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A linear Stirling cooler for extreme ambient temperatures

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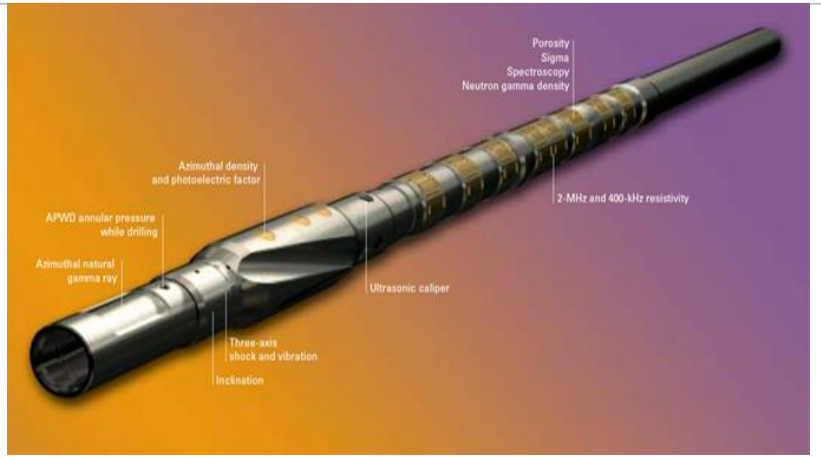
- Cooler type trade-off
- Thermodynamics
- Design challenges
- Test and qualification results
- Conclusions

Background

A customer active in the petrochemical industry is developing an imaging tool to inspect inside oil wells



Oil reserves near the earth surface become depleted

- Maintenance on existing wells is needed
- New wells at increasingly larger depths

For imaging equipment in 'Wireline' tool, an active cooling solution was needed

- Ambient temperature: 150 °C
- Cooling power: 24 W
- Tip temperature: 223 K

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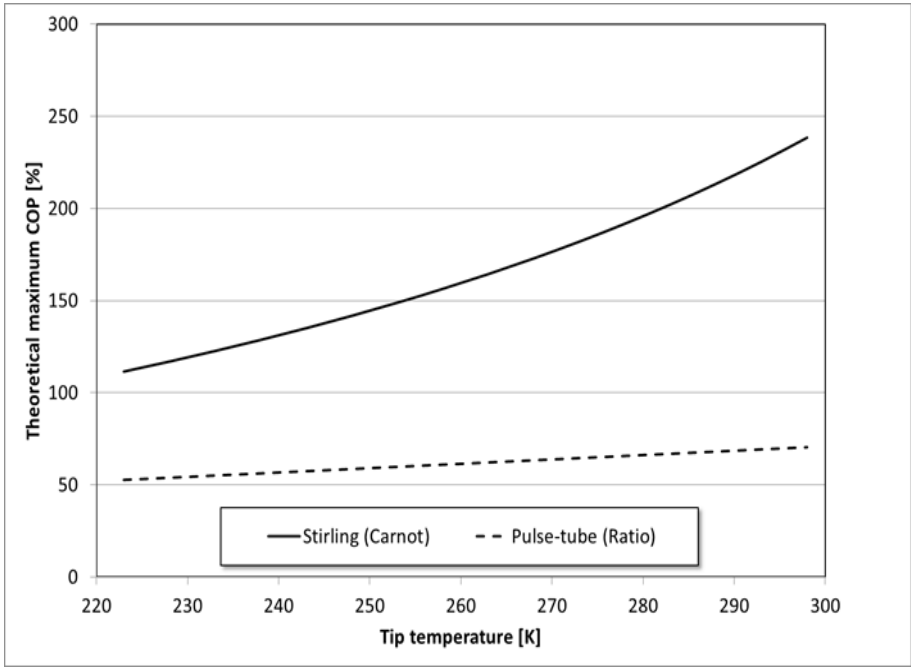
Cooler trade-off and thermodynamics

