

# 4BCO2 Model Validation and Comparisons Between Simulation and Ground and ISS Telemetry Data

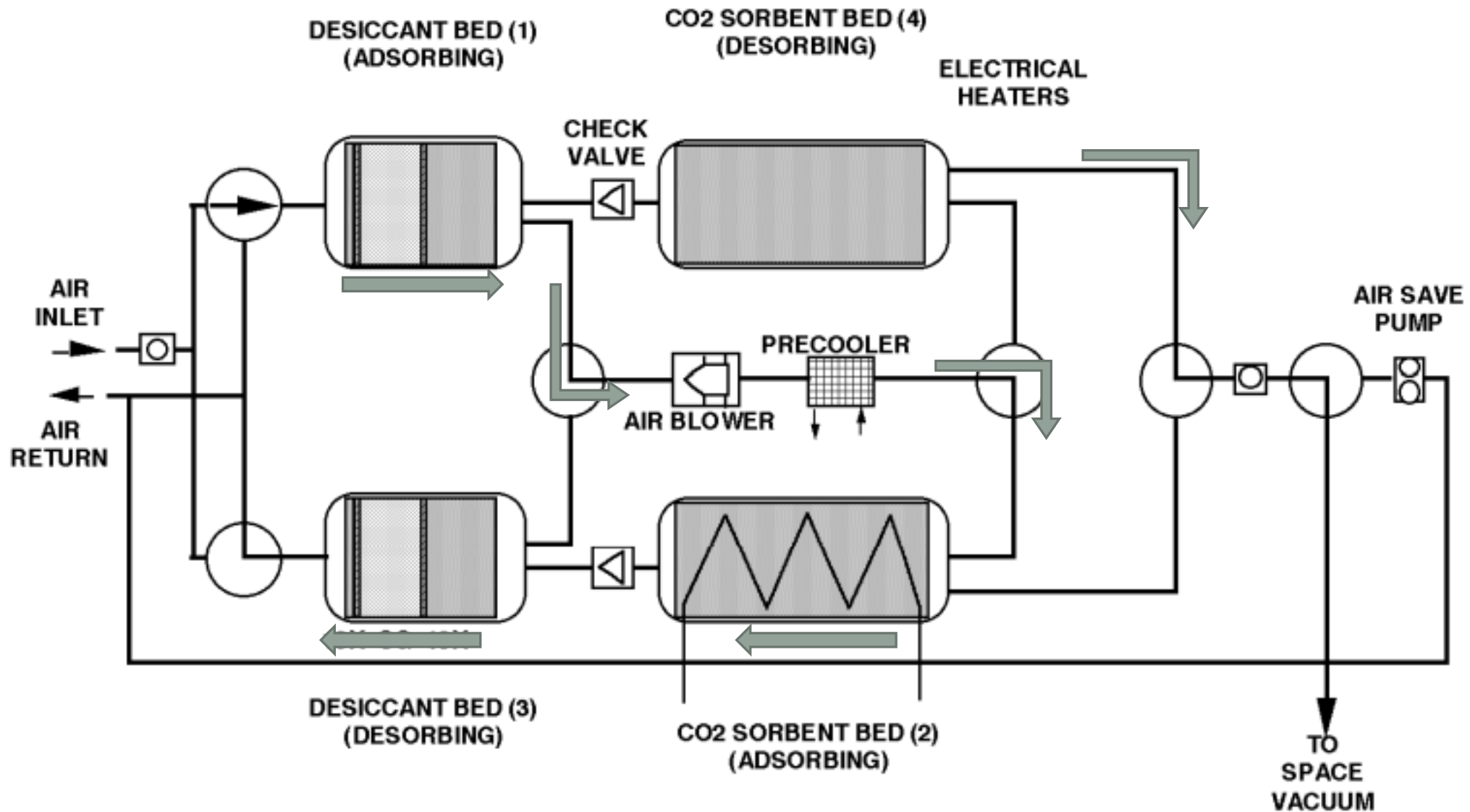
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LARISSA LAGRIA

# 4BCO<sub>2</sub> System

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- ❑ Multiple personnel working and living aboard the ISS = multiple kg of CO<sub>2</sub> produced per day
- ❑ Zeolite dusting, performance, and reliability issues observed over the past 20 years
- ❑ 4BCO<sub>2</sub> improves upon the current CDRA iteration



General schematic of the CO<sub>2</sub> removal hardware, applicable towards the Linus ground hardware, the 4BCO<sub>2</sub> system on orbit, and CDRA

# Current Simulation Model

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- ❑ Runs on the previously established model
- ❑ Runs to convergence criteria based on the average loading of H<sub>2</sub>O in the Adsorbing Desiccant or Desorbing Desiccant beds
- ❑ Last update prior to the end of the Fall 2021 session resulted in capacity to plot data vs simulation temperature, partial pressure, and delta pressure for Linus Ground Test 34 only

# Simulation Model Validation and Modifications

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- ❑ Linus Ground Tests 31, 32, 33, and 34 ran with different blower RPM = different inlet flow rates
- ❑ Validated simulation model against ground test data from Linus Tests 31, 32, and 33
  
- ❑ Modifications:
  - ❑ Vacuum pressure data from Linus Tests 31-34 had to be smoothed out and imported into the Matlab desorbing adsorbent bed wrapper using a COMSOL results table
  - ❑ CO<sub>2</sub> flow rates entering and exiting the desiccant and adsorbing adsorbent beds were updated and exported with completion of each half cycle prior to convergence
  - ❑ Antoine's equation vapor pressure calculations were replaced with Hardy vapor pressure calculations

# Ground Test Removal Rates

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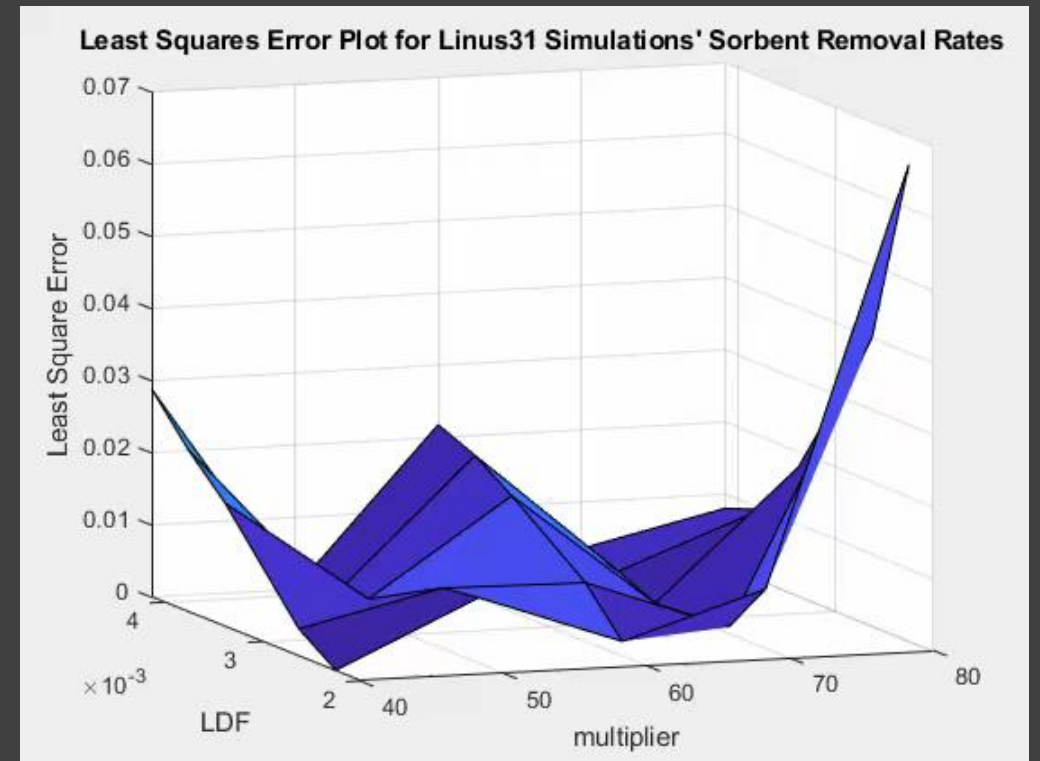
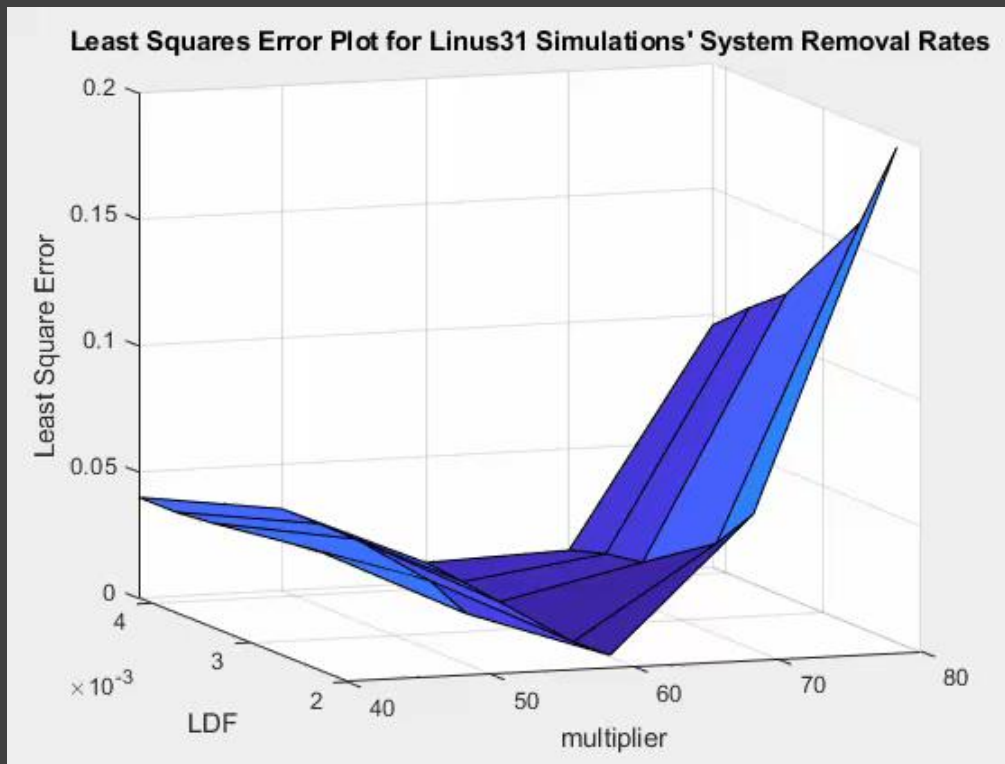
	Linus 31	Linus 32	Linus 33	Linus 34
Inlet CO2 Partial Pressure (mmHg)	2.01	2.01	2.01	2.01
Inlet Dew Point (F)	53.0	52.1	53.0	53.0
Inlet Temperatures (F)	56.0	56.0	56.0	56.0
Blower RPM	150000	145000	140000	135000
Air Flow Rate (SCFM)	27.7	26.7	25.6	24.5
4BMS In/Out Removal (kg/day)	4.97	4.84	4.67	4.46
Sorbent Removal (kg/day)	4.96	4.88	4.76	4.59

