Experimental Design and Preliminary Analysis of a Mars CO_2 Rapid Cycle Adsorption Pump

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Mars In-Situ Resource Utilization

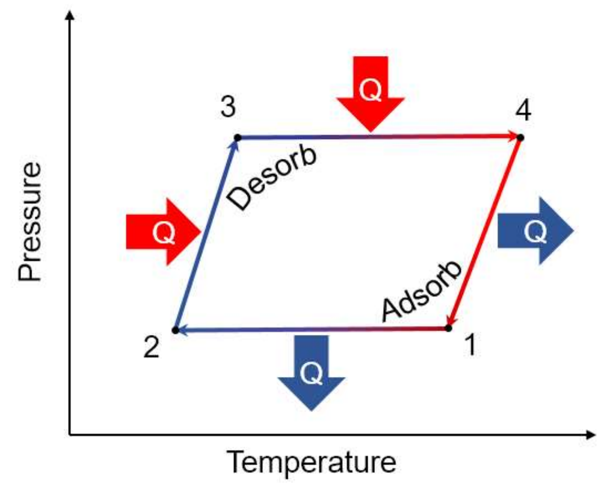
- Use atmospheric CO_2 for propellant production
- Environment
  - 95% CO_2, 5% N_2, Ar, etc. at 5-9 Torr (~0.1 psia)
  - Day: 180-270 K
  - Night: 130-170 K

What are the options?

- Three ways to acquire Martian CO_2
  - Direct compression - High energy, lots of moving parts
  - Cryofreezer - Low temperatures, cycle limitations
  - Adsorption - High mass, rate limited
- Adsorption can be reliable, utilize waste heat and environmental heat sinks

What is adsorption?

- Sorbents are microporous
- Certain gas species “stick” to surface
- Change temperature and pressure to adsorb or desorb CO_2
- Control flow in / out of a fixed volume yields a pump (batch process)



“Rapid” Cycling Advantages

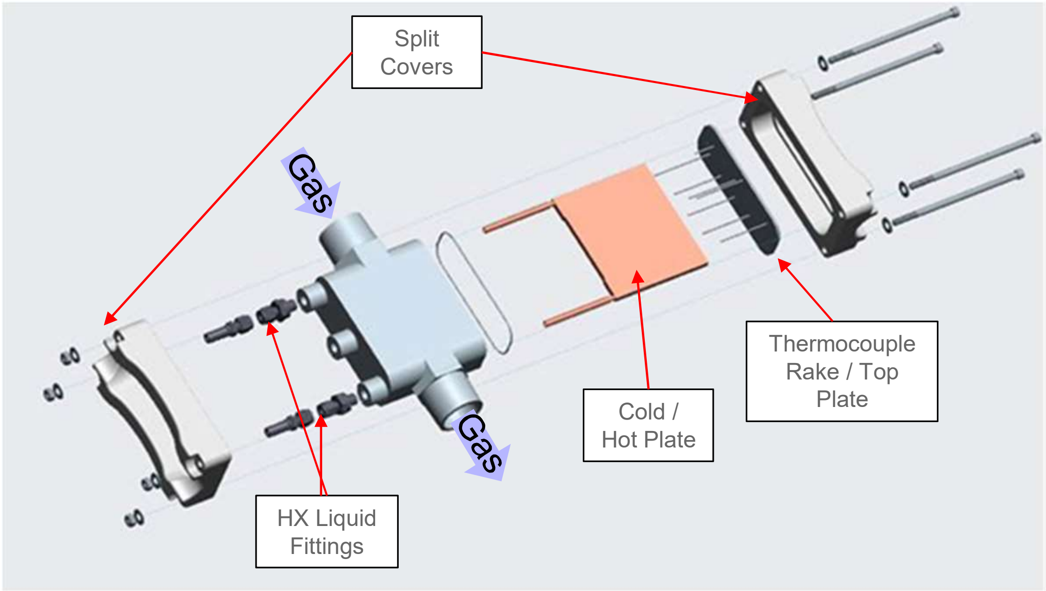
- Original Mars adsorption concepts cycled over whole day
  - Leverages diurnal temperature variation
  - But: still requires active mechanisms for heating and cooling
- Rapid (~minutes-hours) cycling could reduce mass by more effectively utilizing sorbent mass

