Using the Carbon Capture Simulation Initiative (CCSI) Tool to Design the Experiments in the Parametric Campaign of a Novel Compact Absorber for Carbon Capture

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Disclaimer

Climate Solutions, Inc., Nexant and Smith Management Group. This work is conducted under a US DOE award (DE-FE0031733) and project partners and participants are Industrial

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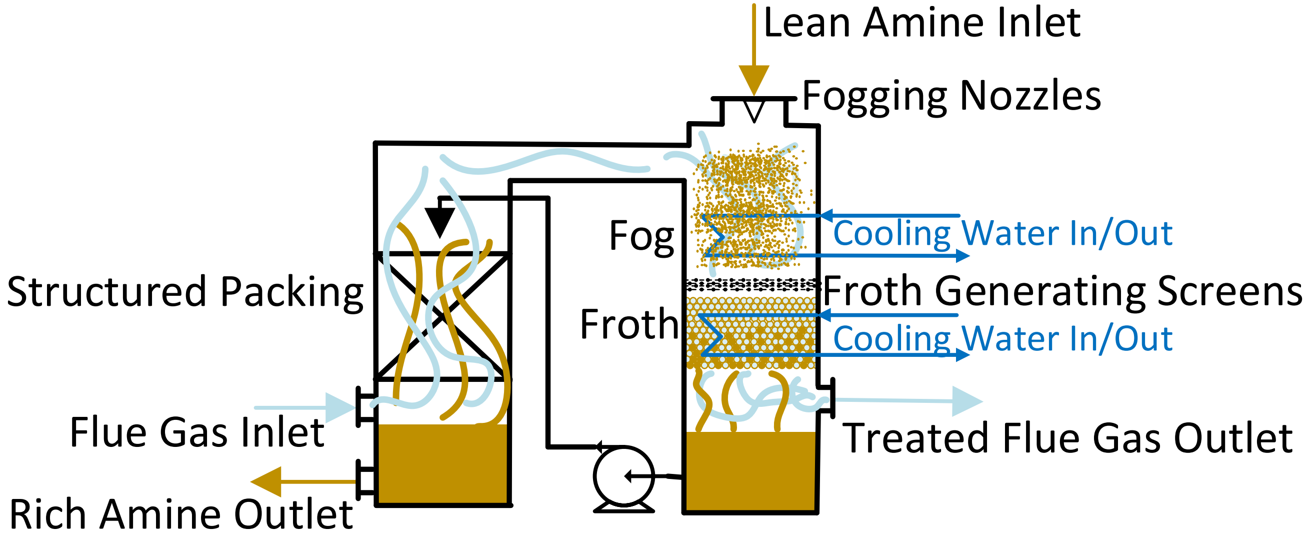
Introduction

