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Development of a thermoacoustic heat pump for distillation column

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- Thermoacoustic heat pump
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- Design and construction
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Industrial applications

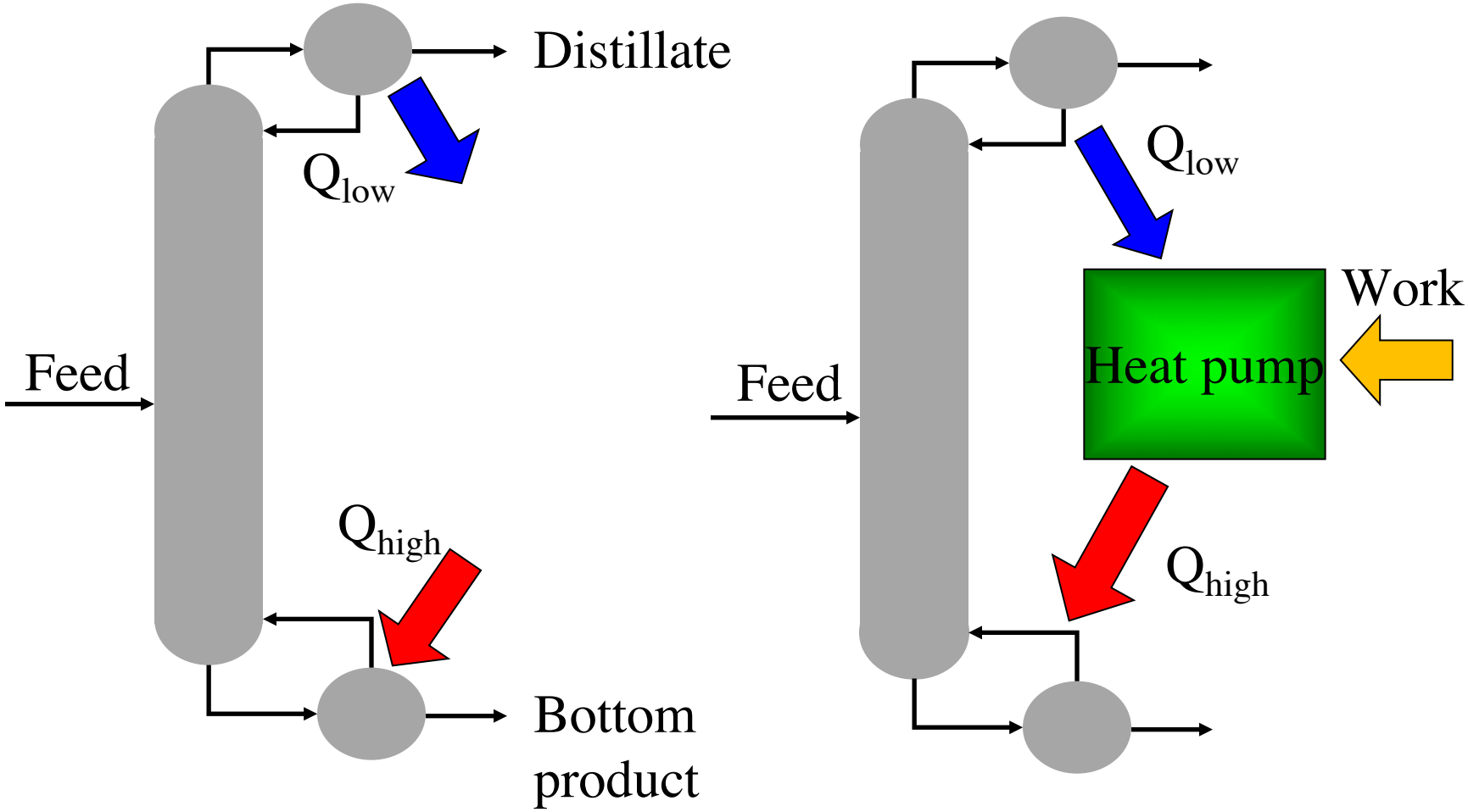
- Upgrading waste heat (50-120°C) to process heat (130-200°C)
  - ✓Paper industry
  - ✓Bulk chemical industry (distillation)
  - ✓Food industry
- Upgrade (waste) heat to cold

  Thermoacoustic cooler

Distillation

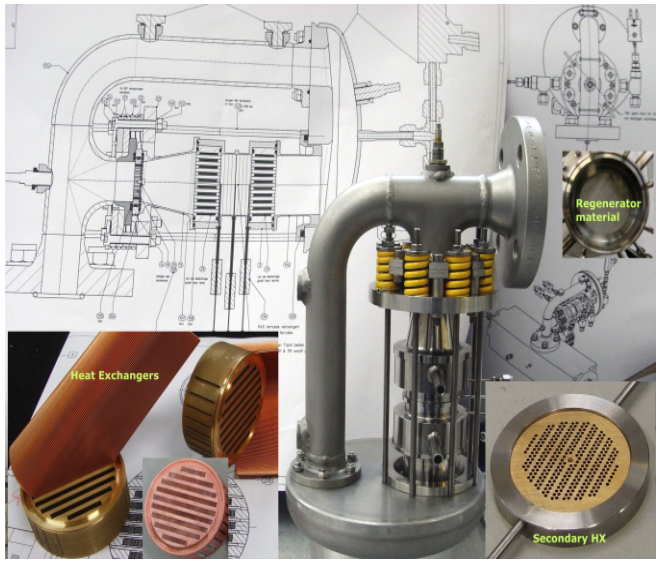
- Distillation requires high temperature heat as input (reboiler) and delivers low temperature heat as output (condenser); the column itself is adiabatic in principle
- A heat pump can upgrade low temperature heat to high temperature heat
- Needed are:
  - Heat pumps that operate in the temperature range of 50 - 200°C
  - Heat pumps that can generate a large temperature lift of >50°C

