MgSO₄ + zeolite-based composite thermo-chemical energy stores (TCES) integrated with vacuum flat plate solar thermal collectors (VFPC) for seasonal thermal energy storage

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MgSO₄ + Zeolite based composite thermo-chemical energy stores (TCES) integrated with vacuum flat plate solar thermal collectors (VFPC) for seasonal thermal energy storage

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CREST
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Introduction

• Thermochemical Energy Storage offers a solution for storing heat indefinitely almost loss free.
• MgSO₄ is a prime candidate
  • Cost effective (£61/Ton), Widely available, High energy density 2.8GJ/m³ (778kWh/m³), Non-Toxic.
• Problems – Material difficult to work with in powder form, agglomeration occurs reducing cycle stability, permeability and power output.

Dehydration (Charging Process)

Heat

\[ \text{MgSO}_4 \cdot 7\text{H}_2\text{O} \rightarrow \text{MgSO}_4 + 7\text{H}_2\text{O} \]

MgSO₄ and H₂O kept separate. Heat Stored indefinitely

Re-hydration (Discharge Process)

\[ \text{MgSO}_4 + 7\text{H}_2\text{O} \rightarrow \text{MgSO}_4 \cdot 7\text{H}_2\text{O} \]

Upon reintroduction MgSO₄ and H₂O react forming MgSO₄·7H₂O and giving off Heat.
Creation of Zeolite + MgSO₄ Composites

• In order to alleviate MgSO₄ issues a composite material is created using Zeolite.
• Zeolite – Can be used as a sorption heat store.
  • Typically highly porous, high surface area and very absorbent.
  • Around 750J/g energy density.
• Higher surface area = larger reaction area = should result in higher power output.
Creation of Zeolite + MgSO\textsubscript{4} Composites

• Composite materials do not suffer from agglomeration after hydration.
• Graph shows DSC dehydration of composite materials (hydrated at 56\%RH & 20\°C)
• Majority of endothermic heat flow below 150\°C = Ideal for VFPC
• 35wt% composite has a dehydration enthalpy, taking sensible losses into account, of ~950J/g using only 56% RH at 20 °C
• Increasing wt% results in decreasing sensible component %. I.e. less wasted energy (~14% for 35wt%)
Vacuum Flat Plate Solar Thermal Collectors

- Conventional flat plate solar thermal collectors

- Vacuum flat plate solar thermal collector.
  - Absorber fills up more of the installed collector area in comparison to evacuated tube solar thermal collectors
  - Vacuum provides greater insulation in comparison to convectional flat plate collectors
Vacuum Flat Plate Solar Thermal Collectors

(EN12975-2:2006) (800 W/m², Ambient temperature is 20°C)

Efficiencies based on aperture area
Vacuum flat plate solar thermal collectors can operate efficiently at temperatures (100°C - 150°C) compatible with the dehydration of MgSO$_4$. Experimental testing has verified level of insulation attainable.
Feasibility Study

• Feasibility of VFPC+TCES system calculated.
• Solar irradiance + ambient temperature calculated using CREST Integrated Electrical and Thermal Energy Demand model - Data generated stochastically
• All systems modelled with 8m$^2$ of VFPC
• Energy density (J/g) and effective heat capacity calculated from DSC tests.

• Main Assumptions:
  • 3 months (summer) charge time.
  • Remaining 9 months the VFPC solar gains are utilised.
  • Inflation and £/kWh rise calculated from historic data.
  • TCES only used throughout winter months.
Feasibility Study

- **MgSO$_4$** and 35wt% composite dehydrated to 150 °C – able to store ~30% of winter space heating demand.
- Store size of MgSO$_4$ and 35wt% composite = 2.09 and 4.75 m$^3$, respectively.

