Bench scale electrically driven thermoacoustic heat pump

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Bench scale electrically driven Thermoacoustic heat pump

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- Industrial applications
- Specifications of the heat pump
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- Test of the heat pump
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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
- Power generation

Upgrading waste heat

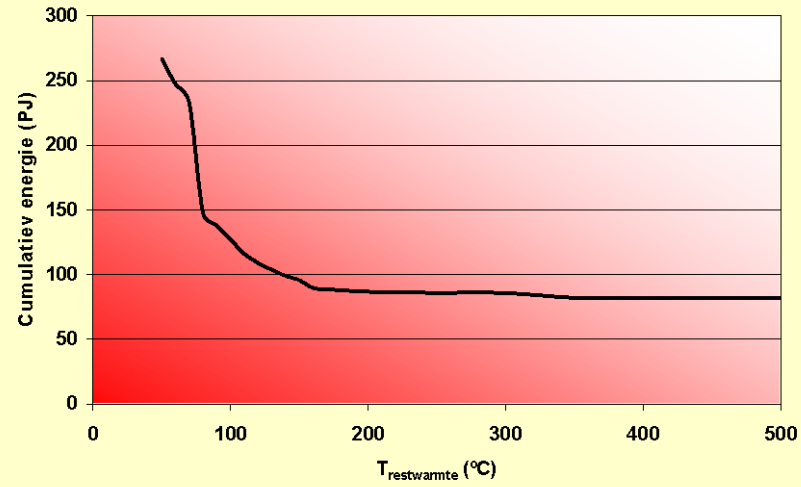
Inventory

250 PJ waste heat in NL T> 50°C

Problem

Mismatch in

- **–Temperature**
- –Time
- –Place



Possible technological solution

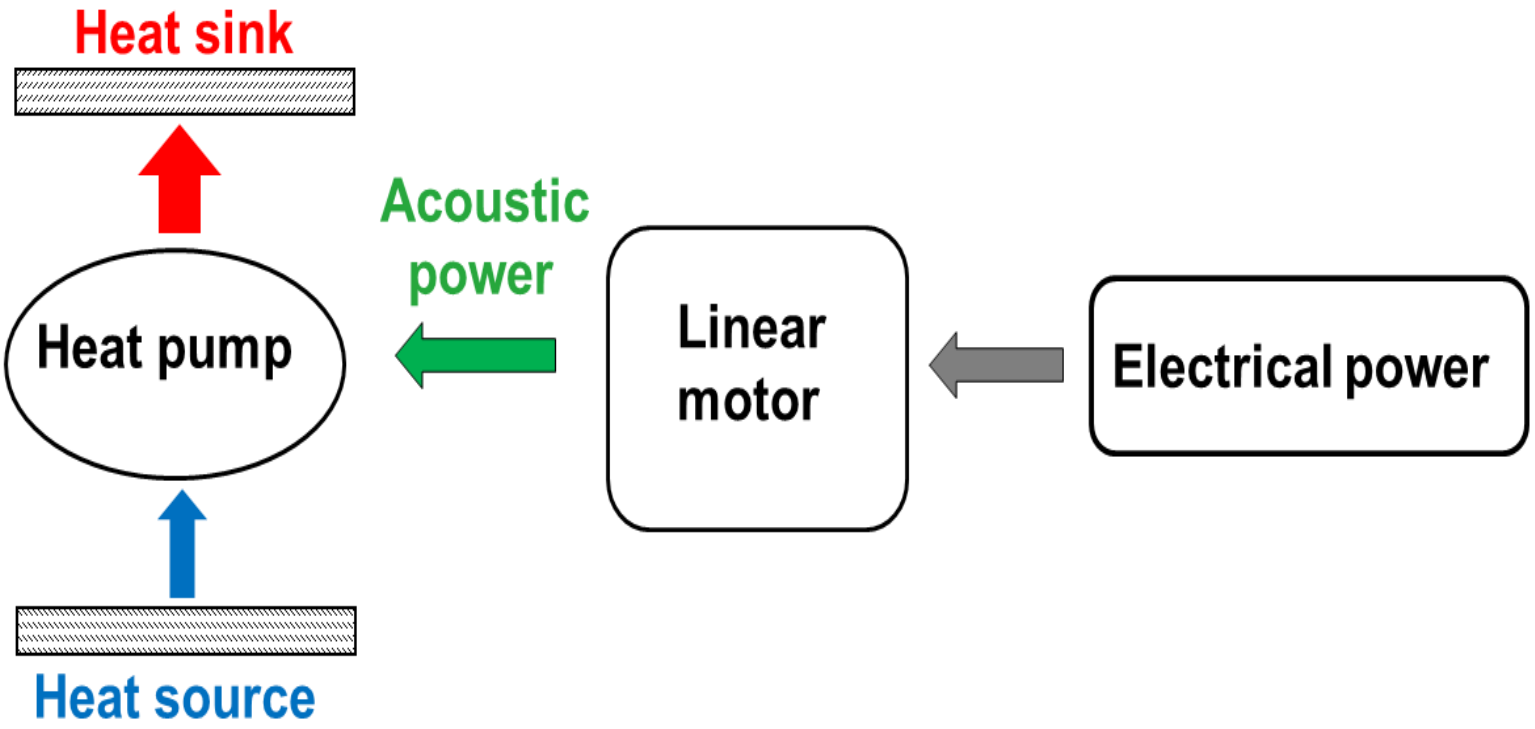
Industrial heat pumps for upgrading waste heat to process heat or cold