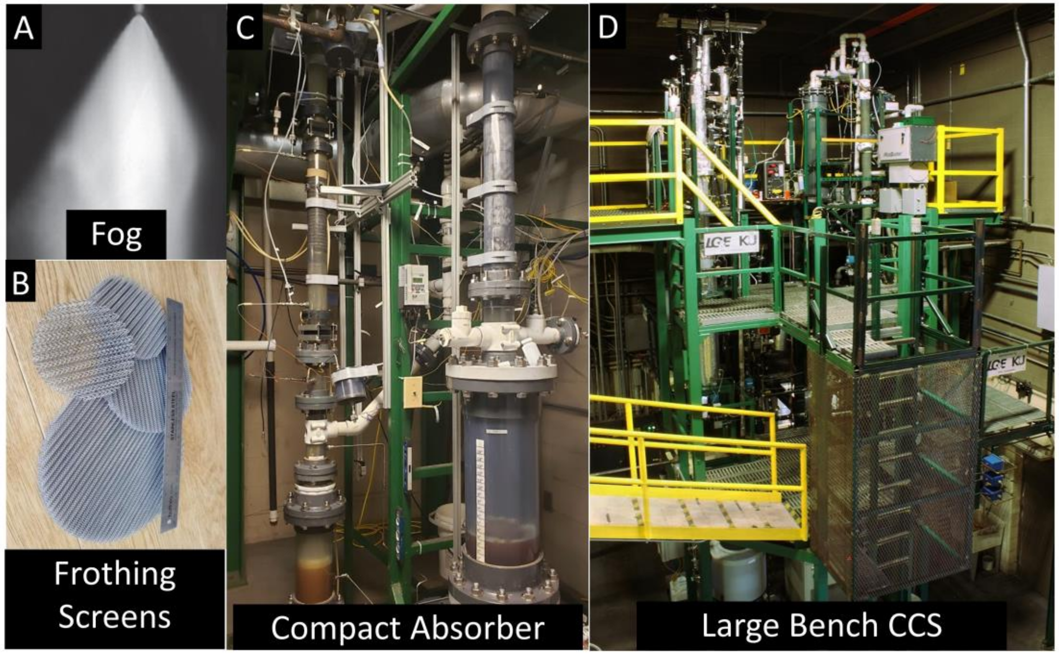
A novel Fog and Froth-based Compact Absorber developed by the UK CAER is designed, fabricated, installed, and tested. The vastly increased liquid/gas contact area and minimized diffusion resistance in this absorber allows the column size to be reduced by up to 70% from a standard absorber design and reduce the CCS capital cost by up to 57%.