Heat pump concept for distillation



Characteristics of thermoacoustic heat pump

- High temperature lift (up to 100 °C) and high heat delivery temperature (200 °C)
- Relative simple components and materials
- Flexible operational conditions
  - No phase change involved
- Environmentally friendly helium as working medium
- Good economics



Electrically driven TA-heat pump

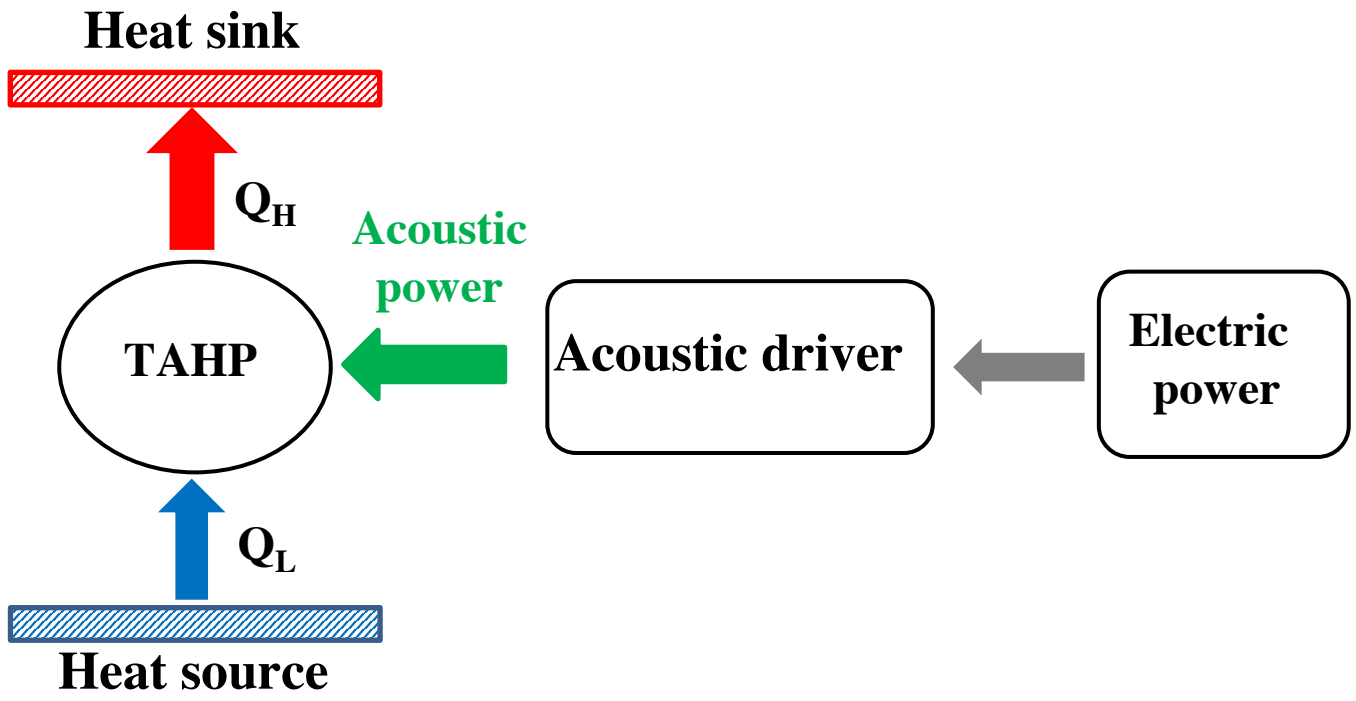
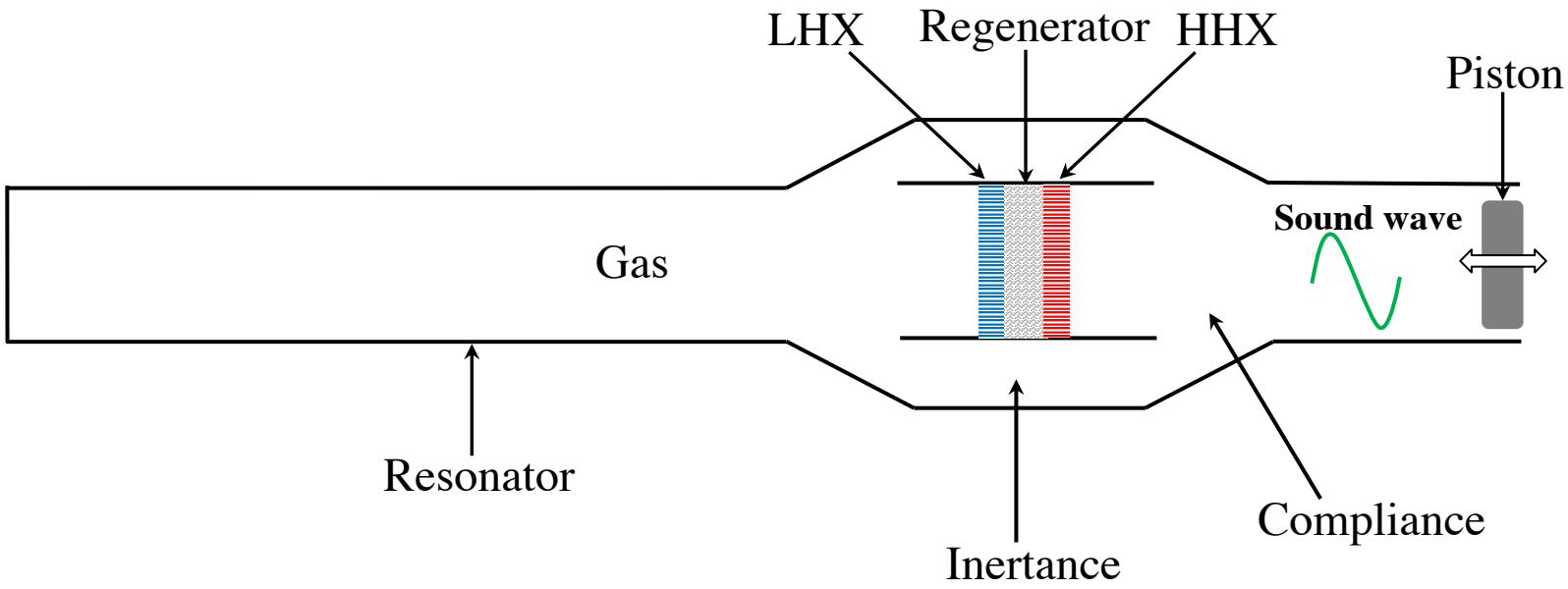