- – high operating temperature (130-200°C)
- – large temperature lift (> 50°C)
- – across the pinch

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

Electrically driven heat pump



Heat pump concept for distillation

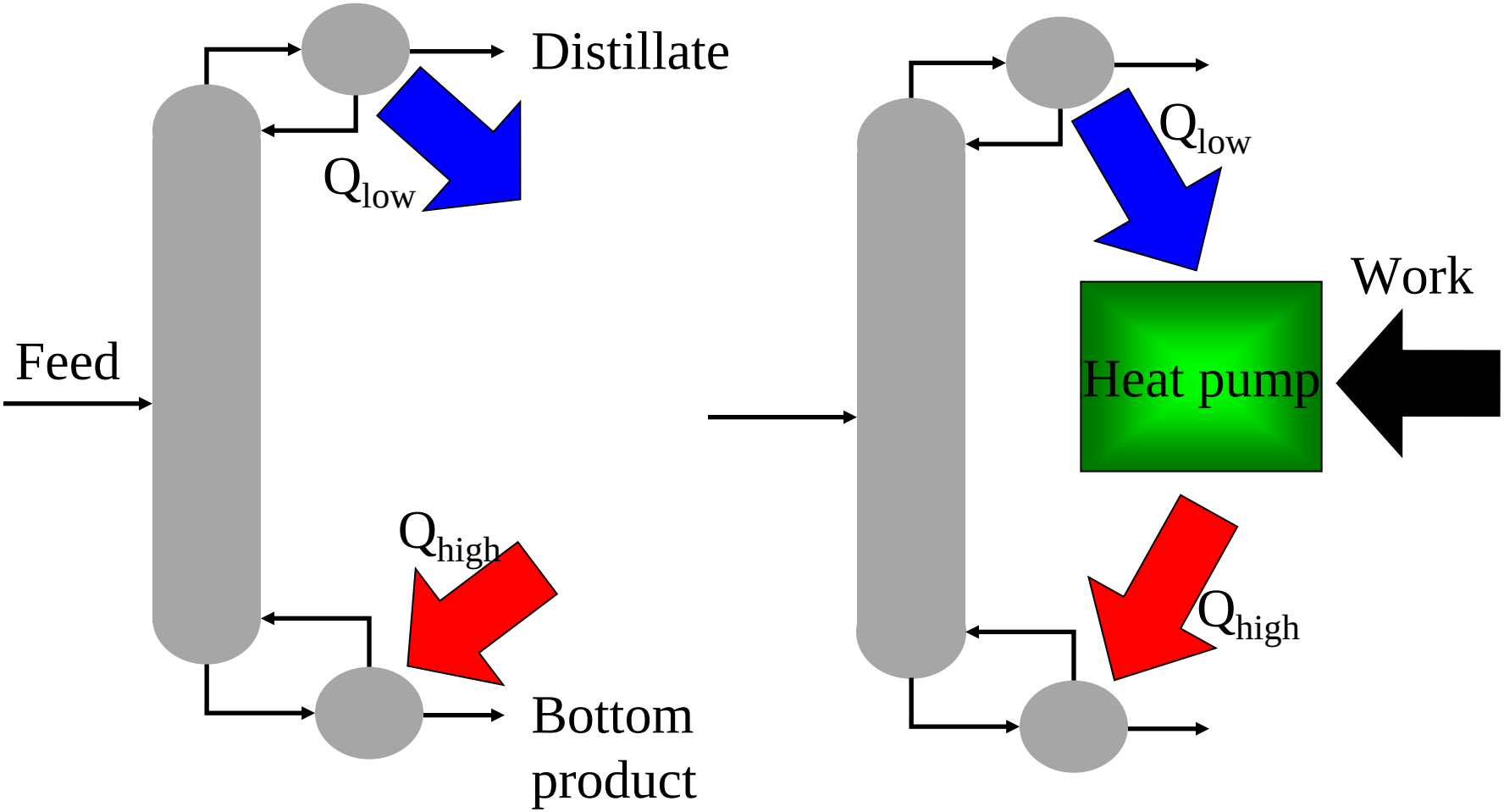
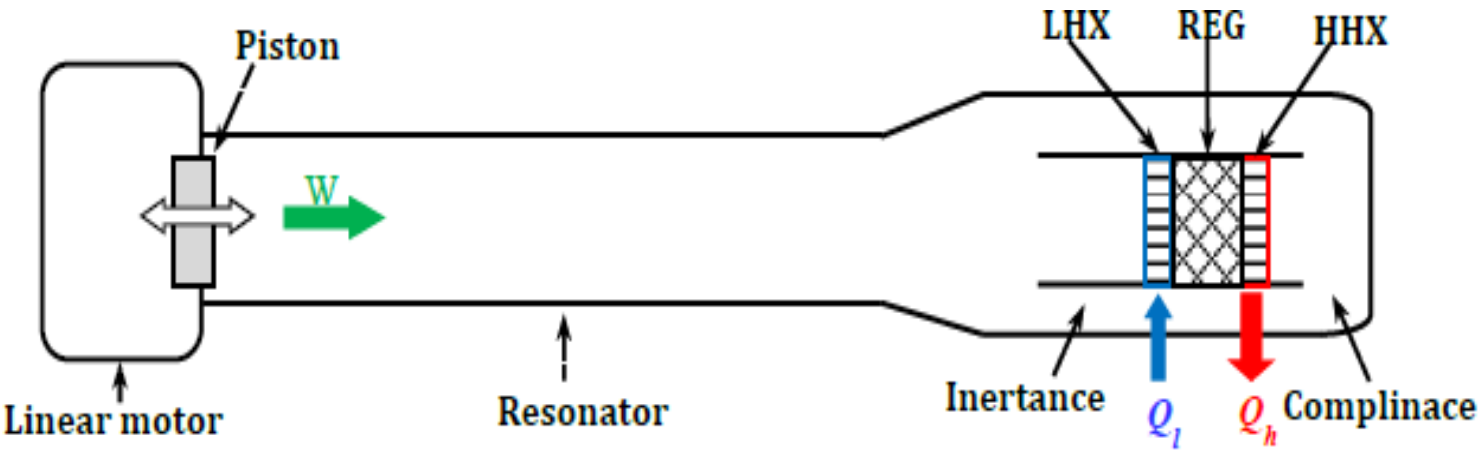


