A THERMO-CHEMICAL SOLUTION

Salt-ammonia reactions, in resorption cycle heat pumps and thermal transformers, for domestic or industrial applications.

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Project aims

• Work on a thermo-chemical solution to the environmental problems
• Researching technology that can provide heating and cooling with greater energy efficiency
• Utilising salt-ammonia chemical reactions within heat powered thermal machines
• Research into resorption cycle heat pumps and thermal transformers
• Domestic and industrial applications
Project background

• Collaboration with Energy research Centre of the Netherlands (ECN)
• Dr van der Pal’s CaCl$_2$ 10kW reactor under test 2016
• Single reactor, evaporating and condensing cycle
Technical introduction

• Solid salt reacting chemically with ammonia gas
• Forming salt-ammonia complex
• Decomposing bonds – heat absorbed
• Synthesising bonds – heat released

\[
\text{exothermic} \quad CaCl_2 + xNH_3 \quad \Rightarrow \quad CaCl_2 \cdot xNH_3 + H_{\text{react}}
\]

\[
\text{endothermic}
\]
Technical introduction

Phase 1
- **LT Salt**
- **HT Salt**

- **60°C**
- **Ammonia flow**

- **Exothermic adsorption** at medium temperature
- **Endothermic desorption** at high temperature

Phase 2
- **LT Salt**
- **HT Salt**

- **0°C**
- **60°C**

- **Endothermic desorption** at low temperature
- **Exothermic adsorption** at medium temperature

2-Salt resorption cycle heat pump

- **Ammonia flow**
- **$P_{high}$**
- **$P_{low}$**
- **$T_{low}$**
- **$T_{mid}$**
- **$T_{high}$**
- **$-1000/T$**

- **Ammonia L/G**
- **LT Salt CaCl₂**
- **HT Salt MnCl₂**
Phase 1
- High pressure
- Endothermic desorption at medium temperature
- Exothermic adsorption at high temperature

Phase 2
- Low pressure
- Exothermic adsorption at low temperature
- Endothermic desorption at medium temperature

Technical introduction

2-Salt resorption cycle thermal transformer

- HT Salt
- LT Salt

Temperature:
- High pressure: 150°C
- Medium temperature: 90°C
- Low pressure: 30°C

Salts:
- HT Salt: CaCl₂, MnCl₂
- LT Salt: CaCl₂

Ammonia flow

Graph:
- ln(P) vs. −1000/T
- P_high
- P_low

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Why resorption, why salts?

• Requires **no electricity** (except for pumps and control) compared with high temperature vapor compression cycles

• Resorption cycles can operate at **lower pressures** than evaporating and condensing cycles,

• Salt-gas **reaction heat is greater than latent heat**

• System **theoretical simplicity** is attractive – no evaporator and condenser

• **Limited number** of research papers on resorption cycle that all show good potential
Challenges

• A single cycle is a batch process rather than continuous
• Expansion/contraction
• Stability of salt and matrix material
• Hysteresis
• Reaction dynamics
• Thermodynamic properties such as \( \Delta H, \Delta S \) for equilibrium lines
• Reactor design is critically important
  • Good heat and mass transfer
Approach

• Computer modelling
• Property measurements

• Experiments
  • Reaction rate – Large Temperature Jump experiments
  • Stability – Long term cycling experiments
    • A rig that can test multiple samples at the same time
    • Gradually increase time period
    • Few weeks or even few months

• Prototype machine testing
  • About 5-10 kW heating output
  • Which represents the average heating demand for a UK dwelling
  • Will also be tested at industrial temperatures
New equipment
New equipment

TMA
- Thermo-mechanical analysis
- A.k.a. Dilatometer
- Measuring expansion and contraction ENG-Salt composite

DSC

TMA
New equipment

DSC
- Differential scanning calorimetry
- Measuring heat absorbed or released from the chemical reactions
New equipment

STA
- Simultaneous thermal analysis
- Combines DSC with weighing function
- Reaction heat
- Gas quantity adsorbed/desorbed

LFA

HFM

TMA
New equipment

LFA
- Light flash analysis
- Light source from a Xenon gas source
- Thermal conductivity measurements of small samples
New equipment

HFM
- Heat flow meter
- Thermal conductivity measurements of large samples
Summary

• Project will investigate salt-ammonia chemical reactions for use in heat driven heating and cooling application

• Project based on resorption cycle which is
  • Theoretically promising and simple
  • Could have a lower capital cost to other sorption technology
  • Improve efficiency and save money

• Project will consist of
  • Property measurements and experimentation
  • A prototype machine
Thank you for your attention
Any questions?

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Cycle A  
In phase 1

Low temperature salt

High temperature salt

Space and water heating demand

Air cooled water

Cycle B  
In phase 2

Low temperature salt

High temperature salt

Water form high efficiency boiler
Technical introduction

Phase 1
high pressure

Condenser
Salt reactor
Evaporator

Ammonia flow
Endothermic desorption at high temperature

Phase 2
low pressure

Condenser
Salt reactor
Evaporator

Ammonia flow
Exothermic adsorption at medium temperature

1-Salt evaporating and condensing cycle heat pump

\[ \ln(P) = \begin{cases} P_{\text{high}} & \text{for } T_{\text{low}} \\ P_{\text{low}} & \text{for } T_{\text{mid}} \end{cases} \]

\[ \frac{-1000}{T} \]

Ammonia flow
Ammonia L/G
LT Salt CaCl₂
HT Salt MnCl₂

\( = \text{Open Valve} \)
\( = \text{Closed Valve} \)