Adsorption Heat Pumps: Challenges and Future Perspectives

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Introduction

- CO2 Emission
- Total: 180Mt CO₂/year
- Heating: 87Mt CO₂/year (48%)
- 29 million Gas boilers (85% Heating Systems)
- 1.3 New installed Gas boilers /year (Replacement and new buildings)
- Need of Heat Decarbonisation to meet 80% reduction of greenhouse gas emission by 2050.

Heat Pumps (HPs) including Thermally Driven Heat Pumps (TDHPs) are part of the solutions.

Advantages of TDHPs:
- Little or no load on Electrical Grid
- Renewable label (Biomass or Hydrogen)

European Market trend: Heating HPs vs. Boilers
Introduction
- Space Heating (SH) and Domestic Hot Water (DHW)
- Residential and light commercial building sectors
Introduction

1. HP Technologies: An overview

2. What are the key factors that are holding back Adsorption HP Technology? Performance? Cost? Others?

3. Examples of ongoing projects (as pathway to short and long terms contribution Adsorption HPs)

4. Conclusions
1. HP Technologies: An overview

Hybrid Heat Pumps (HHPs)

Conventional Electrically Driven Vapour Compression HPs

Heat Pumps (HPs)

Fuel/Waste Heat/Renewable Energy Driven HPs

Thermally Driven HPs

Sorption HPs

Mechanically Driven HPs (Gas Engine)

Other HPs

AdSorption HPs
1. HP Technologies: An overview

Conventional Electrically Driven Vapour Compression HPs

Heat Pumps (HPs)

Hybrid Heat Pumps (HHPs)

Fuel/Waste Heat/Renewable Energy Driven HPs

Thermally Driven HPs

Mechanically Driven HPs (Gas Engine)

Other HPs

AbSorption HPs

AdSorption HPs

Heating Cycle

Mechanical Compressor vs. Thermal Compressor
1. HP Technologies: An overview

Heat Pumps (HPs)

- Conventional Electrically Driven Vapour Compression HPs
- Fuel/Waste Heat/Renewable Energy Driven HPs
- Hybrid Heat Pumps (HHPs)
- Thermally Driven HPs
- Mechanically Driven HPs (Gas Engine)
- Other HPs
- Ab Sorption HPs
- Ad Sorption HPs
3. What are the Key factors that are holding back this technology?

**Adsorption Heat Pump Performance?**

- **Thermally Driven HPs**
  - COP = 1.2 (Thermal)

- **Conventional Electrically Driven Vapour Compression HPs**
  - COP = 1.3 (Thermal)

- **COP = 4.2** (Electrical)
- **COP = 1.3** (Thermal)
- **ηtd = 0.88** (Transmission & Distribution)
- **ηt = 0.35** (Thermal)

Source: www.worldenergydata.org/world-electricity-generation/

- Marginal difference.
- Not really if Fossil Fuel is the source of electricity.
- Conventional Electrically Driven Vapour Compression HPs if renewable energy as source of electricity.
3. What are the Key factors that are holding back this technology?

Adsorption Heat Pump cost? £, $, ...
(Sum of Capital, Maintenance and Running)

- Adsorption HP
- Installation
- Revision
- Repair
- Electricity
- Fuel
- Inspection

Thermally Driven Adsorption HPs VS. Conventional Electrically Driven Vapour Compression HPs

<table>
<thead>
<tr>
<th>Type of system</th>
<th>Cost per kW of heat output</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHP (air to and air to water)</td>
<td>£1,000 to £1,300</td>
</tr>
<tr>
<td>GSHP (open loop)</td>
<td>N/A</td>
</tr>
<tr>
<td>GSHP (closed loop)</td>
<td>N/A</td>
</tr>
<tr>
<td>LPHW boiler</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Source: [Gas driven heat pump (publishing.service.gov.uk)](publishing.service.gov.uk)

<table>
<thead>
<tr>
<th>Type of system</th>
<th>Cost per kW of heat output</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHP (air to and air to water)</td>
<td>£250 to £1,500</td>
</tr>
<tr>
<td>GSHP (open loop)</td>
<td>£1,000 to £2,000</td>
</tr>
<tr>
<td>GSHP (closed loop)</td>
<td>£1,500 to £3,500</td>
</tr>
<tr>
<td>LPHW boiler</td>
<td>£70 to £150</td>
</tr>
</tbody>
</table>

Source: [Carbon Trust](carbontrust.org.uk)
3. What are the Key factors that are holding back this technology?

