Thermoacoustic Heat Pump for Very High Temperature Applications

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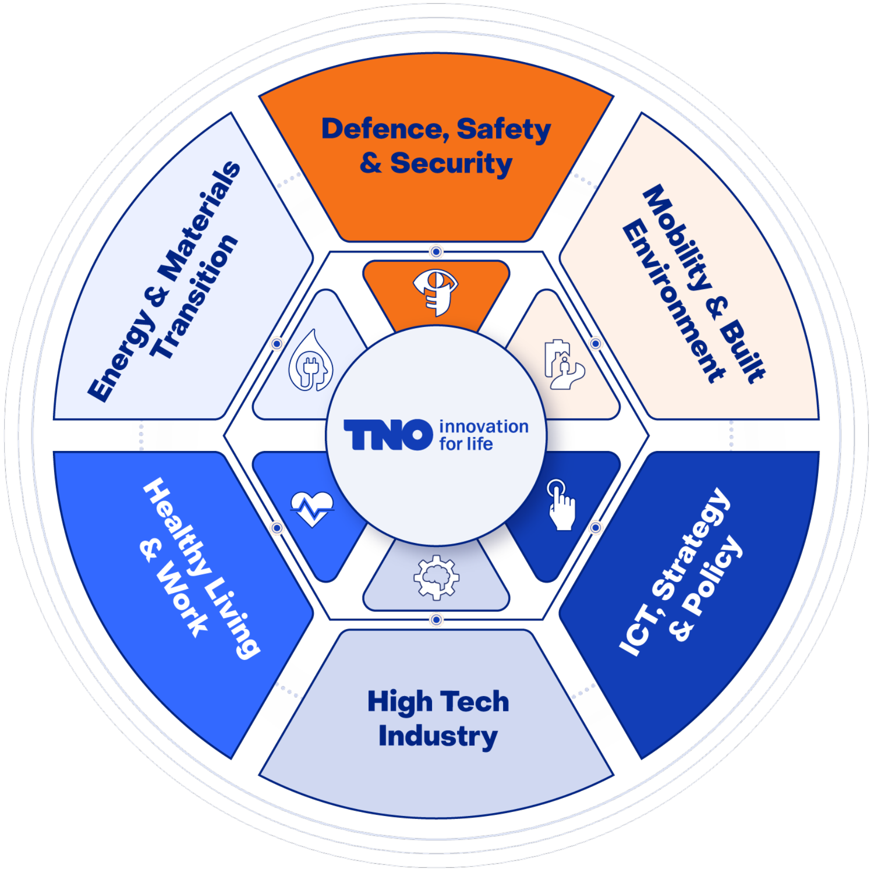
Content

- Introduction TNO
- Thermoacoustic Heat Pump
- Working Principle
- Experimental Setup & Results
- Conclusions & Outlook

TNO

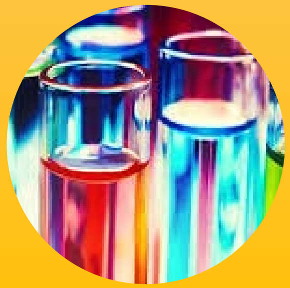


Defence, Safety & Security
Mobility & Built Environment
ICT, Strategy & Policy
High Tech Industry
Healthy Living & Work
Energy & Materials Transition
TNO innovation for life

Groningen
Petten
Amsterdam
Leiden
Soesterberg
The Hague
Utrecht
Zeist
Rijswijk
Delft
Eindhoven
Helmond
Bergen op Zoom
Geleen
Lab facilities
Locations