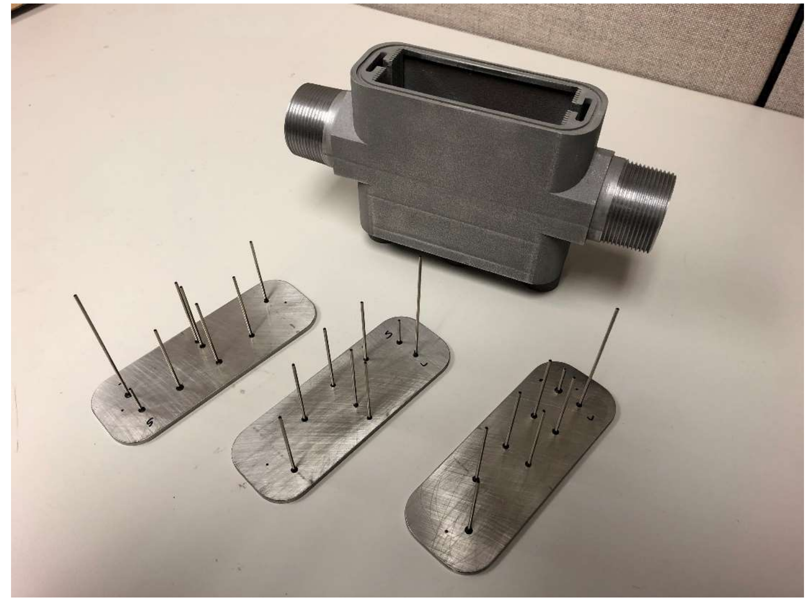
Rapid Cycling Challenges

- Heat transfer in sorbent mass (low conductivity, packed bed pellet contact)
- Mass transfer (CO_2 and inert gases must be moved in and out)
- Parasitic thermal masses (plumbing, valves, heat exchangers)
- Source of heating and cooling

RCAP Test Article

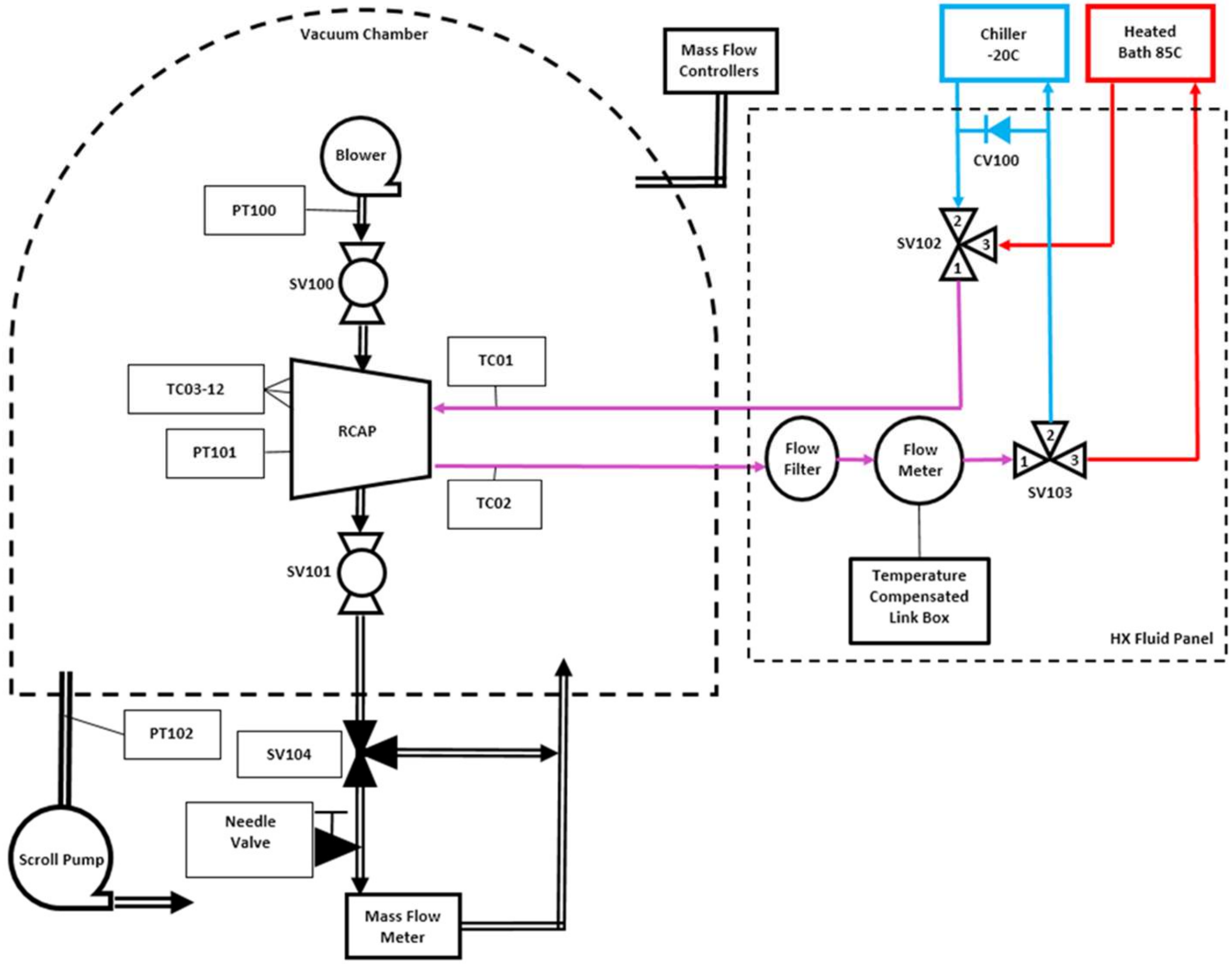
- Central heat exchanger plate, liquid (FC-770 Fluorinert)
- Flow-through design
- Designed to gather data for heat transfer modeling
  - Simple "plane wall" geometry
  - Flexible sorbent bed thickness
  - Bed instrumented with thermocouples

