Ammonia - carbon adsorption heat pump development

Contents

STETO

Heat pump concept

- Box-for-box exchange for conventional domestic gas boiler
- Air source for ease of retrofit
- 30% reduction in gas consumption compared to a condensing boiler
- 10 kW heat output

Rationale

Why a domestic gas-fired heat pump?

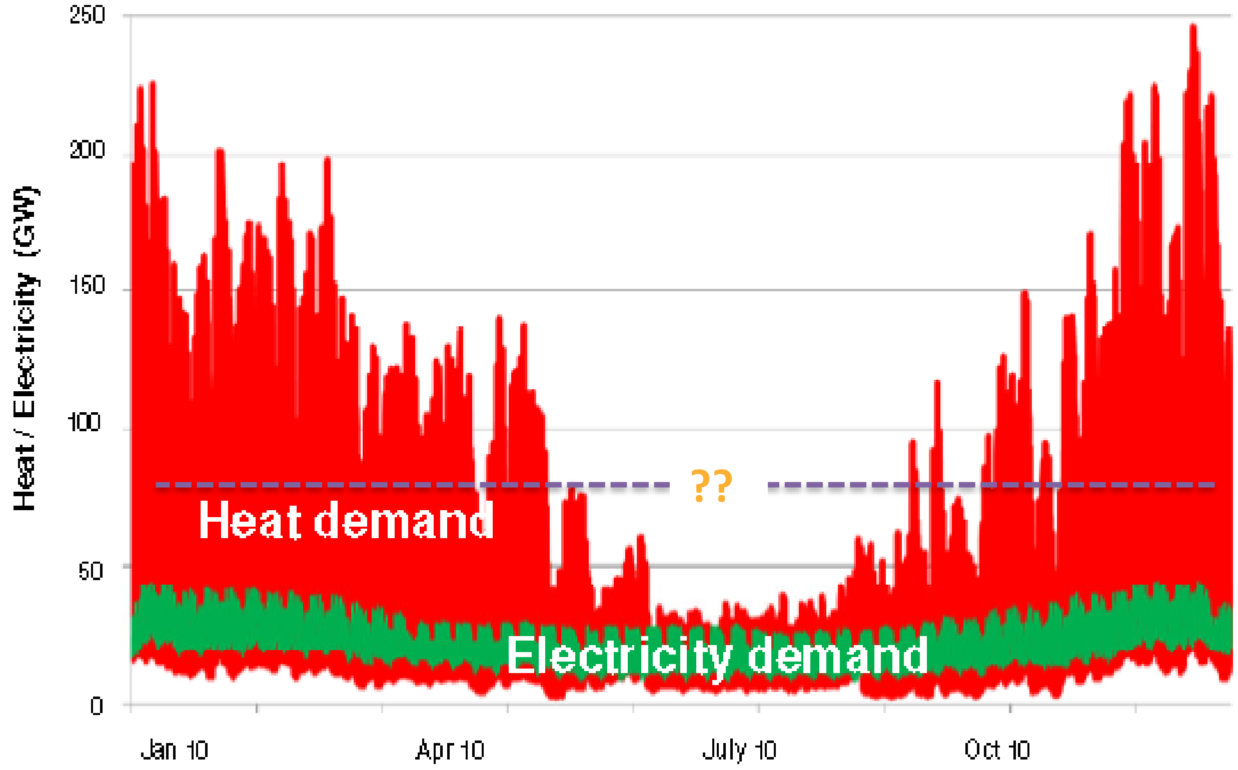
- 300 TWh gas consumption by domestic boilers per annum in the UK
- 100 TWh domestic electricity consumption per annum
- Story is similar in the commercial sector

Electric Heat Pump COP 3.0 → Doubling of average grid capacity required

However….

Rationale: The limitations of the energy infrastructure

2010 UK heat & electricity hourly demand variability



Design point for heat delivery system

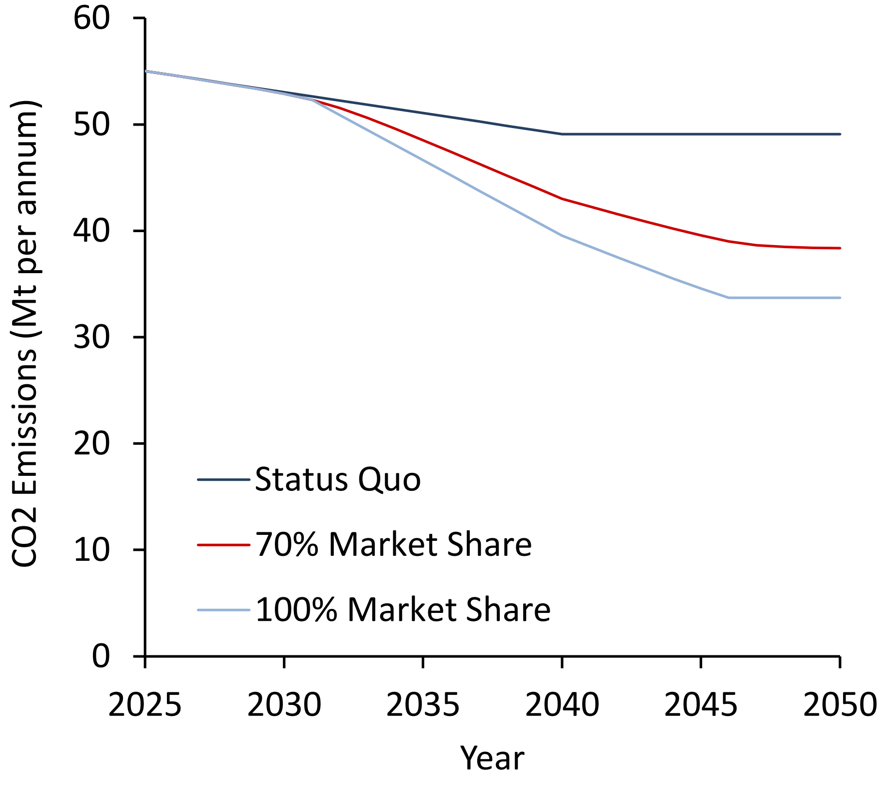
Peak electricity demand will exceed electrical grid capacity in future

Design point for electricity delivery system

- Large variations in heat demand
  - These will not coincide with the availability of renewable electricity
  - Electric vehicles will further increase demand on the electrical grid

Source: Energy Technologies Institute, 2012

Rationale: Potential impact on emissions in the UK



Individual saving c. 33%

- A 2.6% reduction in UK annual CO_2 emissions by 2040 is possible
- There is a potential for an eventual 4.2% reduction in annual CO_2 emissions if all gas boilers were replaced by gas heat pumps

Two Market Scenarios are considered:

- The first assumes that the market for Gas Heat Pumps will saturate at a 70% share of gas heating appliances annual sales after approximately 12 years (the rest of the market remaining as condensing boilers).
- The second assumes that after 7 years on the market, the cost of Gas Heat Pumps reaches the point where legislation requiring their use is introduced, in much the same way as was carried out for condensing boilers replacing non condensing boilers.