What to use: Stirling or Pulse-tube

- Ideal efficiency versus T_{amb}: Stirling much higher
- Stirling cooler typically smaller per watt of cooling power
- Pulse-tube is more reliable, but this high reliability not required in this application

Thus: Stirling cooler for this application



Theoretical efficiency versus tip temperature, Tamb = 150°C

Stirling: $COP_{max} = COP_{carnot} = T_l/(T_h-T_l)$
Pulse-tube: $COP_{max} = T_l/T_h$

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Cooler design

Moving magnet compressor

Pneumatically driven Stirling Cold finger

- Cold finger dimensions close to existing 20 mm LSF9340 cold finger
- Optimized regenerator and displacer tuning

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Design challenges

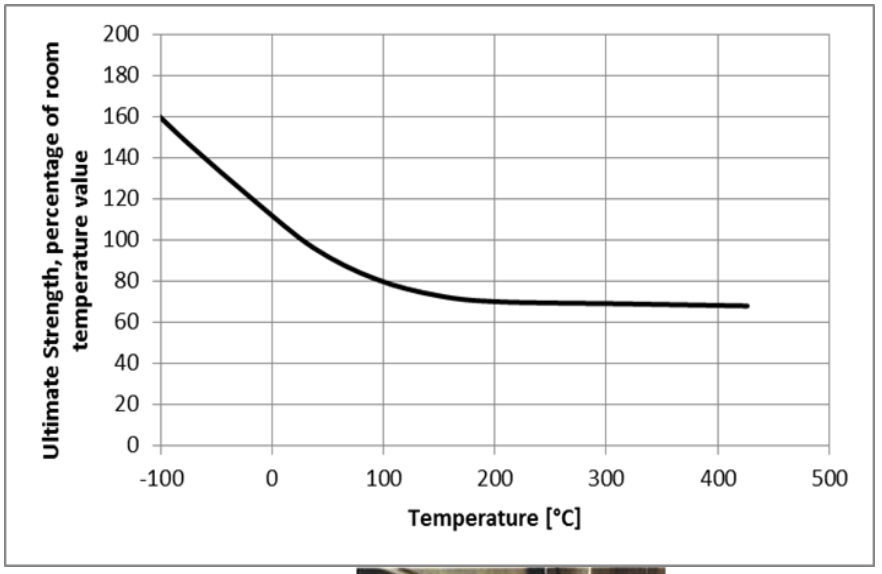
High ambient temperature poses several challenges in the design, such as

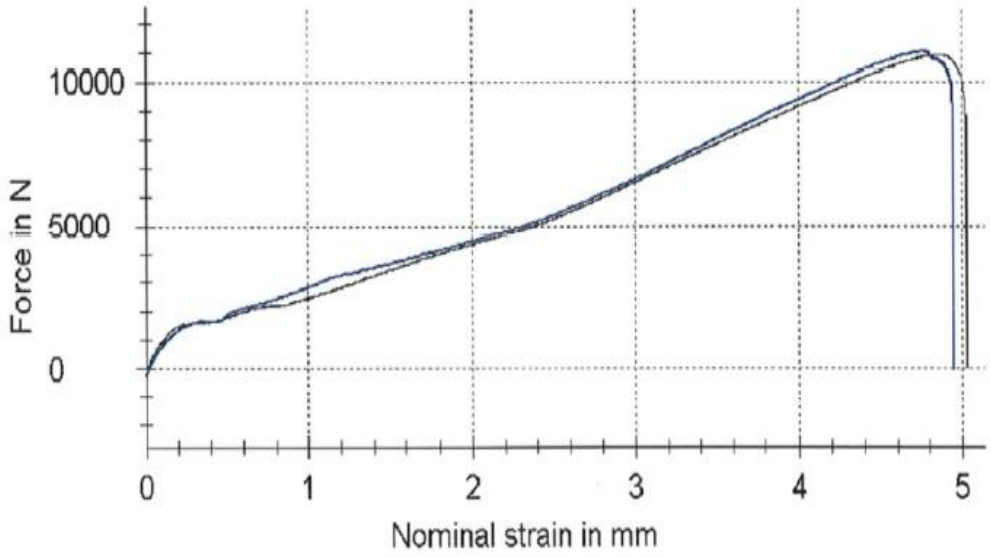
- Materials strength
  - Yield strength, ultimate strength
  - Fatigue
- Materials properties
  - Copper resistivity
  - Curie temperature of magnets

