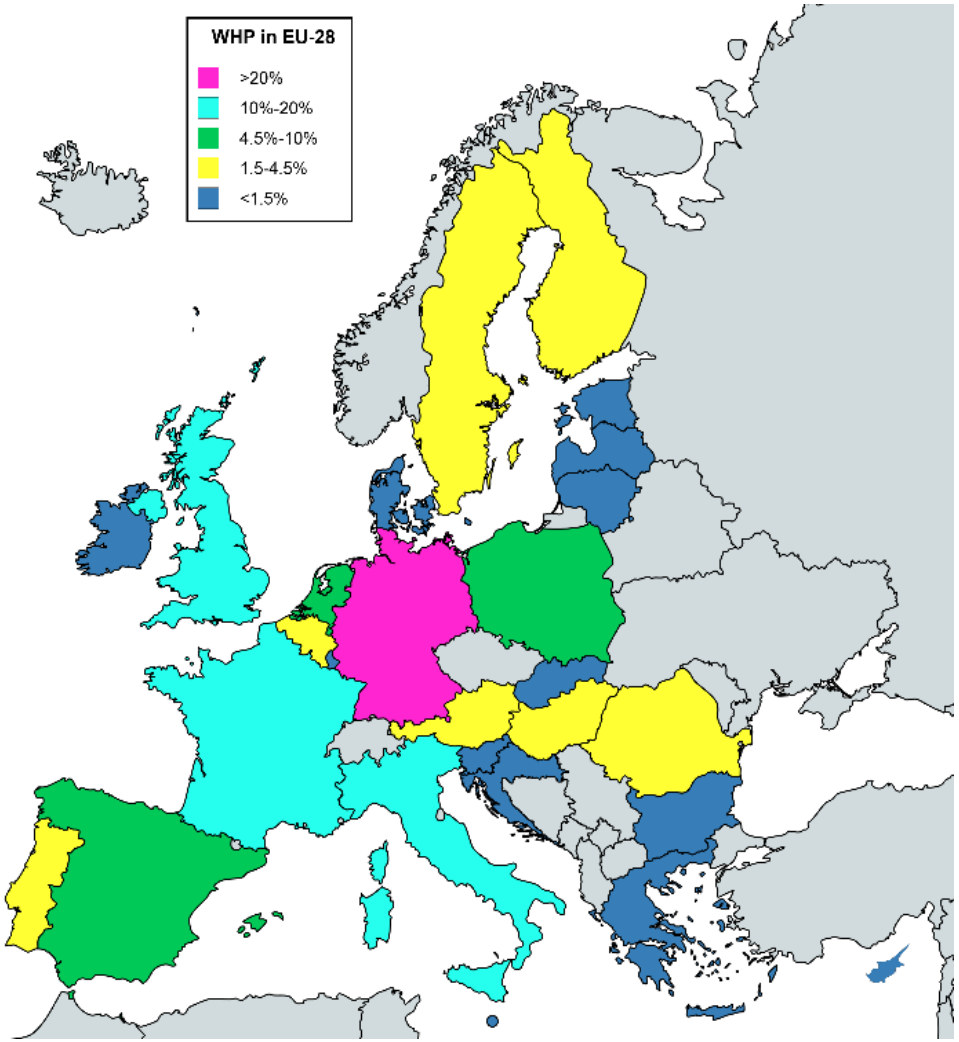
# The opportunity

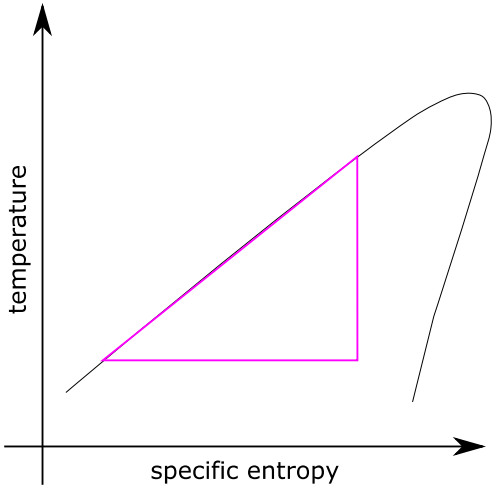


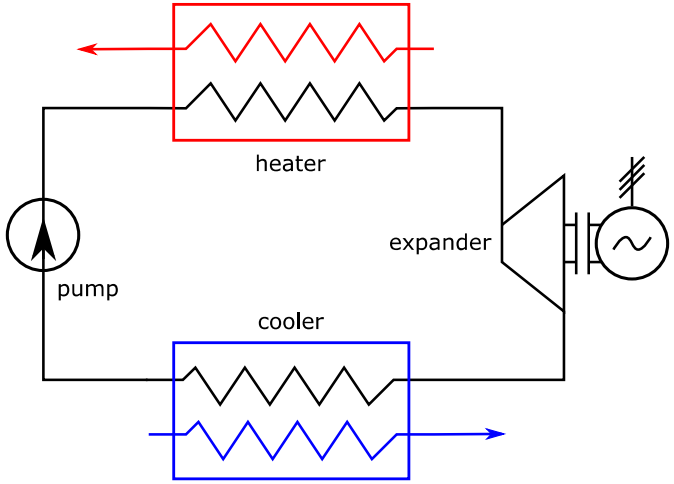



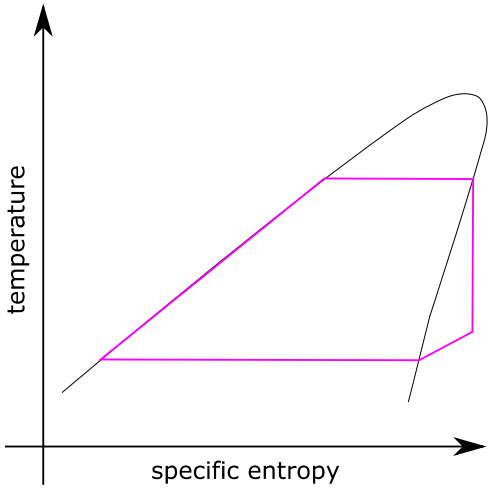




[elaborations from Eurostat database + Forman et al. 2016]

# TFC vs ORC




Single phase heat recovery

- High exergetic efficiency
- High mass flow rate

Two-phase expansion

- High isentropic efficiency
- Large density changes

Multi-phase heat recovery

- Compact heater (evaporator)
- Worse heat utilization

