Crossflow CO_2 Absorption: Solvent Performance Comparison

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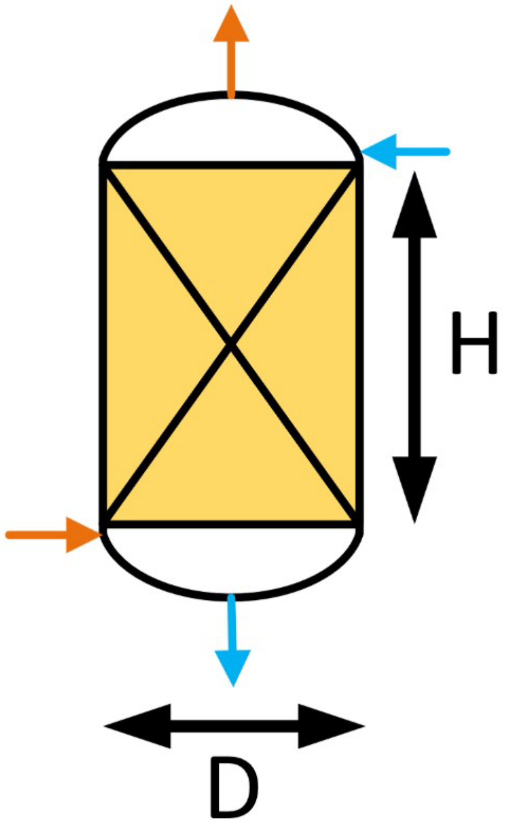
Overview

- Crossflow Absorber Design
- Modeling Methodology
- Case Study
- Simple CFA
- CFA with Pump-around Intercooling
- Conclusions

Countercurrent and Crossflow Absorber Design

Countercurrent

- **D**iameter ∝ Flue gas flowrate
  - 80% flood restriction
- **H**eight ∝ CO_2 removal target