Schematic diagram below.



Compact Absorber

- A) Spray nozzle used to create fog
- B) Frothing screens supplied by Industrial Climate Solutions, Inc.
- C) Compact absorber
- D) Large bench CO_2 capture system equipped with the solvent regeneration system



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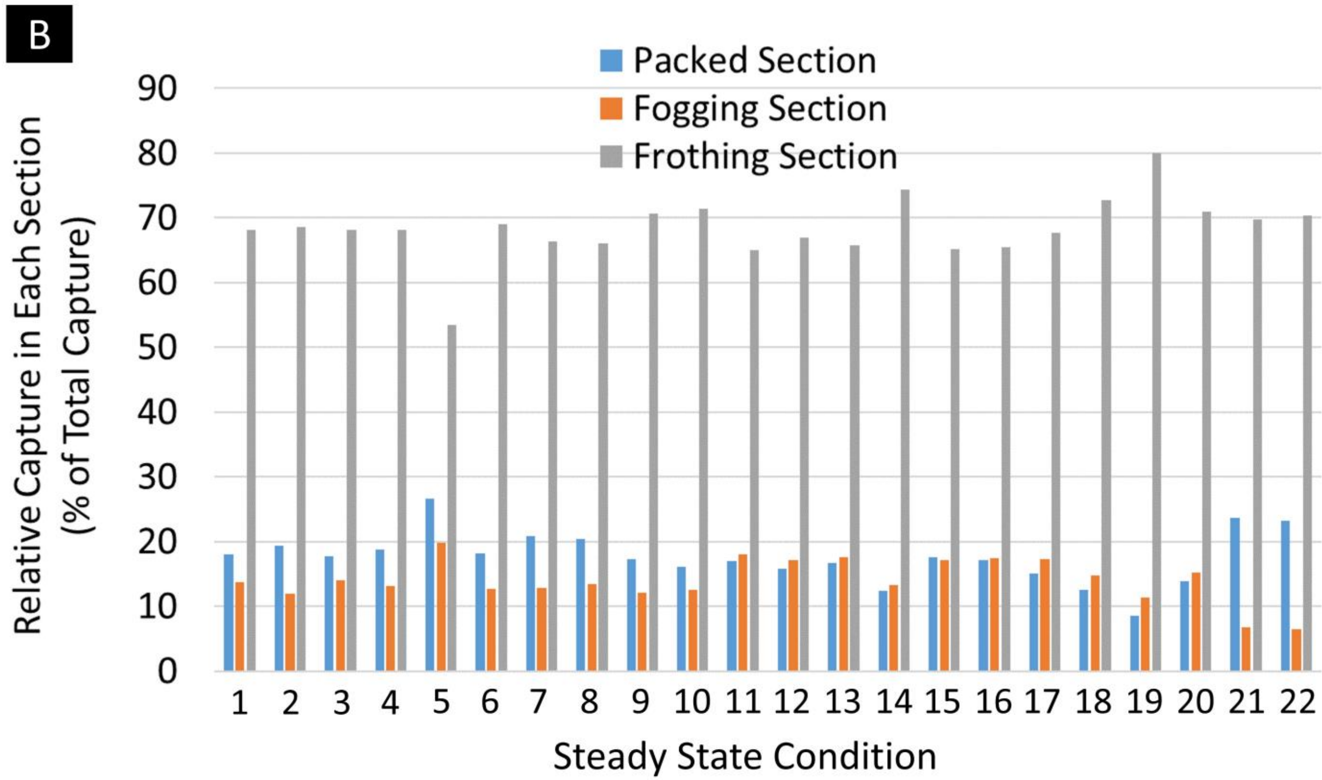
Parametric Campaign Results