Illustration of the EDTA-heat pump

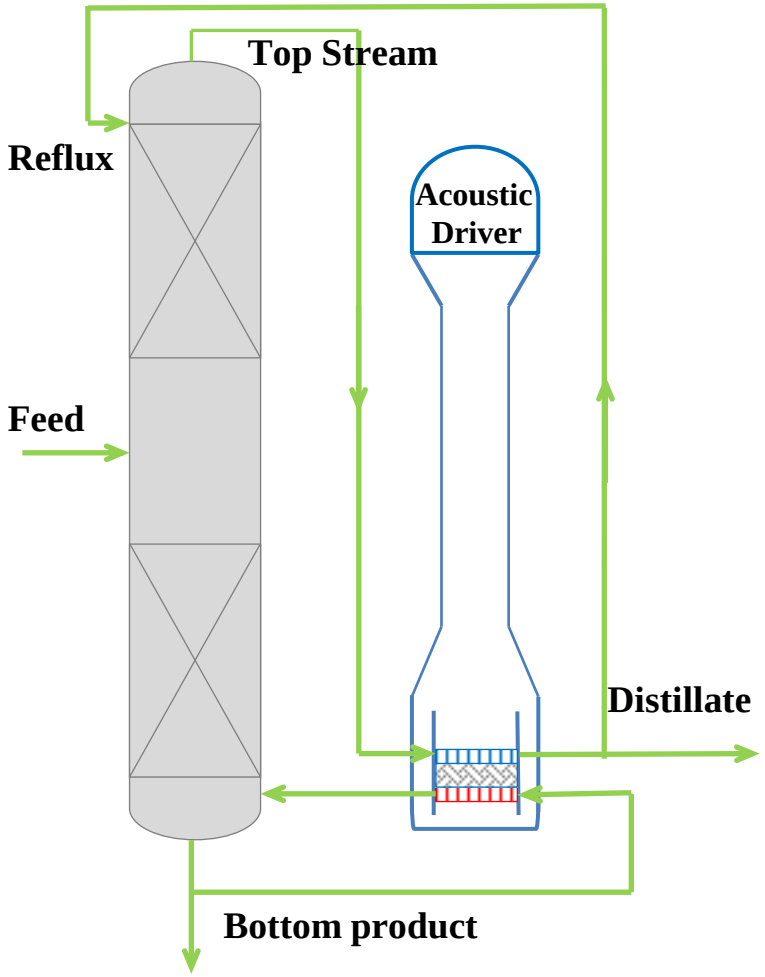


LHX = Low temperature heat exchanger

HHX = High temperature heat exchanger

REG = Regenerator

Application to a distillation column



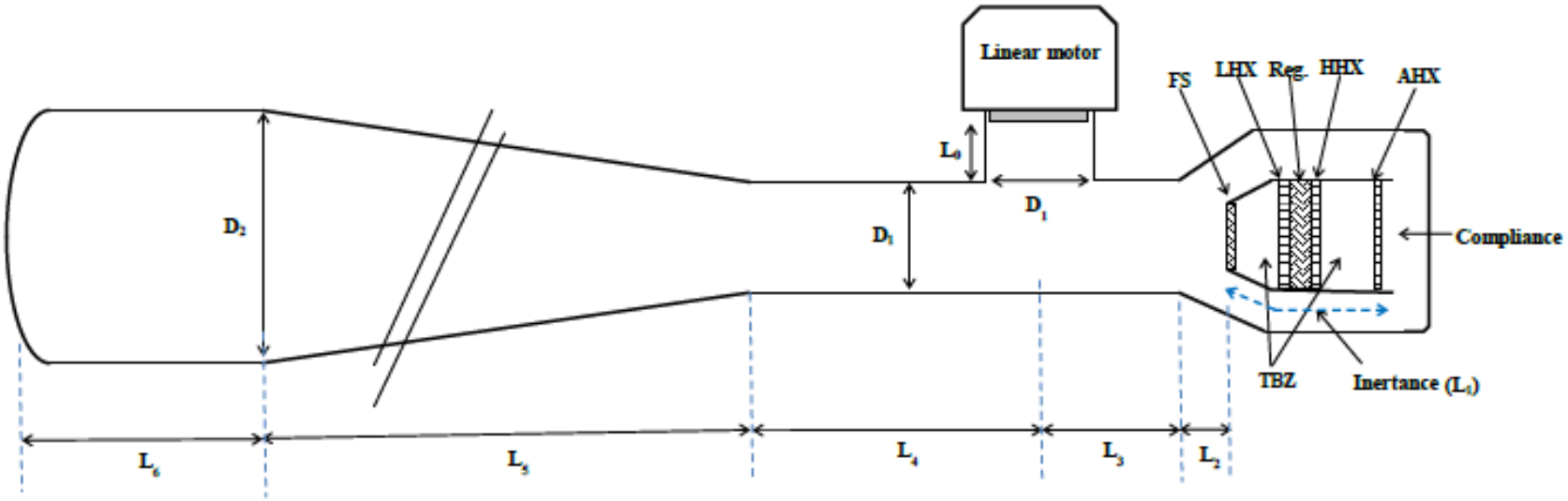
Specifications of the TA-heat pump

Working gas	**Helium**
Average pressure (bar)	**50**
Frequency (Hz)	**80**
Drive ratio (%)	**5**
Operation temperatures (°C)	**65-100**
Thermal power at 100 °C (kW)	**10**

Specifications of the linear motor

Electrical rating power kW)	**5**
BL-factor (T.m)	**55**
Mechanical stiffness (KN/m)	**157**
Mechanical damping (N.s/m)	**54**
Moving mass (kg)	**9.57**
Piston diameter (m)	**0.22**
Stroke (m)	**0.014**