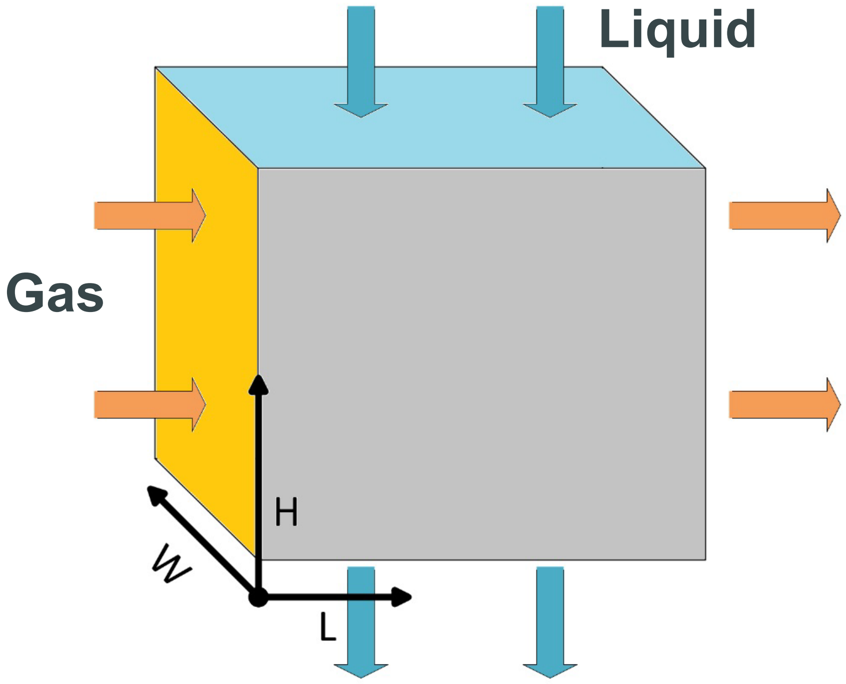


Crossflow

- **H**eight
- **W**idth

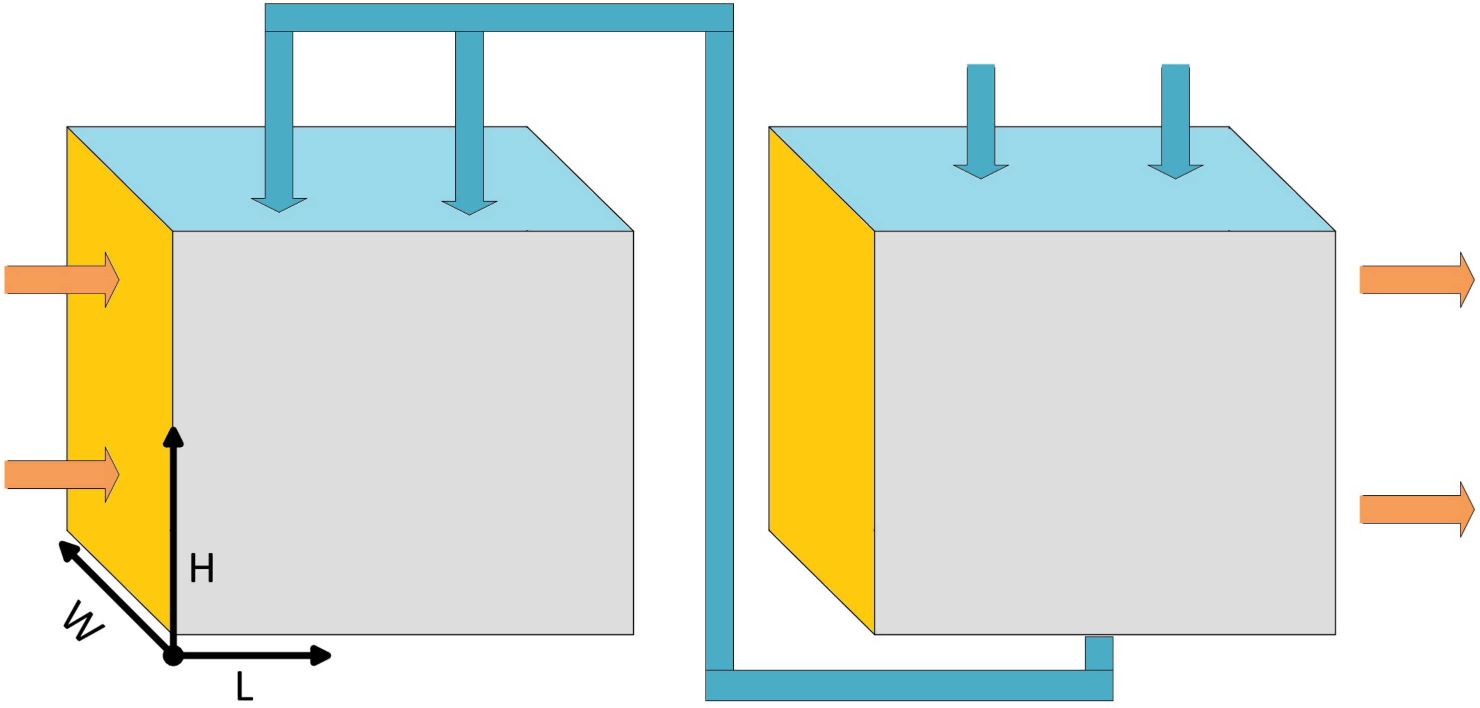
∝ Flue gas flowrate

- **L**ength ∝ CO_2 removal target



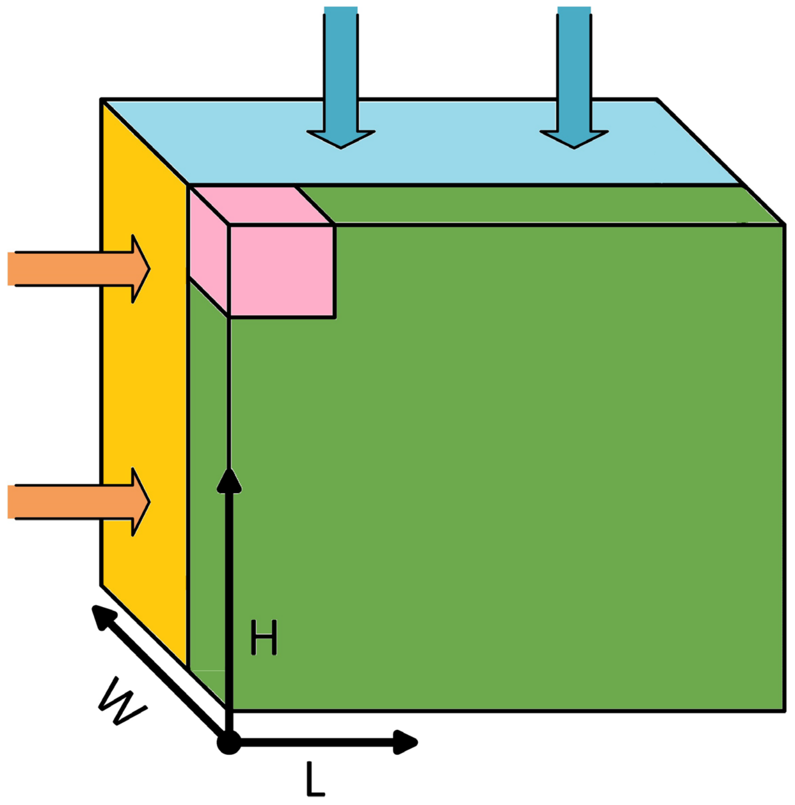
Design Opportunities for Crossflow Absorbers

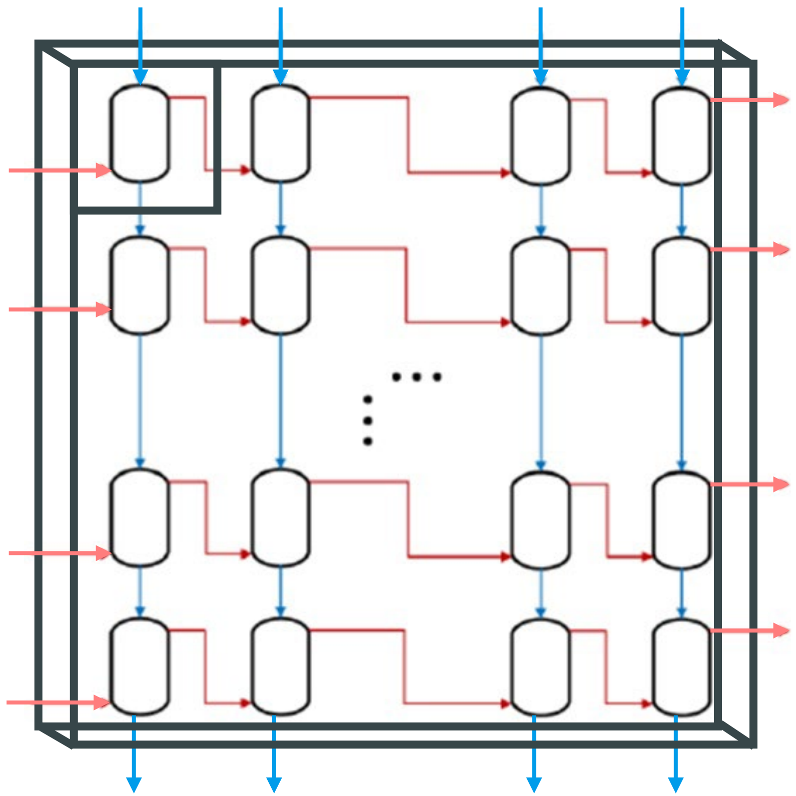
- **High liquid flux can be achieved without backmixing**
- Gas and Liquid flux can be independently optimized
- Can be designed to accomodate space restrictions