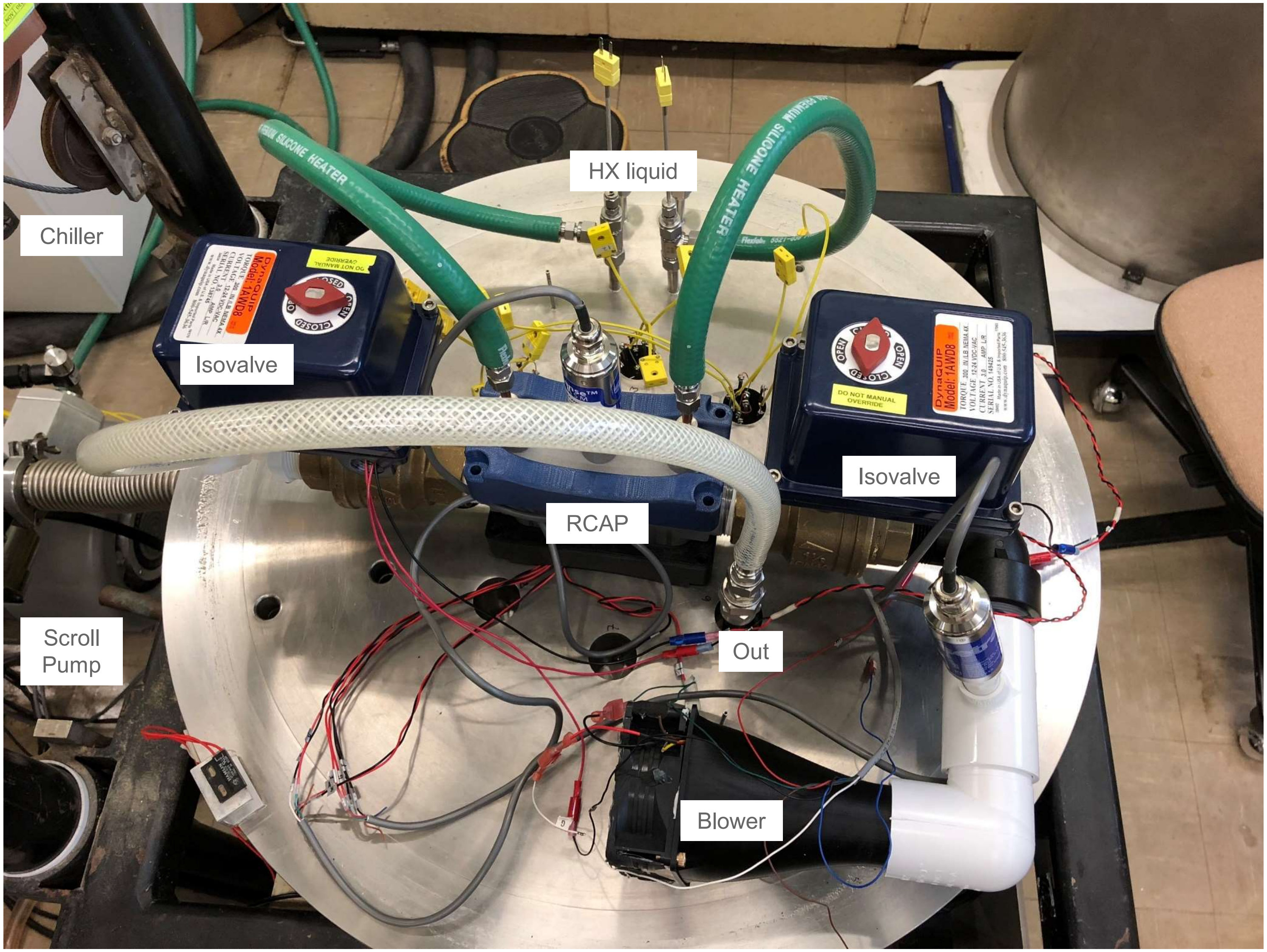




Test Setup

- Chamber atmosphere managed by pressure controller upstream of scroll pump
- Hot / cold heat exchange liquid switched by 3-way valves
- Pump output routed to mass flow meter or back to chamber