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# Model Parameter Minimization

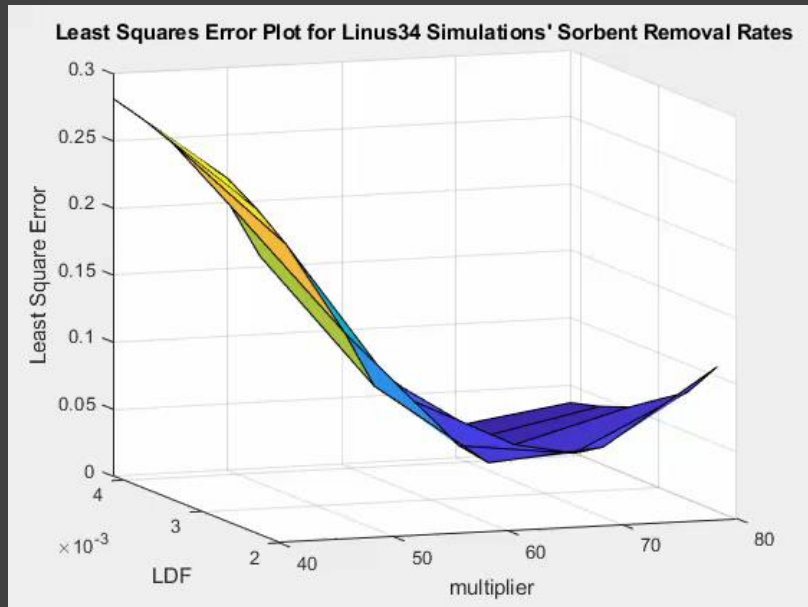
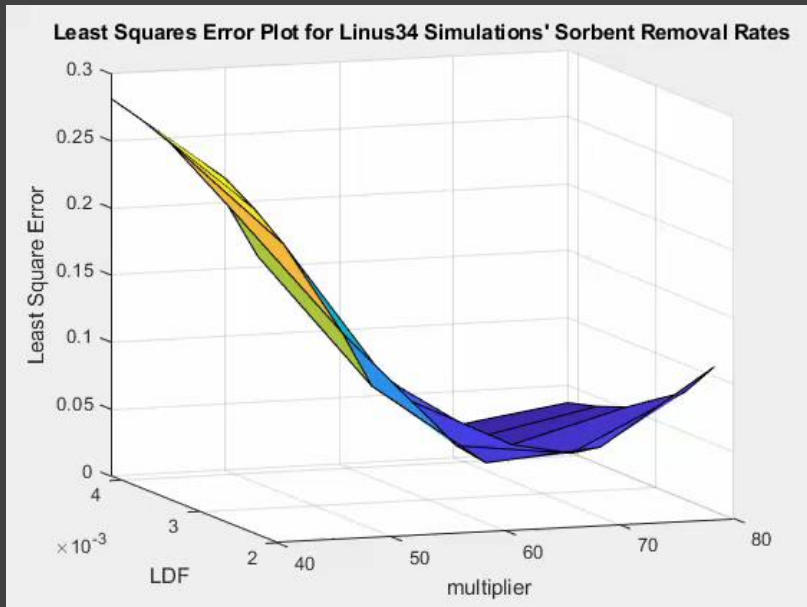
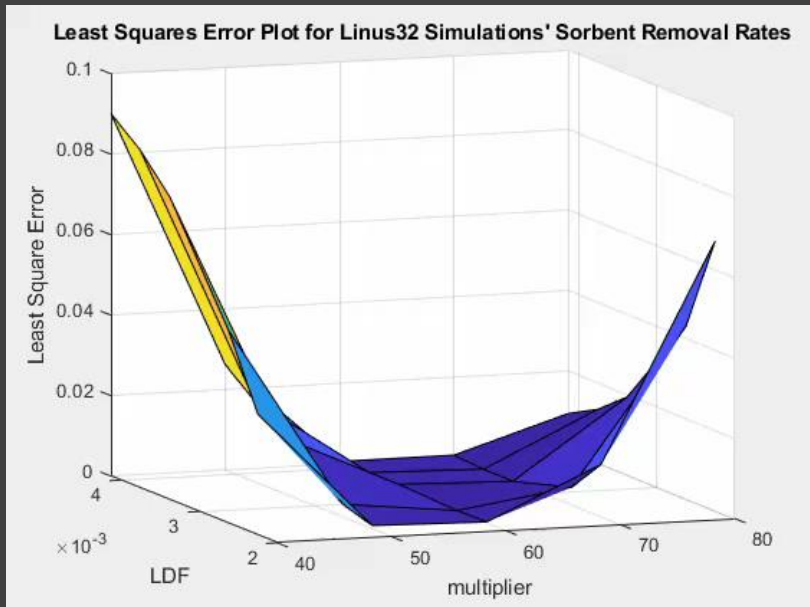
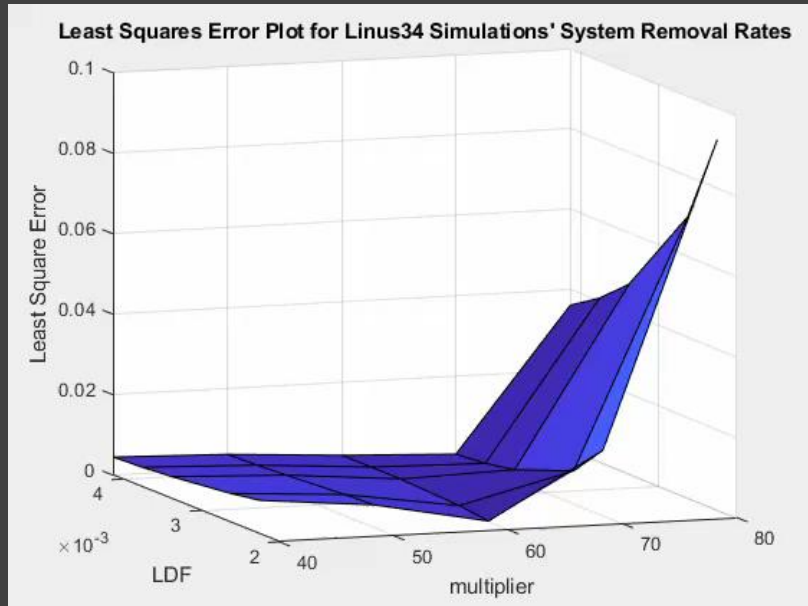
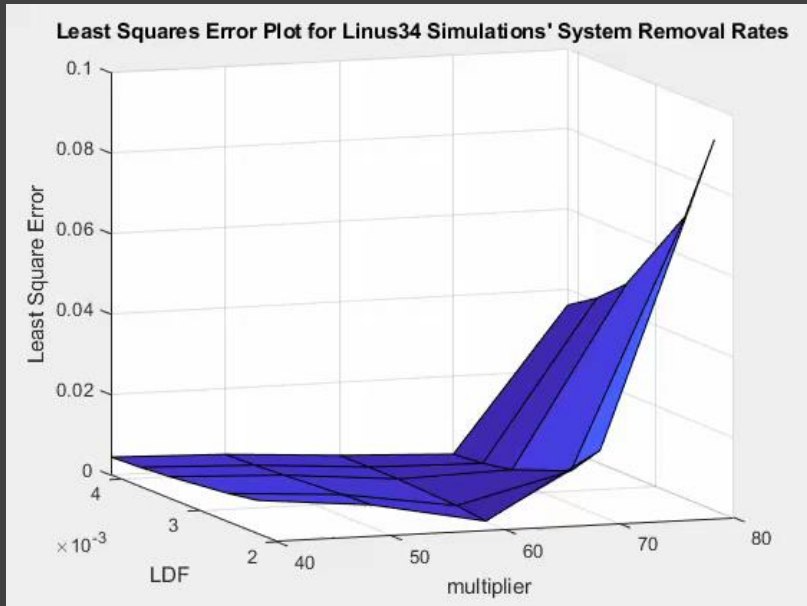
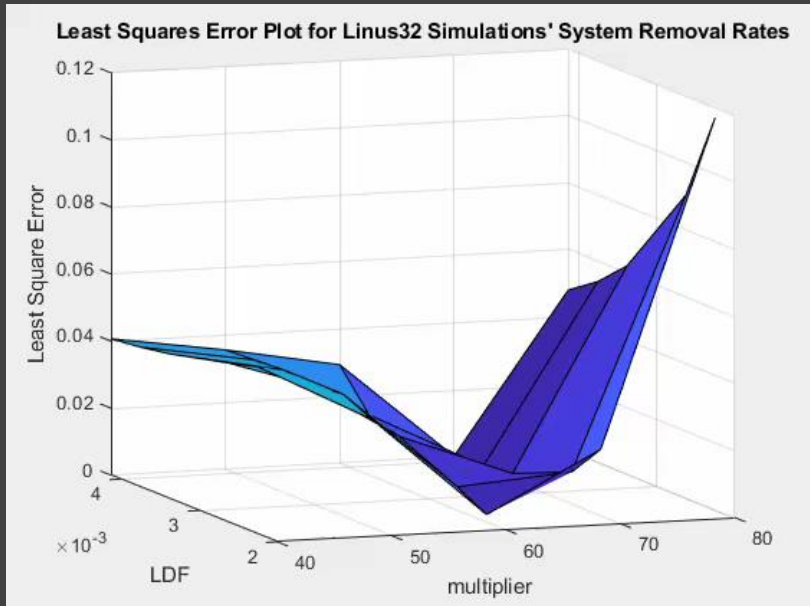
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- ❑ System and sorbent removal rates were determined using the exported CO2 flow rates
- ❑ Tested a range of linear driving force (LDF) and adsorbing adsorbent bed dispersion correction factor multipliers
- ❑ Experimentally determined in independent breakthrough tests: LDF of 0.003375 (LDF #1)
- ❑ Squared error between the simulation removal rate and the Linus Ground Tests' recorded removal rates were plotted for each pair of LDF and multiplier for each Linus Tests 31, 32, 33, and 34
- ❑ Results of minimization tests indicated that LDF of 0.004125 (LDF #2) and multiplier of 70 results in the minimum squared error for Linus 32-34 system and sorbent tests