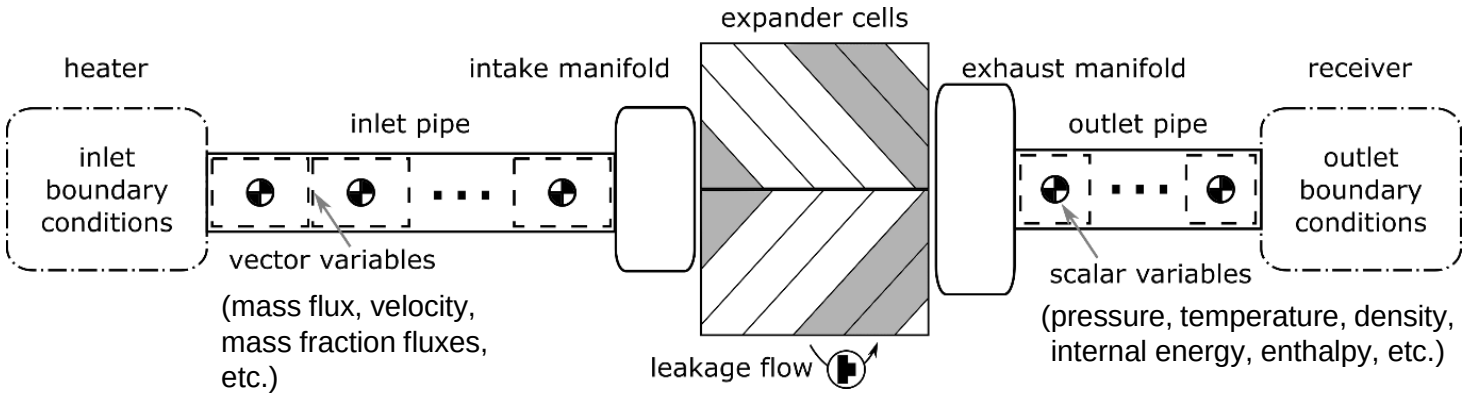
Single phase expansion

- Safer blade environment
- Realistic expansion ratios

# Outline

- ✓ Potential for low grade waste heat to power conversion through TFC systems
- ❑ Modelling approach
- ❑ Input data for twin-screw machines
- ❑ Test case
- ❑ Parametric analyses
- ❑ Next challenges

# Modelling approach




- One-dimensional formulation of Navier-Stokes equations
- Staggered grid spatial discretization
- Leakage paths as orifices