Schematic illustration of the heat pump



Design of the heat pump

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

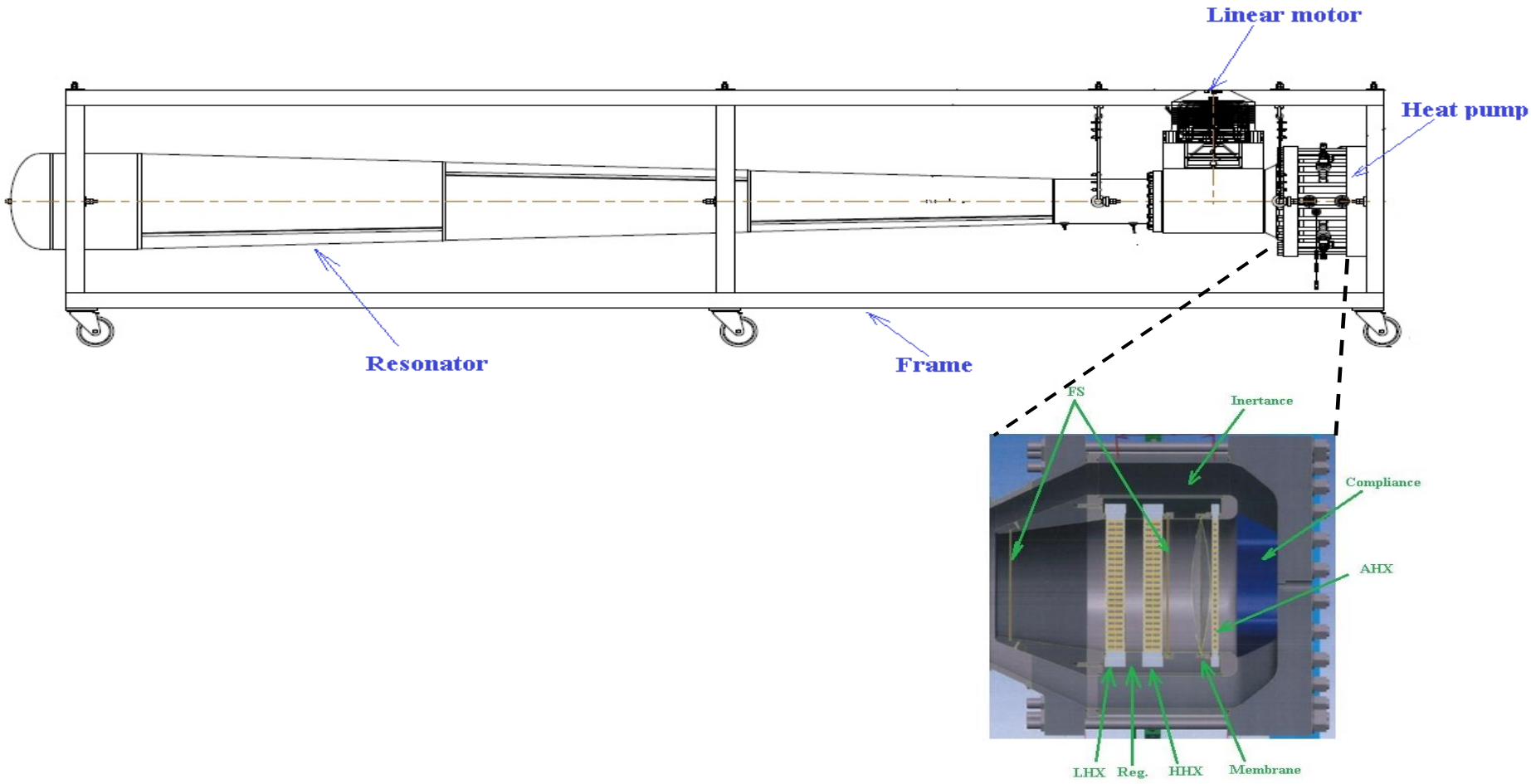
DeltaEC-predictions

- Working medium helium at 50 bar
- Operation frequency 80 Hz
- Thermal power 10 kW at 100 °C
- Temperature lift from 65 to 100 °C
- COP = 3.5 (including resonator efficiency)
- COPR = 0.33
- The calculated efficiency of the linear motor is 83 %
- The calculated efficiency of the resonator is 87 %