TNO Roadmap: Towards Co2 Neutral Industry

Radically New Industrial Processes

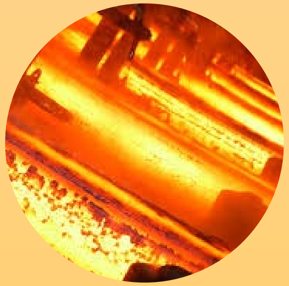


Synthetic Fuels & Chemicals

Biobased Fuels & Chemicals

Clean Hydrogen Production

Energy Infrastructure for Industry



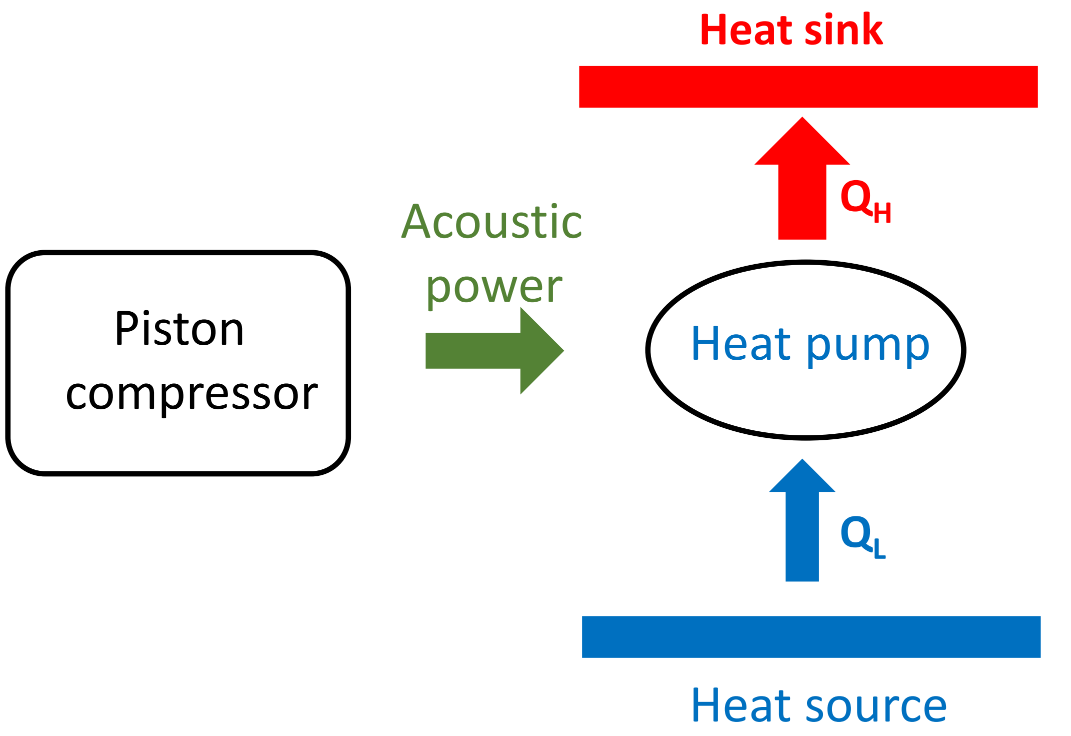
Sustainable Industrial Heat System

Industrial Carbon Capture

Industrial Transformation (multi-unit)

Thermoacoustic Heat Pump

TA-heat pump uses acoustic power to pump heat from a low temperature heat source to a high temperature heat sink



Thermoacoustics

- TA effect: thermal interaction between wave and porous material (regenerator)
  - Pump heat from low temperature to high temperature using high energy-density acoustic wave
  - Produce acoustic power from imposed temperature difference
- Typical properties acoustic wave
  - Helium/hydrogen
  - Frequency: ~ 20 Hz (compressor)
  - System pressure: ~ 50 Bars
  - Pressure oscillation 2.5-5 bars
- Thermodynamically identical to Stirling cycle but without the displacer piston

Benefits Thermoacoustic Heat Pump

- ➢ High temperature lift (up to 100°C) and high heat delivery temperature (> 250°C)
- ➢ Very flexible temperature conditions:
  - Waste heat 50-100
  - Process heat 150-250 °C
- ➢ Gas cycle (Stirling cycle): Helium/hydrogen (environmentally friendly)
- ➢ Relative simple components and materials
- ➢ One standard module: Good economics

