Seminar: Efficient Triple-Energy Outlook and Practices to manage UK's 10-40 TWh of industrial waste heat

Organiser: Energy Institute (EI) North Eastern Branch

Sir Joseph Swan Centre for Energy Research

Date: 11th December, 2013

Time: 2:00 – 3:30pm

Venue: Old Library, Newcastle University, NE1 7RU, UK

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Cogeneration of Cooling and Electricity by Low Grade Heat

Low grade heat driven adsorption-linear-expander cycle for cogeneration of power and refrigeration

(EPSRC - **LH Cogen**)

Sir Joseph Swan Centre for energy research

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Newcastle Institute for Research on Sustainability

School of Mechanical & Systems Engineering

Contents

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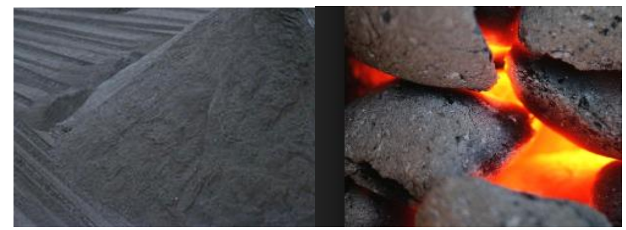
1. Background

This research project is highly relevant to the priority areas of Energy and Environmental Change issues.



Fossil fuels are the main sources of energy we use today

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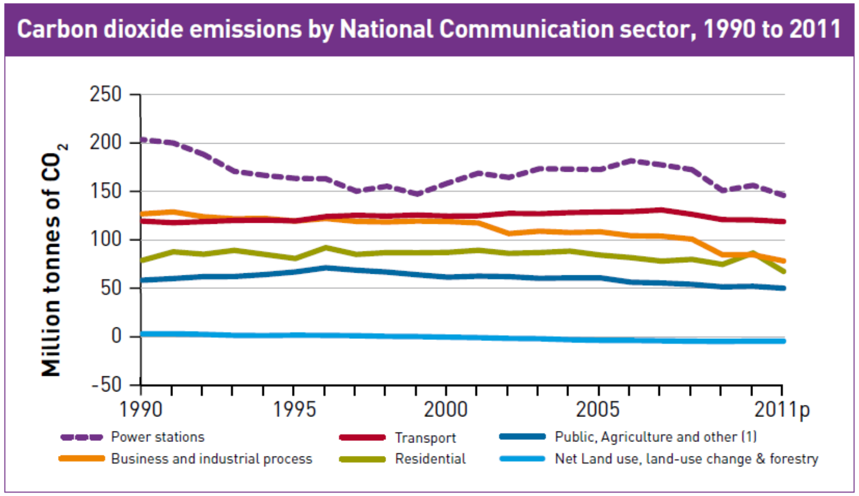
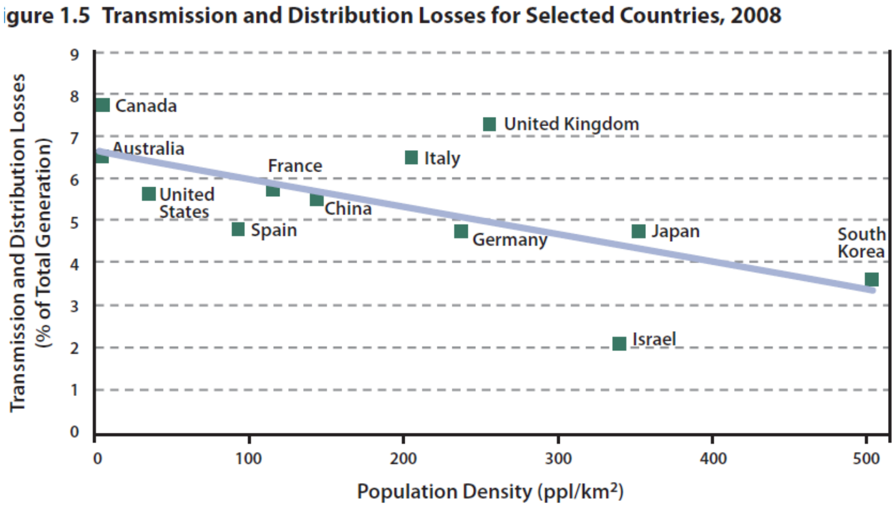
- In UK, the final energy consumption in 2011: **211.7** million tonnes of oil equivalent;
- **18.5%** of the final energy consumed by electricity generation industry
- their average thermal efficiency was **36.8%**;
- **11.7%** of the final energy consumption (**24.75** million tonnes of oil equivalent) was wasted in the form of low grade heat.





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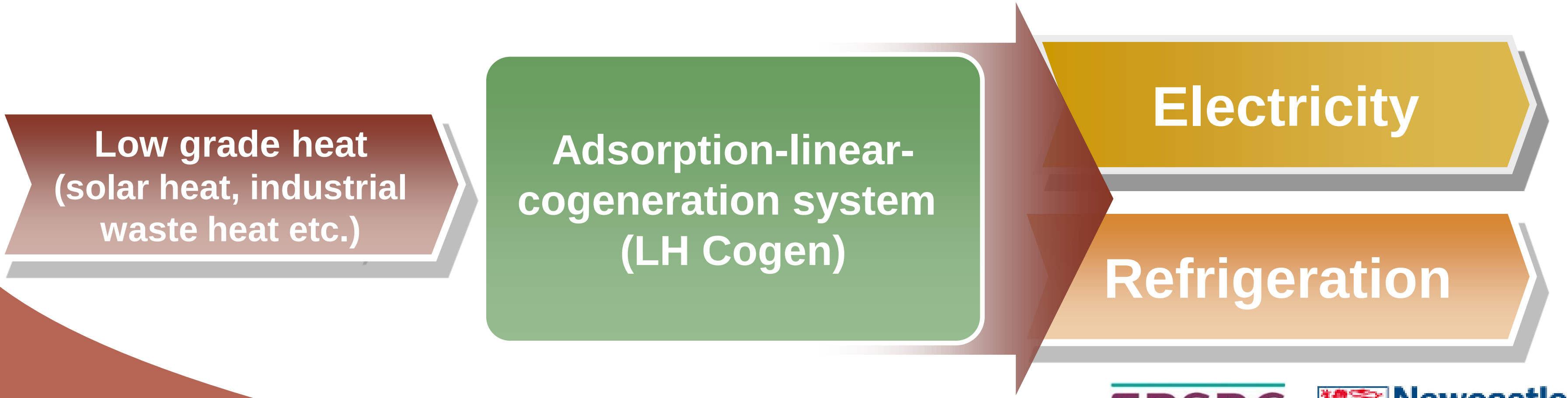
LH Cogen system (Low grade heat driven adsorption-linear-expander cycle for cogeneration of power and refrigeration)

- driven by *low grade heat*, avoiding primary energy consumption, increasing the energy utilisation efficiency;
- using *ammonia* as refrigerant (zero GWP and zero ODP), environmental friendly;
- cogeneration of refrigeration and electricity (*a variety of cooling levels*)
- *Competitiveness* with conventional power/cooling cogeneration technologies: Goswami cycle and APC cycle (absorption power/cooling combined cycle)



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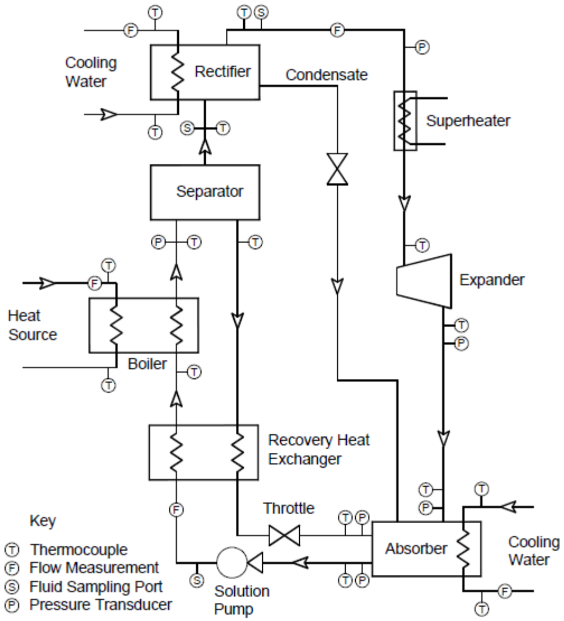
Absorption/Adsorption

- Thermally driven refrigeration: absorption/adsorption
- Refrigerant: ammonia (NH_3), water(H_2O), methanol (CH_4O), lithium bromide (LiBr)…
- Ammonia:
  - ✓ Zero ODP, zero GWP
  - ✓ the most cost effective and energy efficient method of processing and storing frozen and unfrozen foods
  - ✓ its distinctive smell is detectable at concentrations (5 ppm) well below those considered to be dangerous (35 ppm limitation for short term exposure about 15 minutes)
  - ✓ lighter than air
  - ✓ BREEAM, UNEP, ASHRAE etc. have given decent credits to ammonia

Goswami cogeneration cycle

- **absorption-basis cogeneration cycle)**
  - proposed by Goswami in 1995 based on Kalina cycle
  - the binary mixture of ammonia and water
  - Cooling effect extracted from the exhausted low temperature vapor of the turbine (sensible heat)
  - Low or medium heat source from 80 to 200 ^{o}C: thermal efficiency of cooling (COP) 0.01 ~ 0.06; thermal efficiency of power generation 0.05 ~ 0.10.
  - So far no practical application



- **Drawbacks compared with LH Cogen cycle**
  - Require more complex parts, such as liquid pump or rectifier or separator)
  - Limited range of heat source
  - Low refrigeration COP : the working fluid at the exit of the turbine likely remained as wet vapour

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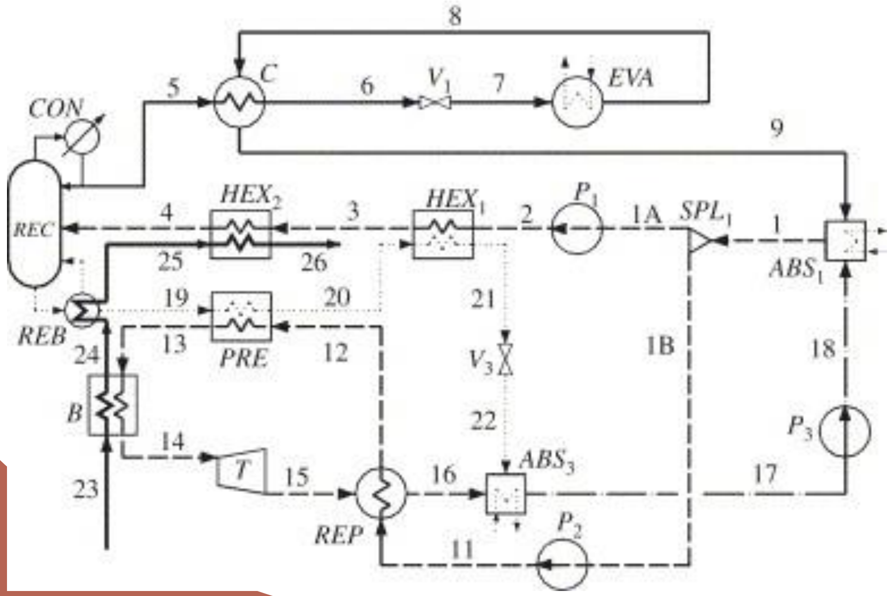
APC cycle

