Sorption Research at the University of Warwick

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Sorption Friends III, Taormina, May 2023

Carbon-Ammonia Gas-Fired Heat Pump

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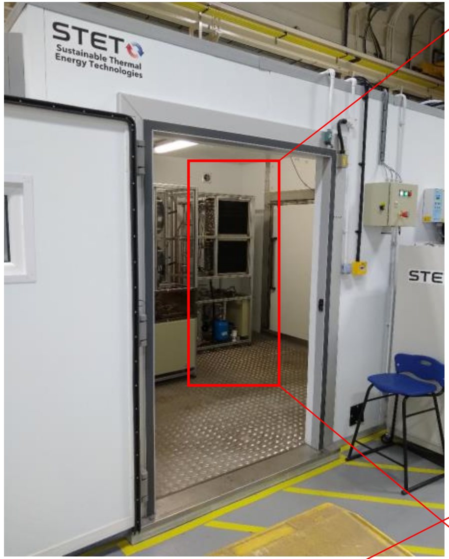
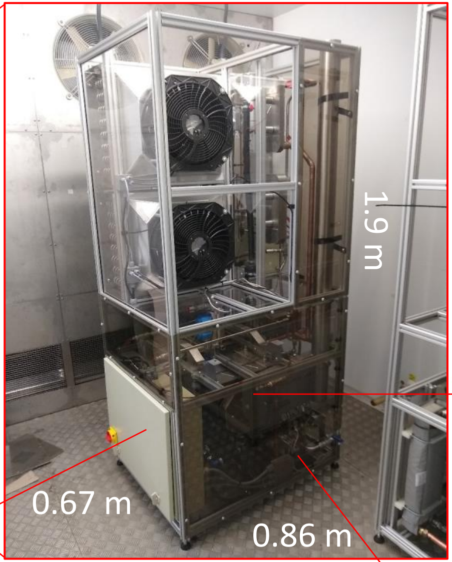
- £2M project from the UK Energy Ministry
- Ended March 2022
- Aim was to develop a production ready 10 kW gas-fired heat pump
- Design consultancy firm contracted to carry out the development

Carbon-Ammonia Gas-Fired Heat Pump





Off-the-shelf burner

Low-cost Arduino-based controller

Productionised water valve

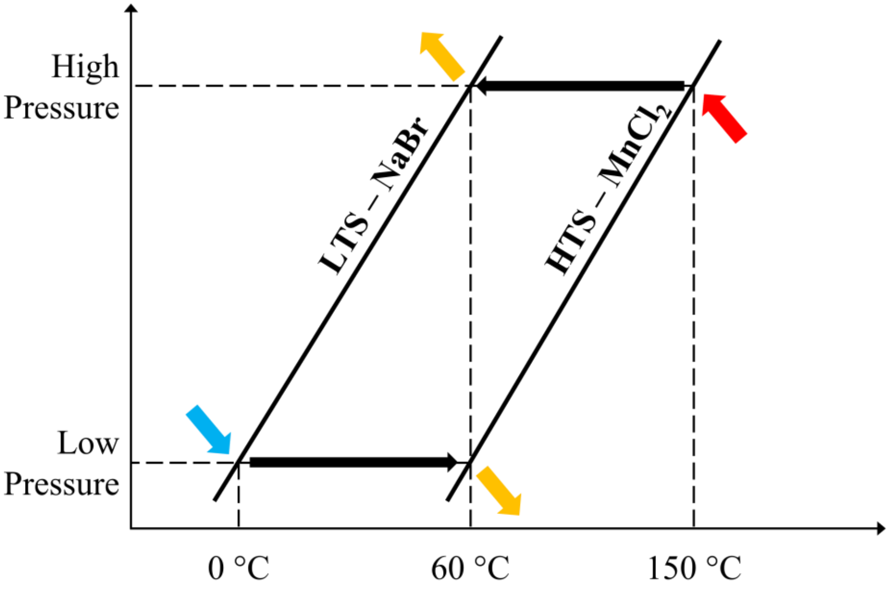
- Some production-ready components developed
- Production-ready generators not delivered
- Machine not properly packaged
- Awaiting the results of resorption to decide on next steps

