Progress Reports, Future Plans
April 2014

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

A reminder of the background:

Rationale

• Up to 50% reduction in CO$_2$ 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

Warm Exhaust Gases

Air-to-Pressurised Water Heat Exchanger

Hot Gases

Final Exhaust Heat Exchanger

Cool Exhaust Gases

Adsorbent Bed 1
Heated

Adsorbent Bed 2
Cooled

Bed 3

Bed 4

Condenser

Ambient Air to Evaporator

Evaporator

Ammonia

Return water from house

Inlet Air

Heated water to house

Cooled Air from Evaporator
Higher calorific value of natural gas used in all cases
Burner efficiency: 84%
Burner exhaust gas recovery: 5% of gas input
Condensing boiler efficiency (assumed constant for simplicity): 91% (SEDBUK)
Water flow rate: 20 l/min
Heating power: 6-7 kW
Burner water temperature: 120-200°C

Note that the COP should never drop below 1.0 (10% better than condensing boiler), within the heat pump operating range.
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

- Top valve assembly
- Bottom valve assembly
- Generators
- Gas heat exchanger
- Burner
- Evaporators
Initial 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 a re-design before further tests.
- Gas burner control difficulties upset the operation of the adsorption system.
CERAMIC DISC VALVES

Bespoke valve developed using ceramic discs in a PEEK body to switch water flows.

Ceramic discs

PEEK body
TESTING WITH DISC VALVES

• Testing with electric heating to remove gas burner control difficulties.
• Valves functioned properly.
• However, performance reduction due to poorer than expected heat transfer in carbon bed.
• Short term solution: Construct larger beds in order to achieve the required power output.
REVISED GENERATORS

Volume increase from 2.2 litres to 6.85 litres

Diameter increased from 95 mm to 145 mm

Length increased from 310 mm to 415 mm
TESTING REVISED GENERATORS

- Power output still lower than predicted
- Ammonia check valve blockage prevented reliable operation of the machine

- Assumed to be an ammonium salt formed from impurities in the carbon
- Remains to be identified
TESTING REVISED GENERATORS

• Low power output caused by deterioration of rapid prototyped water distributors in the generators
TWO-BED SYSTEM

• Decision made to revert to a two-bed system.
• Lower efficiency, but simpler and lower cost.
• Power density of a two-bed system is higher which reduces the overall size of the generators.
• Predicted gas saving of 15-20% compared to a condensing boiler.
System COP: \((1.26 \times 0.8) + 0.1 = 1.1\) gross
Condensing boiler 90%
Gas saving 18%
Heating Power: 5.5 kW

Performance Envelope

System COP: \((1.228 \times 0.8) + 0.1 = 1.08\) gross
Condensing boiler 90%
Gas saving 16%
Heating Power: 9.9 kW
WATER DISTRIBUTION

- Wire mesh over tube inlets
- Impingement/baffle plate to disperse inlet flow

![Image of water distribution system with annotations]
TWO-BED SYSTEM

- Two-bed system installed in environmental chamber.
- Less tightly packaged system to enable easier fault diagnosis and rectification.
- Uses air source evaporator from previous system.
- Electrically heated.
TEST RESULTS

• After repeated evacuating, heating and recharging the ammonium salt reduced in quantity such that the check valves no longer became blocked.
• Heat output was between 7 and 12 kW and in line with model predictions.
• New water distributors increased pressure drop in the generators and reduced water flow rate, particularly during the cooling phase.
• Ammonia concentration swing limited by poor cooling flow which limited COP to 1.05.
MODEL COMPARISON

![Graph showing temperature vs. time for generator water inlet and outlet. The graph compares model predictions with experimental data.](graph.png)
MODEL COMPARISON

- Heating Power Model
- Condenser Power Model
- Heating Power Experiment
- Condenser Power Experiment
## MODEL COMPARISION

<table>
<thead>
<tr>
<th></th>
<th>Model</th>
<th>Experiment</th>
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<tbody>
<tr>
<td>Heating Power</td>
<td>7.4 kW</td>
<td>7.7 kW</td>
</tr>
<tr>
<td>Condenser Power</td>
<td>1.5 kW</td>
<td>1.1 kW</td>
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<tr>
<td>COP</td>
<td>1.17</td>
<td>1.05</td>
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</table>
Next steps:

- Pumps, particularly the cooling pump, must be replaced to increase water flow rate.
- Further testing and analysis required to identify sources of losses.
- Ammonium salt must be identified in order to develop an effective cleaning method for the carbon.
- Heat transfer in the generators must be improved in order to reduce the size of the generators.
Next steps:

1. Generate performance map
2. Get business / investor feedback
3. Possibly go for 2-bed outside i-STUTE, 4-bed in i-STUTE?
WP4.2 Thermal transformers [2nd Wave, Prof. Critoph, UW]

Rationale: Industrial processes commonly reject heat at temperatures of 90\(^\circ\)C 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 above, 4.3 below.

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)
Previous plans:

- Link to EPSRC Grid scale energy storage capital award (LU and UW) – commissioning in 6-9 months
- Solid gas reactions suitable for both heat storage and thermal transformers
- New PhD student at Warwick will probably concentrate on chemical adsorption
- Good links with Japanese and Russian laboratories with physical chemistry expertise in this area
- Will receive a visiting Japanese academic for one year commencing April 2014

Intend to formulate a detailed research plan once the new student is in place and in consultation with LU, TIT, BIC. Will report to next MC meeting in Jan 2014
What happened:

- Link to EPSRC Grid scale energy storage capital award (LU and UW) – commissioning in 6-9 months
- Probably complete by September
- Consists of 4 sources/sinks of heat + pumps, valves, instrumentation
1-salt thermal transformer

Phase 1: Storage of heat at 90°C

Phase 2: Discharge of heat at 120°C

Heat in at 90°C

Desorption at low pressure

Condenser

Heat out at 30°

Adsorption at high pressure

Evaporator

Heat out at 120°C
Phase 1: Storage of heat at 90°C

2-salt thermal transformer

Phase 2: Discharge of heat at 120°C

Heat in at 90°C

Desorption at low pressure

Heat out at 30°

Adsorption at high pressure

Heat out at 120°C
**Phase 1:** Storage of heat at 200°C

**Phase 2:** Discharge of heat at 200°C

**1-salt thermal store**
(c. 2 MJ/litre)
This is the subject of a ‘Working with EUED Centres’ bid to EPSRC

- Not enough money to link in with Russian and Chinese researchers
- Visiting Japanese academic unlikely to make significant contribution
- New PhD student making good progress
WP3.5 Domestic heat emitter study

- Low temperature heat emitters are important to both gas and electric heat pump systems.
- Underfloor heating problematic in retrofit situations.
- Some fan-assisted radiators on the market, but expensive.
- Issues of fan noise, wiring and cost.
WP3.5 Domestic heat emitter study

• Vicky Haynes and Claire Lawson at LU have an initial report on noise of available products
• We hope to take this further with UW, LU, UU and carry out consumer centred research to see if there are good technical solutions that are acceptable/desirable to the consumer.
Thank you for your attention

• Any questions?