Challenges and Development of sCO2 heat exchangers

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Effective January 1, 2019, Meggitt has adopted a new organisation structure, designed to accelerate growth by increasing alignment with our customers whilst simplifying our business.
Heatric Timeline

1985 - Present

- 1985: Heatric founded in Australia, later relocated to UK in 1990
- 1989: Heatric opens sales office in Houston, TX, USA
- 1990: PCHE developed at University of Sydney
- 1998: Heatric's first application in offshore gas processing
- 2010: Heatric opens new Holton Heath Factory
- 2013: Heatric expands, opens sales office in Brazil
- 2015: Heatric opens sales office in Singapore
- 2017: Heatric gains nuclear certification
- 2017: Heatric opens sales office in South Korea
- 2019: Meggitt and Heatric rebranded
Main sCO2 cycles

**Rankine sCO2 Cycle**

**Bottoming cycles**

Mostly used as waste heat recovery applications for gas turbines, industrial heat and high temperature geothermal in the 10s MWe range

**Brayton sCO2 Cycle**

**Baseload cycles**

Developed to displace steam for Fossil, Nuclear and CSP applications for 100s MWe range

**Oxy-fuel sCO2 Allam Cycle**

**Baseload with Carbon capture**

Developed to provide electricity at high efficiency with 100% carbon capture and displace fossil plants with CCS in the 100s MWe range
## sCO2 Cycles

### Extract from DoE Quadrennial Technology Review 2015 - Chapter 4: Advancing Clean Electric Power Technologies

<table>
<thead>
<tr>
<th>Application</th>
<th>Cycle type</th>
<th>Motivation</th>
<th>Size [MWe]</th>
<th>Temperature [°C]</th>
<th>Pressure [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>Indirect sCO₂</td>
<td>Efficiency, Size, Water Reduction</td>
<td>10 - 300</td>
<td>350 - 700</td>
<td>20 - 35</td>
</tr>
<tr>
<td>Fossil Fuel (PC, CFB, …)</td>
<td>Indirect sCO₂</td>
<td>Efficiency, Water Reduction</td>
<td>300 - 600</td>
<td>550 - 900</td>
<td>15 - 35</td>
</tr>
<tr>
<td>Concentrating Solar Power</td>
<td>Indirect sCO₂</td>
<td>Efficiency, Size, Water Reduction</td>
<td>10 - 100</td>
<td>500 - 1000</td>
<td>35</td>
</tr>
<tr>
<td>Shipboard Propulsion</td>
<td>Indirect sCO₂</td>
<td>Efficiency, Size</td>
<td>&lt;10 - 10</td>
<td>200 - 300</td>
<td>15 - 25</td>
</tr>
<tr>
<td>Shipboard House Power</td>
<td>Indirect sCO₂</td>
<td>Efficiency, Size</td>
<td>&lt;1 - 10</td>
<td>230 - 650</td>
<td>15 - 35</td>
</tr>
<tr>
<td>Waste Heat Recovery</td>
<td>Indirect sCO₂</td>
<td>Efficiency, Size, Simple Cycles</td>
<td>1 - 10</td>
<td>&lt; 230 - 650</td>
<td>15 - 35</td>
</tr>
<tr>
<td>Geothermal</td>
<td>Indirect sCO₂</td>
<td>Efficiency</td>
<td>1 - 50</td>
<td>100 - 300</td>
<td>15</td>
</tr>
<tr>
<td>Fossil Fuel (Syngas, nat gas)</td>
<td>Direct sCO₂</td>
<td>Efficiency, Water Reduction, CO₂ Capture</td>
<td>300 - 600</td>
<td>1100 - 1500</td>
<td>35</td>
</tr>
</tbody>
</table>
PCHE pressure and temperature design range

Heatric heat exchanger operating range

Standard heat exchanger operating range
What is a Heatric PCHE?
Printed Circuit Heat Exchangers

Superior Performance

OPEX saving across wide range of processes
Heatric PCHEs are bespoke diffusion bonded compact heat exchangers providing:
- close temperature approaches (>2°C)
- very high thermal performance (i.e. 13.6 MWh/m² s CO₂ recuperator)
- high pressure capability (>1,000 Bar)
- widest range of temperatures (-196°C to 983°C)

Safe

Reduced operational risks
Using diffusion bonding with a fully welded construction, PCHEs:
- can operate at full differential pressure between streams
- are immune to flow induced vibrations and pressure fluctuations
- do not suffer from catastrophic failure mode
- have 30 years track record of safe operation and >3,000 exchangers supplied

