Water adsorbent composites consolidated with graphite flakes for heat driven sorption cooling systems

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Laboratory for Alternative Energy Conversion (LAEC)

- HVAC and refrigeration systems
- Electronic and power electronics cooling
- Adsorption cooling system (ACS)
- Transport phenomena

A view of the SFU Surrey campus

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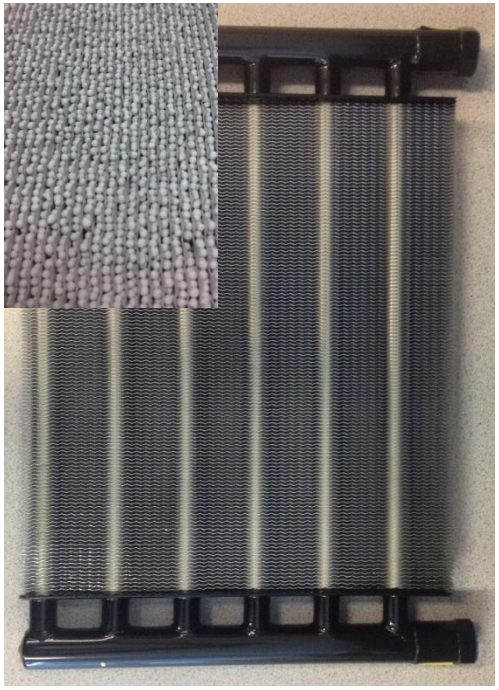
Adsorption Chiller Development

Adsorption system components

- ✓ Adsorber bed design (light-weight, high surface area heat exchanger)
- ✓ Low pressure evaporator
- ✓ Cycle performance

Materials development and characterization



- ✓ Tailored composite adsorbent
- ✓ Durability study over several cycles
- ✓ Mass and heat transfer enhancement of adsorbent

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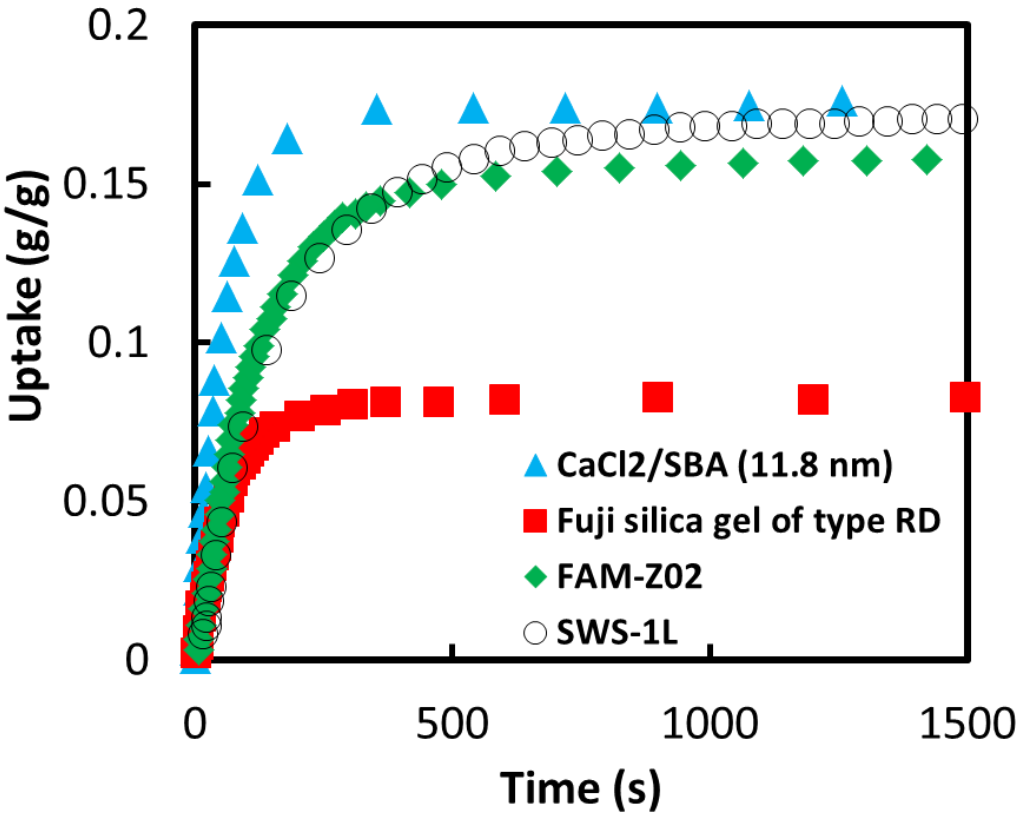
Research Objective