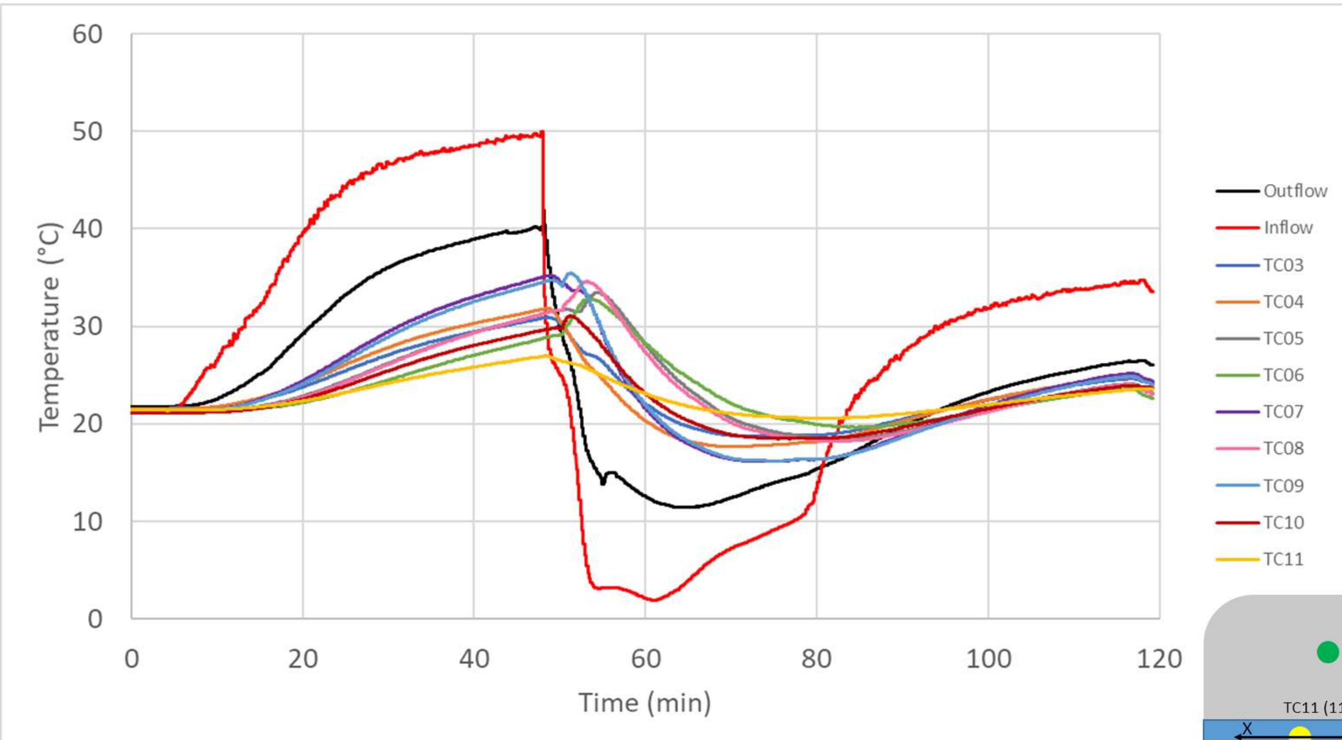

HX liquid
Chiller
Isovalve
Isovalve
RCAP
Scroll
Pump
Out
Blower


Hot bath

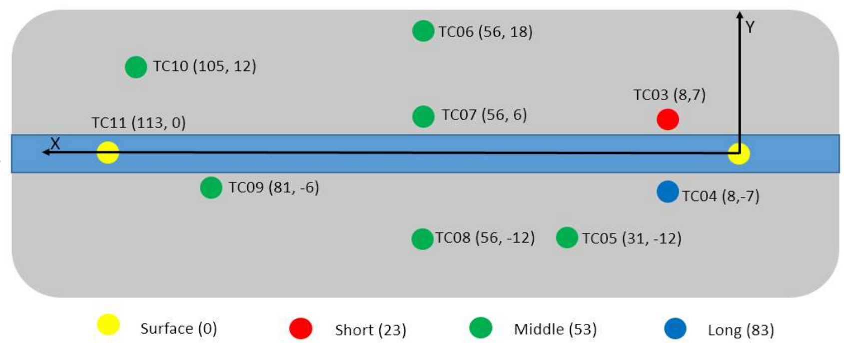
Test Parameters

- Sorbent bed thickness
    - Heat transfer in packed bed, sorbent utilization
- Sorbent pellet size
    - Heat transfer, mass transport, packing efficiency
- Atmosphere
    - Pure CO_2 vs Mars simulated - Residual gas effects

