Progress Reports, Future Plans
April 2015

WP3.4: Gas-fired heat pump
WP4.2: Thermal transformer
WP3.5: Domestic heat emitter study
(David Elmes)
WP3.4 Next generation gas/heat powered heat pump

A reminder of the background:

Rationale

- Up to 50% reduction in CO₂ emissions compared with domestic condensing boilers
- Inability of electricity supply system to cope with an ‘all electric’ future with all homes heated by electric heat pumps – gas (inc. biogas) still has a role to play

Previous research was on a 4-bed, high efficiency system:
Efficiency increases with 4 beds and heat recovery.

Gas Burner

Inlet Air

Return water from house

Evaporator

Cooled Air from Evaporator

Ammonia

Condenser

Ambient Air to Evaporator

Final Exhaust Heat Exchanger

Air-to-Pressurised Water Heat Exchanger

Heated water to house

Cool Exhaust Gases

Warm Exhaust Gases

Hot Gases

Adsorbent Bed 1 Heated

Adsorbent Bed 2 Cooled

Bed 3

Bed 4
Efficiency increases with 4 beds and heat recovery

High COP nearly 1.4 but very complicated!
Concept:

Box-for-box exchange for old boiler

Key competitive advantage
- other gas-fired heat pumps too large for wall mount

Retrofit market >90% of annual sales

Adsorbent Beds (Generators)
Original version, tested May 2011

Evaporators

Top valve assembly

Generators

Gas heat exchanger

Bottom valve assembly

Burner
4 Bed Testing

• Initial testing successfully produced output water at 60°C.
• The machine functioned as per design but excessive heat losses and internal leakage from water valve assemblies lead to low COP.
• Heat transfer in the generators was poorer than predicted – power output approximately only one third of predictions.
• Gas burner control difficulties upset the operation of the adsorption system.
Revised System

- Two bed system with heat recovery between beds.
- Heat input from electric heater to focus development on the adsorption system rather than the gas burner.
- ‘Water source’ for evaporator due to difficulties with air source evaporator.
Revised Generator

Increase from 1 kg carbon to 3 kg carbon

Ø140 mm
Length 400 mm

Ø95 mm
Length 300 mm
Two Bed System
Test Conditions

Driving Temperature: 150°C

Evaporating temperature: 0-7°C

Delivery temperature:
- Underfloor heating: 36°C flow, 26°C return
- Low temp. radiators: 50°C flow, 40°C return
Test Results

Example case for model comparison

- Low Temp Rads
- Underfloor Heating
- Low Temp Rads Fit

COP vs Heating Power [kW]
Model Comparison

- Experiment Condenser
- Experiment Cooler
- Model Condenser
- Model Cooler

Heating Power [kW] vs. Time [seconds]
By engineering standards this is perfect agreement –
After lots of problems we are finally back on track!
Generator Thermal Mass

• Original model predictions included only the thermal mass of the tubes, tube plates, and the water in the inlet and outlet plenums.

• An additional 10 kg of steel equivalent has been added to the model in order to achieve a match with the experiment across all cases.

• This is likely to be as a result of temperature cycling of the water flanges and external pipework.
## Generator Thermal Mass

### Example case

<table>
<thead>
<tr>
<th>Case</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>1.30</td>
</tr>
<tr>
<td>Model – tubes, tube plates and water plenums only</td>
<td>1.38</td>
</tr>
<tr>
<td>Model – 10 kg steel additional thermal mass</td>
<td>1.29</td>
</tr>
</tbody>
</table>
Additional Improvements

- Thermal mass of water flanges could be reduced.
- COP could then approach the theoretical 1.38.
- With the addition of mass recovery to the cycle, the COP may reach 1.4 for the example case of underfloor heating at 7.5 kW heat output.
- With an assumed gas burner efficiency of 80% (higher heating value) and an additional recovery to the load from the burner exhaust of 10%, the overall COP could then reach 1.22.
Current work

• New skinny generator shells under construction
• Plan to test on ThermExS Lab in June
• Need to demonstrate system COP > 1.2 together with compact size
In parallel we need to improve generator heat transfer to return to smaller generator size (1/3 volume)
A) Monolithic Carbon – powder + binder fired at 500°C
B) Silane binders to chemically bond carbon to stainless steel
Targets for next six months:

- Test ‘Skinny’ generators
- Assuming good enough performance, re-engage with industrial contacts
- Test heat transfer of monoliths (and if feasible, coated tubes) in LTJ
- Evaluate mechanical strength, thickness possible with coatings
- Make go/no-go decision on silanes
WP4.2 Thermal transformers [2nd Wave, Prof. Critoph, UW]

**Rationale:** Industrial processes commonly reject heat at temperatures of 90ºC or higher that cannot be utilised close to their source. A thermal transformer can transform some of this heat to higher useful temperatures, rejecting the remainder at close to ambient. There are strong links to WP4.1, 4.3.

**Challenges:** Identifying suitable economically viable major processes that would benefit. Identifying physical or chemical reactions best suited to the major needs.

**Objectives/Deliverables:** Identification of process needs and matching reactions with potentially high efficiency. Construction of laboratory PoC to investigate heat and mass transfer limitations.

**Other applications of fundamental technology:** High temperature heat pumps

**Pathway to Impact:** Via SIRACH and industrial links (Spirax Sarco)
1-salt thermal transformer

Phase 1: Storage of heat at 90°C

Heat in at 90°C

Desorption at low pressure

Salt 1

Condenser

Heat out at 30°C

Adsorption at high pressure

Salt 1

Evaporator

Heat out at 120°C

Phase 2: Discharge of heat at 120°C
2-salt thermal transformer

Phase 1: Storage of heat at 90°C

- Heat in at 90°C
- Desorption at low pressure
- Heat out at 30°C

Salt 1 → Salt 2

Phase 2: Discharge of heat at 120°C

- Heat out at 120°C
- Adsorption at high pressure
- Heat in at 90°C

Salt 2 → Salt 1
Subject of successful Working with EUED Centres bid, IDRIST.
Progress

- Linked to EPSRC Grid scale energy storage capital award ThermExS Lab (LU and UW) – commissioned by June 2015?
Progress

- New PhD student at Warwick (October 2015) will probably concentrate on chemical adsorption.
- Existing student is working on chemical reactions but concentrate on multiple effect heat pumps with very high COPs.
Progress

Bid in to British Council to fund a Russian visitor from Boreskov Institute of Catalysis - Failed

Bid in to EU Marie Curie to fund a Dutch visitor from Energy Centre of the Netherlands – Succeeded!

Michel van der Pal at Warwick for 12 months from June 2015
Targets for next 6 months:

• ThermExS Lab commissioned
• Michel van der Pal settled at Warwick and using new facilities
• IDRIST PDRA appointed
Thank you for your attention

• Any questions?