MI Research in Sorption Heat Pump Systems

Bob Critoph

9th September 2020
A Unique Moment in Time

MISSION INNOVATION
Accelerating the Clean Energy Revolution
www.mission-innovation.net
Affordable Heating & Cooling for Buildings Innovation Challenge (IC7)
Timeline:

- Launch, June 2016
- Abu Dhabi, November 2017
- Pisa, July 2018
- Road map for Sorption Research, September 2018
- .....
Timeline:

- Abu Dhabi, November 2017: Affordable heating and cooling challenge

- Thermal Energy Storage
- Heat Pumps
- Non-Atmospheric Heat Sinks and Sources
- Predictive Maintenance and Optimization
- Physiological Studies for Thermal Comfort
Timeline:

- Abu Dhabi, November 2017:
  Affordable heating and cooling challenge

Key activities in ‘heat pumps’:
1. Converting low grade heat to power (Target 60 °C waste heat)
2. Efficient gas to heat and cold (Target Gas Utilisation Efficiency of 1.6 (air source), 1.7 (water source) and 2.0 (in lab))
Timeline:

- Abu Dhabi, November 2017
- Pisa, July 2018

BEIS commissions a roadmap on Sorption Technologies for heating and cooling from the IEA Annex on Thermally Driven Heat Pumps.
Timeline:

- Abu Dhabi, November 2017
- Pisa, July 2018
- Road map for Sorption Research, September 2018
- .....
<table>
<thead>
<tr>
<th>Country / Organisation – Collaboration Matrix</th>
<th>UK</th>
<th>NL</th>
<th>Germany</th>
<th>Italy</th>
<th>CAN</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UW</td>
<td>TNO</td>
<td>ISE</td>
<td>TUB</td>
<td>THN</td>
<td>POLIMI</td>
</tr>
<tr>
<td>Domestic heat pump application Action Areas:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Demonstration programmes to increase product acceptance.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Refinements to the existing ammonia-water cycle.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Further evaluation of alcohol based absorption pairs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Ammonia adsorption with salts (lower TRL) or active carbon (higher TRL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Development of compact and cost effective zeolite-water based adsorption systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water refrigerant air conditioning/heat pumping Action Areas:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Reducing the possible cooling temperature using novel evaporator designs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Hybrid compressor/sorption systems, multistage cycles particularly useful in large commercial applications.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Novel ad/ab sorber designs with improved heat/mass transfer, compact, economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste heat powered heat transformers Action Areas:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Lithium Bromide absorption systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Ammonia-salt resorption which also offers energy storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Final proposal was a compromise:

- **Budget from UK £300k**
- **Duration 27 months from June 2020**
- **No direct funding of overseas partners, so only voluntary contributions! – but we can fund meetings.**
www.lot-net.org/missioninnovation.html
Domestic heat pumps:

- Simpler
- Low capital cost
- GUE 2 salt – 1.6
- GUE 3 salt – 2.0
D1 (Month 10) Report on equilibrium and dynamic data for a range of salt and salt mixtures for heat pumping, refrigeration and storage measured by UW, SJTU, ICCOM and compiled by UW.
D2 (Month 12) Report on design and expected performance of 2-salt resorption heat pump (UW)

D3 (Month 12) Report on design and expected performance of advance 3-salt system (SJTU).
D4 (Month 27) Report on 2-bed heat pump performance (UW)

D5 (Month 27) Report on 3-bed cascaded heat pump simulation (UW)

D6 (Month 27) Report on 3-bed system performance (SJTU)
D7 a,b,c,d,e,f. UW will organise the kick-off, 6-monthly meetings (4) and Final Workshop, as above. The last will be extended to include a 3rd ‘Sorption Friends’ meeting, maximising the dissemination opportunity.

D8 (Month 31) The final ‘Sorption Friends’ meeting will be used to generate a final experts report to cover technical and economic potential, policy implications, etc.
Other activities that are not deliverables:

**CNR-ICCOM** (Pisa) characterization of ammonia adsorption into salt mixtures by NMR and FTIR techniques, including the verification of any degradation process due to aging.

**CNR-ITAE** (Messina) will model alternative applications of the technology to higher temperatures (for use in industry) and storage as well as simulating and optimising different reactor designs.
Other activities that are not deliverables:

**SJTU** (China)

- Share in experience of ammonia – salt systems and combatting long-term cycling degradation
- When material equilibrium and dynamic properties are characterised by UW (4th quarter 2020) they will use them to simulate the realistic machine performance that can be expected of a number of advanced 3-bed cycles and will build a 3-salt prototype by 2022
- Host a project meeting in 2021 linked to ICCR2021
Other activities that are not deliverables:

**SFU (Canada)**

- Assist in developing a long-lasting composite sorbent materials
- Graphite heat exchangers for sorption reactors
- Analytical model that can be used for design and optimization
- SFU will also host a mid-term (Summer 2021) workshop / meeting for all participants
Other activities that are not deliverables:

TNO ????
Warwick research
LTJ Tests:

Large Temperature Jump Reactor

TC positions

½ inch pipe centre
1 inch pipe jacket
PTFE to fill heated volume
O-ring Swagelok face seal fitting
LTJ Tests:
LTJ Tests:

LTJ Experimental Cycle Result

- LTJ wall top T
- Exp V T
- ENG T
- Inside Pipe
- LTJ Wall Bottom T
- Pressure

Temperature (°C) vs. Time (seconds)
Current work

**REACTIVE SAMPLES**

- **LTS**
- **HTS**

**Diagram:**
- **SS OUTER TUBE**
- **HEAT TRANSFER FLUID (OIL)**
- **ENG + SALT**
- **SS INNER TUBE**

**Images:**
- Reactive samples
- Coin-like objects
Current work

Salt

Exp. Vessel

RADIAL DIRECTION

ADIABATIC SURFACES

nr NODES

Oil Flow

NH3 Flow

AXIAL DIRECTION

nz NODES

Desorption

Adsorption

LoT-NET
Plan of action (inline with MI timeline)

<table>
<thead>
<tr>
<th>Jun ‘20</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Temperature Jump tests on BaCl₂, CaCl₂, MgCl₂ and any recommended mixtures by research partners</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MATLAB Modelling single salt (Ad/Desorption)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTJ rig for dynamic testing of salts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactor (Adsorbent heat exchanger)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two-bed resorption heat pump design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cycling rig:
Analytical equipment:

- Rubotherm magnetic suspension balance
- High pressure DSC for sorbate properties
- Thermal conductivity
- STA high pressure ammonia
ThermExS Lab:
Condenser

Michel van der Pal’s CaCl$_2$ - NH$_3$ reactor under test

Evaporator

Reactor
Thank you!

Questions??