Objective

- Preparation and textural characterization of composite materials with high adsorption capacity which can be regenerated at low temperatures;
- Improving the heat transfer properties of adsorbent materials by adding thermally conductive additive

Developing high performance composite for adsorption cooling systems

Adsorbent Selection



Adsorbent	Average pore diameter (nm)
$CaCl_2$/SBA	11.8
Fuji RD	2.2
SWS-1L	15
FAM-Z02 (Silicoaluminophosphaste Zeolite)	0.38

Grain size: 0.8-0.9 mm
Vapor pressure: 1.23 kPa
Temperature drop: 60 to 35°C

Adsorbent pore size and geometry have great effect on sorption properties

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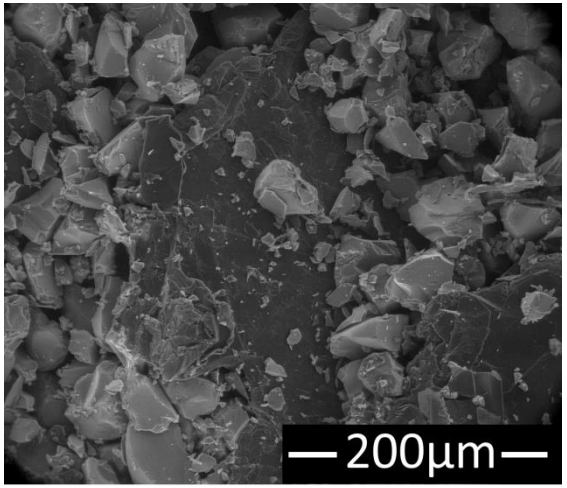
Composite Preparation

Composite SF6-$CaCl_2$-PVP40

- Composites of silica gel (40-63 µm), salt ($CaCl_2$) and organic binder (polyvinylpyrrolidone-MW 40,000) were oven baked in two steps (50 ˚C , 1 hour, followed by 200˚C for 1 hour)

- Graphite flake (5-20 wt%) was added to create sample series SF6-$CaCl_2$-PVP40-G (SF6 is stand for SiliCycle F60)

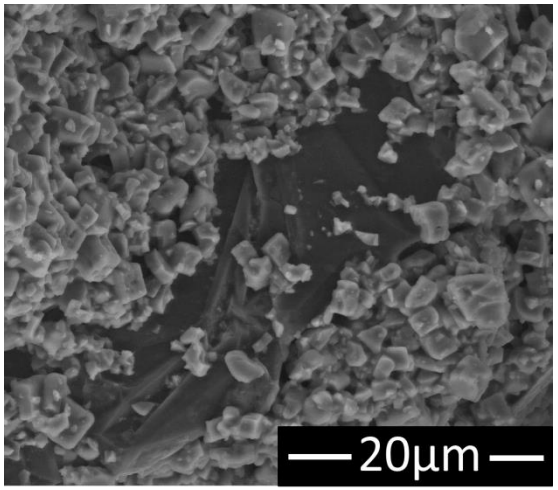


SF6-$CaCl_2$-PVP40-20%G

Composite FAM Z02-PVP40

- Composites of FAM Z02 and organic binder were oven baked in two steps (50 ˚C , 1 hour, followed by 200˚C for 1 hour)