- **Ammonia absorption power/cooling combined cycle (APC)**
  - an improved Goswami cycle, employing a throttle valve to ensure the sub-cooling state before vaporisation,
  - Much more complex system
  - Medium heat source from 200 ^oC to 450 ^oC: thermal efficiency of cooling and power was 0.06 and 0.21 with 450 ^oC heat source.
  - So far no practical application



- **Drawbacks compared with LH Cogen cycle**
  - Require more complex parts, such as liquid pump or rectifier or separator, throttle valve
  - the complex design compromises the compactness
  - Low refrigeration COP

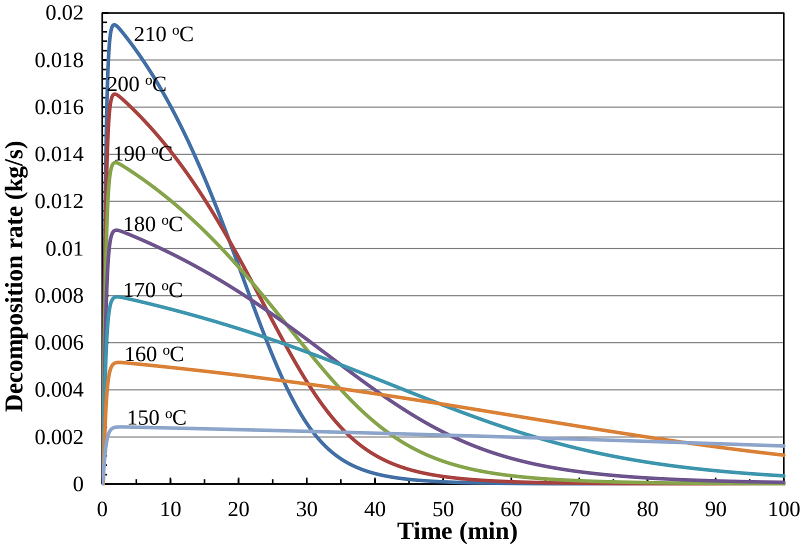
LH Cogen cycle

- **LH Cogen (adsorption-basis cogeneration cycle)**

  Inherits the merits of adsorption over absorption

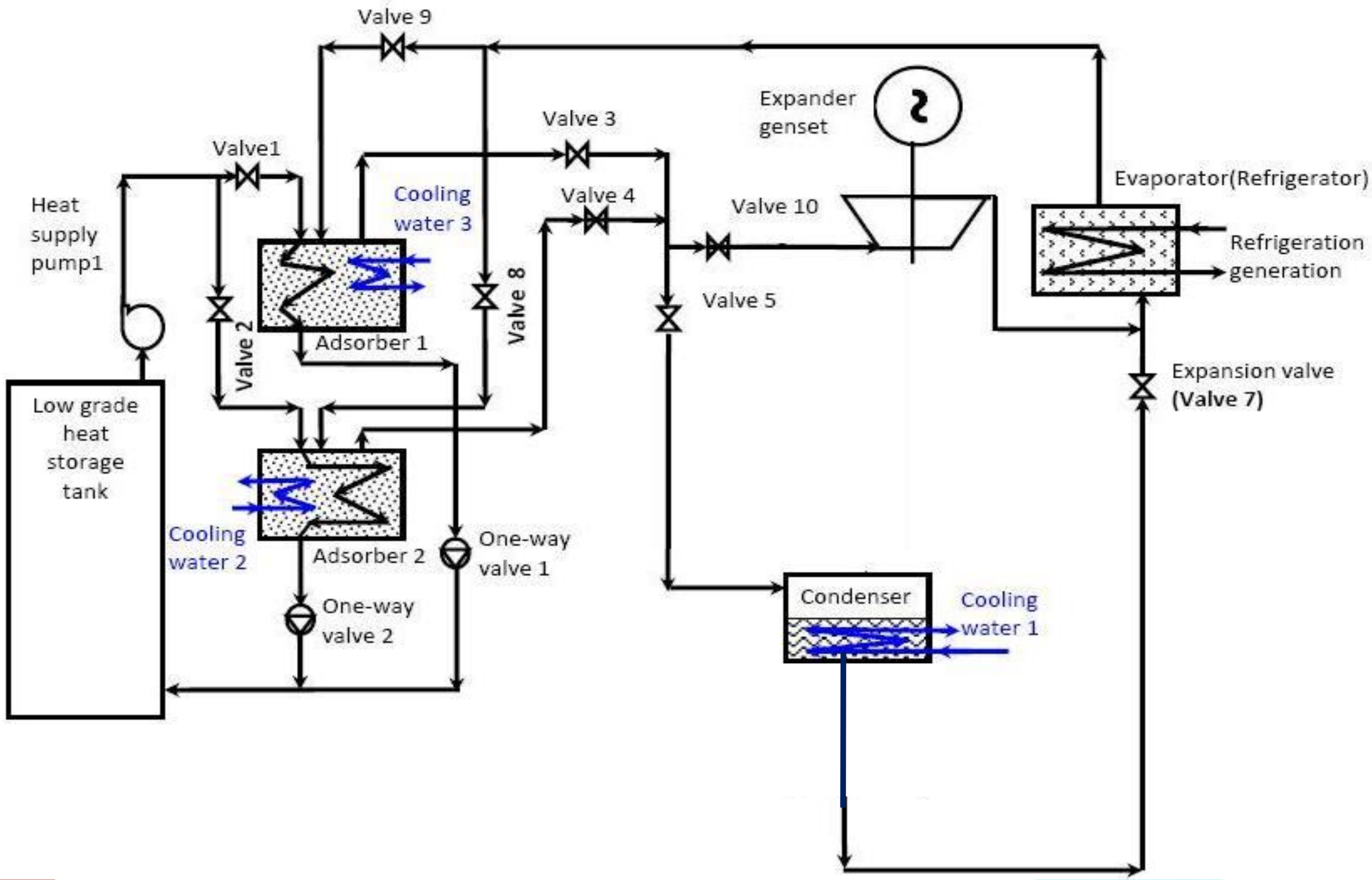
  - a wider range of thermal energy utilisation, 50 ~ 600 °C ($NiCl_2/MnCl_2/BaCl_2/CaCl_2/MgCl_2/NaBr/SiCl_2$……)
  - a much simpler construction requiring easier operation and maintenance (no liquid pump or rectifier or separator for refrigerant)
  - Evaporation refrigeration (latent heat), ideal COP as 0.4 (Goswami and APC < o.1), ideal thermal efficiency of p

- **Drawbacks compared others**
  - Natural Intermittence
  - Relatively unstable reaction rate, impact on the expander performance.



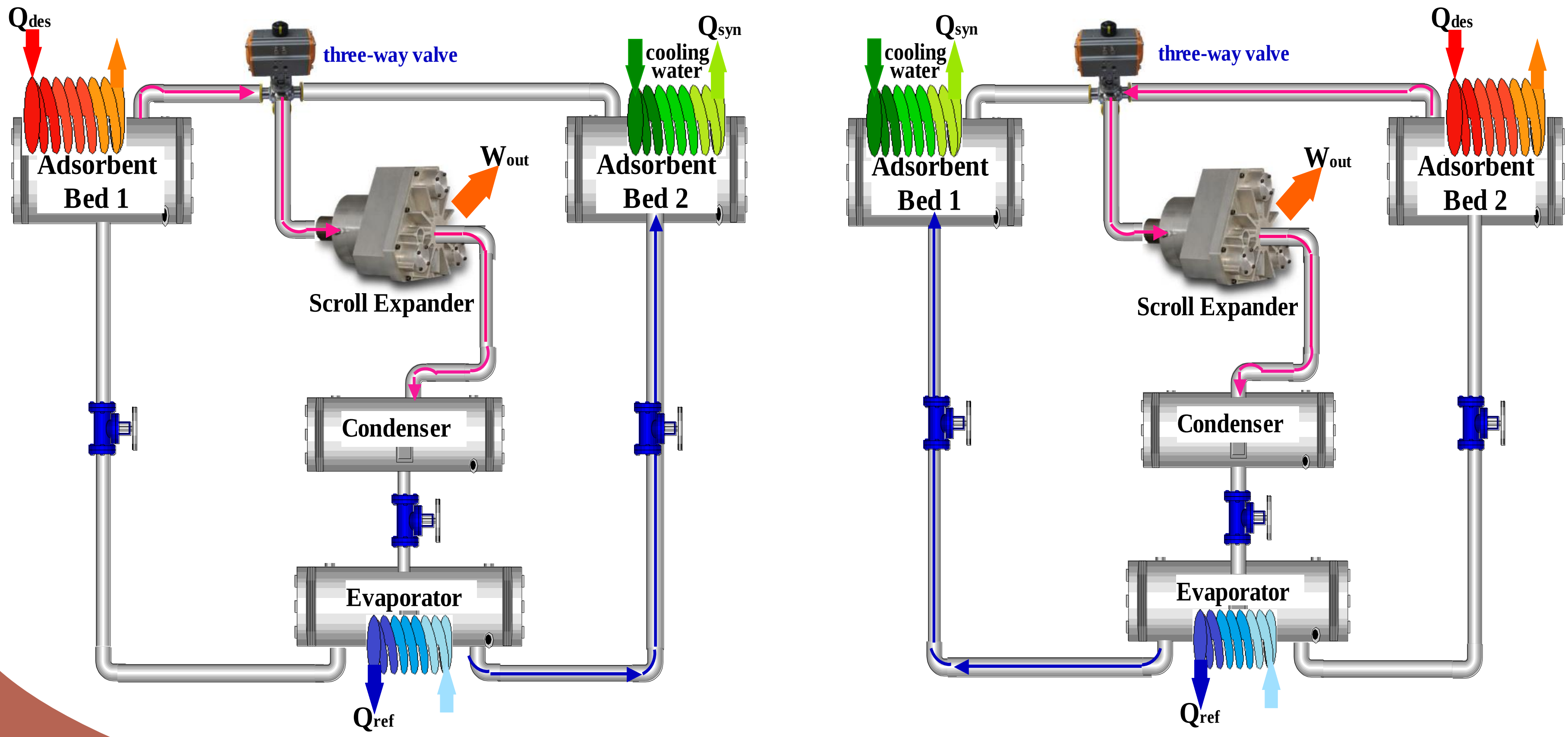
2. Design and manufacture of LH Cogen system