A - Based on mass transfer in the fogging and frothing sections, the surface area is increased by 6.8 times that of 250Y structured packing. Based on the fogging section mass transfer the bubble size is <3.7 mm. Based on mass transfer in the fogging section, the droplet size is estimated to be 82-165 µm.

A	Specific Absorption (mol C/hr·ft^3)	Improvement Over Traditional Packed Absorber	Droplet Size (µm) and Bubble Size (mm) Based on Measured Mass Transfer
Compact Absorber Fogging Section	69-266	2.3-4.6 times	82-165 µm
Compact Absorber Frothing Section	189-782	6.5-13.5 times	<3.7 mm
Compact Absorber Packed Section	22-102	0.75-1.76 times	
Traditional Packed Absorber	29-58		

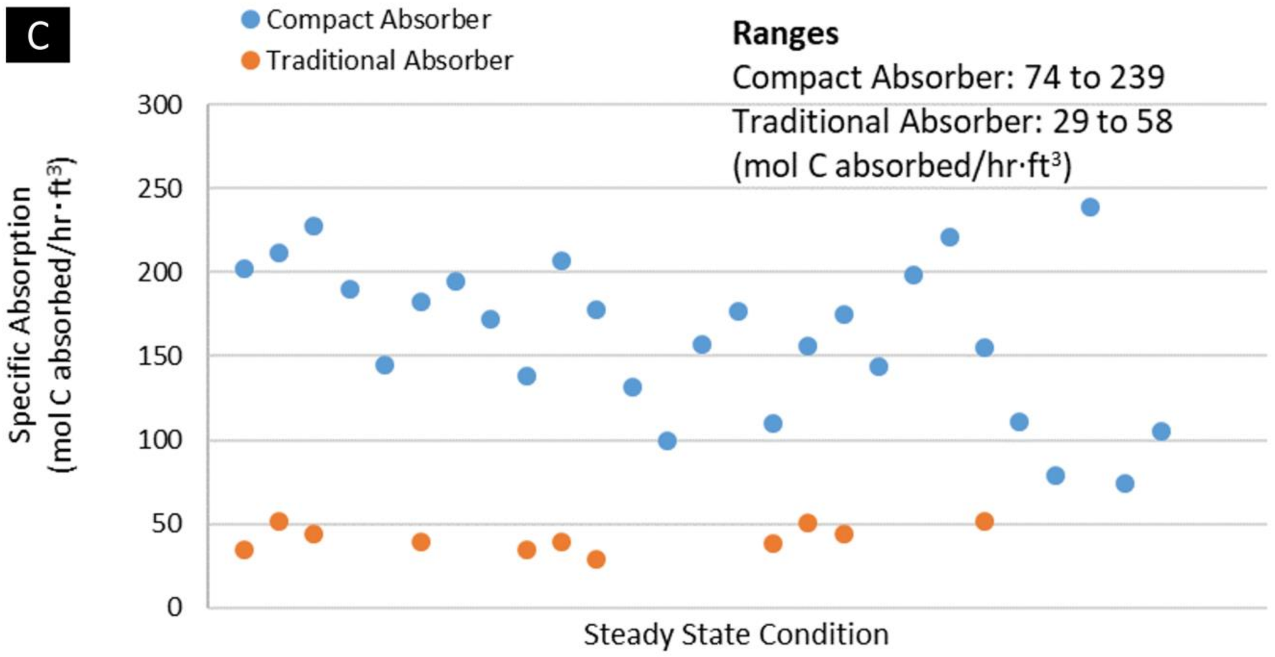
Parametric Campaign Results

B - Of the total CO_2 captured in the parametric campaign, 6-20% occurs in the fogging section, 54-80% in the frothing section, and 9-27% in the packed section. Data collected from approximately 160 operational hours.



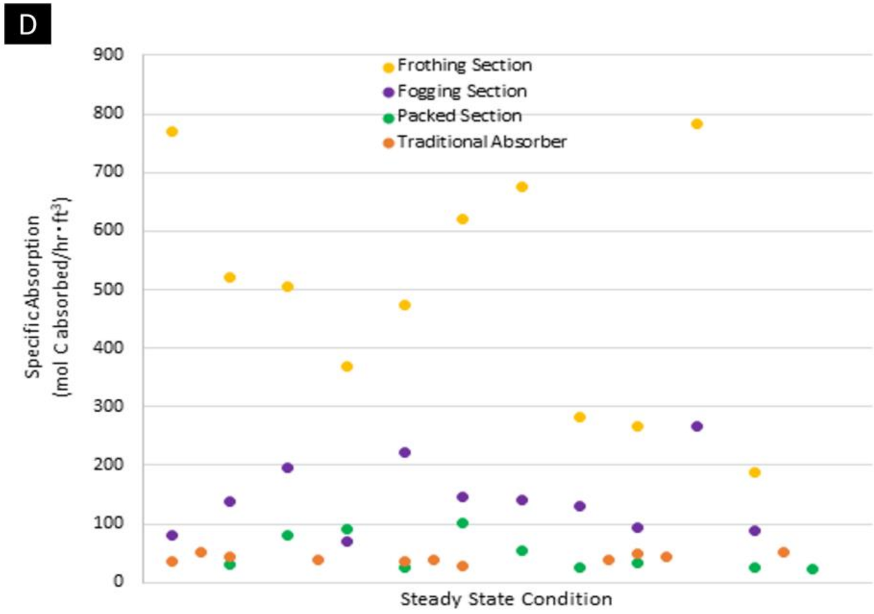
Parametric Campaign Results

C - Comparing the UK CAER compact absorber performance with a previous campaign using a traditional absorber with structured packing and the same solvent and varying operating conditions, the specific absorption in the compact absorber is notably higher than in the traditional absorber, 2.6 to 4.1X, depending on the operating parameters.