STETO

Rationale

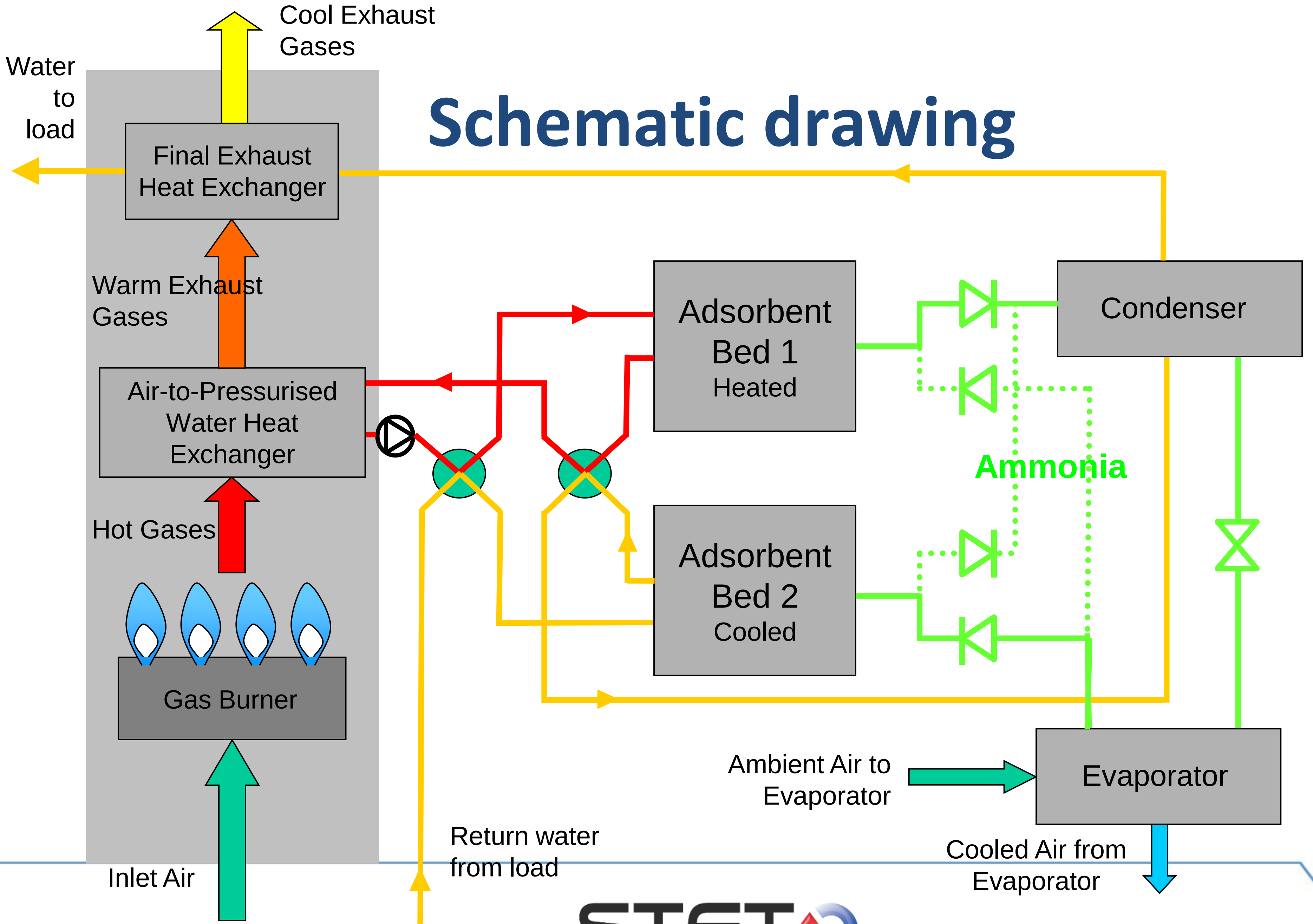
Why ammonia?

- Operates below 0°C evaporating temperature for air source operation
- High working pressure enables → compact machine: power density is almost entirely heat transfer (not mass transfer) limited

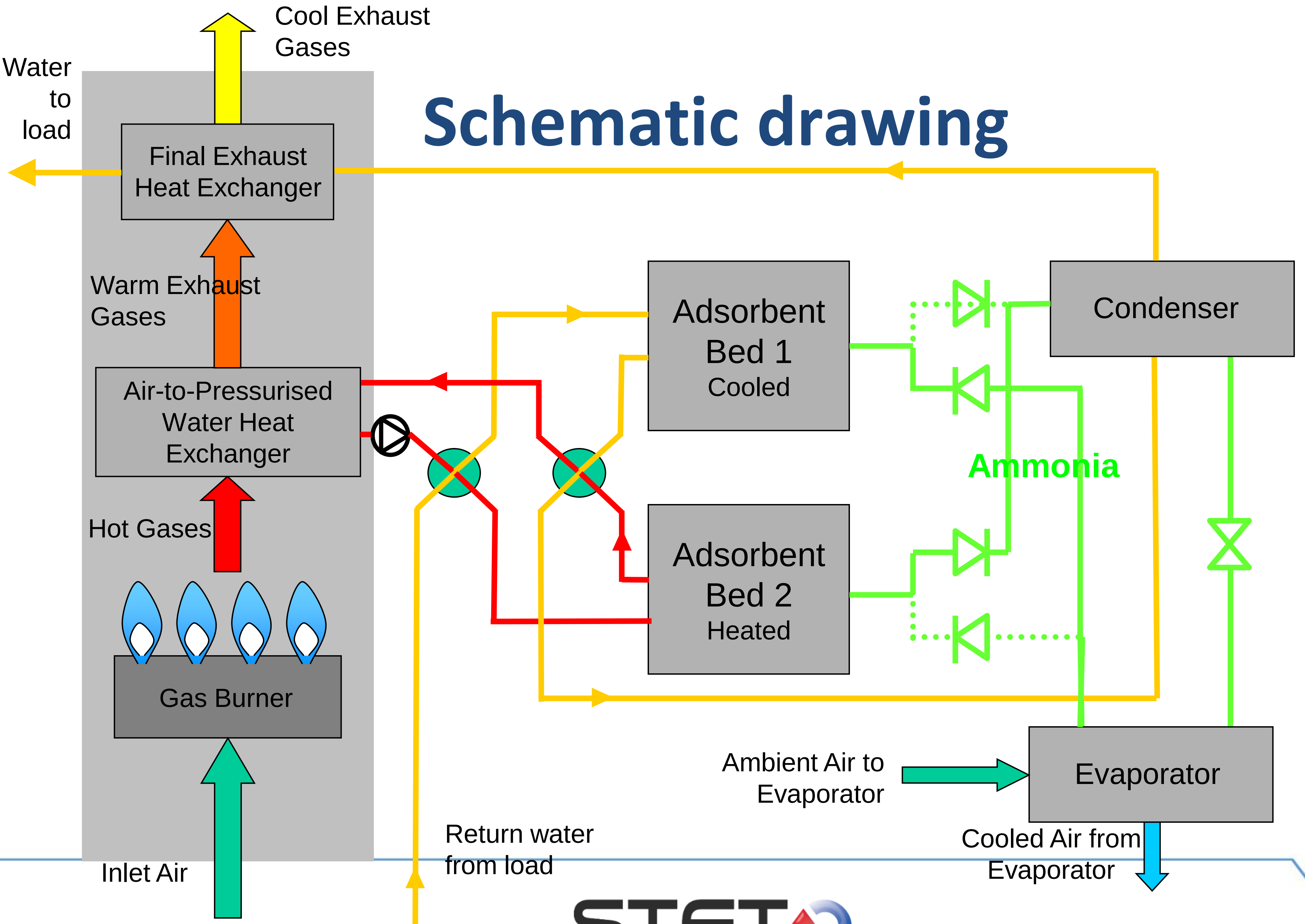
Why carbon?