Principle of LH Cogen system



Principle of LH Cogen system

two sets of adsorption cycle are working out-of-phase to overcome the intermittence of adsorption



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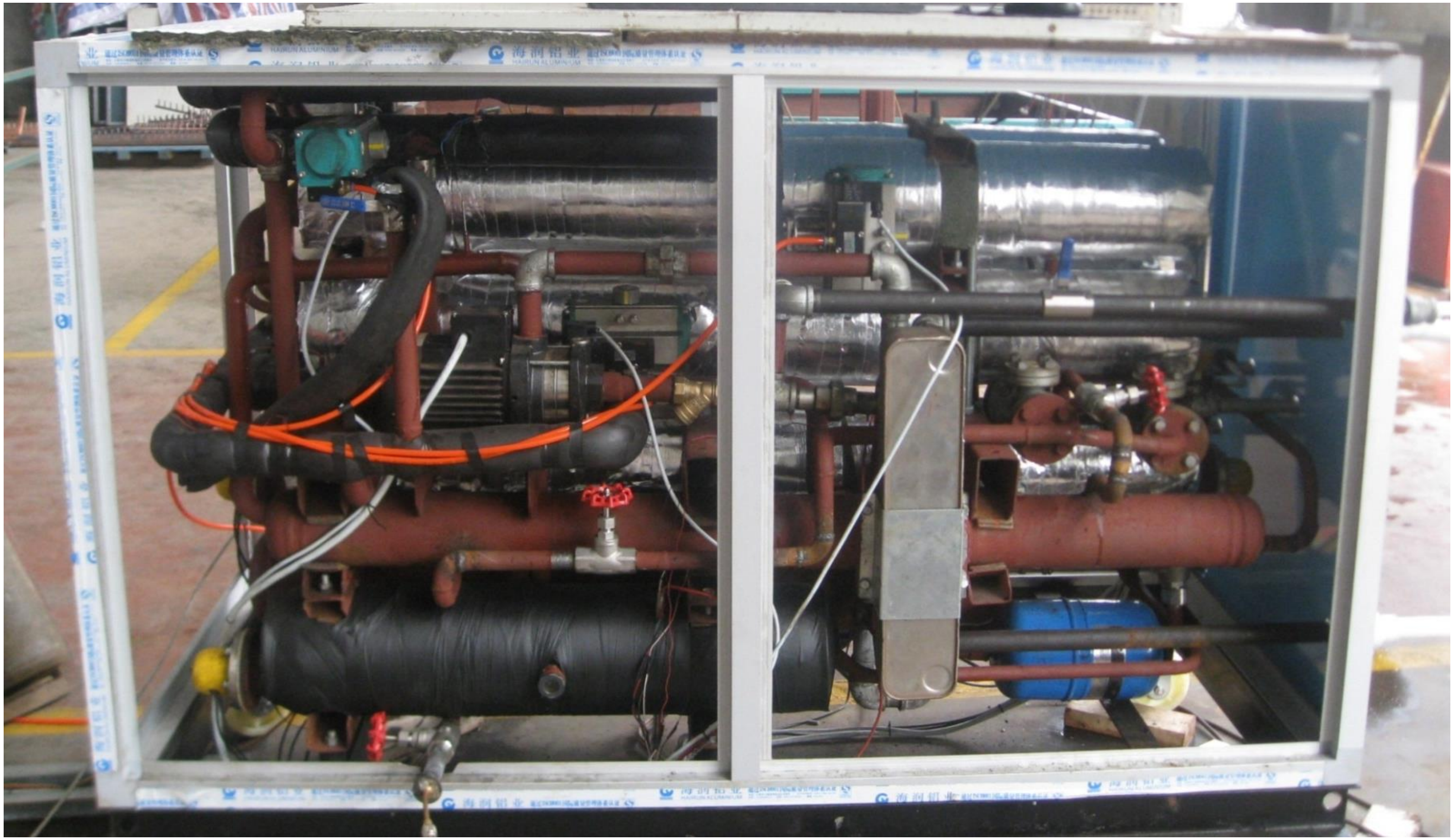
Photos of adsorption chiller



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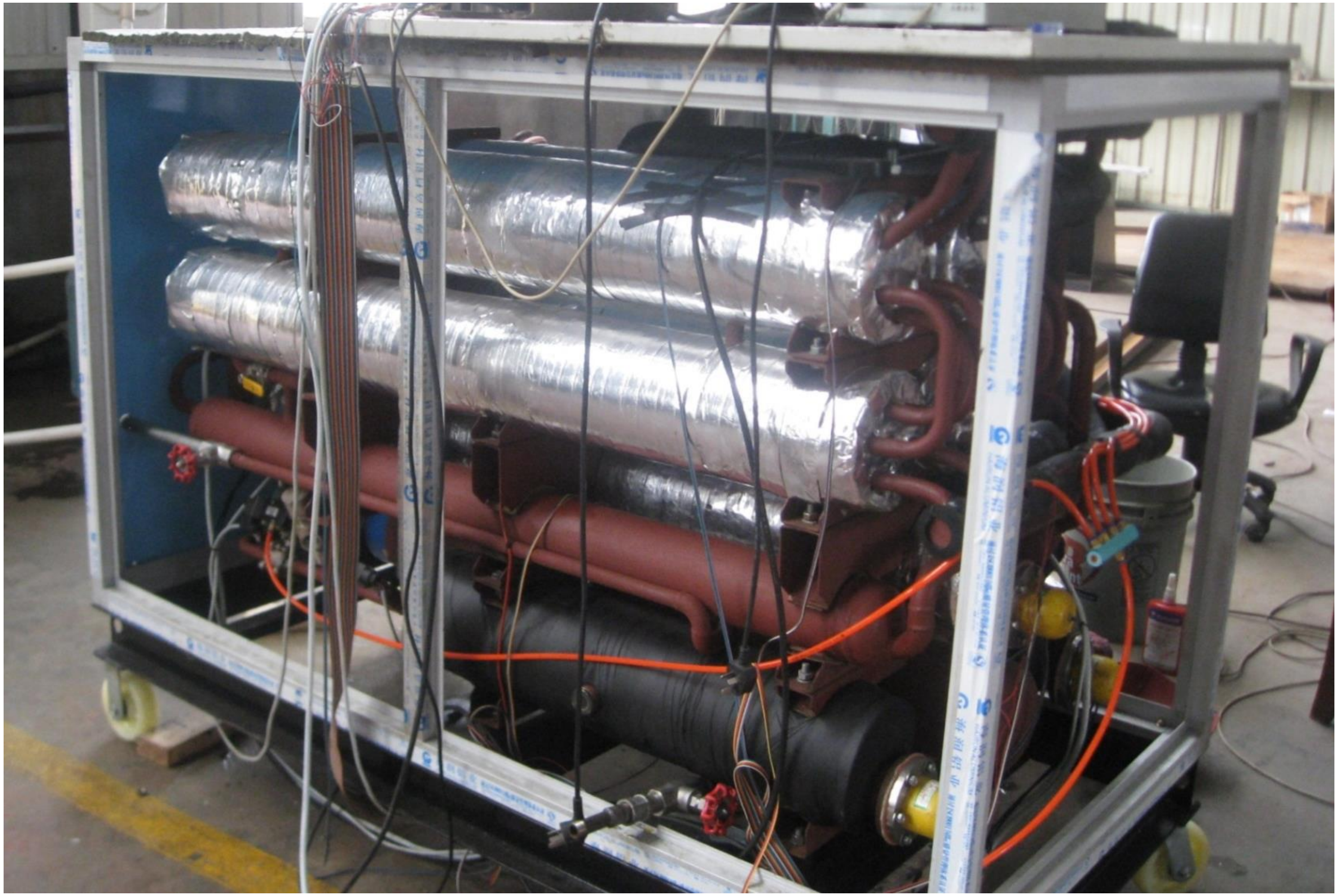
Photos of adsorption chiller



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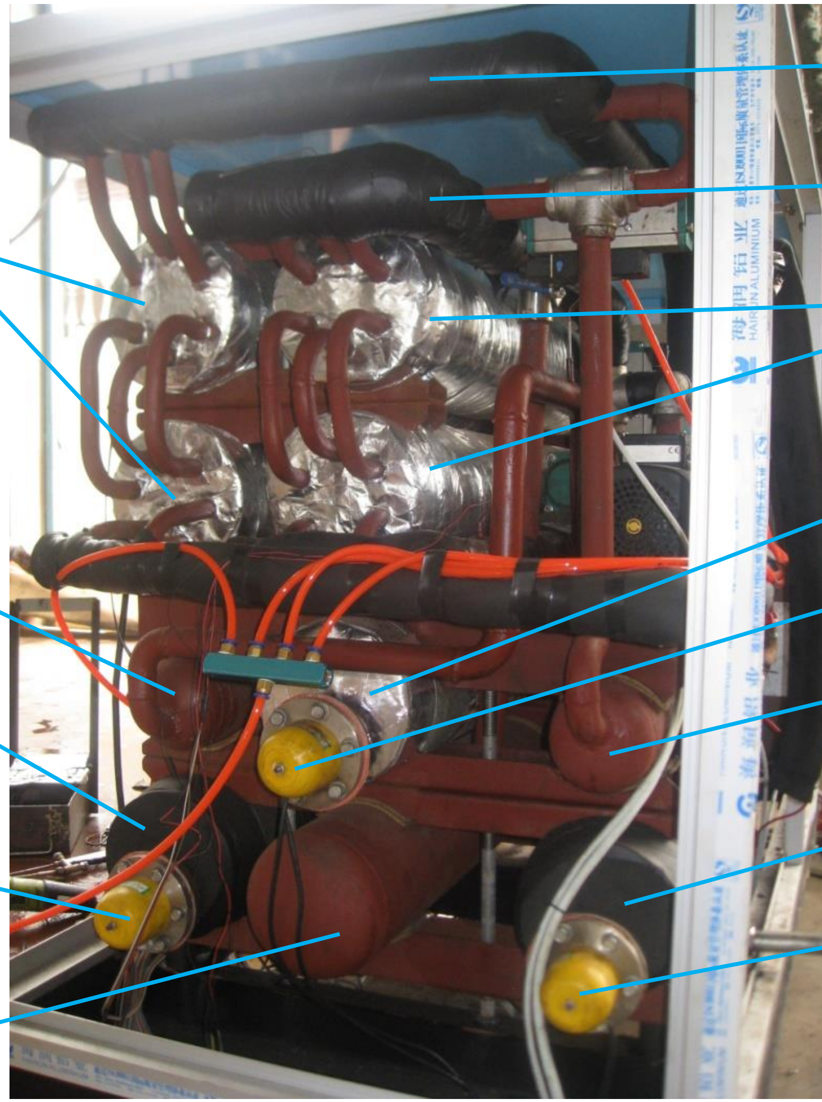
Components of the chiller



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3. Experimental studies and modelling analysis