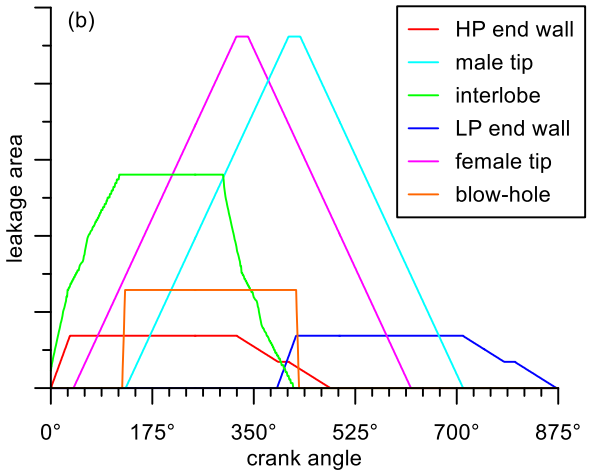
$$\gamma = \gamma_{vap}\, x + \gamma_{liq}\,(1-x)$$

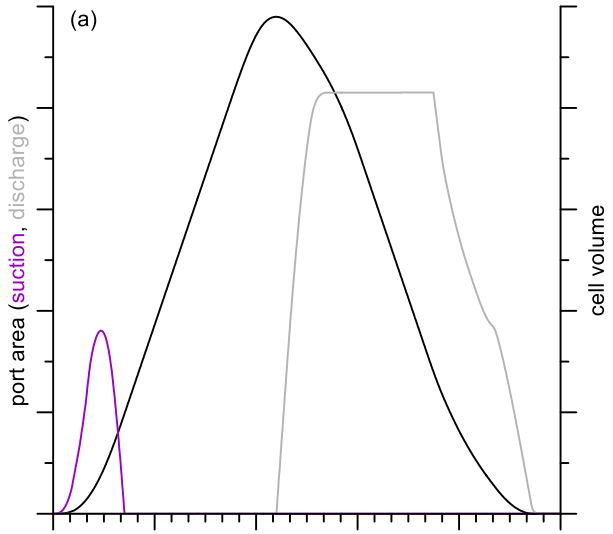
- Thermo-physical properties from REFPROP® v9.1
- Explicit Runge-Kutta scheme