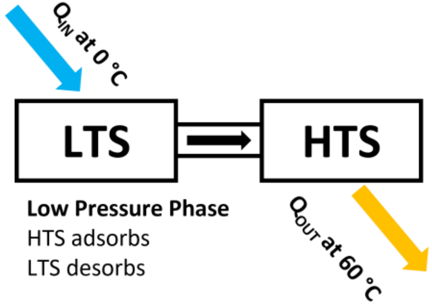
Resorption HP and Heat Transformers

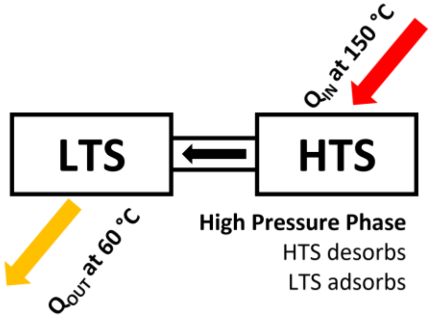
- Two salt **domestic heat pump** using ammonia-salt

LTS – NaBr

HTS – $MnCl_2$







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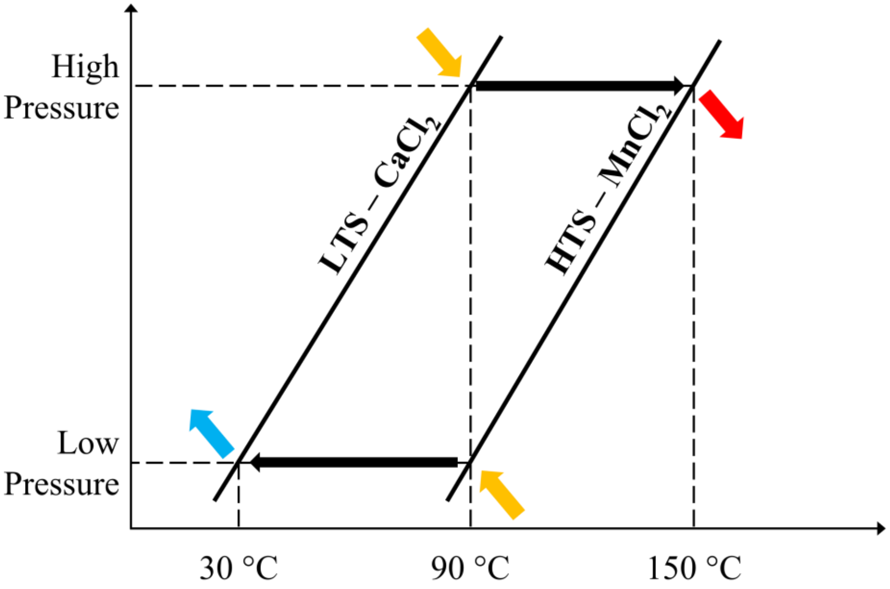
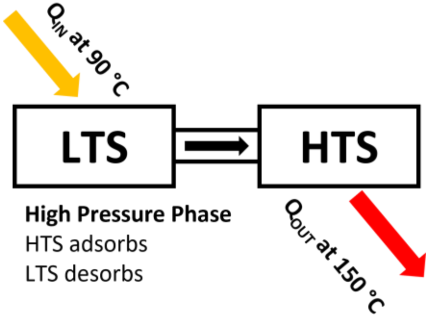
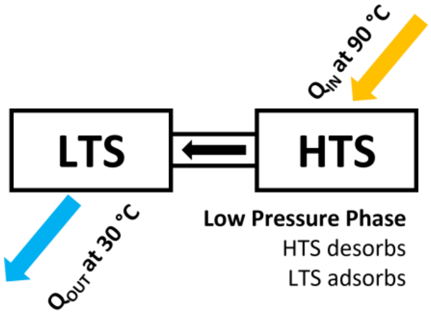
- Two salt **industrial thermal transformer** using ammonia-salt