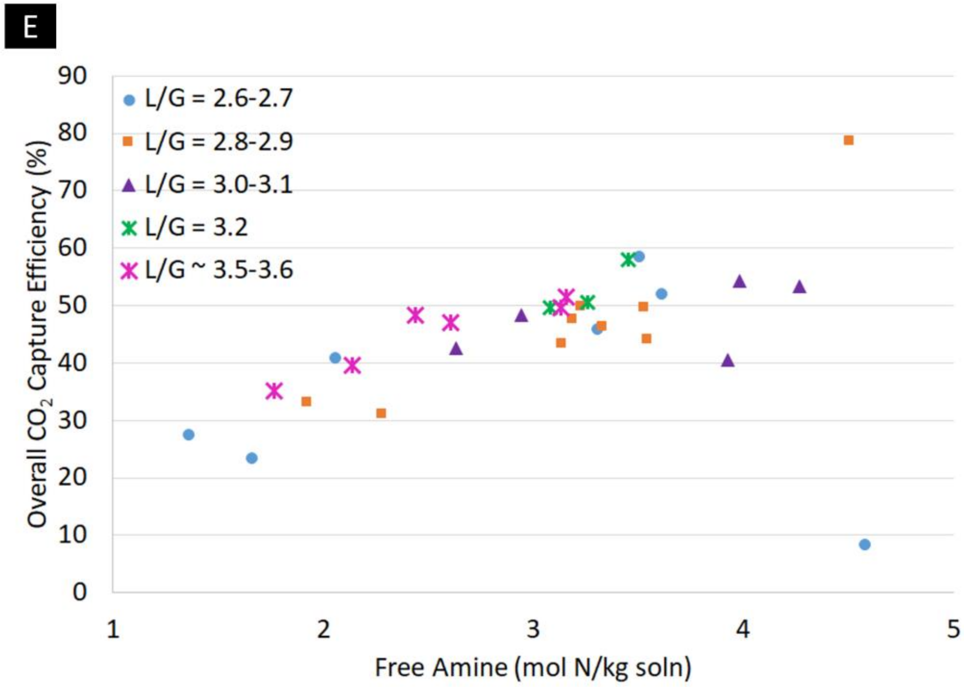
Parametric Campaign Results

D - The specific absorption (volumetric) in the packed section of the compact absorber was 22-102 mol C/hr ft^3, depending on the operating conditions. This is very similar to the performance of the traditionally packed column with 29-58 mol C/hr ft^3 measured during a previous campaign. Improved absorption by 2.3-4.6 times and 6.5-13.5 was observed in the fogging and frothing sections, respectively.



Parametric Campaign Results

E - As the free amine available for absorption increased from 1.5 to 4.5 mol N/kg solution, the overall compact absorber CO_2 capture efficiency improved from 20 to 80%, where the the free amine available for CO_2 absorption, which combines all influence factors (solvent flowrate, carbon content and amine concentration in the lean solution) into one parameter.



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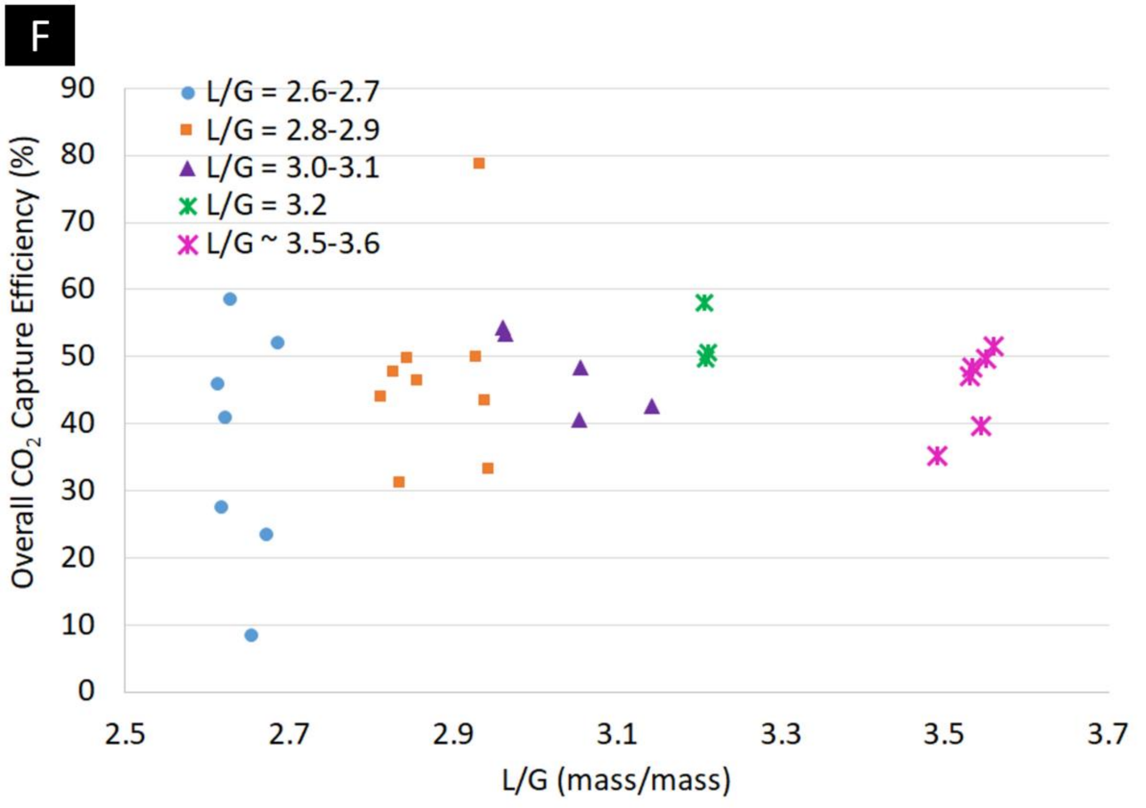
Parametric Campaign Results

