Optimization of Intensified Towers with Internal Heat Exchangers for CO_2 Capture

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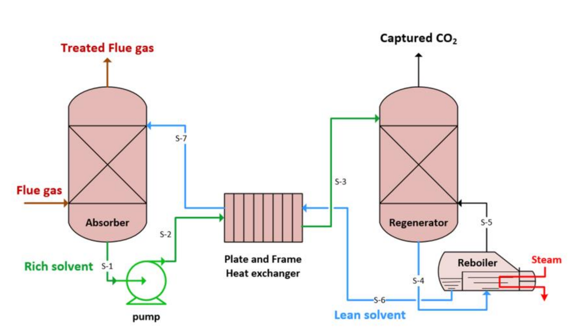
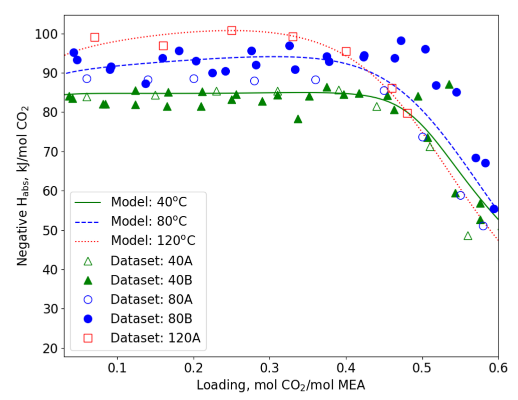
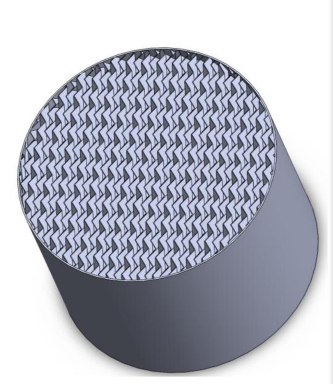
Motivation: Process Intensification of Packed Columns

- Exothermic reactions in the capture process results in higher temperatures and lower efficiency.
- Intercoolers only remove heat at discrete locations and cannot keep the tower at thermodynamic optimum.
- Internal cooling can help in achieving an optimal temperature profile throughout the tower and can be accomplished with 3D printing.
- However, adding more heat exchanger volume reduces the area of packing for mass transfer, and so can have a diminishing effect.
- The study seeks to answer questions like: Should such internal HE be placed all along the tower or should placement be varied spatially? How do the operating conditions affect the optimal placement? What are the optimal flow configurations for the cooling water?