Yield strength of austenitic stainless steels

Austenitic stainless steels

- Strength decreases to about 70% of room-temperature value
- Separate weld qualification performed at high temperature





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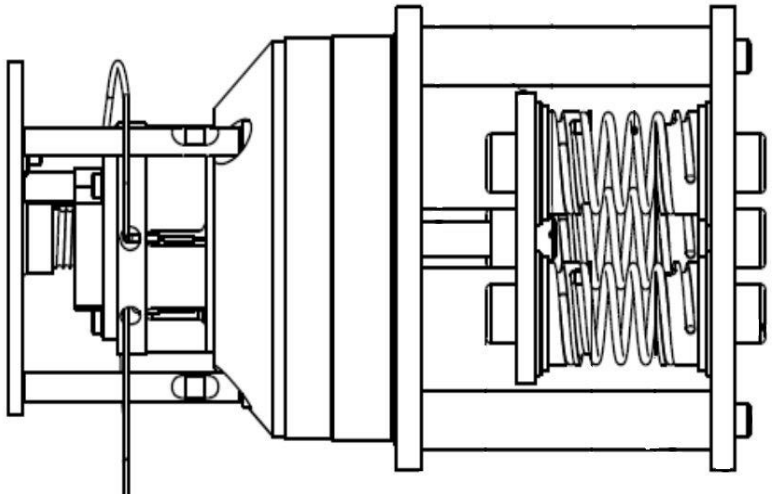
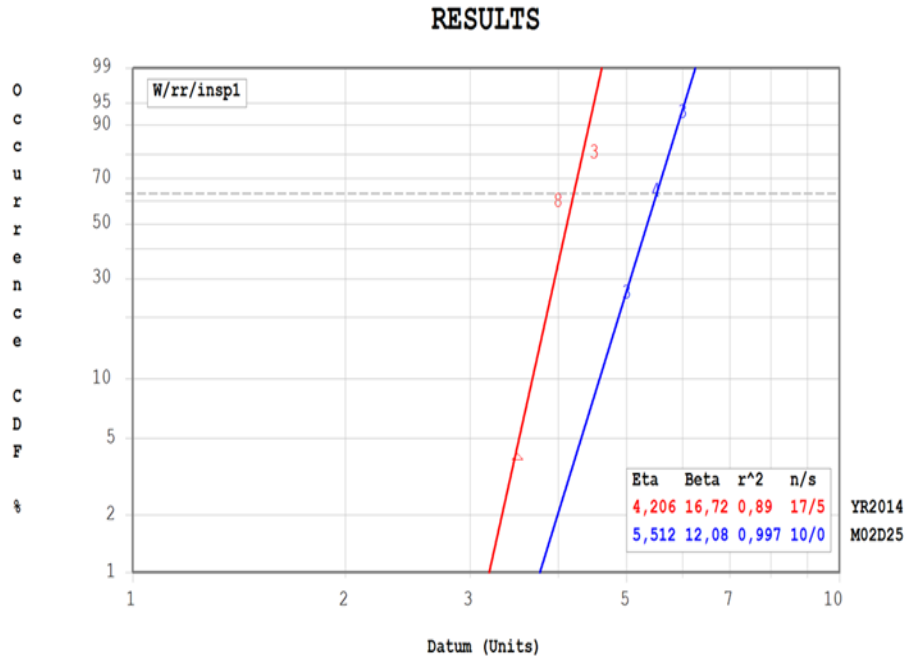
Fatigue limit of spring steels

