Consolidated composite with increased thermal conductivity and sorption capacity for heat-driven sorption cooling systems

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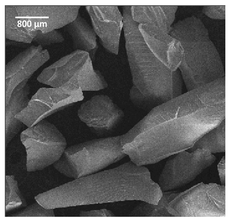
Introduction

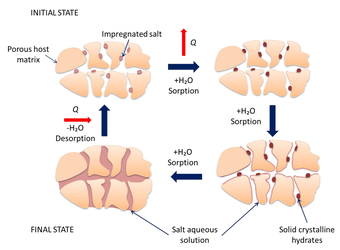
- Thermally-driven adsorption cooling systems are an emerging green technology.
- Adsorption cooling systems can operate through utilization of waste heat or solar thermal energy.
- Adsorbate (refrigerant):
  - **Water**
  - Ethanol
  - Methanol
  - Ammonia
- Adsorbent:
  - Silica gel
  - **Hygroscopic salt + porous support**
  - Zeolite
  - Activated carbon
- Challenge:
  - Require durable sorbent materials with high heat and mass transfer rates
- Objectives:
  - Develop composite adsorbent with tailored properties
  - Evaluate properties of $CaCl_2$ confined in silica gels with a range of pore size distributions
- Approach:
  - Hygroscopic salt confined in a silica gel porous host matrix
  - Organic binder, polyvinylpyrrolidone (10,000 and 40,000 MW), and graphite flakes added to improve heat transfer between adsorbent and heat exchanger surface

Adsorption cooling system lab-scale prototype



SEM image of silica gel

SEM image of S6-$CaCl_2$-PVP40



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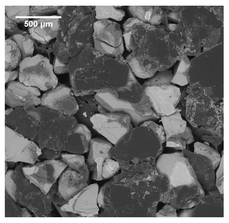


SEM image of S6-$CaCl_2$-PVP40-20%G

Sample Preparation

Composite S6-$CaCl_2$

- Mesoporous silica gel (SiliaFlash B60) with irregular grains (0.2-0.5 mm) and 6 nm average pore diameters was wetted with ethanol, and then soaked with concentrated aqueous $CaCl_2$ solution
- The mixture was dried in a fume hood and baked at 200 ˚C to produce 28 wt% $CaCl_2$ composite

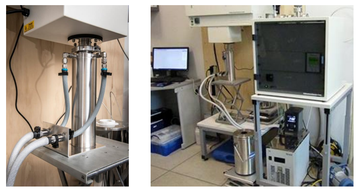
Composite S6-$CaCl_2$-PVP10 & PVP40

- Composites of silica gel, salt and organic binder (15 wt%) were oven baked in two steps (50 ˚C , 1 hour, followed by 200 ˚C for 1 hour)
- Graphite flake (5-50 wt%) was added to create sample series S6-$CaCl_2$-PVP40-G and S6-PVP40-G

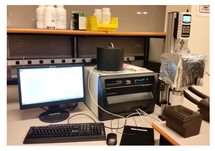
Composites containing silica gel organic binder and graphite flake

Methods

- Surface area and pore size analysis: N_2 isotherms, Micromeritics ASAP 2020
- Water sorption: Thermogravimetric sorption analyzer, Hiden Isochema IGA
- Thermal conductivity: Transient plane source (TPS) analyzer
  - Utilizes a thin foil double-spiral of nickel to resistively heat the sample and monitor the temperature change as a function of time
  - Measures thermal conductivity, thermal diffusivity and heat capacity



Thermogravimetric vapor sorption analyzer



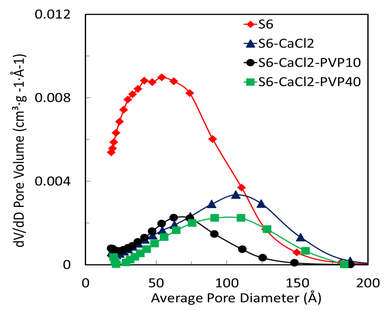
Transient plane source (TPS) thermal properties analyzer

Results

Surface area analysis

Pore volume, d*V*/d*D*, plots for mesoporous silica gels, silica-supported $CaCl_2$ and composite (28% wt salt) generated by BJH model fit of adsorption isotherm.