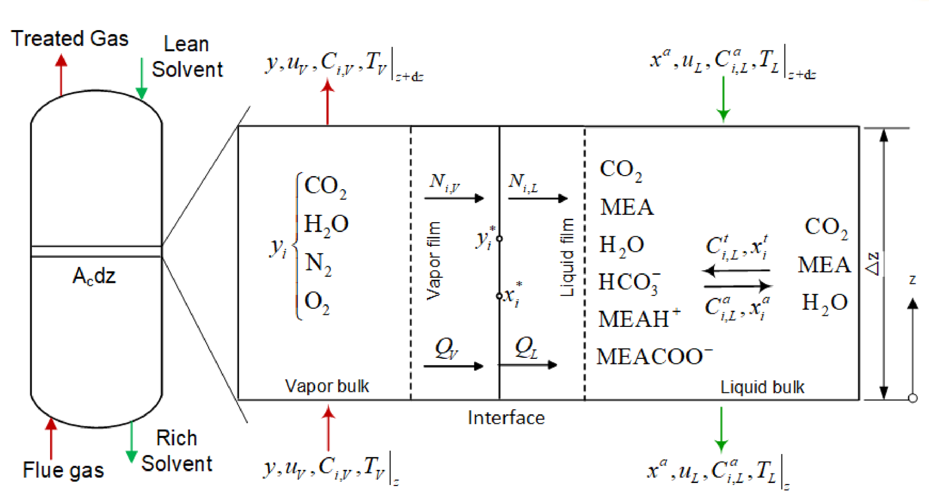


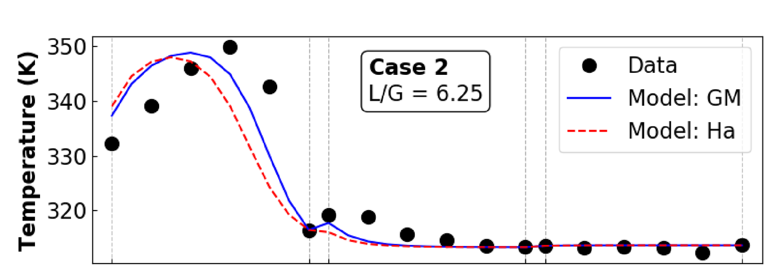


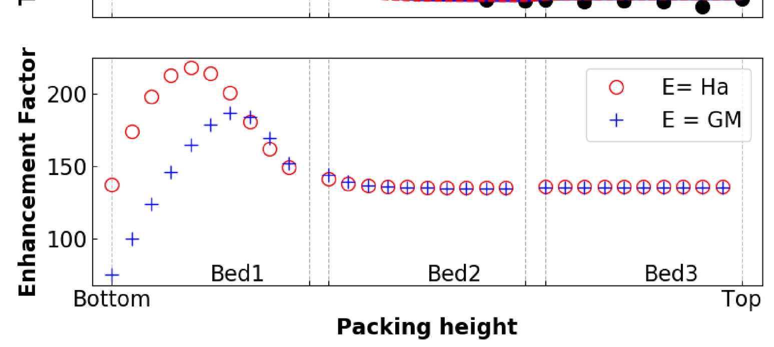
* Images are from Oak Ridge National Lab

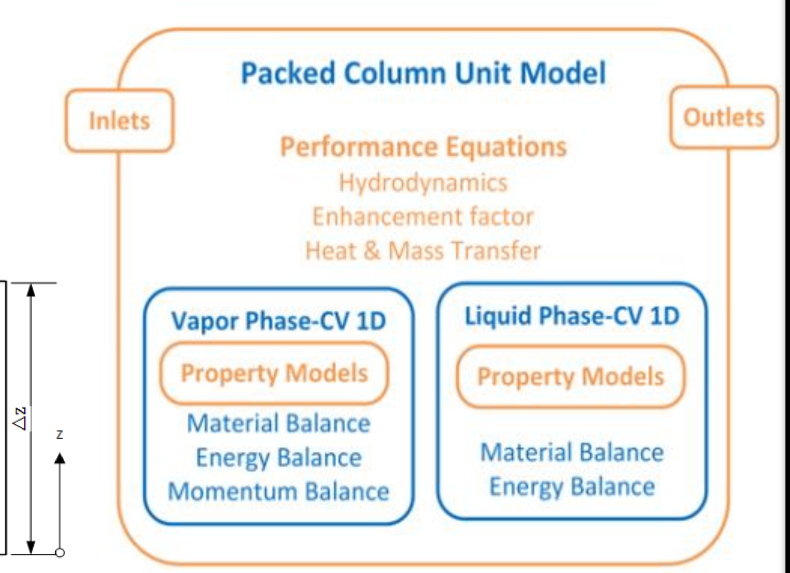
Tower Model Development and Validation[1,2]