Experimental setup

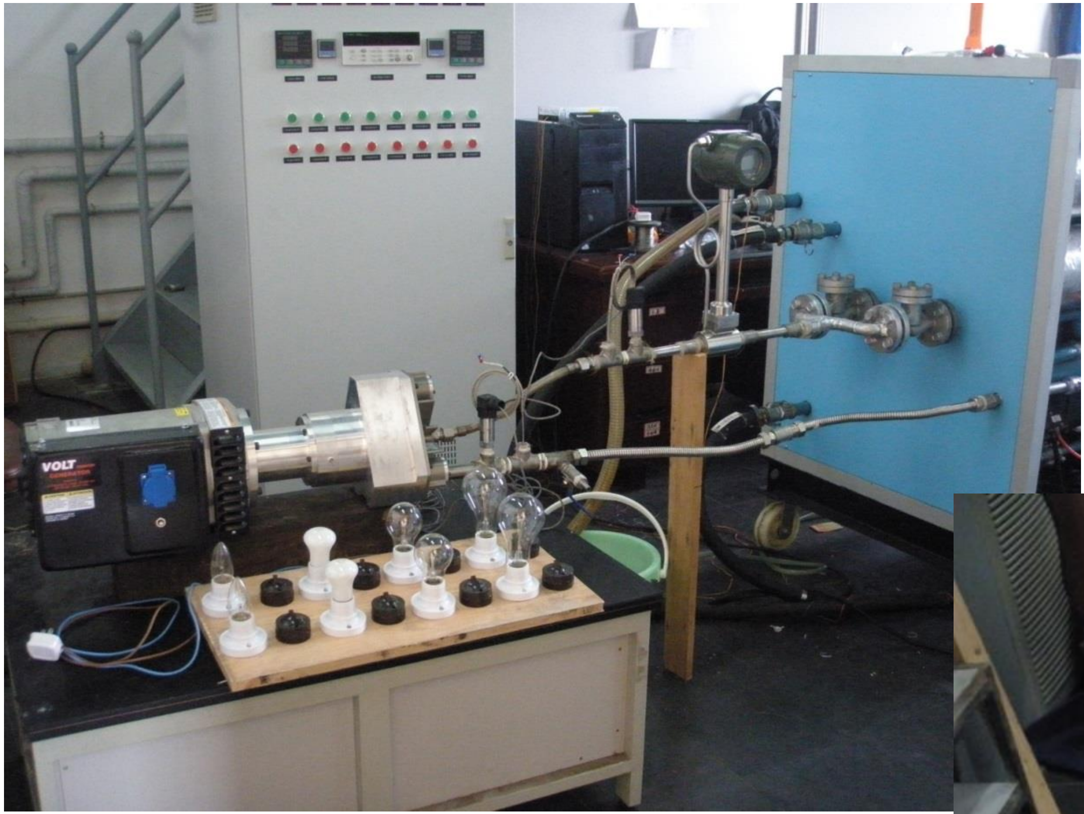
Adsorption chiller

Cooling tower

Data collection devices

Control panel of chiller

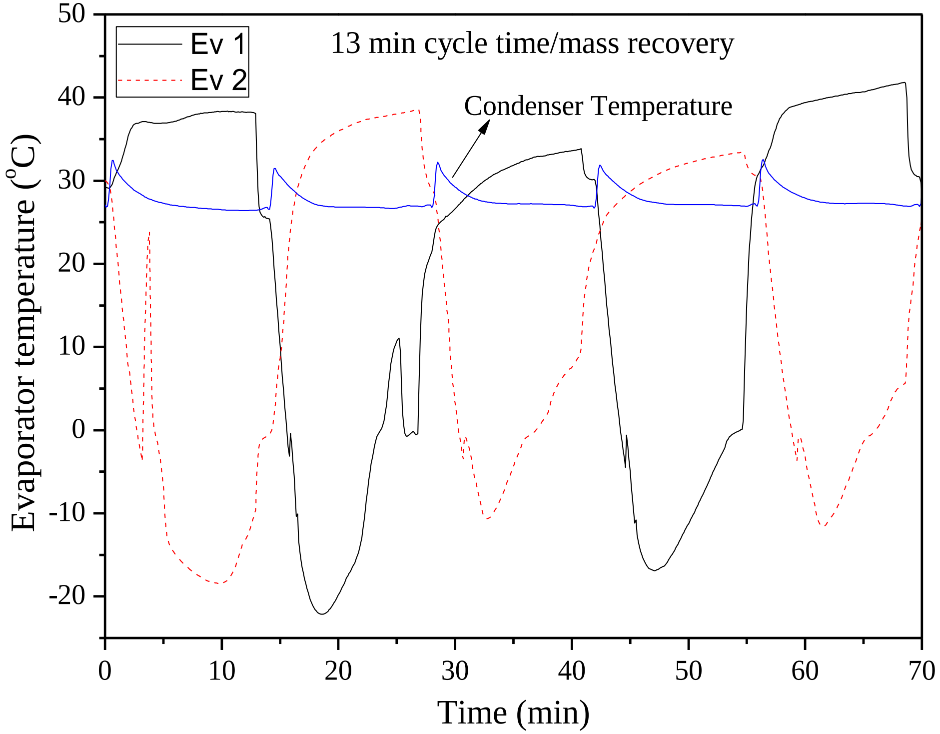
Integration with scroll expander

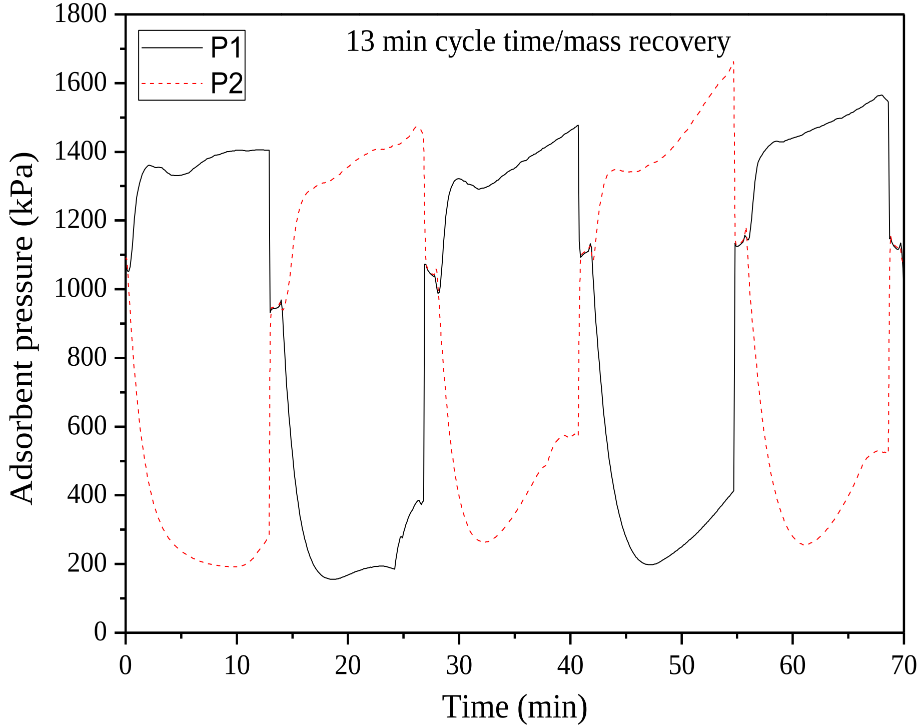


Light bulbs as load bank

and skills

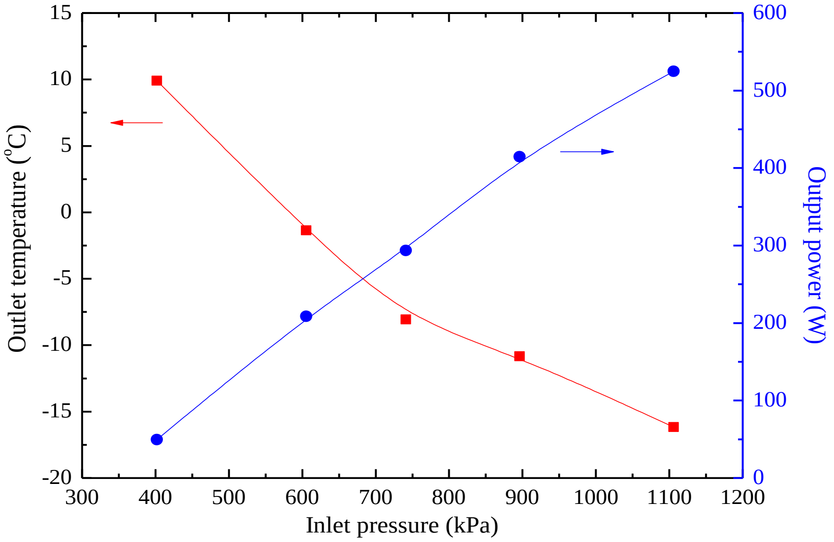
Result: Adsorption chiller performance

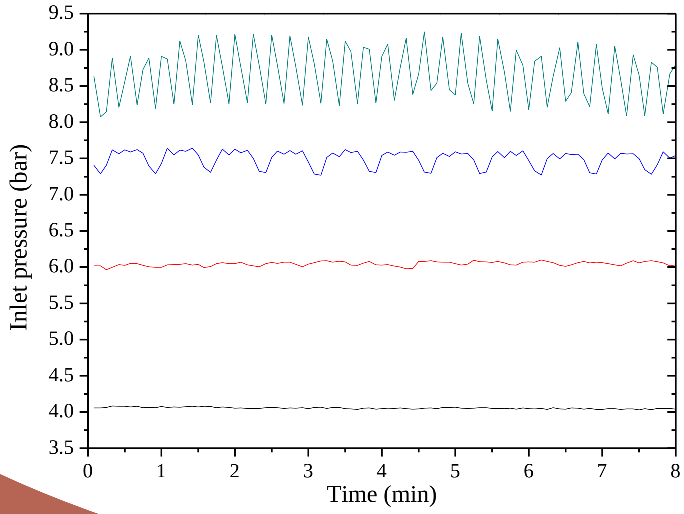


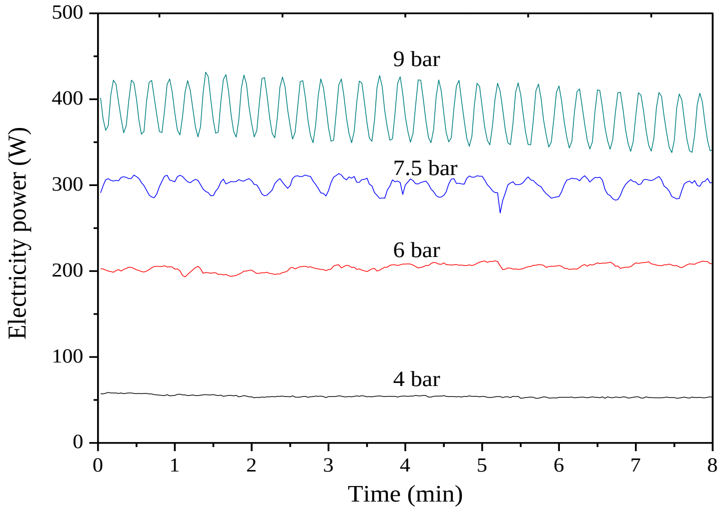


	Cycle time (min)	Average heating temperature (°C)	Average refrigeration temperature (°C)	Average cooling power (W)	COP
MR	13	125	-2.50	3190	0.20
Non- MR	13	126	-0.02	2090	0.14
MR	26	124	-0.80	2410	0.14