LTS – $CaCl_2$

HTS – $MnCl_2$





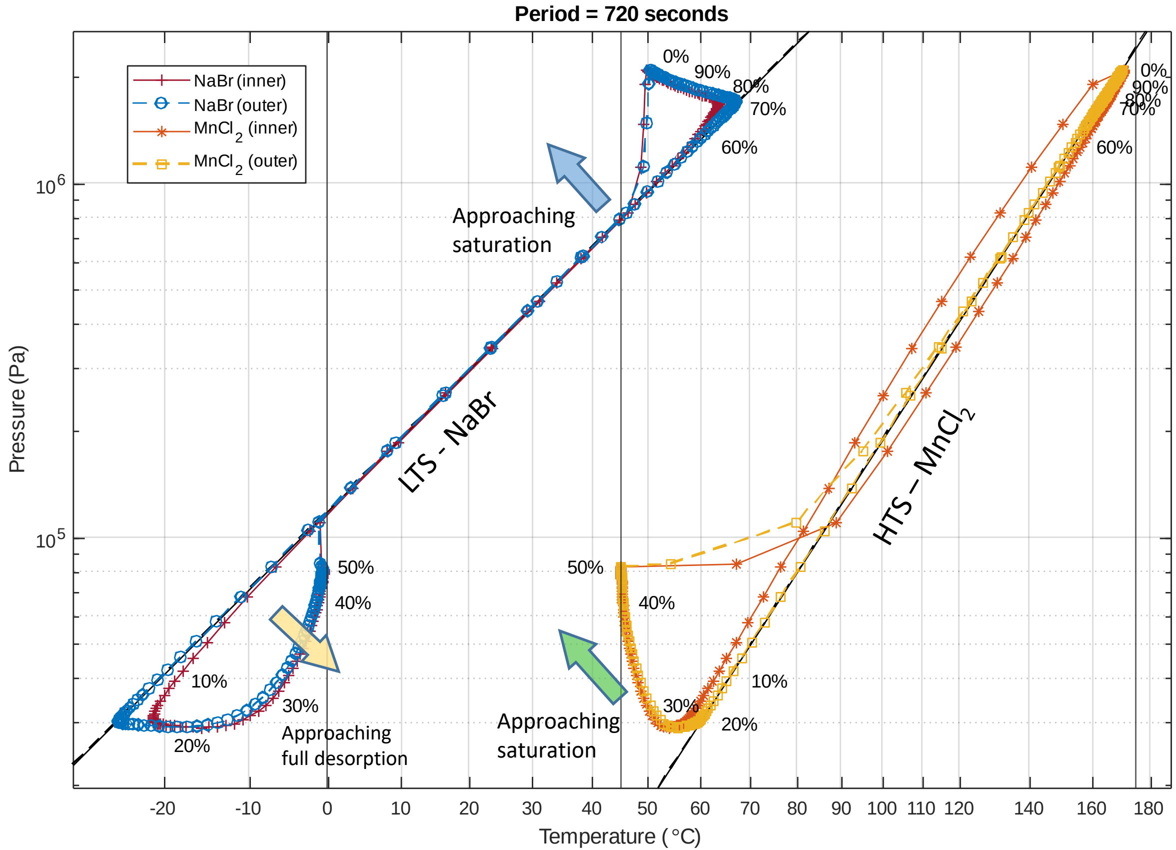


Construction and testing

Results and conclusions

- COP ≈ 1.25 at around 1 kW power output.
- Lower than anticipated, but 100+ tests now conducted with repeatable results.
- Third reactor for heat transformer to follow.
- H_2 burning HP might have GUE of 1.4 – looking for funding

Resorption cycle modelling in Matlab



- Parametric model
- 2D axisymmetric grid (hexagonal biscuits modelled as circular rings) in each reactor
- Uses Matlab's solvers for linked ODE systems
- Temperature from conduction and heat generation calculation
- Calculation repeats over all reactions (e.g. 8-4, 4-2, 2-1).

Desorption rate equation (state J $\rightarrow$ K)