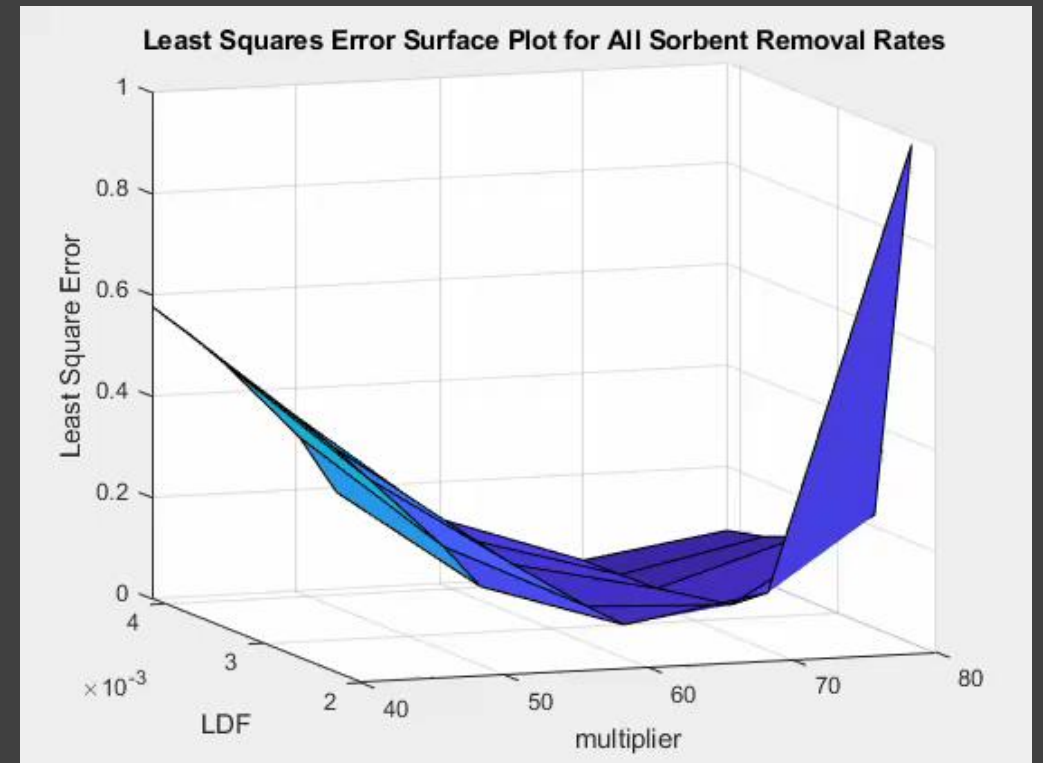
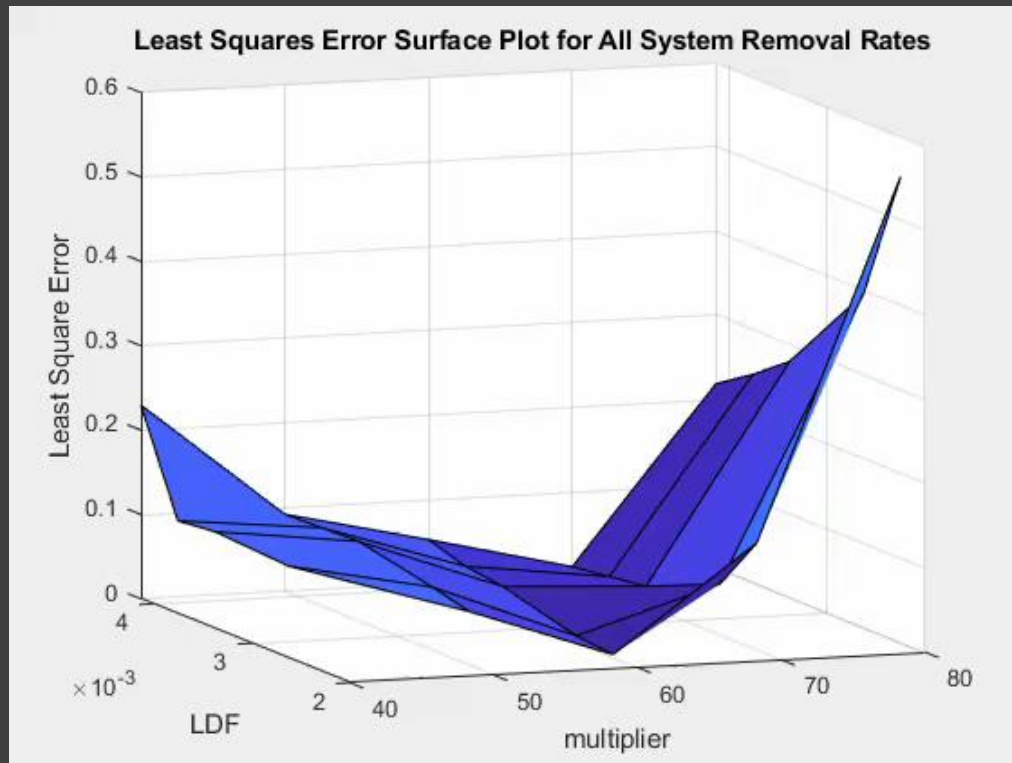