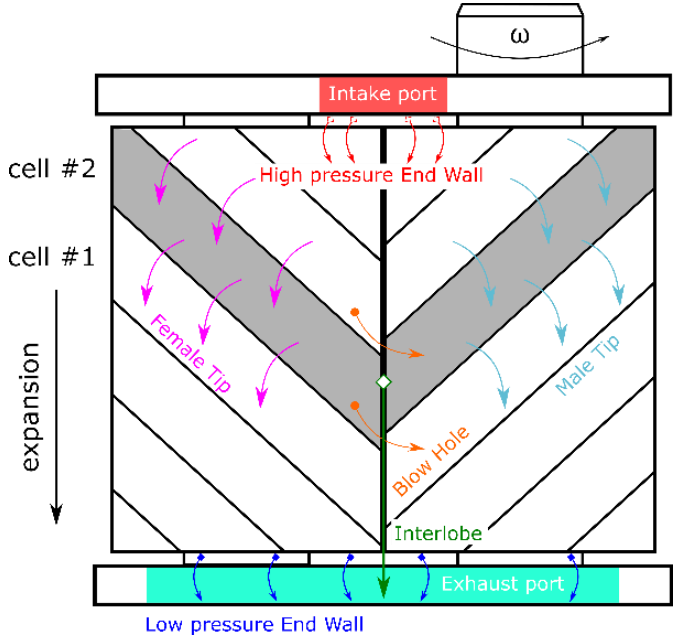
# Input data

## Geometrical data from pre-processor or CAD drawings

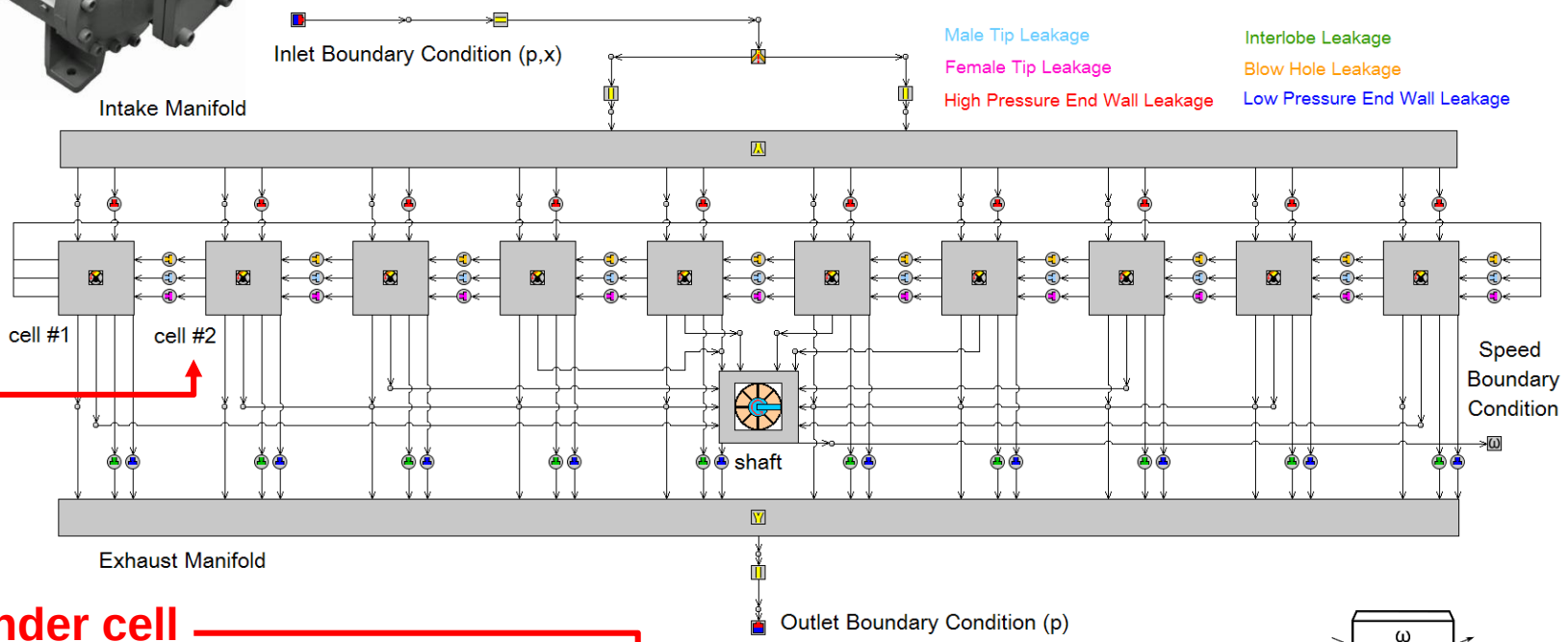
| | |
|---|---|
| Rotor Diameter | 127 mm |
| Aspect Ratio (L/D) | 1.65 |
| Built-in Volume ratio | 5 |
| Male / Female rotor lobes | 4/6 |
| Suction / Discharge ports arrangement | axial / axial |
| Revolution speed range | 1500-6000 RPM |
| Tip speed range | 10.01-40.06 m/s |
| Weight | 220 kg |