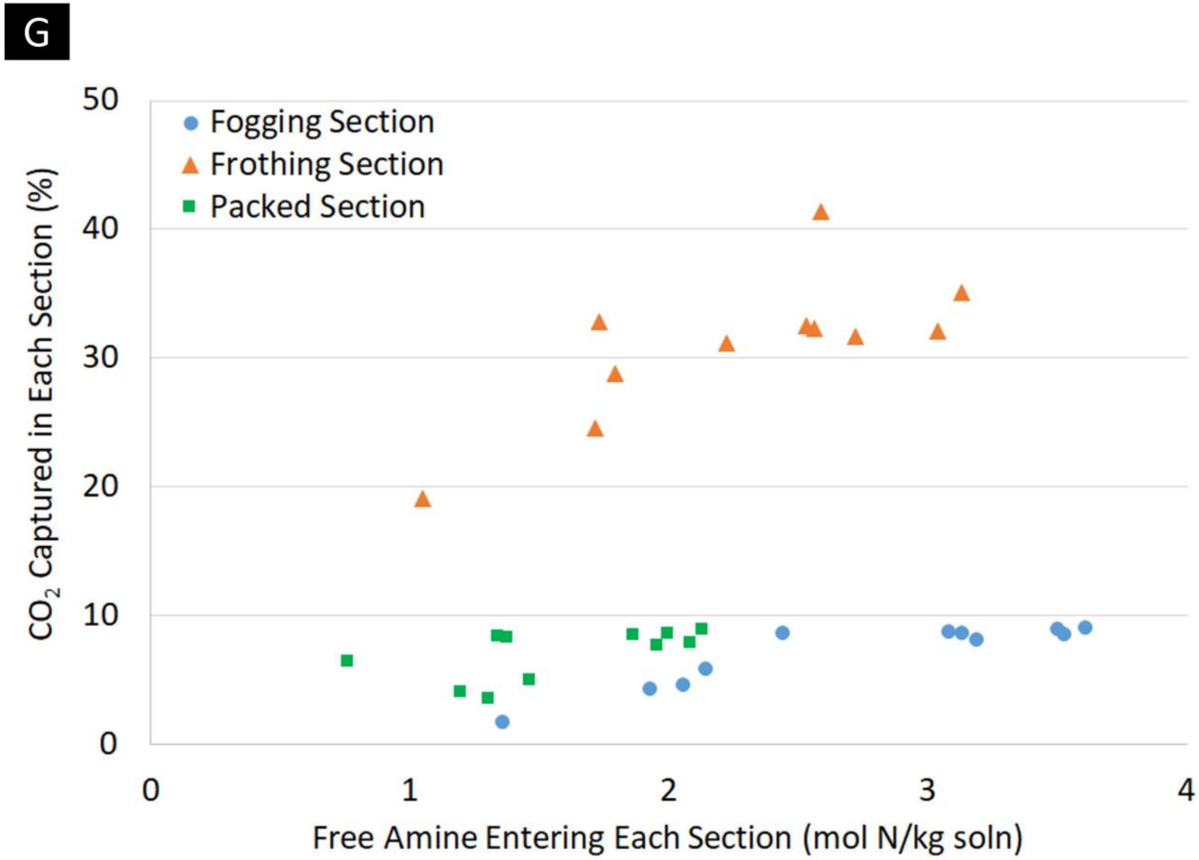
F - Increasing L/G does not correlate to increased CO_2 capture efficiency, meaning that overall, the limitation is the gas residence time in the column.