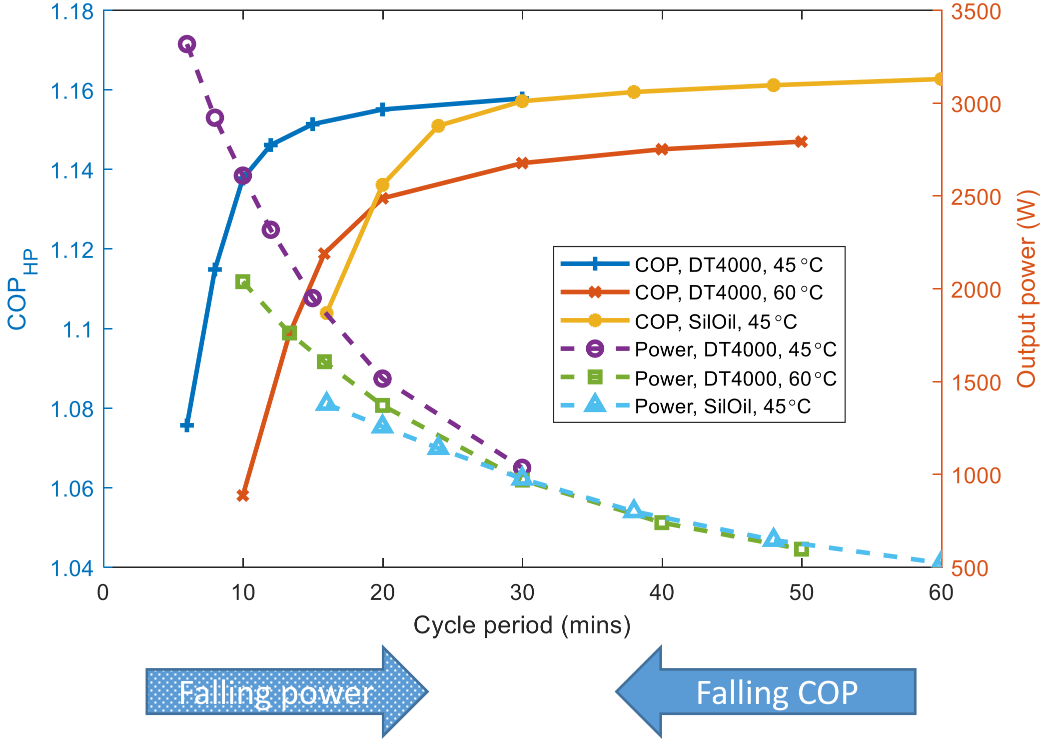
$$\frac{df_K}{dt} = -\frac{df_J}{dt} = A_d \left(f_J + f_K \right) \left(\frac{f_J}{f_J + f_K} \right)^{y_d} \left(\frac{p_{eq,d} - p}{p} \right)$$

$p < p_{EQ}$ causes desorption i.e. positive $\frac{df_K}{dt}$

For adsorption use A_a, y_a, $p_{eq,a}$

$p > p_{EQ}$ causes adsorption i.e. negative $\frac{df_K}{dt}$

Using multiple simulations to identify the optimum cycle conditions for COP and power density.



Comparison of two heat transfer fluids:

- DowTherm 4000 (water-glycol)
- Huber SilOil 235.

for 45 & 60°C output.

Good heat transfer and low sensible heat capacity are essential.

Thermochemical district networks

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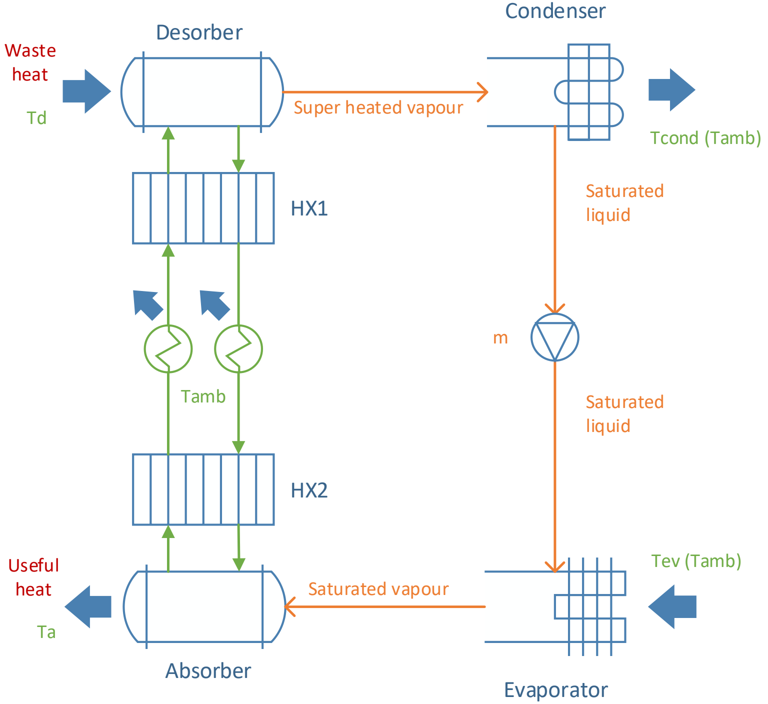
Thermochemical district networks are a new technology for district networks that can provide heating and cooling in one **heat loss-free** network.