Result: Scroll expander performance







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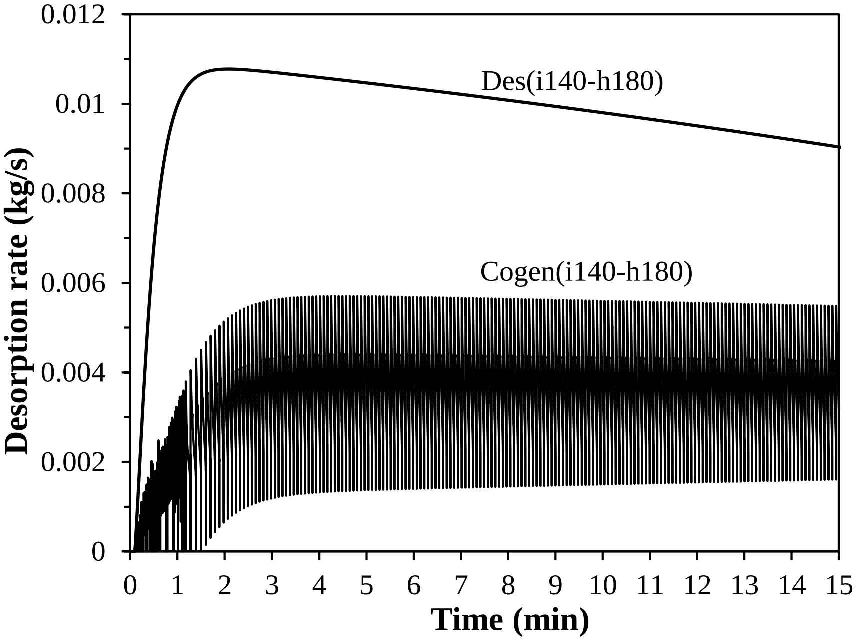
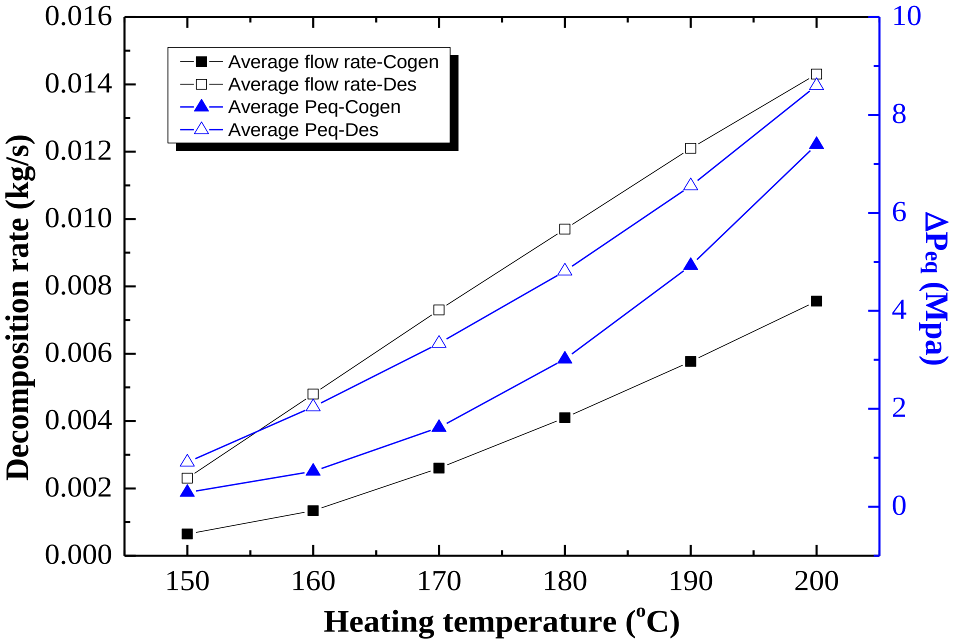
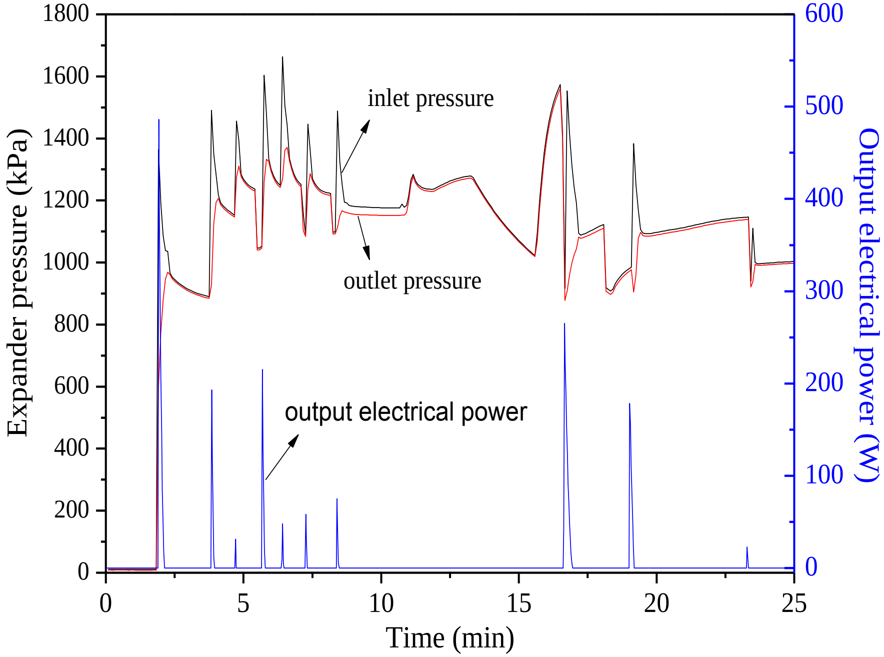
Result: Modelling simulation analysis

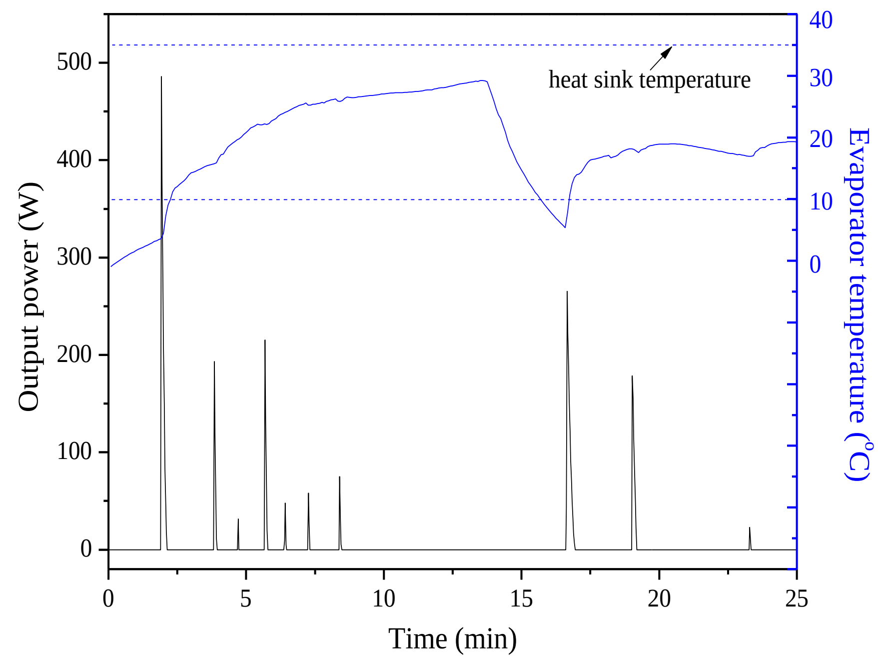




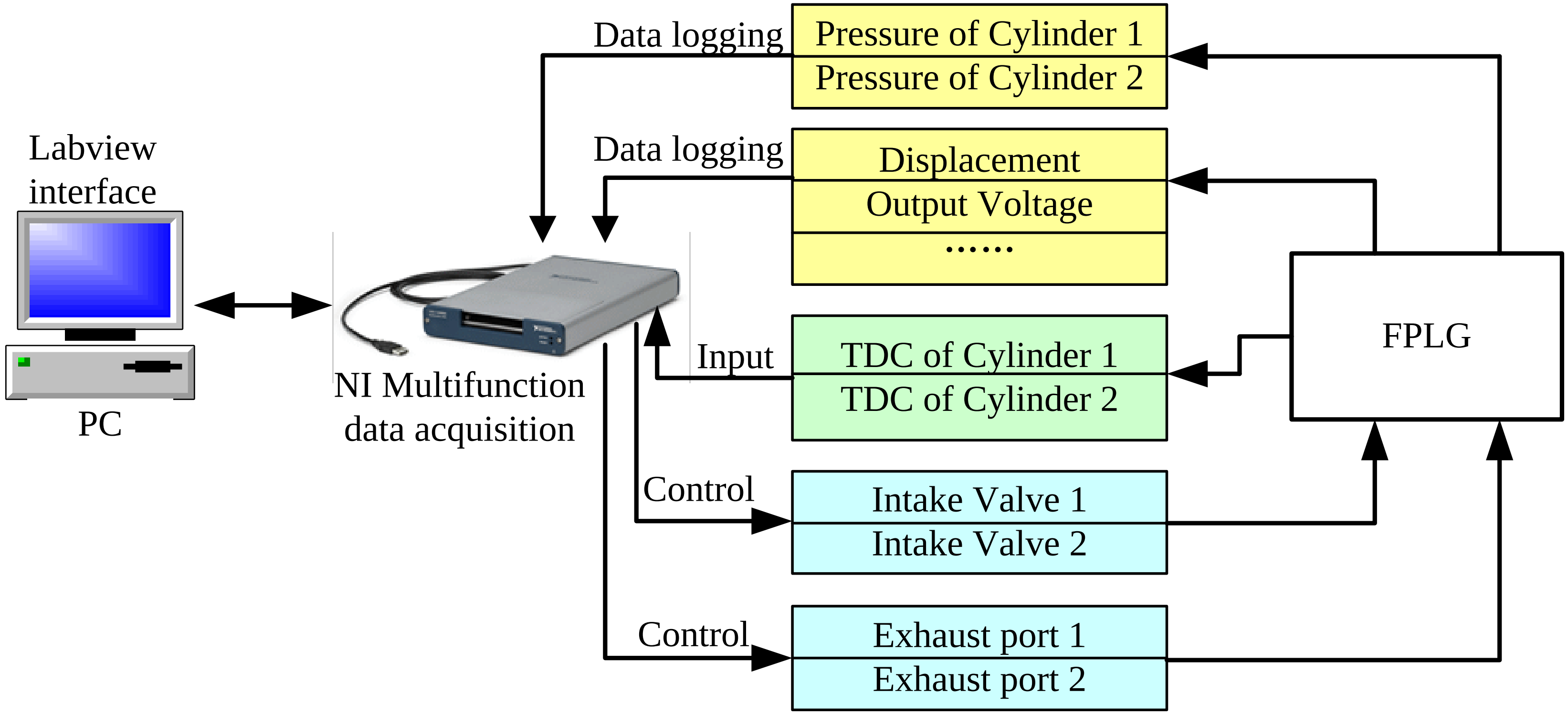
Strong mutual restricts between desorption and expansion