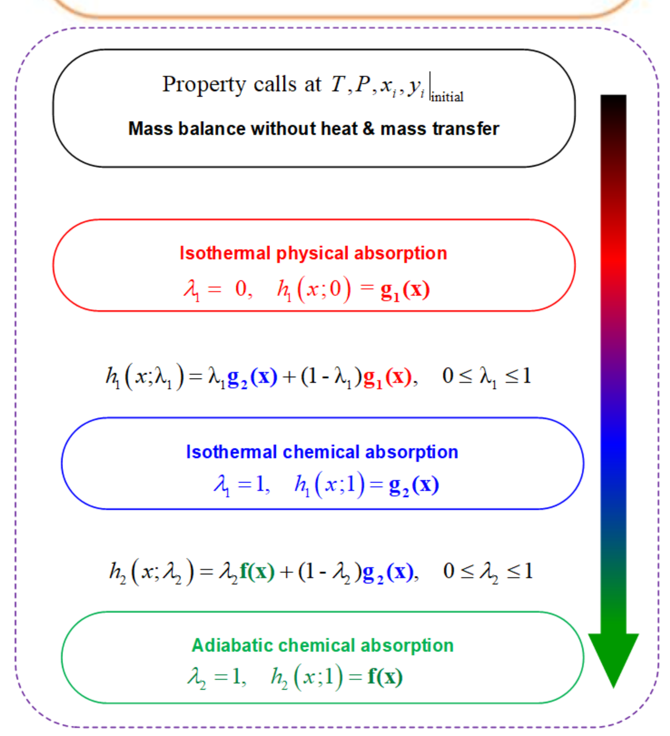
- Two-film model with thermo-, chemistry, and properties models
- 1D in axial direction
- Validated using data from NCCC











References

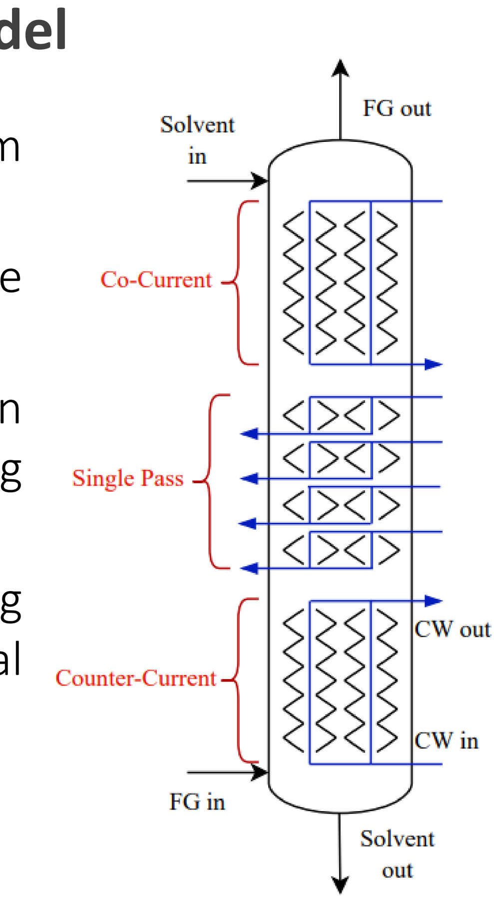
[1] Akula, P, Lee, A, Eslick, J, Bhattacharyya, D, Miller, DC. Model Development, Validation, and Optimization of an MEA-Based Post-Combustion CO2 Capture Process under Part-Load and Variable Capture Operations. Ind. Eng. Chem. Res. 2021; 60(14).

[2] Akula, P, Lee, A, Eslick, J, Bhattacharyya, D, Miller, DC. A modified electrolyte non-random two-liquid model with analytical expression for excess enthalpy: Application to the MEA-H2O-CO2 system. AIChE J. 2023; 69(1).

[3] Moore, T, Nguyen, D, Iyer, J, Roy, P, Stolaroff, JK. Advanced absorber heat integration via heat exchange packings. AIChE J. 2021; 67(8).

Internal Heat Exchanger Model

- Internal heat exchangers remove heat directly from liquid phase[3].
- Penalty to mass transfer area due to increase in the heat transfer area is accounted for.
- The model includes options for setting flow direction of cooling water and inlet and exit point of cooling water
- A minimum size constraint is imposed for the cooling section to account for possible mechanical/structural and manufacturing limitations.