**Adsorption Heat Pump cost? £, $, ... (Sum of Capital, Maintenance and Running)**

- **- Adsorption HP**
- **- Installation**

- **- Revision**
- **- Repair**
- **- Inspection**

- **- Fuel**
- **- Electricity**

**Thermally Driven Adsorption HPs**

**VS.** **Conventional Electrically Driven Vapour Compression HPs**

<table>
<thead>
<tr>
<th>Natural Gas</th>
<th>Oil</th>
<th>LGP</th>
<th>Wood pallet</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>p/kWh</td>
<td>7.4</td>
<td>11.8</td>
<td>15.5</td>
<td>9.9</td>
</tr>
<tr>
<td>kg CO2e/kWh</td>
<td>0.215</td>
<td>0.298</td>
<td>0.240</td>
<td>0.053</td>
</tr>
<tr>
<td>Standing Charge (£/year)</td>
<td>99.35</td>
<td>62.84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electricity</th>
<th>Off-Peak</th>
<th>On-Peak</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>p/kWh</td>
<td>16.7</td>
<td>34.1</td>
<td>28.3</td>
</tr>
<tr>
<td>kg CO2e/kWh</td>
<td>0.231</td>
<td>0.231</td>
<td>0.231</td>
</tr>
<tr>
<td>Standing Charge (£/year)</td>
<td>165.80</td>
<td>165.48</td>
<td></td>
</tr>
</tbody>
</table>
3. What are the Key factors that are holding back this technology?

**Adsorption Heat Pump cost? £, $, ...**  
*(Sum of Capital, Maintenance and Running)*

- Adsorption HP
- Installation
- Revision
- Repair
- Inspection
- Fuel
- Electricity

**Thermally Driven Adsorption HPs** VS. **Conventional Electrically Driven Vapour Compression HPs**

- Little or No moving parts
- Complex layout

- Moving parts
- Simple layout

Fairly similar cost on balance: in the order of £200 to £500 per year
3. What are the Key factors that are holding back this technology?

Other Heat Technologies competing with Adsorption Heat Pump?

Thermally Driven Adsorption HPs

- Viessmann (Vitosorp)
- Vaillant (zeoTherm)
- Robur
- Bosch
- Viessmann
- Daikin
- Cool Energy
- Ideal
- Vaillant
- BAXI
- Fujitsu General
- Grant
- Lochinvar
- LG Electronics
- Mitsubishi Electric
- Nibe Energy Systems
- Panasonic
- ............

Gas Driven Stirling Cycle HPs

- Boostheat (Hybrid)
- ..........

Conventional Electrically Driven Vapour Compression HPs

- Bosch
- Viessmann
- Daikin
- Cool Energy
- Ideal
- Vaillant
- BAXI
- Fujitsu General
- Grant
- Lochinvar
- LG Electronics
- Mitsubishi Electric
- Nibe Energy Systems
- Panasonic
- ............