Result: Cogeneration performance





Test rig of linear expander generator driven by compressed air (1)



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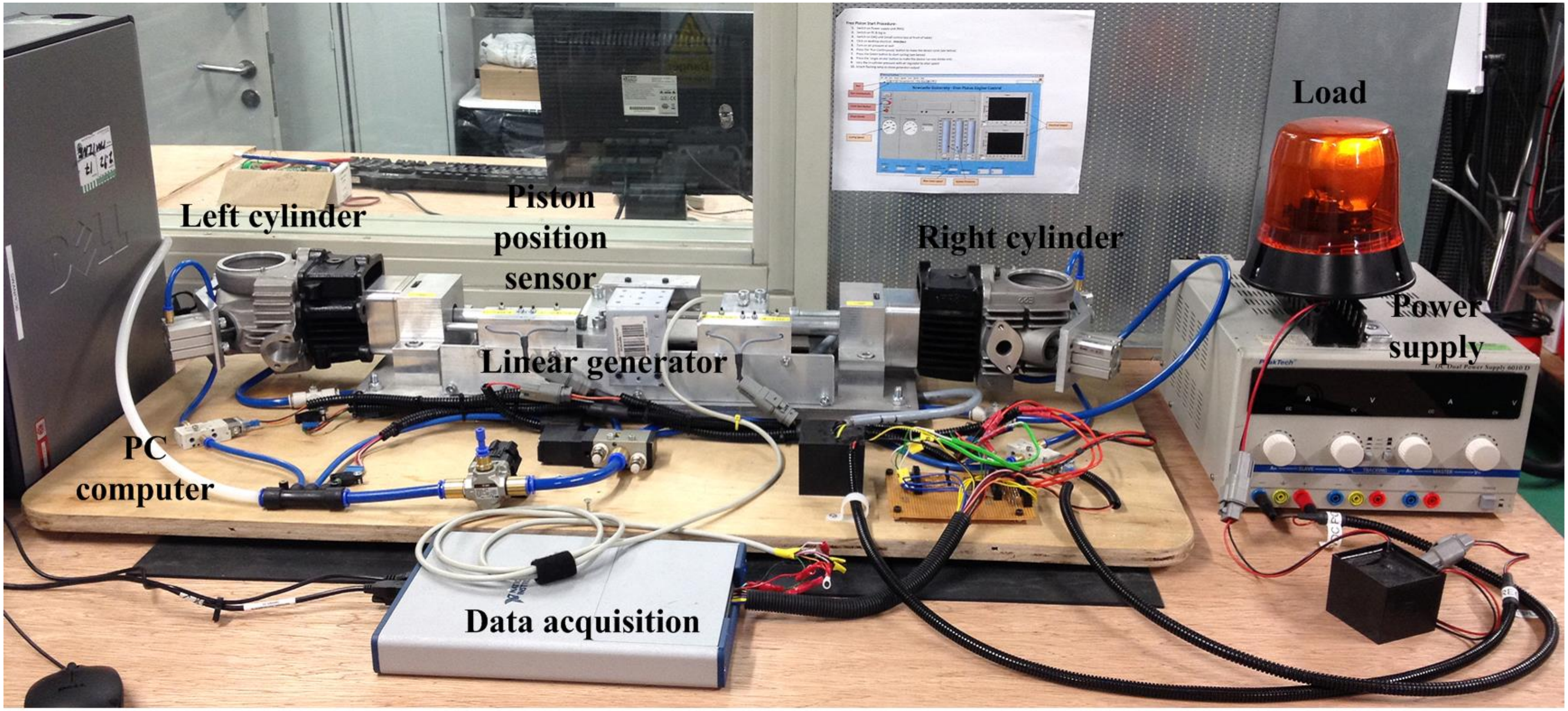
Prototype of linear (free-piston) generator test rig (2)



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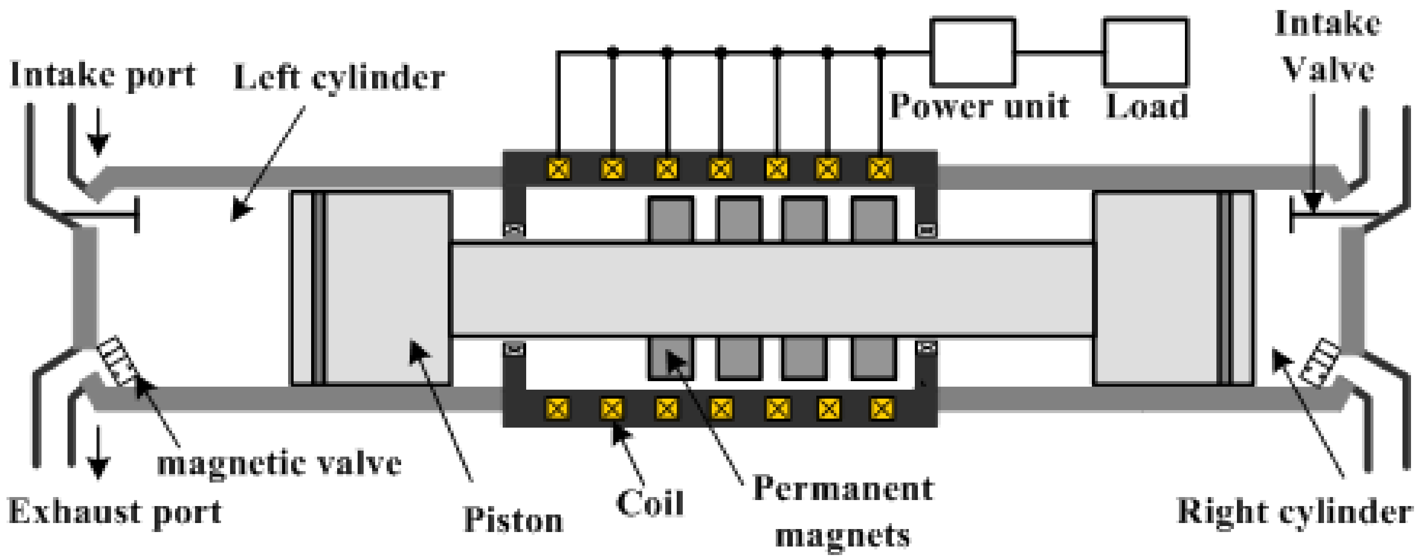
Schematic diagram of linear expander generator



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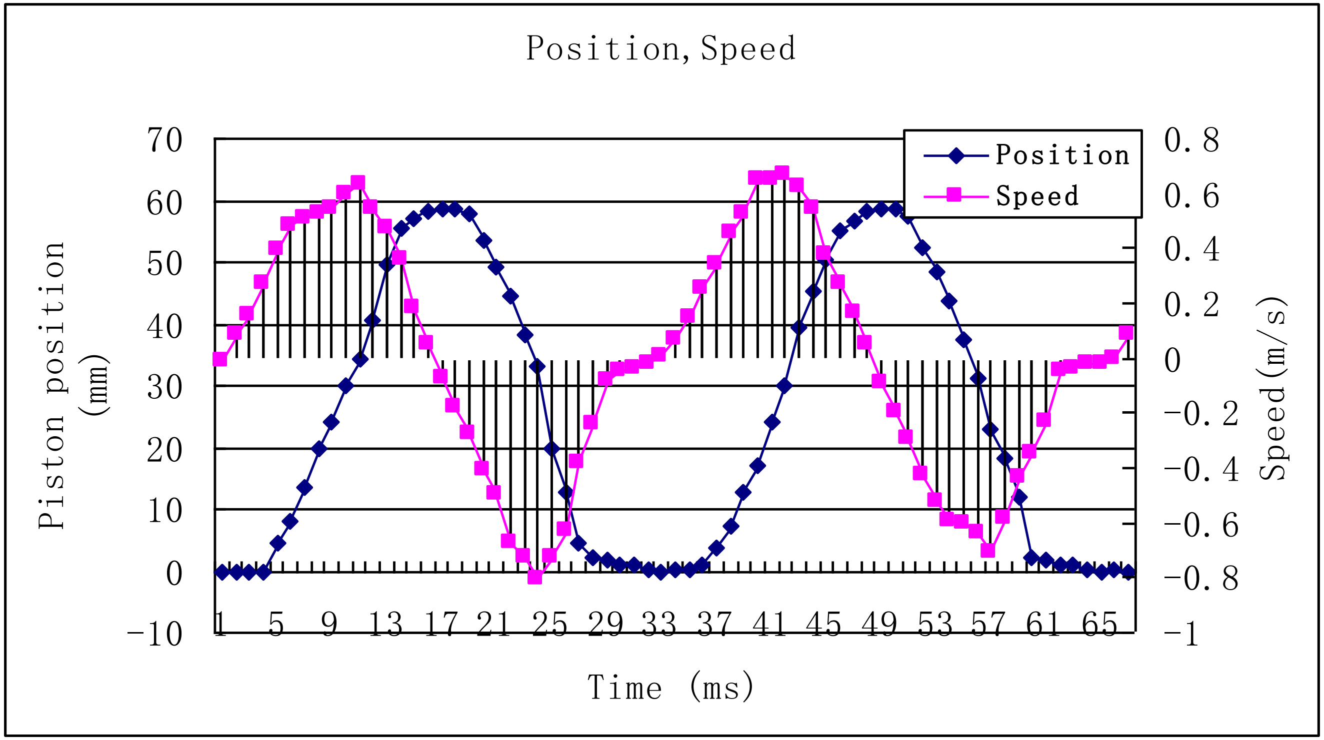
Test results of linear expander generator driven by compressed air