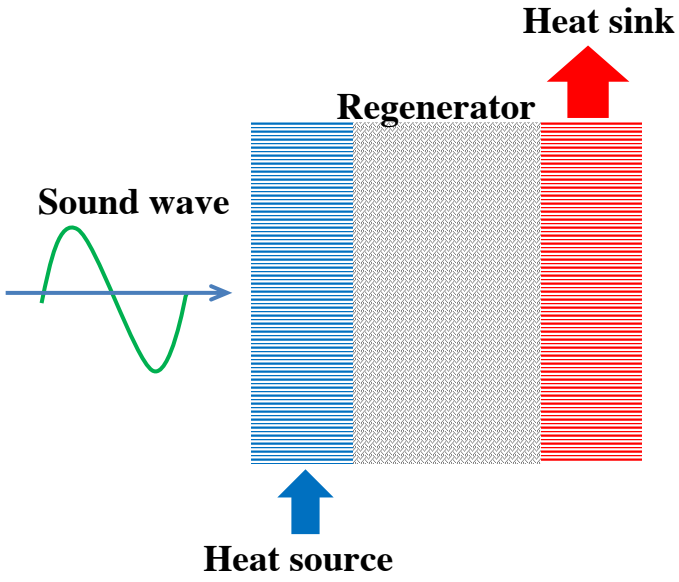
Illustration of a TA-heat pump

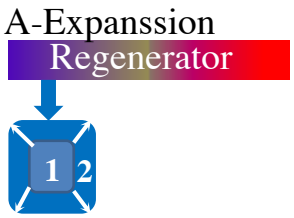


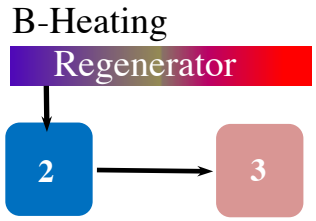
LHX = Low temperature heat exchanger

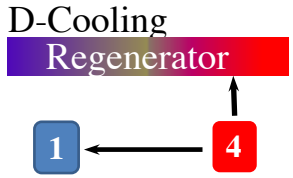
HHX = High temperature heat exchanger

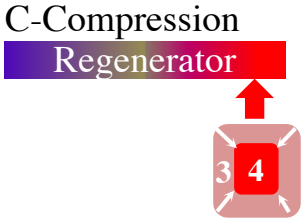
Thermoacoustic cycle (Stirling)