The innovation is the use of thermochemical fluids as transport medium (concentrated salt solutions).

The chemical potential is used to generate useful heat (or cold) from ambient heat at the place and time of demand.

Advantages:

- Heat loss free
- Less investment (no insulation, smaller pipe diameters, reduced capital cost of trenches)
- Longer distances

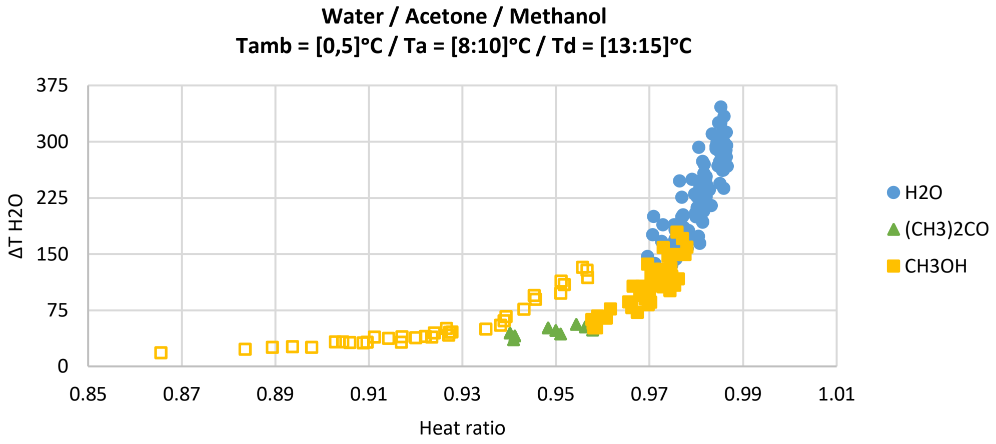


Modelled pairs

The absorbate must be high latent heat.

Water is ideal, but the lower limit for boiling water in practical equipment is around 5°C, which means that in winter months the system would have to use heat from the ground or an aquifer.

Methanol and **acetone** are not quite as good as water thermodynamically but can be boiled at sub-zero temperatures so could use an ambient air source in winter.