Large bed, large pellet, 30 minute hot / cold, CO_2

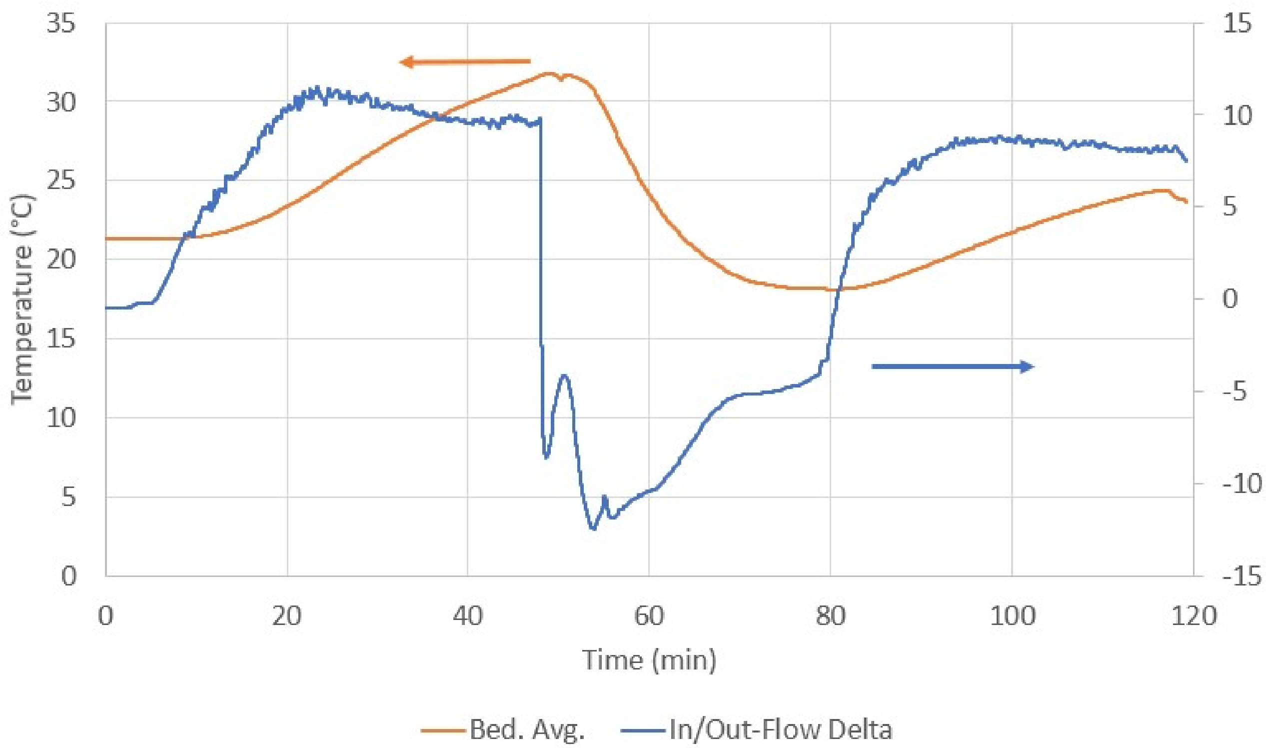


- TC07, 09 closest to plate track plate temp best
- Temp. bump when adsorption starts
- TC05, 08 lag due to location, but temp. "catch up"