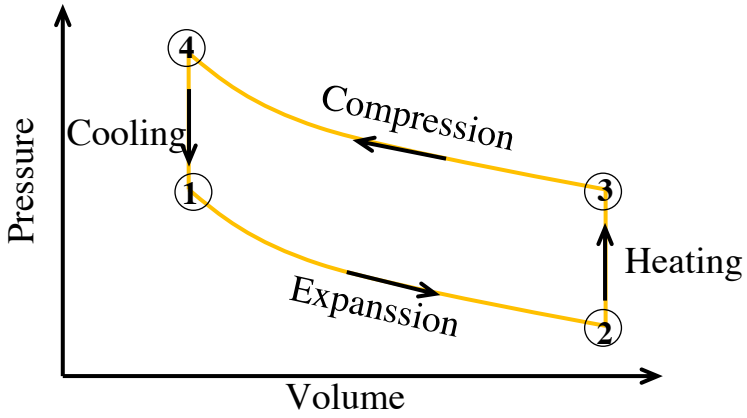






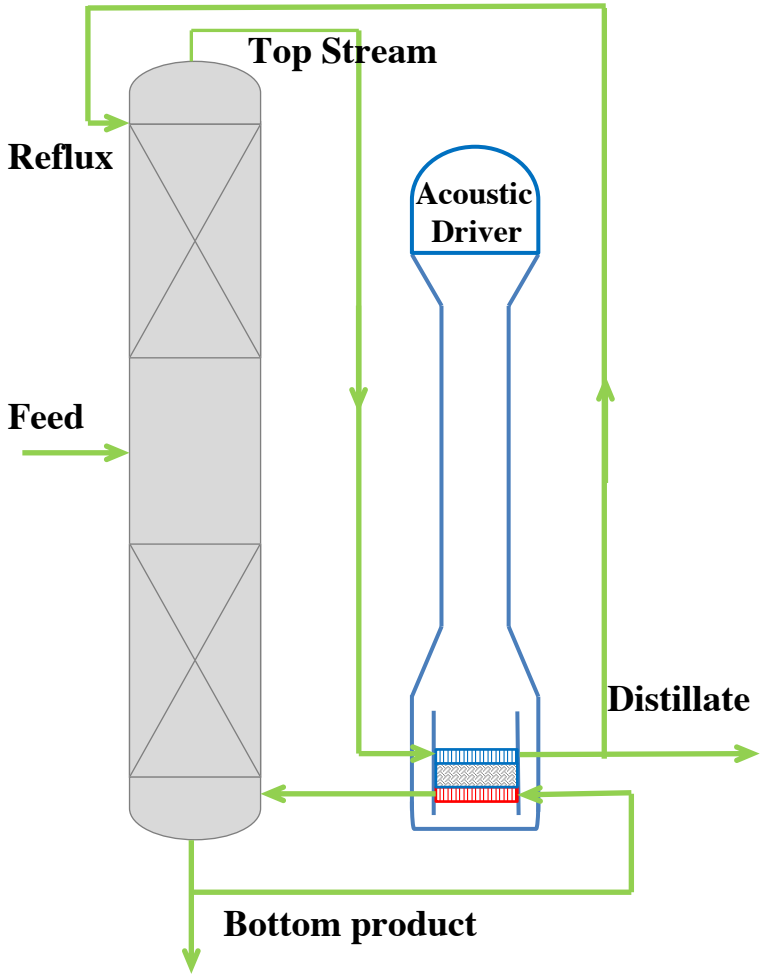






Travelling wave TA-heat pump
⇒ Stirling cycle
Reverse process gives TA-engine

Application to a distillation column



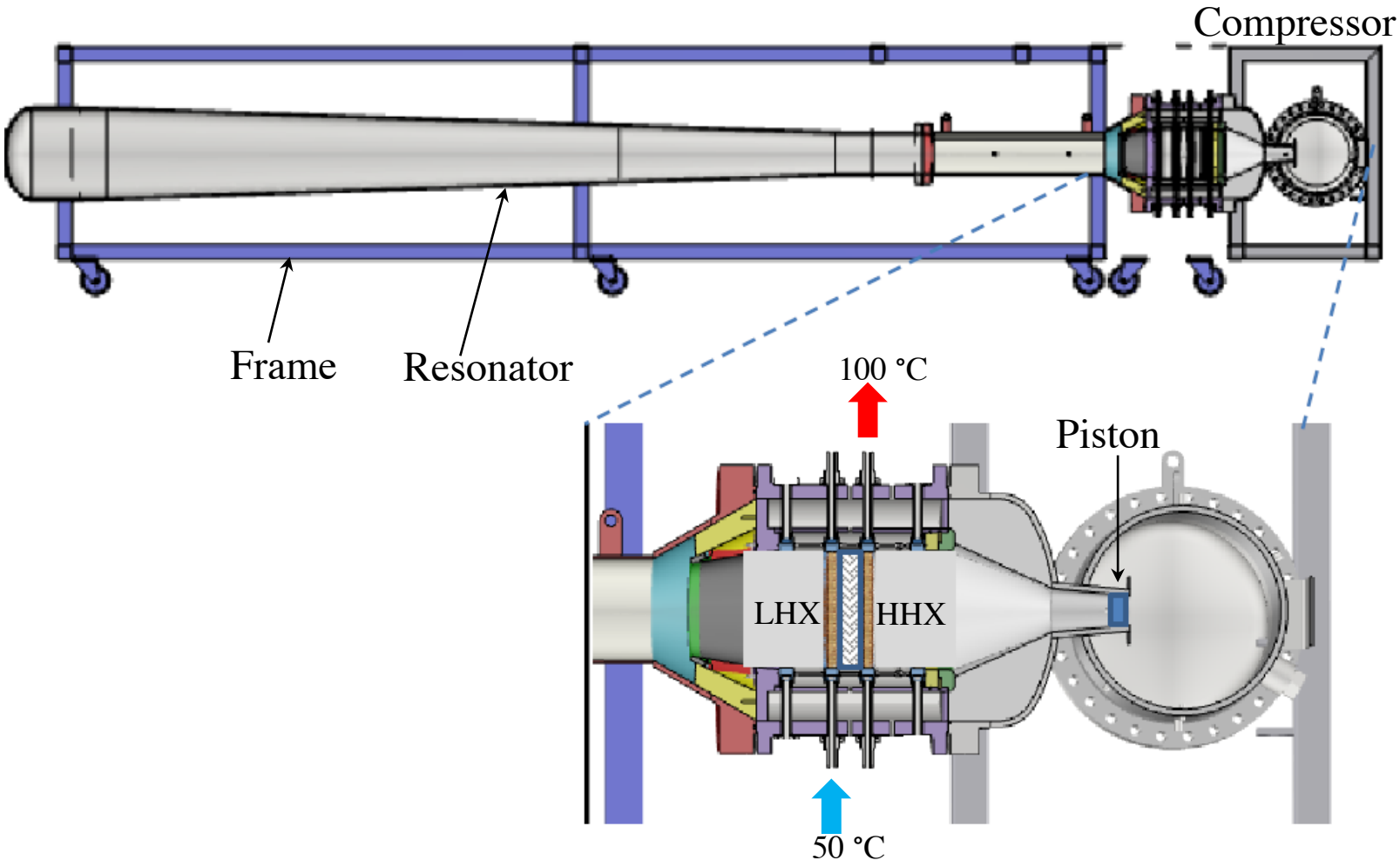
Specifications of TAHP

Working gas	Helium
Average pressure (bar)	50
Frequency (Hz)	80
Operation temperatures (°C)	60-100
Thermal power at 100 °C (kW)	10

Design of the heat pump

- DeltaEC is used to design, simulate, and optimize the TA-heat pump
- The characteristics of the piston compressor are used in the DeltaE-model