Countercurrent Slab Approximation

- Section of crossflow unit is modeled using a countercurrent slab in Aspen Plus®
- Uses countercurrent mass transfer performance correlations (a_e, k_L, k_G)
- Does not consider liquid drifiting





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Gao, 2021; Abreu, 2024

CCSI2 Model for Countercurrent Absorption with MEA

TotalEnergies

- Aspen Plus model for 30 wt% MEA
  - Developed by NETL (US DOE)[1]
- Includes solvent thermodynamics, kinetics, physical properties, and mass transfer performance
  - Solvent thermodynamics and kinetics adapted from Phoenix model[2]
    - T: 25 – 130°C; Loading: 0,003 – 0,6 mol/mol; MEA: 6,5 – 45 wt %
  - Packing performance parameters and diffusivity models regressed using air/water data (UT-SRP[3]), wetted wall data[4], and small-scale pilot plant data[5]
  - Validated against NCCC data (8 – 11,6 mol % CO_2) and TCM (3,6 mol % CO_2)
- Underpredicts performance for small bed heights (< 6 m)
  - Reported by USheffield during Bechtel Panda Sherman FEED
  - Likely due to error in wetted area subroutine
    - Fixed in this work

1 – Morgan et al., 2018; 2- Plaza, 2012; 3 - Tsai, 2010; 4 – Dugas, 2009; 5 – Tobiesen et al., 2007

Case Study

- 120 MW Natural Gas Combined Cycle (NGCC) flue gas (3,6 mol % (wet) CO_2)
  - Integration within hull of floating structure: height restriction of 7 m
  - Option for direct contact cooler (DCC) and pre-quench or feeding gas directly to the absorber
  - Intercooling at 28 °C

- 30-35 wt % MEA as capture solvent
  - LLDG down to 0,1 mol/mol to take advantage of low energy cost

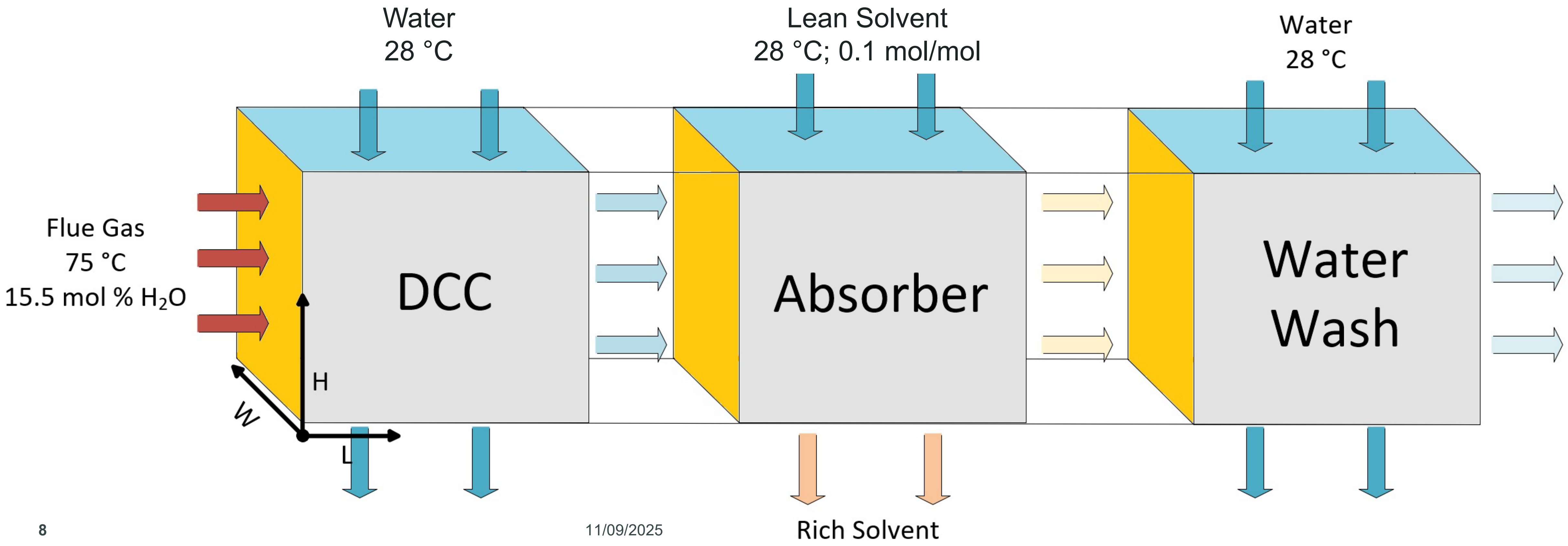
- All designs from minimum liquid rate analysis (optimum assumed at $1{,}2L_{Min}$)

- Previous study with 30 wt % PZ (5 m; 0,2 LLDG) showed CFA to underperform compared to countercurrent units despite some packing savings[1]
  - Did not explore high liquid flux designs