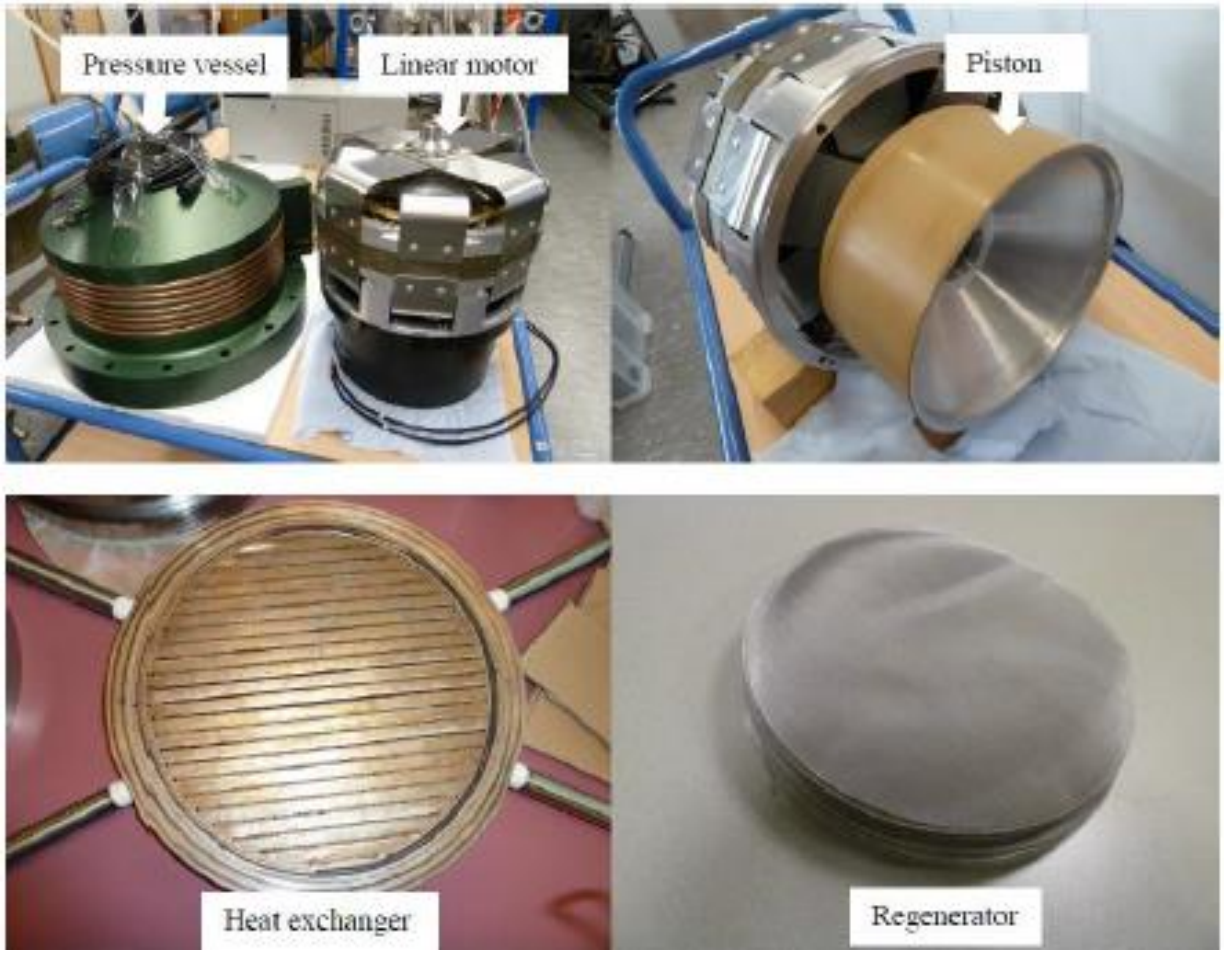
Dimensions of the components

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

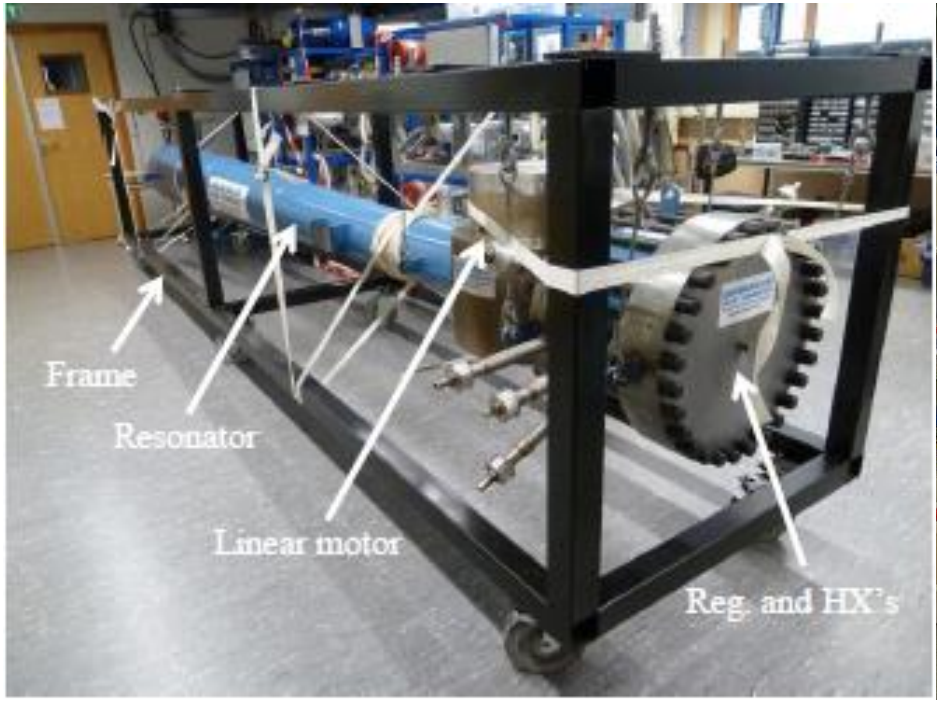
Illustration of the bench scale TA-heat pump