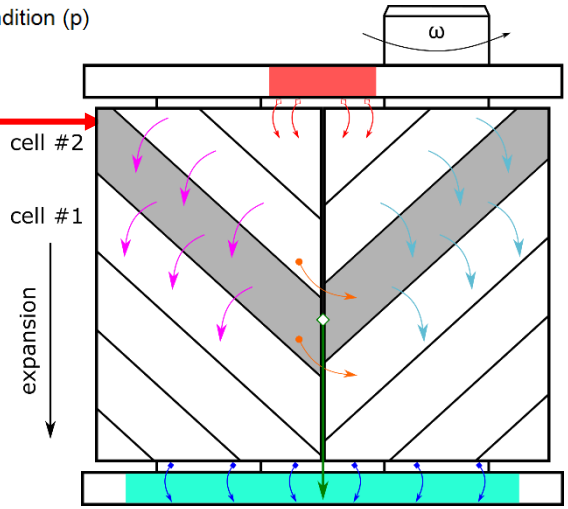



# GT-SUITE® model




**Expander cell**




## Scaling procedure

$$SF = 360 / \Delta\alpha = \omega_{sim} / \omega_{real}$$

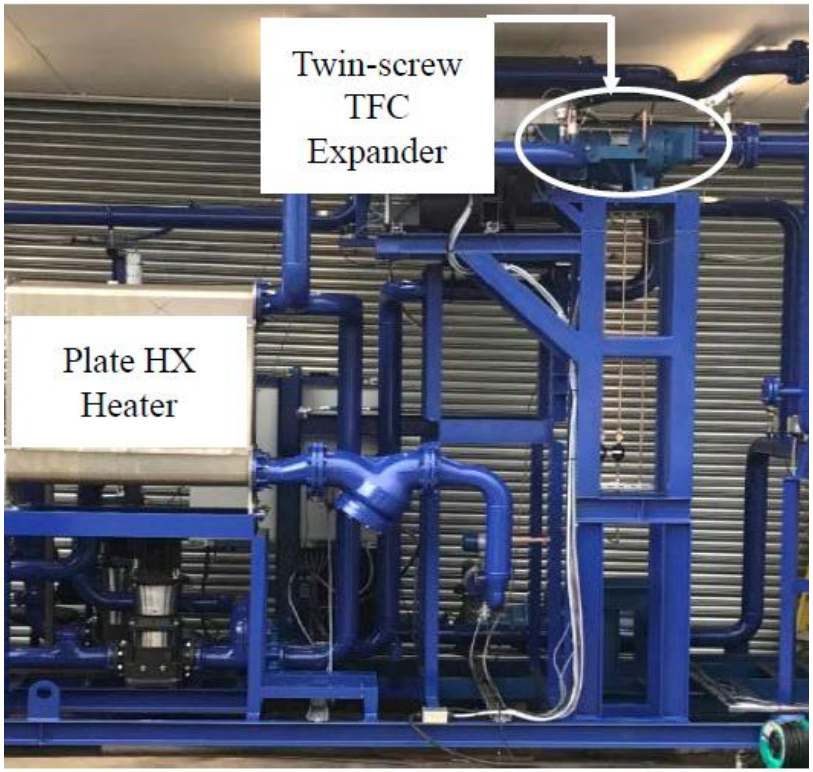
$$Z_{sim} = ceil\left(\frac{\Delta\alpha \; Z_{male}}{360}\right)$$

# Test case – TATA Steel UK

| Stream | Flowrate (kg/s) | Inlet/max Pressure (bar) | Outlet/min Pressure (bar) | Inlet Temperature (°C) | Outlet Temperature (°C) |
|---|---|---|---|---|---|
| **Waste heat stream** | 10.39 | 4 | 3.5 | 70 | 24 |
| **R245fa stream** | 31.4 | 5.47 | 1.18 | 66 | 19 |
| **Condensing water stream** | 90.85 | 4 | 3.5 | 12 | 17 |