- Stable to high driving temperatures
- Low and more gradual concentration change than other adsorbents or salts, but does not suffer from a sudden ‘switch off’
  → Will continue to operate over a wide range of delivery and evaporating temperatures

Schematic drawing

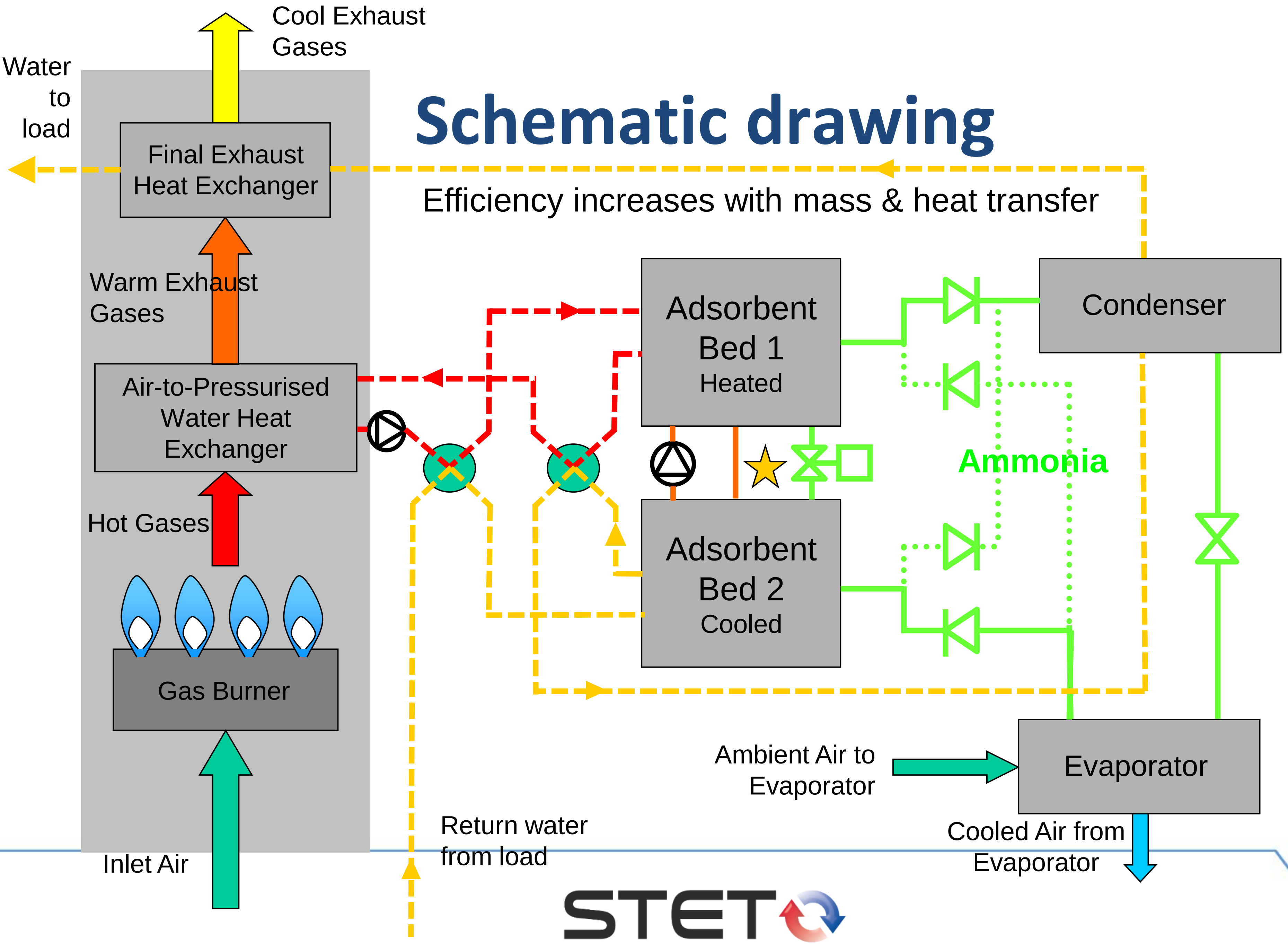


Schematic drawing



Schematic drawing

Efficiency increases with mass & heat transfer



STET

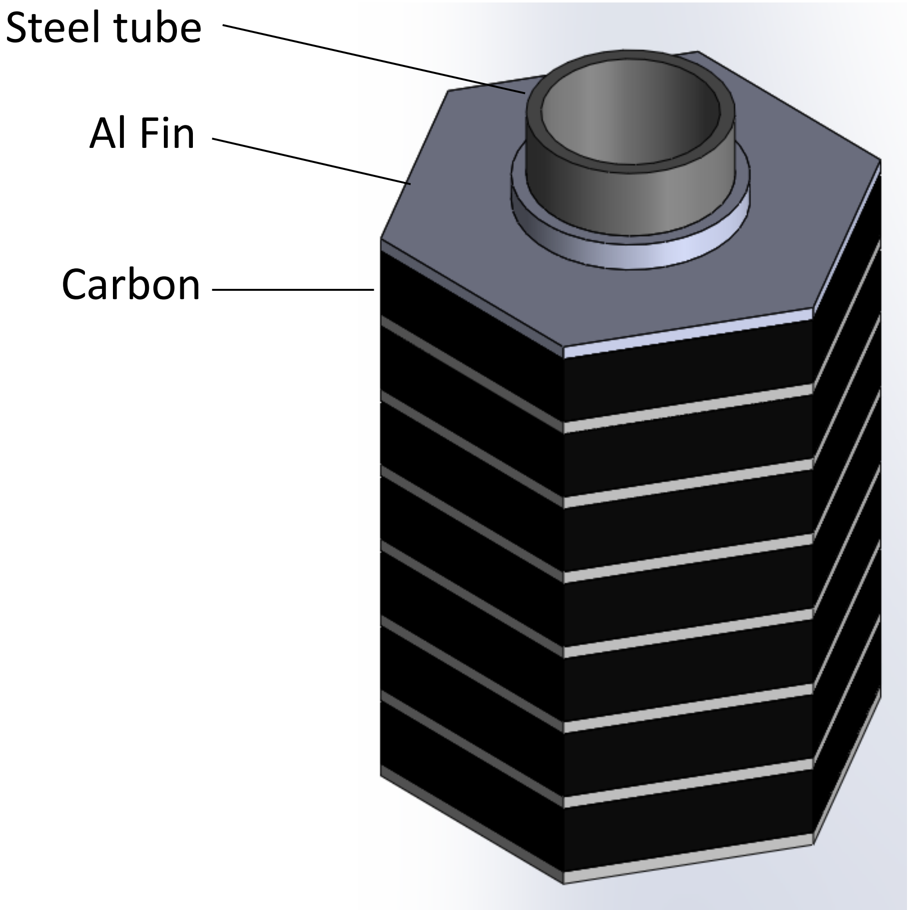
Generator design

Shell and finned tube

Design Parameters:

- Tube diameter
- Tube pitch
- Carbon thickness
- Fin thickness

Detailed simulations in Matlab



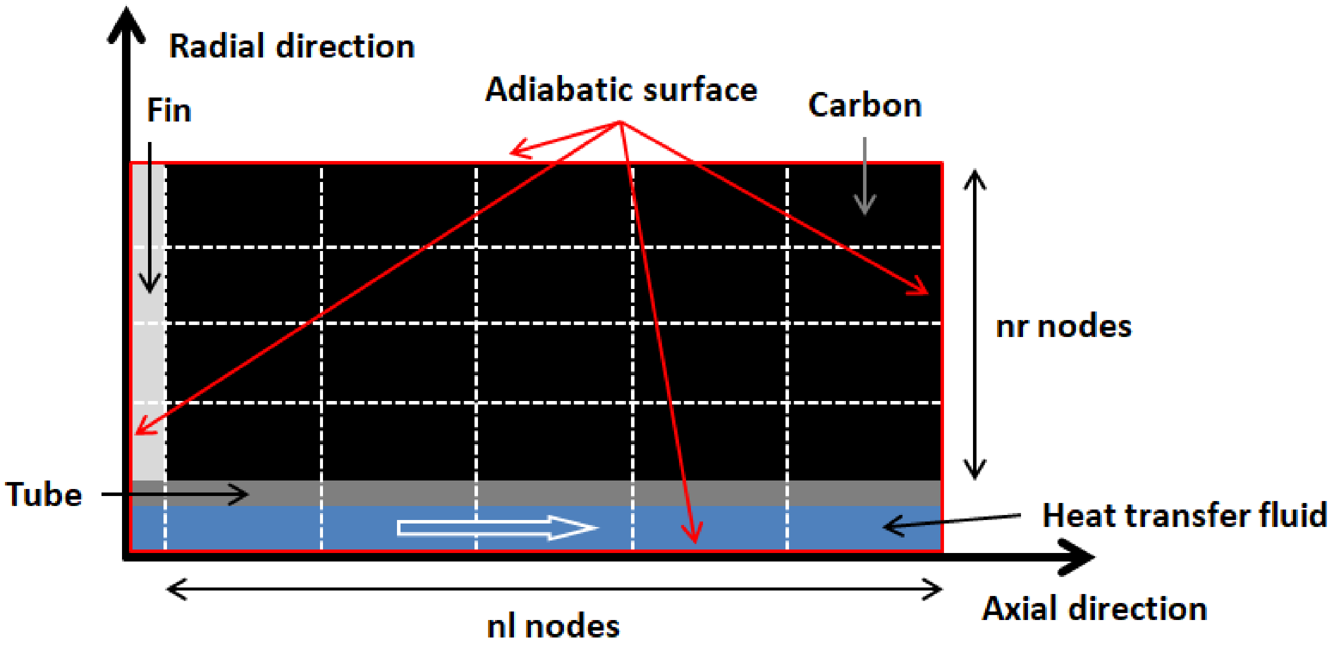
Generator design

Target performance:

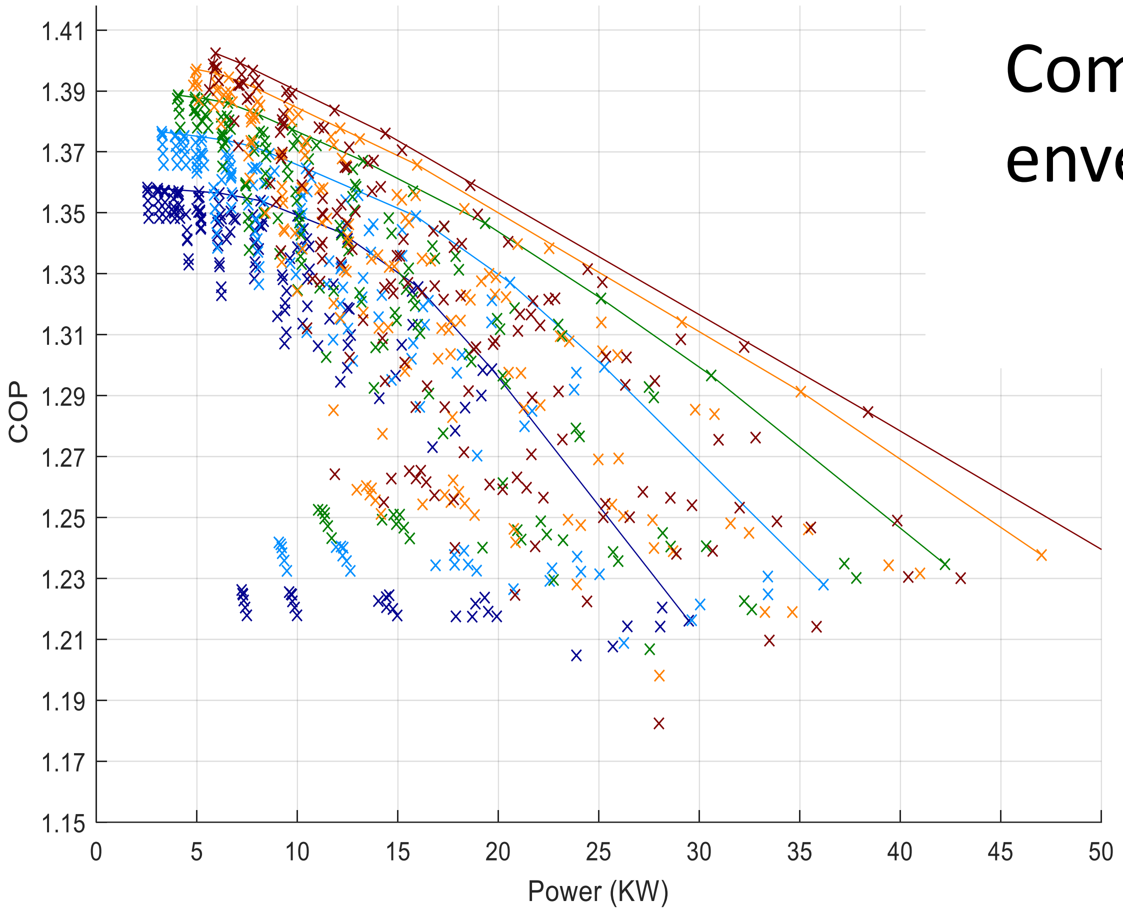
- Heating power 10 kW
- Total generator volume ≤ 10 litres
- Internal COP ≥ 1.4 (GUE ~1.25)
  - Heating water delivery temperature 55°C
  - Evaporating temperature 0°C

Computational modelling

A two dimensional finite difference simulation model in MATLAB has been written to explore how varying the geometry of the generator, dimensions and control parameters affect the Coefficient of Performance (COP) and power output under specified conditions and sorption materials. The adsorbent thermal properties used in the simulation were the ones previously tested and presented.