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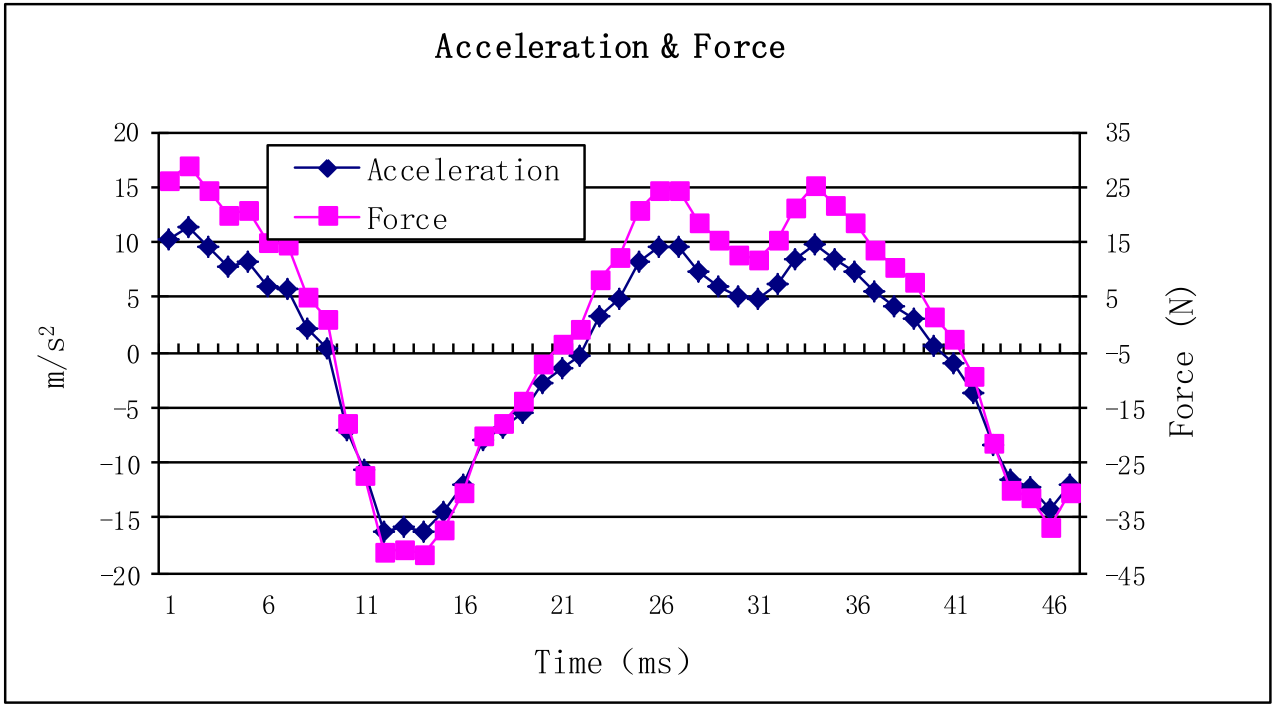

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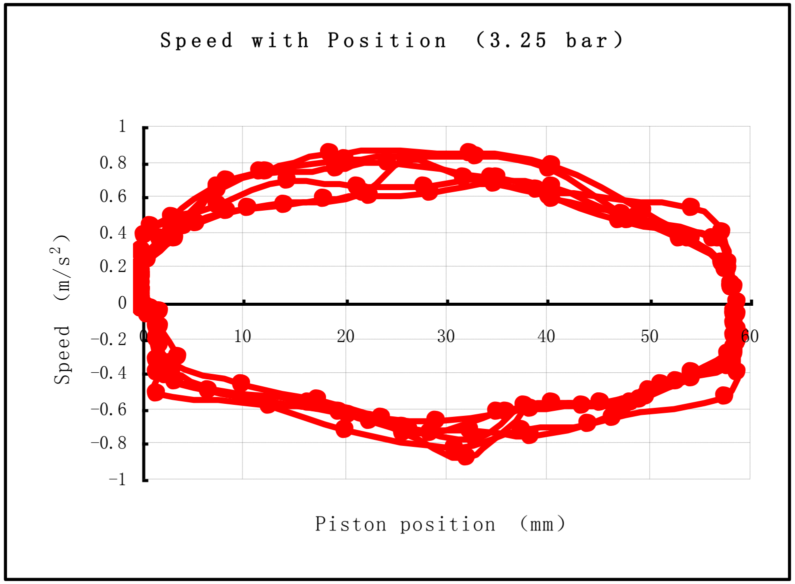
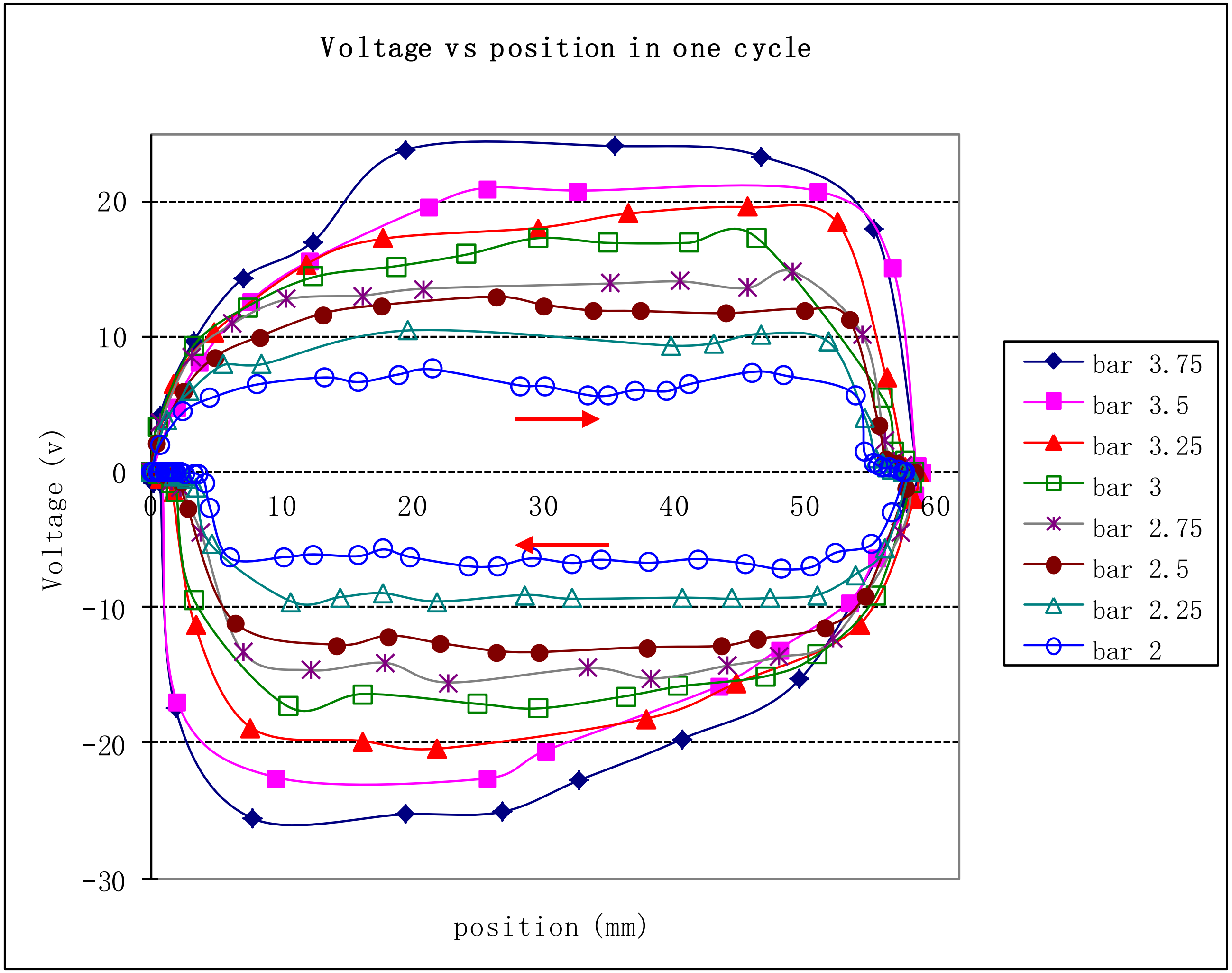
Test results of linear expander generator driven by compressed air

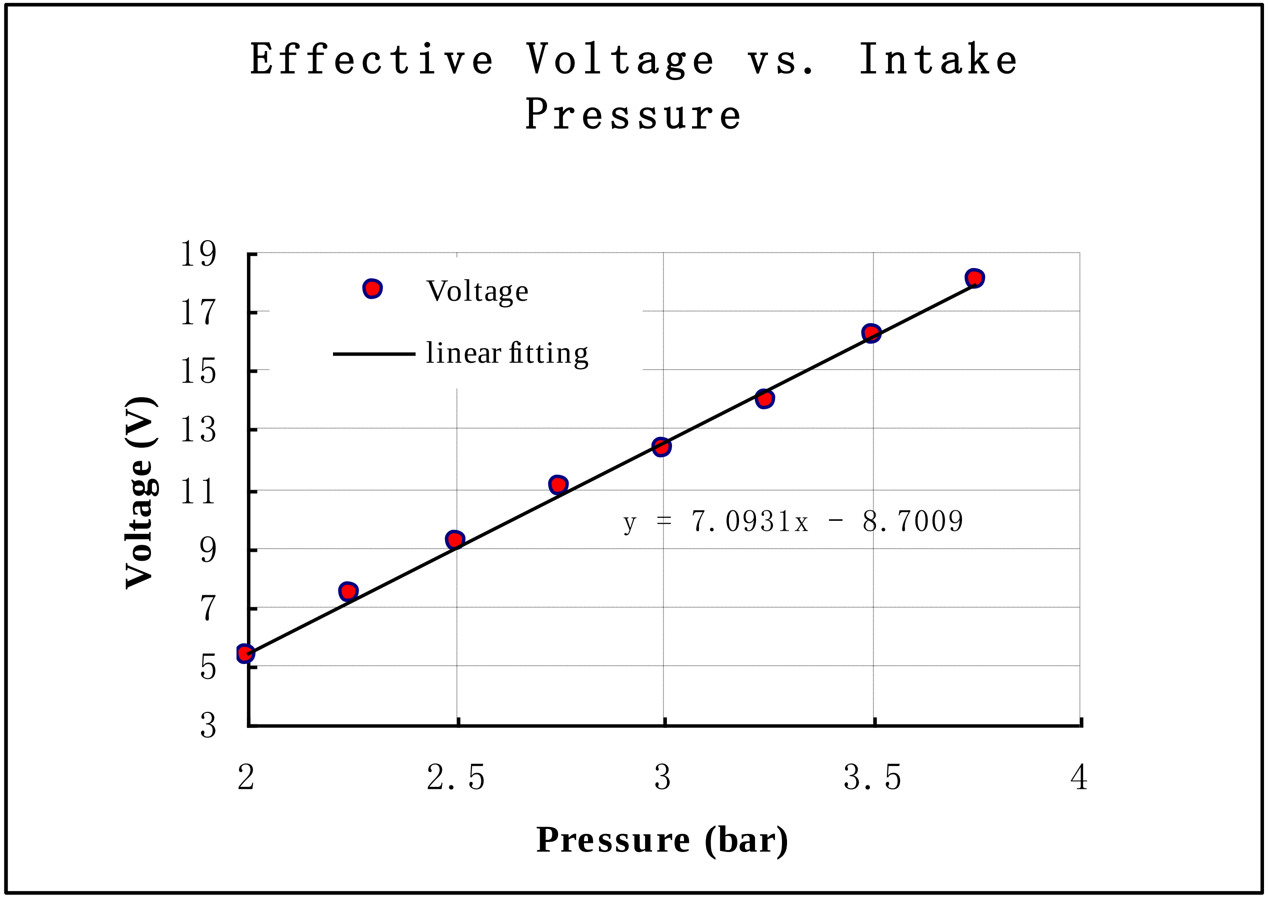


Piston velocity as a function of piston position at steady running condition. (pressure 3.25 bar)