Standard spring steel not suitable for high temperature use

- New material selected. Fatigue limit experimentally verified





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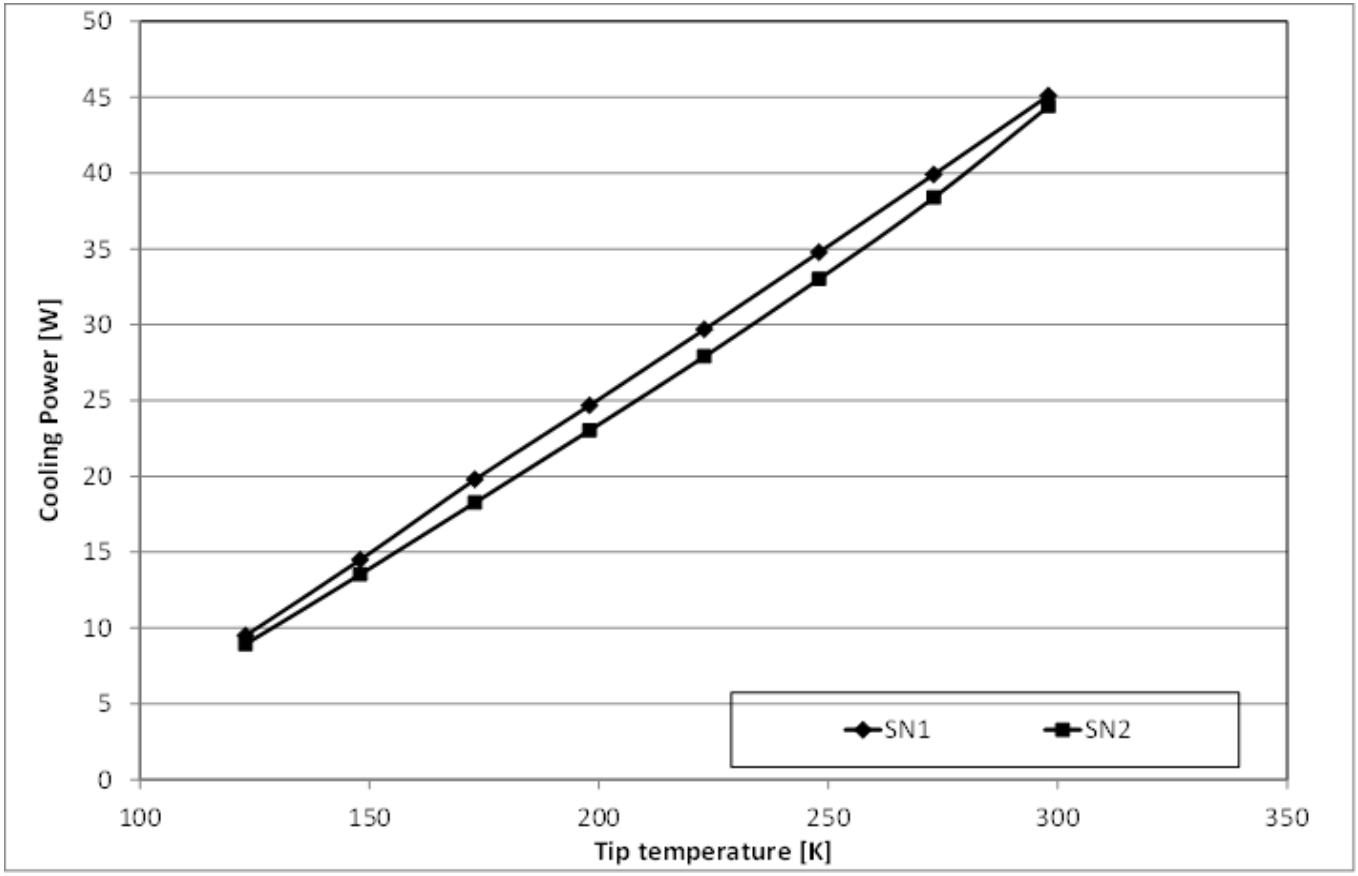
Performance – Qualification Models