- ❑ Least squares error plots for Linus 31 system and sorbent removal rates
- ❑ Different LDF and multiplier result in minima compared to the rest of the Linus minimization tests
- ❑ All 8 plots resemble folded paper, with some valley to indicate minima





# Plots: Minimization, Summed Linus Tests

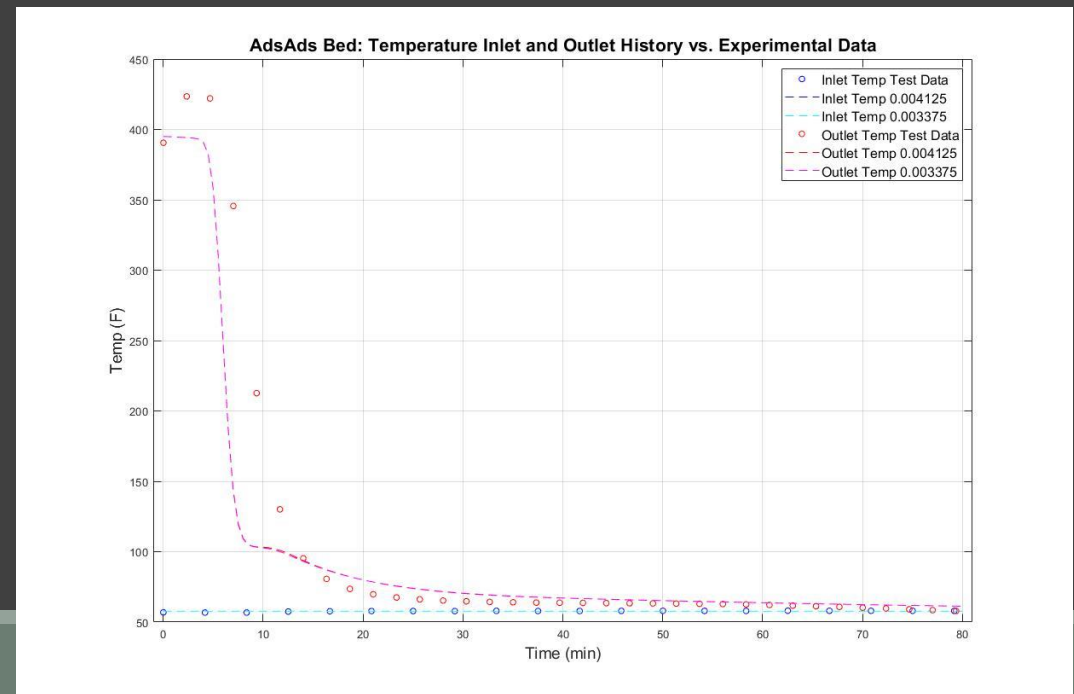
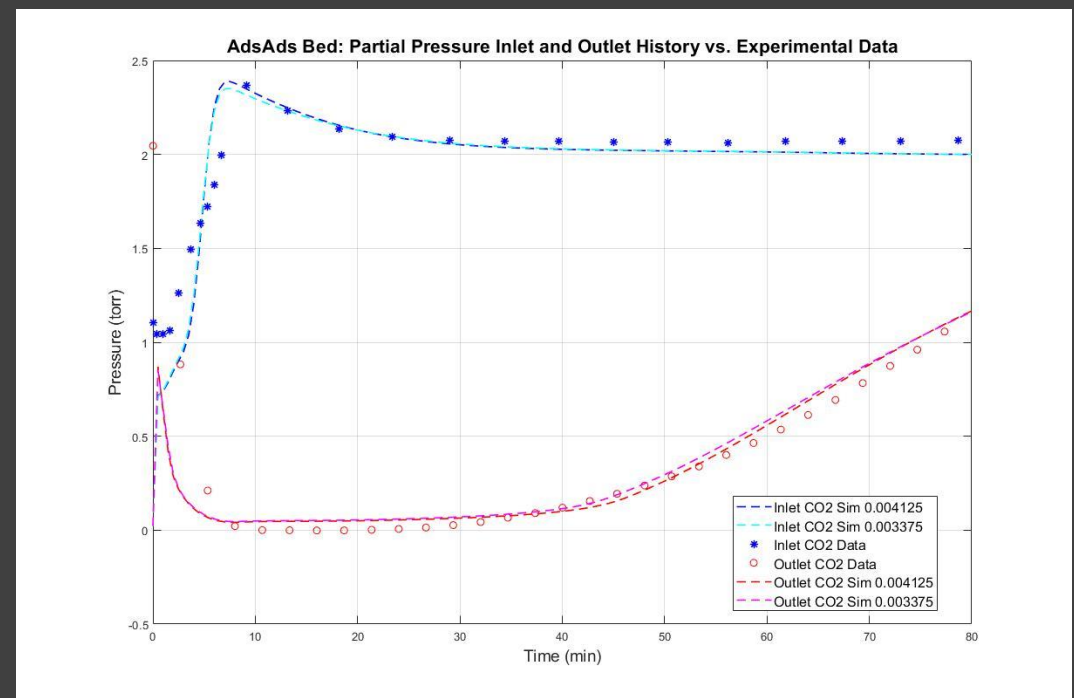
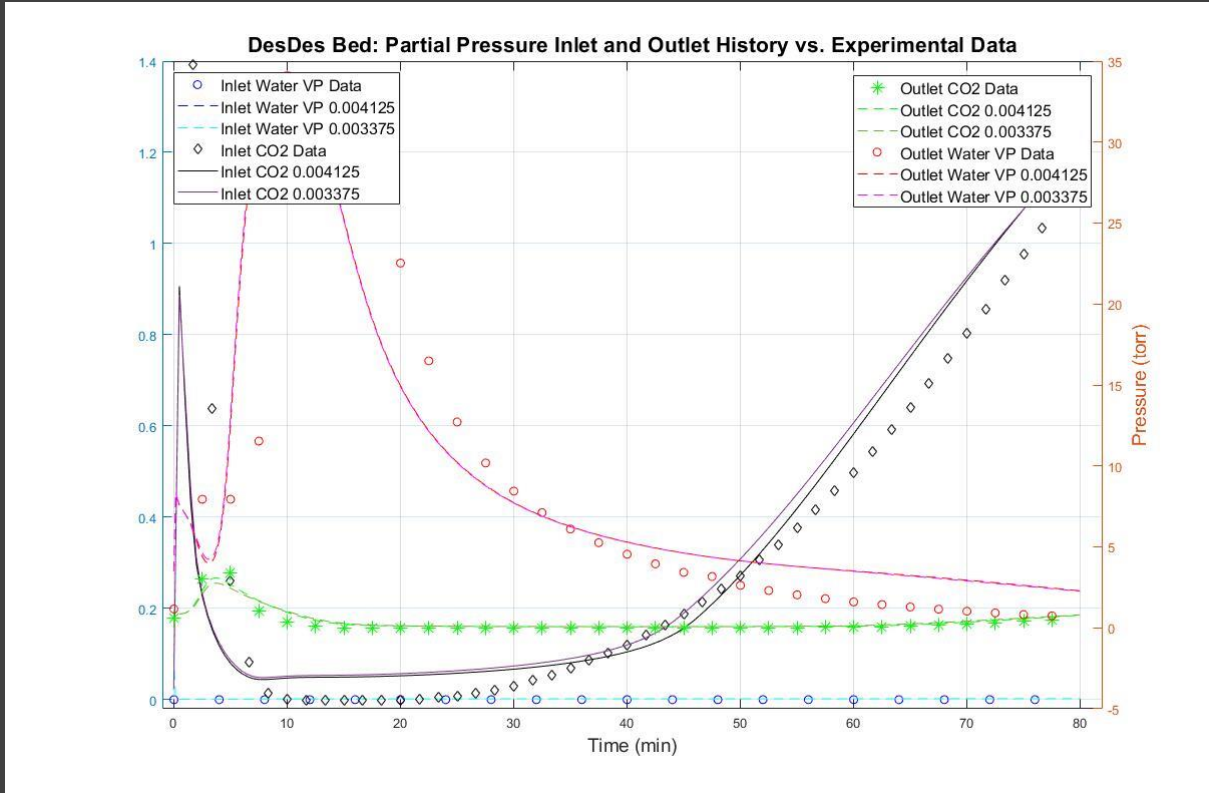