Model Setup

Software:

- Pyomo/IDAES
- IPOPT

Simulation conditions:

- Solvent: 30% MEA, 70% H_2O
- Flue gas: 4.2% CO_2, 5.4% H_2O, 13% O_2

<u>Minimizing Emissions</u>

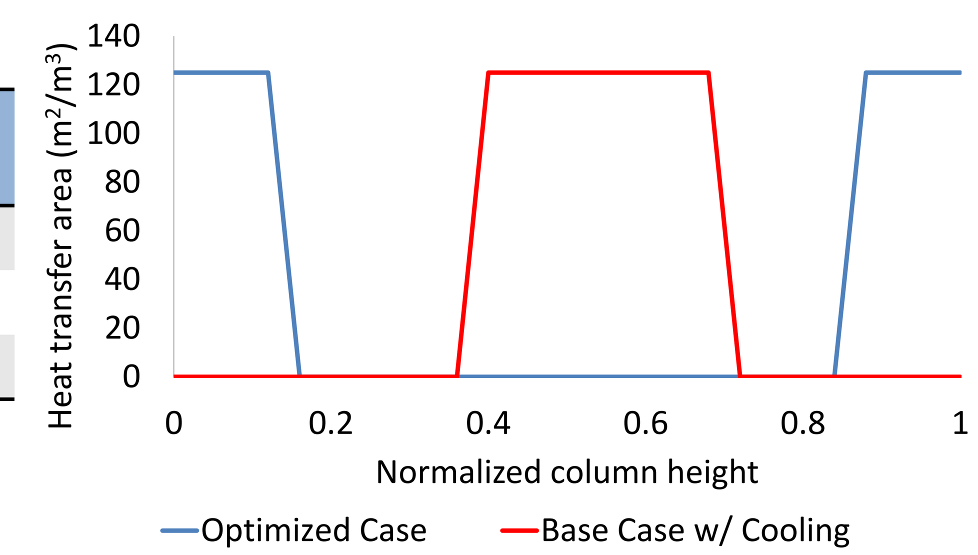
$$\min_{\varepsilon^{cw}, y, y^{start}, d} F^{V,out}_{CO_2}$$