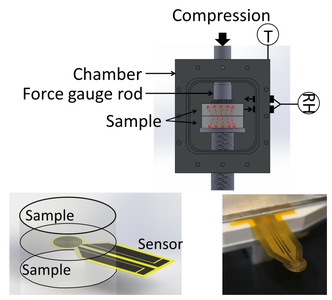
- Surface analysis confirms $CaCl_2$ is confined in silica gel pores
- Addition of $CaCl_2$ reduces the specific surface area (S_{BET}) and pore volume
- Increase average pore diameter of composite samples indicates the finest pores are preferentially filled



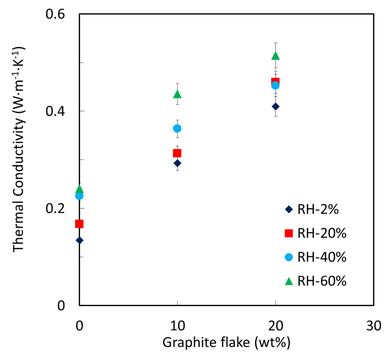
Sample	S_{BET} (m^2/g)	V (cm^3/g)	D (nm)
S6	494	0.77	4.8
S6-$CaCl_2$	134	0.31	7.0
S6-$CaCl_2$-PVP10	91	0.15	4.8
S6-$CaCl_2$-PVP40	102	0.21	6.1

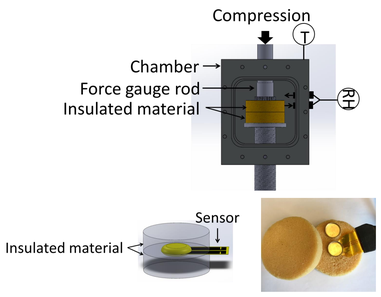
Thermal conductivity

Thermal conductivity of loose grain and composite materials with different amount of graphite flakes had been studied

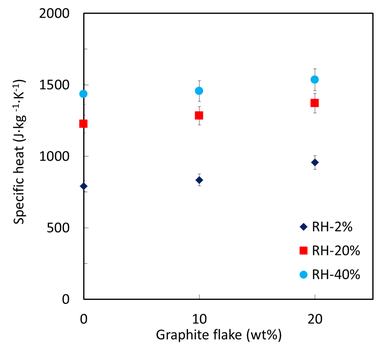


Schematic of transient plane source Thermal conductivity measurement



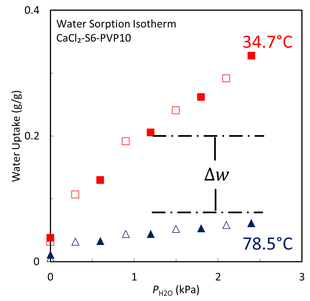


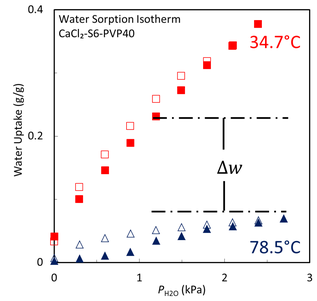
Schematic of transient plane source Specific heat measurement



Results

Water uptake





- Water sorption isotherms for $CaCl_2$ in silica gel consolidated with PVP-10 and PVP-40 binders
- Sorption cooling systems operate with temperature cycles and vapor pressure cycling from adsorbing to desorbing conditions

$$\Delta W = \frac{(madso_{rption} - mdeso_{rption})}{m_{dry\ adsorbent}}$$

Target conditions:

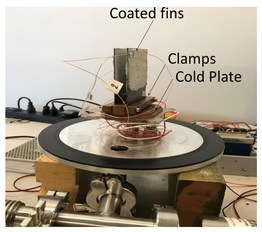
- Adsorption: 12 mbar, 35 ˚C
- Desorption: 42 mbar, 80 ˚C

- Water sorption isotherms $CaCl_2$ confined in silica gel consolidated with PVP40 binder and graphite flakes

Sample	H_2O uptake capacity (mass%)		Δw (dry weight of $CaCl_2$ and silica gel only)
	35°C, 1.1kPa	80°C, 2.3 kPa	
S6	0.54	0.20	0.34
S6-$CaCl_2$	0.33	0.10	0.22
S6-$CaCl_2$-PVP10	0.20	0.43	0.19
S6-$CaCl_2$-PVP40	0.23	0.33	0.23

Conclusion

- Fine pores of micro-porous silica gel are filled by $CaCl_2$.
- Adding graphite flakes to composite coating adsorbent improves thermal conductivity.
- Loose grain $CaCl_2$-silica gel samples have higher water uptake.
- 15 wt% binder (dead weight) in composite adsorbent has small effect on water uptake capacity.
- In future, water uptake of small scale coated heat exchanger will be studied.



Small scale pressure jump thermogravimetric analyser

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