Cooling power versus tip temperature

- 175 W input power, 150 °C ambient temperature



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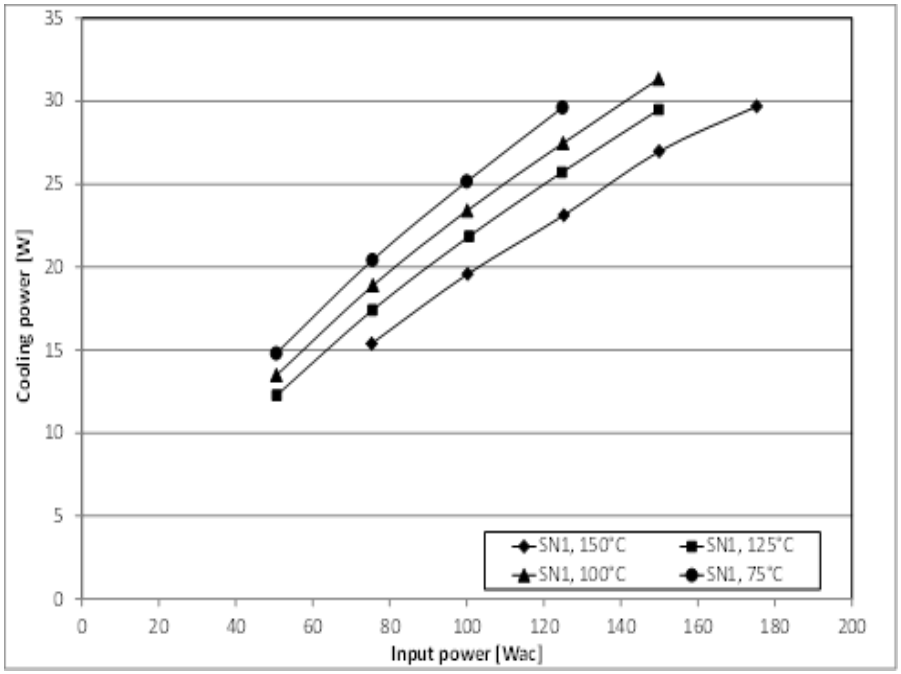
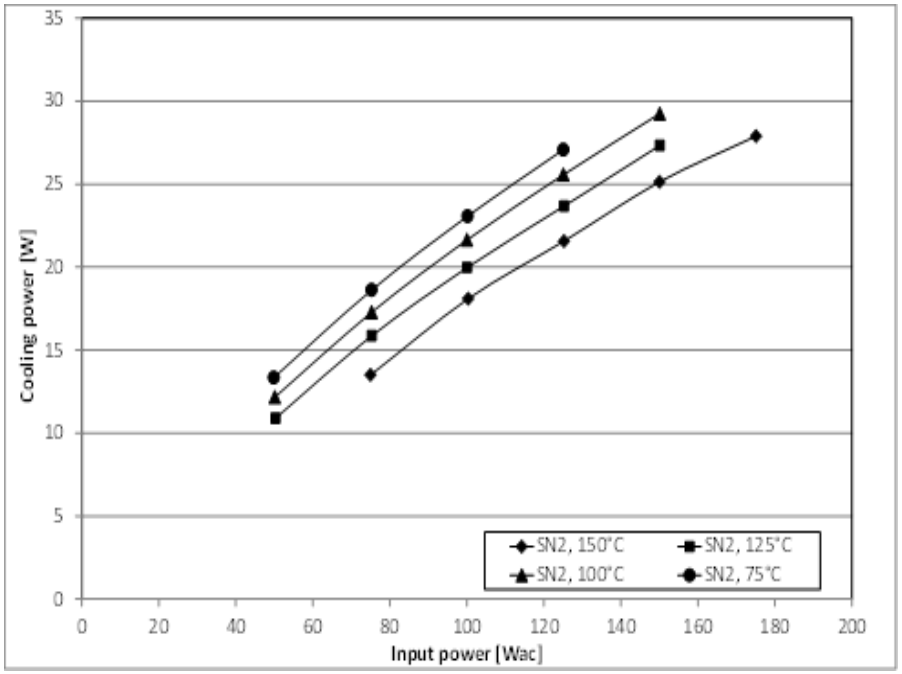
Performance – Qualification models