Compact and Modular

Overall project CAPEX saving
Heatric PCHEs are up to 85% smaller than Shell and Tube exchangers, offering:
- modularisation for ease of transport, on-site installation
- reduced foundation structure
- reduced pipework and safety valves
- retrofit capability in lieu of S&T
Heatric sCO2 Key Delivered Project Timeline

Since 1994

1994
- Heatric supply to their first PCHE Recuperator for Tokyo Institute of Technology sCO2 loop

2003
- First PCHE using sCO2 - Offshore re-injection

2009
- Heatric supply to Echogen EPS 100, the world’s first commercial sCO2 WHR unit

2011
- Heatric supply three PCHEs to Sandia National Laboratories sCO2 Brayton test loop

2016
- Heatric supply to NETPower Pilot Plant in Texas

2017
- Heatric supply to China Western Power Company Biomass test loop

2019
- Several on-going WHR and Baseload projects
Heatric sCO2 Exchangers – 18 Major Projects to date*

* 40 sCO2 exchangers delivered, 270 sCO2 projects quoted, >1,000 exchangers bespoke designs
Heatric Component cost - 316, 347, 617 Pipe (ASME B31.3)

316 Pipe thicknesses vs. design temperature (250 Bar design pressure)

316, 347, 617 Pipe thickness reduction vs. temperature (250 Bar pressure)

316 Pipe thickness vs. Std Pipe schedule (250 Bar pressure)
Lesson learned

\textbf{sCO2 heat exchangers are expensive?}

Yes they can be depending on the process design:

\textbf{Increasing design temperature:}

- May shift equipment built from conventional material to high grade alloys (10x – 20x more expensive)

\textbf{Increasing design Pressure:}

- Will require thicker walls with much more expensive non standard product forms for some components (i.e. hubs, special forgings, pipes)

\textbf{Temperature approaches:}

- Will lead to diminish efficiency returns versus exchanger potentially doubling in size for minimum gains ($Q=U.A.LMTD$)

\textbf{Allowable pressure drop:}

- Will lead to very high free flow area requirements increasing the size of the exchanger potentially beyond compressor / pump cost savings

\textbf{sCO2 process design must be balanced between equipment cost and efficiency gain}
Path to commercialisation

**Supply Chain**
Cost reduction  
Product availability

Even in stainless steel, material price and product form availability can be a challenge; Supply chain must be engaged with to providing competitive materials in suitable product forms.

**Standardisation**
Process | Products  
Performance

Standardisation of the various sCO2 processes will lead to standard products, potential for off-the shelf with mass production and guaranteed performance based on previous supplies results operational records.

**Modularisation**
Flexibility | Footprint  
Plant integration | Deployment

Modularisation brings benefits in flexible designs with minimum changes, defined footprints facilitating plant integration and facilitation deployment even in remote area (i.e. containerized).

**Collaboration**
Faster R&D | No duplication  
Better use of funds

Improve international coordination / communication to ensure most R&D activities going forward are not replicating existing research in other territories / regions.

Making sCO2 Viable?
Technology development

**PCHE**

PCHEs typical channels are 1 mm deep (2 mm semi circular)

They are well suited for sCO2 but not for exhaust side due to pressure drop constraints

PCHEs are already used as Recuperators in sCO2 systems

Heatric has developed deep etch technology currently able to achieve 2.5 mm deep channel (5 mm semi circular)

**HYBRID**

H²Xs aim to combine 2 or more different product forms in a single product

To date H2X has been considering combining Fins to PCHE channels

Work is in progress to validate H²X as part of the Cranfield test loop

Further work is on-going to expand channel size on the exhaust side to dH > 5 mm
Sandia National Laboratories - sCO2 Brayton Cycle

- **HT Recuperator**
  - 2.27 MW
  - 482°C (900°F)
  - 17.24 MPa (2500 psig)

- **LT Recuperator**
  - 1.6 MW
  - 454°C (849°F)
  - 17.24 MPa (2500 psig)

- **Gas Chiller**
  - 0.53 MW
  - 149°C (300°F)
  - 19.31 MPa (2800 psig)

3 sCO2 exchangers delivered
>2.2 tons combined
Echogen EPS100 - sCO2 Rankine Cycle

3 sCO2 exchangers delivered
>30 tons combined
Net Power 25MWe - sCO2 Oxy Fuel Allam Cycle

4 sCO2 exchangers delivered (including one 617 unit)
60 tons combined
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