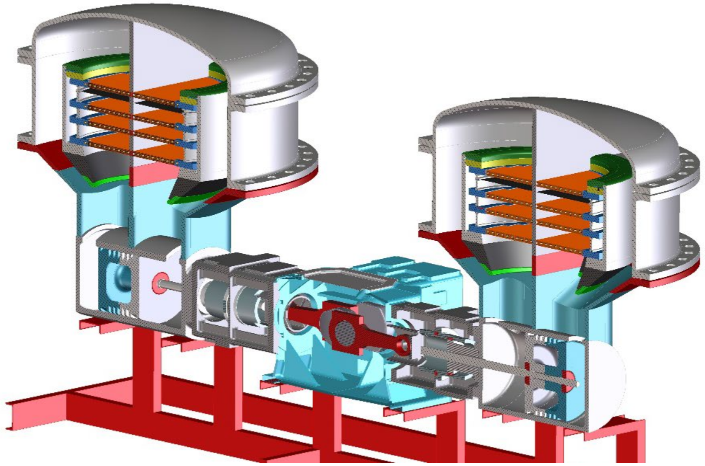
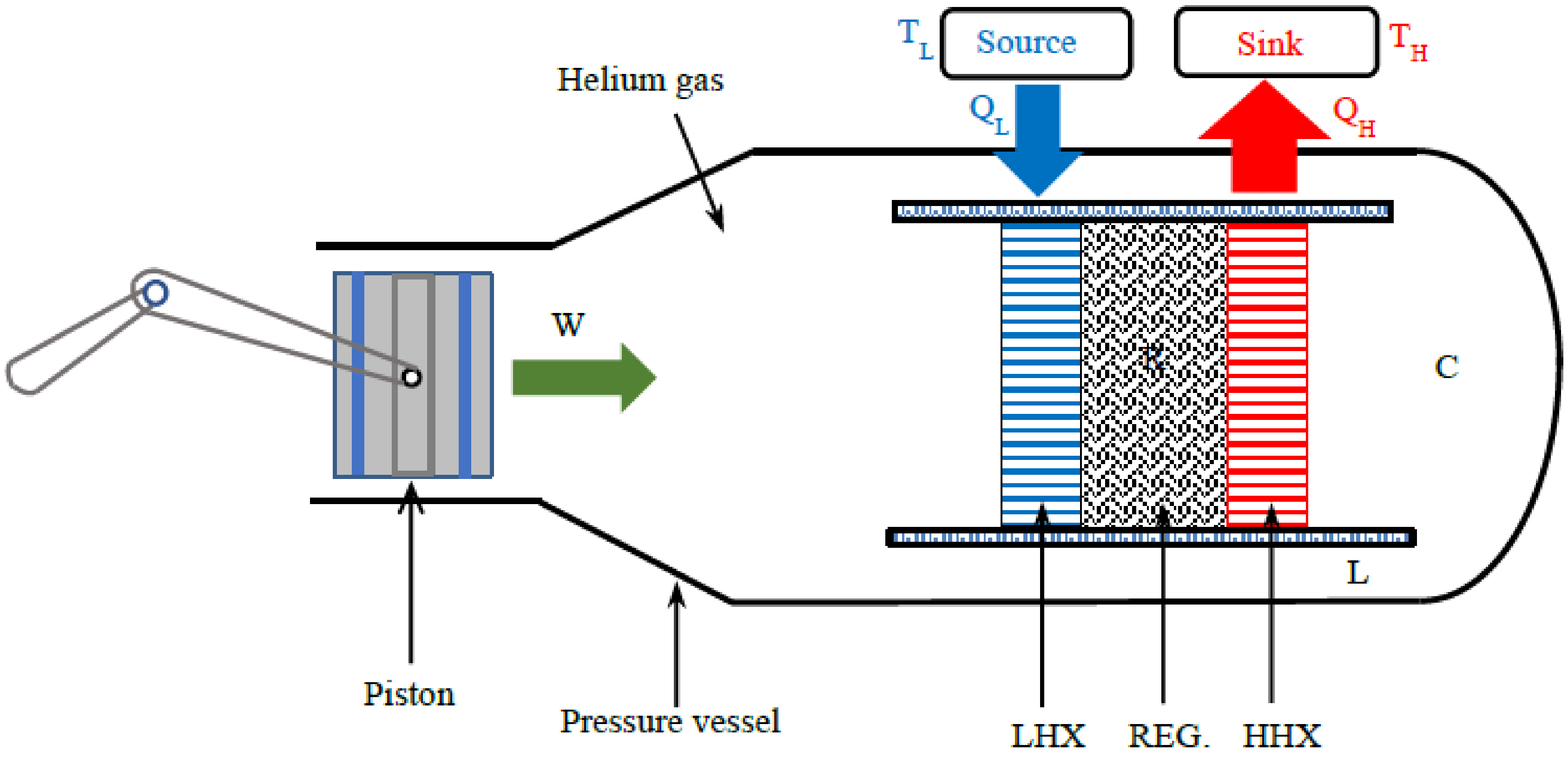