1 – Abreu, 2024

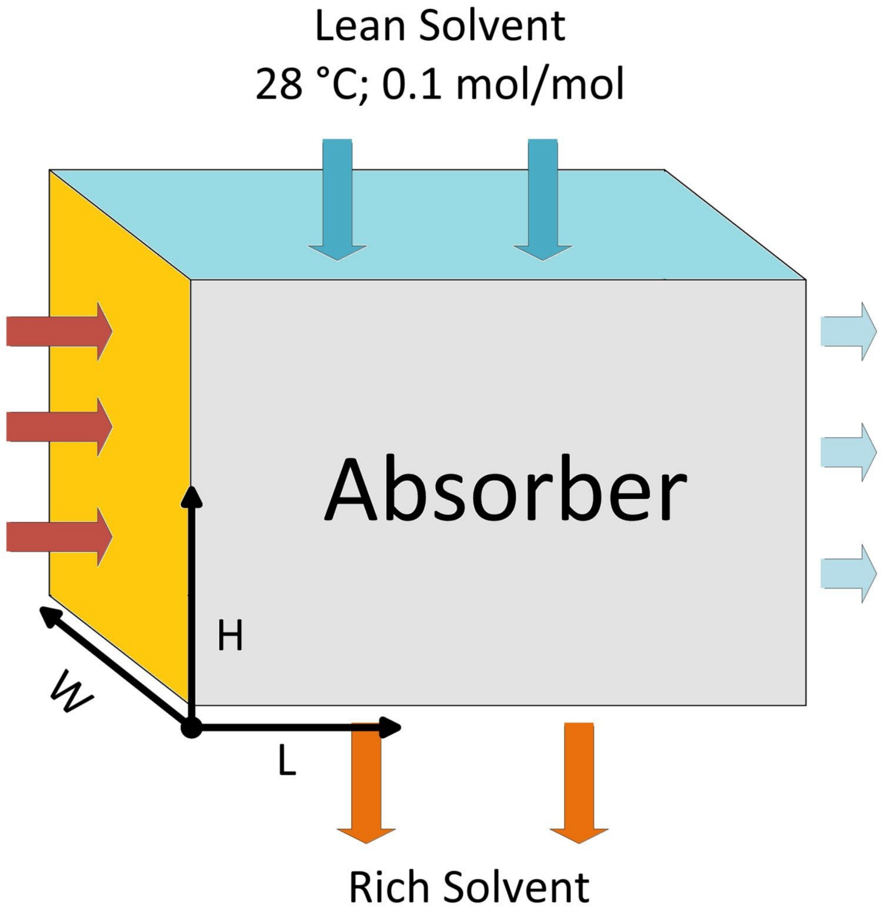
Simple Crossflow Absorber

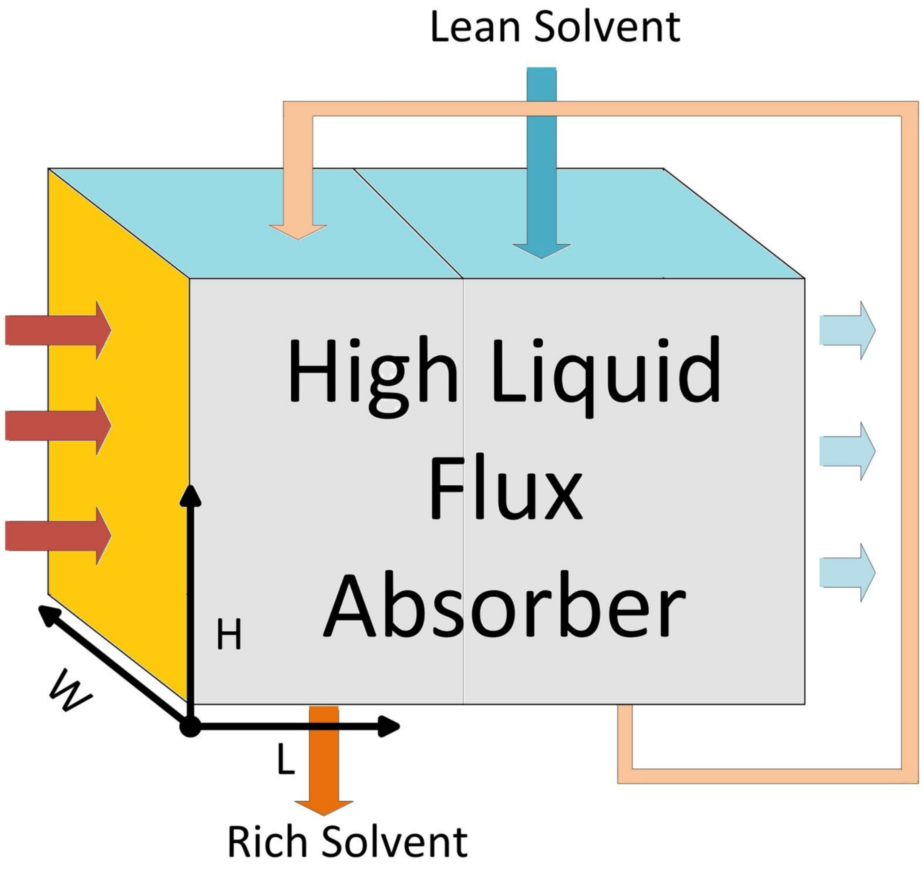
- Pre-Quench + DCC + Simple Absorber + Water Wash
  - Lean solvent at 28 °C
  - Variable length units: height and width fixed at 7 m (best performing for 5 m PZ)