# Varying LDF

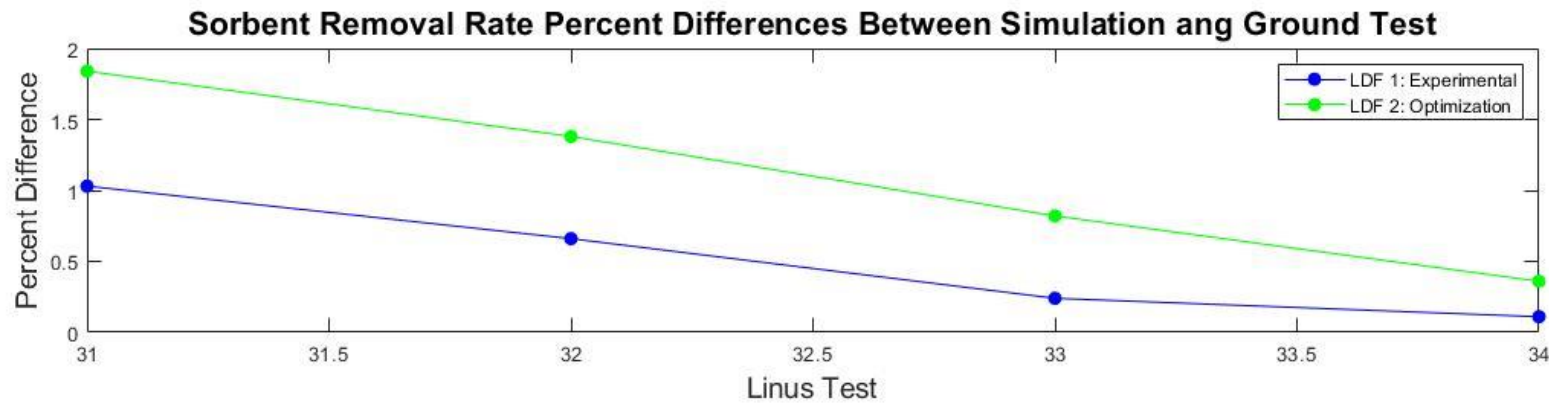
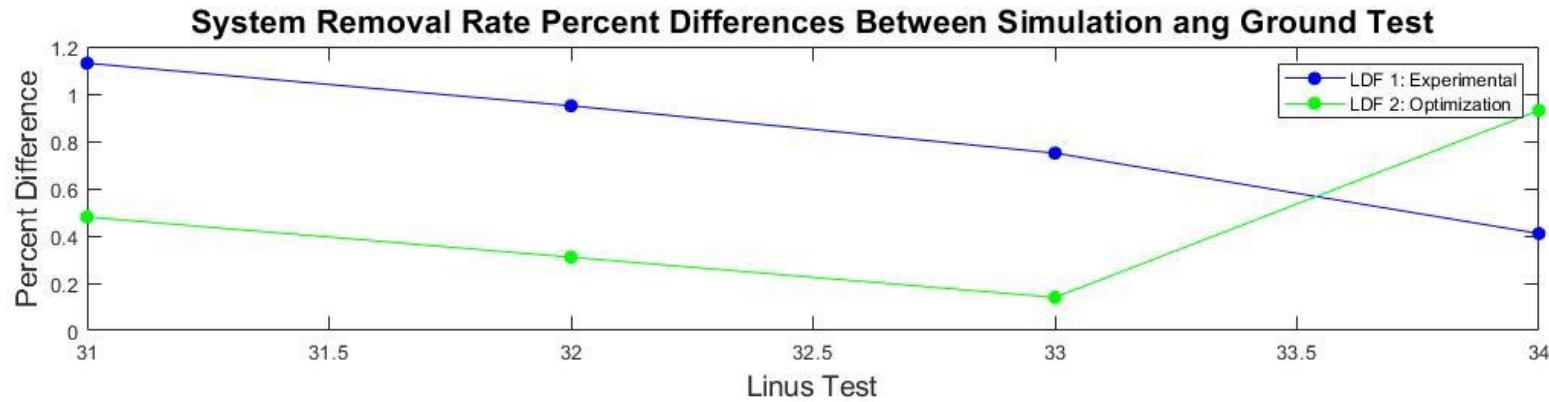
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- ❑ Recall LDF #1 was experimentally determined in independent breakthrough tests
- ❑ Simulations run with both LDFs and multiplier of 70 to gauge extent of effect on simulation temperature and pressure plots

# Plots: Comparison of Varying LDF, Linus 31 Example



# Results of Varying LDF

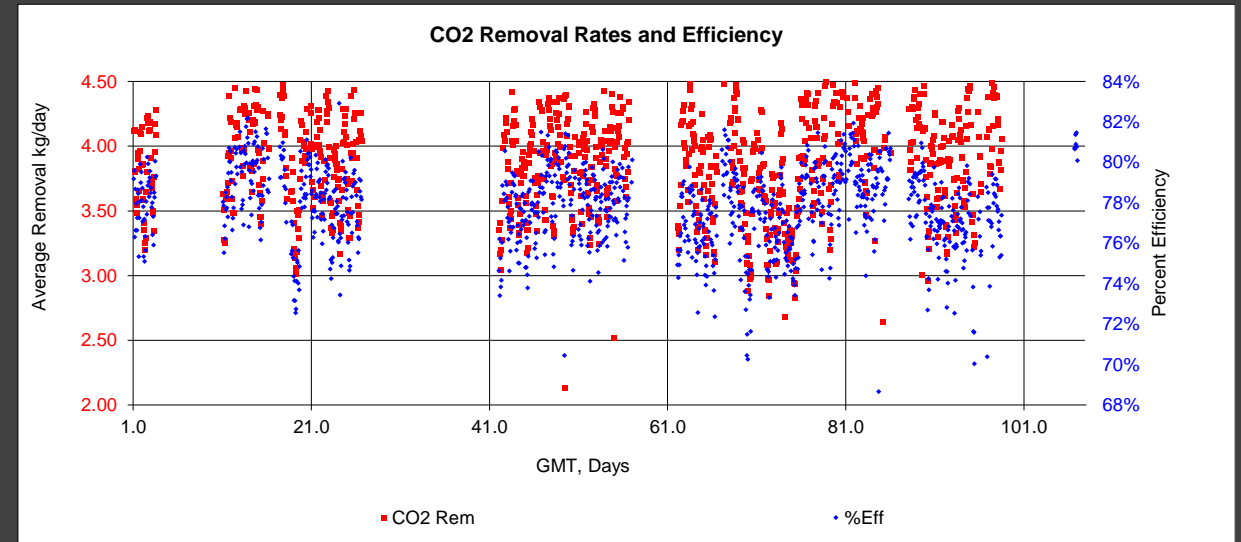


- ☐ LDF #2 displays lower percent differences in the system category vs the sorbent
- ☐ Less than 2% difference between simulation and ground test data overall