CAD-Illustration of the piston compressor driven TA-heat pump



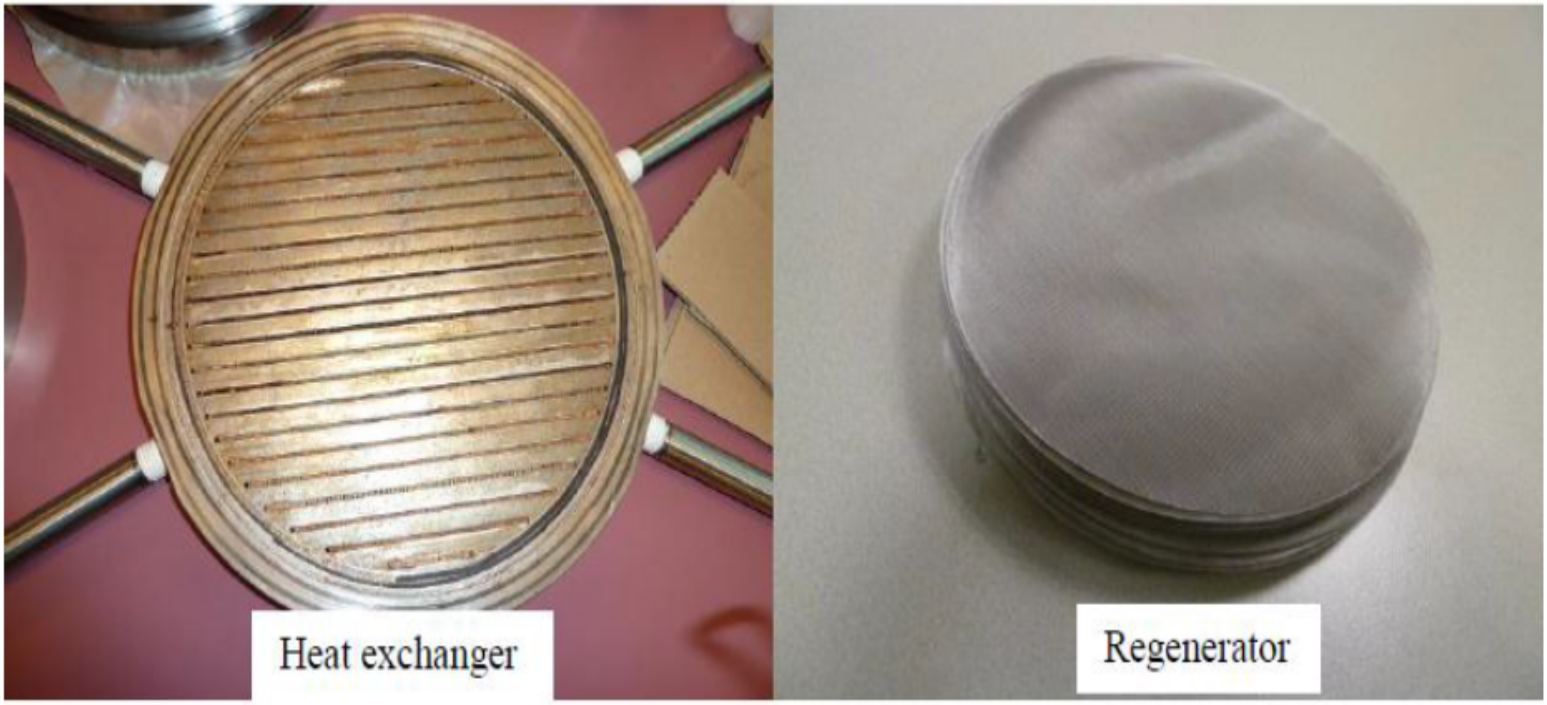
Design results

Acoustic power (kW)	Thermal power (kW)	COP	COPR
3.5	10	2.8	0.45

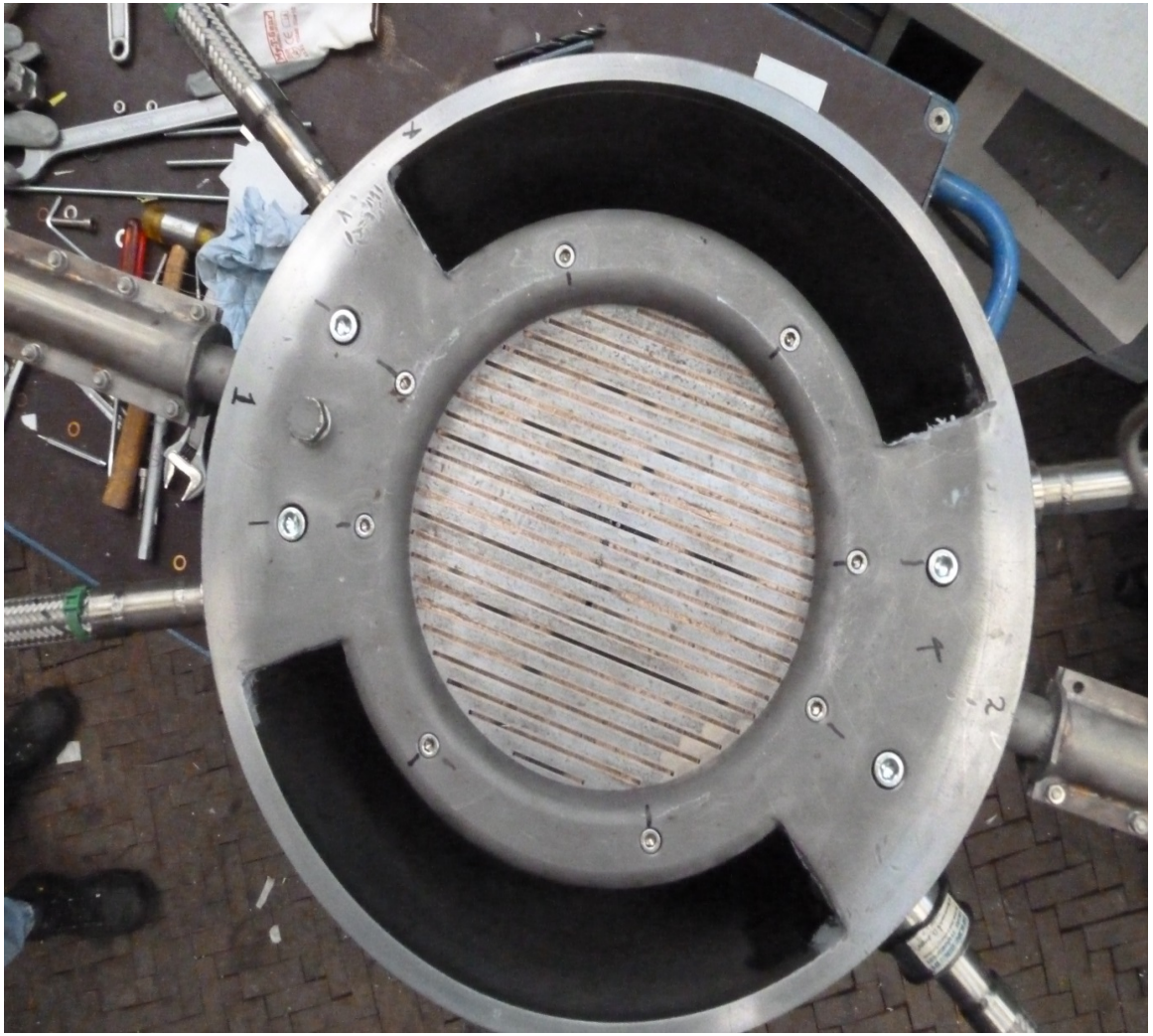
Dimensions of the components

Components	Type	Length (cm)	Diameter (cm)
Regenerator	Stacked screen: mesh 150, d_{wire}= 36µm	3	26
HHX	Fin-Fin	3	26
LHX	Fin-Fin	3	26
TBZ	Tube	8	26
Inertance	Annular space	56	-
Resonator	Tube + cone	600	22 to 48 cm