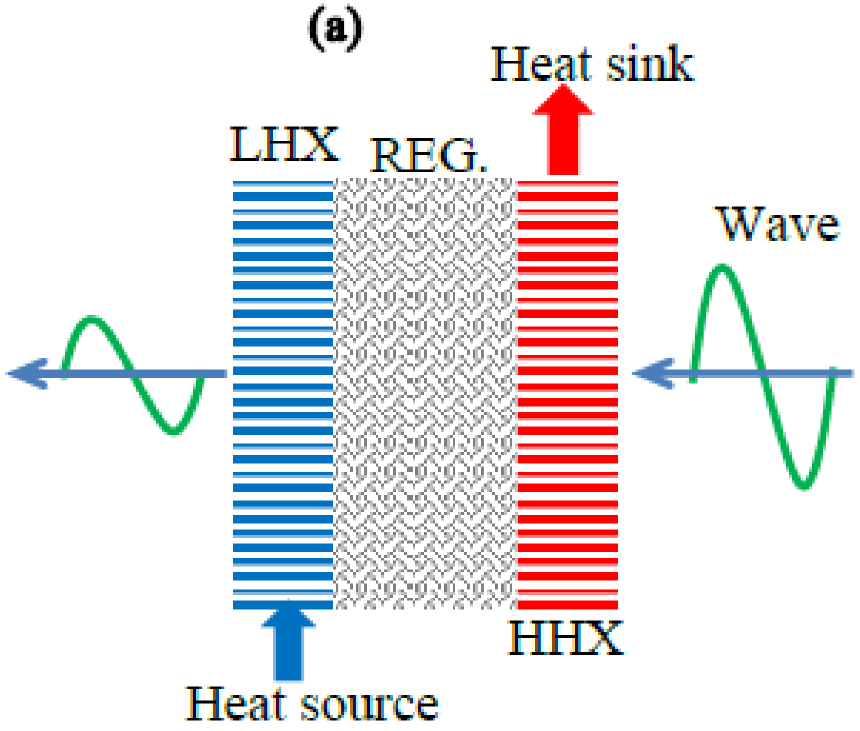
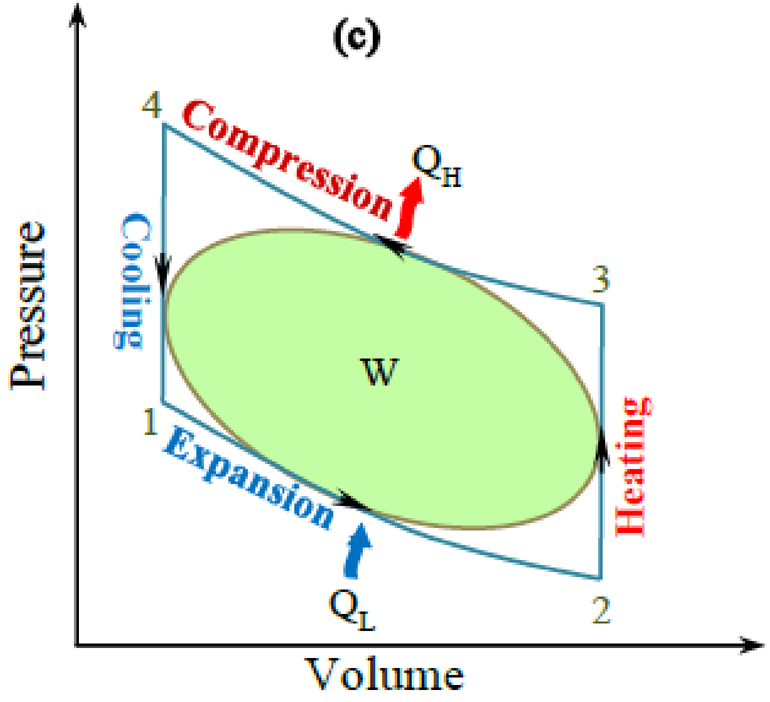