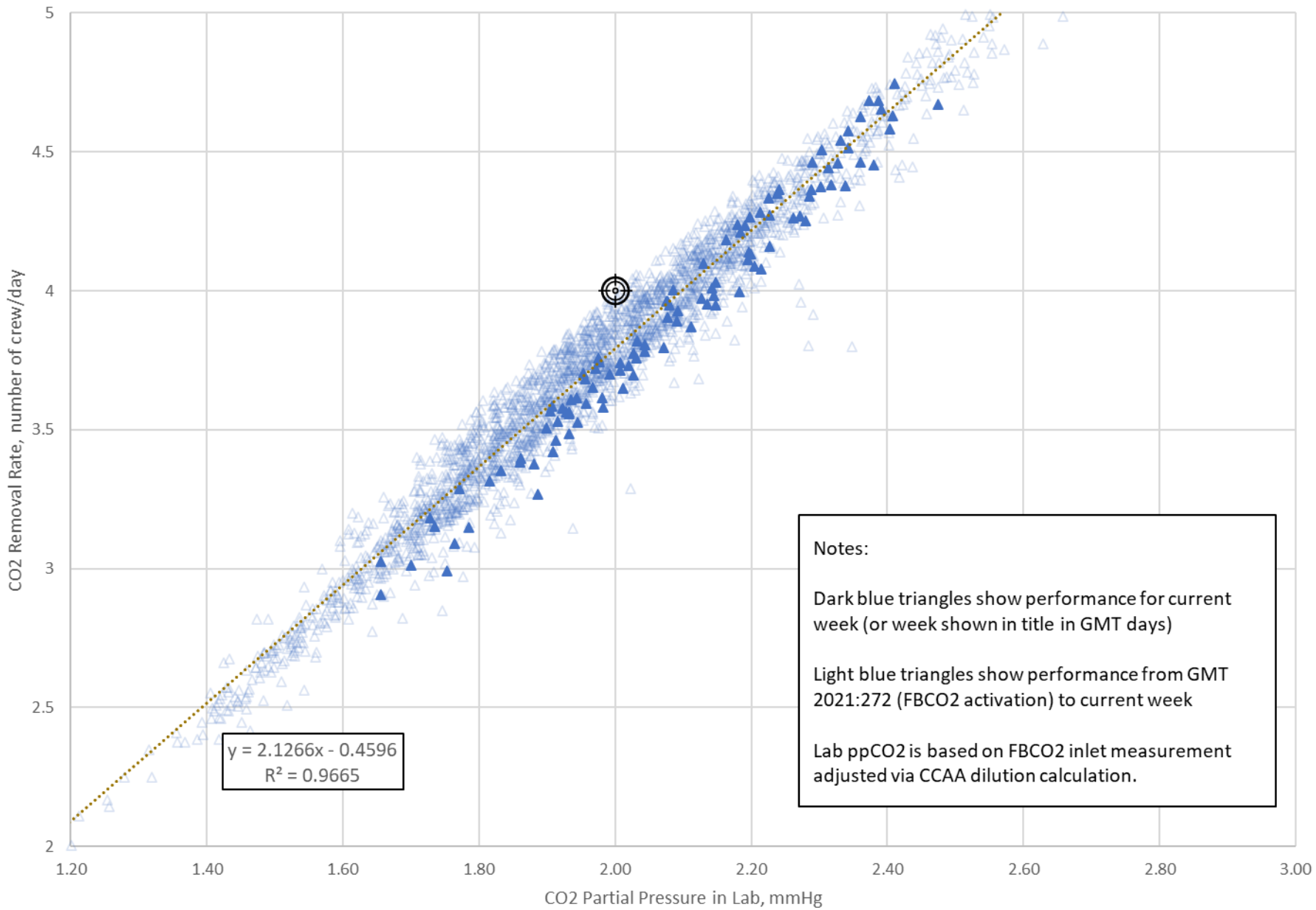
Removal Rates		Linus 31	Linus 32	Linus 33	Linus 34
LDF 2	system	4.95	4.82	4.66	4.49
	sorbent	5.06	4.91	4.71	4.47
LDF 1	system	4.91	4.79	4.64	4.47
	sorbent	5.02	4.87	4.68	4.45

# Flight Telemetry Data Processing

- 150 + days of telemetry data collected and processed since start of operation
- Analysis updated weekly and plots provided for review by ISS ECLSS Exploration Integrator and Flight Controllers
  - Created plots to highlight current performance vs historical data
- Created macro to separate data from 2021 and 2022 to develop yearly plots of removal rate, efficiency, inlet and outlet and coolant temperature, blower RPM, air save pump RPM, power metrics, etc.



4BCO2 CO2 Removal Performance for GMT 114 to 121



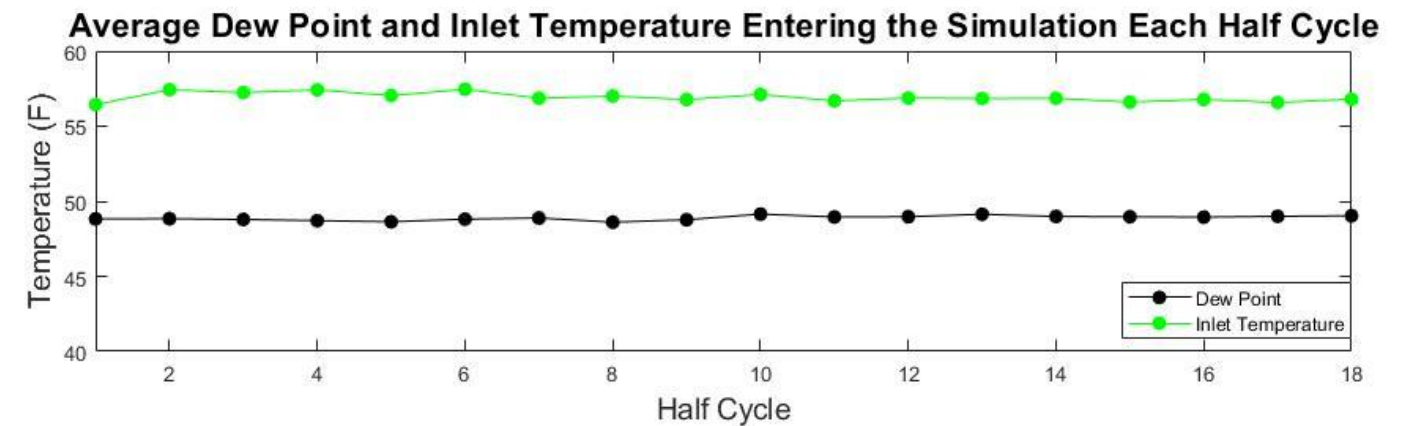
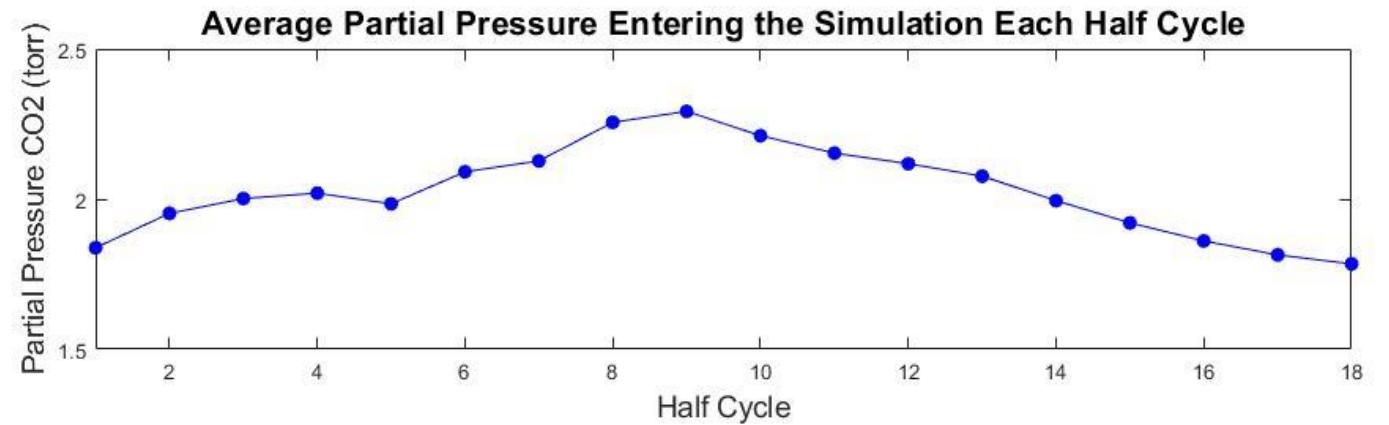
Notes:

- Dark blue triangles show performance for current week (or week shown in title in GMT days)
- Light blue triangles show performance from GMT 2021:272 (FBCO2 activation) to current week
- Lab ppCO2 is based on FBCO2 inlet measurement adjusted via CCAA dilution calculation.