Components



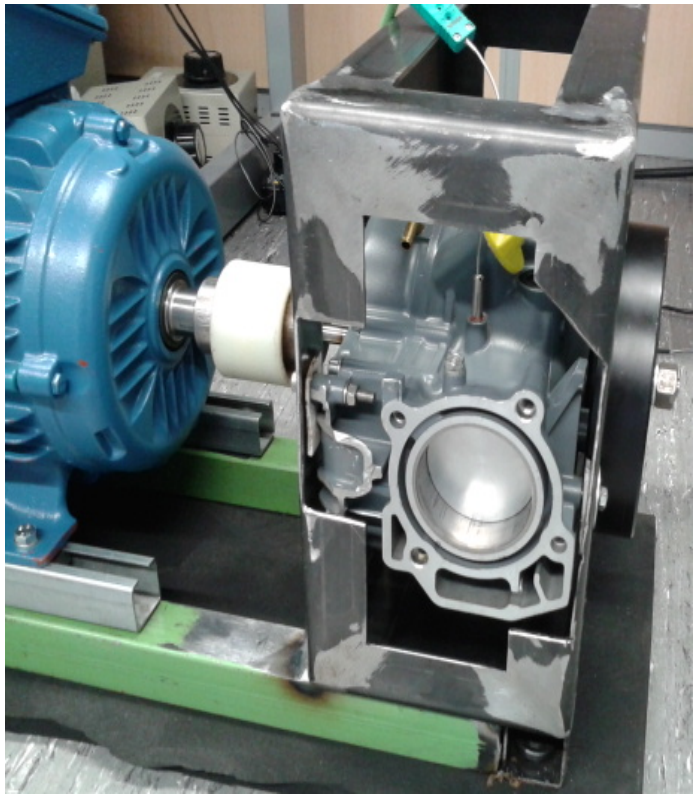
TAHP



Compressor

Operation frequency (Hz)	80
Piston diameter (mm)	> 50
Mean pressure	50 bar
Swept volume (liter)	0.14
Maximal acoustic power input (kW)	4
Lubrication	Oil free