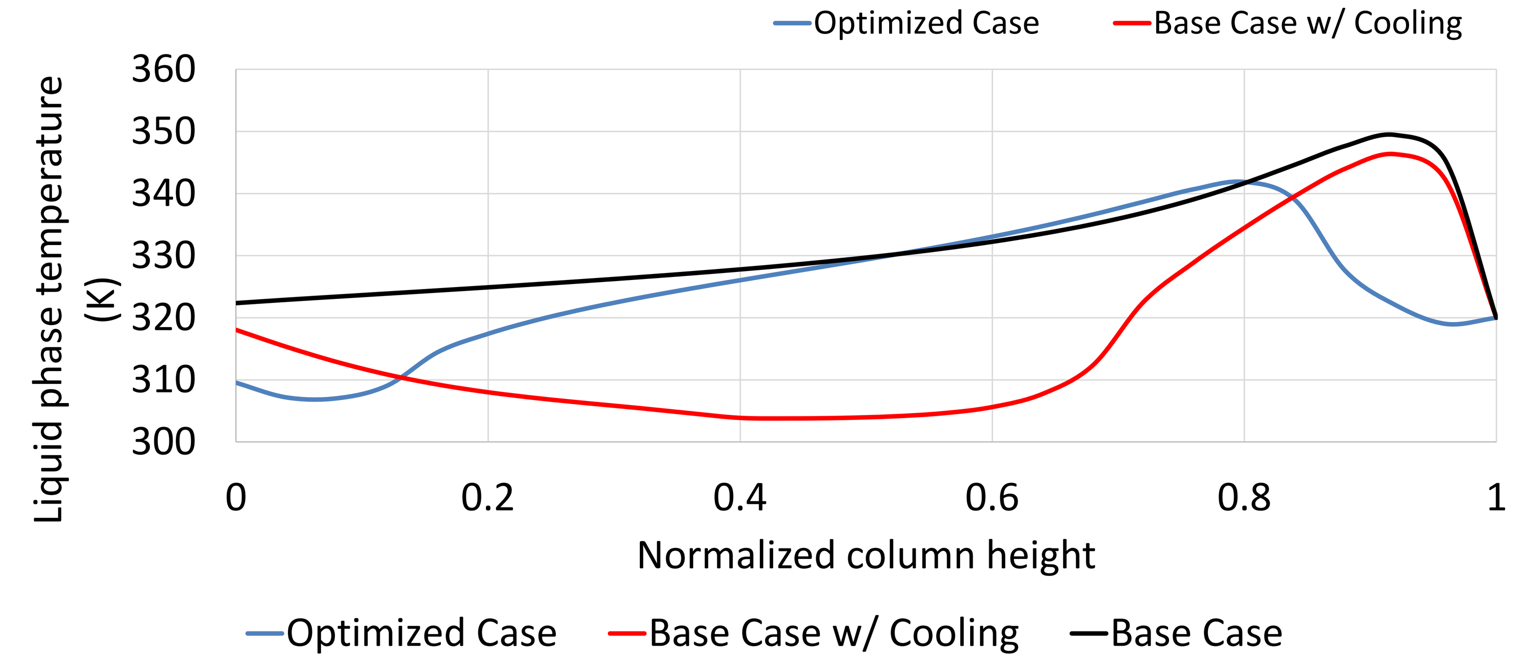
Tower Design and Operating Conditions

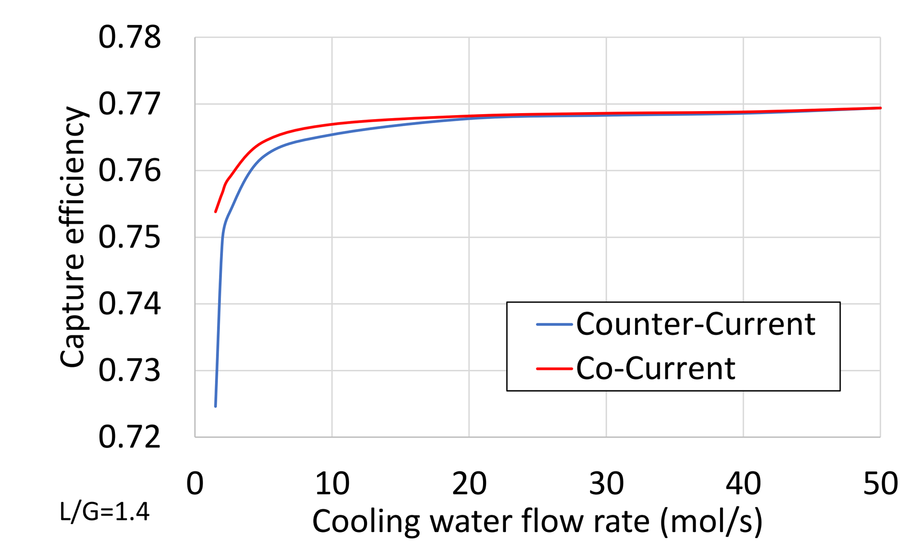
	Height (m)	Diameter (m)	$F^{V,in}$ (mol/s)	L/G
Base Case	15	0.65	22	1.4

* 0 and 1 indicate bottom and top of tower, respectively

Case	Capture percent
Base Case	72.46%
Base Case w/ Cooling	75.63%
Optimized Case	76.94%







Co-Current flow of cooling water has slight advantage of counter-current flow at lower rates, but nearly identical at higher flowrates