2MW thermal

design power output
120 kW electrical

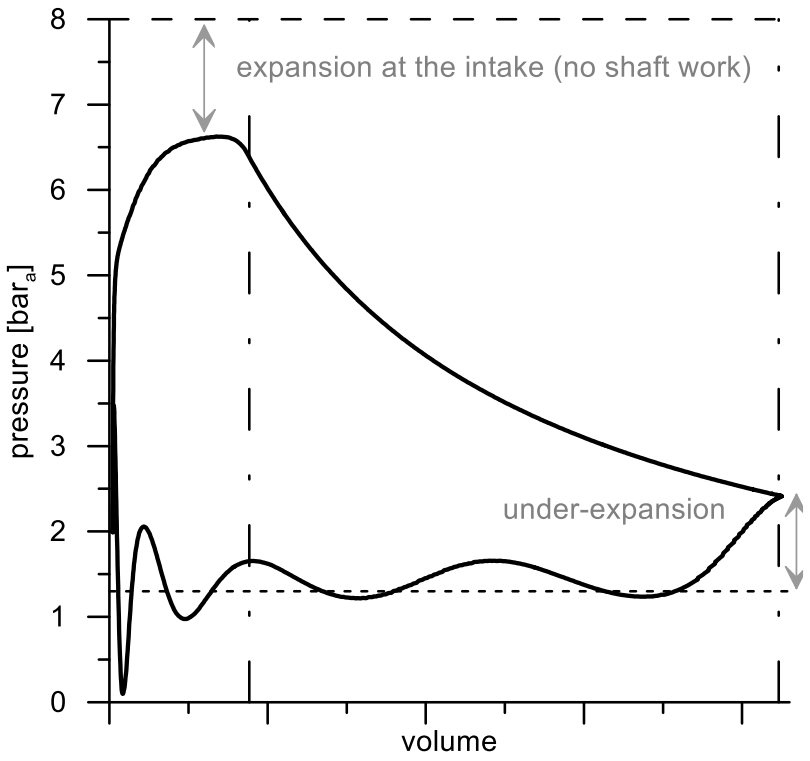



pilot test rig (1:10) at Spirax Sarco UK

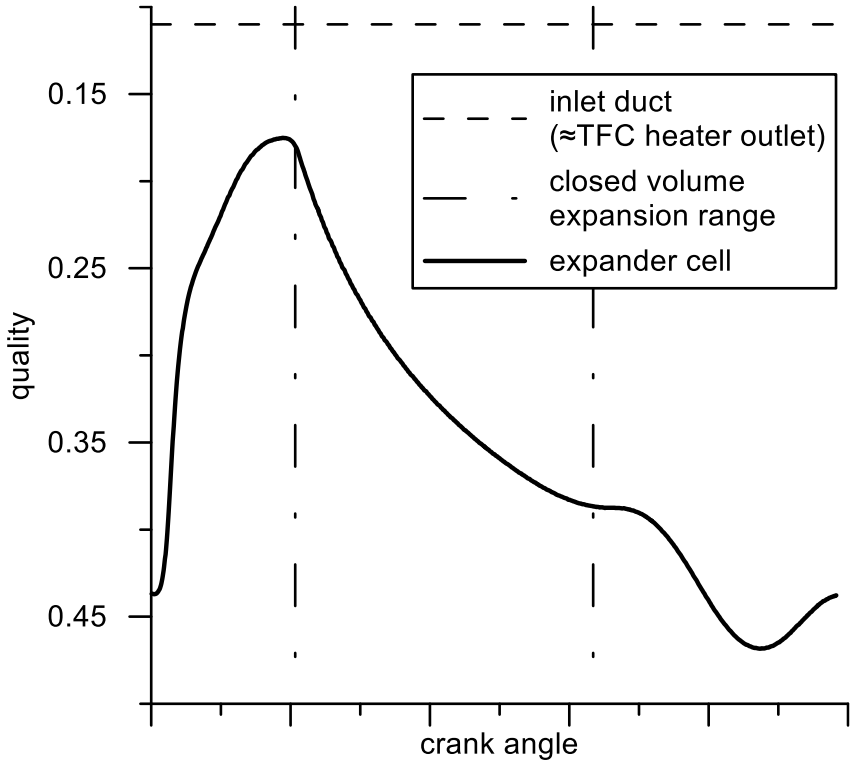
# Simulation results

| Inlet pressure | Inlet quality | Revolution speed | Outlet pressure |
|---|---|---|---|
| 8 $bar_a$ | 0.11 | 4070 RPM | 1.3 $bar_a$ |

## Indicator diagram (p-V)




## Quality-angle diagram

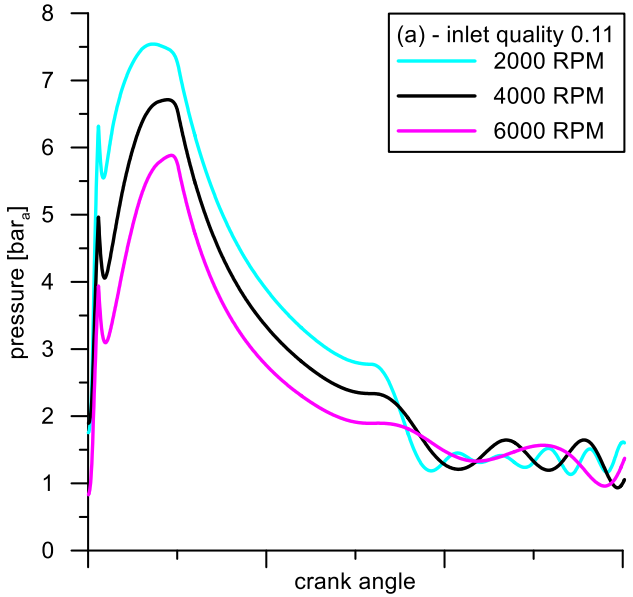


# Parametric analyses

Constant inlet quality upstream the expander

Variable revolution speed

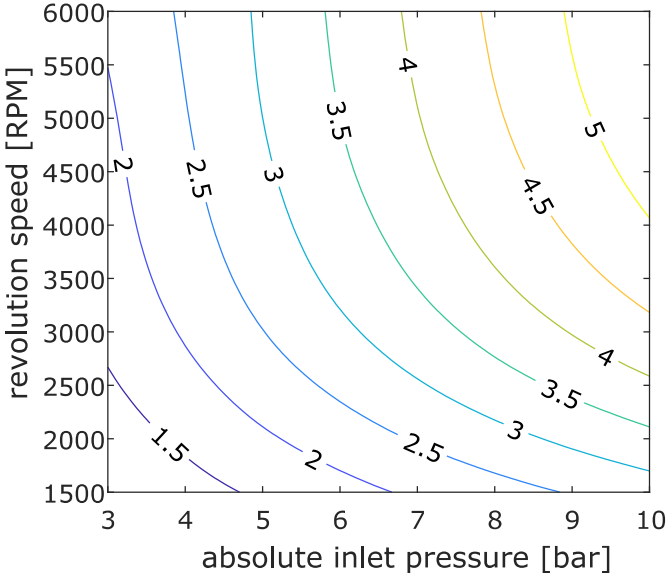
Inlet pressure 8bar




Greater revolution speeds

- Increase the expansion in the manifold
- Lower the volumetric efficiency
- Increase the indicated power, but <u>not proportionally</u>