Parametric Campaign Results

G – The performance of the packed and fogging sections improves with increasing free amine up to a point and then it becomes relatively flat. The performance in the packed and fogging sections does not show improvement past a free amine concentration of about 1.3 and 2.5 mol N/kg solution, respectively and free amine flow rate per unit of gas flow of 4 and 9 mol N/kg gas, respectively. Below these values, the CO_2 mass transfer is controlled by the surface area and reaction rate and above these values mass transfer can be viewed as an instanteous reaction and the residence time is the limiting factor rather than gas-liquid contact surface or interface diffusion resistance. In these sections there is not enough time to capture CO_2 at the higher free amine concentrations and flow rates.

Parametric Campaign Results



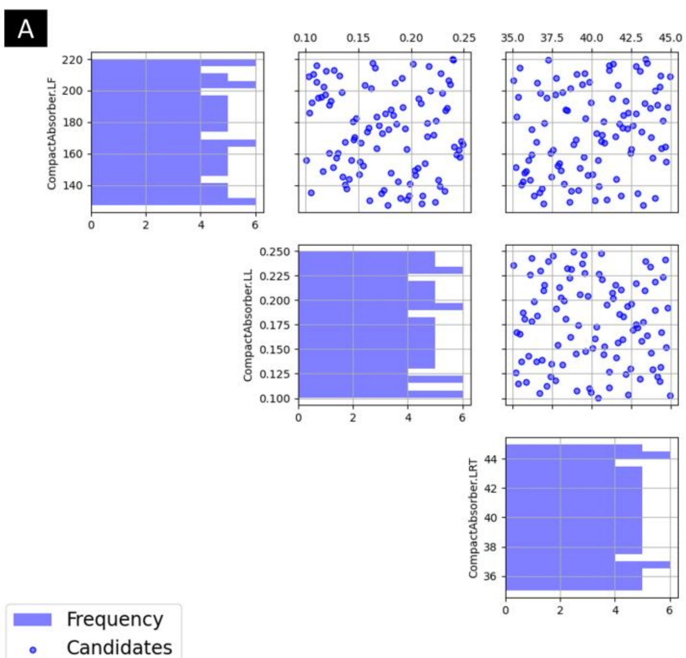
Sequential Design of Experiments

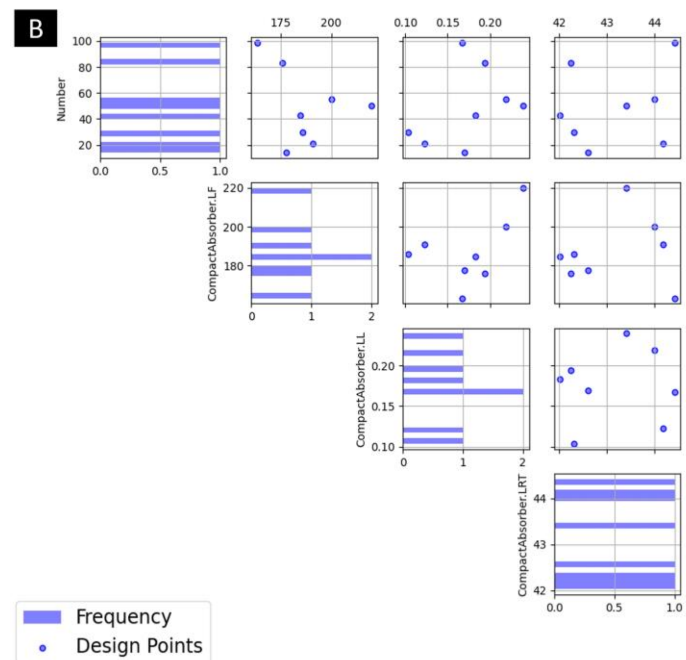
SDOE tool from the CCSI toolset was used using FOQUS software. Eight uniformly distributed parametric conditions were selected out of the 100 randomly generated conditions to run in the campaign. As the steady-state was achieved performance was assessed from data collected. Scatter plots were generated using the USF model in FOQUS. SDOE was used to determine the uniformly distributed conditions in the input space considering the inputs and constraints.