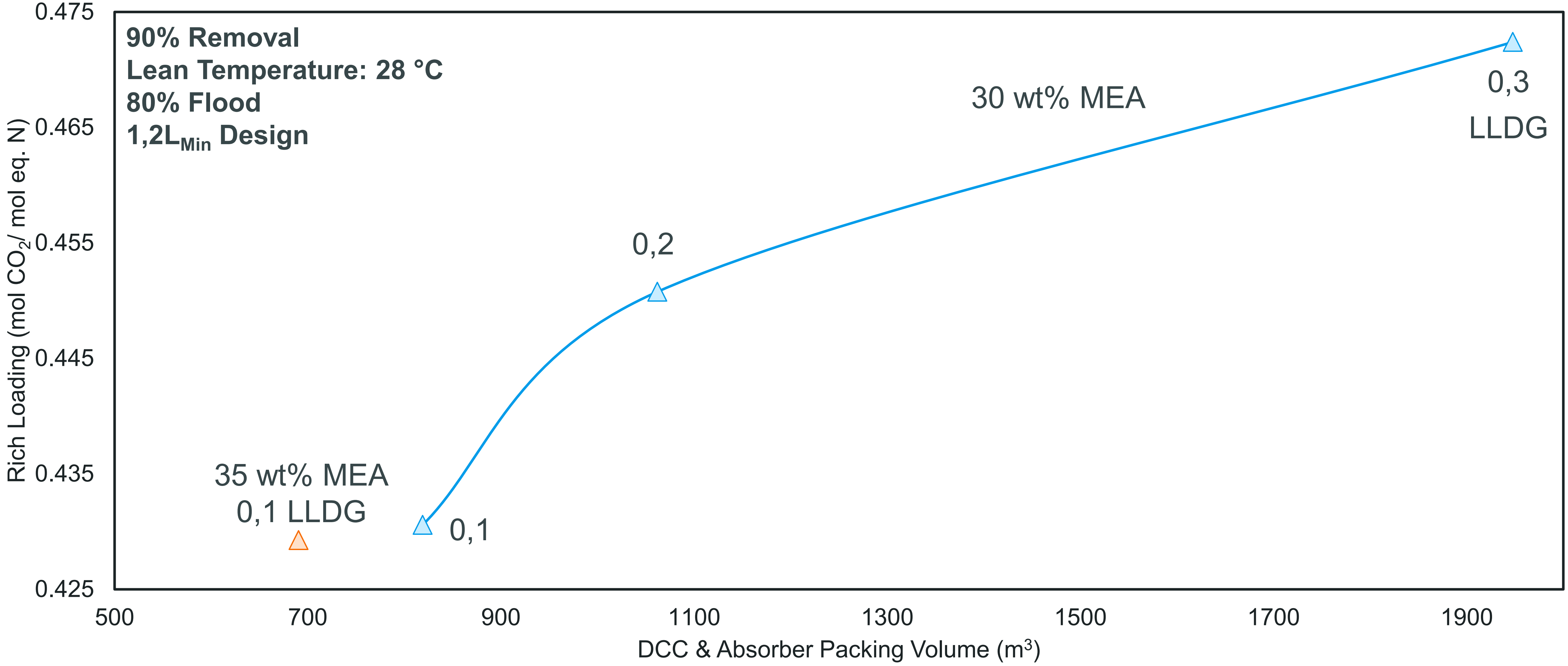
Simple Crossflow Absorber w/ High Liquid Flux

- Liquid flux in packing section can be increased by diving the absorber into multiple sections