- Graphite flake (5-20 wt%) was added to create sample series Z02-PVP40-G



Z02-PVP40-20%G

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Porosimetry

- Sorption of N_2 gas by the sample is measured at a series of pressures
- The isotherm shape reflects the sub-monolayer to multilayer condensation of N_2 on pore walls
- The isotherm can be fitted to determine the surface area and pore dimensions of the material

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Surface Area of Silica Gel based Composites

Silica gel	BET Surface area ($m^2 \cdot g^{-1}$)
SF6-$CaCl_2$-PVP4	105.82
SF6-$CaCl_2$-PVP40-10%G	88.76
SF6-$CaCl_2$-PVP40-20%G	65.77

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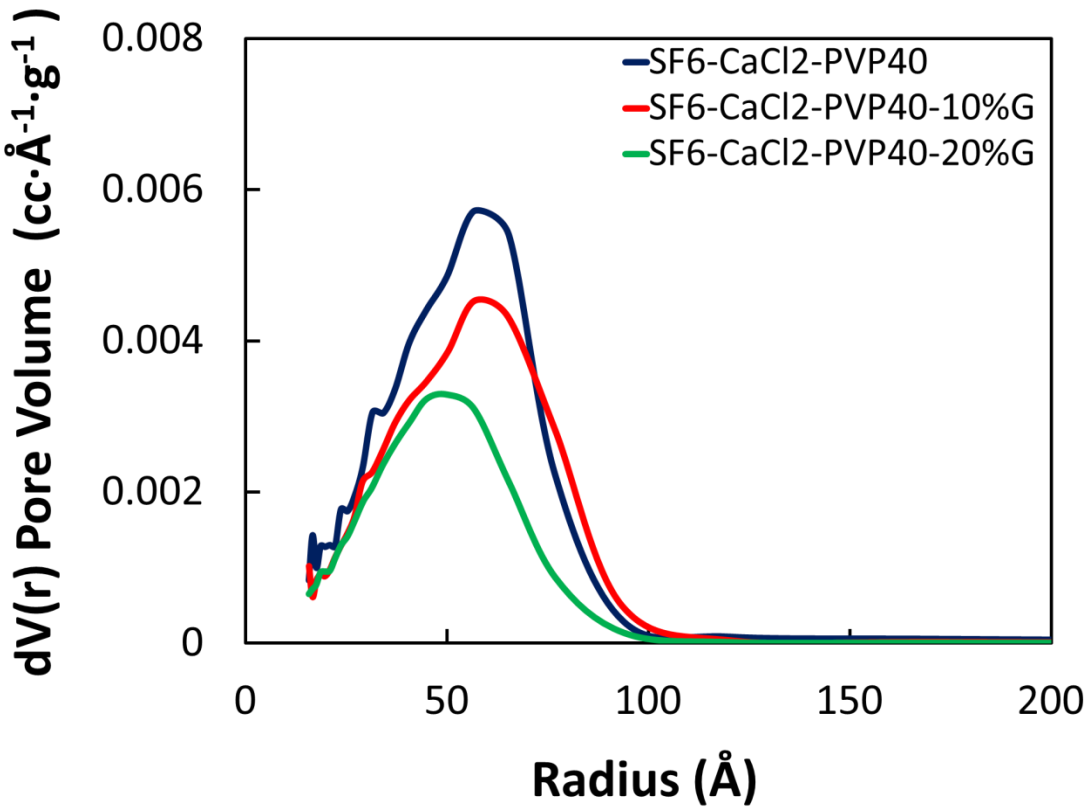
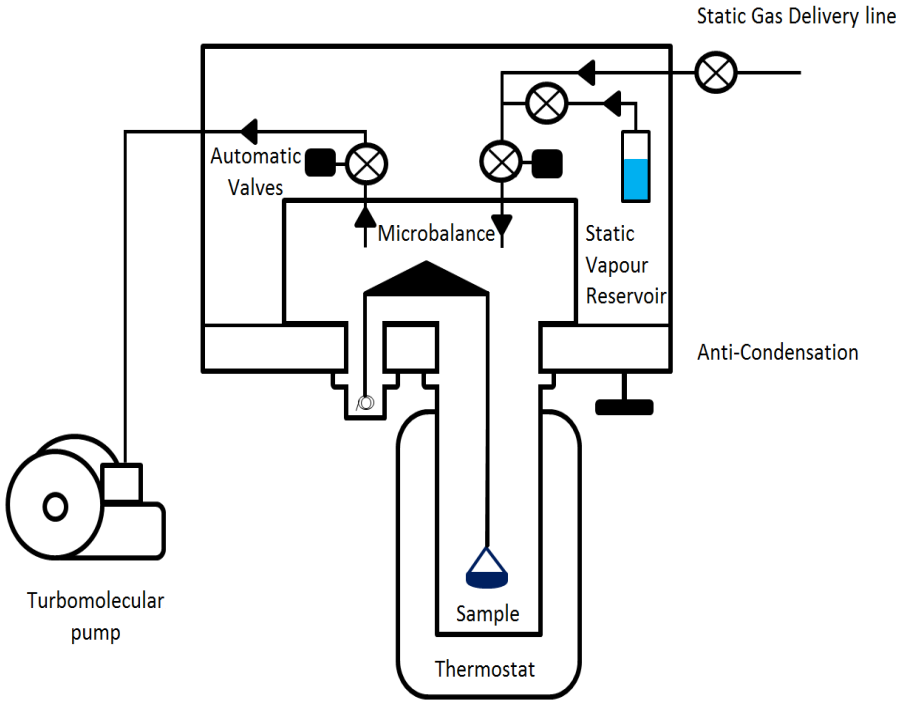
Pore Volume vs Pore Size Distribution