Test results of linear expander generator driven by compressed air



Test results of linear expander generator driven by compressed air



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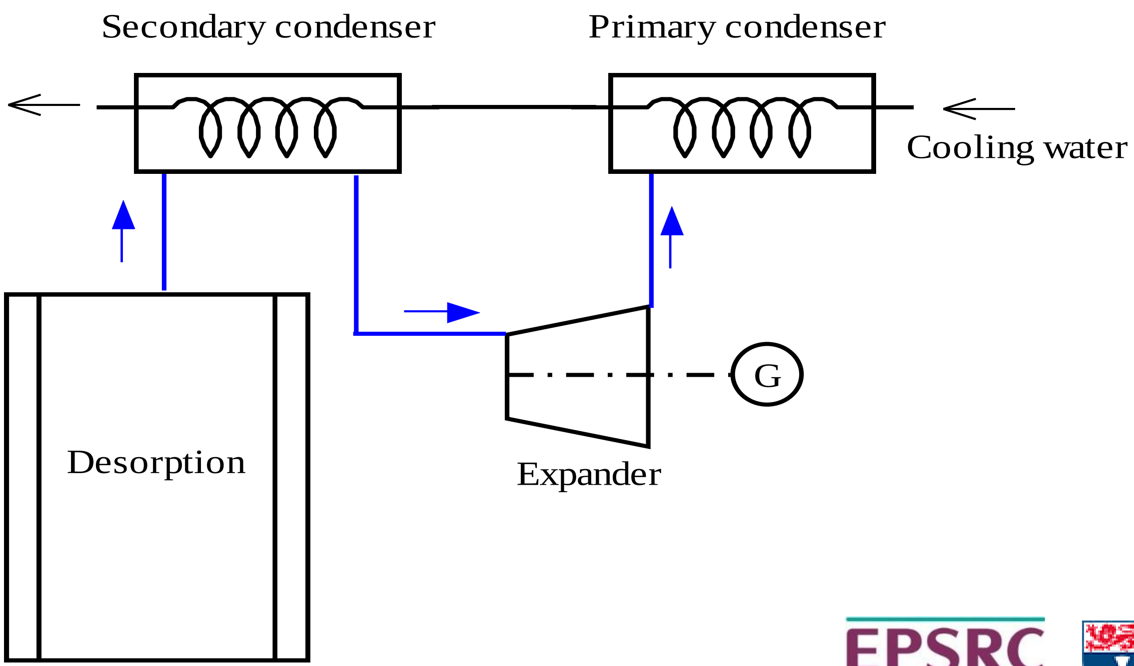
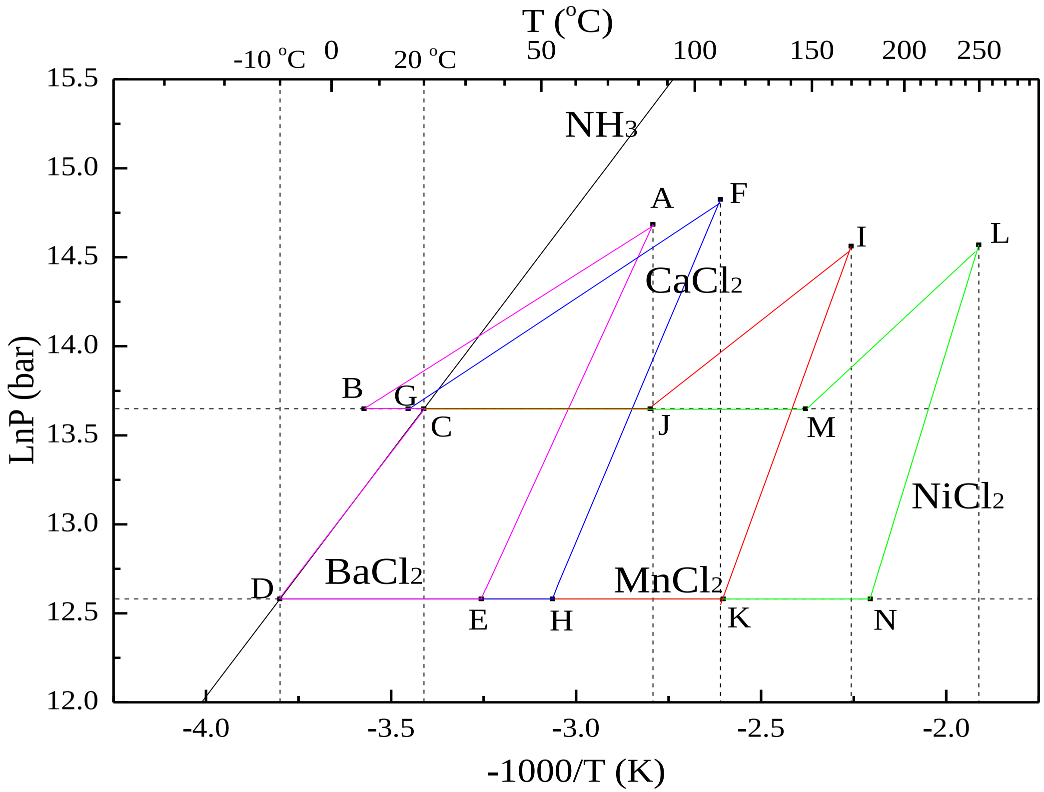
4. Improvement and potential application

Improved design

A possible solution may mitigate or even eliminate the mutual restricts between the decomposition in reaction bed and the expansion process in the expander

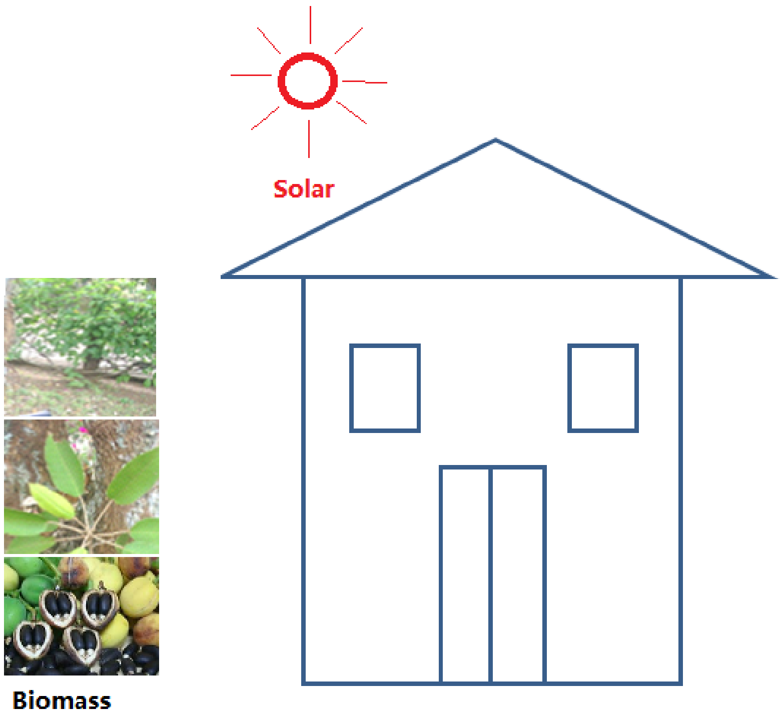


Potential reactive materials



Salt complexes	Desorption temperature (°C)	Desorption pressure (MPa)	Reaction enthalpy ΔH ($J/mol(NH_3)$)	COP	Exergy efficiency	
					Power	Refrigeration
$BaCl_2$ (8-0 NH_3)	85.2	2.4	37665	0.57	0.39	0.23
$CaCl_2$ (8-4 NH_3)	106	2.4	41013	0.41	0.24	0.13
$MnCl_2$ (6-2 NH_3)	174.8	2.4	47416	0.42	0.19	0.089
$NiCl_2$ (6-2 NH_3)	255	2.4	56160	0.34	0.14	0.056

Potential applications



or

Small scale household systems combined with biomass boiler / solar thermal units

Utilizing abundant waste heat in industries

5. Conclusions

- The adsorption cogeneration concept has been demonstrated and the viability has been preliminarily proven.
- The major challenge is the mutual restricts between the desorption process and the expansion process of the expander.
- Both linear expander and scroll expander are working driven by gases (air or ammonia).
- The contradiction between the mountain-shaped desorption rate and the stable inlet required by power generation.
- Better refrigeration capacity than absorption-basis cogeneration technologies.

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Future Work

- Different complex salts may be considered for different refrigeration levels.
- An advanced system could be developed with a secondary condenser potentially can be used to mitigate the above problems.
- Due to the unsteady output, an energy storage unit may be added to the LH Cogen, using electricity storage devises such as batteries and supercapacitors.
- Further tests on linear expander using NH3 is necessary, when funding available to build a new unit using materials adaptable/suitable for NH3.
- Re-design, manufacture and optimise the LH Cogen system including the adsorption unit, the linear expander.
- Further field tests using different low grade heat sources.

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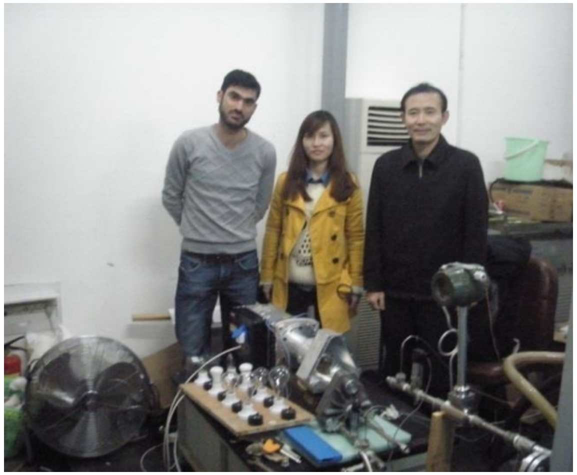
Acknowledgement

This research outcome is from the research projects funded by Engineering and Physical Sciences Research Council (**EPSRC**):

- '**LH Cogen**: **Low grade heat driven adsorption-linear-expander cycle for cogeneration of power and refrigeration**' (EP/I027904/1)
- '**GLOBAL - Sustainable Energy through China-UK Research Engagement** (**SECURE**)' (EP/K004689/1) .

Thank You!



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