Cooling power versus input power

- 223 K tip temperature, different ambient temperatures





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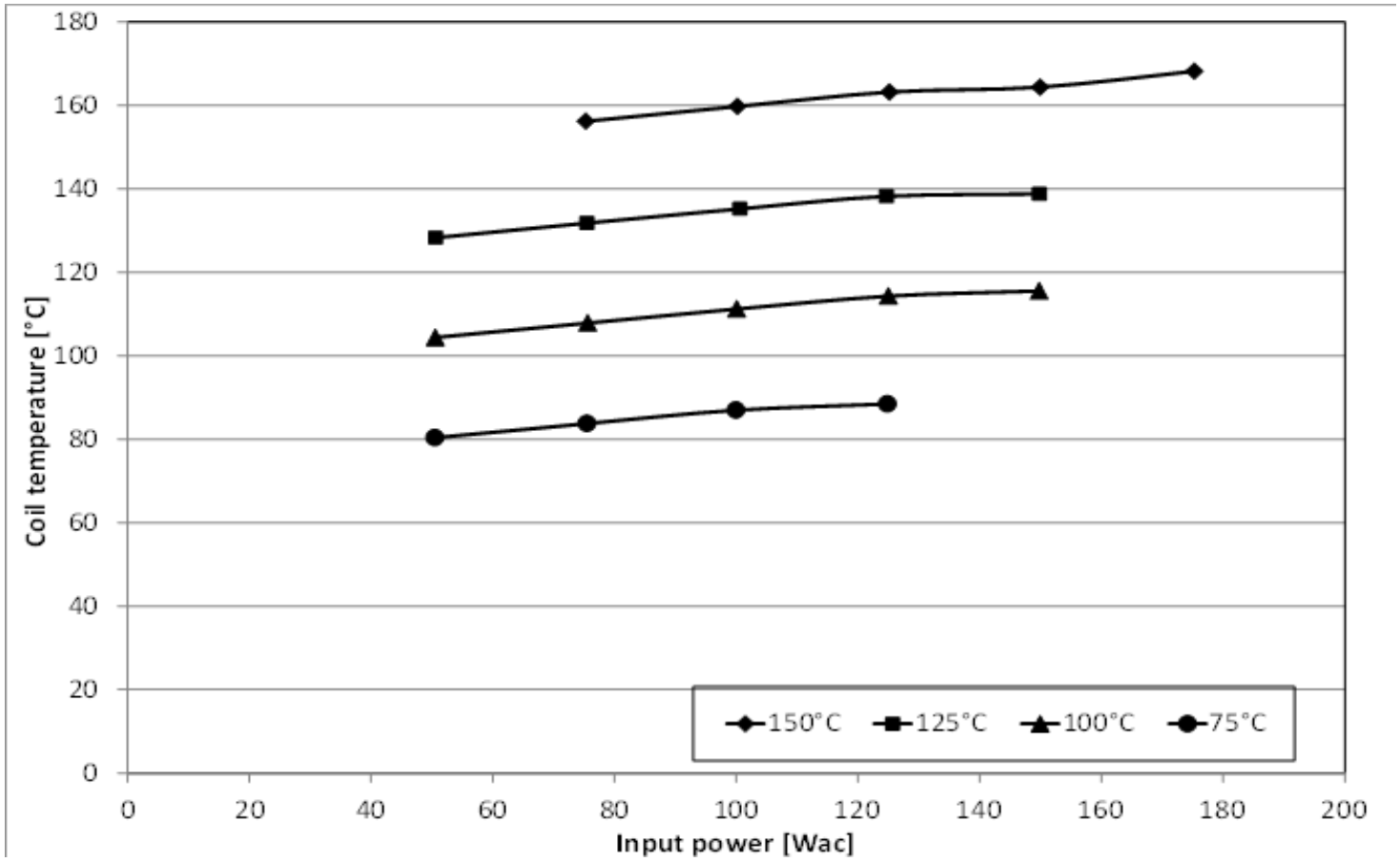
Performance – Thermal management of coils