![Store Temperature with Time graph](image)
System Payback

• Graph shows the system payback with time.
• \( \text{MgSO}_4 \) dehydrated to 80\(^\circ\)C and 150\(^\circ\)C as well as 35wt\% dehydrated to 150\(^\circ\)C are viable.

```
System Payback with time / Savings against standard Energy Costs (VFPC + TCES)

- \( \text{MgSO}_4 \) - 80\(^\circ\)C. 23.5\% of winter
  SHD. 3.76\( m^3 \) Store size

- \( \text{MgSO}_4 \) - 150\(^\circ\)C. 28.3\% of winter
  SHD. 2.09\( m^3 \) Store size

- 35wt\% - 80\(^\circ\)C. 22.8\% of winter
  SHD. 12.23\( m^3 \) Store size

- 35wt\% - 150\(^\circ\)C. 31.4\% of winter
  SHD. 4.75\( m^3 \) Store size

- Zeolite-Y - 150\(^\circ\)C. 28.3\% of winter
  SHD. 9.74\( m^3 \) Store size
```
UK CO₂ Savings

• Graph shows the amount of CO₂ saved, in the UK, using each of the different systems over a 30 year lifetime.
• It assumes the systems are completely 0 carbon and 10% of all UK households have a system.

**CO₂ Saving over the lifetime of the system (TCES only)**

- MgSO₄ - 80°C. 23.5% of winter SHD. 3.76m³ Store size.
- MgSO₄ - 150°C. 28.3% of winter SHD. 2.09m³ Store size.
- 35wt% - 80°C. 22.8% of winter SHD. 12.23m³ Store size.
- 35wt% - 150°C. 31.4% of winter SHD. 4.75m³ Store size.
- Zeolite-Y - 150°C. 28.3% of winter SHD. 9.74m³ Store size.
UK CO$_2$ Savings

• Graph shows the amount of CO$_2$ saved, in the UK, using each of the different systems over a 30 year lifetime.
• It assumes the systems are completely 0 carbon and 10% of all UK households have a system.

**CO2 Saving over the lifetime of the system (VFPC + TCES)**

- **MgSO4 - 80°C. 23.5% of winter**
  - SHD. 3.76m$^3$ Store size.

- **MgSO4 - 150°C. 28.3% of winter**
  - SHD. 2.09m$^3$ Store size.

- **35wt% - 80°C. 22.8% of winter**
  - SHD. 12.23m$^3$ Store size.

- **35wt% - 150°C. 31.4% of winter**
  - SHD. 4.75m$^3$ Store size.

- **Zeolite-Y - 150°C. 28.3% of winter**
  - SHD. 9.74m$^3$ Store size.
Social Savings

• The graph shows the “social savings” from the reduction in the CO\textsubscript{2} emissions.
• Assuming the systems are completely carbon free and 10% of all UK households have a system.
• ~£4 250 million savings over 30 years
Social Savings

• The graph shows the “social savings” from the reduction in the CO$_2$ emissions.
• Assuming the systems are completely carbon free and 10% of all UK households have a system.
• ~£14 000 million savings over 30 years
Cost/kWh

• Graph shows the Cost/kWh of energy produced from the VFPC+TCES systems.
• £/kWh will only increase over time from traditional source’s

### kWh cost for each material (assuming use of energy from VFPC at 8 m²)

- **MgSO₄ - 80°C. 23.5% of winter SHD. 3.76 m³ Store size**
- **MgSO₄ - 150°C. 28.3% of winter SHD. 2.09 m³ Store size**
- **35wt% - 80°C. 22.8% of winter SHD. 12.23 m³ Store size**
- **35wt% - 150°C. 31.4% of winter SHD. 4.75 m³ Store size**
- **Zeolite-Y - 150°C. 28.3% of winter SHD. 9.74 m³ Store size**

- 14p/kWh = current electricity cost
- 5p/kWh = current average space heating cost
Integration of VFPC+TCES
Conclusion

• Huge potential for a VFPC + TCES system along side existing DHW and space heating solutions.
• Potential to dramatically reduce energy consumption from typical (dirty) sources.
• Feasibility study suggests the MgSO$_4$ and 35wt% (dehydrated to 150°C) pay for themselves after around 25 years of use.
• Potential to make huge social savings for the UK economy (in the order of +£460 million/year)

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