Capacitance-resistance-modeling of sorption thermal energy storage systems

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Capacitance Resistance Model (CRM)

- A lumped-parameter capacitance resistance model (CRM) is developed to design, optimize, and control thermal energy storage (TES) systems, which offers a reasonable trade-off between accuracy and computational time.

- Thermal network of the CRM:
  - Heat transfer resistance + Resistance
  - Thermal mass + Capacitance
  - Sorption, evaporation, and condensation energy + Current sources
  - Inlet temperatures of HTF, coolant, and chilled water + Voltage sources

- Assumptions:
  - Thermodynamic equilibrium between sorbent and sorbate
  - Uniform temperature and solute distribution inside sorbent
  - Uniform sorbent size
  - Negligible heat loss

- Equations:
  - Heat balance of the sorbent, evaporator and condenser
  - Mass balance of sorbate
  - Sorption equilibrium equation

- The kinetic properties of the sorbent bed, including the mass diffusivity (D_ads) and characteristic energy (E_s), which are obtained from our in-situ mass measurement of the full-scale sorbent bed, are fed to the proposed CRM.


Results

- A CRM is developed that significantly simplifies the assessment of the impact of materials, components, and processes on overall performance metrics and enables real-time control of the thermal storage system based on demand, supply, and state-of-charge of sorption thermal energy storage systems.

- The present model is successfully validated with the experimental data, which was collected from a custom-built S-TES in our lab, under various operating conditions.

- For heat storage (HS) coated FAM-202 S-TES, the material-based energy storage density (ESD) of 0.934 MJkg⁻¹ (0.607 GJm⁻³) and averaged specific power (SP) of 504 Wkg⁻¹ are measured.

- For cold storage (CS) coated FAM-202 S-TES, the material-based ESD of 0.493 MJkg⁻¹ (0.320 GJm⁻³) and averaged SP of 267 Wkg⁻¹ are obtained.

- Considering the optimum discharge-to-charge time of 1.6, a maximum SP of 1.207 and 335 Wkg⁻¹ are measured for heat storage, HS, and cold storage, CS, coated S-TES, respectively.

Experimental Study

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Nomenclature

- $T$ (°C): Temperature
- $Q$ (W): Heat flow rate
- $t$ (s): Time
- $m$ (kg): Mass
- $C$ (J/kg°C): Thermal capacitance
- $R$ (W/K): Resistance
- $D$ (m²/s): Diffusion coefficient
- $E$ (J/kg): Energy
- $S$ (J/K): Specific power
- $A$ (m²): Area
- $h$ (W/m²K): Overall heat transfer coefficient
- $f$ (kg/s): Flow rate
- $z$ (mm): Thickness
- $L$ (m): Length
- $T_s$ (°C): Sorbent bed temperature
- $T_c$ (°C): Condenser temperature
- $T_e$ (°C): Evaporator temperature
- $P$ (W): Power
- $G$ (kJ/kg): Activation energy
- $K$ (kJ/kg°C): Equilibrium water uptake
- $S$ (W/kg°C): Specific power

- $R_{sorb}$ (W/K): Resistance between the sorbent bed and the environment
- $R_{cond}$ (W/K): Resistance between the condenser and the coolant fluid
- $R_{ch}$ (W/K): Resistance between the condenser and the sorbent bed
- $C_s$ (J/K): Thermal capacitance of the sorbent bed
- $C_c$ (J/K): Thermal capacitance of the condenser
- $C_p$ (J/kg°C): Specific heat capacity
- $P_{disch}$ (W/kg): Discharge power
- $P_{chrg}$ (W/kg): Charging power
- $E_{esd}$ (MJ/kg): Energy storage density
- $t_{disch}$ (h): Time of discharging
- $t_{chrg}$ (h): Time of charging
- $SP$ (W/kg): Specific power