Coil temperature versus input power

- Different ambient temperatures



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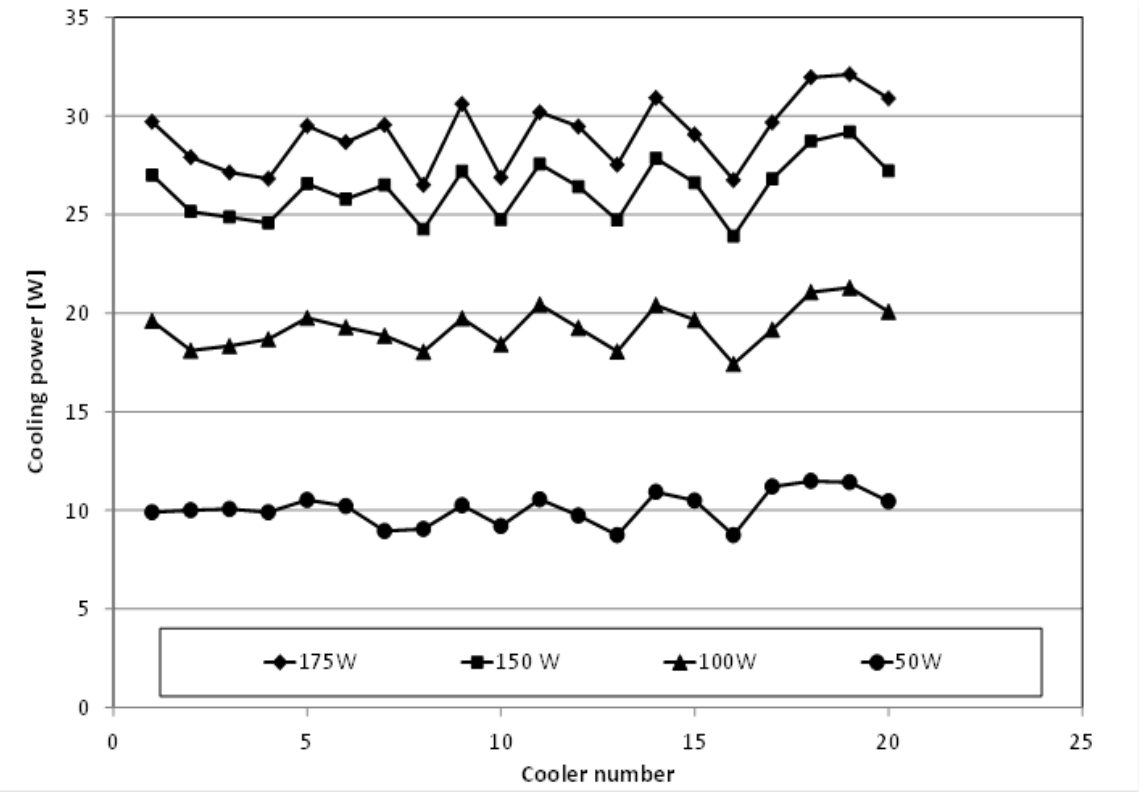
Performance - Series

In total, 20 coolers built to date



- ATR measurement: cooling power at 223 K tip and 150 °C ambient for different input powers

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Conclusions

- A linear Stirling cooler for extreme ambient temperatures is successfully designed, built and tested
- Main challenges in the impact of the high temperature on materials properties
- Cooler successfully tested and qualified for performance and environmental conditions
- Up to now, 20 coolers built with consistent performance

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