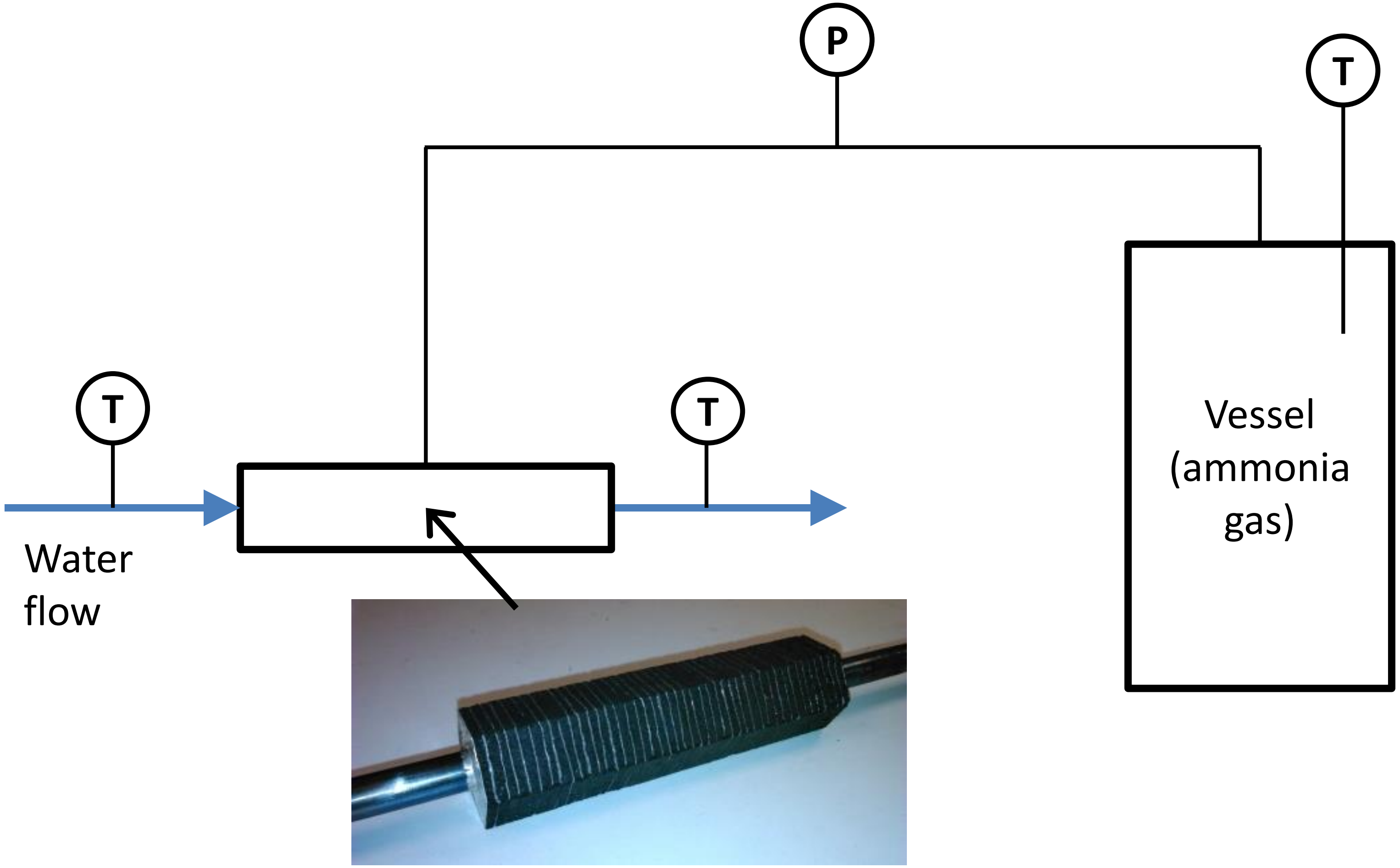


Performance predictions

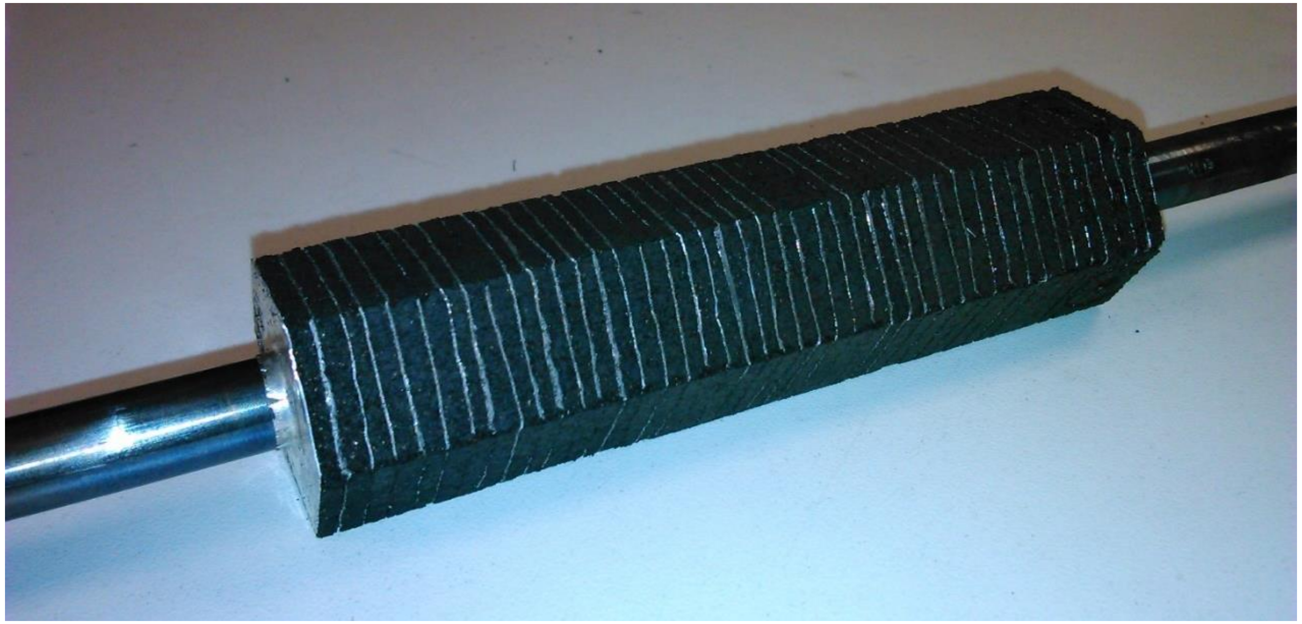


Comparison of performance envelopes for various geometries

Large Temperature Jump Test

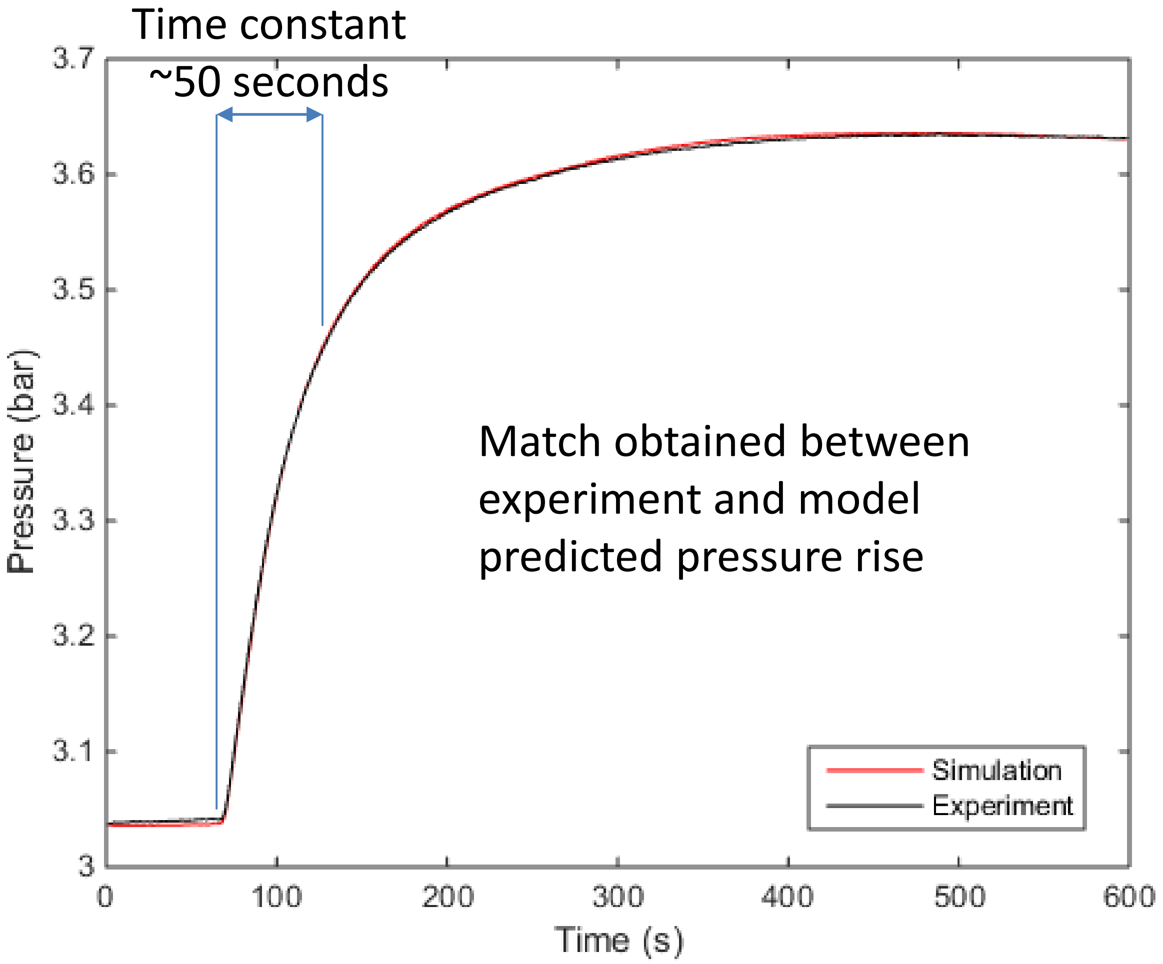


Large Temperature Jump Test



Test samples

Large Temperature Jump Test



Machine construction

STETO

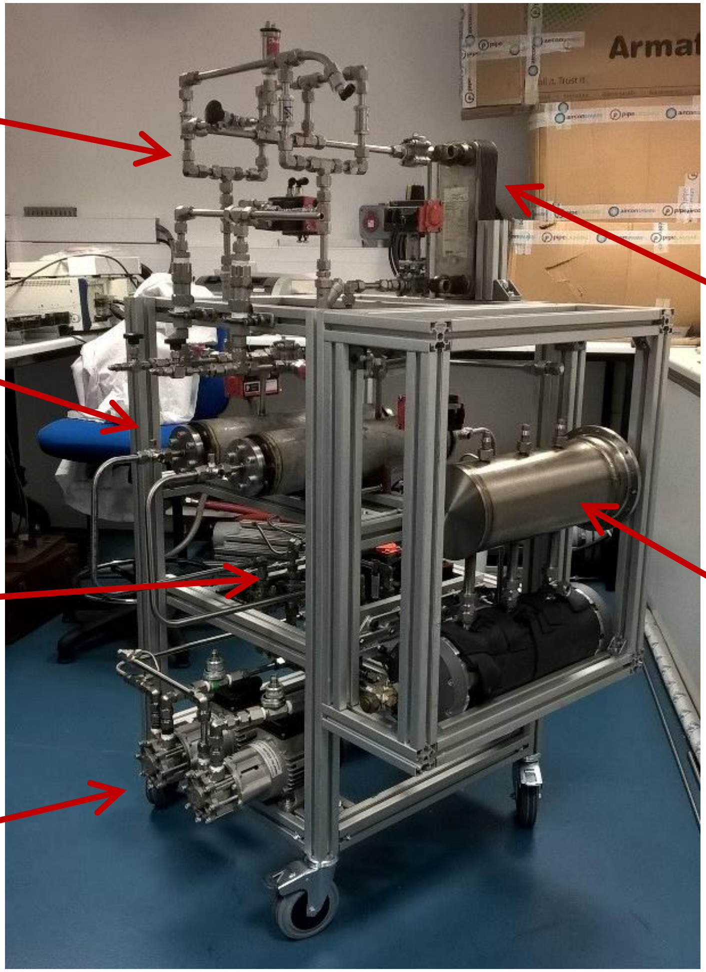
Machine construction

Ammonia Check Valves

Generators

Water valves

Water pumps

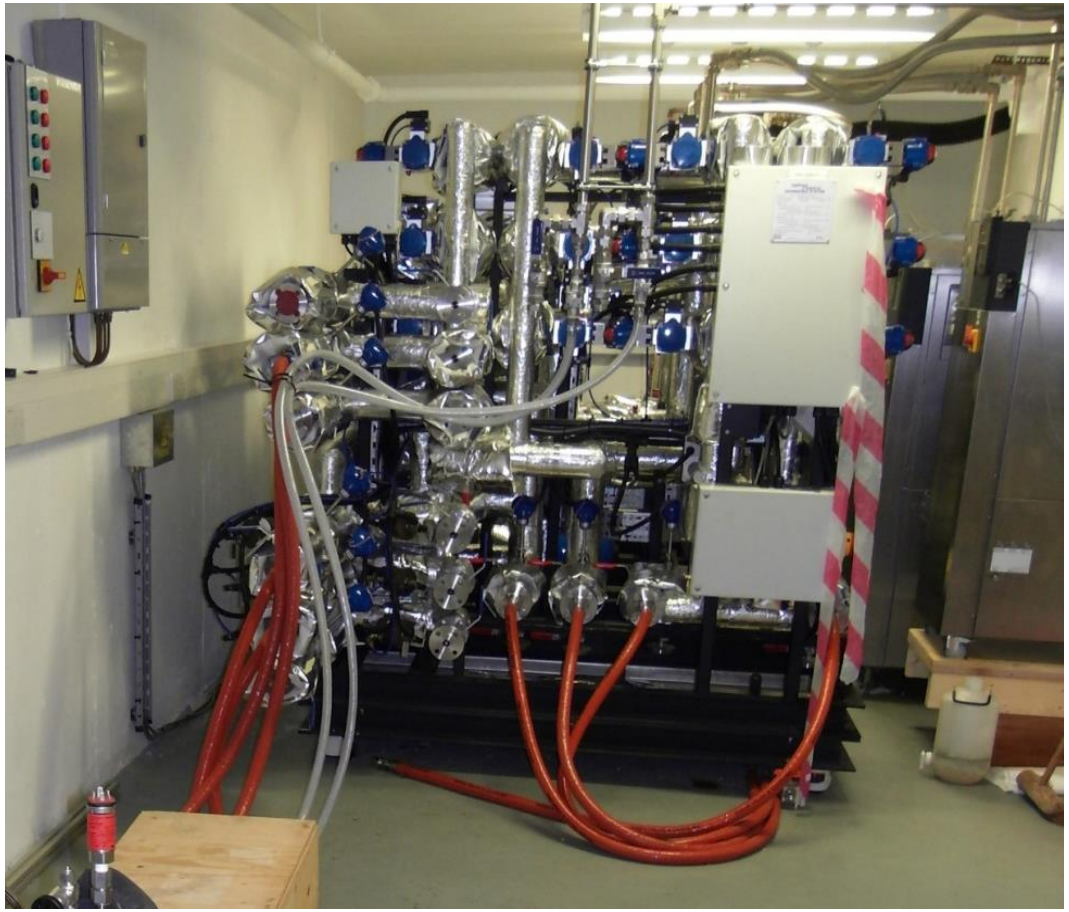


Condenser

Evaporator

STETO

Machine testing

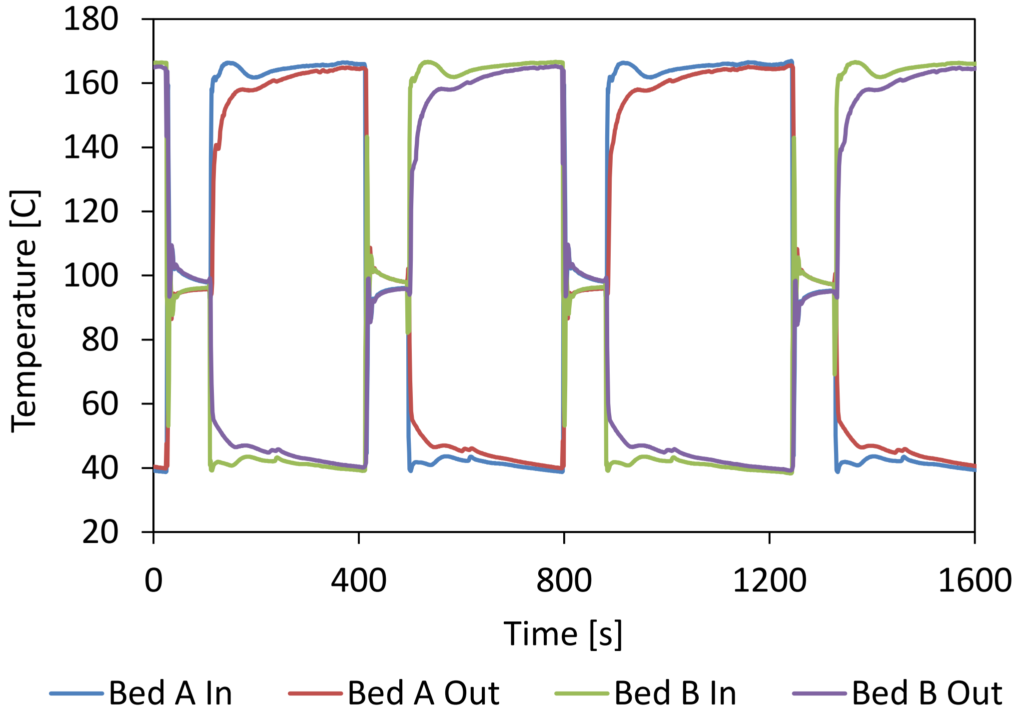


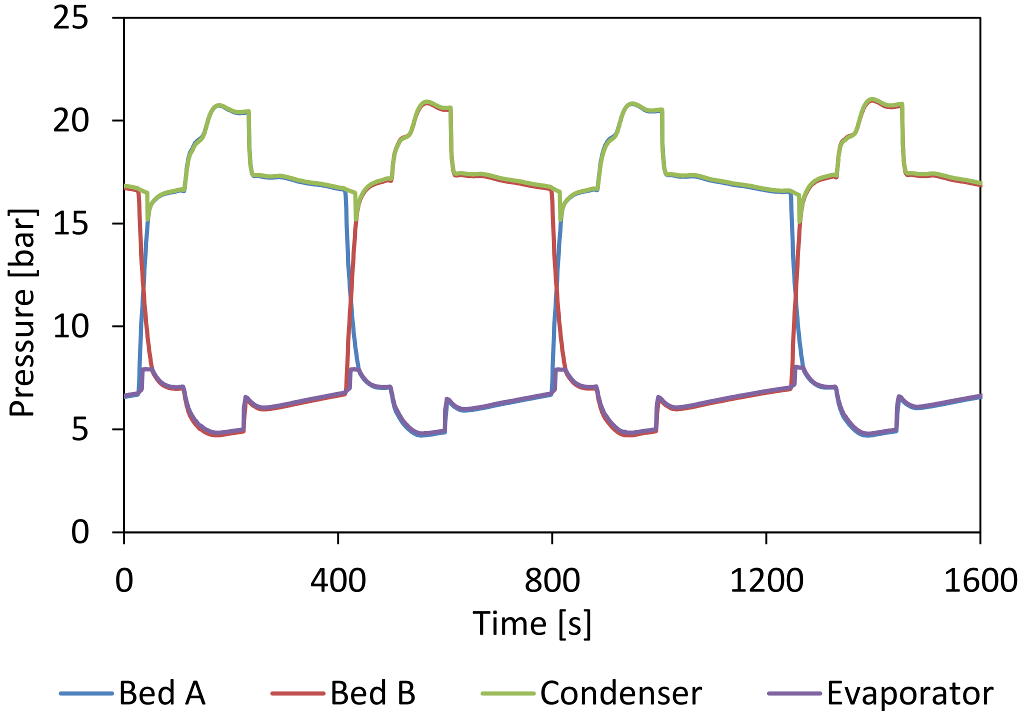
System of heating and cooling baths to provide:

- Up to 170°C pressurised water for high temperature heat input