- Silica gel with 6 nm pores
- $CaCl_2$ partially filled silica gel pores

Sample	Pore volume (cc·g^{-1})	D (nm)
SF6-$CaCl_2$-PVP4	0.26	5.6
SF6-$CaCl_2$-PVP40-10%G	0.22	5.6
SF6-$CaCl_2$-PVP40-20%G	0.14	4.9

Thermogravimetric Sorption Analysis



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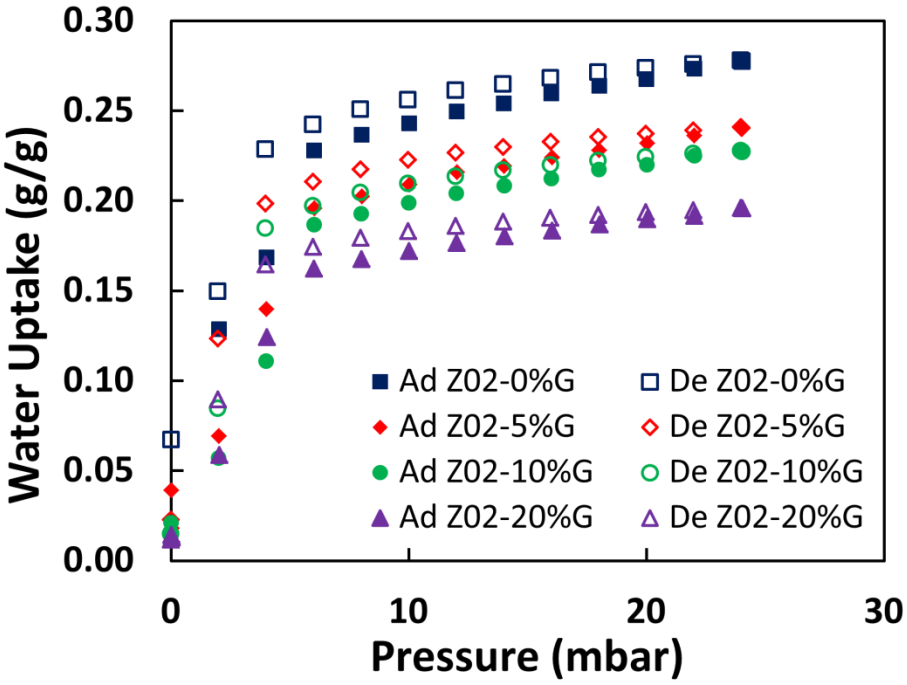
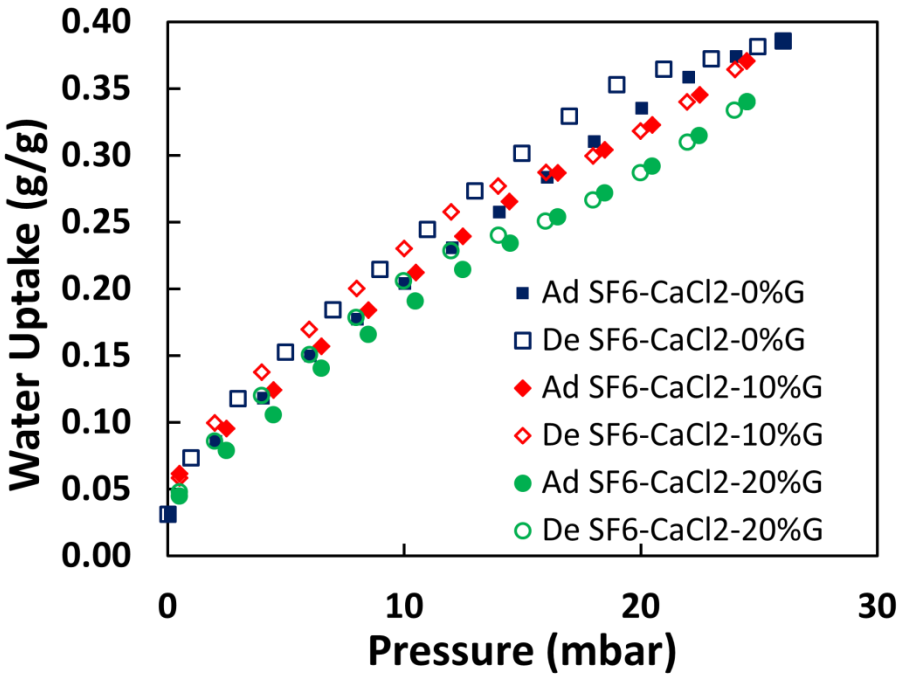
Sorption Isotherms of Consolidated Adsorbents





- Water sorption isotherms of graphite-doped consolidated adsorbent with different amount of graphite flakes content at 35°C
- Adding graphite flakes decrease sorption performance of composite adsorbent.

Sample name	w* (g/g)
Z02-0%G	0.24
Z02-10%G	0.20
Z02-20%G	0.17

20%

Sample name	w* (g/g)
SF6-$CaCl_2$-0%G	0.23
SF6-$CaCl_2$-10%G	0.23
SF6-$CaCl_2$-20%G	0.21

*** Water uptake at 35°C and 12 mbar water vapour**

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Adsorbent Thermal Conductivity

Effective parameters on thermal conductivity of adsorbent

- Water content
- Presence of thermally conductivity additives or/and binder
- Experiment conditions (Relative humidity (RH), and temperature)

Previous Studies on Thermal Conductivity

Adsorbent	Thermal conductivity $W \cdot m^{-1} \cdot K^{-1}$	Measurement method and experiment condition
Calcined silica gel (KSK)/$CaCl_2$ [1]	0.1-0.5	- Transient hot wire method - Water content (0-0.8 g/g) - Temperature 16-27°C
Consolidated silica gel (KSK)/$CaCl_2$ [2]	0.12-0.16	- Transient hot wire method - Air pressure: 10-1000 mbar - Binder: 20%wt aluminium hydroxide
Consolidated silica gel [3]	0.24-0.26	- Guarded-hot plate apparatus - Temperature: 35-50°C - Contact pressure: 0-90 bar - Polyvinylpyrrolidone used as a binder (15 wt%)