Plot of CO2 removal rate as a function of CO2 lab partial pressure highlights current performance against the historical data

# Telemetry Simulations

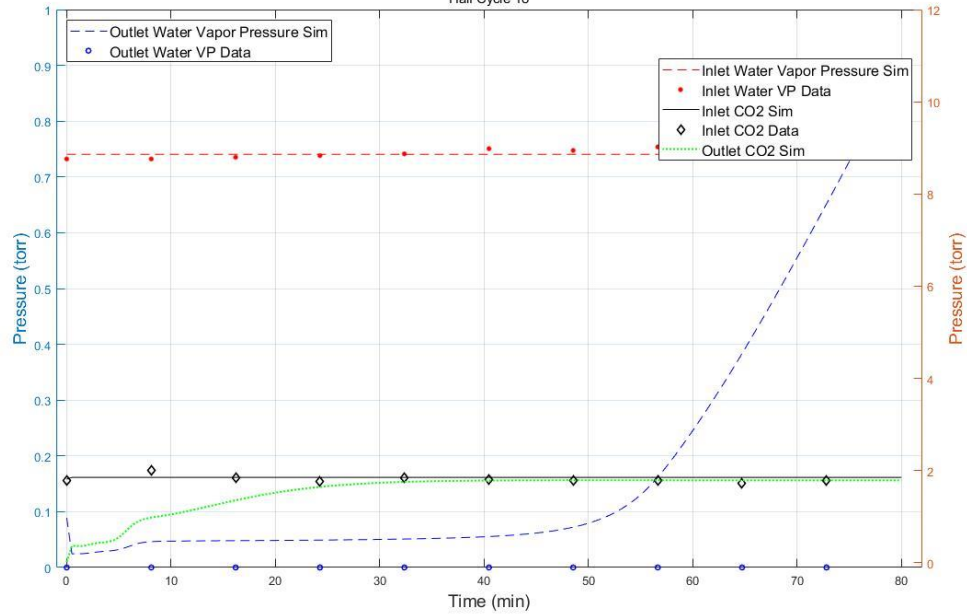
- Model applied to real-time data received from the ISS
- Data over 24 hours (18 half cycles) pulled from telemetry as parameters for model and to compare simulation results with real data





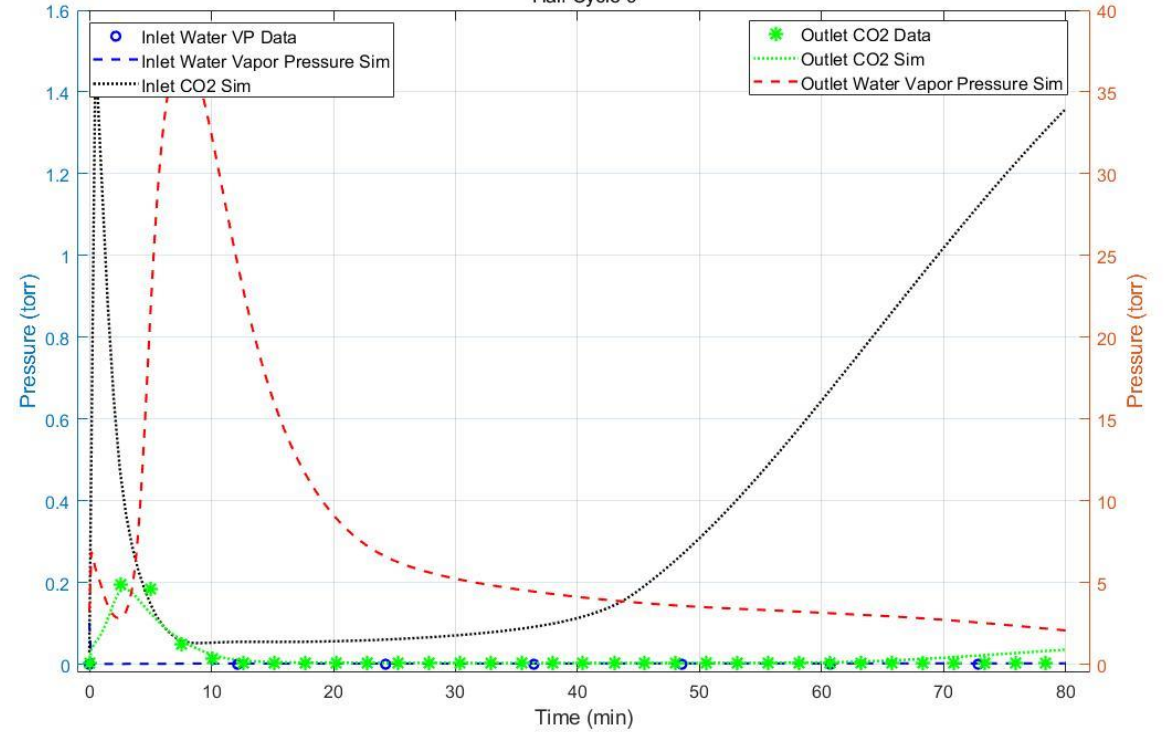
AdsDes Bed: Partial Pressure Inlet and Outlet History vs. Experimental Data

Half Cycle 18



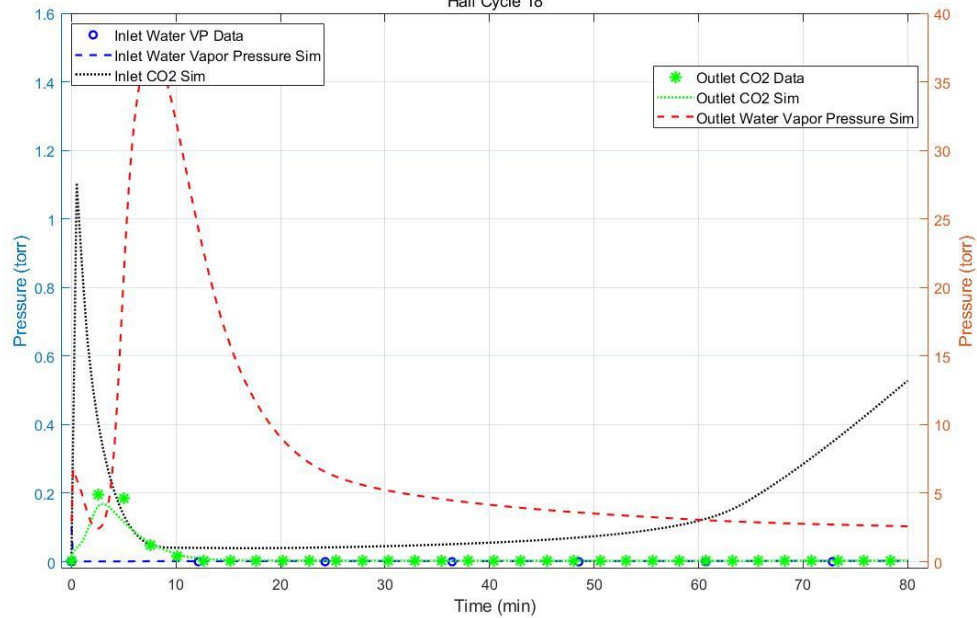
DesDes Bed: Partial Pressure Inlet and Outlet History vs. Experimental Data

Half Cycle 9



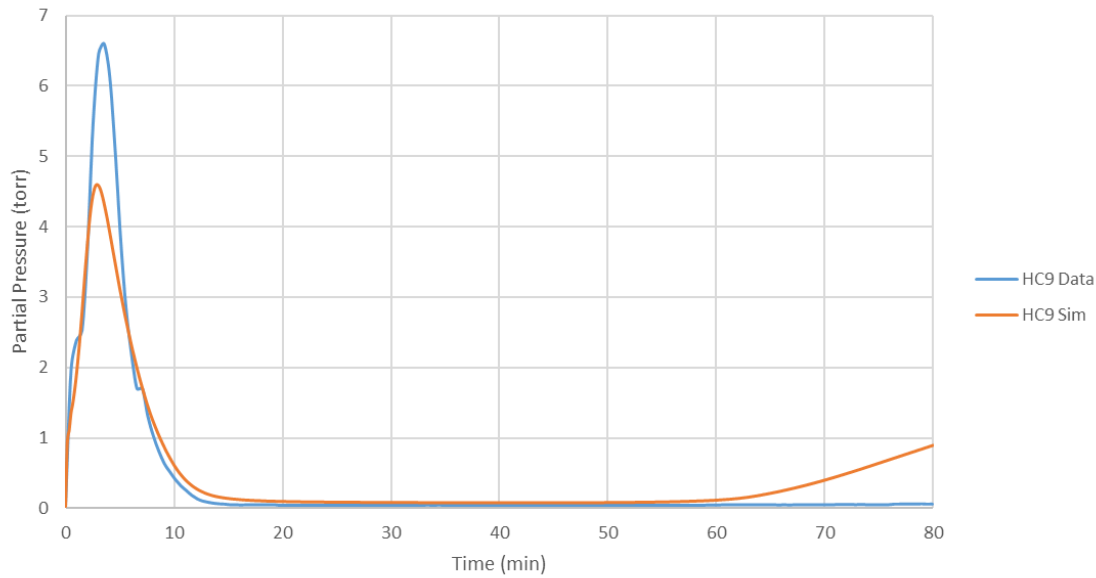
DesDes Bed: Partial Pressure Inlet and Outlet History vs. Experimental Data