Illustration of the TAHP



Working Principle (Stirling cycle)



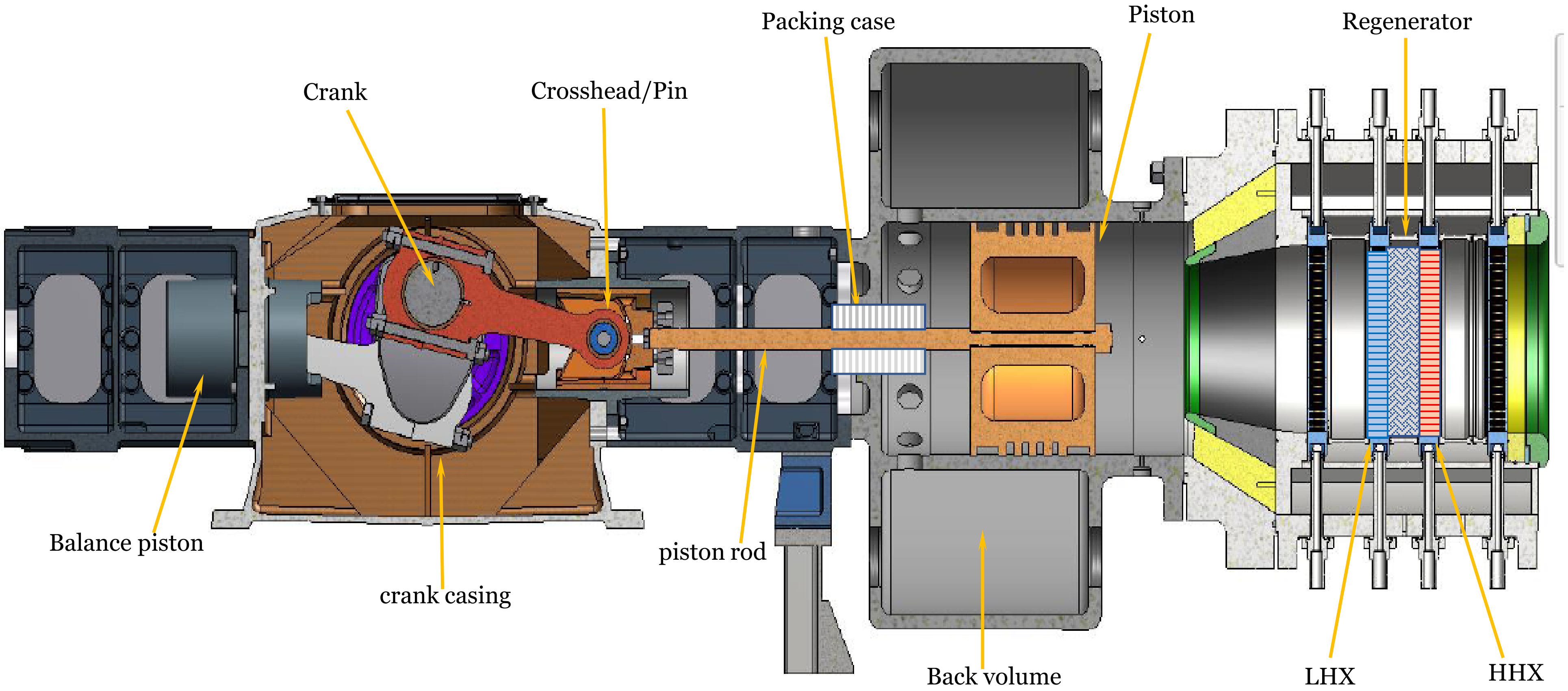


https://resource.isvr.soton.ac.uk/spcg/tutorial/tutorial/Tutorial_files/longipatm.gif