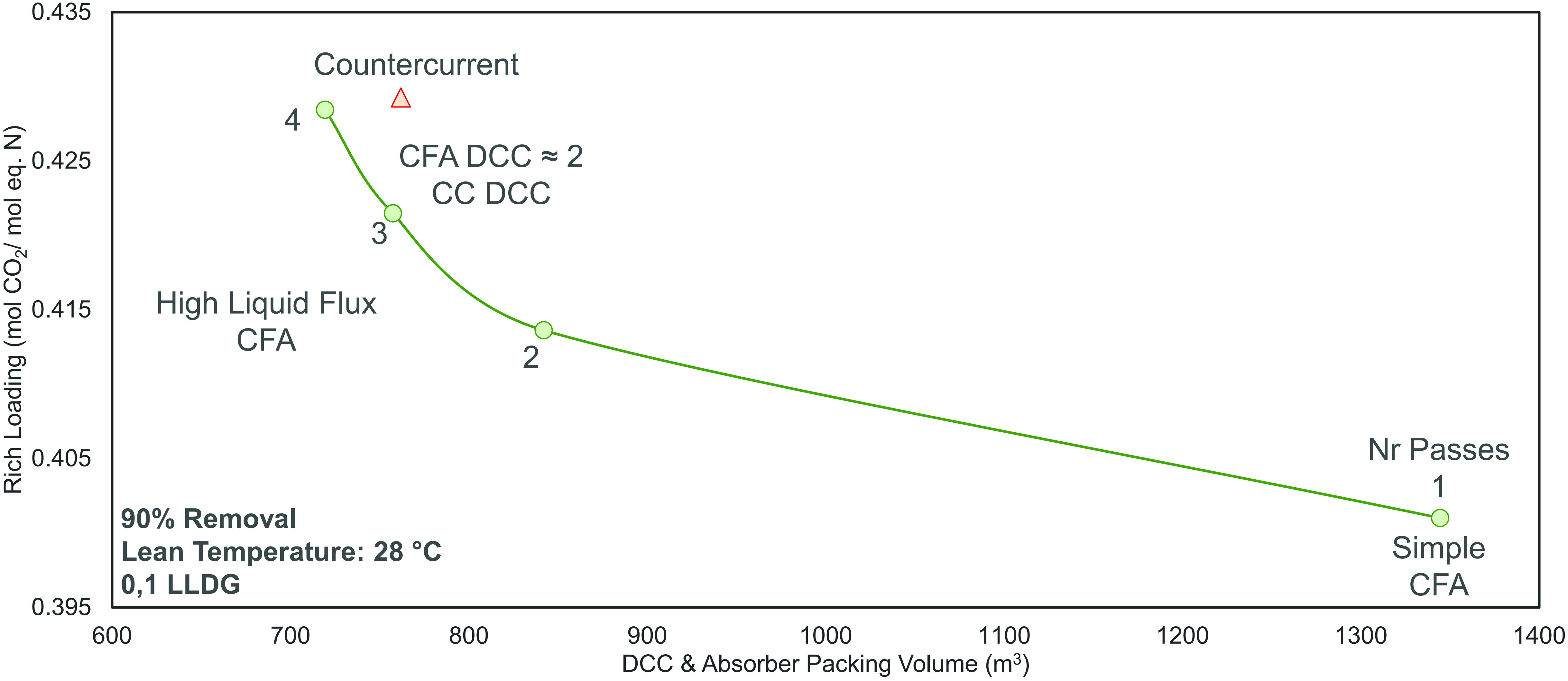




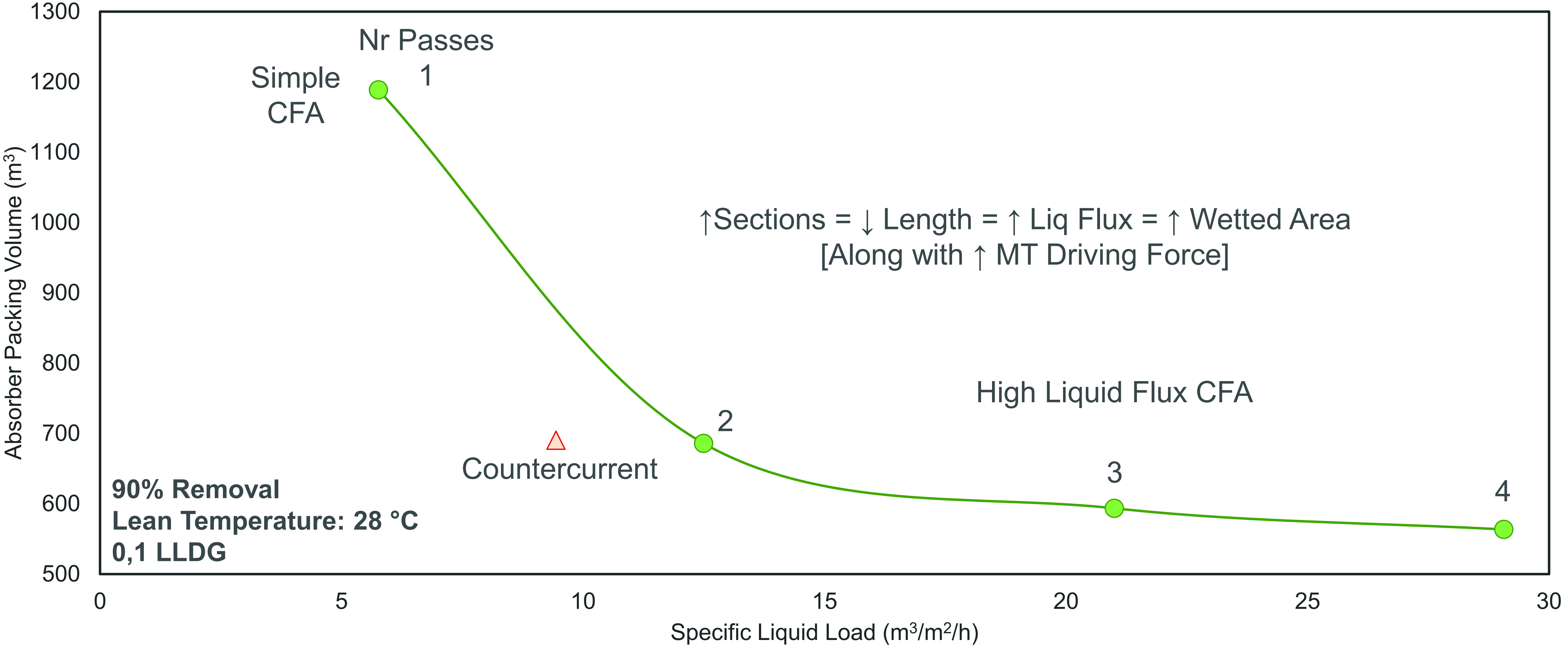
Baseline Countercurrent Design



Crossflow Train Can Match Countercurrent Performance Using High Liquid Flux Configuration