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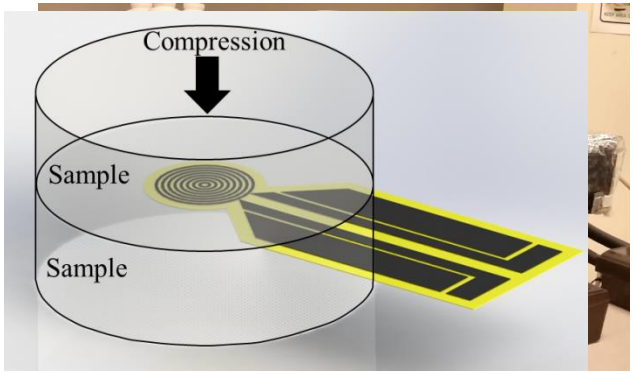
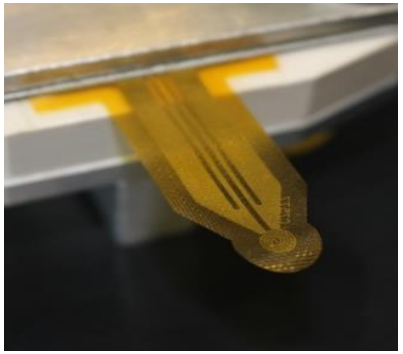
1. Y. Y. Tanasheva, Yu. I. , Aristov, *J. Eng. Phys. Thermophys.*, vol. 73, no. 5, pp. 876–883, 2003
2. A. Freni, M. M. Tokarev, G. Restuccia, a. G. Okunev, and Y. I. Aristov, *Appl. Therm. Eng.*, vol. 22, pp. 1631–1642, 2002
3. Sharafian, K. Fayazmanesh, C. McCague, and M. Bahrami*Int. J. Heat Mass Transf.*, vol. 79, pp. 64–71, 2014

Transient Plane Source (TPS)

- 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.
- transient plane source method and theory in accordance with ISO Standard 22007-2.2
- Uncertainty of equipment is **±0.05**.