A) Randomly generated 100 parametric conditions within the input space

B) Eight uniformly distributed parametric conditions selected using SDOE and USF model

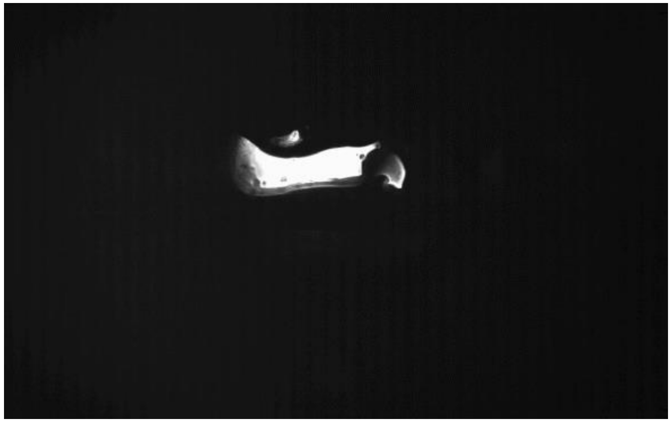
- CCSI - Carbon Capture Simulation Initiative - A set of tools (open source) that can be used for Computational Modelling and Simulation to accelerate the commercialization of Carbon Capture Technologies from discovery to development, demonstration, and deployment
- FOQUS - Framework for Optimization, Quantification of Uncertainty, and Surrogates is a software platform with the graphical interface for several CCSI tools
- USF - Uniform Space-Filling Model

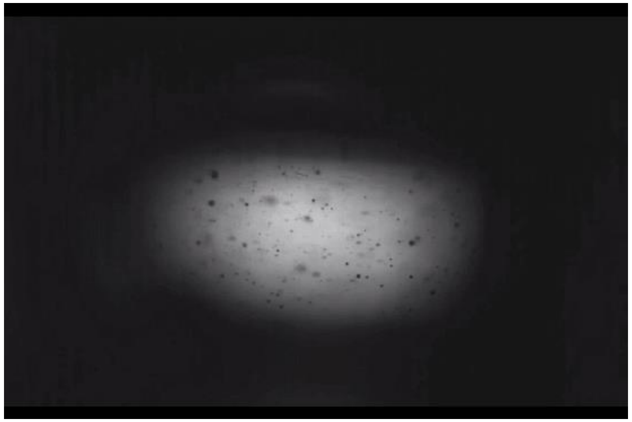




Videos

- With the BETE PJ32® nozzles, the fogging section droplet size is estimated at 106-175 Sauter Mean Diameter, with 11.5-30.3% of the droplets having a hydraulic diameter <50 µm.
- Left - Slow motion video showing the formation and dispersion of froth bubble between the frothing screens
- Right - Slow motion video showing the fog droplets in the fogging section.
- These videos were captured using a Phantom high-speed camera operated by Brandon Heller, Department of Mechanical Engineering, University of Kentucky.





Thank you.