- 10 kW of heat rejection for the condenser and cooler
- Glycol flow down to -10°C for evaporator

Machine testing results

Although temperature and pressure profiles seem correct and very repeatable, the COP and powers delivered were lower than expected.





STETO

Machine testing results

Low COP and heating power → due to an unexpected low amount of refrigerant cycled during the testing (approximately 1/3 lower than predicted by Rubotherm).

In the **Rubotherm** the **sorption characteristics** are obtained after a long set point time **equilibrium** is reached. But in the **machine** adsorption and desorption happen in a **shorter period of time**.

It is believed that some of the binder used in the carbon composite is causing blockage of the pores.

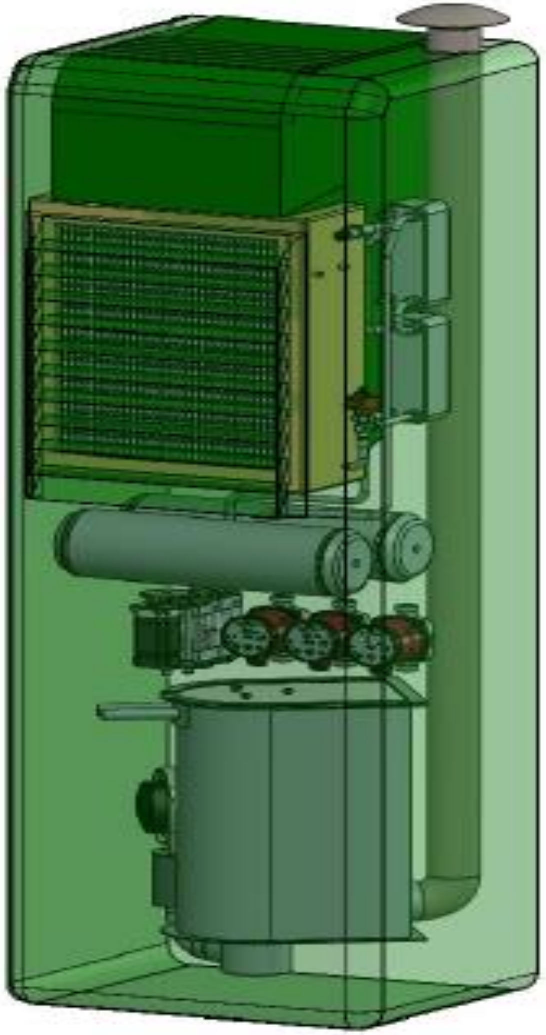
- Pore obstruction not observed during desorption phase but observed during adsorption phase → affects the refrigerant cycling quantities.

Action taken

- New binder mixes evaluated in both desorption and absorption in LTJ test
- Degradation effects overcome
- Most of the new kebabs required have been manufactured and performance tested in LTJ

and

- New project funded by BEIS (UK Energy ministry) will productionise design… Aims to have three production-ready prototypes in 2 years.



System concept CAD model:

1.9m (h) x 0.6m (w) x 0.5m (w)

Key findings re production and costs

- With the exception of the generators ALL components can be sourced commercially and do not require bespoke development.
- There are promising mass production routes available for kebab manufacture
- Gas burner and heat exchangers currently under test with good indicative results
- Present estimates of factory cost around £2100

Further work

- New generators will be lab tested when available
- Other components will be introduced to the lab system as they become available.
- Complete prototypes scheduled for delivery July 2020 – one for testing in environmental chambers

Conclusions

- Finned tube generator designs were investigated with MATLAB model
- Complete machine constructed as a test bed for generator and other components
- Prototypes scheduled for July 2020, complete with costed manufacturing supply chain

Thanks for your attention!