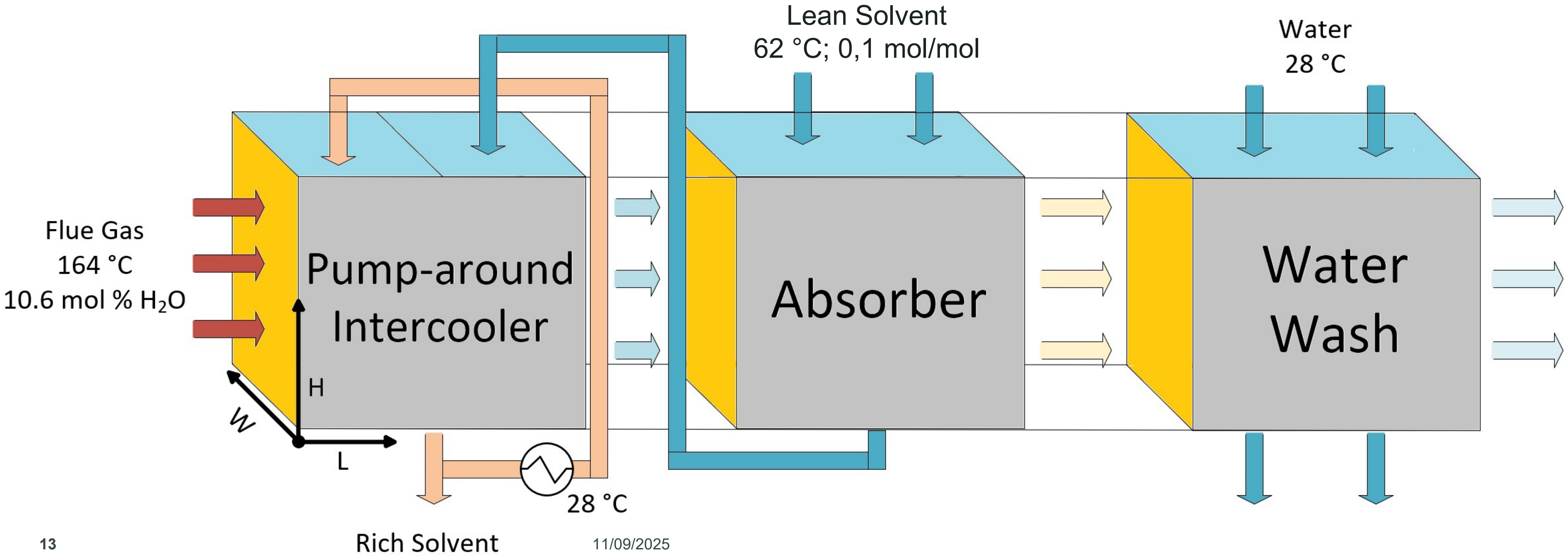


Increasing Number of Passes Substantially Increases Liquid Flux



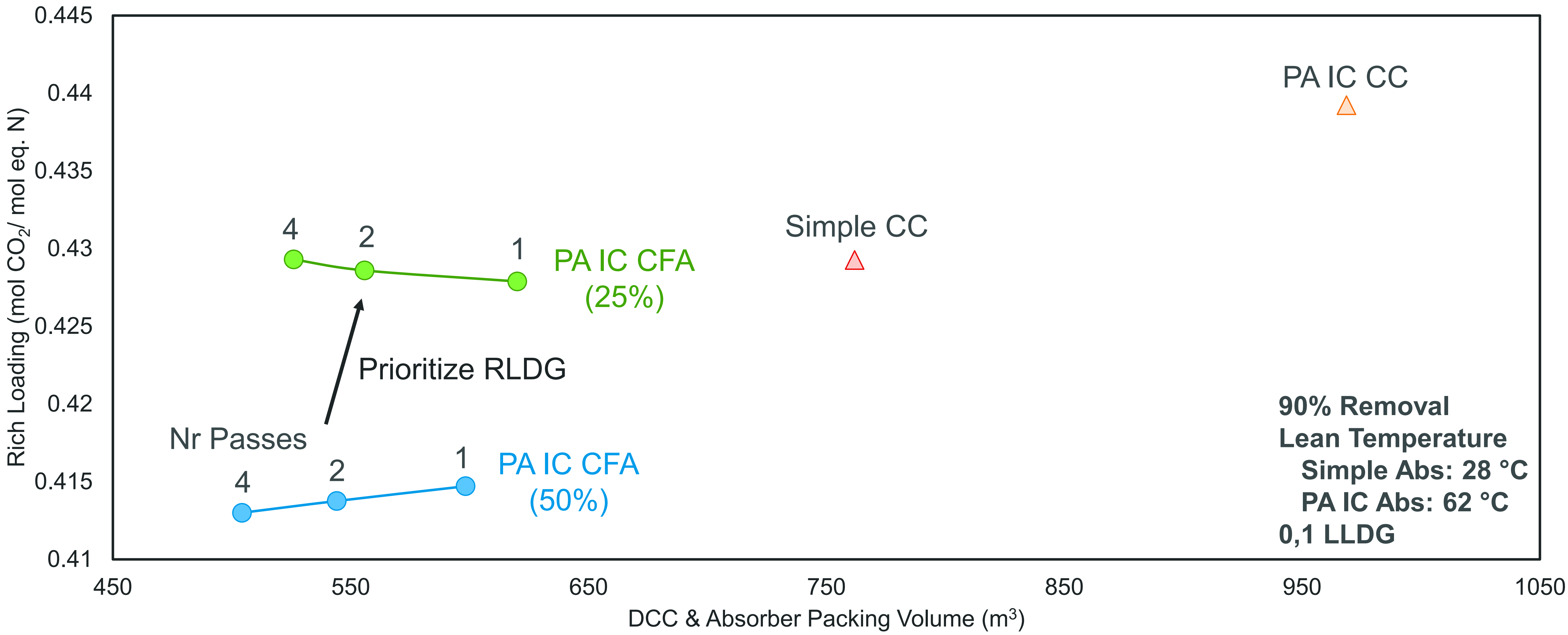
Pump-around Intercooler Crossflow Absorber Train

- Absorber with pump-around intercooler (PA IC) + water wash (w/o pre-quench)
  - PA IC L/G fixed at 3.5 kg/kg and 28 °C
  - PA IC and Absorber section are cubes of the same size
  - High liquid flux option for absorption section (multiple pass design)