Boilers

- Worcester Bosch
- Viessmann
- Alpha
- Ideal
- Vaillant
- BAXI
- Glow-Worm
- Lochinvar
- Potterton
- Intergas
- Vokera
- Grant
- .............
• Boostheat (Hybrid)

Thermal Compression by BOOSTHEAT

<table>
<thead>
<tr>
<th>Ext. Temp. °C</th>
<th>Heating Curve °C/°C</th>
<th>Heat Output kW</th>
<th>Heat Output HP kW</th>
<th>Gas Input HP kW</th>
<th>GUE HP %</th>
<th>Heat Output Boiler kW</th>
<th>Gas Input Boiler kW</th>
<th>GUE Boiler %</th>
<th>GUE BH20 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10</td>
<td>55 / 41</td>
<td>20</td>
<td>7.25</td>
<td>6.39</td>
<td>113%</td>
<td>12.8</td>
<td>12.9</td>
<td>99%</td>
<td>104%</td>
</tr>
<tr>
<td>-7</td>
<td>52 / 39</td>
<td>17.7</td>
<td>7.43</td>
<td>6.04</td>
<td>123%</td>
<td>10.3</td>
<td>10.3</td>
<td>100%</td>
<td>109%</td>
</tr>
<tr>
<td>2</td>
<td>42 / 33</td>
<td>10.8</td>
<td>7.88</td>
<td>5.25</td>
<td>152%</td>
<td>2.79</td>
<td>2.69</td>
<td>104%</td>
<td>136%</td>
</tr>
<tr>
<td>7</td>
<td>36 / 29</td>
<td>6.9</td>
<td>6.87</td>
<td>4.15</td>
<td>166%</td>
<td>0.049</td>
<td>0.047</td>
<td>106%</td>
<td>165%</td>
</tr>
<tr>
<td>12</td>
<td>30 / 25</td>
<td>3.1</td>
<td>3.08</td>
<td>2.37</td>
<td>130%</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-130%</td>
</tr>
</tbody>
</table>

Seasonal Gas Utilization Efficiency 135 %

3. Examples of ongoing projects

Cooll (Netherlands)
- AC-Ammonia
- Driving Temp: 180 °C
- Water Supply Temp: 60 °C
- Cycling Time: 5 minutes
- Air source
Source: Technology | Cooll

Oak Ridge National Lab (US)
- Nanocoated SaltX-Ammonia
- Driving Temp < 200 °C
- Water Supply Temp: 55 °C
- Air source
- 83,000 BTU/h ~ 24.3 kWth
- COP ~ 1.2-1.4

Fraunhofer-ISE (Germany)
- SAPO 34 Zeolite-Water
- Driving Temp <100 °C
- Water Supply Temp: 55 °C
- Ground/Air source
- 20 kWth
- COP ~ 1.2-1.4

UW-STET (UK)
- AC-Ammonia
- Driving Temp: 170 °C
- Water Supply Temp: 55 °C
- Air source
- 10 kWth
- COP ~ 1.2-1.4

Key focus point of R&D: Cost effective Thermal Compressor
3. Examples of ongoing projects

Fraunhofer-ISE (Germany): Gas Fired Adsorption Heat Pump (Zeolite-Water)
Oak Ridge National Laboratory (US): Gas Fired Adsorption Heat Pump (SaltX-Ammonia)
Cooll (Spin Off Company – University of Twente - Netherlands): Adsorption Heat Pump (Activated Carbon-Ammonia)

Generator design (Thermal compressor)

Shell and finned tube

Design Parameters:
- Tube diameter
- Tube pitch
- Carbon thickness
- Fin thickness

Detailed simulations in MATLAB

ICR2019 Critoph R.E.

Performance predictions

Target performance:

• Heating power 10 kW
• Total generator volume ≤ 10 litres
• Internal COP ≥ 1.4 (GUE ~1.25)
  - Heating water delivery temperature 55°C
  - Evaporating temperature 0°C

ICR2019 Critoph R.E.

Lab Prototype (2020)
COP ~ 1.2
(under target of 1.4)

Final Prototype with integrated boiler under construction (2022)
4. Conclusions

- **Performance**: Not more or less a barrier.

- **Cost (Capital/Running)**: Main barrier.

- **Market competition**: Main barrier (linked to cost).

- **More work**: R & D on cost effective thermal compressors.
Thanks