  - Mass transfer better than heat transfer?

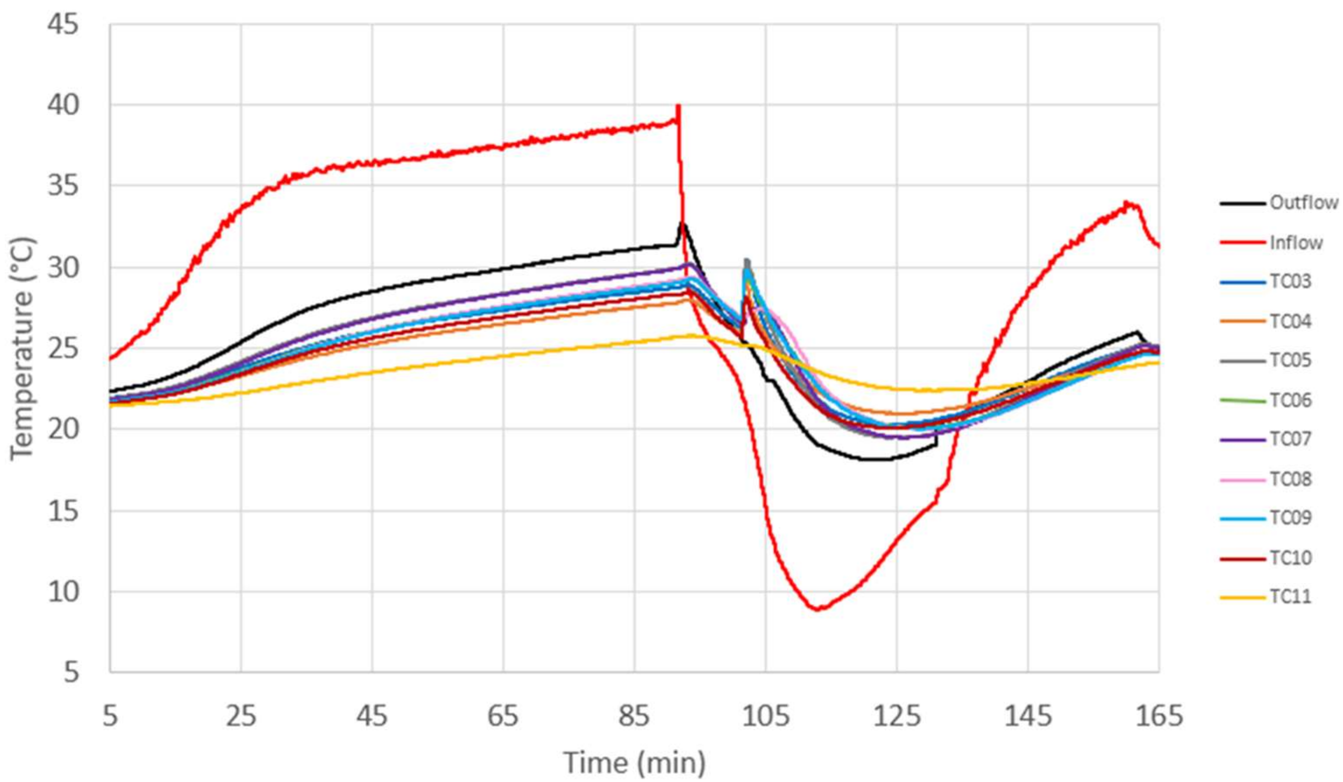


Average bed temperature, HX plate inflow / outflow

- Overall bed temperature swing only 5-6° C
- ~10° C temperature delta across plate
- Bad chiller performance