Sample arrangement schematic in TPS 2500S Transient plane source set-up



Double spiral “hot disk” nickel sensor

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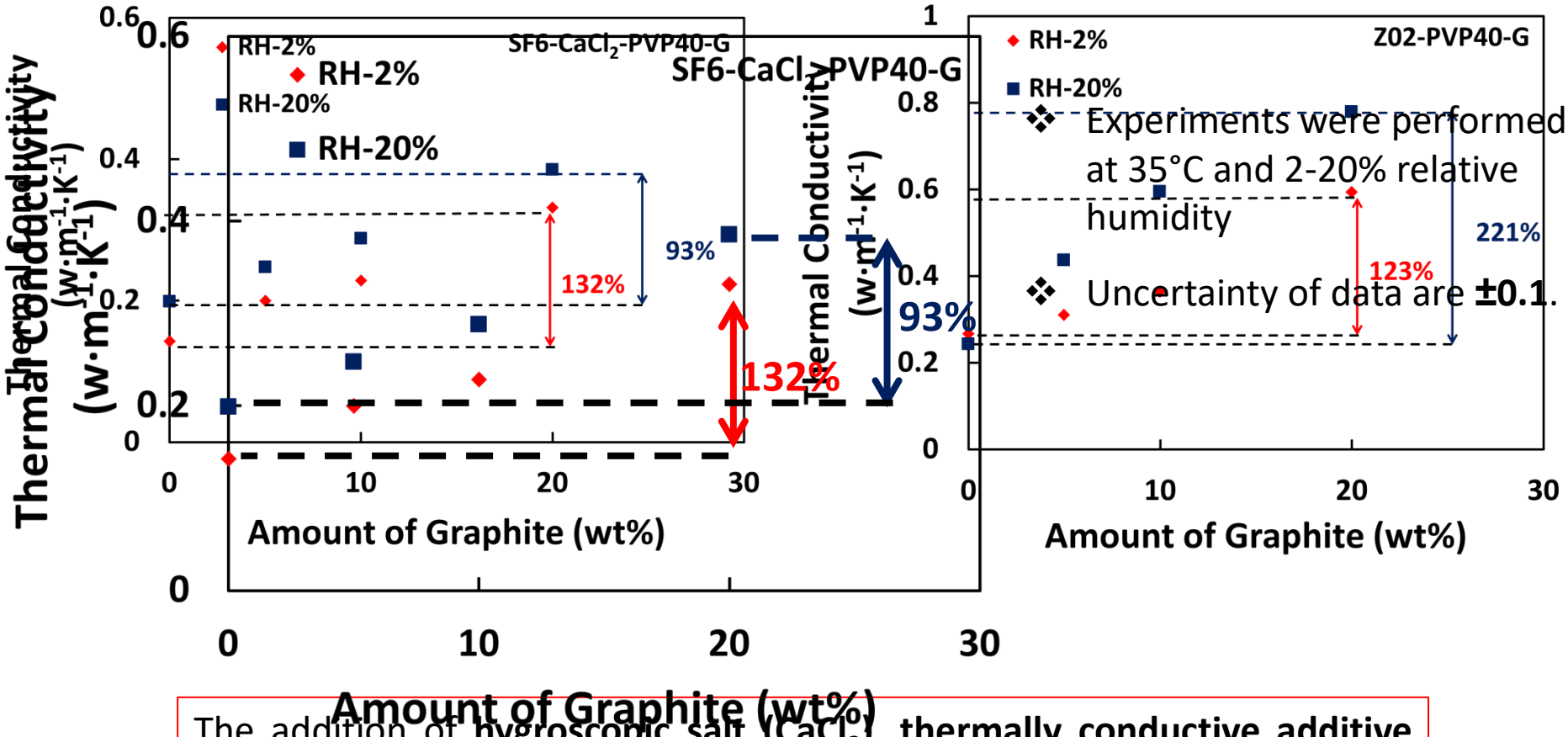
Composite Thermal Conductivity



The addition of **hygroscopic salt ($CaCl_2$)**, **thermally conductive additive (graphite flakes)**, and implementation of **humidity** during measurement have impact on the thermal conductivity of consolidated composites adsorbent.

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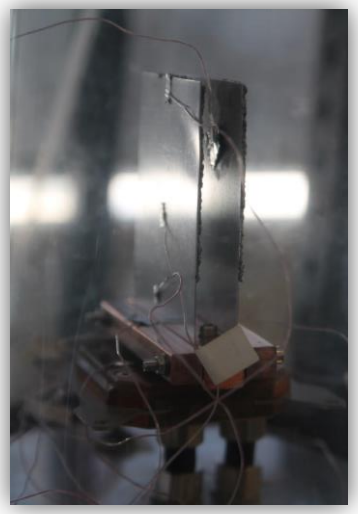
Conclusions

- The water uptake of samples with thermally conductive additives is reduced, however when the weight of the active (adsorbing) material in the composite is considered, the effect on water uptake is minimal.
- Thermally conductive additive can improve heat transfer through consolidated adsorbent while there is a small drop in water uptake.
- Thermal diffusivity of adsorbent materials are under study at different RH%.

Conclusions

- Fin tester set-up built for graphite sheets coated by adsorbent.



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Amount of Each Active Material

Sample name	Adsorbent	PVP	Graphite flakes
S-$CaCl_2$-0%G	4 g, 1.71 g	1 g	-
S-$CaCl_2$-10%G	4 g, 1.71 g	1 g	0.74 g
S-$CaCl_2$-20%G	4 g, 1.71 g	1 g	1.67 g
Z02-0%G	4 g	1 g	-
Z02-5%G	4 g	1 g	0.26 g
Z02-10%G	4 g	1 g	0.5 g
Z02-20%G	4 g	1 g	1.25 g

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