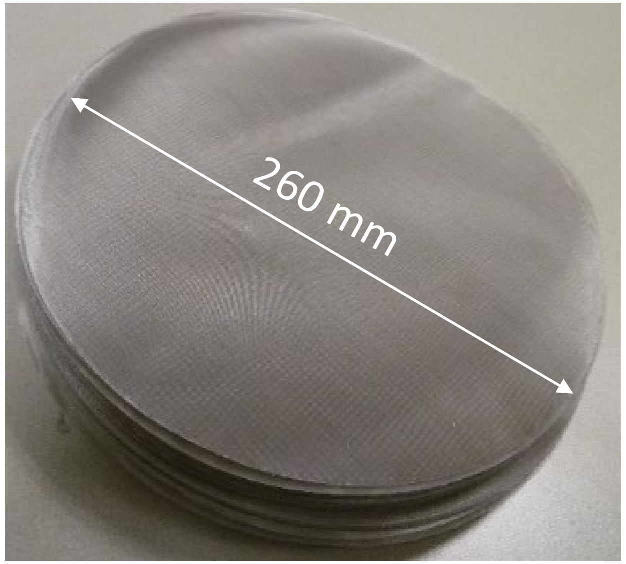
Setup


Steam Vessel
Thermal bench
TAHP
Compressor Control
Compressor

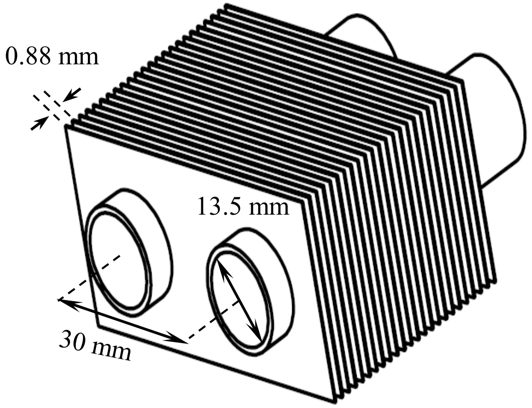
CAD-Cross-sectional view of the TAHP

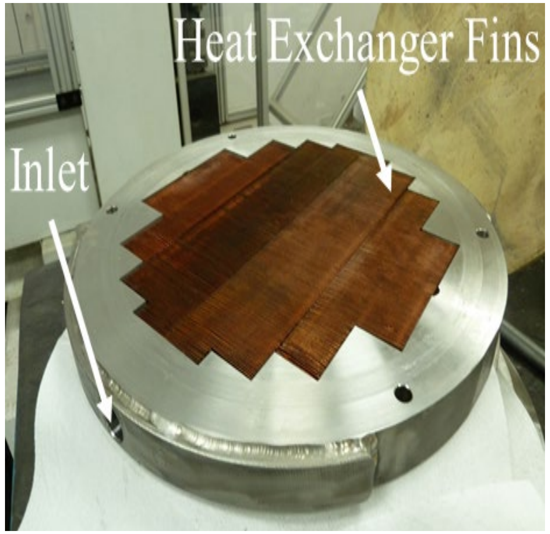


Components



Regenerator





Heat exchanger

Operation Conditions

Working gas	Helium
Average pressure (bar)	30
Frequency (Hz)	20
Sink temperatures (°C)	100-200
Thermal power at 180 °C (kW)	6.8
Drive ratio (%)	10.4

The drive ratio is the ratio of the acoustic pressure amplitude at the piston and the mean pressure of the gas