Acetone pair

$(CH_3)2CO – ZnBr_2$

Methanol pairs

$CH_3OH – ZnBr_2$

$CH_3OH – LiBr+ZnCl_2$

$CH_3OH – LiBr$

$CH_3OH – LiI+ZnBr_2$

$CH_3OH – LiBr+ZnBr_2$

Water pairs

$H_2O – LiBr$

$H_2O – LiBr+LiI$

$H_2O – LiCl$

$H_2O – LiCl+LiNO_3$

$H_2O – LiI$

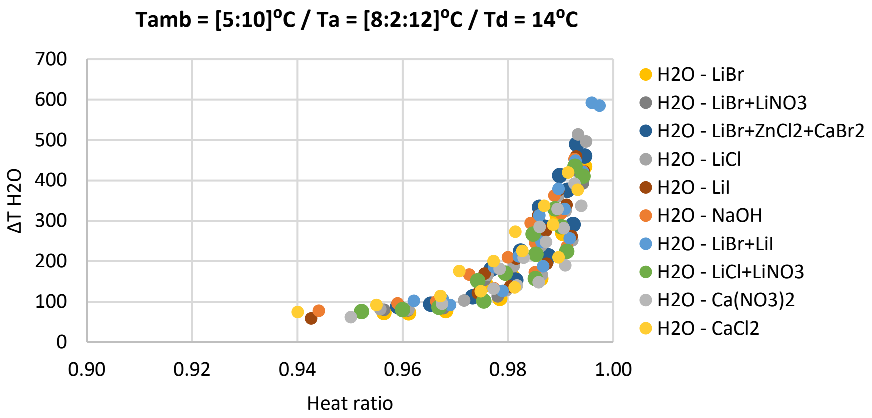
$H_2O – LiBr+LiNO_3$

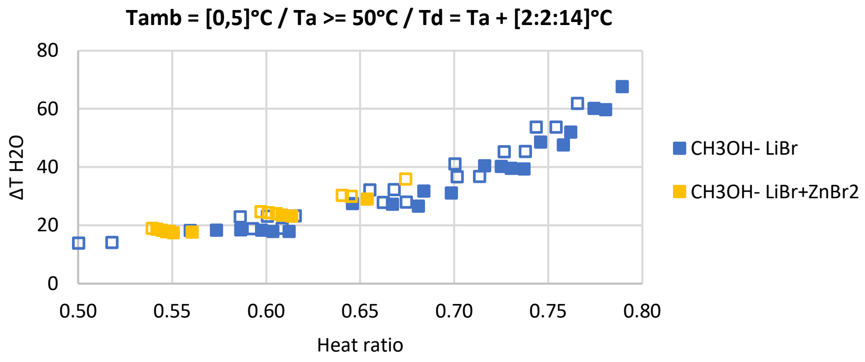
$H_2O – NaOH$

$H_2O – Ca(NO_3)_2$

$H_2O – LiBr+ZnCl_2+CaBr_2$

Network characteristic options





Two options have been looked at:

- ‘Ambient loops’ (14/4°C)
- ‘Low temperature loops’ (55/45°C)

The first transfer heat from waste or recovered heat sources to HPs that upgrade it for local use.

The latter deliver heat to buildings directly or via a HX.

The utility of the TC systems was characterised by:

- ’Heat Ratio’
- ‘DeltaT H_2O’ (the equivalent temperature differential in a sensible water loop that would transfer the same heat using the same pumped volume).

Thus, a value of 10°C would correspond to a normal LT system with a drop from 55 to 45°C and a value of 100°C would require only 10% of the flow to be pumped compared to a conventional system.

Absorption based thermal storage

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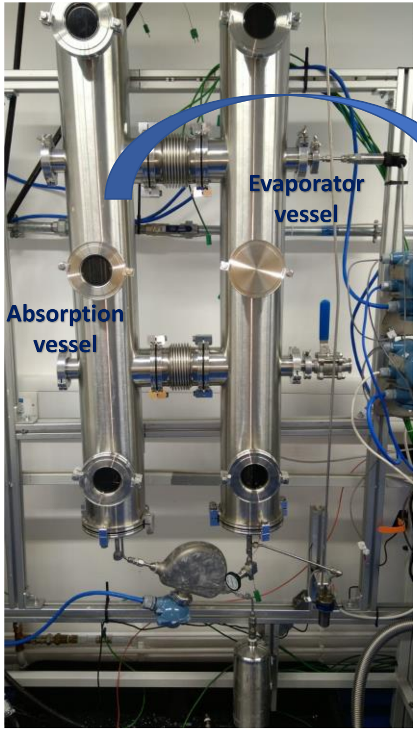

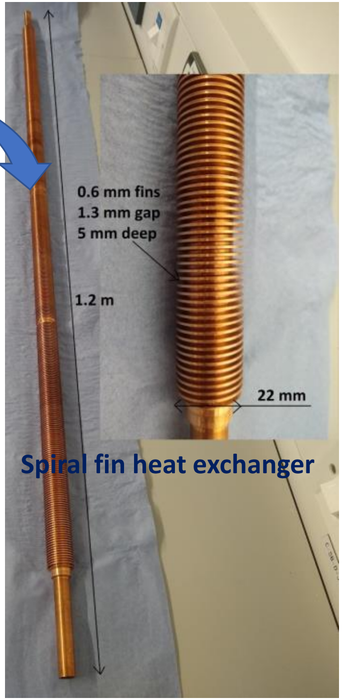

- $NaOH$-H_2O pair studied for domestic heating applications.
- Absorption performance is evaluated over spiral finned heat exchangers.
- The setup is being scaled to provide a discharge power of up to 8kW.

Results and conclusions

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Impact of varying cooling water inlet temperature

Case	Solution flow rate (g/min)	Cooling water inlet temperature(°C)	Heating power	Solution outlet concentration
1	5.8	21.3	150.7	30%
2	7.5	25.4	99.0	37%
3	6.5	29.6	69.9	39%

Impact of varying solution flow rate

Case	Solution flow rate (g/min)	Heating power	Solution outlet concentration	Average solution temperature (°C)
2	5.7	80.7	36%	34.4
	7.5	99.0	37%	36.4
	9	61.1	42%	32.3

- Optimum operating conditions are determined through parametric analysis.
- A storage density of 1900-2250 MJ/m^3 is evaluated.