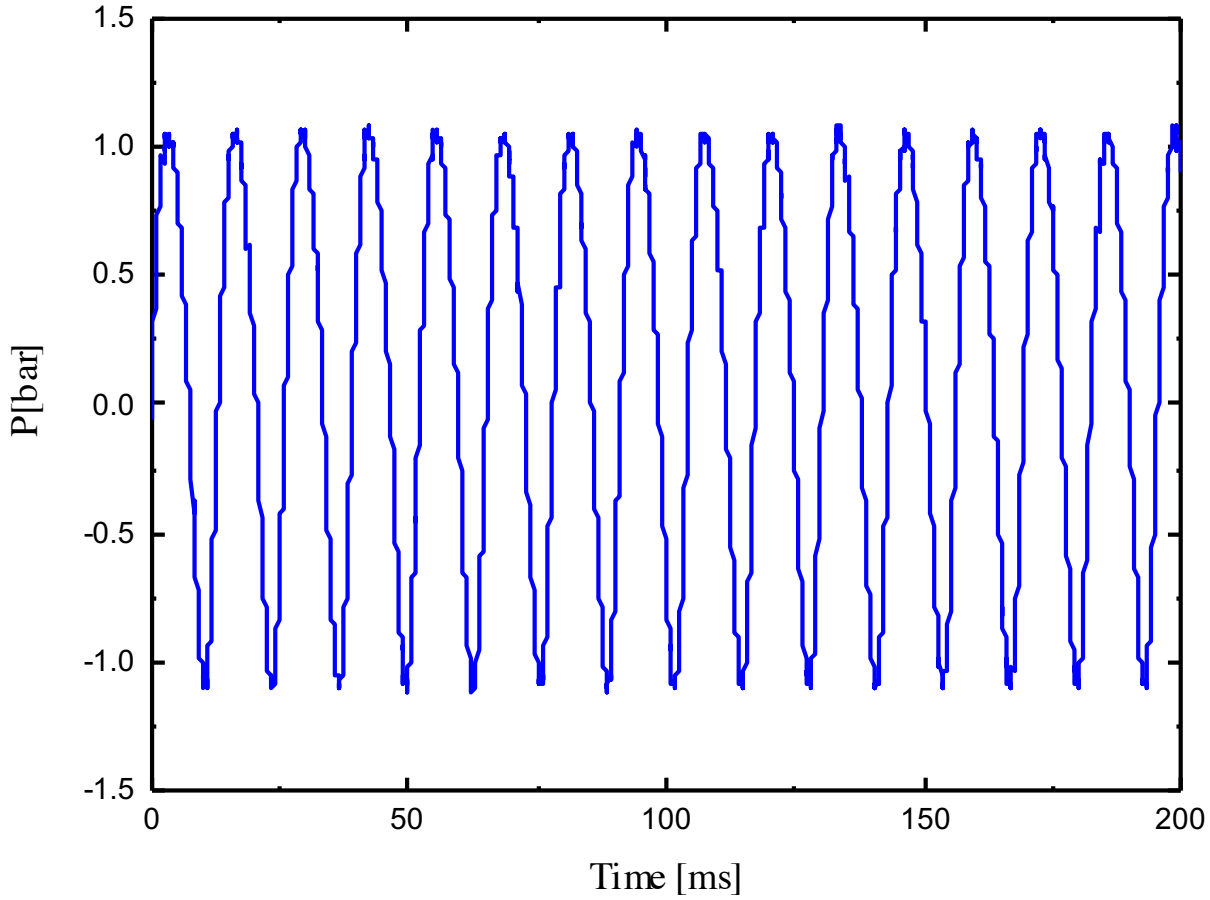
Outboard engine



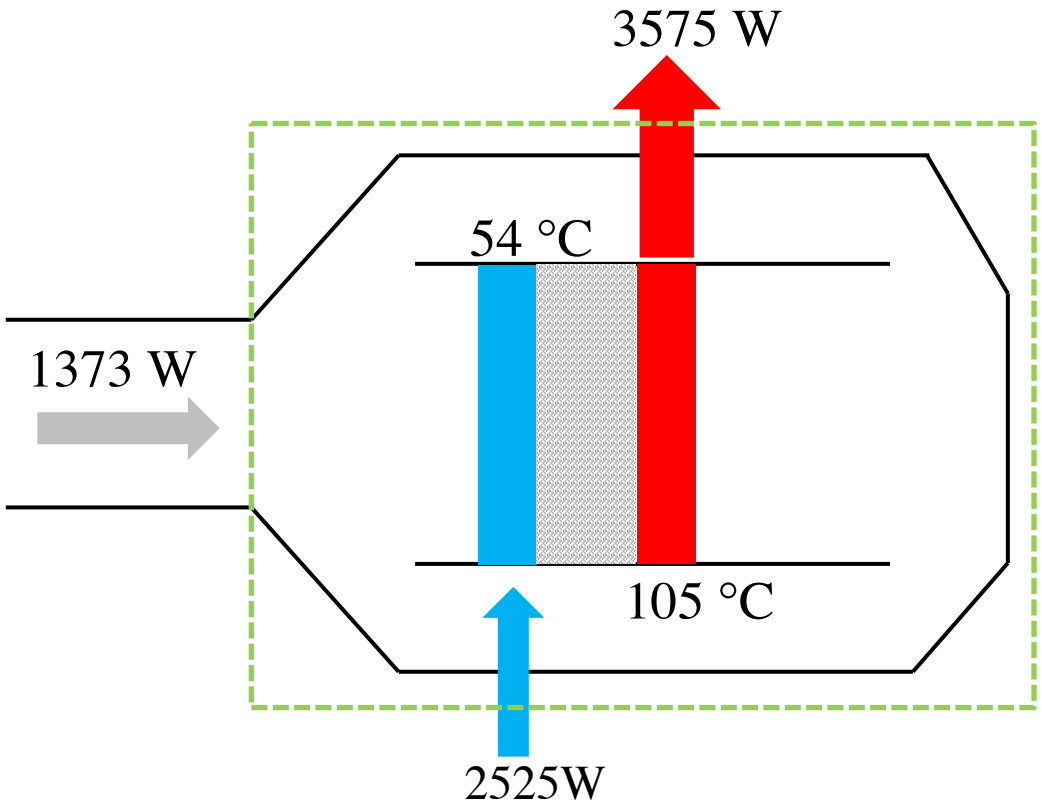
Compressor in pressure vessel

Picture of the TAHP

Experimental results (acoustics)



Performance results



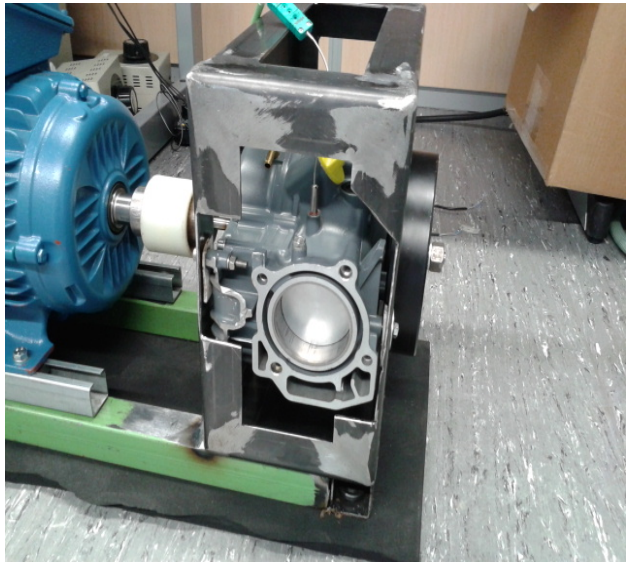
Conclusions

- Bench scale electrically driven thermoacoustic heat pump is designed, built, and tested.
- The heat pump delivers about 4 kW of thermal power at 105 °C with a COP of 2.6 corresponding to 39 % of Carnot performance.
- Problems with heat leakage and acoustic losses.
- It is expected that if these problems are solved successfully, the heat pump will deliver the required 10 kW of thermal power at 105 °C with the specified design performance.

Next steps

- Bench scale in new project
  - Improve the system performance
  - Higher temperatures (steam production)

- Next step
  - Development of 100 kW steam production TA heat pump
  - Onsite testing



Current partners TA development

- Equipment suppliers
  - Bronswerk heat transfer B.V. Nijkerk
  - Howden Thomassen Rheden
- Industrial End users TASTE project
  - Smurfit Kappa
  - Dow
- Institutes/Universities
  - NRG
  - Twente University
  - Delft University

Questions ?