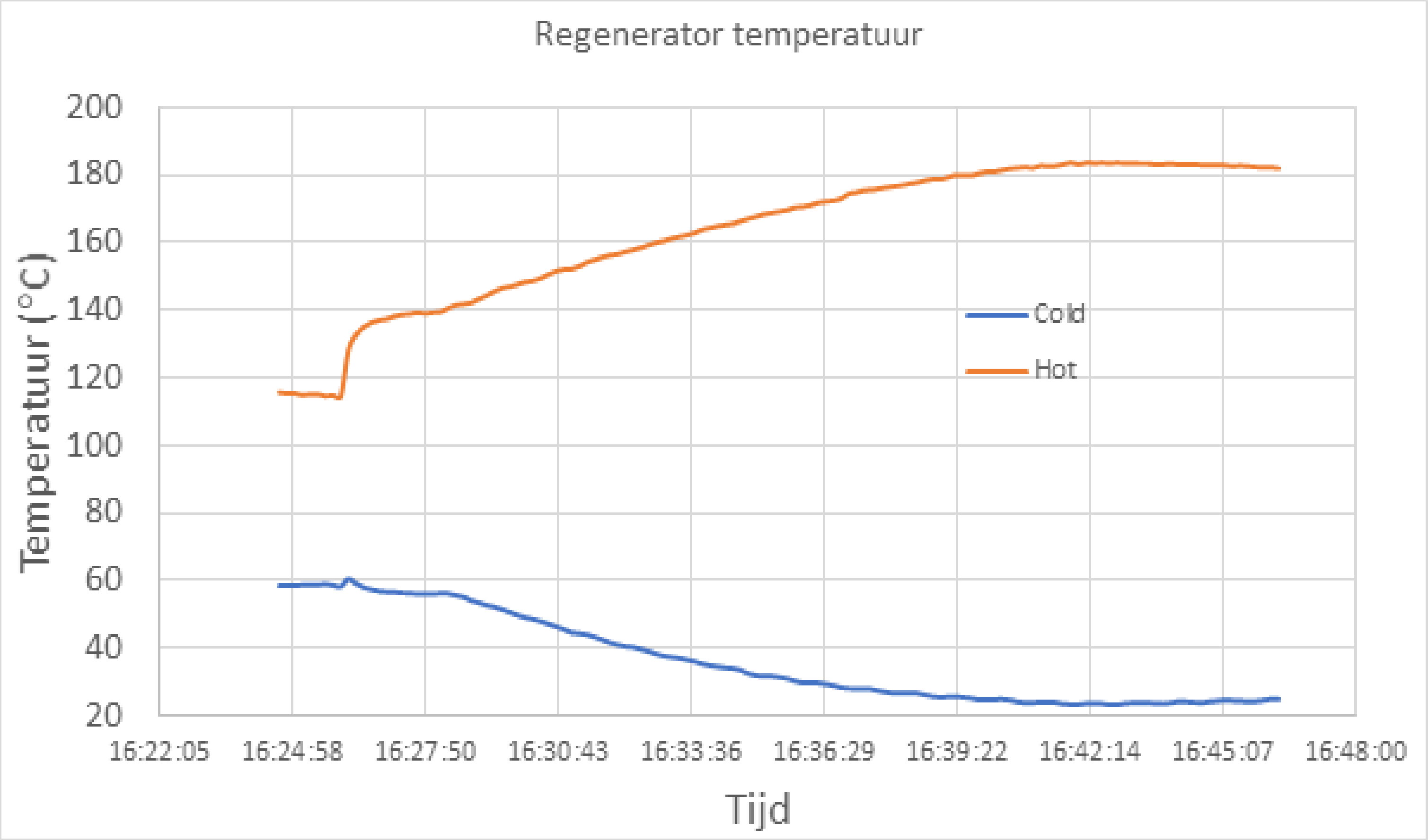
Objectives

- Build a compact TAHP without resonator
- Possibility to use piston compressor as driver for TAHP
- Produce steam at temp.>150°C
- Improve the performance of the system by minimizing losses

With Resonator

Without Resonator

Regenerator Temperatures



Experimental Results

Dr (%)	T_{LHX}(°C)	T_{HHX}(°C)	$T_{reg\text{-}H}$(°C)	$T_{reg\text{-}L}$(°C)	Q_H(kW)
10.4	94	152	186	45	6.5
10.2	94	170	194	60	4.7

The heat pump produces steam at different temperatures up to 170°C, supplying waste heat at 94°C. Higher temperatures can be achieved but not feasible with the current heat exchangers. The heat pump generates 4.7 kW of thermal power with a COP of about 3, excluding the losses in the compressor and internal heat losses. Large temperature differences are measured across the heat exchangers which indicates a poor heat transfer coefficient.

Conclusions & Outlook

Conclusions

- An electrically driven thermoacoustic heat pump is designed, built, and tested
- It can be concluded that a piston compressor can be used as acoustic driver for a TAHP resulting in a compact and scalable system without acoustic resonator. Piston compressors are commercially available at different scales up to MW's
- The heat pump produces steam at different temperatures up to 170 °C, using waste heat at 94°C.
- The heat pump generates 4.7 kW of steam at 170 °C with a COP of about 3, excluding the losses in the compressor and internal heat losses

Outlook

In the near feature an optimal regenerator and optimized heat exchangers will be implemented to improve the performance of the heat pump and to generate steam at higher temperatures (> 200 °C)