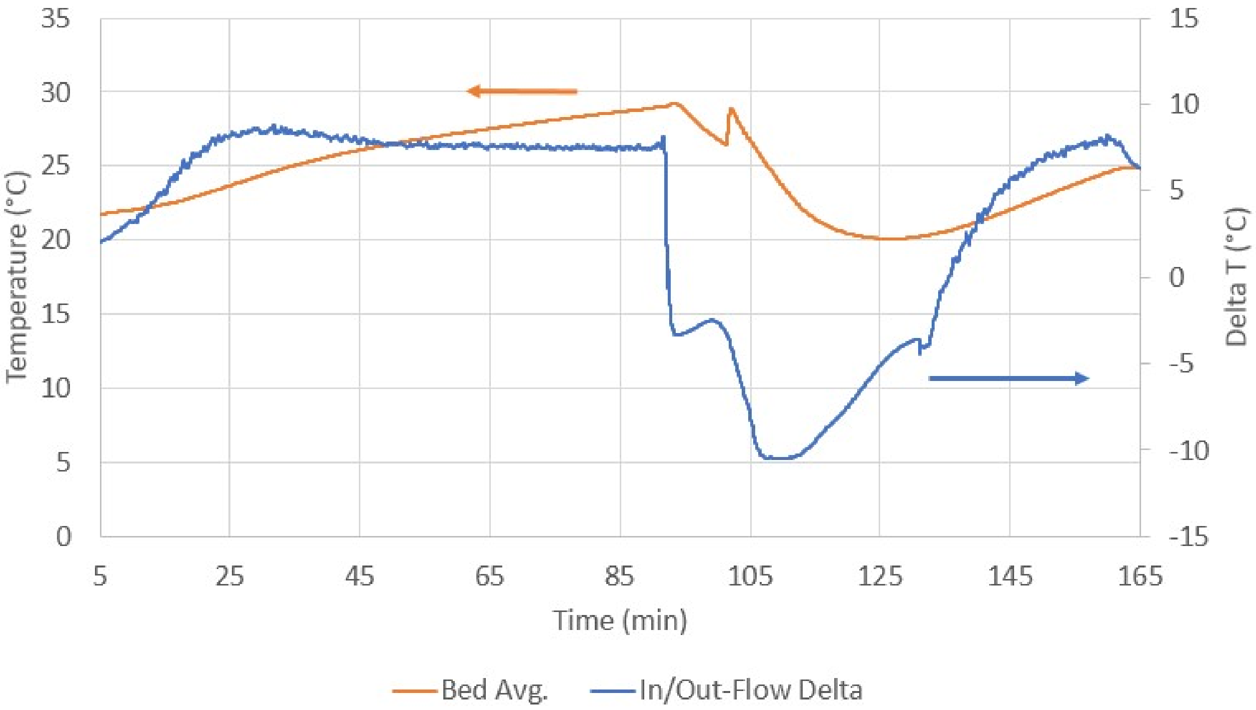


Small bed, medium pellet, 30 minute hot / cold, CO_2



- Bed temperatures less distinguished
- More noted adsorption temperature spike

Average bed temperature, HX plate inflow / outflow



- Bed temperature more affected by adsorption start
- Similar delta T across inflow / outflow
    - Plate / flowrate limited?

Tentative observations

- Heat transfer is even more challenging than anticipated
- Driving temperatures are critical and related to architecture choices
- Heat exchanger geometry may help, but has issues
- Trade of heat exchanger mass vs. bed mass, vs. average bed temperature

Forward Work

- Improve test setup
  - Correct poor chiller performance
  - Better pumps
- Complete test matrix
  - Full bed / pellet size comparison
  - Mars gas comparison
- Two-stage
- Full modeling