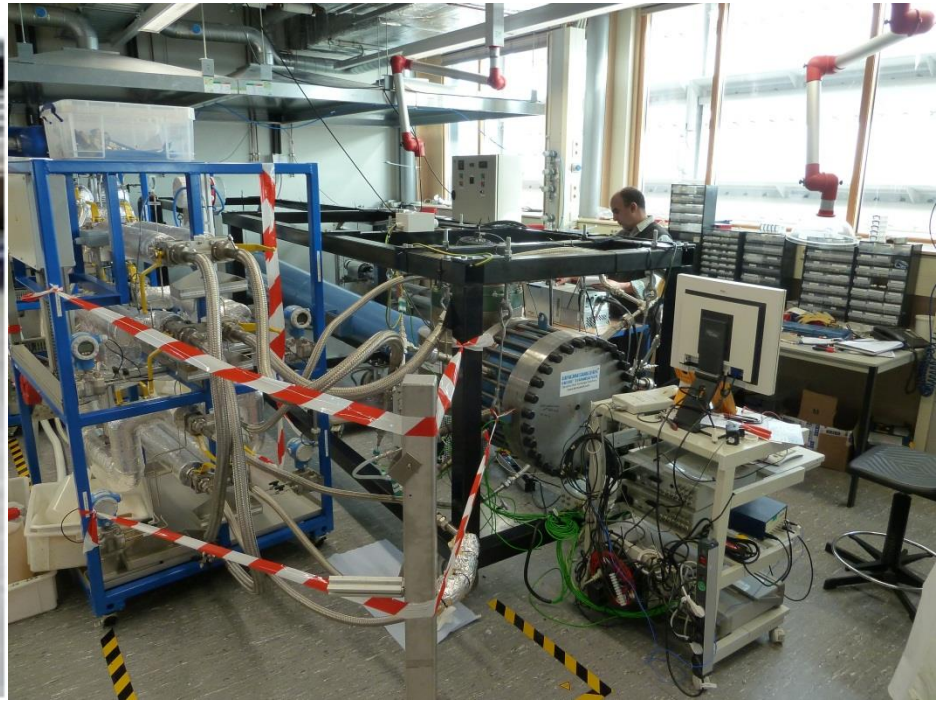


Components


Pressure vessel
Linear motor
Piston
Heat exchanger
Regenerator

Benchscale Electrically driven TAHP



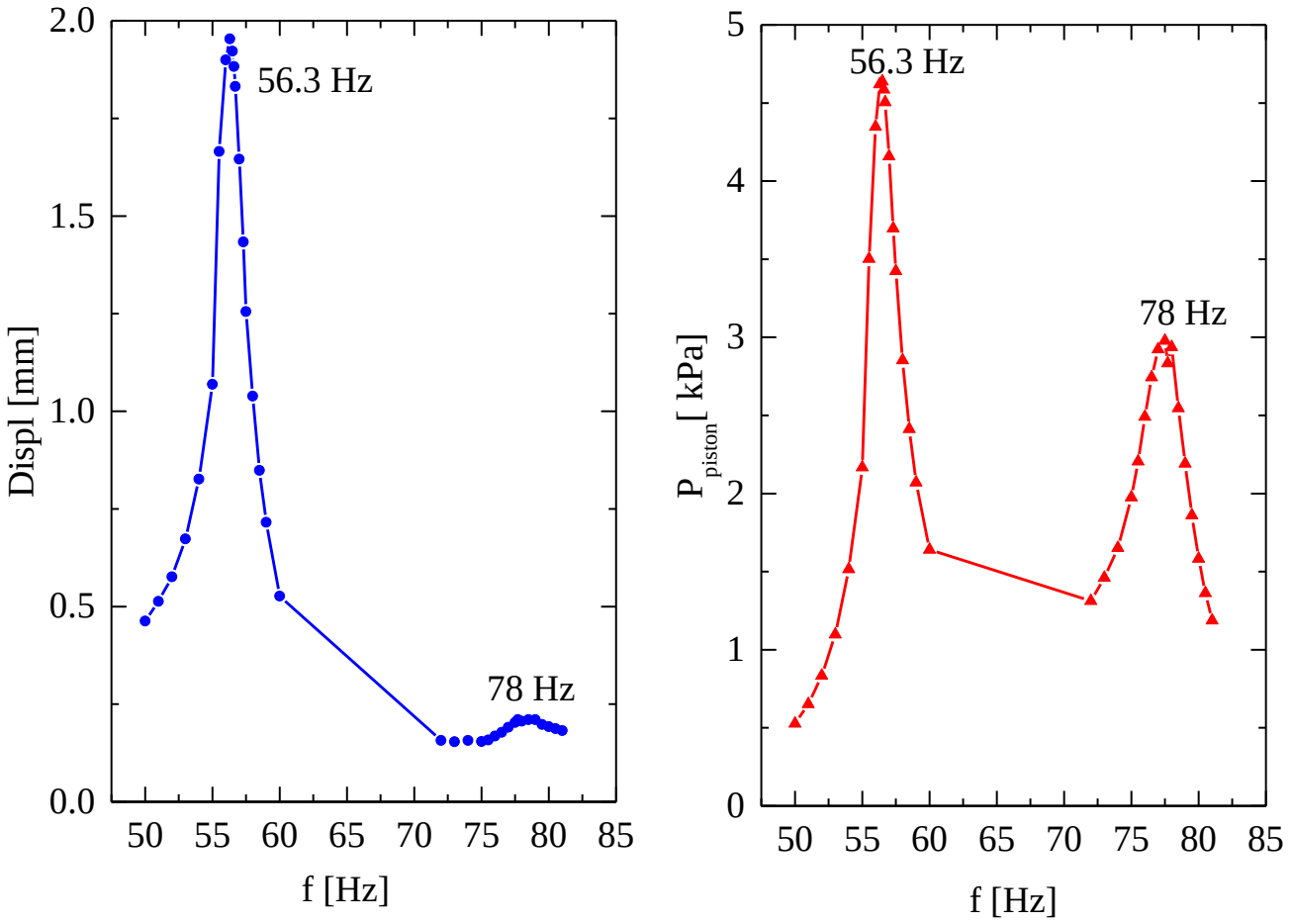


Test of the bench scale TA-heat pump

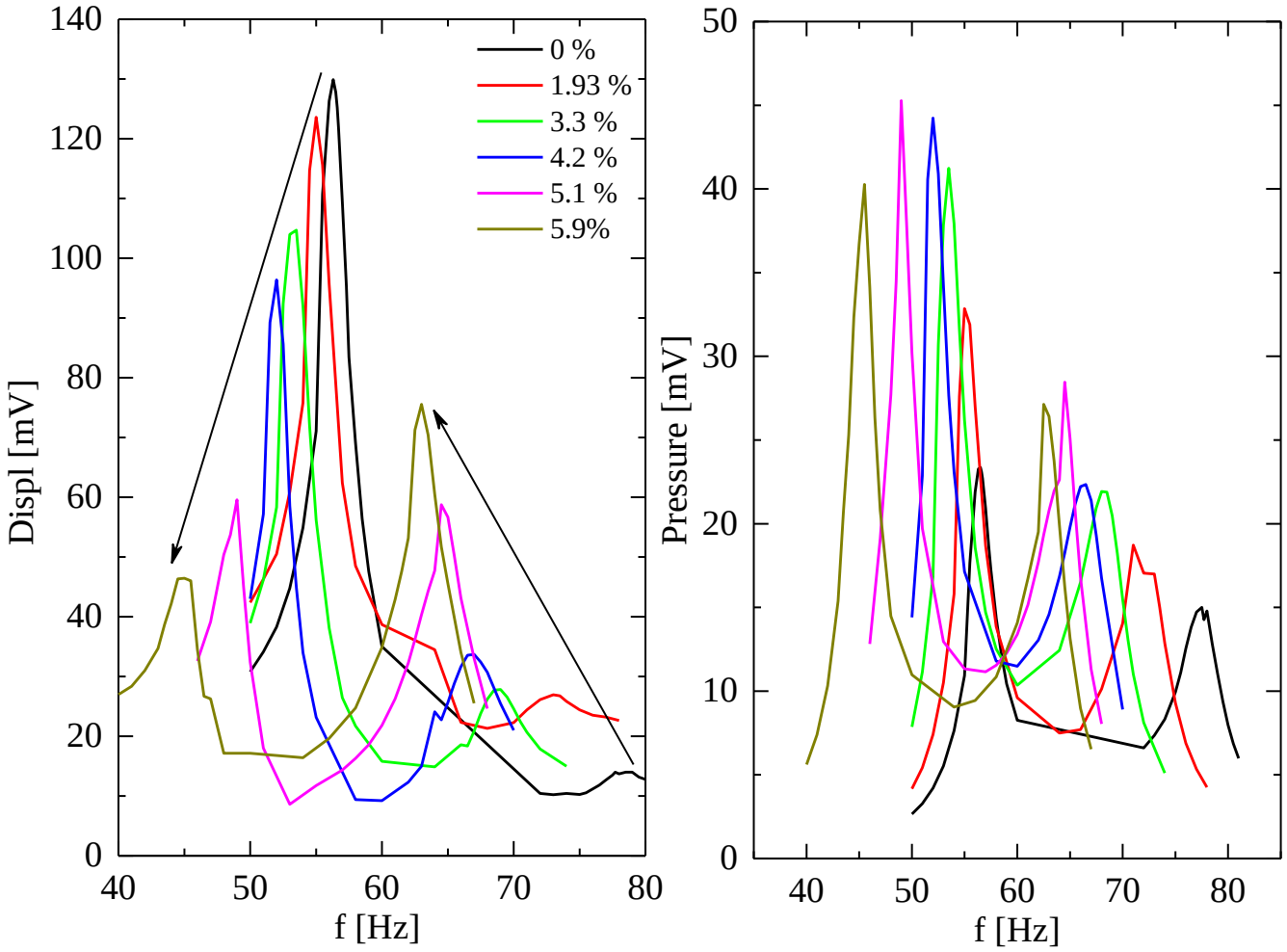
- The heat exchangers of the heat pump are coupled to a thermal bench. The thermal bench simulates the heat source and heat sink for the heat pump.
- The system is filled with 50 bar helium and the measured resonance frequency is 78 Hz.
- The measured drive ratio is only 1 % much smaller than the expected 5 %.
- Mismatch problem between resonance frequency of the heat pump and that of the linear motor.
- Internal acoustic leakage

Resonance measurement

Experimental resonance frequency scan at P_m = 50 bar helium, Voltage = 11.3 V



Helium-Argon gas mixture



Test of the bench scale TA-heat pump

- Improving the internal acoustic seal and using HeAr gas mixture resulted in an increase of the drive to 2.7 %
- Heat pump delivers 3 kW of thermal power at 109 °C with a COP of 3.02 corresponding to 42 % of Carnot performance.

Conclusions

- Bench scale electrically driven thermoacoustic heat pump is designed, built, and tested.
- At a drive ratio of 2.7 % the heat pump delivers 3 kW of thermal power at 109 °C with a COP of 3.02 corresponding to 42 % of Carnot performance.
- The drive ratio can be further increased to 5 % by reducing the internal acoustic leakages and by improving the matching between the resonance frequencies of the linear motor and the heat pump.
- It is expected that if these problems are solved successfully, the heat pump will deliver the required 10 kW of thermal power at 109 °C with the specified design performance.


Questions ?

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