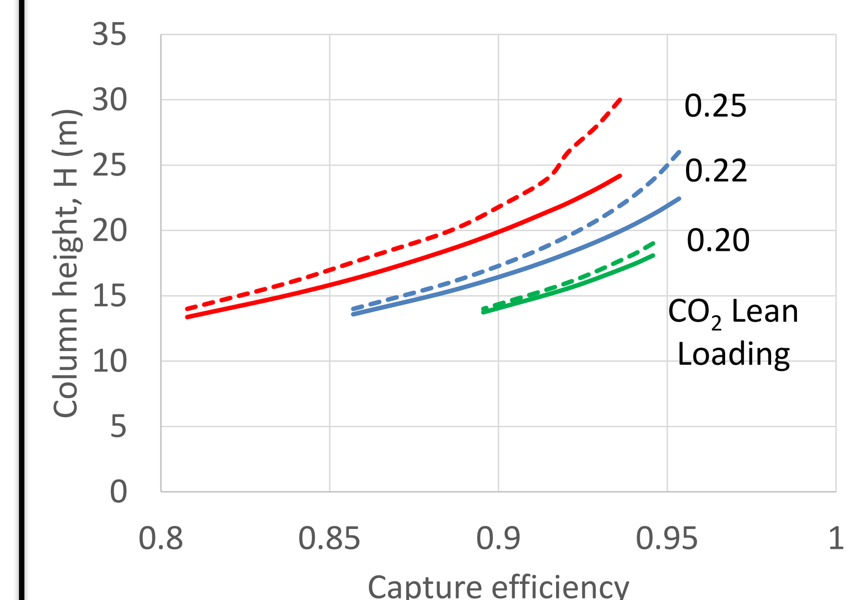
Optimization Case Studies

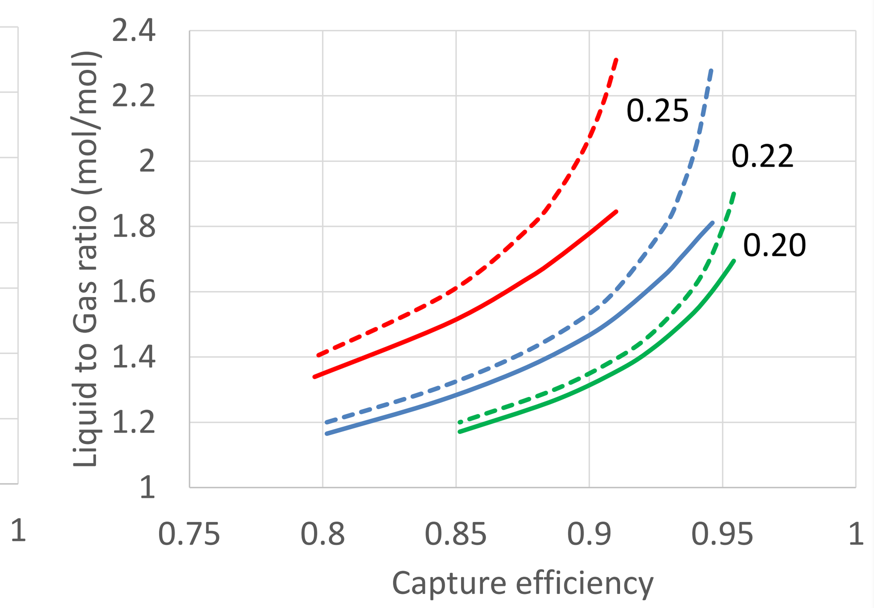
- Several optimization studies are conducted with the scaled-up absorber
- Internal heat exchangers are observed to be increasingly beneficial as the capture efficiency and CO_2 lean loading increases.

<u>Objective Functions</u>

$$\min_{\varepsilon^{cw}, y, y^{start}, d} H \quad s.t.\ \eta_{capture} \geq C, \quad L/G = 1.83$$

$$\min_{\varepsilon^{cw}, y, y^{start}, d} L/G \quad s.t.\ \eta_{capture} \geq C, \quad H = 20\ m$$





Both column height and solvent flowrate can have significant reductions while retaining capture efficiency due to optimally placed internal heat exchangers (**solid line**) compared to standard packing (**dashed line**), especially at higher capture rates

Summary & Conclusions

- Optimal design and placement of the internal heat exchanger are found to result in considerable reduction in the tower height for a given L/G ratio or reduction in L/G ratio for a given tower height, essentially when capture efficiency and CO_2 lean loading increase.
- Relative improvement in capture is very high as the cooling water flowrate is increased initially and then there is hardly any improvement beyond certain cooling water flowrate. Relative improvement with the change in the cooling water flowrate depends on the flow configuration.
- Future work will include economic optimization for varying flue gas loads.

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