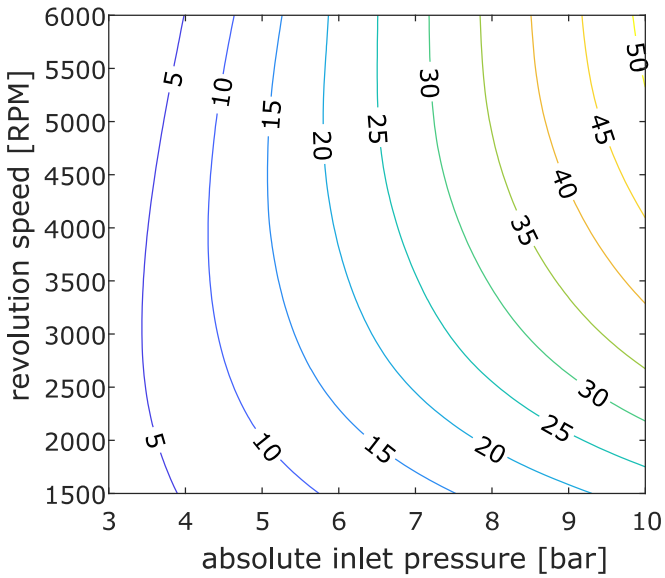
**(a) mass flow rate [kg/s]**




$$\eta_{vol} = \frac{\dot{m}}{\rho_{suc} V_{suc} Z_{male} \dfrac{\omega_{real}}{60}}$$

$$P_{ind} = Z_{male} \frac{\omega_{real}}{60} \oint pdV$$

**(b) Indicated power [kW]**



# Parametric analyses (cont'd)

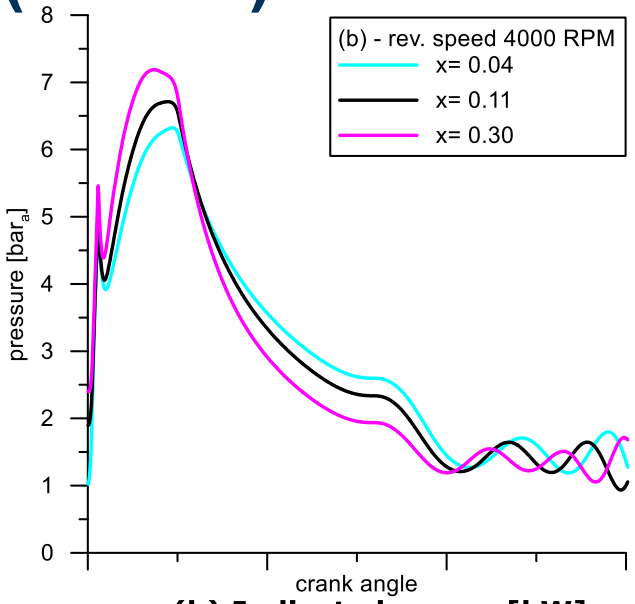
Constant revolution speed

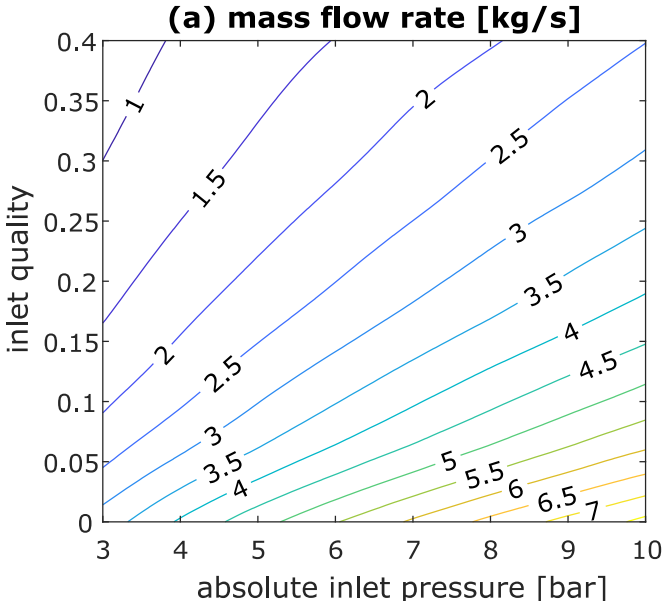
Inlet quality is set upstream the expander

Inlet pressure 8bar

A greater inlet quality

- Lowers the mass flow rate
- Increases the volumetric efficiency
- Reduces the indicated power