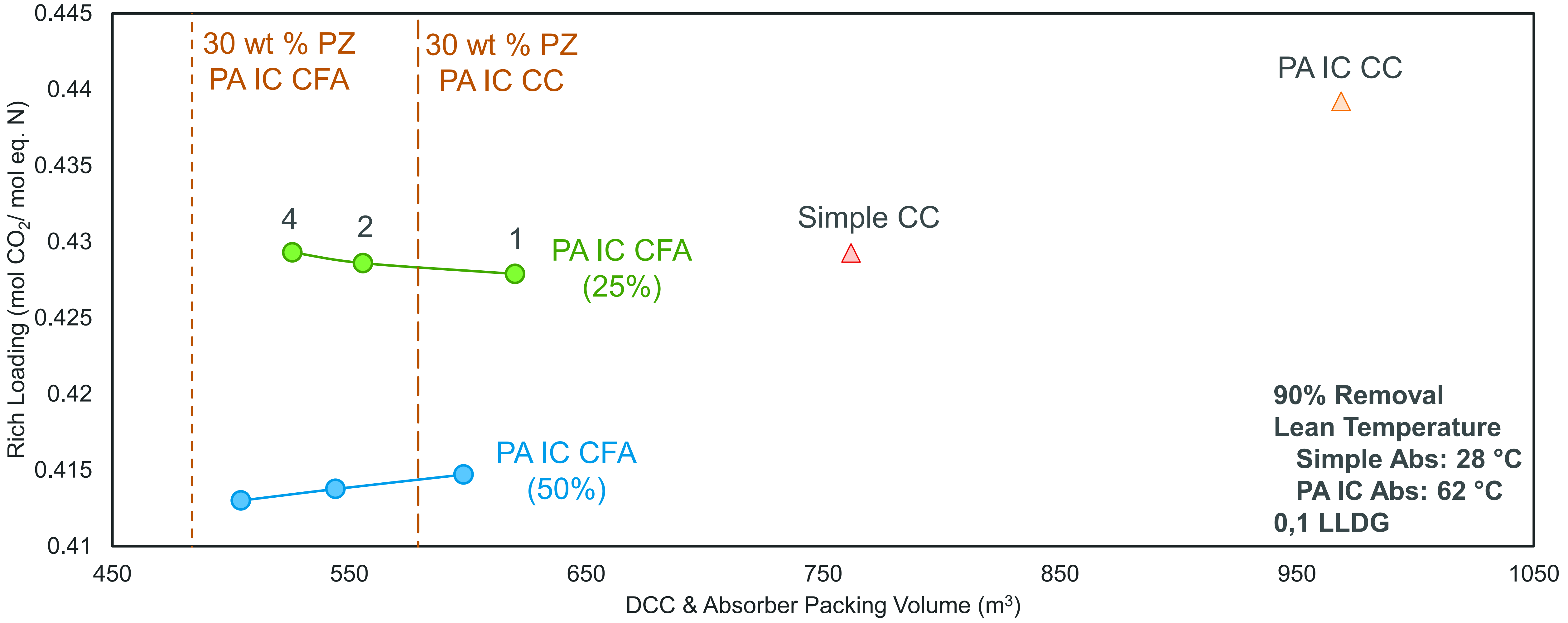


CFA PA IC Provides Substantial Packing Savings at Performance Similar to Simple CC Absorber

TotalEnergies



35 wt % MEA with PA IC CFA Packing Requirements are Competitive with 30 wt % PZ at 0,2 LLDG



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Conclusions

- Simple CFA with high liquid flux configuration (4 passes) requires less packing than an analogous countercurrent design
  - Liquid load: CC Design: 9,4 $m^3/m^2/h$ vs. 4-Pass CFA: 29 $m^3/m^2/h$
  - Similar performance (~ 0,43 RLDG)
- CFA with pump-around intercooling underperformed compared to analogous countercurrent design, but provided substantial packing savings
  - Packing requirements: PA IC CC: 970 m^3 vs. 4-Pass PA IC CFA: 526 m^3
  - Solvent performance: PA IC CC: 0,439 vs 4-Pass PA IC CFA: 0,430
- Packing requirements for CFA with pump-around intercooling with high liquid flux with 35 wt % MEA (0,1 LLDG) are comparable to 30 wt % PZ (0,2 LLDG)
  - Packing requirements: PZ CC: 579 m^3; PZ CFA: 484 m^3

Thank you

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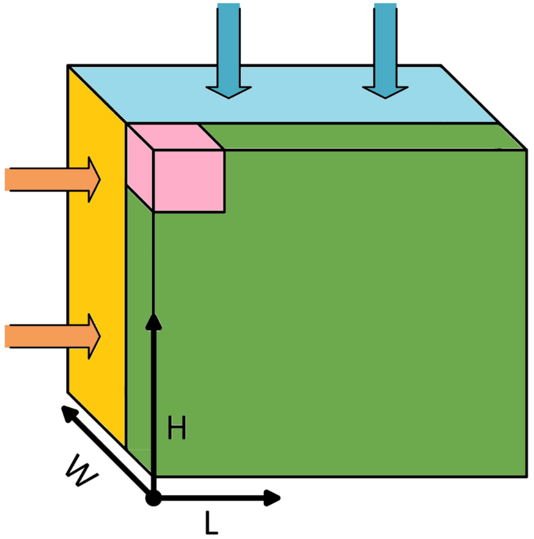
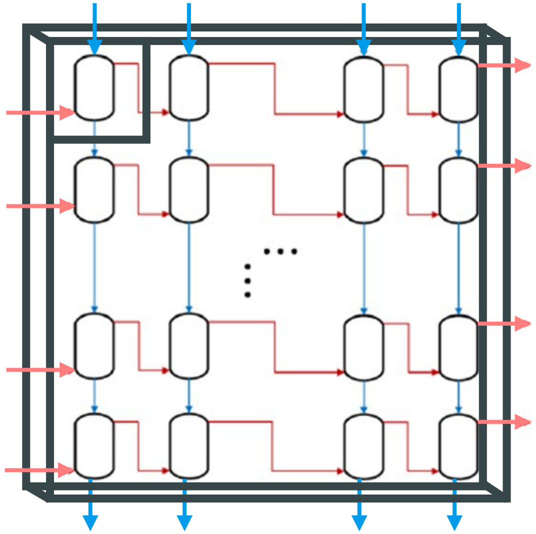
Appendix

Countercurrent Slab Approximation

- Cubic Crossflow Element ≡ Countercurrent Element
  - Same flow path length (Height CC element)
  - Same gas and liquid flux (Diam CC element)
- CC and CF slabs have the same packing volume
  - Size of CC cell defines grid dimensions
  - Gas and liquid flow scaled by number of slabs and cells
- Drawbacks
  - Does not model true crossflow driving force
  - Computationally intensive
  - Grid size is not always reasonable





Gao, 2021; Abreu, 2024

Known Issues and Limitations

- Underpredicts performance for small bed heights (< 6 m)
  - Reported by USheffield during Bechtel Panda Sherman FEED
  - Likely due to error in wetted area subroutine
    - Fixed in this work
- Single packing type included
  - Only data from MellapakPlus 250Y was used for model adjustment and validation
    - Fixed but not required due to matching packing types
- Physical properties subroutine (namely surface tension)
  - Does not work as intended in the absence of a loaded MEA solution (such as in the DCC)
    - Fixed in this work

Degrees of Freedom in Crossflow

- In CO_2 Absorption, the flux of CO_2 into the solvent is directly proportional to the packing wetted area

$$N_{CO_2} \propto a_e \propto Liquid\ Flux$$

Countercurrent

$$Liquid\ Flux = \frac{4Q_{Liq}}{\pi D^2}$$

- But design is based on gas flux

$$Flood \propto Gas\ Flux = \frac{4Q_{Gas}}{\pi D^2}$$

Crossflow

$$Liquid\ Flux = \frac{Q_{Liq}}{L \times W}$$

- Only width is restricted by gas flux

$$"Flood" \propto Gas\ Flux = \frac{Q_{Gas}}{H \times W}$$

Fractional Wetted Area – M250Y – Tsai 2010