Half Cycle 18



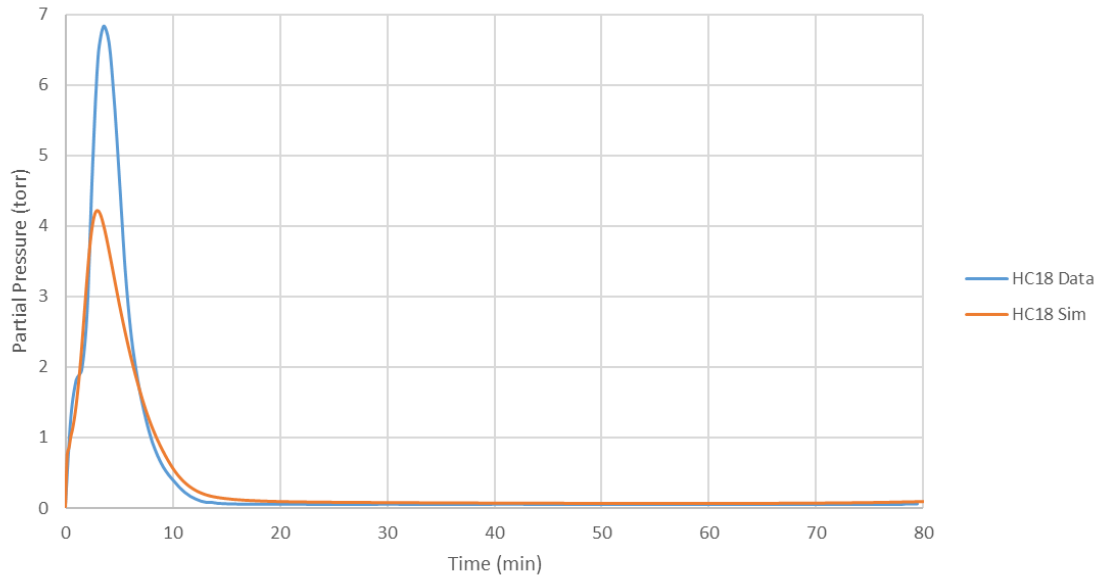
Plots: Comparison of Simulation and 4BCO2 Telemetry Data

Simulation vs Flight Data Outlet ppCO2: Half Cycle 9



❑ Differences between the outlet ppCO2 telemetry data and simulation are strongly affected by the CO2 inlet partial pressure: high CO2 inlet partial pressure corresponds with the breakthrough curve for the simulation plot of half cycle 9

Simulation vs Flight Data Outlet ppCO2: Half Cycle 18



❑ CO2 adsorption dependent on H2O influence in the desiccant beds; less CO2 adsorption occurs at the higher inlet ppCO2 levels

❑ Weak point in the current model; can be investigated in future sessions

# Telemetry vs Simulation Removal Rates

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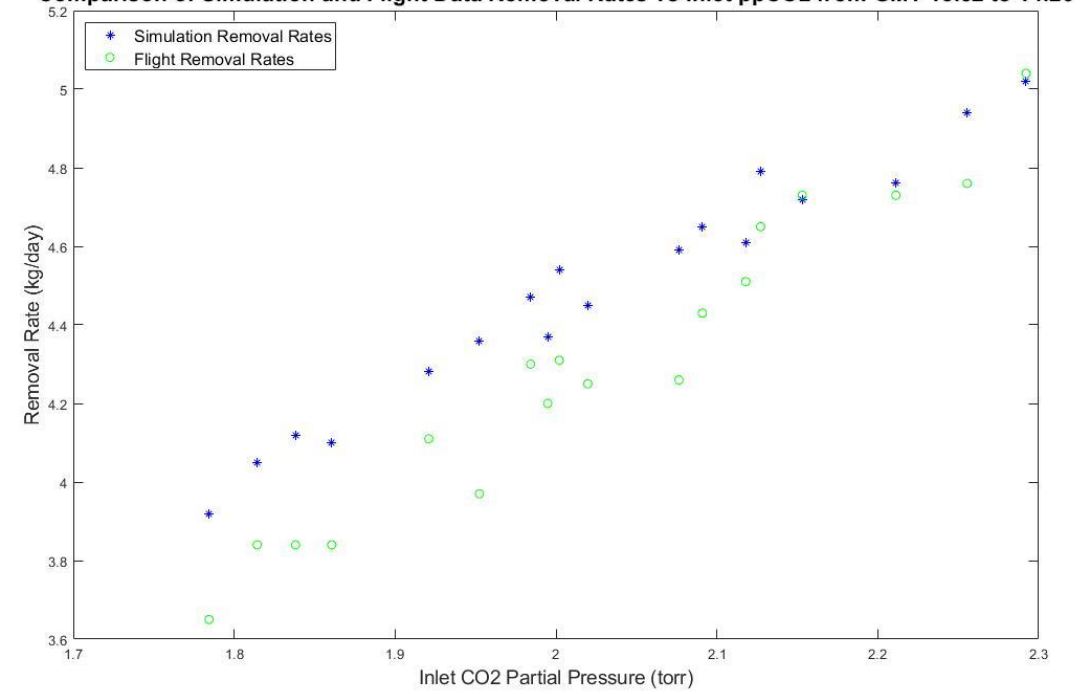
	C1 HC1	C1 HC2	C2 HC1	F2 HC2	C3 HC1	C3 HC2	C4 HC1	C4 HC2	C5 HC1
System Removal Rate (kg/day)	4.12	4.36	4.54	4.45	4.47	4.65	4.79	4.94	5.02
% Difference	6.87%	8.96%	5.02%	4.60%	3.80%	4.66%	3.02%	3.64%	0.31%

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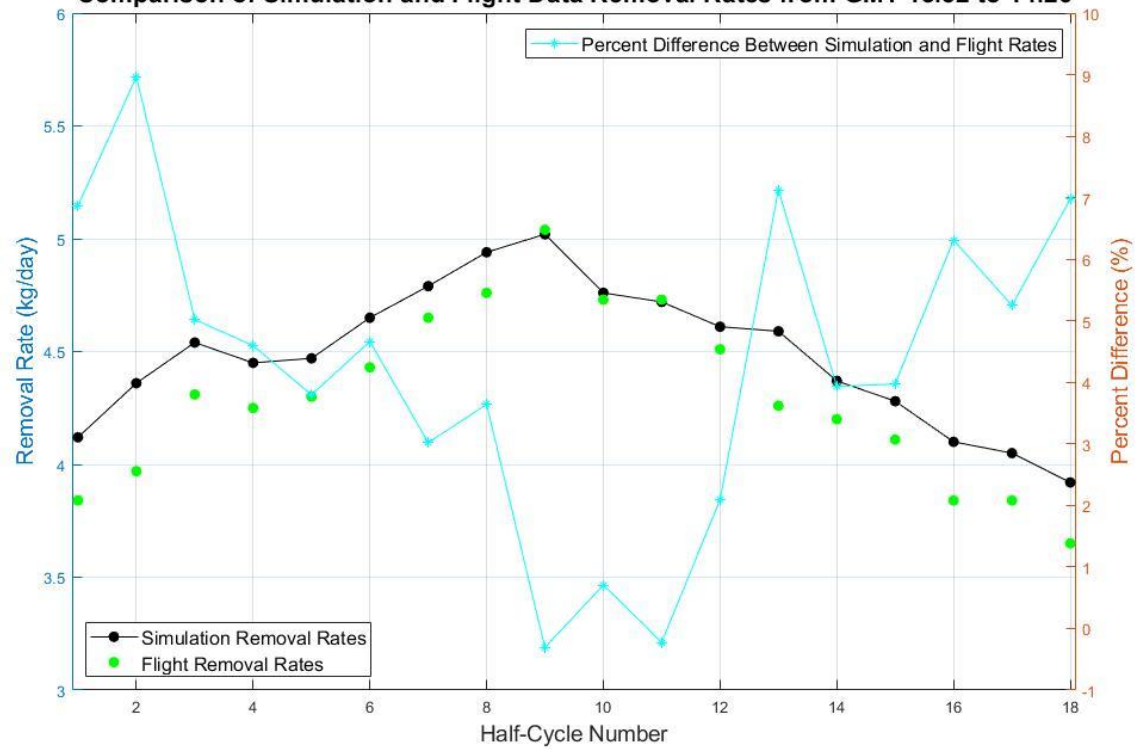
	C5 HC2	C6 HC1	C6 HC2	C7 HC1	C7 HC2	C8 HC1	C8 HC2	C9 HC1	C9 HC2
System Removal Rate (kg/day)	4.76	4.72	4.61	4.59	4.37	4.28	4.10	4.05	3.92
% Difference	0.71%	0.22%	2.09%	7.13%	3.93%	3.97%	6.31%	5.25%	6.98%

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Comparison of Simulation and Flight Data Removal Rates vs Inlet ppCO<sub>2</sub> from GMT 13.32 to 14.26



Comparison of Simulation and Flight Data Removal Rates from GMT 13.32 to 14.26



# Acknowledgements

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- Dr. James Knox, Mentor
- Dr. James Nabity and Sam Eshima from UC Boulder