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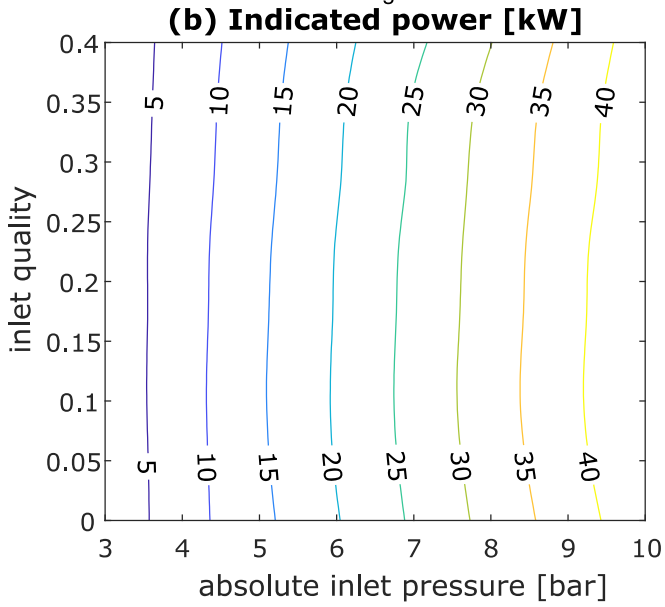
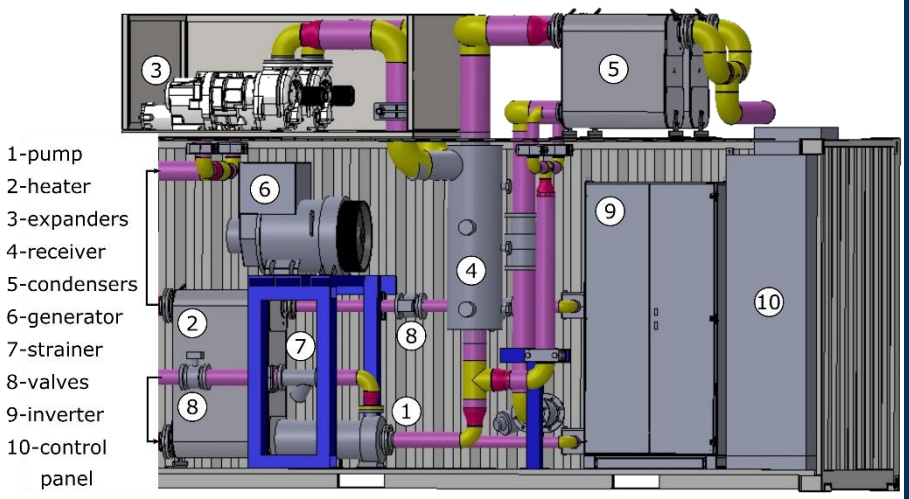


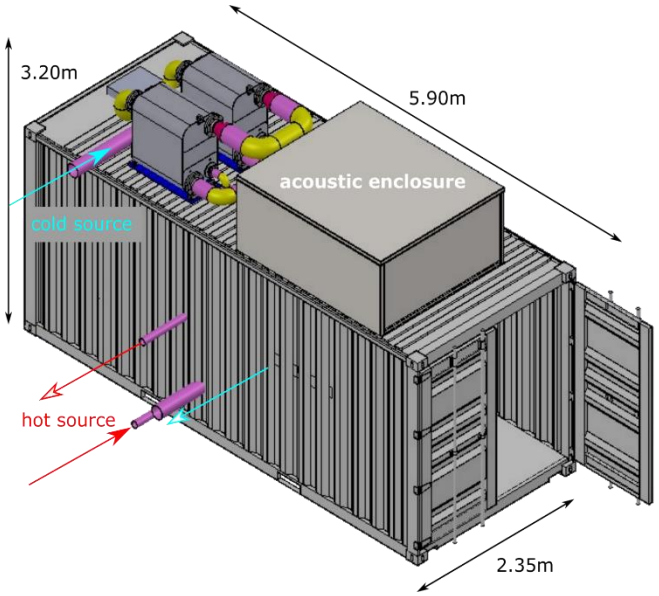
# Conclusions

- Potential of low grade heat to power conversion assessed
- Similarities and differences between TFC and ORC outlined
- Modelling procedure for twin-screw machines in GT-SUITE® developed
- A twin-screw expander for TFC applications modelled
  - Pre-expansion in the intake manifold highly affects the expander performance
  - Actual expansion ratio of the Trilateral Flash Cycle is significantly influenced by the expander operation

# Next challenges

- ✓ Upscaling the prototype unit
- ➢ Testing in real industrial environment
- ❑ Model setup on large size expanders
- ❑ Validation
- ❑ Transient modelling of the whole TFC system



# Acknowledgements


**www.itherm-project.eu**

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CSEF Centre for Sustainable Energy use in Food chains

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